MODELING AND ANALYSIS OF NEXT GENERATION 9-1-1 EMERGENCY MEDICAL DISPATCH PROTOCOLS

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In this thesis I analyze and model the emergency medical dispatch protocols for Next Generation 9-1-1 (NG9-1-1) architecture. I have identified various technical aspects to improve the NG9-1-1 dispatch protocols. The specific contributions in this thesis include developing applications that use smartphone sensors. The CPR application uses the smartphone to help administer effective CPR even if the person is not trained. The application makes the CPR process closed loop, i.e., the person who administers the CPR as well as the 9-1-1 operator receive feedback and prompt from the application about the correctness of the CPR. The breathing application analyzes the quality of breathing of the affected person and automatically sends the information to the 9-1-1 operator. In order to improve the human computer interface at the caller and the operator end, I have analyzed Fitts law and extended it so that it can be used to improve the instructions given to a caller. Using EEG waves, I have analyzed and developed a mathematical model of a person's cognitive impairment. Finally, I have developed a mathematical model of the response time of a 9-1-1 call and analyzed the factors that can be improved to reduce the response time. In this regard, another application, I have developed, allows the 9-1-1 operator to remotely control the media features of a caller's smartphone. This is needed in case the caller is unable to operate the multimedia features of the smartphone. All these building blocks come together in the development of an efficient NG9-1-1 emergency medical dispatch protocols.

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CHAPTER 1

INTRODUCTION

The United States Emergency Dispatch services, also referred to as the 9-1-1 System, originated in 1958 when the Commission on Law Enforcement and Administration of Justice suggested replacing local police and fire numbers with a single, easily remembered, national emergency number. Their rationale for this change was that response time during emergencies would be reduced as those calling for help would not need to search for phone numbers. Since then, the 9-1-1 System has evolved (figure 1.1) from the first 9-1-1 call placed in February 1968 through an Enhanced 9-1-1 System to the NG-9-1-1 architecture [1]. Emergency Dispatch services (9-1-1) have become an important part of modern society. While the three-digit number has improved response times overall, improved response time is still needed. Now, with the advent of new telecommunications technologies, we can use multimedia services for 9-1-1 rather than being limited to voice services. Such additions to the 9-1-1 service promise to reduce response time even more, saving significantly more lives. Since 2005, designers have been developing architecture for integrating these multimedia services (also called Next Generation 9-1-1 services [NG9-1-1]).

The central interaction point for 9-1-1 calls is a dispatcher at a 9-1-1 center. This dispatcher must respond to an emergency in an appropriate manner within a short time.

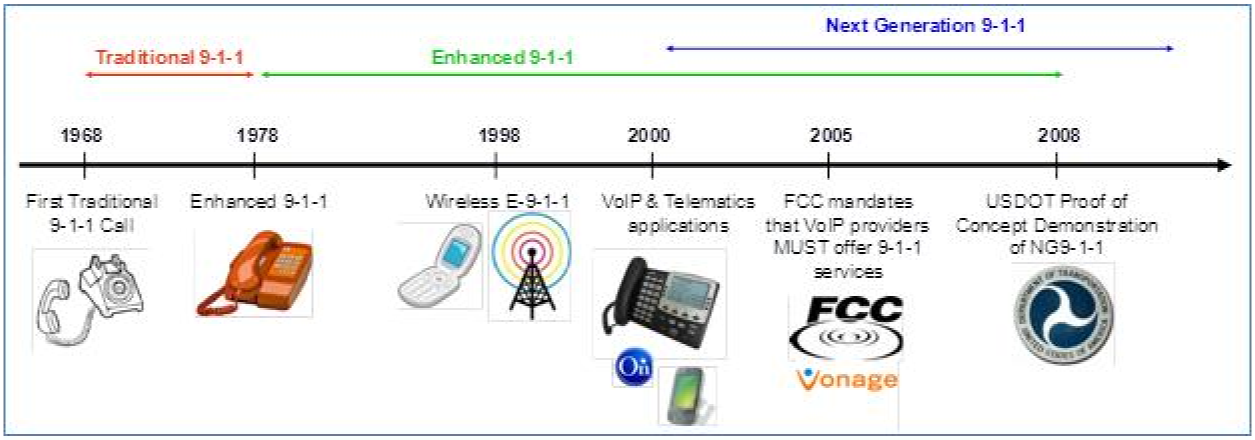


Figure 1.1. Timeline of the North American emergency calling system (9-1-1).

(The NG9-1-1 target is to have a response time of 60 seconds.) Responding to the emergency involves asking the caller specific questions to determine the type of emergency and, then, to decide on an appropriate course of action. To accomplish this, 9-1-1 operators currently use Dispatch Protocols that guide the operator as to which questions to ask and what actions to take. However, existing protocols assume a voice-only call. But, protocols within the NG9-1-1 system must allow for multimedia calls using video, voice, and pictures. For example, many callers now have mobile devices, (smartphones) which facilitate sending of pictures and video. Using this technology means 9-1-1 operators will be able to view pictures and video of the emergency scene in real time, improving their ability to respond. These smartphones also have sensors that can be used to diagnose certain medical conditions - further enhancing the information available to dispatchers. These technological developments render existing Emergency Dispatch protocols obsolete. It has become obvious that there exists a need to redesign the emergency protocols so that they reflect available multimedia technologies. Should we do so, 9-1-1 dispatchers will be able to better assists people during emergency situations.

1.1. Motivation and Objective

The goal of protocols for 9-1-1 services is to improve not only the response time but the quality of responses in emergency situations. Protocols for NG9-1-1 services will use developments in technologies such as multimedia calls and smartphones to improve dispatchers response time and quality. These new technologies have turned mobile phones into personal devices using embedded sensors. Given that smartphones have become highly popular, the likelihood that at least one will be present at an emergency scene means the NG9-1-1 architecture can use the presence of these sensors for initial health diagnoses. For example, as reported in this dissertation an application has been developed where the NG9-1-1 architecture can take advantage of the presence of an accelerometer to evaluate breathing quality or to measure a persons breathing rate with about 90% accuracy; a second application running on a mobile phone can guide a person to administer CPR properly and can provide real-time feedback about the quality and effectiveness of such CPR. Similarly, smartphone sensors can provide heart rate and blood pressure readings with an accuracy of about 90%. Another factor which the NG9-1-1 architecture must respond to occurs when physically or cognitively impaired callers cannot handle a mobile phones camera controls properly. In these instances, the emergency dispatcher must be able to gather information remotely. This dissertation discusses a third application that allows an NG9-1-1 operator to remotely control camera zoom, lighting, and other multimedia features so that the dispatcher can evaluate the emergency efficiently and can provide appropriate help.

This dissertation focuses on redesign of the Emergency Dispatch protocols to take advantage of newer technologies. In the process I designed three applications that can be used in smartphones to assist the caller and the dispatcher. These applications assist in conceptualizing how we can redesign emergency dispatch protocols to reflect the technologies now available. In this redesign, I focus first on the Human Computer Interface (HCI) between the dispatcher and the computer and, second, on the interface between callers and their smartphones. Using applications as presented here ensures that redesigned protocols not only reduce response time but also improve the quality of responses.

1.2. Overview of Each Chapter

Chapter 1 provides an overview of the Emergency Dispatch protocols. I discuss the problem statement. Finally I give an outline of the study and contribution of each chapter in this document.

Chapter 2 discusses evolution of Next Generation 9-1-1 (NG9-1-1) archiecture and the issues and challenges relating to a NG9-1-1 emergency response system.

Chapter 3 discusses the difficulties NG9-1-1 dispatchers face when needing to evaluate the quality of CPR administration when neither professional emergency personnel nor medical equipment are available at the emergency scene. In this chapter, I discuss an application I have developed that takes advantage of sensors currently available in smartphones to assist dispatchers in ensuring that those in the field are administering CPR efficiently and accurately. In this chapter I also present how I used a smartphone application to calculate frequency and depth of compressions and to give real-time guidance to improve CPR. Finally, I integrate, with the CPR process, an application which measures oxygen saturation in blood, providing an additional measure to dispatchers for evaluating the effectiveness of in-the-field CPR.

Chapter 4 describes use of smartphone sensors to evaluate breathing quality. In this chapter I present experimental results of a smartphone application which evaluates vital factors dispatchers use to determine breathing quality. In the chapter I also discuss the smartphone placement and orientation on the body (chest or upper abdomen) to get the best results. Finally, I describe how the application can also evaluate breathing regularity and effort.

Chapter 5 discusses Fitts law, an important tool in the study of Human-Computer-Interface design (HCI). Fitts law, which predicts the time required to move to an object given the distance to the objects center and its size, has been applied to single joints. The objective was to use Fitts law to design an efficient HCI for Emergency Dispatch protocols. It can also be used to enhance design of joints of robotic body parts or prosthetics. In this chapter, I extend Fitts law to model movement by multiple joints. To accomplish this, I first establish a relationship exists between the performances of joints using the concept of *atomic movement* - the movement of the fastest joint from amongst the joints under consideration. I argue that movements of other joints are a multiple of this *atomic movement*. In this chapter, I further enhance Fitts law to reflect multiple movements to complete a task.

Chapter 6 describes a study to model two types of impairment: that caused by physical stress and that caused by alcohol consumption. This chapter discusses how EEG waves can be used to study such impairments. The chapter presents the results of this study and discusses implications for design of NG9-1-1 emergency dispatch protocols.

Chapter 7, describes the improvements in HCI during a NG9-1-1 call. I first present a mathematical model of the time to respond to a 9-1-1 call. Second, I discuss factors which improve the HCI so that response time is reduced. In addition, I present two smartphone applications I have developed to improve HCI. The first application allows the NG9-1-1 operator to control media features of an impaired callers smartphone. The second application, called Text to Speech synthesis, allows the NG9-1-1 operator to send text to a caller. The callers smartphone then converts the text to speech. This reduces the operators need to read or repeat standard instructions while freeing him to complete a related activity. I also describe in this chapter the high-level software design for these applications.

Chapter 8 discusses modifications of the Emergency Dispatch Protocolsguidelines that 911 operators follow for each emergency. Specifically, in this chapter I discuss how I have modified the New Jersey Emergency Dispatch Guidecards to demonstrate how using a smartphones embedded sensor technologies effectively reduces the questions operators must ask when they can look at a scene via video and pictures, reducing the emergency response time.

CHAPTER 2

NEXT GENERATION 9-1-1: ARCHITECTURE AND CHALLENGES IN REALIZING AN IP-MULTIMEDIA-BASED EMERGENCY SERVICE

2.1. Introduction

Enhanced 9-1-1 (E9-1-1) service is an essential component of crime prevention units. Quick, efficient emergency response systems result in timely amber alerts and timely deployment of police personnel at crime scenes. Firefighting services and health care services can enhance their operational efficiency with the support of E9-1-1 services. Transportation departments make use of E9-1-1 services by responding to automatic crash notifications in a timely manner. More recently, the state of the E9-1-1 system has become pivotal to the operation of the U.S. Department of Homeland Security, which makes use of automatic surveillance information in conjunction with information provided by its citizens. In an effort to overcome the limitations of current E9-1-1 services in supporting new technologies and communications devices, the idea of a NG-9-1-1 architecture has been discussed since the late 1990s. NG-9-1-1 is not only an adaptation of current E9-1-1 system to support new technologies but also a whole new concept based on open standards and new technologies. NG-9-1-1 is a dramatic change from the current E9-1-1, for it is based on two main principles: support of multimedia information and Internet Protocol (IP)-based communications. The main contribution of this chapter is a brief description of NG-9-1-1 system and related issues and topics that still require investigation. The focus is on research trends rather than on implementation trends. In section 2.2 I first provide an overview of how current 9-1-1 works and how it has evolved. Section 2.3 briefly describes the building blocks of NG-9-1-1, showing how a voice over IP (VoIP)-based emergency call is handled and the network architecture and protocols needed to support it. In Section 2.4 I address the main research challenges that must be solved to allow for a flexible, secure, and robust NG-9-1-1 architecture. In the concluding section 2.5 I discuss the current and future work related to NG-9-1-1.

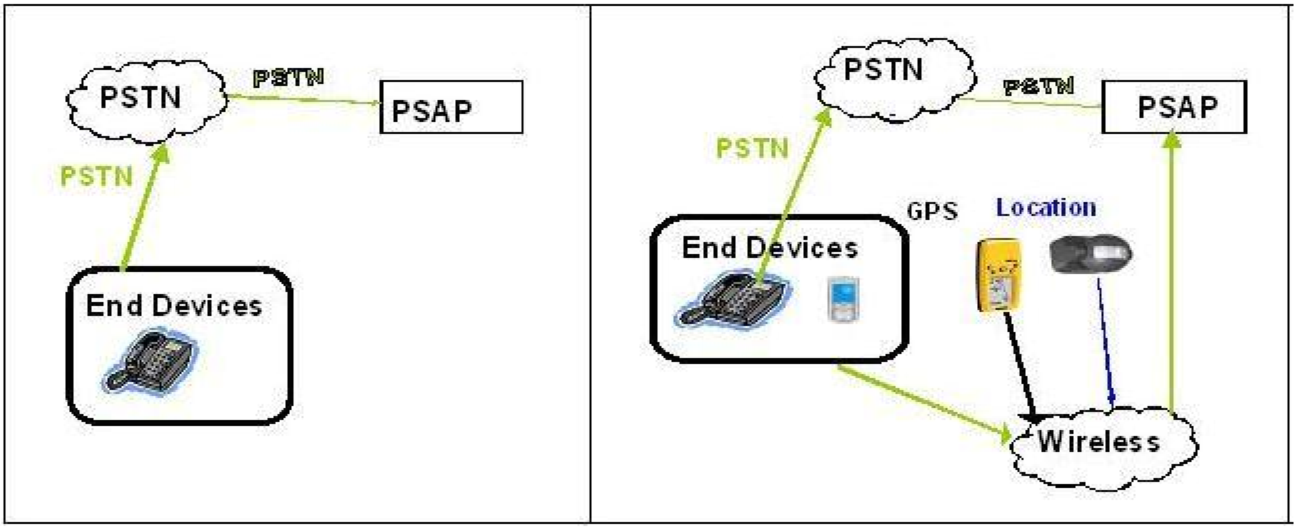


FIGURE 2.1. a: PSTN-based 9-1-1 system; 2.1b: Evolution to E9-1-1

2.2. State of the Current 9- 1-1 System

When users dial 9-1-1, the calls are routed to special call centers, which must quickly deploy emergency services (e.g., police personnel, firefighting services) to the user's location. The special call centers that answer these calls are called Public Safety Answering Points (PSAPs).

Traditional 9-1-1 systems, which date back to the late 1960s, are based on the Public Switched Telephone Network (PSTN). PSAPs are connected to the telephone company's local exchange office through dedicated trunks, as shown in Figure 2.1a. Some telephone carriers have 9-1-1 Selective Routers that distribute calls directly to the PSAPs. The user's geographic location is very important for routing the call to appropriate PSAP, and to the deployment of emergency services. To obtain the caller's location, the PSAPs access the automatic location identification (ALI) databases, where the telephone number of each user is mapped to a physical, street address. With the introduction of mobile phone usage, the traditional 9-1-1 services had to adapt to the user's mobility. New requirements were imposed on the 9-1-1 system, and the new system became E9-1-1. With the explosive growth in the mobile user population, the 9-1-1 methods used to locate landline phones were inadequate for cellular phone callers. Thus, in 1996, the Federal Communications Commission (FCC) mandated that wireless carriers add location information as well as the phone number of the caller in all emergency calls.

To comply with wireless E9-1-1, some wireless carriers have adopted network-based location techniques [7], while others require phones to use Global Positioning system (GPS) technology. Figure 2.1b shows this evolution from PSTN-based architecture to E9-1-1. Here, the wireless network needs the location of the caller and can use GPS or a location server. E9-1-1 was an improvement over the traditional 9-1-1 architecture, but it still had many limitations. The lack of interoperability among the various communication devices used by first responders makes it difficult to coordinate first responders during large-scale emergencies. In some counties, analog centralized automatic message accounting (CAMA) trunks between the local exchanges and PSAPs cause delays of several seconds. This situation is further aggravated by the use of low-speed modems when accessing the automatic location identification (ALI) databases by the PSAPs. The current E9-1-1 services also have limited resiliency because the primary PSAPs can route calls only through one secondary PSAP. In an era of global wireless mobility, the current E9-1-1 communication technology lacks global number portability; that is, the system can only handle US numbers. The capability to handle international numbers is now a mandatory requirement in the current era of increasingly mobile cell phone and VoIP devices working across the number plan boundaries. E9-1-1 services are based on voice media only, whereas the latest multimedia technology has great potential to improve emergency services. NG-9-1-1 will not only support the current communication devices that we have right now much more cost-efficiently, but it should also be "able to adapt to new technology and support new devices" [148]. Moreover, the goal of an NG-9-1-1 system has always been clear: to enable the transmission of voice, video, text messages, and data in emergency communications. Text messages, images captured by cellular phones, video images, and automatic crash notification messages can dramatically enhance 9-1-1 services by expediting emergency responses.

Typically, multimedia-capable communication devices use VoIP technology [93, 13, 76, 79]. VoIP has established itself as the next-generation technology because of its efficiency

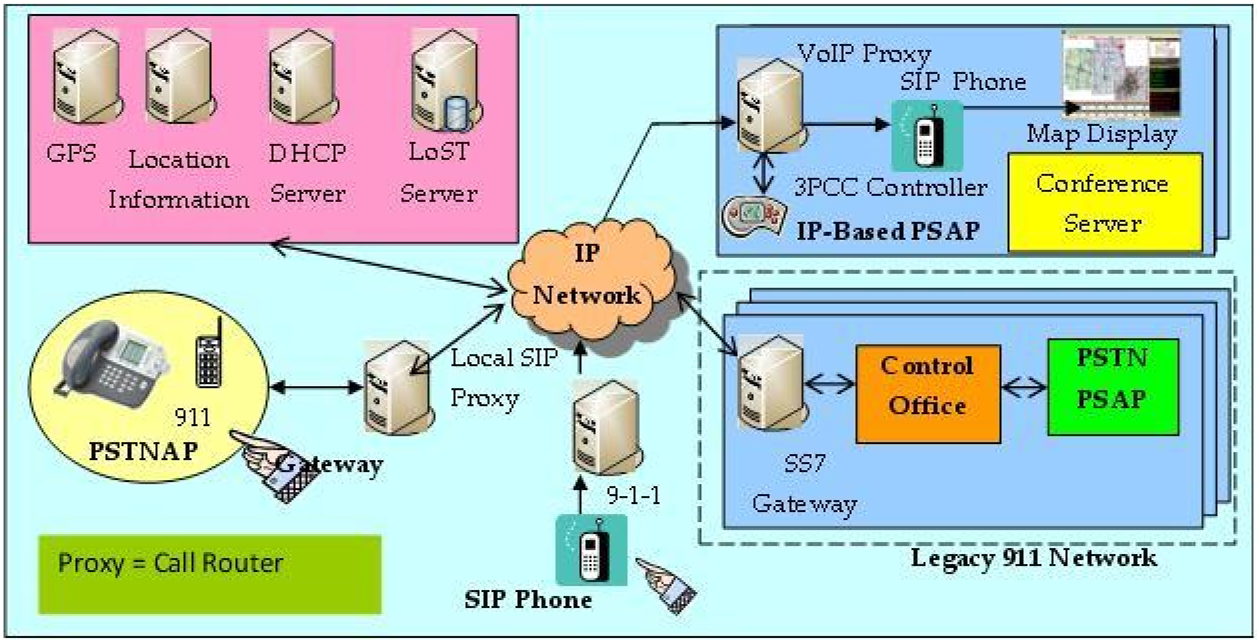


FIGURE 2.2. Main components of an IP-based NG9-1-1 network

and cost effectiveness.

2.3. NG-9-1-1: How it Works

It will be a long time before we see the complete departure of existing PSTN based PSAPs. IP-based PSAPs will take the place of PSTN-based PSAPs during the next few years, creating a "converged network" that must interoperate successfully [15] . In a converged network, the calls initiated by IP phones can also be routed over non-IP networks; and calls initiated over non-IP phones can be routed over IP networks. The protocol used in the network to set up calls is Session Initiation Protocol (SIP) [96]. The main components of an IP-based NG9-1-1 network are shown in the figure 2.2. If a 9-1-1 call is made from the PSTN, it is routed through a PSTN-IP gateway to an IP network. A call from a SIP phone is directly routed to the IP network. The IP network first determines the caller's location and then routes the call to an appropriate PSAP.

- An IP phone or a VoIP phone is a device that converts audio signals and telephone control signals into IP packets. These stand-alone devices plug into (connect to) data networks (such as Ethernet) and operate like traditional telephone sets. Normally, a stand-alone phone is called a hard phone, and a personal computer-based phone is called a soft phone. A caller initiates a call by dialing the appropriate digits; for example, 9-1-1.

- A SIP user agent (UA) exists on the caller side and the called side. The main functions of the UA are on the caller side are to identify the dialed digits as an emergency call, determine the location of the caller, and determine the address of the serving PSAP [93].
- The SIP UA then sends a query to the location information server (LIS).
- The next step is to find the address of the PSAP to contact by using location-to-service translation (LoST) protocol, developed to map geographic location to uniform resource locators (URLs) of serving PSAPs [171]. The SIP UA uses this address to contact the PSAP.
- The SIP proxy resolves the SIP URL to a reachable address and then routes the call to a destination, possibly a destination SIP proxy.

A list of requirements for emergency calls made using IP phones to IP-based PSAPs is defined by the IETF [78]. In summary, when a user dials an emergency number from an IP phone, the call setup signaling should support different emergency numbers (e.g., dial strings) in VoIP calls. In a SIP-based IP call, it should identify the call as an emergency call in the initial SIP call setup signaling. A device located near the caller should add location information or a reference to a location server in the call setup signaling. The network then finds an appropriate PSAP based on the location information and routes the call to the PSAP. A basic call flow is shown in Figure 2.3.

2.4. Main Challenges of NG-9-1-1

In Section 2.3, I briefly described the main building blocks for IP-based emergency communications. NG-9-1-1 is based on IP network, which allows support for new and enhanced services. The networks are required to support multiple modes audio, video, and text. The fact the network is IP-based facilitates meeting this requirement easily. The flexibility provided by IP-based networks also brings with it issues and challenges that need

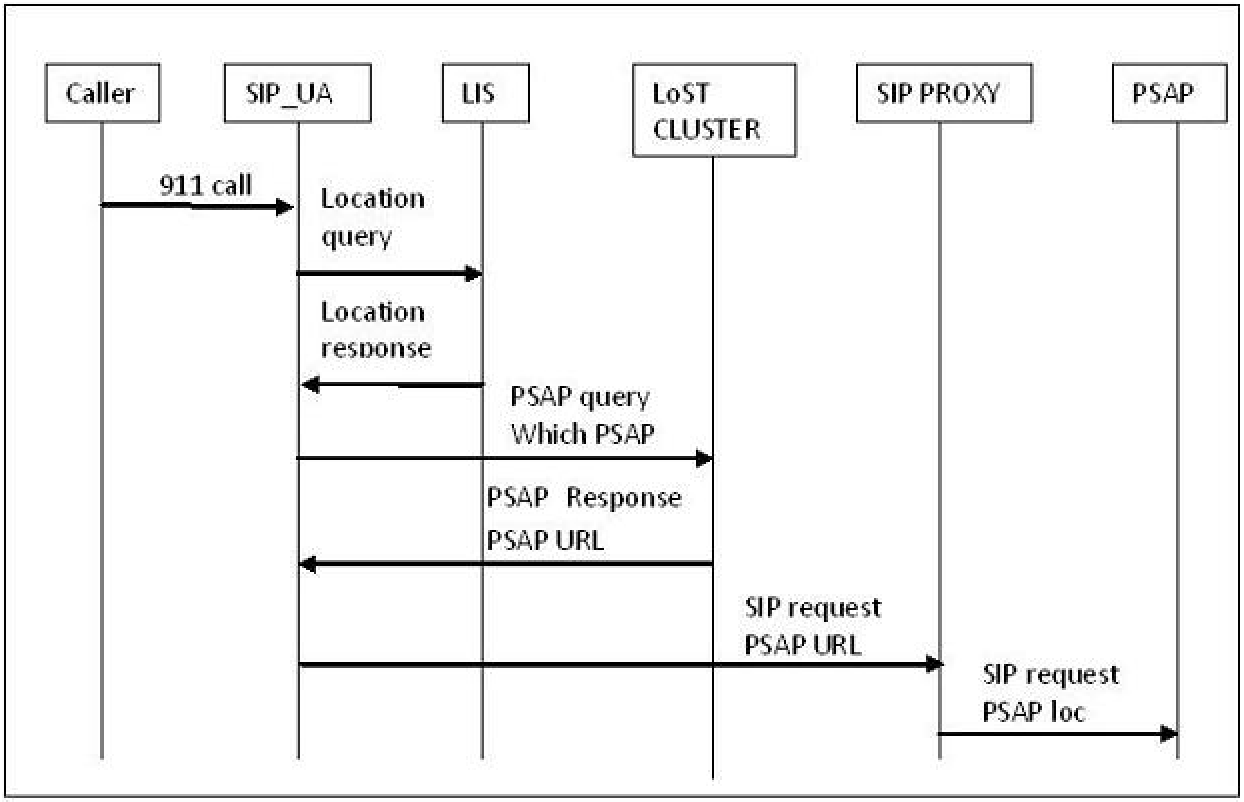


FIGURE 2.3. NG-9-1-1 call flow

to be resolved. In this section I describe the new and enhanced services that the network facilitates and the challenges and issues that need to be addressed in this network.

2.4.1. Support for New and Enhanced Services

2.4.1.1. ***NG-9-1-1 Services Using Short Messaging Service (SMS) and Instant Messaging (IM)***

Emergency calls can have a significant effect in saving people's lives. When seconds can make a difference, rapid and effective communication with the emergency call service becomes extremely important. IP-based networks allow IM and SMS services to be integrated into emergency communications systems. IM and SMS services are useful in several scenarios where voice calls are not possible. These services can be used to give anonymous crime tips to the authorities. In case of disaster situations, voice calls may not be possible because of network overload. In this situation, people can communicate better through IM and SMS

[187]. One of the most important uses of IM and SMS is by the deaf and hard of hearing. In the event of a 9-1-1 call received from a deaf person on a TTY device, the call taker makes use of the text messaging facility to ask a set of questions for determining the location and for obtaining emergency details (from a documented list of 30 questions). There may be a time delay in SMS communications because carriers may not give priority to SMS transmissions. In addition, because SMS length is limited to 160 characters, the messages use acronyms ("SMS lingo"), which the 911 operators would need to learn.

There is also an issue with connection management. For a 9-1-1 call, the user would like to talk to the same operator. But based on current technology, a subsequent SMS sent for the same call may be routed to a different operator in the same PSAP. In addition, if the SMS is sent from a mobile phone, the subsequent SMS may be routed to a different PSAP. This situation is not desirable and needs to be resolved. With availability of cheap mobile phones, it is possible for someone, even with marginal resources, to create problems for networks using SMS; and it would be hard to locate the source of such an attack. A network can be flooded with large amounts of SMS messages. Swatting and spoofing becomes easier, especially with the availability of spoofing services. Finally, if SMS messages have multimedia attachments, like video or photos, the issue of attached viruses and Trojans needs to be explored [167].

2.4.1.2. *NG-9-1-1 Services Using Images and Videos*

One of the important improvements in NG-9-1-1 is the ability to transfer images and video as a part of a 9-1-1 call. This ability can be used in several scenarios. Highway cameras and security cameras deployed at strategic points can automatically transfer images of people to a remote database location. At this location, a computer can compare the images with a database of images of known criminals or terrorists. If there is a match, it can alert emergency personal automatically and provide them with location information. It would be possible to send maps and layout of the building. Alarms and sensors can be installed at strategic points in buildings and homes. In case of any problem or unauthorized access,

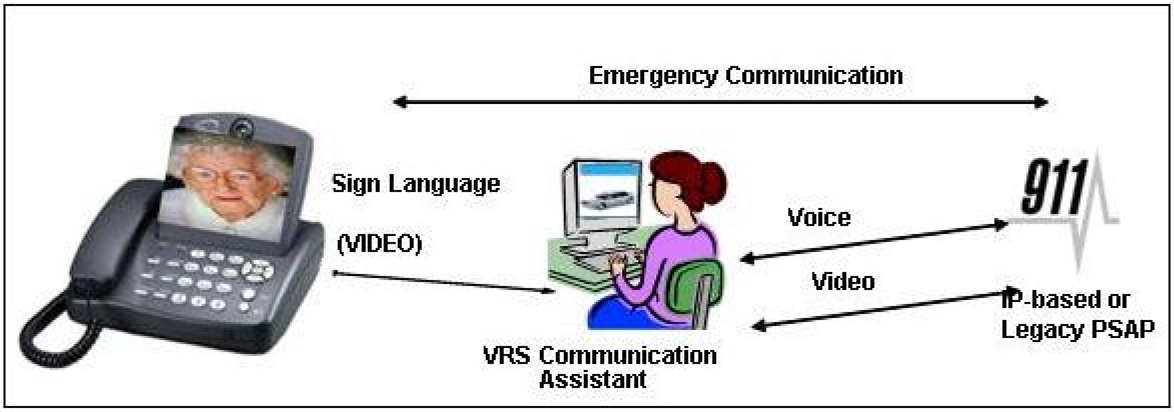


FIGURE 2.4. Video relay service (VRS) in emergency calls

they can automatically transfer images and/or video of the location to emergency personal. Personal medical devices can be installed at homes or institutions serving the elderly or the disabled. In case of medical emergencies, these devices can then automatically call for help. When a person with speaking and hearing disabilities has an emergency, the need for visual communication becomes important. Video phones can efficiently communicate with the hearing-impaired. The use of sign language as a special category call is needed. In normal situations (not necessarily only for emergencies), this kind of call is handled by video relay service (VRS) [119]. With VRS, the caller can use a computer with a video camera and a high speed internet connection to contact a VRS communication assistant who can communicate in sign language with the caller. In an emergency, the VRS communication assistant will be a facilitator between the caller and the PSAP (as shown in figure 2.4). In other words, when a VRS user has an emergency, the call is first established with the VRS communication assistant, who then calls the PSAP.

2.4.1.3. *An Efficient Reverse-9-1-1 Service for VoIP and Mobile Devices*

Call services that inform the public of impending emergencies and recurring problems are called reverse 9-1-1 (R9-1-1). The computational capabilities and intelligence of VoIP phones can be explored to implement innovative authorityto- citizen notifications. For instance, with IP-based devices, it is now possible to initiate automated actions, such as locking doors or closing air intake valves or controlling cameras remotely to zoom in or focus. An efficient IP-based R9-1-1 system can potentially deliver emergency notifications to users outside the area that is affected by the emergency; for example, when a user's child is in the emergency-affected area. Current systems that offer emergency notification services to communities (e.g., reverse9-1-1 at www.reverse911.com), universities (e.g., Code Maroon at Texas A&M University), and public authorities send automatic calls to users in a selected geographical area. The basic concept adopted by such systems is one in which users subscribe to the service and have the ability to select some preferences. The preferences can include the day and time when the user is willing to accept automated calls, the type and nature of calls the user is willing to accept, the type of end device to receive the message, and the name of the agency from which messages are accepted. As it is now possible to localize user preferences to the IP phone, it is envisioned that peer-to-peer communication instead of a broadcast capability can improve current R9-1-1 systems.

An initial architecture for IP-based emergency notification systems was proposed by Schulzrinne and Arabshian [76]. A more recent work by the IETF's ECRIT working group [159] presents the main requirements for emergency notification protocols. In addition, the OASIS standardization organization has created the Common Alerting Protocol (CAP) [169]. In the case of R9-1-1 calls, an important issue is whether the authorities will be able to deliver notification messages not only to users residing in the area but also to users temporarily visiting the area (workers, travelers, commuters). The need for this capability brings back issue of locating mobile users and VoIP phones (fixed/mobile). In addition, Norreys et al. [159] specify a requirement related to the converged IP and PSTN-based network, in which the emergency notifications should be able to traverse a gateway to the PSTN.

2.4.1.4. *Human Machine Interface (HMI) Improvements and PSAPs*

With the possibility of multimedia access for NG-9-1-1 networks, the job of call takers at PSAP becomes more complex. The NG9-1-1 system will have inputs from several different sources simultaneously for the same emergency call - video or text or sensor data in addition to voice. The HMI display will offer many features:

- zooming
- links to additional information
- capability to process images, video, and text
- multiple screens or multiple windows on the same large screen to display different kinds of data
- capability to switch between different responders from different PSAPs to efficiently direct an emergency response
- capability to select a call to answer from the queue, initiate conference calls, and forward calls
- capability to map so that the call takers can select the appropriate dispatch unit based on the emergency type
- capability to access supplementary data - data that is not needed by the call taker but that may be needed by the dispatch unit (for example, the call taker need not know about the current medications the caller may be taking, but the medical dispatch unit may need that information)

The amount of information available, due to multi-media services, may be difficult to manage from a single screen. The screen may be crowded with information, affecting the operator's ability to respond, thus requiring the screen layout to be optimized. For example, supplementary data should not be displayed on the screen because the call taker does not need it, but the data should be accessible to him/her for forwarding to the dispatch unit. Because multiple screens may be needed, making it difficult to navigate between different screens and applications, the HMI display needs to be redesigned with the aesthetics of the screen in mind (for example, the font size and the display colors). With the increased complexity of input data, the need for standardization becomes apparent [50]. If computer systems in two different PSAPs cannot communicate with each other, then it would not be possible to take full advantage of these enhanced services and would require more comprehensive and thorough training for the call takers. From a network perspective, if the PSAP system has a limited bandwidth, then video and data downloads may be slow. Even though the HMI may be capable of handling multimedia input, a low bandwidth would prevent the transfer of complete information from the caller to the call taker and slow down the response time of the call taker.

2.4.2. Accurate Localization of Emergency Calls in Highly Mobile Environments

Determining the location of 9-1-1 calls is one of the main challenges of NG-9-1-1 and involves a two-part procedure. The first part is an accurate determination of the location of the caller. Second, based on the caller's location, the routing functionality needs to determine the location of the PSAP that serves the caller.

2.4.2.1. *Obtaining Caller location Information*

Since VoIP devices can get service from any IP network/any network port, VoIP service providers may not have the user's most up-to-date physical address. In most cases, it is the subscriber's responsibility to provide his/her location to the VoIP service provider; however, the subscriber may not update this information when the VoIP device is moved to a different location. Furthermore, VoIP 9-1-1 calls can be made from wireless devices; e.g., dual-mode cellular phones with 802.11 radio, laptops, and personal digital assistants (PDAs). In all cases, the Federal Communications Commission (FCC) requires the ISP to give the location of the 9-1-1 callers. In outdoor locations, GPS receivers can provide the location, but they are unreliable in urban canyons. Network-based location techniques [7] are not reliable in networks with a larger footprint compared to cellular coverage. For instance, in WiMAX networks, which are becoming popular in the metropolitan areas, locating callers is a challenge. Assisted GPS (A-GPS) [157] has been considered a potential solution for locating callers.

Determining location indoors is also a challenge, as GPS generally does not work inside buildings. There have been a number of location configuration protocols proposals to deliver location information to end systems: DHCP [94], LLDP-MED [176], HELD [113], but all of them rely on system administrators to map every Ethernet jack and wireless access point and store the correct location in a location database (LIS - location information server). Another approach for indoor location is to use Bluetooth-equipped devices that can deposit their location knowledge within a building and transmit this information to mobile users (for example, see http://www.wirelesswerx.com). Additionally, the secure transmission of the location information to the end user is an issue. Among the location protocols, only HELD provides security and information protection. In addition, the call signaling messages must be transported over the network using secure signaling protocols, such as Transport Layer Security (TLS) or IPsec with cryptographic capabilities.

2.4.2.2. *Determining PSAP location and Call Routing*

Consider the case of the user's location provided by the access network (e.g., an Internet access provider). Issues have been raised about Internet access providers that can potentially hide or not provide the detailed location of the end user [77]. Among the problems this issue may cause is the misrouting of the emergency call to the wrong PSAP. To convey location information to the PSAP, location by reference, in which the end user's location can be accessed at a remote server, can be used. However, location by reference cannot be used as an input to LoST servers for routing calls. The misrouting of emergency calls often happens for callers using cellular phones. The location provided by the cellular network usually is based on signal strength and not on PSAP locations. Call routing based on the cellular tower's location may lead to calls being routed to the wrong PSAP. This problem has been common for E-9-1-1 calls made near highways or jurisdiction boundaries (county, city, or state boundaries) [95]. Research work is needed on call admission of emergency calls in cellular networks, where knowledge of the PSAP boundaries could be embedded to the cellular base station's infrastructure to allow proper routing of a call.

2.4.2.3. *Location databases maintenance, synchronization, and security*

When the end user acquires the location information or whenever this location is updated, the end user accesses the LoST server [171, 75] to map the location to a PSAP URL, which is used to route the call. Maintenance of location databases such as LoST is an important issue. These LoST servers will usually consist of a large number of synchronized servers [74] and not simply one large server performing on its own. Hardie et al. [171] have described a proposal for a distributed and hierarchical architecture of LoST servers. These servers can be synchronized in the same hierarchical format as they are designed, as described in a recent IETF's ECRIT draft [74]. In other words, in a "query/response" communication, each level of the server hierarchy can communicate with other servers at the same level. There is also the issue of accuracy of the information in the databases. As there are changes in the road maps, new construction, and changes in the PSAP areas, the databases need to be changed.

In the NG-9-1-1 architecture, it is recommended that the location databases be located in the Emergency Services IP Network (ESN), which is a private IP-based network that interconnects the PSAPs and receives VoIP calls [185, 148, 132, 134]. As a result, there are questions on how to provide high speed, secure access to these location databases to the millions of users located in a non-secure network (the Internet), and protection to the servers against unauthorized modification. The main security mechanisms for location servers [135] are the use of Public Key Infrastructure (PKI) to verify credentials, the use of passwords, SIP authentication features, and login tracing, as documented in the NENA, i3 requirements document [131]. These procedures are needed to keep the privacy of people whose information may be stored in these databases and prevent unauthorized access.

2.4.3. Securing PSAPs: Vulnerabilities of the NG9-1-1 Network

2.4.3.1. *Securing PSAPs: prevention of Denial of Service (DoS) attacks*

The objective of Denial of Service (DoS) attacks to a computer system or network is to make this resource unavailable to its authorized users. In the emergency services context, DoS attacks can impact the availability of three types of resources: PSAP network facilities

[124, 25], both at the network layer and the call signaling level; call-taker resources; and first responders. Two types of attacks from IP-based devices were considered as security threats by the IETF in RFC 5069 [130]. The first involves the use of emergency service URN in the signaling of a non-emergency call so that the malicious caller can reach the PSAP's network resources. The second involves the location-to-service mapping [171], which can create a new form of DoS attack in which actual emergency calls are directed to a different place than the appropriate PSAP. The methods used to prevent these attacks involve providing PSAPs and the emergency services IP network with firewalls, authentication and authorization schemes, message integrity protection, content filtering, verified service provider, and verified location before forwarding a call. Such measures have been proposed by NENA [133].

However, the performance of IP-based PSAPs with respect to location identification of malicious calls and scalability are still open problems [174]. False positives mean detecting a DoS attack that is not really an attack, but an emergency overload condition (e.g., due to a large-scale emergency situation). False positives must be avoided in PSAPs because counter measures to this false attack detection will prevent actual emergency calls from being answered.

2.4.3.2. *Signaling interworking (PSTN and IP) vulnerabilities*

Another challenge is to secure PSTN-based PSAPs in the converged network (figure 2.3). The traffic from one domain can affect the performance of the other domain. The PSTN consists of thousands of interconnected network elements over dedicated circuit-switched facilities that use the SS7 (Common Channel Signaling System No.7, SS7 or C7) system, which relies on a model of trusted neighbors. These gateways have the ability to provide protocol translation between circuit and packet-based networks (i.e., SS7 and IP, respectively). Since there are no concrete security controls to prevent malicious messages traversing the SS7 network, vulnerabilities that exist in IP-based networks may propagate and thereby affect SS7 networks. The work of Sengar et al. [80] addresses several of these vulnerabilities; for example, a blind conversion of a SIP header into an ISDN User Part (ISUP) parameter.

For an emergency call that is originated at the PSTN and destined to IP-based PSAPs, one threat is the falsification of automatic message parameters such as ”caller ID,” which can lead to DoS.

2.4.4. Continuous Availability of PSAPs

2.4.4.1. *When a communication link fails*

We foresee an immediate need for highly available 9-1-1 service in the converged networks (PSTN and IP-based). This means keeping 9-1-1 sessions alive even when the PSAP or links fail in the middle of a call. This is very difficult while a session is in progress. In VoIP networks, this switching should happen within 50 ms (this is 99.999% availability and translates to 5 minutes of downtime for 1 year) [184]. During the switchover, we need to keep the existing sessions active and at the same time complete the new calls. Furthermore, when a large SIP proxy with Transport Layer Security (TLS) support goes down, it takes a significant amount of time before all the SIP user agents can re-establish a transport control protocol (TCP) connection and a security association. It can be life threatening when one tries to dial 9-1-1 and fails to complete the call due to a flood of TCP and TLS resynchronization mechanisms.

2.4.4.2. *Fault Tolerance and Redundancy*

A lot of literature is available on redundancy and fault tolerance; but by and large, they do not address the problem of transferring multilayer contexts between the active and backup nodes, particularly when changeovers in the middle of a session are required. One of the methods of achieving redundancy is by connecting one or more network processing systems in parallel and connecting each network processing system to its redundant mate. The redundant network processing systems continuously exchange the state information using out-of-band network.

2.4.5. Addressing the Challenges in the NG-9-1-1 Architecture

Figure 2.2 illustrates the architecture and protocols of a successful deployment of NG9-1-1 system that also addresses some of the challenges mentioned in the previous sections (based on the "system of systems" defined in NENA [134, 137]. IP-based end devices receive their physical location from any number of LCPs (DHCP, HELD [113], LLDP-MED, GPS, etc.) and query the LoST server with that location for the correct PSAP URI. In the event of an emergency call, the correct PSAP will be contacted regardless of whether it is PSTN-based or IP-based. Each call must be made under a secure SIP transmission and carry location information encapsulated within a PIDF-LO document. If the call reaches a PSTN-based PSAP, the receiving SIP proxy must translate the IP messages to the SS7 gateway for secure delivery over the PSTN network. If the call reaches an IP-based PSAP, security measures must also be taken to ensure that the caller's location will only be accessed by the appropriate parties such as the PSAP call taker and the necessary authorities. For highly mobile users, we envision more dynamic location systems provided by the environment. If GPS is not available, the use of location-aware sensors or special devices, and even neighboring users in a peer-to-peer fashion, might be able to wirelessly inform the mobile device of its location. However, attention must be placed on the format and security of the location information when using different location techniques. Moreover, the interoperability between PSAPs and different location configuration protocols must be carefully validated. To ensure continuous availability, the timely re-routing of calls between IPbased PSAPs and successful transfer of media context is required; and the SIP protocol must be able to support that. In addition, a SIP-based third-party call controller (3PCC) must be available not only to ensure the handling of calls at the PSAPs [185] but also the communication between emergency responders and other public safety agencies.

The implementation of the security protection on the border of the Emergency Services Network (ESN) has been discussed in a NENA document [137] that shows the use of Session Border Controllers, which receive the SIP messages before the messages are sent to the Emergency Services Routing Proxy. Border Session Controllers can be seen as firewalls for VoIP applications. This solution is still under discussion as there are scalability and reliability issues for using such devices to intercept and filter all emergency call requests.

2.4.5.1. *When there is a large-scale emergency*

During mass casualty events, each incident is likely to trigger dozens or hundreds of calls, as callers independently call 9-1-1, largely reporting the same information. Often, such redundant calls can be identified on the basis of their location. With IP-based PSAPs, calls that overflow the primary PSAP can easily be redirected to other PSAPs outside the affected area or even to third parties, such as Red Cross volunteers. The advantages of VoIP services have been observed during disaster relief operations in the last few years. VoIP services provide a backup to the traditional PSTN services. VoIP technology has been used by several entities like the FEMA, the Red Cross, the army, hospitals, emergency responders, call centers, utility workers and also private businesses affected by disasters to restore services. This backup can be achieved by moving the communications services equipment outside the affected buildings. VoIP is proving to be an efficient and effective disaster recovery solution, for example during the Katrina disaster and the Mississippi floods. After Katrina disaster, the New Orleans city officials, hospitals and homeless shelters relied on VoIP-based services for several days. The storm had knocked out millions of phones lines, cellular sites and also emergency call centers. VoIP based services provided a quick and reliable back-up to restore communications. When Mississippi faced vast floods, VoIP network was able to provide relief to the affected areas by critical communications to the relief agencies. This shows the robustness of this technology as the basic landline services had failed during the crisis.

2.5. Current and Future Work

2.5.1. NG-9-1-1 Progress

A prototype of a NG-9-1-1 is described in the work of Kim et al. [192]. More recently, a proof-of-concept NG-9-1-1 system was demonstrated at SIGCOMM 2008 [185]. It showed calls, with different media types, originating at different access networks (e.g., PSTN-based devices, and IP-based devices). The calls were routed to emergency services router proxies (ESRPs) and directed to IP-capable PSAPs. At the PSAPs, a third-party call controller handled the calls, directed them to call takers, and allowed a conference system with emergency responders. This NG-9-1-1 proof-of-concept was the result of a project sponsored by the USDOT, implemented by students at Columbia University and Texas A&M University, and managed by Booz-Allen Hamilton. The system implemented in both universities was able to test calls originating at Booz-Allen Hamilton's office to PSAPs in different locations throughout the country. The NG-9-1-1 proof-of-concept represents a critical step and an important building block to validate the IP-based NG-9-1-1 system. It allowed the testing of IP-based emergency calls to IP-based PSAPs based on five main scenarios: calls from traditional wireline phones, calls from cellular phones, text messages (SMS), telematics service messages (e.g., automatic crash notification system), and calls from fixed/enterprise VoIP devices. In this testing, location conveyance in the signaling messages using PIDF-LO was implemented. Emergency call routing using LoST protocol and ESRPs were also validated.

In the NG-9-1-1 proof-of-concept, the idea of using ESRPs for policy-based routing was tested and showed the flexibility to re-route emergency calls to any PSAP (e.g., PSAPs that are not overloaded or PSAPs with special capabilities, such as with operators who understand sign language). Note the extension of this idea that a PSAP can now be anywhere, even in a mobile device such as laptop. This proof-of-concept and all the technology behind it will require people to adapt to this new idea, in which a PSAP does not have to be a centralized call center as before but rather can be a much more flexible, portable, and less costly system.

However, the NG-9-1-1 proof-of-concept showed the need for much more work, mainly to address the challenges covered in Section 2.5. Standards are still being developed; and work is needed to define the operational policies, not to mention the transition issues that need to be solved to allow for widespread use of NG-9-1-1 services.

2.5.2. Future Work - A New NG-9-1-1 Test Bed

The standards being developed by IETF, NENA and other standard bodies represent the future of telecommunication networks, which are a critical infrastructure for emergency communications throughout the world. However, there is no measured data on the scalability and vulnerability of these protocols. Hopefully, a test-bed will fuel the research on this emerging area, and make the deployment of the NG-9-1-1 system feasible in the next 4-10 years. As a follow-up to the DOT's NG-9-1-1 proof-of-concept project, a test bed and experiment with the NG9-1-1 system will be developed. It is a multiuniversity project (geographically distributed) funded by the National Science Foundation (NSF). The test bed will support experiments that can be used for research and development of NG-9-1-1 services [152]. Early implementations of the test bed will concentrate on the core 9-1-1 functionality and the issues related to high availability, security, and disaster recovery.

CHAPTER 3

EFFECTIVE CPR PROCEDURE WITH REAL TIME EVALUATION AND FEEDBACK USING SMARTPHONES

3.1. Introduction

Cardio Pulmonary Resuscitation (CPR) is an emergency procedure performed on people under cardiac arrest and on people who stop breathing due to reasons such as drowning [128]. CPR's main benefit is that it maintains blood flow, which prevents tissue and brain damage. The procedure involves creating artificial blood circulation by applying rhythmic pressure to a person's chest. The blood then carries oxygen to body organs.

References to resuscitation attempts can be found in ancient texts that date back thousands of years [181], but the first known attempts at resuscitation in modern times occurred in the 18th century. Practitioners, then, used various techniques to resuscitate a person who was unconscious or not breathing. These included blowing air into the mouth, massaging the chest, tickling the throat, or applying manual pressure to the abdomen [144, 56, 37, 178]. These methods were most effective when used for drowning victims. Over the years, practitioners refined the techniques, and until 1950s, the accepted resuscitation method was applying back pressure and arm lifting [56]. James Elam developed the currently used CPR method in 1954 [177]. He along with Dr. Peter Safar demonstrated the superiority of their CPR method to earlier methods. Their method used chest compressions in combination with periodic mouth-to-mouth breathing. Latest guidelines from the American Heart Association have modified the Elam and Safar CPR approach; the AHA recommends using Continuous Chest Compression (CCR) because this approach works better than periodically stopping compressions for mouth-to-mouth breathing [128, 153, 104, 57, 65]. The first organized attempt to make citizens part of the emergency procedure in cases of cardiac arrest was made in Seattle in March of 1970 [35, 40]. Fire department personnel were trained in CPR so that they could perform it on the victim before paramedics arrived to attempt defibrillation. The data gathered from this exercise proved that when CPR was started within 2-3 minutes of the event, survival chances increased. In 1972 the project was expanded to train over 100,000 people [36]. Over the years, community-based CPR training of general public has expanded across the United States. In 1981, Washington State started a program to give telephone instructions for CPR [39, 55]. Emergency professionals learn to provide CPR instructions to the callers before the paramedics arrived. This increased the rate of bystander-provided CPR by over 50%.

3.1.1. Effective CPR

Effective CPR consists of the following procedure [128, 181]:

- Lay the person flat on his back.
- Place your hand flat on the person's upper chest between the nipples. For infants only two fingers are used the middle finger and the index finger. For adults only, place your second hand above the first hand (for children only one hand is used).
- Start applying pressure to compress the chest.
- The recommended rate of chest compressions is about 100 per minute.
- The depth of chest compression is about 2-2.5 inches for adults, about 1-1.5 inches for children, and about 1/3 inch for infants.

Original AHA guidelines emphasized A-B-C as a CPR guideline. In the acronym, A stands for airways, meaning that the person giving CPR needs to make sure that the airways are open; B stands for Breathing, meaning that the person giving CPR does mouth-to-mouth breathing; and C stands for Chest Compressions. In traditional methods, periodic mouth-to-mouth breathing is also done to replenish oxygen supply, but newer guidelines suggest that continued compression is more important. The acronym has been modified to C-A-B. Consequently, mouth-to-mouth breathing has now become the third, optional, portion of CPR [128, 181]. The primary reason for the change is that most bystanders or paramedics hesitate to use mouth-to-mouth breathing with unknown people because mouth-to-mouth breathing may cause spread of infectious diseases [24, 21, 164, 186]. Apart from concerns over infections, there has also been discussion on how often to give mouth to mouth breathing. Normally there is enough oxygen in the blood stream to only do continuous chest compressions. Breathing is needed only if the oxygen saturation in the blood stream falls. Since an oximeter may not be available at that moment, there is no way to determine the oxygen level; therefore, it is difficult to determine whether mouth-to-mouth breathing is required. Making mouth-to-mouth breathing optional ensures that chest compression begins within the critical survival window.

Experts are also debating the need to give mouth-to-mouth breathing in cases where the blood oxygen saturation level falls. A person's Blood Oxygen Saturation Level (BOS) indicates how efficiently a body's blood cells retain oxygen. Cardiopulmonary Resuscitation is performed to force the movement of oxygenated blood through the circulatory system and prevent the damage of vital organs in the body. The level is measured by analyzing the ratio between the amount of oxygenated hemoglobin and the total amount of hemoglobin present. The ideal ratio ranges from 95% to 100%. Among other things, BOS level ranges can help to determine a person's risk of lung disease and tissue death. This chapter, however, focuses on the BOS level's ability to determine the Cardiopulmonary Resuscitation's efficiency. With the knowledge of a victim's blood oxygen saturation level, the decision to give mouth-to-mouth breathing may be necessary to keep oxygenation at a healthy level.

3.1.2. Use of Technology for Effective CPR

Over the years, awareness amongst the general public that CPR can be a lifesaving procedure has increased. There is a growing use of technology that aids people in performing CPR. Several devices provide CPR training. These devices improve the quality of CPR by providing feedback on proper placement of hands on chest and the correct frequency and depth of compressions [193, 19, 105]. Mechanical devices which give accurate frequency and depth of chest compression provide automatic CPR. Studies have shown that these automated CPR devices improve the survivability of patients who need out-of-hospital CPR [97]. During an emergency it is likely that a person trained in CPR may not be available. In such situations 9-1-1 operators help the caller to administer CPR by giving instructions over a phone. In such instances, a readily available technology would be useful in ensuring that people untrained could deliver CPR properly. Recently smartphone applications have provided video instructions on how to give CPR [100]. If the application is not available, a 9-1-1 operator can help in downloading that application. However, having to download the application and then watch the video seriously reduces the window of survivability for the injured person. Alternatively, there exist devices that give real-time feedback on the quality of CPR [66]. This chapter reports on such a real-time feedback application that I have developed.

3.2. Motivation

During an emergency situation, it is highly likely that persons trained in CPR are unavailable. Even though devices can provide automatic CPR, these devices are highly unlikely to be accessible at the time of need. In such cases, an untrained person will need to administer CPR. In these situations, 9-1-1 operators provide CPR instructions over a phone. However, the success of such an approach depends upon the emotional and physical capabilities of the person actually administering the CPR. With newer technology, the operator may even attempt to send video instructions, which may assist in improving the CPR given. However, again, the 9-1-1 operator may not have all the information necessary to determine whether the CPR is being done efficiently and helping the injured person.

Currently, 9-1-1 operators cannot evaluate the results of CPR remotely and, in fact, there is no proven method to evaluate CPR effectiveness even when a trained person is giving the CPR. In this chapter, I present a method to evaluate CPR performance in real-time without the need of special devices. Using the sensors in a smartphone, such as an accelerometer, I describe an application that can evaluate and guide a person in giving effective CPR while providing timely feedback to the 9-1-1 operator. Figure 3.1 depicts a flow chart of a CPR evaluation system. A mobile phone controller (box 1) holds an algorithm to evaluate data from sensors (box 3). The system (box 2) consists of the affected person and the person giving the CPR. A feedback loop to the System (CPR giver) provides corrective action.

As mentioned in prior sections, continuous chest compressions have been emphasized

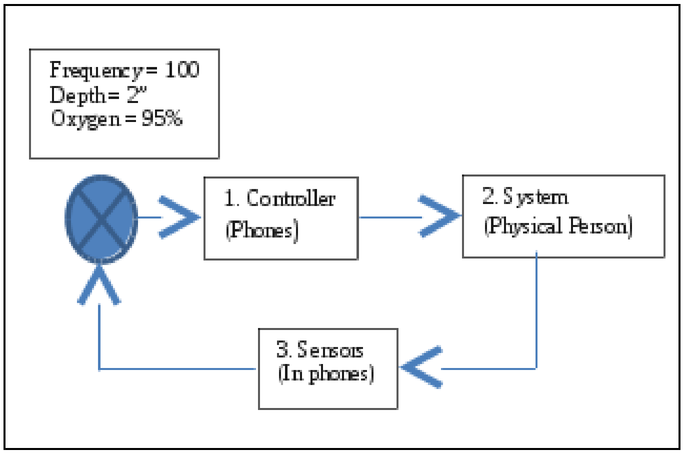


FIGURE 3.1. Flow Chart of a CPR Evaluation System. The smartphone's sensors provide feedback about chest compression frequency and depth, and about blood oxygen saturation levels.

over cardiopulmonary resuscitation as the most critical CPR procedure to perform in an emergency. That said, mouth-to-mouth breathing remains a viable option in certain cases, especially when trained personnel are present. I present a smartphone application which measurers the blood's oxygen saturation level without specialized equipment. In conjunction, one smartphone can be used by the person giving the CPR where it measures the frequency and depth of compressions. A second smartphone can then be used to measure the oxygen saturation level. The data from these smartphones is continuously reported to the 9-1-1 operator who can use the information to guide the CPR giver. A patent has been filed by one of the authors for devices that can measure the vital signs using sensors of the smartphones [44]. Figure 3.2 summarizes how CPR could be enhanced with these devices.

3.2.0.1. *Issues and Source of Errors*

Calculating depth using an accelerometer does not present a trivial task. It involves integrating acceleration readings to compute velocity and further integration of the calculated velocity to find the displacement or distance of movement. This error-prone process requires a sophisticated algorithm to determine the displacement. Several sources of error may arise in this process:

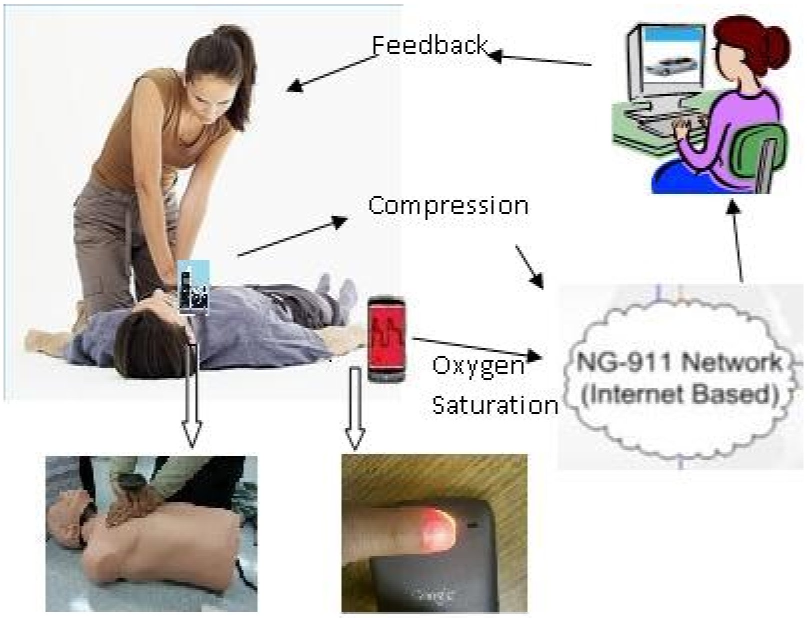


FIGURE 3.2. CPR and Its Evaluation. The compression frequency, depth and the oxygen saturation levels are reported to the 9-1-1 operator. The person giving CPR has a phone tied to the hands, as shown in the picture below the arrow. A smartphone is also placed near the hand of the person receiving the CPR with finger on the camera lens as shown in the second picture below the arrow.

- Errors inherent in the accelerometer or caused by noise from the electronic signal.
- External errors: errors caused by force applied to the accelerometer such as lateral movements of the hands during CPR or movement in a vehicle when a patient is being transported while receiving CPR.
- Error due to drift: these errors are introduced during the compression of the chest. For example, the chest may not fully recover to its normal position before the next compression is started. This drift results in the device reporting an incorrect starting position of the compression.

Unfortunately the process of double-integration on these readings compounds these accelerometer reading errors - even a small error can produce large variation in calculated displacement.

Measuring blood oxygenation levels using a smartphone is even trickier because the method has to be non-invasive, should not require additional devices, and should be simple and quick for anyone to use, even if not a health professional.

3.2.1. Methodology for Measurement:

This section discusses the methods to measure the frequency and depth of chest compressions and the oxygen saturation levels using smartphones. These three figures can guide persons administering CPR, even when they lack CPR training.

3.2.1.1. ***Frequency of compressions:***

An accelerometer measures acceleration of movement in the x, y, and z axes. When people lie on their backs, chest compressions are in the direction of the Z axis. So, each upward movement is considered to be negative acceleration; each downward movement is considered to be positive acceleration. A complete up and down movement counts as one compression. I, therefore, calculate the frequency of compressions as up-down movements.

3.2.1.2. ***Depth of compressions***

The compression depth is calculated using the acceleration measurement. The accelerator sends measurements to the smartphone's processor every few milliseconds. The processor, in turn, calculates the compression depth. Travers, et al. offer a basic theoretical framework for measuring distance (depth) from acceleration [181]. Their straight-forward approach is to:

(1) Calculate velocity from acceleration as follows: Given acceleration (a) and a period of time (t), it is possible to calculate the change in velocity during the relevant time period. If the original velocity is available, the change in velocity at the end of the time period is calculated using the equation:

$$\Delta v = at \tag{1}$$

where Δv is the change in velocity during time period t. If the velocity at the start of the time 0 is v_0, then velocity at time t is:

$$v = v_0 + \Delta v \tag{2}$$

(2) Calculate the distance as follows:

$$\Delta d = \frac{(v_0 + v)}{2} * t \tag{3}$$

where Δd is the change in distance, v_0 is the velocity at time 0, and v is the velocity at the time t. If d_0 is the distance at time 0, the distance at the time t is:

$$d = \Delta d + d_0 \tag{4}$$

Unfortunately, these calculations assume a straight-line motion, which is not the case for CPR. CPR measurements, instead, resemble sine curves. Consequently, I require other methods to calculate displacement. More importantly, I need to calculate displacement in real-time. This means I need to find velocity and displacement while the accelerometer readings are still being logged, and so I need to use numerical methods that allow for integration on data readings as they are logged. One method, trapezoidal rule, offers an approximation technique for calculating the integration.

The existing literature on calculating displacement from accelerometer readings is based on devices that are dedicated to CPR compressions. Dedicated devices can be calibrated accordingly. In most emergency situations special devices may not be easily accessible, but a smartphone with an accelerometer is more likely to be available. The project assumed that an untrained person administers the CPR and does not have access to such dedicated devices. I was unable to collect experimental data when CPR is performed on actual person. For obvious reasons it is not feasible to perform CPR on healthy people. I could collect data in CPR classes which use manikins that simulated chest compressions. For the experiments, I collected data by placing the smartphone in the middle of the chest.

3.2.1.3. *Blood Oxygen Saturation level:*

The Blood Oxygen Saturation Level is determined by using the camera lens of the smartphone [71]. Pulse oximeters measure the visible and infra-red spectrum of the oxy-hemoglobin and de-oxy hemoglobin, respectively. A pulse oximeter works by exploiting particular properties of light. When light passes through a substance (such as blood), the substance absorbs a certain amount of light. The amount of absorbed light depends on the sample's concentration, the sample's absorbance capacity, and the light's path length. The BOS level is calculated using Beer-Lambert's law:

$$A = abc \tag{5}$$

where, A is absorption; a is molar absorptivity of the sample, c is concentration of the sample, and b is path length.

Oxy-hemoglobin (HbO2) and deoxy-hemoglobin (Hb) absorb light at different wavelengths. Oxy-hemoglobin (HbO2) absorbs more infra-red light than deoxy-hemoglobin (Hb); Hb absorbs more red light. The color red is in the spectrum 660nm. The infrared spectrum has a wavelength of 820nm-950nm. Oxygen saturation is calculated using the following relation:

$$SpO2 = f(\phi); where\ \phi = (\frac{AC_{red}/DC_{red}}{AC_{ir}/DC_{ir}}) \tag{6}$$

3.3. Experiments and results

I conducted several experiments to collect data. During each data collection, problems were encountered that required resolution. In this section I discuss issues encountered during data collection and the steps I took to resolve them.

One of the first problems resolved concerned placement of the smartphone on the person receiving CPR. CPR cannot be performed if the phone lies directly on the chest. Such a placement can be extremely uncomfortable and can cause injury if the smartphone is pressed against the chest during CPR. Placing the smartphone between the palms of the person giving CPR is also not feasible. The screen may crack under pressure. Additionally,

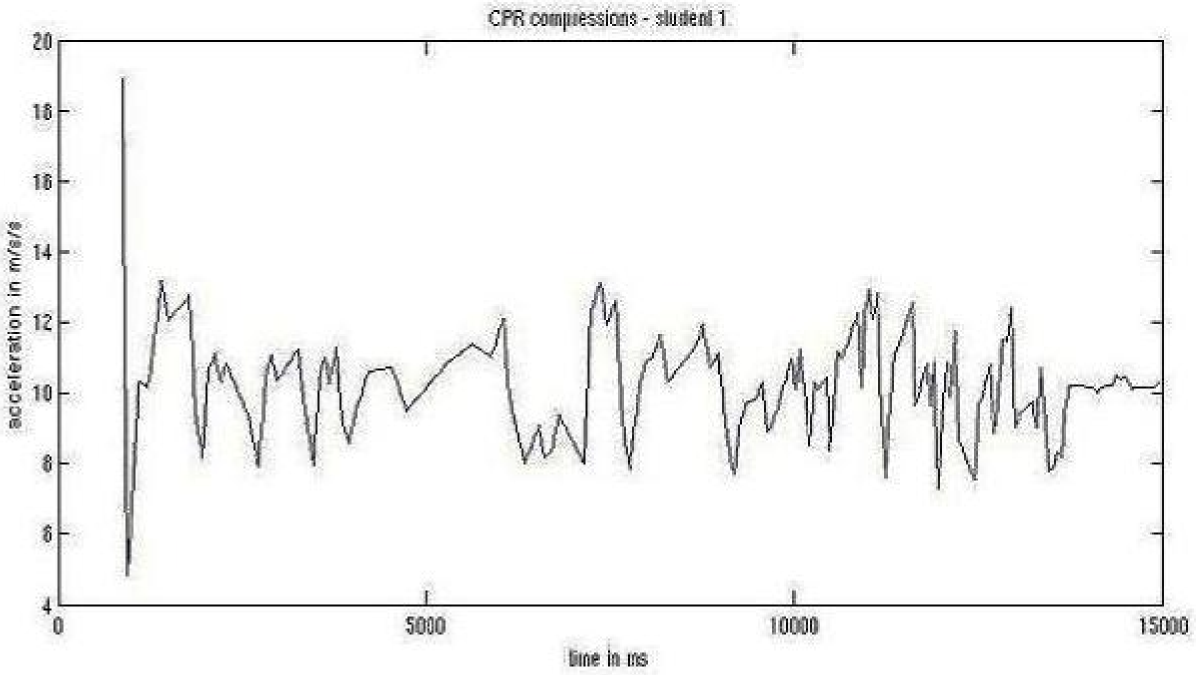


FIGURE 3.3. Accelerometer Readings Plot for Student in CPR Training. Compressions are not uniform over time. Depth is inconsistent over time.

this placement is uncomfortable for the person giving the CPR. The ideal solution was to place the phone above the hands of the person giving the CPR (Figure 3.2). In these experiments, I tied the smartphone to the hands so that it did not fall off. This can be done by any piece of cloth such as a shirt or undershirt. Another issue that needed to be resolved was which type of manikin to use. There are two kinds of manikins used for training: a soft-chest (sponge) manikin and a hard-chest manikin. Figure 3.3 shows the accelerometer plot for a student performing CPR on a soft-chest manikin; Figure 3.4 shows a similar plot for an instructor performing CPR on a soft-chest Manikin. Figure 3.5 shows the same instructor doing CPR on a hard-surface manikin. It may be observed that the best results were from the instructor doing the CPR on a hard-surface manikin. I used a hard Manikin to test my algorithm.

3.3.1. Algorithm for calculating Frequency and Depth of Compressions

Calculating the frequency of CPR compressions is done with an accuracy of greater than 95%. When the accelerometer moves towards gravity, the acceleration is considered

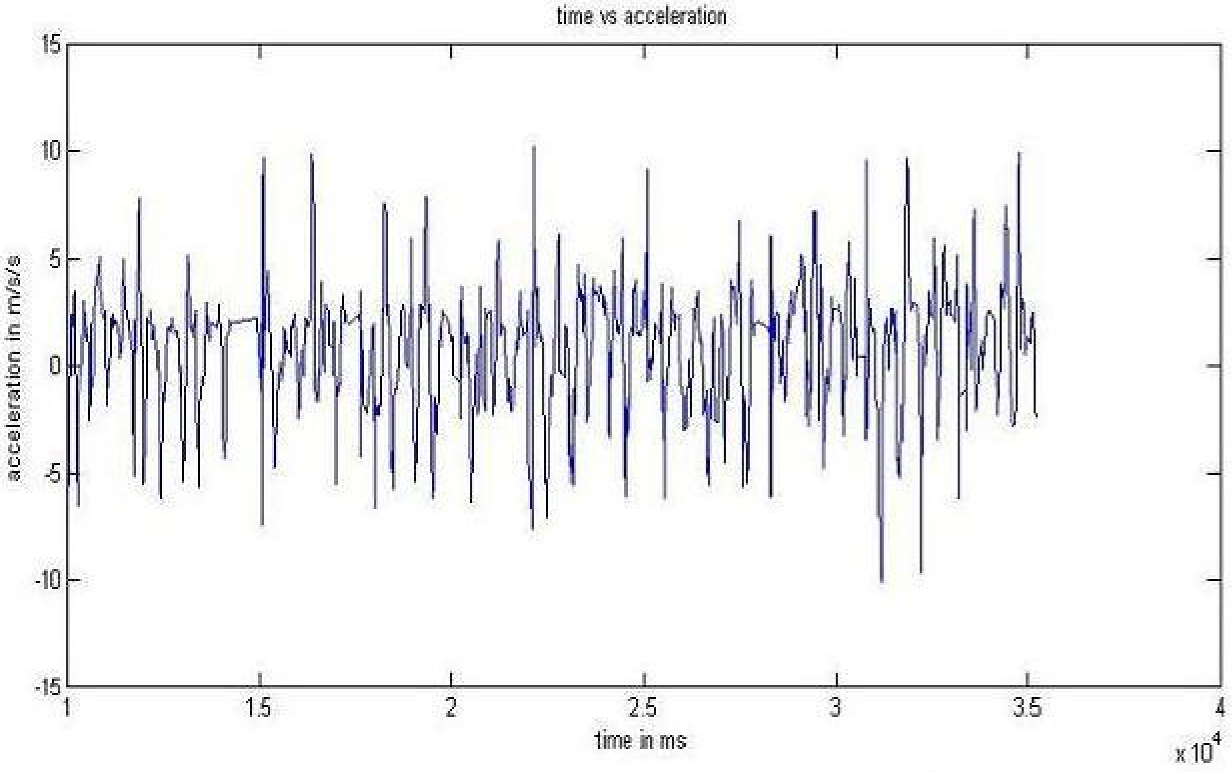


Figure 3.4. Accelerometer Readings for Instructor Doing CPR Using a Sponge Manikin.

positive and when it moves against the gravity, it is considered as the negative direction. I count the number of times the accelerometer readings show a change in the sign of magnitude from positive to negative number.

However, calculating depth of compression is subject to errors from several sources, and so I fine-tuned my algorithm to reduce the influence of such errors on the results. In this section I document efforts to improve the accuracy of calculation of depth of CPR compressions. When I used a simple method of double integration to calculate the compression depth (see Figure 3.6), the depth of compression varied up to 40 cm. The method needed correction to more accurately measure compression depth.

The first issue to resolve is the granularity of accelerometer measurements. During the first attempt at collecting the CPR data, I used smartphone model Google-1. This accelerometer logged in its readings with time gaps between tens of milliseconds and hundreds of milliseconds. As a result, the calculations derived from these readings were inaccurate

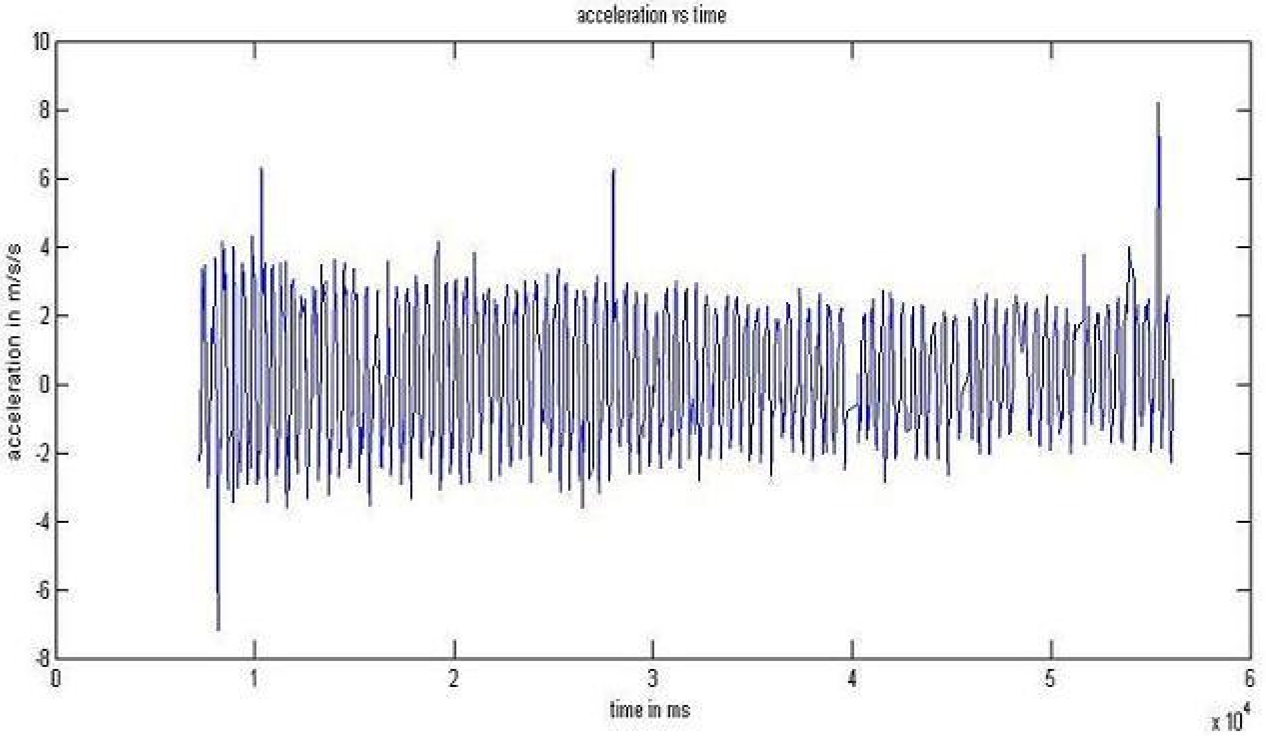


Figure 3.5. Accelerometer Readings for Instructor Doing CPR on Hard Manikin. Compressions are uniform over time. Depth is consistent over time.

and inconsistent. One of the reasons for this was the large time gap in the readings. The integration function uses the magnitude of acceleration and velocity over the time period between two successive readings. So, if the time between two successive readings was large, the algorithm calculated too large a displacement value. A more modern version of the smartphone [Samsung Galaxy] provided a higher granularity of readings, giving more than 100 readings per second. Furthermore, the readings are spaced at a more uniform time gap, increasing the accuracy of depth calculation. A major change in the basic algorithm to calculate the depth used the fact that CPR involves restricted and repeated movements in a vertical direction.

As mentioned earlier several sources can cause errors in displacement measurement. I found even a minor error in the acceleration magnitude results in a large error in displacement measurements. One way to reduce such errors employs calculating a rolling average of velocities. I modified the algorithm to calculate a rolling average after a number of accelerometer

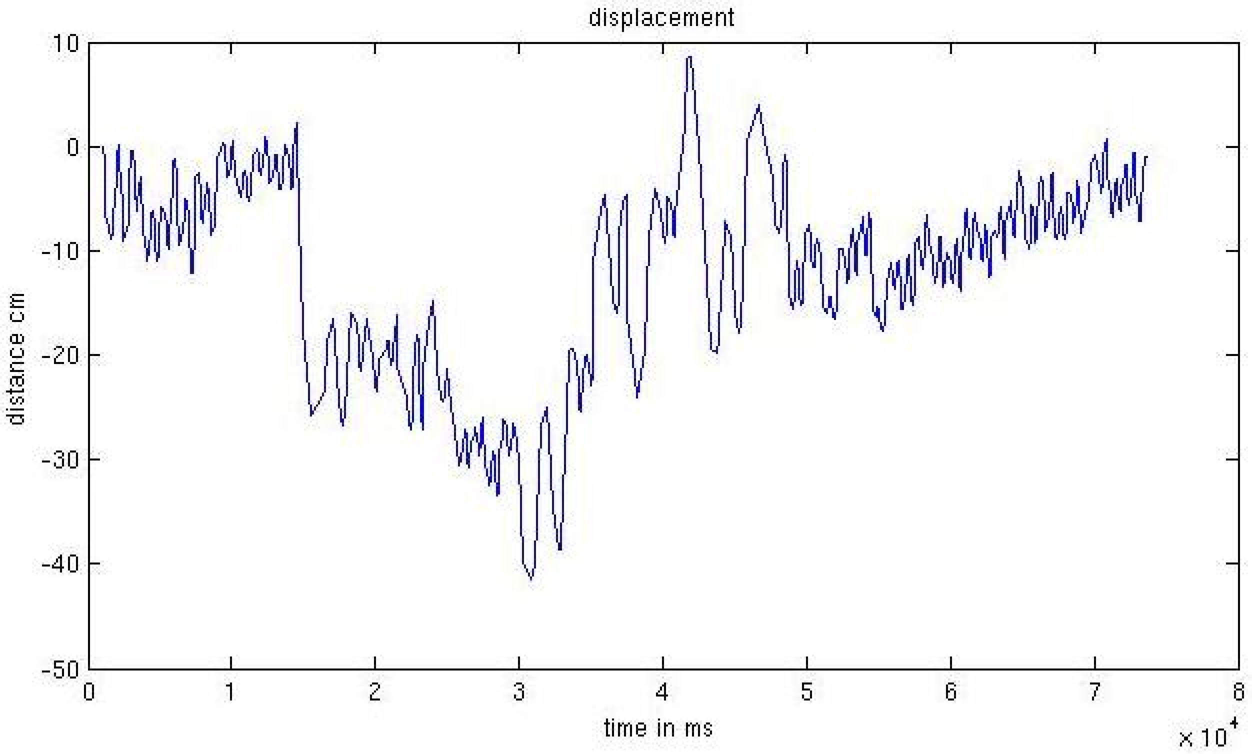


Figure 3.6. Calculation of CPR Compression Depth Using Simple Double Integration Without Using Correction. Calculated depth is out of range. Errors over time accumulate.

readings were logged.

Finally, the following method to reduce the errors has proved to be the most promising. First, I took advantage of the fact that CPR movements are in vertical direction and are repeated motions within a range of 2-2.5 inches. I used this fact to reset the calculated velocity to zero each time the motion changed direction. Note that compressions have zero velocity points twice during each chest compression - velocity is zero at the start of the compression, but the velocity also returns to zero when the chest, fully compressed, starts to return to its normal position. I determined these two points and reset the velocity to zero, even when the calculated velocity was not zero. This avoided error build up. Similarly, I reset the depth calculation to zero at the start of each compression, even though the calculated depth might be non-zero. Figure 3.7 shows a plot of the acceleration magnitude and the corresponding velocity and the calculated distance.

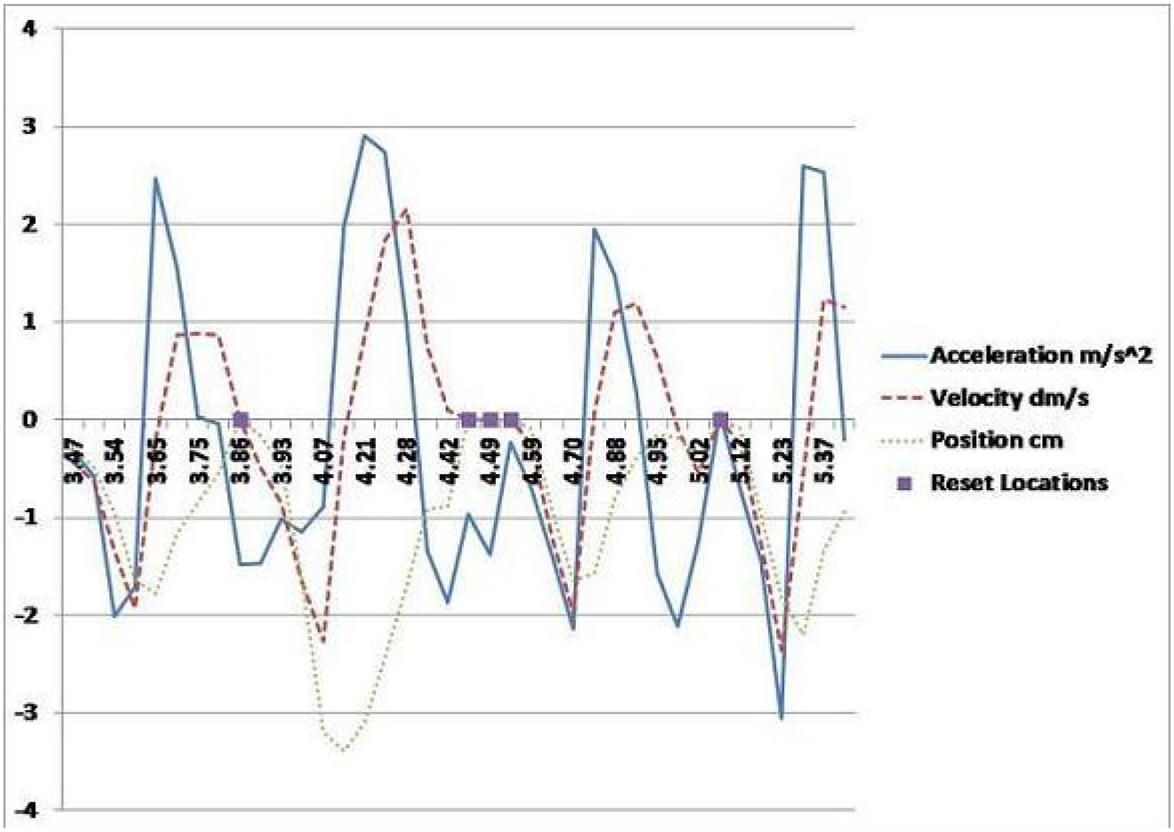


FIGURE 3.7. Acceleration, Velocity and Distance. Dots indicate points where velocity is reset to zero.

The bold dots show the points where velocity is reset to zero. This solution localized errors of magnitude to within one compression, which provided further correction to errors that build over time. Particularly, this adjustment to the algorithm reduced error caused by drift.

3.3.2. Accuracy of the Distance Calculation

In this section I describe the method used to determine the accuracy of distance calculations. The experimental setup consists of the following steps:

- Write an android application to calculate the CPR depth from the smartphone's accelerometer.
- Use a commercially available manikin designed for CPR training to collect data. The force required to press the manikin's chest matches the actual force required to press a human's chest during a real CPR.

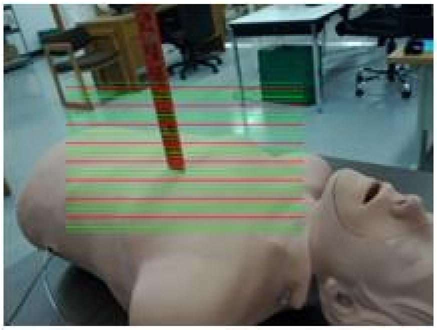


Figure 3.8. Manikin for CPR. Lines of scale are superimposed to calibrate movement as the manikin chest is compressed.

- Use a Mobotix camera to record CPR compressions. The professional security Mobotix camera allows us to study video frame by frame and determine actual depth of compression.
- Compare the calculated CPR depth for each compression with the actual movement observed on video.

Figure 3.8 shows the manikin used in the experiments. I overlaid a scale on the image to allow us to calibrate the actual movement during CPR as compared to the observed movement on the video frame. As CPR was performed, the smartphone recorded the calculated depth in a file. The Mobotix camera recorded the CPR process in a file. After recording 40 seconds of CPR, the video file was played frame by frame and the actual depth of CPR was measured. My algorithm then compared the two to determine the difference between the actual depth of compression (as observed on the video frame) and the depth calculated by the application.

3.3.3. Results

In this section I present the experimental results. I discuss the application's accuracy of depth calculation. The application prompts the CPR giver to increase or decrease the depth of chest compression to meet the 2-2.5 depth requirement. I, also, discuss the accuracy with which the application provides alerts. Similarly, the application gives a prompt when the frequency of compressions is not within a range of 90-100.

I conducted experiments using 40 volunteers. Each volunteer performed CPR for

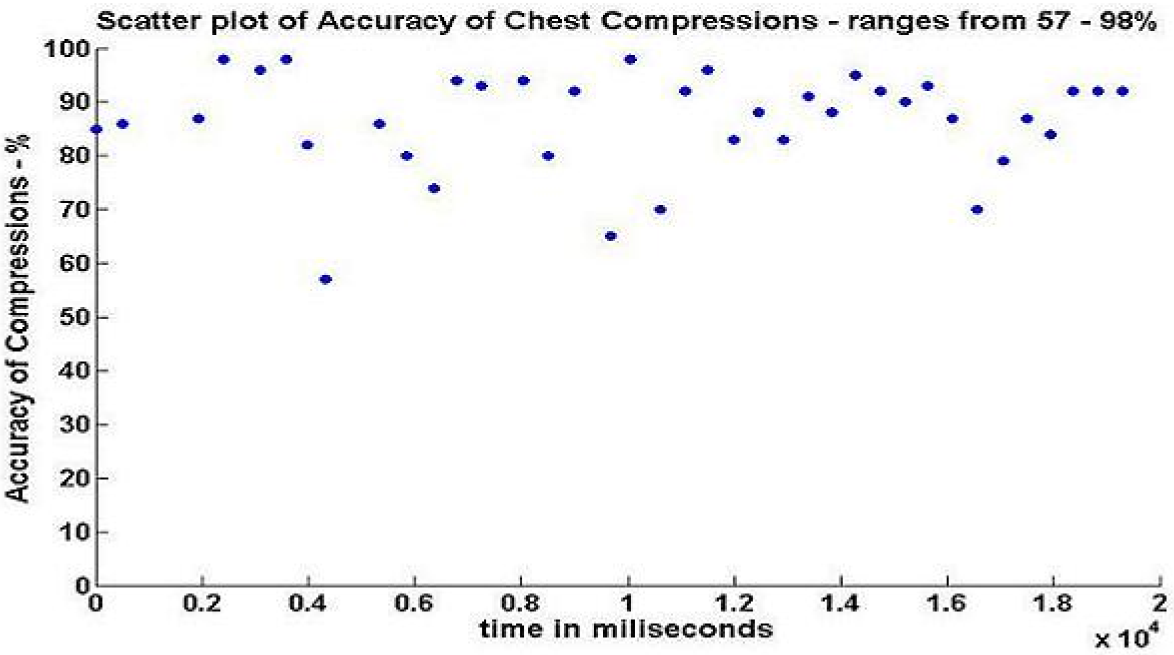


FIGURE 3.9. Accuracy of Each Compression as Calculated by the Application for One Volunteer. The range is from a low of 57% to a high of 98%.

about 30 seconds. The number of compressions volunteers performed during these 30 seconds ranged from 30 to 50. Figure 3.9 shows a scatter plot of each compression for one subject. It shows the accuracy of the depth calculation done by the application as compared to the actual depth as observed in the Mobotix video. The application's accuracy ranged from a low of 57% to a high of 98%. The other 39 subjects had similar ranges of accuracy.

3.3.4. Accuracy and Frequency of Alerts

In the previous section I discussed the accuracy of the application to determine the depth of compression. The focus was on how accurately the application can calculate the depth as compared to the actual depth. In this section I focus on the frequency and accuracy of giving alerts.

As has been noted earlier, the person administering the CPR must accurately judge whether the chest has been compressed to the recommended depth before releasing the chest to return to normal. The application gives an alert when the depth of the compression falls outside an acceptable standard range. One of the questions I had to answer was "When

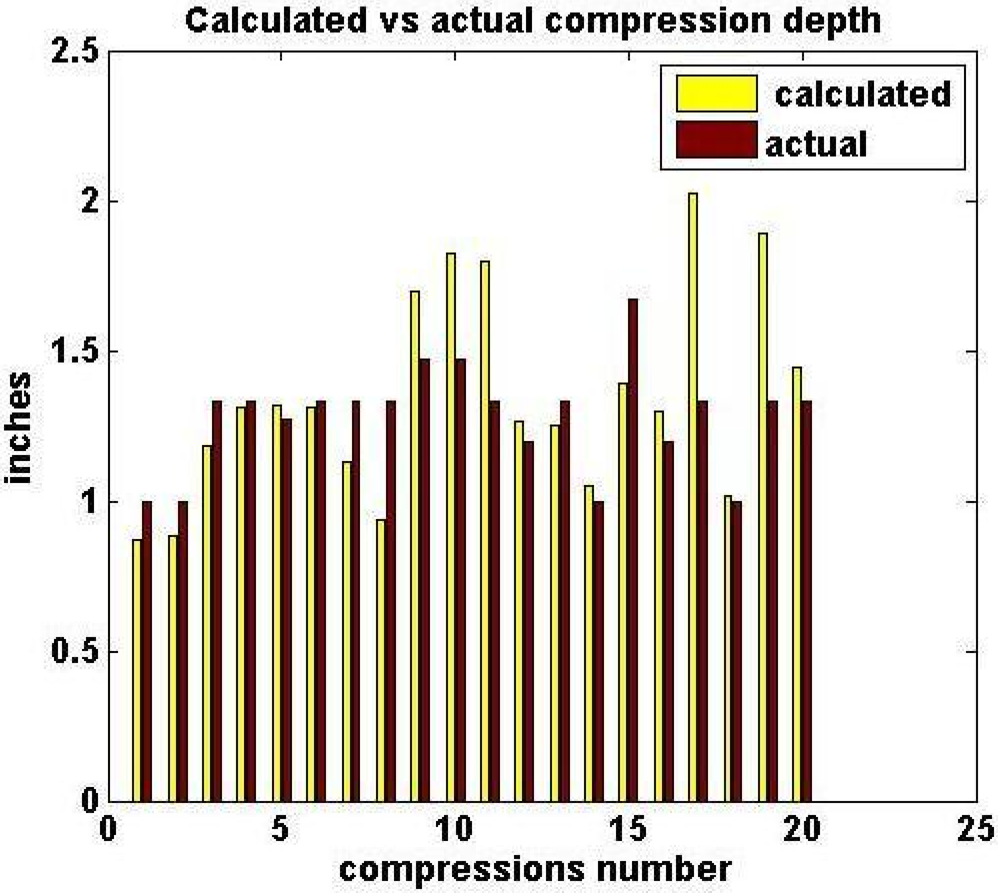


FIGURE 3.10. Comparison of Calculated Compression Depth and the Actual Compressions Depth for an Individual.

should the application provide an alert?” One of the factors I considered was the accuracy of application’s calculation. If the accuracy of a particular calculated depth of compression is low, then the decision to provide an alert by the application may be inaccurate. Figure 3.10 shows a bar plot comparing the actual compression depth and the calculated compression depth for the same volunteer as in Figure 3.9. It may be observed that the calculated depth value reaches near 2 inch value for many compressions, but the actual depth never reaches the 2 inch value. So, for these compressions, the algorithm will not give an alert, even though it should have given one. I address this issue by averaging the calculated depth over a period of time. Some of the calculated errors have a positive magnitude and some have a negative magnitude. So an average provides a better accuracy. Table 3.1 shows the accuracy of average over different time durations ranging from 1 second to 10 seconds.

A second factor is alert frequency. It is not feasible to alert for every compression. Too frequent alerts can overwhelm the person giving CPR. A person requires a few seconds to understand and respond to an alert. By the time the person reacts, another alert may already have sounded. This leads to confusion and the person may not be able to adjust their compressions accurately and in a timely manner.

I did an analysis to decide how frequently the alert should be given (Table 3.1). When the application gave an alert for each compression, out of a total of 38 alerts (for 38 compressions in that session), 21 alerts were less than 90% accurate. This means that for 21 alerts the accuracy of calculated depth as compared to the actual depth was less than 90%. When the application gave an alert every second, I averaged the calculated depth of all compressions within each second. As Table 3.1 indicates, the total number of alerts for one second will be 20. Of these 9 alerts will be less than 90% accurate. When the application gave an alert every 6 seconds, then 4 alerts were more than 90% accurate. I continued this analysis through 10 seconds. At 10 seconds, the application gave two alerts, each 100% accurate. I conclude that the accuracy of alerts increases when an alert is given every few seconds rather than for every compression. The accuracy improves because the errors with negative magnitude adjust the errors with positive magnitude with in the time period. So the overall accuracy improves. Within the 6-7 second range, the application's accuracy is reasonable at more than 90%. But, the experiments suggest an alert every 6-7 seconds does not provide persons giving CPR enough time to adjust their CPR compression depth. The experiments also suggest that an optimum time for giving alerts is every 10 seconds. However, I still need to decide the optimum time gap between alerts.

As explained, alerts provide feedback to a person giving CPR so that person can adjust the compression depth or frequency to fall within a prescribed range. Figure 3.11 shows a scatter plot of the compression depth for one subject. The duration of CPR session depicted in this plot was 120 seconds. The application issued alerts when the compression depth fell below 1.5 (Low Alert) or rose above 2.5 (High Alert). Initially, the compression depth was 1.4. The application provided a Low Alert at 10 seconds and then, again, at 20

Frequency of Alerts	Total Alerts	Accuracy Range for Alerts				
each compression	38	6	7	8	12	5
1 second	20	3	3	3	8	3
2 second	10	0	0	3	4	3
3 second	7	0	0	3	2	2
4 second	5	0	0	1	3	1
5 second	4	0	0	1	2	1
6 second	4	0	0	0	4	0
7 second	3	0	0	0	1	2
10 second	2	0	0	0	0	2

TABLE 3.1. Accuracy of Alerts Over Time. The rows show accuracy for alerts given for each compression, and for each second between 1 and 10 seconds. Frequency of Alerts shows the time period analyzed. Total Alerts shows the total number of alerts that occur during the specified time period. Accuracy Range for Alerts (%) shows, in 5% increments, the number of alerts with compression accuracy. For example, when an alert is given every second, 6 alerts of the 20 alerts have a compression accuracy of less than 85%. However, when an alert is given every 5 seconds, all the alerts have compression accuracy greater than 85%.

seconds. At 30 seconds, compression depth increased to 1.8 and the application gave another Low Alert. The compression depth then increased to more than 2 for a 30-second period, so no alerts were issued. At 80 seconds, the depth was greater than 2.5, so the application provided another alert. I concluded that the application achieved its purpose of providing alerts to the CPR giver, which enabled the CPR giver to adjust to more effectively administer CPR.

Table 3.2 shows the overall compression depth accuracy of CPR sessions for all participants. The results show that the accuracy ranges from a low of 77% to a high of 99%.

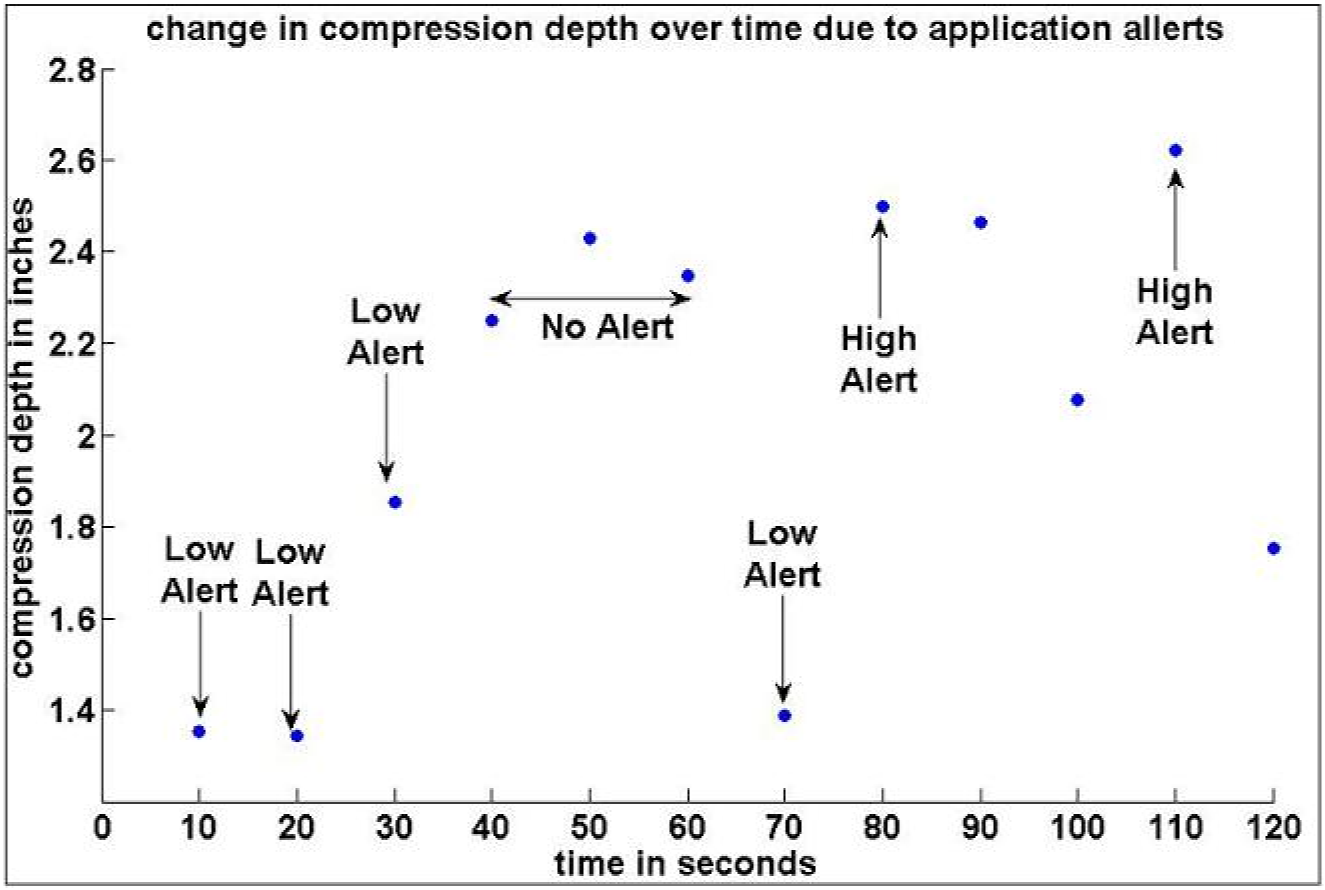


FIGURE 3.11. Compression Depth Alerts. Low alerts indicate compression depth should be increased. High alerts indicate compression depth should be decreased.

Average%	Minimum%	Maximum%	Median%
93.8	77	99.6	88

TABLE 3.2. Accuracy of Depth Calculation for All Participants

The average accuracy is 93.8%. But most readings are more than 90% accurate. Only 3 people had an accuracy of less than 90%

3.3.5. CPR in a Moving Vehicle

In certain situations, one may have to give CPR as the patient is being transported in a moving vehicle to the hospital. Several factors come into play in a moving vehicle that increase the difficulty of calculating the compression depth accurately when using a

Average Compression	Median Compression	Standrd Deviation
1.721	1.664	1.085

Table 3.3. Results of CPR in a Moving Vehicle, Showing the Depth of Compressions in Inches

smartphone accelerometer. The first, a vehicle moving affects accelerometer readings. If shock absorbers are inadequate, an accelerometer records vehicle movements in the Z axis, skewing the Z axis motion of the chest compressions. Road condition presents another major factor that contributes to increased errors. Bumps in the road, lane changes, and traffic turns also affect readings. Traffic patterns also add to the randomness of readings. The vehicle may have to be slow at times and then accelerate as the traffic moves. It may have to stop at traffic lights and then accelerate. Even if I keep factors constant, such as using the same vehicle, driving on the same road and even driving at the same speed, randomness of a traffic pattern still produces different results each time the CPR is attempted.

I ran an experiment with extremely controlled conditions. I selected a smooth road with no bumps. The road had almost no traffic, required no turns for a few miles, and had no traffic lights. I, then, drove at a constant speed of 30 mph to minimize movements due to vehicle motion. The results of the experiments are shown in the Table 3.3.

3.3.6. Calculation of Oxygen Saturation of Blood

CPR's purpose is to circulate oxygen-carrying blood through the body. Should the injured person's Blood Oxygen Saturation (BOS) Level drop precipitously, the person may suffer physical deterioration and even death. To reduce this risk, the algorithm must monitor the BOS levels while it is measuring compression frequency and depth. In this section I describe a procedure that uses smartphones to measure the BOS level using principles of optics [166, 121, 146, 183, 165, 71]. While a person gives CPR, this information can assist in deciding whether to give breathing. Mouth-to-mouth breathing replenishes the oxygen in the blood stream. However, many prefer to avoid using the technique unless absolutely necessary because of possible exposure to infectious diseases. The algorithm needed to provide a method for the 9-1-1 dispatcher or the person giving the CPR to determine whether mouth-to-mouth breathing was really necessary. To resolve this issue, the application makes use of the smartphone's optical capabilities. The surface of the injured person's fingertip (the area of analysis) is placed on the smartphone's camera lens. By taking a video, a beam of near-infrared light is passed through the finger. As the light passes through, the smartphone creates video of the area of analysis. The video is then analyzed to determine the RGB values (red green blue). RGB values of the refracted light in the blood are then analyzed for the scattering effect of near-infrared light. This scattering effect allows determination the BOS level.

3.4. Conclusions

The advantages of timely CPR have been well recognized in the medical community. There are programs in place to teach people how to administer effective CPR. But, in emergency situations, a trained person may not be available. The application described in this chapter uses a smartphone to evaluate the CPR being given. The application then provides feedback to the person administering CPR to improve its effectiveness. Existing applications available on smartphones simply furnish a short video tutorial on how to perform CPR. The smartphone application prompts the CPR giver in real time on when and how to adjust their frequency and depth of chest compressions to meet CPR guidelines. The experiment's results show that the smartphone application can be used to effectively administer CPR, even by people who have not been trained to give CPR. In emergency situations, where a trained person may not be easily available and timing is crucial, these devices can mean the difference between life and death. Additionally, the device's sensors can also help by continuing to provide vital information to paramedics as they rush a patient to a hospital. By measuring oxygen decay using the smartphone camera, the application allows accurate determination of the blood oxygen saturation level. By using the ubiquitous smartphone, people performing cardiopulmonary resuscitation can also determine when the frequency and depth of their compressions enhance blood flow. For example, the oxygen saturation level may offer a better indicator of CPR effectiveness than the depth or frequency of compressions. This also improves the CPR procedure for the trained people. They can determine when to provide mouth-to-mouth breathing.

For future work, additional experiments may improve the CPR depth calculations in a moving vehicle, in actual traffic and in uncontrolled conditions. Also future studies may help determine a more accurate time between alerts rather than the 10 seconds I used. The oxygen saturation evaluation also shows promise. It provides new and additional information for effective CPR administration.

CHAPTER 4

EVALUATION OF RESPIRATION QUALITY USING SMARTPHONE

4.1. Introduction

The vital signals of human body give critical information about its functioning. There are five vital signals that are considered important from a medical point of view. These are: body temperature, heart rate (pulse rate), blood pressure, respiration rate and oxygen saturation level. The normal equipment needed to measure these vital signs includes thermometer for body temperature; sphygmomanometer for blood pressure, and the pulse rate; pulse oximeter to measure oxygen saturation level and respiration rate is measured by observation over a period of time using watch. Normally some kind of training is required to measure these vital signs and use these devices. However, over the years these devices have improved such that even a novice can use them to get reasonably accurate results. In this chapter I focus on the evaluation of respiratory quality.

Respiratory rate is considered as one of the vital signs of human body. It is also the vital sign most often ignored by the doctors [38, 172, 106]. Abnormal respiratory rates and changes in it can be an important and early indicator of some major physiological problem. A respiratory rate that is greater than 24 per minute is able to identify 50% of patients at serious adverse risk with an accuracy of about 95%. Patients with greater than 25 breaths per minute died in the hospital [38]. One of the ways of measuring respiratory rate is manually counting the number of inhalations and using a watch to measure the time. But there are several situations where use of some kind of device to measure the respiratory rate is useful and even necessary.

The definition of a normal respiration is not precise. Among the important factors to consider are breaths per minute, regularity, effort and depth of breathing. There is a fairly well established range of respiratory rate as follows:

- Newborns: Average 44 breaths per minute, can vary anywhere between 30 to 60 breaths per minute.

- Infants (up to 6 months): 20-40 breaths per minute.
- Preschool children: 20-30 breaths per minute.
- Older children: 16-25 breaths per minute.
- Adults: 12-20 breaths per minute.

A regular respiration means that the number of breaths per minute must be the same for each minute. In an irregular respiration the rate of breathing changes periodically between fast and slow. A normal breathing should be effortless. But sometimes a patient may have breathing which is hard and labored using force or it may be a shallow breathing.

4.2. Breathing and 911 Calls

911 services play an important role in a nation's emergency response preparedness during disaster situations. Responding to health related emergencies is one of the critical situations that help save lives. The time it takes to send paramedics after the initial 911 call can be anywhere from few minutes (2-3) to several minutes, depending on the distance of the incident from nearest response center and traffic situation. It is important that this time is used for some initial diagnostics so that by the time the paramedics arrive they have some information about the patient and are prepared for an appropriate response on the way to the emergency scene. Most states have prepared emergency protocols, which are guidelines that the operator follows for each emergency situation. These protocols consist of several questions that the operator asks the caller to determine the situation. For example the operator might ask the caller to check if the patient is breathing. The caller then makes observations about the breathing and reports to the 911 operator. Evaluation of quality of breathing provides an important indication about the medical condition of the patient [101, 175, 112]. A device to evaluate a patient's breathing and automatically report to the 911 operator can be useful in such situations.

4.3. Devices to Measure Vital Signs

Over the years there are many consumer devices that allow people to measure some of the vital signs on their own. Thermometers have been used by people to measure the body temperature for many decades. In the last 25 years or so there have been several devices in the consumer market to help people measure the blood pressure outside a clinical setting. Heart rate monitoring devices have been available in the market since 1980s. These devices can be worn as a wrist watch by athletes or other people to monitor their heart rate. Respiration rate can be measured by manually observing breathing pattern and using a stop watch. All of the devices are special devices meant to measure the vital signs. In recent years technology has advanced to a point where many sensors are integrated into the smartphones. There are methods being developed to use these sensors to measure the vital signs [27, 189, 190, 84]. This is of great advantage during emergency situations when the special devices may not be readily available. In such a situation, the sensors in the smartphones may be used to measure the vital signs and report the results to the 911 operator and other paramedics while the medical personnel are still on their way to the emergency scene. In this chapter I present results of experiments that use the accelerometer in the smartphone to evaluate the breathing quality.

4.4. Objective

There have been several publications that report the use of devices to study various respiration patterns [72, 99, 9, 51, 48]. The main objective of the experiments is to evaluate whether one can use the sensors in the smartphones to measure the quality of breathing. Recording and measuring an accurate respiratory rate is more than just a simple number of breaths. It is relatively easy to calculate the respiratory rate. One can watch the rise and fall of a person's chest cavity and count it for a full minute. But it is not easy to measure other factors that determine the quality of breathing. In an emergency situation it is much better if a device that is easily accessible, such as a smartphone, can evaluate the respiration quality and automatically transmit this to the 911 caller. My objective in these experiments is to use the smartphone to evaluate the quality of breathing using three of the factors the respiration rate, regularity of respirations and the effort involved in breathing.

4.5. Experimental Setup

The experimental setup consists of a smartphone with accelerometer. One of the important issues to resolve is the placement of the smartphone on the body. One can place the smartphone on the stomach, abdomen or on the chest. It can be placed in the horizontal or the vertical position. The accelerometer sensor on a smartphone measures acceleration magnitude along the x, y and z axis. So the placement may determine which magnitude gives the best results for respiration rate, along the x axis or y axis or along the z axis.

4.5.1. Placement of the smartphone

I did several experiments to determine the placement of the smartphone. We did experiments by placing the smartphone on stomach, abdomen and on the chest. For each of these placement positions on the body, I experimented with two orientations of the smartphone - vertical placement and the horizontal placement. The subject was asked to place the smartphone and breathe normally. At the start of the smartphone application the subject was asked to count the number of breaths. Each experiment was run for duration of two minutes; the application timer would indicate the end of experiment. The accuracy of the application is determined by comparing the breathing rate from the application with the actual breathing rate of the subject. We repeated these experiments 10 times each. I determined that on the chest the z-axis readings gave the best results when the orientation of the smartphone is vertical. Figure 4.1 shows the plot of accelerometer readings along the z-axis.

In case of horizontal orientation of the phone on the chest the y and the z axis data gives a good measure for the frequency of breathing. Figure 4.2 shows a plot of the horizontal placement on the chest along the z-axis.

The same experiment was repeated by placing the smartphone in vertical and horizontal position abdomen. I repeated these experiments 10 times each. The conclusion was that the y-axis and the z-axis give accurate results. Figure 4.3 shows a plot for the y-axis when the smartphone is placed on the abdomen.

From these plots I conclude that the z-axis reading gives the best results when the

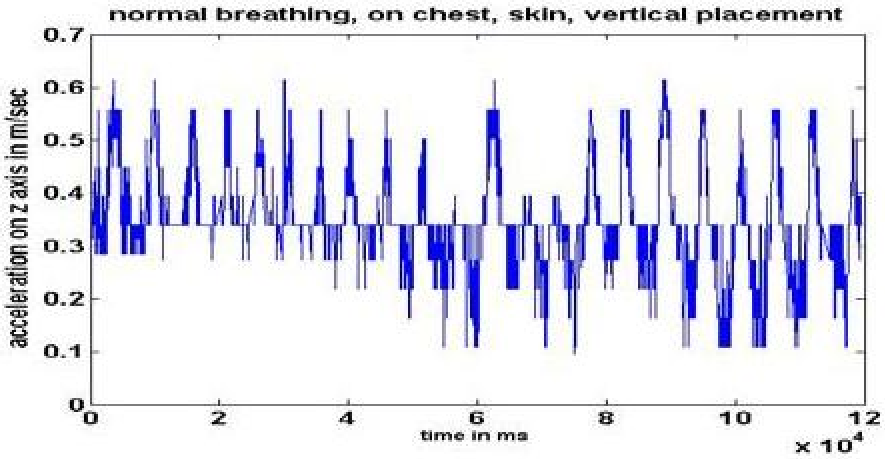


FIGURE 4.1. smartphone placed on the chest, directly on the skin and in a vertical placement.

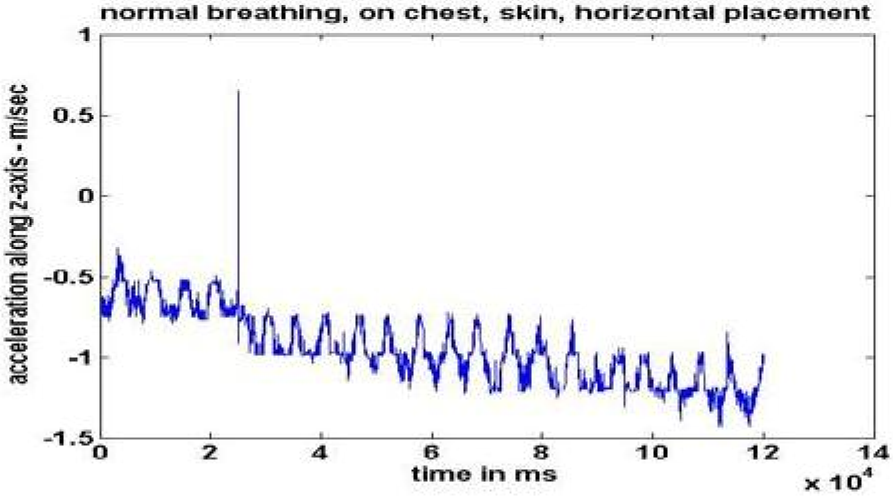


FIGURE 4.2. smartphone placed on the chest in a horizontal direction.

smartphone is placed on the chest or the abdomen in a horizontal position. In the next section I present the results of experiments to determine the quality of breathing. Figure 4.4 shows the placement of the smartphone on the abdomen.

4.5.2. Quality of Breathing Slow Breathing

In the next set of experiments I determined if the smartphone can recognize a slow breathing pattern. In all these experiments the smartphone was placed on the abdomen and in a horizontal position.

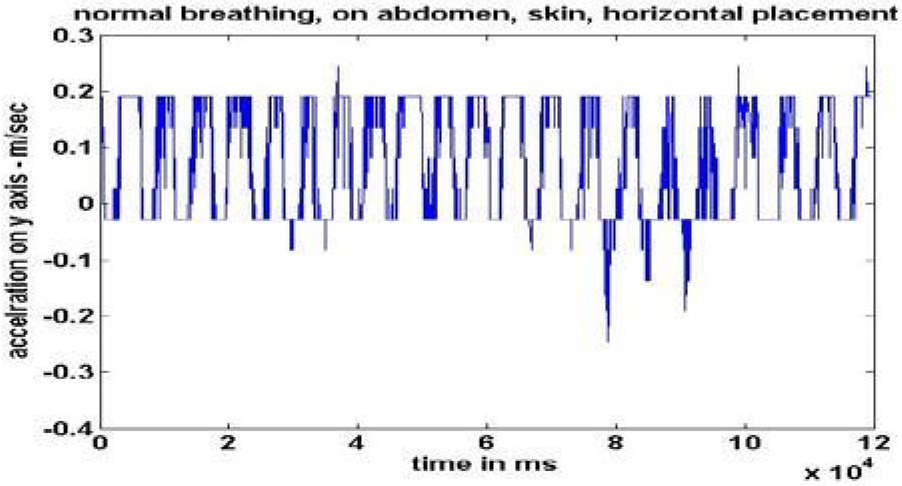


FIGURE 4.3. smartphone placed on the abdomen, horizontal position.

FIGURE 4.4. smartphone placement on the abdomen.

Figures 4.3 show the pattern for normal breathing for a subject and it shows the number breaths per minute to be approximately 11. Figure 4.5 shows the slow breathing pattern and it shows the number of breaths per minute to be approximately 5. I can conclude that even if the breathing rate is slow, the smartphone application can measure it accurately.

4.5.3. Quality of Breathing Fast Breathing

In the next experiment I measured a fast breathing pattern. Figure 4.6 shows the fast breathing pattern and it has the breathing rate at about 60 per minute. The experiment was repeated 10 times and I concluded that the application did evaluate a fast breathing

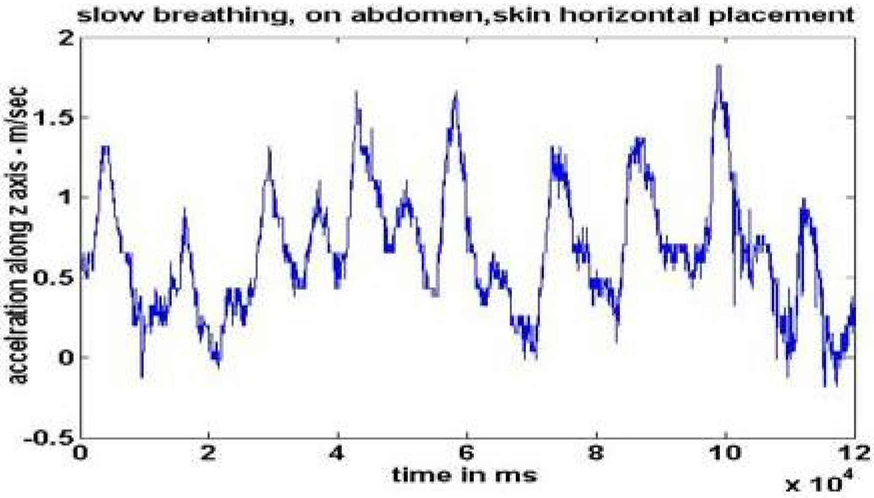


FIGURE 4.5. Slow breathing by the subject, the smartphone was placed on the abdomen in a horizontal position.

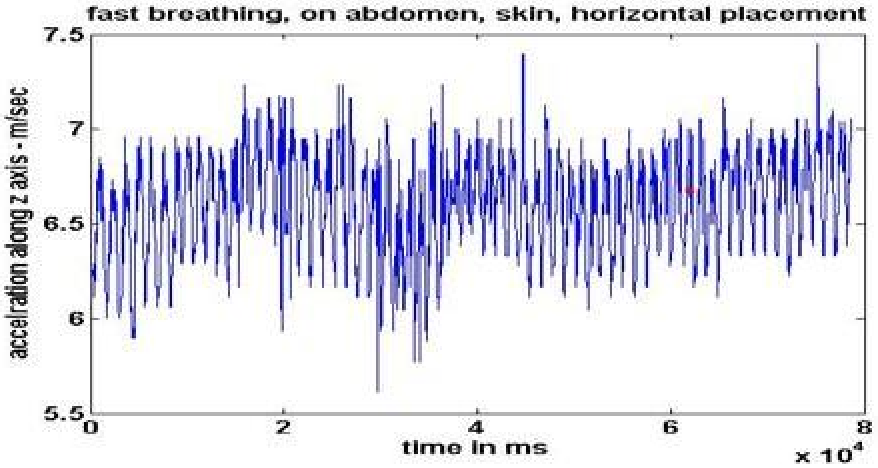


FIGURE 4.6. Fast Breathing, smartphone placed on the abdomen in the horizontal direction.

pattern also accurately.

4.5.4. Quality of Breathing Irregular Breathing

Regularity in breathing is defined as a breathing pattern where the under normal circumstances the number of breaths per minute is the same for every minute. The next experiment was done to attempt to capture an irregular breathing pattern. The smartphone placement was same - on the abdomen and in the horizontal position. The subject simulated irregular breathing pattern by doing fast breathing for a few seconds and then changing

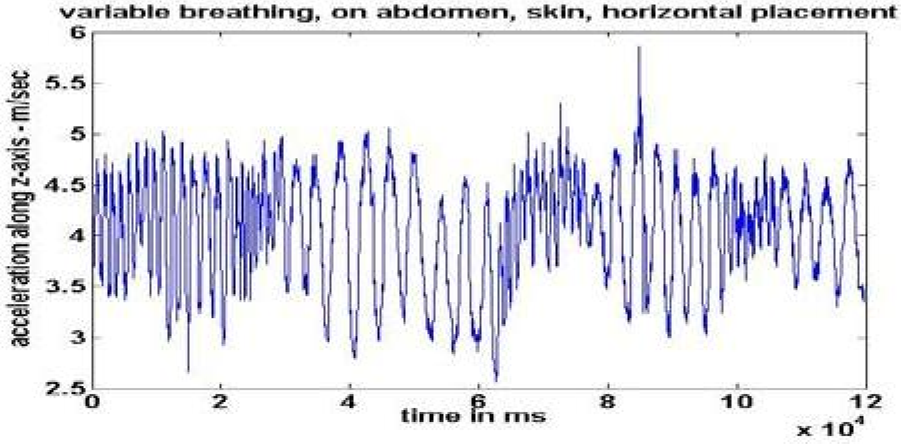


FIGURE 4.7. Irregular Breathing, smartphone placed on the abdomen in the horizontal direction.

to slow breathing and then changing to normal breathing pattern. This was repeated at random intervals. Figure 4.7 shows the plot of irregular breathing pattern. It shows that the accelerometer does capture the irregular pattern accurately.

4.5.5. Quality of Breathing Effort to Breath

Another factor that determines the quality of breathing is the effort in breathing. This is defined by shallow breaths or deep breaths. One can look at figures 4.1-4.3 to determine the effort involved in breathing in a normal manner. In the case of normal breathing the figures show the magnitude of acceleration is in the range of 1-2 m/s2. In the case of slow breathing, the plot in figure 4.5 shows the acceleration along z axis to be in the range of 0 to 1.5 m/s2. This implies that in the case of slow breathing there was less effort in breathing as compared to normal breathing. This would also imply that for fast breathing the range of acceleration magnitude should be higher than the normal breathing range. A look at the plot of figure 4.6 confirms that for fast breathing the magnitude of acceleration is in the range of 6 to 7 m/s2.

4.5.6. Accuracy of Results

The experiments have been conducted changing several variables. Table 4.1 shows the results for each of the variables. Another way of looking at the results is that smartphone can evaluate the person's respiration, i.e. it can evaluate if the person is breathing at a rate recommended for his age. I verified the data using t-test (h=0, p=0.533, ci=-.77 to 1.44).

4.6. Conclusions

From the experiments conducted and the results presented in the previous sections, I conclude that the accelerometer sensor on the smartphone can actually help us determine the quality of breathing automatically. I determined that the right placement of the smartphone on the body is important. Also it was determined that the readings along the z axis gave the best results. Also, while the readings from the placement on the chest were also accurate, the placement on the abdomen was better. It was also possible to accurately determine if the person was breathing slow or fast. Finally the accelerometer readings also gave a good indication of the effort used to breathe. The last factor that determines the quality of breathing is the odor. At this time there is no sensor on the smartphones that can automatically determine this. One has to rely on another person to actually make an attempt to determine the odor manually.

4.7. Future Work

The results for determining the quality of breathing have been very encouraging. One can continue the research to enhance the use of smartphone sensors to make additional diagnosis in a non-clinical setting. In this section I list some of these areas of interest.

Determine the volume of air intake during breathing. A mathematical formulation can be derived from the breathing plot. A spirometer is normally used to measure the volume of air inhaled and exhaled during breathing. The data from spirometer can be compared with the data from the accelerometer and a normalizing function may be derived. This function can then be used to calculate the volume from accelerometer data. Sleep apnea is a condition where a person stops breathing for up to 45 seconds. This can be an indication of some other serious problem [51]. Determining the sleep apnea condition using the accelerometer can be another enhancement in this project. One can use audio recording of respiration to estimate

Variable	Accuracy of the results
Age (15 yr - 55 yr)	95 % - 100 %
Gender	95 % - 100 %
smartphone Type - google, nexus etc.	90 % - 100 %
position of the person - sitting, lying down	93 % - 100 %
moving vehicle	90 % - 95 %

TABLE 4.1. Accuracy of the results - Actual number of breaths vs. breaths recorded by smartphone

the effort involved in breathing determine if it is it noisy, and also determine the kind of noise.

CHAPTER 5

FITTS LAW MODIFICATIONS FOR APPLICATION TO EMERGENCY DISPATCH PROTOCOLS

5.1. Introduction

Human movement science, the study of human body movements, has applications in several fields. In medicine, studying psychological impairment and impairment of body limb functionality enables development of new therapies, creation of better treatments, and design of more effective artificial limbs. Researchers in Computer Science also benefit from these studies of human movement as they create applications that focus on human-robot interaction or human-computer interaction (HCI) when designing human-machine interfaces. HCI design has become particularly vital when developing Emergency Dispatch protocols: guidelines that operators follow when they receive a 9-1-1 call. These guidelines involve a set of questions that an operator asks a caller to determine an emergency's nature and to determine an appropriate response. In addition, an operator may ask a caller to perform certain tasks involving interaction with cell phones or some other devices, similar to human-robot or human-computer interaction. The results of human movement studies allows designers to consider what body movements are efficient and, accordingly, design devices so that untrained people can also use them. Similarly, in Emergency Dispatch protocols an optimal instruction set, based on efficient HCI design, may save crucial, life-saving seconds.

Fitts Law has become an important tool for HCI. The law predicts the time required to move to an object given the distance to that object's center and size. For example, if a hand is moving a mouse cursor towards a specific point on the screen, the Fitts Law predicts that the time it takes to reach the target is a logarithmic function of width of the target and the distance to the target. The original Fitts law was applicable to only one dimensional movement of the arm [145]. Subsequent extensions of this law have studied movements in two dimensions [91], three dimensions [6] or even cyclical [67] movements. In this chapter I present the results of experiments to study applicability of Fitts law for remote task control.

I also present experiments to model Fitts law for different joint movements and multiple joint movements. Based on the results of these experiments, I extended Fitts law. An important application of such a modified Fitts law is in the design of HCI for emergency dispatch protocols.

5.2. Fitts law and Task activities

In this section I present literature survey to show the variety of experiments and studies done using Fitts law. This study relates to tasks that may involve multiple activities directed from a remote site.

5.2.1. Fitts Law and Current Literature

Frederick Winslow Taylor pioneered the concept of Time and Motion studies [61]. Frank and Lillian Gilbreth later refined the Time and Motion Study. They studied actions taken by workers in completing a task to streamline the process [59]. In 1954, Paul Fitts proposed the original Fitts law which describes an aimed, rapid type of motion [145]. Since then, Fitts Law has been used to design efficient Computer interfaces and layouts of the computer display screens, as a part of Human Computer Interaction applications. HCI researchers employ Fitts Law to model motion of human body parts in a single dimension. But, one can also consider the law to be a part of time and motion studies. Researchers have extended Fitts Law to account for 2-dimensional motion [91, 154], for 3-dimensional motion [6, 31], and for circular motion [67]. These studies establish that Fitts law applies to several types of motion. The initial experiment to establish Fitts law was done on rapid hand movement to reach a target of a given width. Over the years, several studies have been done on various movements of different body parts.

The application of the Fitts Law has opened new areas of research and application. For example, Fitts Law can be used when designing computer games requiring not only one-direction hand movements but also movements of other body parts in several directions. Studies about effectiveness of Fitts law have been done on head movements [155, 2, 63], fingers [3, 4, 90, 115], hand and foot movement [149, 62, 92], movement of eyes [26], tongue

[17] and even a vocal joystick [158]. In addition, studies of Fitts Law applicability have examined virtual pointing [43] and movements underwater [150]. Most studies of Fitts law focus on arm movement in a given direction and aim at reaching a target of a specified width. While researchers have used Fitts Law to study motor activities of children [20, 8], Fitts Law also has been used to study developmental deficiencies and learning disabilities of impaired children [151]. Similar studies have been done of elderly people and of people with disabilities or physical impairments [120, 64, 53, 52, 114].

Following an analysis of these studies of arm and head movements, I propose that one can apply Fitts law to the motion of other joints. For example, in a 3D gaming environment a player may use wrist motion to move knobs. When using Emergency Protocols, a 9-1-1 operator may give instructions to a caller to administer emergency aid. Such instructions may be explicit steps to move human joints. I hypothesize that Fitts Law will provide a baseline for efficient interaction between the operator and the caller. Equation 7 shows the original Fitts law:

$$T = a + b * log_2(\frac{2D}{W}) \tag{7}$$

Where T= the time it takes to complete a movement, D= the distance of the movement to the center of a target object, W= width of the target object; a,b= constants.

An equation based on Shannon's [54] formula (8) provides a better fit with the observations. Thus, it is more commonly used.

$$T = a + b * log_2(\frac{2D}{W} + 1) \tag{8}$$

Index of Difficulty (ID) is defined as in Equation 9:

$$ID = log_2(\frac{2D}{W} + 1) \tag{9}$$

I replace the ID in Equation 8 and rewrite it as in Equation 10:

$$T = a + b * ID \tag{10}$$

All variations on Fitts law focus on modification of the ID. Equations 7 - 10 assume movement in one dimension. Mackenzie and Buxton [91] extend the Fitts law equation to two-dimensional movement as follows:

$$ID = log_2(\frac{D}{min(w_1, w_2)}) \tag{11}$$

Where w_1 = the target's width in X-direction and w_2= the target's width in Y-direction. In Equation 11, the ID uses a minimum of the two widths for its evaluation.

Equation 12 shows a similar extension to 3-dimensions as follows:

$$ID = log_2(\frac{D}{min(w_1, w_2, w_3)}) \tag{12}$$

Where w_3= target's width in Z-direction and the ID uses a minimum of the three values of width. In the next section I present the motivation for the study and why the focus is on tasks that are directed from a remote site.

5.2.2. Remote Task Control

In many situations, a 911-operator remotely controls a caller's actions. Such control may be through a device such as a smartphone. In these instances, a capability to quickly assess a situation and direct a caller's actions can reduce the impact on an injured person. For example, when a person calls 9-1-1 to report an emergency, the operator may ask the caller to perform tasks before an emergency team arrives. In medical emergencies, tasks may involve checking a patient's state, such as level of consciousness, breathing pattern, or alertness. Tasks may also require directing a caller to provide first aid before medical help arrives. In emergency situations it is critical that the caller follows instructions accurately and in a timely manner. It, therefore, becomes necessary to formulate instructions a caller can easily understand and execute accurately. Operators must also be able to monitor task execution so they can advise callers on how to perform the task correctly. The task monitoring assumes importance because callers may themselves be cognitively impaired when they are close relatives or friends of the injured person. Or callers may be physically impaired if they themselves are the injured person.

Fitts law has been traditionally used to study body movements where separation between observer and performer does not become a relevant factor. And, as has been noted, such studies frequently focus on single movements physically reaching an actual target. I hypothesized that one can use the Fitts law to study movements that occur in performing remote tasks where instead of physically reaching a target, the target is brought into view of a camera lens [116, 188]. For example, when emergency operators need to see injuries, they may ask the caller to show them the injury using a smartphone camera. An application using an amended Fitts Law can remotely analyze the caller's movements, transmit them to the operator, and, thereby, enable the operator to revise instructions to work within a caller's physical and cognitive capabilities.

5.2.3. Task Activity

In current applications of Fitts Law, tasks are considered to be one action, usually movement in one direction. However, when working with multiple-joint movements as frequently occurs in emergency situations, one needs to consider situations where an activity may involve more than one action. Therefore, I propose to extend the Fitts Law to incorporate motion activity involving multiple-joint movements in sequence, for example, a 911 operator asks a caller to move a body part such as shifting a leg by walking. This could be followed by asking the caller to move the arm (for example point the video camera at the victim's face). Such studies have been carried out in the past [58, 107].

5.2.4. Problem Definition

In many emergency situations, more than one joint needs to be considered. My ultimate goal is to develop an application which uses Fitts Law to accurately analyze such multiple-joint movement. To date, as discussed in the previous section, researchers have used

Fitts law to model motion of human body parts, particularly one-dimension arm movement. In this research, I had two goals. One was to study the effect of multiple movements by joints to determine whether Fitts Law could be enhanced to take this multiple movement into consideration [58, 107]. The second was to study the comparison between the movements of different joints to determine how this relationship would affect Fitts Law. For example, I wanted to evaluate whether a mathematical relationship existed between one wrist-joint movement and one elbow-joint movement. An attempt at such a comparison has been made in the previous studies [147]. But in those studies no mathematical formulation was made. Based on the mathematical formulations arrived at in the study, I propose to enhance Fitts Law so that the equation reflected the mathematical relationship occurring with multiple-joint movement.

5.3. components of modified fitts law

5.3.1. Motion Activity

Fitts Law's original equation in assumed a physical motion along one dimension. Later modifications amended the equation to include motions along 2-dimensions and 3-dimensions for one joint. However, many HCI tasks involve moving more than one body part in sequence. HCI in gaming activity involves not only movement of one body part but may also require moving two or more body parts in sequence. Similarly, Emergency Protocol tasks may involve moving two or more body parts. The current Fitts Law equation does not distinguish between movements of one body part as compared to another. For example, walking to an object (moving legs) will have a different difficulty level than moving an arm or a hand. Also, a task may involve a complex movement such as moving several joints in multiple directions to complete the task successfully. The objective is to extend Fitts law to account for different joints having differing IDs.

To acceptably extend Fitts Law, I first needed to resolve whether one can compare movement of two or more joints. That is, can I define a Difficulty Index for each joint so that one can compare ID of one joint with the ID of another joint? To compare different joints' IDs, I introduced the concept of atomic movement. I define atomic movement as one by the joint that moves the fastest unit distance. I consider every other joint movement as a multiple of this atomic movement. If I denote α as a factor whose value depends on the joint that is moved, I write the modified Equation 9 for Difficulty Index as follows:

$$ID_{joint} = \alpha * log_2(\frac{2D}{W} + 1) \tag{13}$$

I write Equation 13 for atomic joint as follows:

$$ID_{atomic} = \alpha_{atomic} * log_2(\frac{2D}{W} + 1) \tag{14}$$

Where $\alpha_{atomic} = \alpha$ value of the atomic joint, the joint used to define atomic movement.

Similarly, I write Equation 14 for any joint, $joint_1$ as follows:

$$ID_{joint1} = \alpha_{joint1} * log_2(\frac{2D}{W} + 1) \tag{15}$$

Using equations 14 and 15, I express the relationship of one joint to another as follows:

$$\alpha_{joint1} = \lambda_{joint1} * \alpha_{atomic} \tag{16}$$

Where λ_{joint1} is the ratio of atomic movement between the *atomic joint* and $joint_1$, I can rewrite equation 15 for index of difficulty for $joint_1$ as in equation 17:

$$ID_{joint1} = \lambda_{joint1} * \alpha_{atomic} * log_2(\frac{2D}{W} + 1) \tag{17}$$

Equation 17 represents a relationship between the atomic joint and the index of difficulty for any joint. A task's completion may involve multiple motions. So, I derive a composite Index of Difficulty (ID) by applying Fitts Law to each motion:

$$ID_{motion} = \sum_{i=1}^{n} \{\lambda_i * \alpha_{atomic} * log_2(\frac{2D}{W} + 1)\} \tag{18}$$

Where n is the number of motions needed to complete a task. Equation 18 does not take into account that multiple movements may add difficulty to an overall task. The effect on the ID increases non-linearly when moving each additional type of joint. For example, a task involving two movements in sequence will be more difficult and will have a higher factor than a task involving one movement; similarly, a task involving three movements will have a higher factor than a task with two movements. Based on this, we can modify Equation 18 for ID as follows:

$$ID_{motion} = \sum_{i=1}^{n}\{\beta_i * \lambda_i * \alpha_{atomic} * log_2(\frac{2D}{W} + 1)\} \tag{19}$$

Where β represents a factor that takes into account the multiple motions needed to complete a task. If there is only one motion, β_1 will have a value of 1, which indicates a normal Difficulty Index.

In the following subsections I present results of experiments to demonstrate these concepts. I did two sets of experiments for motion activity. In the first set of experiments I validated that the b parameter's value is higher for tasks involving movement of more than one joint. I also present an example of calculations of α and λ parameters based upon the experimental results. In the second set of experiments I validated my concept of atomic movement by showing that bigger joints move faster than smaller joints. I also confirmed that the time required to move smaller joints is a multiple of the time required to move bigger joints.

A motor motion takes a few seconds to complete. An arm or a leg's full, free movement takes approximately 4 to 5 seconds. This short duration makes the experiment error prone. Careful planning was needed to complete the experiments successfully. Error also can be introduced not only from the measurement of the time but due to the variable nature of a body's joint movement. Each repetition of a joint movement can give a different timing. Given each measurement is of the order of 2-3 seconds, a small error in measurement can contribute to an accumulation of wrong results. To reduce this error, I conducted the experiments with repeated motions several times and averaged the measurements.

5.3.2. Methodology for first Set of Experiments

As mentioned earlier, the goal was to establish a mathematical relationship between movements of different joints. In this section I present the results of experiments designed to achieve this goal. To collect data for the remote task control, I simulated the conventional experiments for Fitts Law. Instead of physically moving towards the target and reaching it, in the experiment, participants stood at a distance from a 1-inch-wide target. The participant then moved a camera towards the target to bring the target into view through the lens. I performed three experiments, each using a different joint movement to move the camera to bring the target into view. In the first experiment, the participant moved a shoulder joint from a preset position and stopped when the target could be viewed through the camera lens. In the second experiment, the participant moved only the elbow joint; and, finally, in the third experiment only the wrist joint was moved. In each experiment I collected 4 data points to plot. For each data point, the subject repeated the movement 10 times to reduce the margin of error.

To further increase the accuracy of each measurement, I used a video camera to record each movement. I set the accuracy of the timestamp on the video frames to a granularity of milliseconds. I analyzed the video frames and the time stamp corresponding to each frame to measure the exact time of movement.

The data collected from these three experiments was also used to establish the mathematical relationship between the movements of the three joints. I calculated and observed the changes in the joint's Difficulty Index. I measured the time necessary to move specific joints to establish a baseline identifying the fastest (*atomic*) movement and to determine the relationship of other joints to this baseline. Specifically, from the data collected in these experiments, I evaluated the atomic value (α) and the ratio (λ) between each of them.

5.3.3. Results of First Set of Experiments

In the first set of three experiments I studied movement of the shoulder, the elbow, and the wrist joints. For each experiment, participants performed the joint movement 4 times to give four data points. As mentioned each of these gives four data points and the distance for each data point was recorded by repeating the same motion 10 times. To calculate the values of the constants, I used the Matlab function Polyfit. Using the recorded data, the constant values, I calculated the Difficulty Index using Equation 8 of Fitts Law.

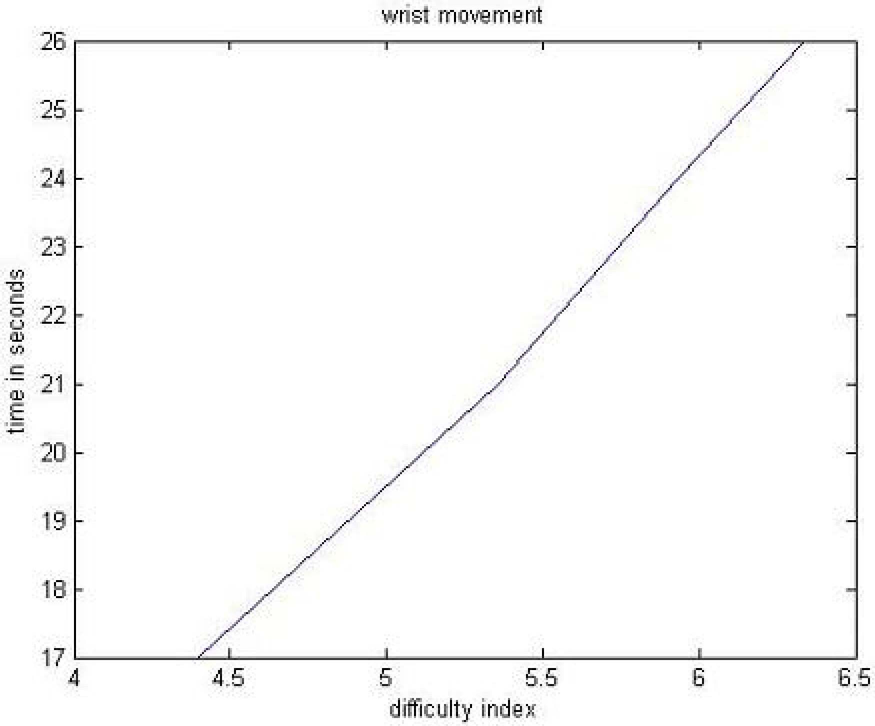


FIGURE 5.1. Fitts Law for Wrist Movement

Figure 5.1 shows a plot of the time required for wrist movement. The time required to complete the wrist-joint movement ranged from 17 to 26 seconds. The distance for wrist joint movement was recorded in 20-inch increments, ranging from 20 to 80 inches. The calculated Difficulty Index ranged from 4 to 6.5. For wrist-joint movement, Polyfit calculated a constant value of a = -3.4955 and b = 4.6312. .

Figure 5.2 shows a plot for the time required to move the elbow joint. The time required for elbow-joint movement ranged from 22 to 36 seconds. The distance for elbow joint movement was recorded in 100-inch increments, ranging from 100 to 400 inches. The calculated Difficulty Index ranged from 6.5 to 9. For elbow-joint movement, Polyfit calculated a constant value of a = -20.5081 and b = 6.5095.

Finally, Figure 5.3 shows the plot for the time required when moving the shoulder joint. The time required for elbow-joint movement ranged from 20 to 50 seconds. The distance for shoulder joint movement was measured in 240-inch increments, ranging from 240 to 960 inches. The calculated Difficulty Index ranged from 7.5 to 10. For shoulder-joint

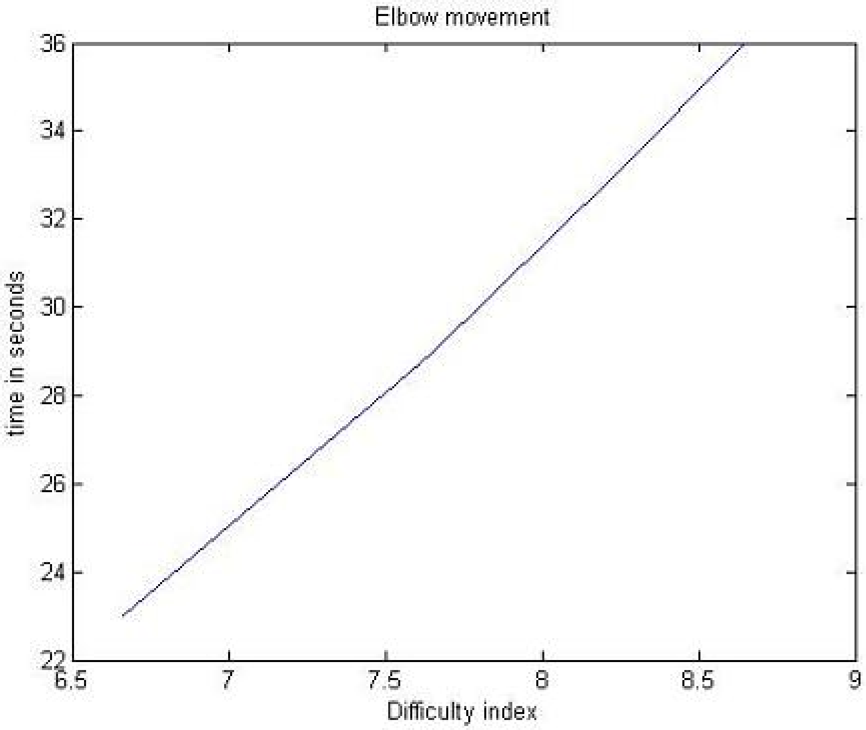


FIGURE 5.2. Fitts Law for Elbow Movement

Type of movement	b Parameter	distance	Normalized b (value) b value/inch	Ratio (value)
wrist	4.6312	20	.23156	4.286
elbow	6.5095	100	.06509	1.20
shoulder	12.9676	240	.05403	1

TABLE 5.1. Ratio of Difficulty as a Multiple for Each Joint Movement

movement, Polyfit calculated a constant value of a = -81.1875 and the value for constant b = 12.9676. I also observed that the value of constant b increased as the size of the joint increased.

Table 5.1 shows the Ratio of Difficulty as a Multiple for each joint movement. Column "b parameter value" shows the value of constant b for each movement type. Normalized b value provides the atomic movement value. The normalized value of b parameter is obtained by dividing the b parameter value by the distance. The fifth column lists the ratio of the two constant values.

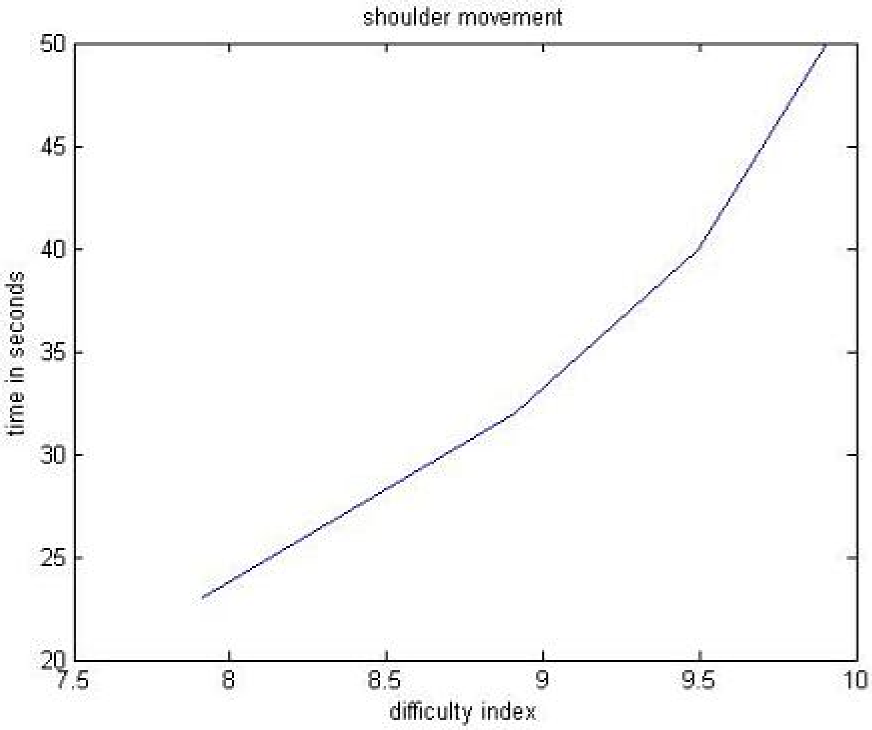


FIGURE 5.3. Fitts Law for Shoulder Movement

Time	Shoulder distance	Wrist distance	Total Distance	Log2(D/W+1)
50	240	20	260	7.9129
55	480	20	500	8.9099
65	720	20	740	9.4939
80	960	20	980	9.9084

TABLE 5.2. Shoulder/Wrist Combined Movement Data

Since the shoulder is the fastest amongst the three joints, the shoulder movement's *normalized b* value is the $\alpha_{atomic} = .05403$, and is assigned a $\lambda_{shoulder}$ value of 1. The elbow movement's *Normalized b* value is $\alpha_{elbow} = .06509$. I calculate:

$$\lambda_{elbow} = \frac{\alpha_{elbow}}{\alpha_{shoulder}}$$

Therefore $\lambda_{elbow} = 1.20$. Similarly, the value $\lambda_{wrist} = 4.286$. In the table 5.2, I give data for a combined movement of shoulder and wrist. The width of the target for each entry was 1".

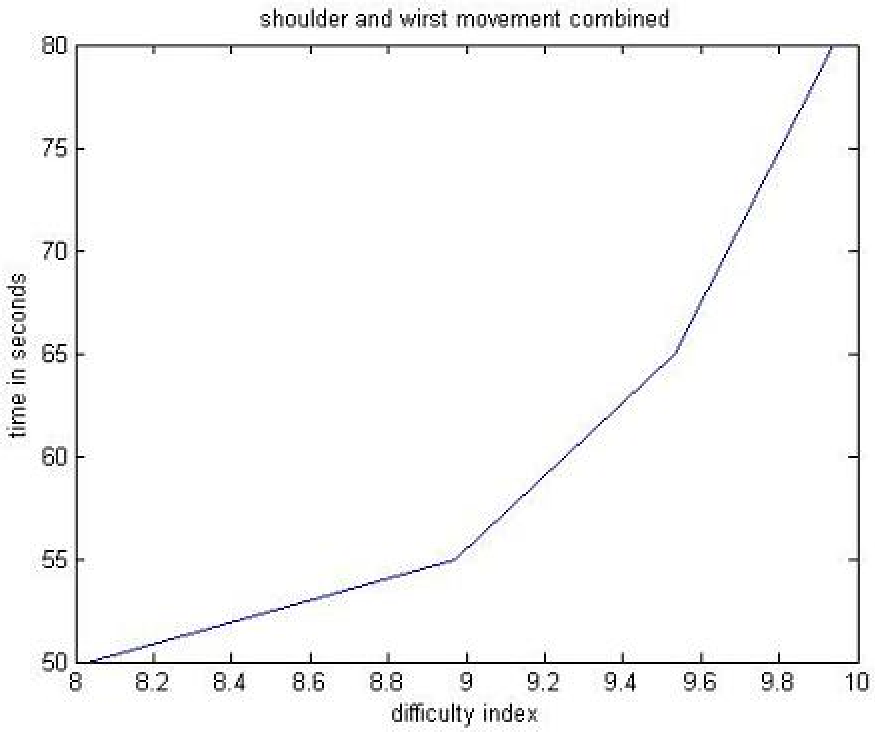


Figure 5.4. Fitts Law Plot for Combined Shoulder/Wrist Movement.

Figure 5.4 shows the plot for the Index of Difficulty versus time for the combined movement of shoulder and wrist joints. The Polyfit function gives the value of constant a= 71.1559 and the value of constant b= 14.6601. The normalized value of b is .0564. The combined value for two joints has a higher value for constant b as compared to the value for any single movement of each joint.

5.3.4. Conclusions for the First Set of Experiments

The analysis of data from the experiments leads to two conclusions about the mathematical relationship between movements of joints. First, the results showed that the Difficulty Index for each joint differed from those of other joints. Second, I also found that the value of the constant for each joint is a multiple of smaller joints. For example, the combined movement of shoulder and wrist joints had a higher Difficulty Index and a higher value of constant b as compared to any single joint. This higher value of b indicates that an action that involves two or more joints is more complex than the movement of a single joint.

5.3.5. Methodology for Second Set of Experiments

The second set of experiments was carried out to further confirm the following hypothesis:

- The bigger joint moves faster than the smaller joint.
- The slower moving joints are a multiple of the faster moving joint.

This experiment involved motion of four joints.

- Hip joint (walking)
- Shoulder jointmoving the arm all the way up,
- Elbow jointfull elbow joint movement
- Wrist joint movement.

For this study, 20 males and females of different heights and weights participated. Volunteers were unaware of the experiment's purpose.

Joint movements are angular in nature. Therefore, to calculate the distance moved, I measured the total distance that the extremity of the body part moved. I asked the volunteers to move at their normal speed. I used the stop watch in a Google phone (which had an accuracy of milliseconds) to measure the time the subject required to complete a motion. To collect hip joint data, I asked each participant to walk a fixed distance once. But, to gather data on movement of the shoulder, elbow and wrist, I asked volunteers complete five repetitions. This repetition prevented skewing results as would occur if volunteers moved the joint once. This method reduced the error margin because we determined the average distance moved.

5.3.6. Results of the Second Set of Experiments

Figure 5.5 shows the relative speeds of four joints for each participant. The bar graph shows the time per inch of movement for each joint. For all participants the Hip joint movement had the smallest time. The shoulder joint movement had the next smallest time, and so on. This confirms the first hypothesis that the larger joint is consistently faster than the smaller joint.

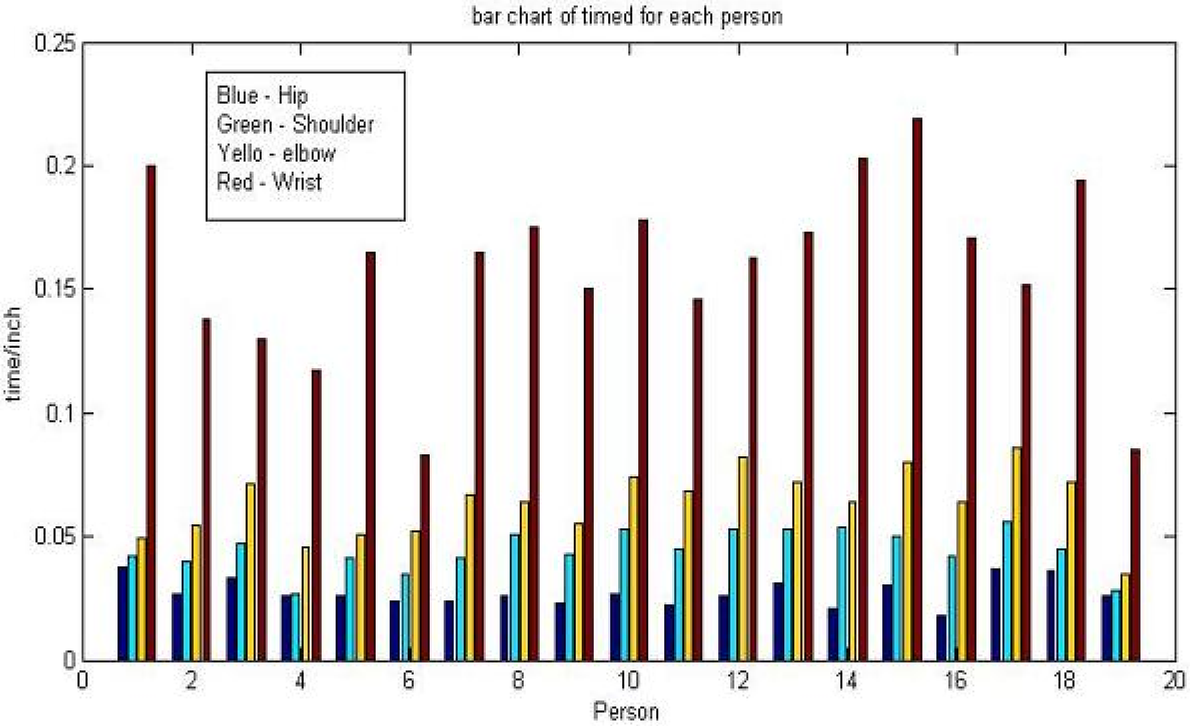


FIGURE 5.5. Bar Graph Showing Relative Speeds of Joints for Each Subject.

I calculated the ratio of each joint movement to compare the performance of each joint. The time of hip joint was given a value of 1. Figure 5.6, shows the relative speed of joints as a ratio of time to move the hip joint. One can observe that the ratios are consistent with the hypothesis that the movement of all joints is a multiple of the fastest joint and this observation is consistent across all subjects.

Figure 5.7 shows a comparison of the speed of each joint with respect to the index of difficulty for each subject. The times are based on an average of the subject's speed for each of four joints. The X-axis provides the range of the Index of Difficulty from 0 to 4. The Y-axis shows the time per inch of movement. Each plot line represents a participant in the experiment. This confirms the assumption that as the difficulty increases the time necessary to move joints increases.

5.3.7. Conclusions of Second Set of Experiments

The results for the first experiment pointed to interesting conclusions. The intuitive hypothesis was that the biggest joint would have the fastest movement. Hip joint being the

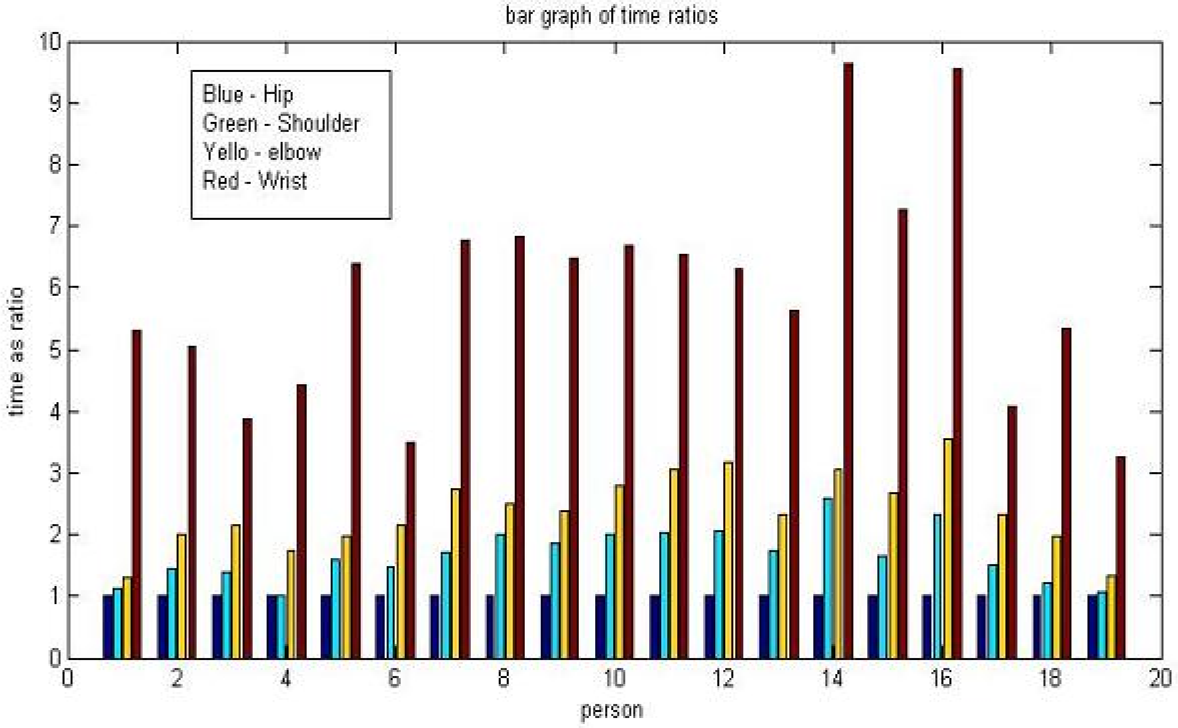


FIGURE 5.6. Comparison of Ratio of Speed for Each Joint for Each Subject, hip joint is given a value of 1.

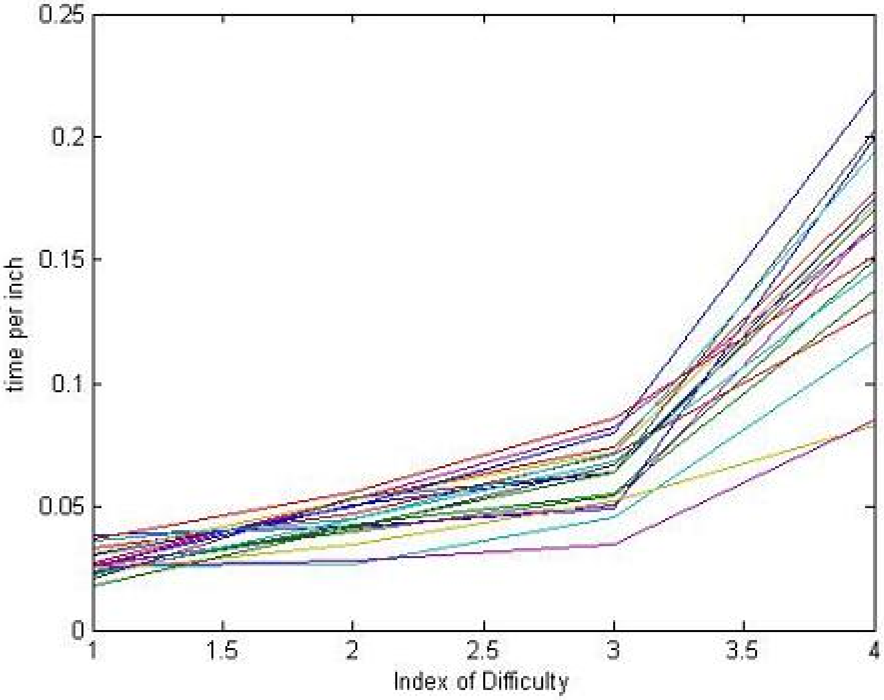


FIGURE 5.7. Plot of Index of Difficulty for each person showing the increase of time.

body's biggest and strongest joint was a natural candidate for the fastest joint. The data from experiment showed that the hip joint was consistently faster than the knee, elbow and wrist joints. Future research should expand this study to consider other joint movements to further confirm the hypothesis. Also, the ratios of time/difficulty-index and time/speed showed a consistent trend. A more accurate timing and different distance movements may further confirm that this ratio is consistent across participants.

5.4. Conclusion and discussion

The analysis of data collected supports the following conclusions.

Several studies have been done to confirm the validity of Fitts law for analyzing movement of joints. I wanted to study if there is a correlation between joint movements. The first goal was to define a mathematical relationship between different joint movements. Second, I wanted to confirm that the time it takes to move two or more joints is more than the sum of individual joint movements. Third, I wanted to create a model that would allow us to more precisely time the multiple-joint movements. The experiments confirmed that larger joints move more quickly than smaller joints. When I calculated the ratio of speeds of any two joints, the results indicated that the ratio for same joints was consistent across all participants. Based on these results, I have formulated a mathematical model of joint movements and have modified Fitts Law as given in Equation 19.

5.4.1. Applications of this study

Next Generation 911 Dispatch Protocol Design: Dispatchers require instructions that consider the 911 caller's sensory and cognitive states, as well as their physical capabilities. Current protocols assume that dispatchers will gain needed information verbally through questions and statements. However, with the advent of Voice over IP-related technology in telecom networks and user devices, dispatchers can use other ways to gain needed information. Protocol designers can incorporate multiple-joint data into their designs when deciding what kinds of instructions are more efficient. In addition, the extension of Fitts law permits such protocols to use remote control features to decrease time between answering and responding to a caller's emergency.

Rehabilitation of Physically-Impaired Individuals: The extended Fitts Law permits researchers to investigate multiple-joint movements in both unimpaired and impaired individuals. Using this comparative data, researchers can design effective physical therapies for physically impaired individuals.

Human Computer Interface Design: Newer mobile devices are not only decreasing in size. They also incorporate more embedded sensors which allow efficient and timely data gathering on-site. The new mobile devices with embedded sensors require that Human Computer Interfaces evolve to access the data from these sensors. The interaction with the devices will require different kinds of interaction with HCI. The extended Fitts Law will allow these movements to be more efficient.

Robotic Design: Currently, designers calculate movement requirements for robots as if the robot has one joint. However, most robots have two or more joints which work in conjunction. In essence, Robots mimic human body movements. Robotic designers can design robots to function more realistically if designers follow Fitts Law as it applies to multiple-joint movement.

5.4.2. Future Work

Future work should, first, focus on studying more subjects to gather more data on multiple-joint movement, sensory indicators, and cognitive indicators. Future studies should evaluate the effect of impairment by analyzing EEG waves. Especially, future studies should extensively study the effects physical activities have on EEG waves. In an emergency situation an action may have many choices so a model that combines hook's law and Fitts law may be used to design optimum dispatch protocols.

CHAPTER 6

QUANTIFYING COGNITIVE IMPAIRMENT DUE TO PHYSICAL OR MENTAL STRESS

6.1. Introdcution

Cognitive impairment can occur for several reasons. Transient or short term impairment can be caused by physical or mental stress. Attempts have been made to study and model Cognition using EEG waves [125, 191]. Cognitive state estimations have been done using EEG waves [42]. Neural signals are obtained by placing electrodes on the scalp and measuring small electrical signals called EEG brainwaves. These EEG waves record the electrical activity in the brain in terms of waves of various frequency bands. These bands have been divided into several categories.

- Delta Waves: These waves are associated with the deepest levels of sleep. They are in the frequency range of 0-4 Hz.
- Theta waves: These waves appear during the drowsy state or sleep state (not the deep sleep). These waves are in the frequency range of 4-7Hz.
- Alpha waves: These waves appear during the phase when a person is awake but the eyes are closed. The frequency range of these waves is 8-12 Hz.
- Beta waves: These waves are in the frequency range of 12-30 Hz. They are associated with the normal wakeful state of consciousness.

The effect of exercise on brain using EEG waves has been documented in several studies, showing that exercise does cause enhanced brain activity and is captured by Alpha and Beta waves of EEG [182, 162, 73, 161]. Studies have been done to document cognitive impairment due to daily physical and emotional stress and anxiety [11]. The caregivers of palliative patients experience a high level of emotional stress causing transient impairment in them [118]. Researchers have also used EEG to study how music cognition affects emotional aspects of the brain system [127, 126]. Another interesting use of EEG is to study changes in EEG waves due to the driving distractions [111, 109]. EEG waves are also used in several other applications such as its use to distinguish epileptic seizures [194], patients in coma [117], depth of anesthesia [108] and motion sickness [110]. In this paper I present the results of some experiments done to determine the mental impairment as measured by EEG waves. We have done experiments in physical exercise involving walking, climbing stairs and sit-ups. It is not possible to induce emotional stress, so I influenced the brain by having a subject spin in a revolving chair to cause dizziness in the brain, similar to motion sickness. Finally, I studied the effect of alcohol on brain as measured by EEG waves.

6.2. Objectives and Outline

The objective of this study is to determine the cognitive impairment of individuals during activities that influence the brain. The brain influence may be caused by emotional issues or by physical stress or by other actions. In these experiments I influenced the brain activity by doing physical exercise of varied strenuousness. It is not possible to actually simulate emotional issues, but I influenced brain by having a subject sit in a revolving chair and then rotate the chair. This causes dizziness in the brain, similar to motion sickness, causing transient impairment. I also study the effect of alcohol on brain activity as measured by EEG waves. In the following sections I write about the various experiments I have done. In section 4.1 I plot a baseline of the EEG waves in a meditative state. The results of all other experiments are then compared with this baseline state. In section 4.2 I document an experiment where a subject is made to sit in a revolving chair and then the chair is spun. In Section 4.3 I show the results of the walking exercise. In section 4.4 I show the results of the sit-ups. In section 4.5 I show the results of climbing stairs. In section 4.6 I document the magnitude of EEG waves after alcohol consumption. I also did two additional variations in the experiments. In section 4.7 I write the results of comparing heart rate with EEG waves as a subject climbed stairs. In section 4.8 I document another variation in which a subject just imagines doing the physical exercise of walking or sit-ups while I recorded the EEG waves.

6.3. Experimental Setup

In this section I describe the equipment used to do these experiments. The device to measure the waves consists of:

- A Neurosky head band with a dry electrode is placed on the forehead. The device is easy to place on the forehead without any discomfort.
- A second electrode on the head band is placed on the ear lobe.
- Software that records the EEG waves sent from the head band. The communication between the computer and the head band uses blue-tooth protocol.
- The heart rate is measured using a hear rate monitor that is worn on the chest.

6.4. Experimental Results

In this section I present the results of the experiments to simulate impairment. In each experiment the Neurosky band is tied to the forehead such that the electrode touches the middle of the forehead. A second electrode is tied to the ear with a clip. The software uses Bluetooth to communicate between the Neurosky band on the head and the computer. I focus on the alpha and the beta waves as these waves are of interest during the wakeful state. All the plots from these experiments show the magnitude of EEG waves on the y-axis. The meditation state experiment is important to baseline the magnitude of EEG waves. A meditation experiment done on one day may not be valid on another day. The reason is that the state of mind is different on different days. So it is important to do this baseline experiment before each impairment experiment.

6.4.1. Meditation State

In this experiment, the subject sat still on the chair with the eyes closed for about 2 minutes. This is used to baseline the least impaired state of the mind, the meditative state. A total of 10 experiments were done for the meditation state. Figure 6.1 shows a plot of the Alpha waves.

The mean of the magnitude (y-axis) of the alpha wave is .62 and the range is from 0.17 to 1.52. The results for other meditation experiments showed similar results. A slight

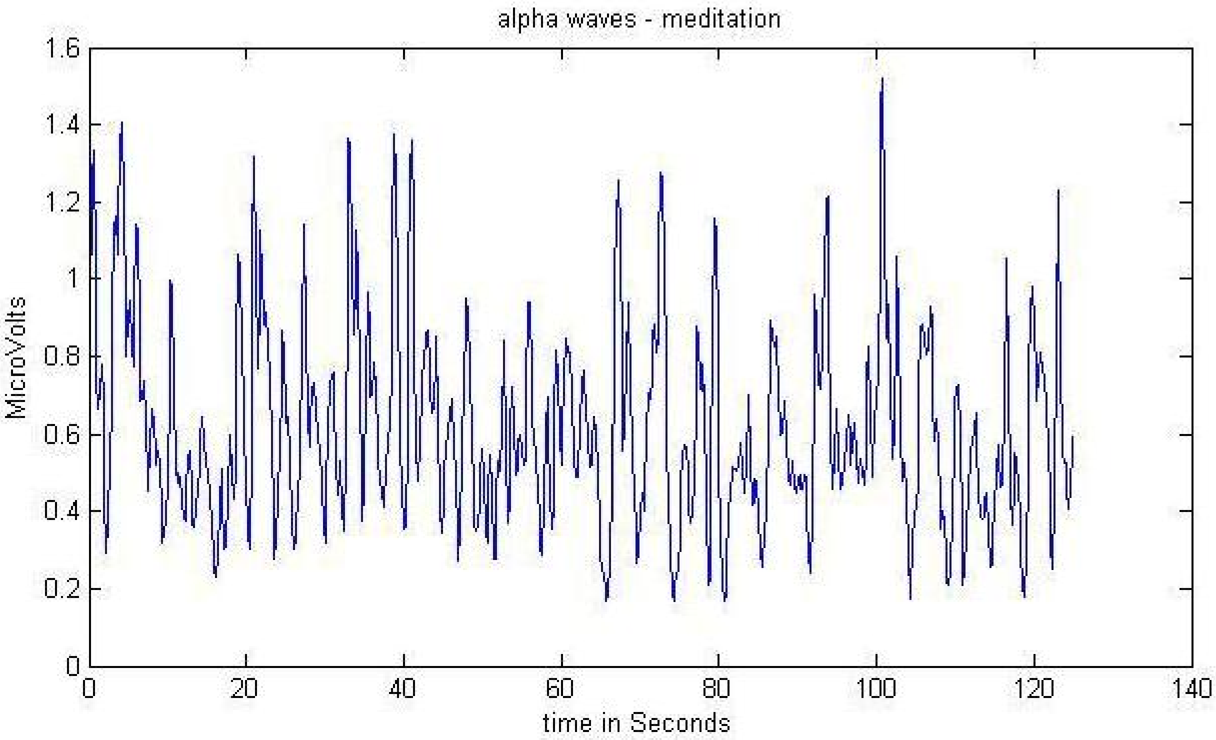


Figure 6.1. Alpha waves, meditation state while sitting. This state is used to baseline the EEG waves for comparison with other experiments. High values on Y-axis indicate more activity and therefore less alertness.

variation to the meditation state was done for the next experiment. Instead of sitting, the subject was made to stand still with eyes closed. The mean of the magnitude in the case of person standing is .94 and the range of the magnitude is from .26 to 2.8. A comparison with the statistical values of meditation while sitting shows that the max, min and mean values are higher for standing up as compared to meditation. This suggests that when a person is standing the concentration of his mind is less than compared to sitting.

6.4.2. Spinning in a chair

The meditation experiment provides a baseline data point to compare with the other exercises. In this experiment, I first simulate mental impairment by spinning a chair while a person is sitting in it. If a person sits in a revolving chair and the chair is spinning, he will feel dizziness similar to the motion sickness. The Neurosky band was attached to the head of a person sitting in the chair with his eyes closed. Another person pushed the chair

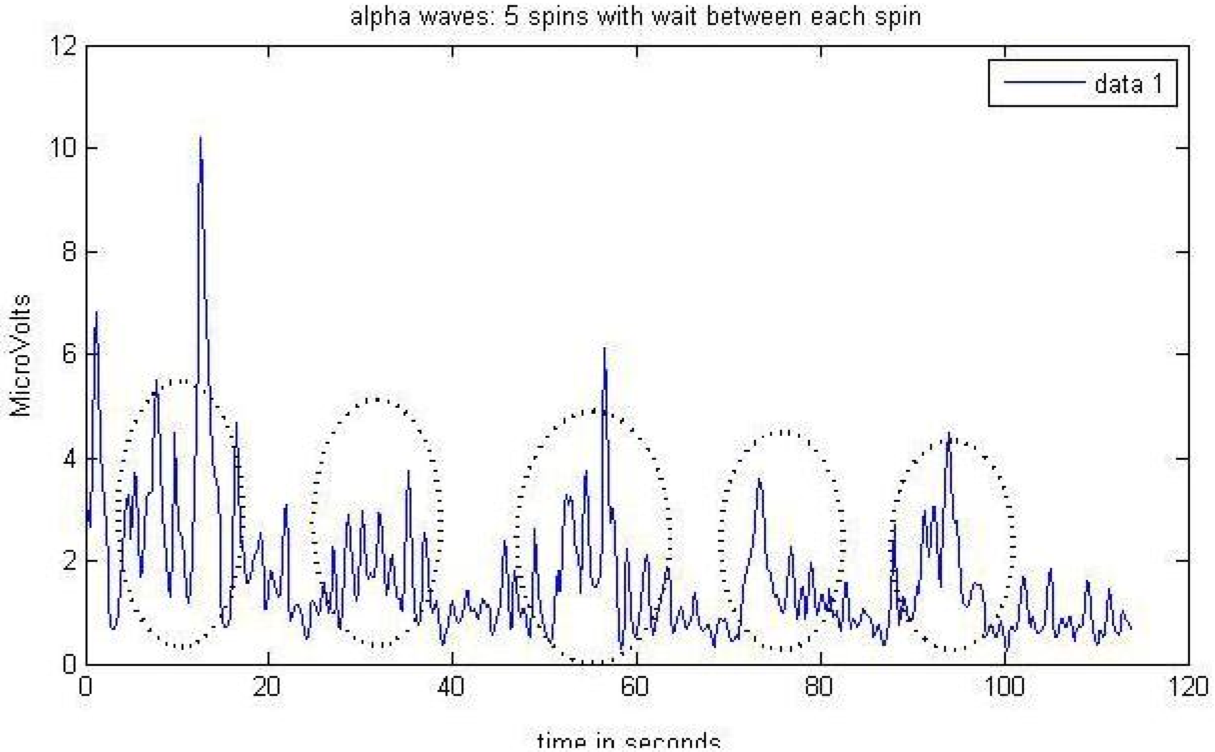


Figure 6.2. Alpha waves, 5 spins with eyes closed and wait of 10 seconds between each spin. Each spin is shown with an ellipse around the part of the plot. High values of peaks mean less alertness as compared to the meditation state.

repeatedly to spin the chair. Several experiments were done spinning the chair. The number of the spins varied from 1-5 between each experiment. I also varied the speed of spin during different experiments. For each variation I did 10 sets of experiments.

The plot for this experiment of 5 spins is shown in Figure 6.2. The statistical data for this plot shows the mean is 1.67 and the range is from .26 to 10.8. The values for 3 spins give a mean of 1.41 and the range is 6.44 for the high and approximately .27 for the low. Most of the peaks are between the magnitude of 4 and 6. Other graphs plotted for this experiment with different numbers of spins showed similar results. It was observed that if the number of spins increases, the mean value also increases and the max value also increases. Similarly the mean for the alpha waves during spinning increases to a magnitude of about 1.41 from the value of .62 for no spin. The magnitude of the raise varies depending on the number of

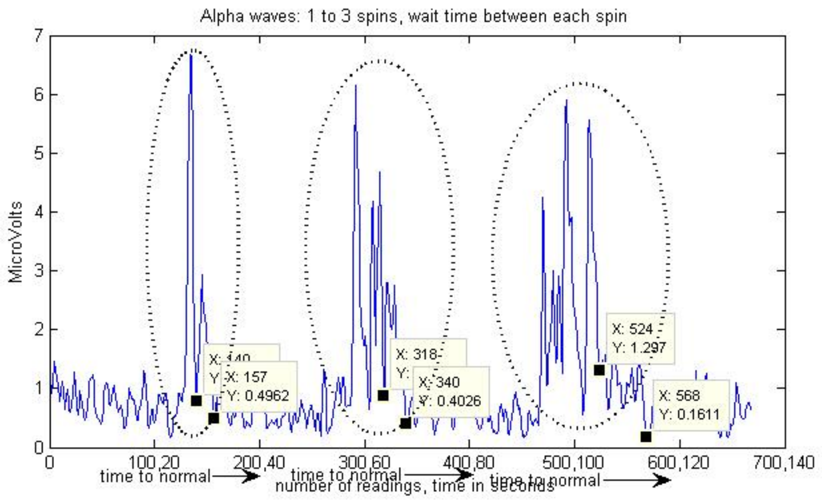


FIGURE 6.3. Alpha waves, 3 sets of spins - 1 spin, rest; 2 spins, rest; 3 spins and rest. The arrows along x-axis show the time it takes to go back to normal after the spins. High values at peaks mean less alertness.

spins and possibly on the state of mind of the subject. But the conclusion is that the mean and the high values of the range increases in value. The increase in value means that there is an increase in activity for the particular region of the brain as indicated by the alpha waves, leading to a decrease in alertness.

The two sets of experiments do show the effect of mental impairment on the alpha waves. But there cannot be any conclusion made about the relationship between the number of spins and the level of cognitive impairment. The effect on the magnitude is still inconclusive. The goal is to find the relationship of magnitude with increased cognitive impairment. Another set of experiments was done to arrive at such a relationship. In this experiment the number of spins was increased after a brief rest. The experiment started with 1 spin and after a rest of 10 seconds, two spins were done and then after a rest of another 10 seconds, 3 spins were done. The hypothesis is that the x-axis should reflect that the time to get back to normal after 3 spins should be more than the time to get back to normal after 1 spin.

The result is shown in Figure 6.3. There are 3 sets of peaks. The first set shows one peak for one spin, the second set shows 2 peaks for 2 spins and the third set shows 3 peaks for 3 spins. The x-axis shows the number of data points as also the time in seconds. It can

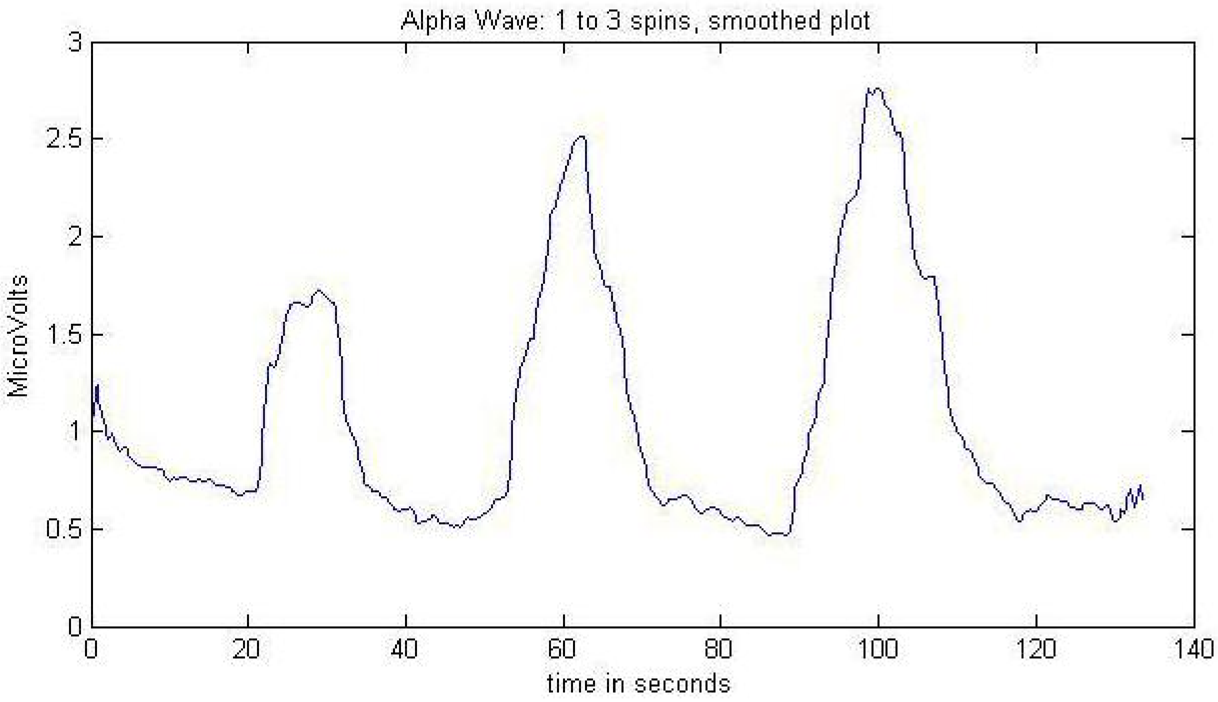


FIGURE 6.4. Alpha waves; 1 to 3 spins; smoothed plot.

be seen that after the first spin, it take 17 data points (157-140) to go back to the normal state, which corresponds to approximately 3 seconds. After two spins it takes 22 data points (about 4 seconds) to go back to the normal state and after 3 spins it takes 44 data points (about 8 seconds) to go back to the normal state. This experiment does confirm that there is a relationship between the number of spins and the time it takes to go back to normal state. Another view of the same plot is generated using the smoothing function of Matlab. The result is shown in Figure 6.4.

In the next sections I describe some of the experiments done to cause impairment by doing physical exercises.

6.4.3. Walking Steps

In the previous experiment, there was no physical exercise, but the act of spinning does cause impairment in the brain. In this set of experiments the EEG waves were recorded as the subject walked several steps. The subject walked 10 steps in one set of experiments. These were repeated 10 times each. Figure 6.5 shows the plot for 10 steps.

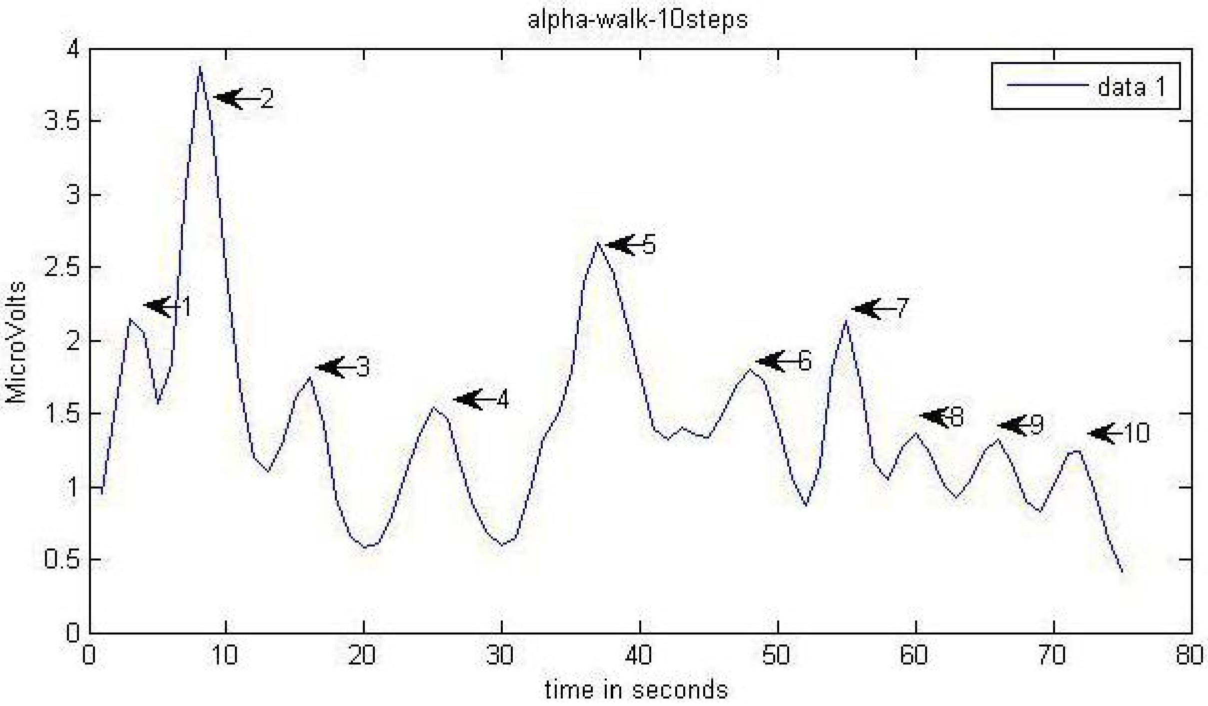


Figure 6.5. Alpha waves, eyes closed, walk 10 steps. The arrows show the peaks during each walking step.

For the 10 steps the mean is 1.42 and the range is between .41 and 3.87. The experiment was repeated for 15 steps and showed similar results. In both the cases it showed that the mean and the high range value is higher than the meditation state value.

I tried another variation of the walking experiment. In this experiment, the subject did 10 steps but stayed in the same place. This was to minimize any effect of actual movement. The mean in this case is 1.44 and the range is from .59 to 3.37. These results are consistent with the actual walking experiments.

6.4.4. Sit-Ups exercise

In this set of experiments, the EEG waves were measured as the subject did sit-ups. The subject did 10 repetitions of the experiments for 5 sit-ups and similarly repeated the experiments for 10 sit-ups and 15 sit-ups. The plot for 5 sit-ups is shown in figure 6.6. The mean of the Alpha waves magnitude is 7.32 and the range is from .98 to 18.2.

The magnitude for these experiments showed the highest values as compared to other

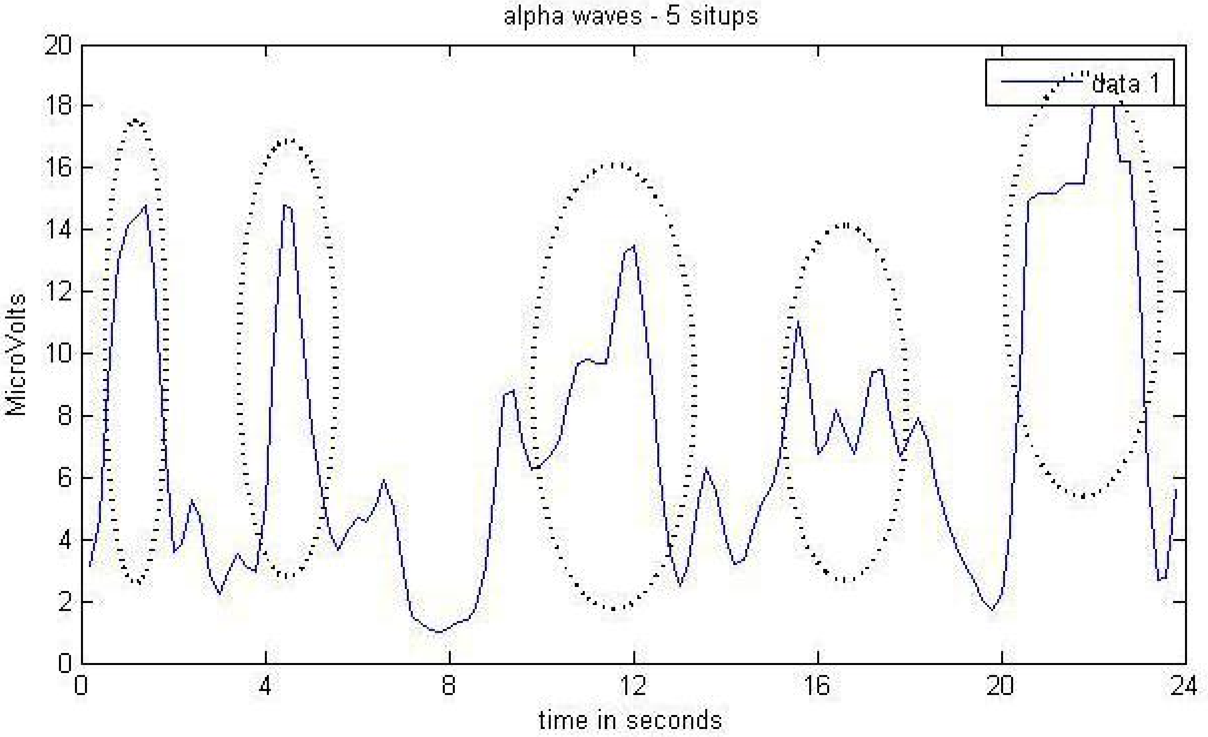


Figure 6.6. Alpha waves, eyes closed, 5 sit-ups. Each sit-up peak is shown by the ellipse around the part of the plot. High value of y-axis magnitude means a low level of alertness. As compared to other plots, the sit-ups have a low alertness due to higher physical stress.

experiments. Doing sit-ups is more strenuous than walking or spinning in the chair. This would suggest that the magnitude value of Alpha waves increases with higher physical stress, causing lower alertness. I repeated this experiment 10 times each for 10 sit-ups and 15-sit-ups and the results were consistent.

6.4.5. Climbing Stairs

In this experiment the subject climbed stairs while wearing the Neurosky band. The subject eyes are not closed but open. So I studied the Beta waves of EEG for this set of experiments. The plots are also analyzed for any trends linear or non-linear. An attempt is made to come up with a mathematical model of this trend.

Figure 6.7 shows the plot for stair climbing. The mean is 3.24 and the range is from .68 to 25.3. It may be observed that the trend of the waves is of increasing magnitude over

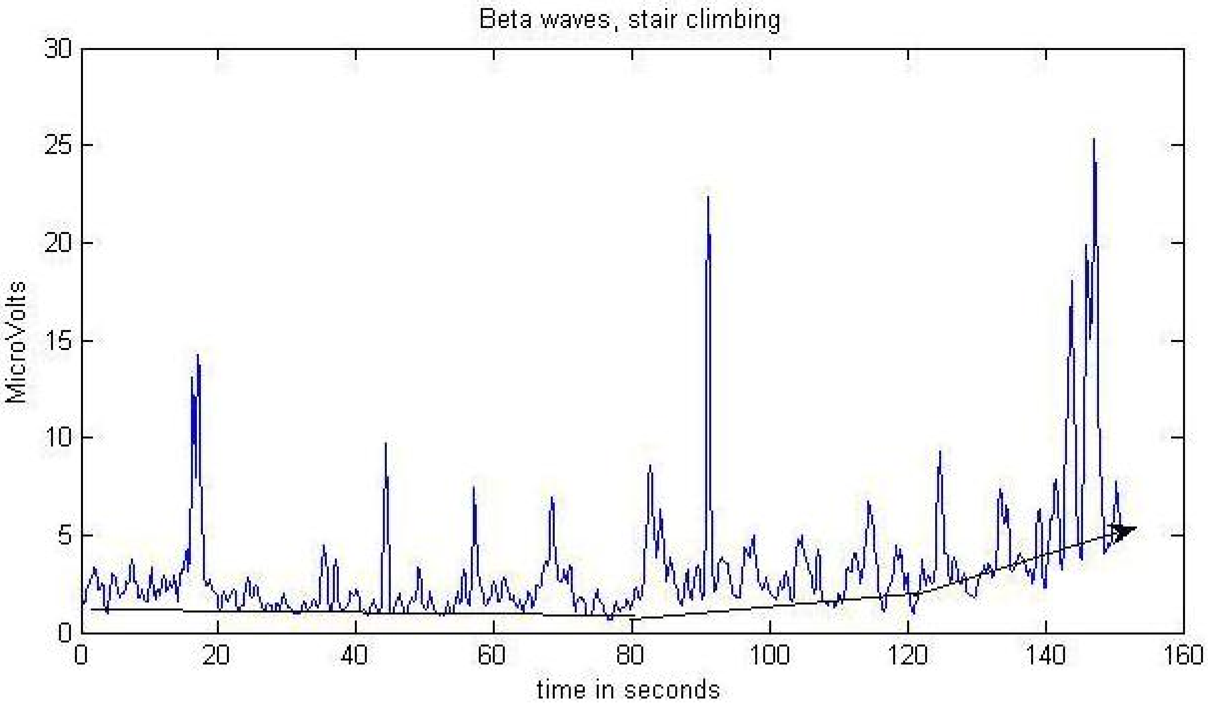


FIGURE 6.7. Beta Waves, Climbing stairs, eyes open. The arrow at the base of the plot show the increase over time is exponential.

time. The arrow line at the base shows the rise in the curve. It also shows that the increase is non-linear. The mathematical model for the increase in trend is plotted using three possible categories of equations, exponential, polynomial and power. I used Matlab toolkit to plot these curves. The fitting of exponential equation shows the best fit for the curve.

6.4.6. Experiments after Alcohol Consumption

Drinking alcohol also impairs mental capability. The type of impairment for all the categories is not same. For example, a person under stress due to life threatening emergency is under a different type of impairment as compared to the impairment after exercise or impairment after drinking alcohol. But my attempt is to see if I can observe the phenomenon of impairment using the EEG waves. The experiments were repeated after intake of alcohol. The meditation state experiments, the sit-ups and the stair climbing experiments were repeated after drinking various quantities of alcohol. The quantity was sufficient to cause impairment in the subject. The results in each case showed that the

Experiment Type with Alcohol	Mean	Min	Max
Meditation moderate alcohol	.75	.25	2.25
Stairs climbing after alcohol	2.46	.22	13.39
Sit-ups after Alcohol	9.14	.7522	34.51

Table 6.1. Alpha waves magnitudes after drinking of Alcohol, the high values as compared to non-alcohol consumption indicate lower alertness.

magnitude of the waves was higher as compared to the meditation state reading. Also in most cases the readings after the alcohol for similar exercise was higher than the readings before the alcohol intake which indicates a decrease in alertness. These experiments were repeated 10 times during each session of alcohol consumption and it was repeated over 3 sessions. Table 6.1 shows the results of these experiment. These sets of experiments were done by the author himself and no other subject was involved in the consumption of alcohol.

6.4.7. Correlation of Heart Rate and Beta waves during exercise

Alpha and Beta waves measure the brain activity when the person is awake. During these exercises the heart rate also changes, based on the duration and intensity of the exercise. The hypothesis was that there is a correlation between heart rate and the EEG waves. There have been very few studies to establish correlation between the EEG waves and heart rate. Abdallah et al [10] have done studies to establish correlation between EEG waves and heart rate during various sleeping patterns. Their focus is on the effects of sleep apnea, which is a sleep breathing disorder that brings about changes in heart rate, neurological activity. The conclusion was that the EEG waves corresponding to Delta, Sigma and Theta bands had strong correlation with heart rate at different sleep stages. Derbali et al [46] did a study on the prediction of motivation of players in a serious game using the EEG waves and any correlation with heart rate. The conclusion of the study was that the theta waves were positively correlated with motivation. However the heart rate did not show any correlation with this activity. In this section I present the results of experiments done to study the correlation of Beta waves and the heart rate.

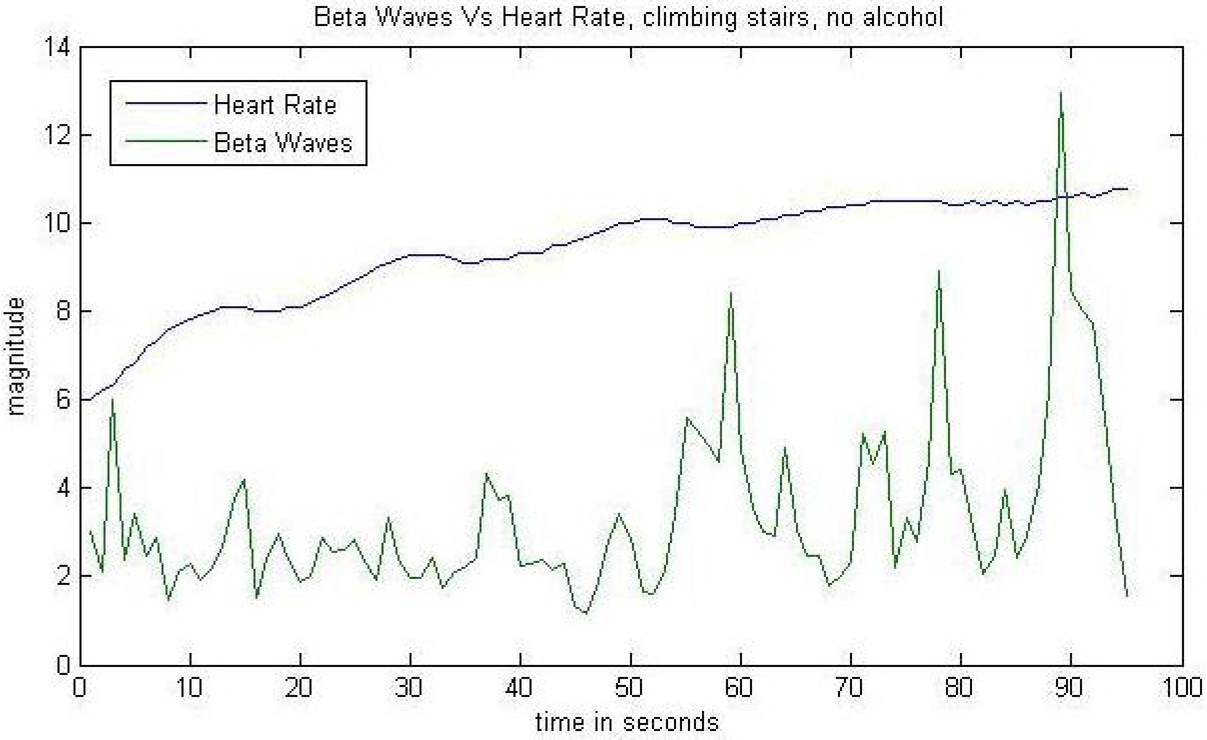


FIGURE 6.8. Beta waves and hear rate comparison, climbing stairs.

In this experiment the heart rate was also recorded simultaneously with the EEG waves. The plot is shown in Figure 6.8. The x-axis in this plot is modified to show time scale in seconds. This is done to have a correlation with the heart rate readings, which are recorded once per second. As mentioned earlier, the Beta wave magnitude is recorded 4-6 times every second. In this plot, the magnitude in each second is calculated by taking an average of all the Beta wave readings in each second. The y-axis shows the magnitude of Beta waves. The heart rate magnitude is normalized so that it is on a similar scale as the beta waves.

There does not seem to be a direct correlation between increase in heart rate and the increase in Beta waves. Heart rate increase starts as soon as exercise is started. But the Beta wave magnitude increase does not start immediately. Heart rate magnitude begins to flatten after a certain magnitude is reached, but the Beta wave magnitude starts to increase later in the exercise.

6.4.8. Thinking Exercise

I did some experiments where the subject does not actually do any physical exercise but only imagines it. I first asked the subject to imagine he was walking and take 10 steps. The plot for this experiment did not show any correlation with actual walking. I repeated this experiment for sit-ups. I asked the subject to imagine doing 10 sit-ups. Again the plot did not show any correlation with the plot of actual sit-ups. The main reason is that imagining does not cause real physical or emotional stress. So the EEG waves do not record any change. Also it is difficult to imagine walking or doing sit-ups in a consistent manner. The time interval between each walking step cannot be consistent without actually taking the steps. Similarly the time interval between each sit-up cannot be consistent.

6.5. Discussion of Results

I make the following conclusions from the set of experiments.

- The magnitude of the Alpha waves is affected by cognitive impairment. The magnitude of the median Alpha waves increases with cognitive impairment. The high value of Alpha waves range also increases with increased activity.
- The time it takes to reach normal state increases with increased cognitive impairment. This conclusion is reached with the experiment whose plot is shown in figure 6.3.
- As the intensity of exercise increases, the magnitude of alpha waves also increases. This was consistently shown when I compared the standing state with the meditation state and then progressively with the walking state and finally during the state of doing sit ups. The increased magnitude indicates a decrease in alertness.
- The Alpha waves do record the number of steps taken while walking. The subject walked with eyes closed (to avoid eye ball movement) and no movement in the head to avoid the effects of any artifacts causing these peaks. This experiment was repeated by making the subject take 10 and 15 steps staying at the same place physically (stationary walk). This was done to further limit the effect of moving.

Experiment Type	Mean	Min	Max
Meditation, Sitting	.62	.17	1.52
Meditation Standing	.94	.26	2.78
Spinning in a revolving chair - 3 spins	1.41	.27	6.44
Spinning in a revolving chair - 5 spins	1.67	.26	10.18
walking steps	1.42	.41	3.87
Sit-Ups	7.3	.98	18.2
Climbing Stairs	3.24	.68	25.3

TABLE 6.2. Comparison of all results, higher values mean higher power levels of the waves, which implies higher brain activity indicating lower alertness.

- The Alpha waves do record the number of sit ups. In this case also the subject did sit ups with eyes closed and no movement of head.
- The mathematical modeling of the trend lines shows that the exponential equation is a better fit for the curve.
- In the study of Alpha waves, the magnitude of Alpha waves did show an increase in the magnitude of mean value and the high value of the range after alcohol consumption.
- There does not seem to be a direct correlation between increase in heart rate and the increase in Beta waves.

Table 6.2 summarizes the results of the experiments. The main conclusion I have is that the value of Alpha waves magnitude is higher for exercises that are more strenuous and also higher as compared to stationary case. The higher value means less alertness. The results were consistently observed over several repetitions of the same experiments.

6.6. Conclusion and Future Work

In this chapter I attempted to simulate transient impairment by doing physical exercise, causing dizziness by spinning and by consumption of alcohol. The results consistently showed that the brain activity showed higher levels in Alpha and Beta waves. It also showed that more intense the exercise the higher the magnitude of power level of the waves. After the consumption of alcohol the EEG levels were higher as compared to the EEG levels before the consumption of alcohol.

Further studies on different level of exercise can further confirm these conclusions. I used equipment manufactured by a company called Neurosky. Further experiments can be done by using a variety of head bands manufactured by other companies.

CHAPTER 7

HCI

7.1. Objective

The objective of NG9-1-1 is to improve and enhance the effectiveness of 9-1-1 calls. At this time 9-1-1 calls are voice only calls. With the implementation of NG-9-1-1 architecture, multimedia calls will be possible. The caller and the PSAP operator will be able communicate using video, images, text in addition to the voice, using smartphone. There are many aspects of improving the multimedia interaction between the caller and the 9-1-1 operator. In this chapter I focus on the problem of control of multimedia and improving the Human Computer Interface (HCI) for the caller and the operator. I first present a mathematical model of the 9-1-1 call, showing the factors that influence the time to respond to a 9-1-1 call. I then describe two applications that I have developed to improve the HCI for the 9-1-1 operator and the caller. These applications not only improve the quality of the HCI but will also reduce the time to complete the call.

If the caller is stressed and impaired physically or mentally, he may not be able to use the multimedia controls. For example if the operator wants to zoom in, the caller may not know how to do it. In such a situation it would be preferable if the operator can take over the control of the caller's multimedia controls. The first application achieves the remote media control. I specifically focus on the video and audio control functions during the call. The remote media control helps the caller in case he is not able to or does not know how to handle the media control buttons of the smartphone. The second application helps in the audio communication between the caller and the operator. I use the Text-to-Speech engine in an Android smartphone to develop the application. In this application, the 9-1-1 operator may type in a text for the caller, the Android API uses the Text-to-Speech (TTS) engine to convert the typed text to speech. The caller would hear the text typed by the operator but spoken by the TTS engine in the smartphone. This function frees the operator from speaking well known instructions or questions and also avoid the need to repeat them if

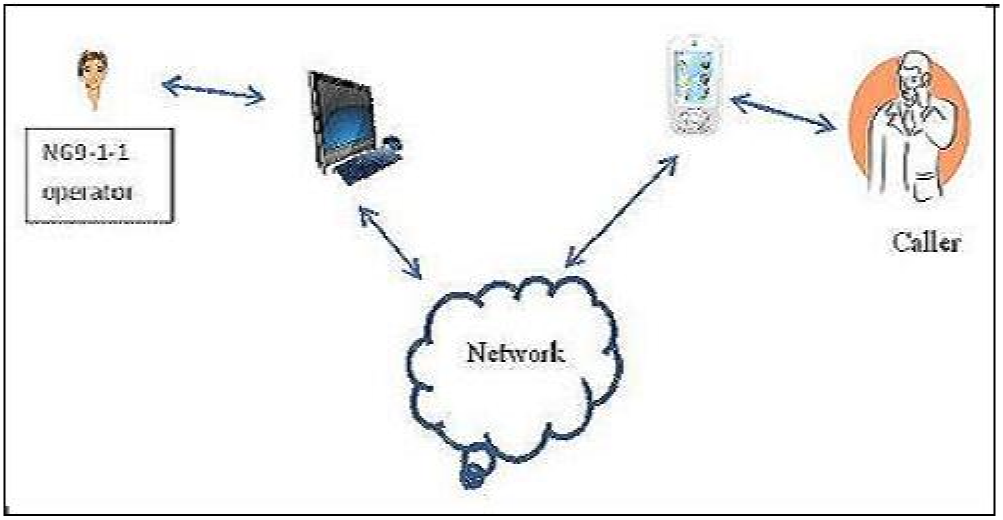


FIGURE 7.1. 911 call Human computer interface

needed. He can just click on the question or the instruction and it is sent to the caller where the TTS engine would speak to the caller. Another advantage is that the speech accent of the operator will not prevent the caller from understanding the spoken words. The TTS engine at the caller's smartphone can be programmed to speak in an accent understandable to the caller.

7.2. Mathematical Model of a 9-1-1 Call Time

NG-9-1-1 allows an emergency call using multimedia services. One of the challenges of a 911 call has been to respond within 60 seconds of the call - called the 60 second challenge. A redesign of 911 call model using the multimedia services can meet this 60 second challenge. In this section I present a mathematical model of the 911 call and then consider factors that can improve the response time of the call. I consider the 911 call model from human computer interface point of view. The call involves an interaction between the caller and his phone; and the 9-1-1 operator and his equipment (phone/computer). Figure 1 shows a representation of this call with the telephone network facilitating the call.

A basic call scenario involves the operator asking questions from the caller to determine the nature of emergency. These questions are standardized into a set of protocols called Emergency Dispatch Protocols. The operator then responds to the information received by giving some instructions. In this call model I analyze the factors that determine the total time to respond. I then focus on some of the factors to make the interaction more efficient. In figure 7.1 one can see that there are several interface points in the interaction between a caller and the operator. I identify three interface points in 7.1:

- Human-Computer Interface at the 9-1-1 operator end.
- Human-Computer Interface at the caller end.
- Computer-Computer Interface across the Telecom network.

The total time for the call consists of time spent by the operator asking questions and giving instructions; time spent by the caller in answering questions and doing tasks that the operator asks him to do and the time of telephone network delay. I can write the total response time as:

$$T_{response} = T_{operator} + T_{network} + T_{caller} \tag{20}$$

In the following sections I will discuss some of the factors that determine the time of the operator, the caller and the network.

7.2.1. Factors at the Operator Interface

In this section I discuss the factors that contribute to time from the operator's end of the call.

At the Operator side, the contribution to the total response time consists of time to ask questions, and time to take any actions by the operator. The actions by the operator could consist of moving cursor on the screen to move to the next step of EMD protocol, or to click on the map to see the address of the caller. I can express this time as:

$$T_{op} = O_q + O_a \tag{21}$$

Where T_{op} is the operator's contribution to the response time, O_q is the time to ask questions, and O_a time to do actions. If the total number of questions asked is n, then I can write the time to ask questions as:

$$O_q = \sum_{i=1}^{n} \tau_i \tag{22}$$

Where τ_i is the time for asking i^{th} question. And n is the total number of questions.

Similarly I can write the time to do actions as:

$$O_a = \sum_{j=1}^{m} \tau_j \tag{23}$$

Where τ_j is the time it takes to do j^{th} action, and m is the total number of actions.question.

The operator actions involve moving cursor on the computer screen to achieve an objective. These motions have been studied using Fitts law. The computer screens can be designed so that time to move the cursor and select the appropriate choice takes minimum time. According to Fitts law, the time to achieve the task (τ) is defined by:

$$\tau = a + b * log_2(\frac{2D}{W} + 1)$$

Where D is the distance moved and W is the width of the target; a and b are Fitts constants. Since each of the movements by the operator are going to be on the computer screen, moving a cursor, the same Fitts law equation will apply for all actions of the operator. So I could write the time to do actions as:

$$O_a = m * (a + b * log_2(\frac{2D}{W} + 1))$$

Where m is the total number of actions. So the final equation for Operator's time is:

$$T_{op} = \sum_{i=1}^{n} \tau_i + m * (a + b * log_2(\frac{2D}{W} + 1)) \tag{24}$$

From the equation 24, I conclude that the operator's response time can be improved by improving his time to ask questions and the time to do his actions. Some of the ways to reduce the time are as follows:

- Design and use of Emergency Medical Dispatch Protocols.

  The EMD protocols are a set of cards with questions and instructions on each card. Based on the answers to the questions, the operator is instructed to move to the next card for further set of instructions. This selection of the next card can take a little time as the operator has to flip through the deck of instruction cards. An online graphical model of the instructions can help in quick movement from one card to the next. In this case the operator selects the correct instruction on the computer screen and based on the response, the screen automatically moves on to the next question card. The existing protocols are based on the voice only calls. A redesigned protocol would also take into account the existence of multimedia technology (appendix A). The new protocols will have fewer questions to ask, further reducing the time of response for the call.
- Use of Technology, Equipment/Screens that allow efficient use of multimedia.

  Text-to-Speech (TTS) allows the standard instructions from the operator be sent as text rather than operator actually reading them. If the Dispatch Protocol Instructions are converted to an electronic format rather than the paper format, TTS will save time by letting the operators click on the written questions and instructions on the screen, instead of reading them. Remote Media Control allows the operator to take control of far end smart phone of the caller.
- Training/expertise of the operators.

  The operators will need training in the use of new screens, new ways to handle instructions.

7.2.2. Factors at the Caller Interface

In this section I discuss the factors that determine the time spent on the caller's side of the interface.

I can write the time spent by the caller, during the call before the operator can respond as:

$$T_{caller} = C_q + C_a$$

Where T_{caller} is the time spent by the caller, C_q is the time in answering operator's questions, C_a is time spent in doing actions. These actions could be walking towards the action scene, talking to the victim, observing the victim's injury or doing some other motion. So the actions of the caller are more varied in terms of movements as compared to the actions of the operator.

I can write the time to answer questions as:

$$C_q = \sum_{i=1}^{n} \tau_i$$

Where τ_i is the time for answering i^{th} question. And n is the total number of questions.

Similarly the time to perform the actions during a call as:

$$C_a = \sum_{j=1}^{m} \tau_j$$

Where τ_j is the time do j^{th} task. And m is the total number of tasks.

Each question from the operator would involve some action or response from the caller. This could be making a simple observation like, "Is the patient bleeding", to an actual action like walking to the victim to see if he is breathing. If the caller is the injured person, or the injured person is a close friend or relative of the caller, then the caller may be in an agitated state of mind or may be mentally impaired. This can result in delayed response to instructions from the operator. And for each such action there is a possibility of delay due to impairment. So I can write the time for action by caller as follows:

$$C_a = \sum_{j=1}^{m} (\tau_j + I_j)$$

Where, I_j is a delay factor that is introduced due to the condition of the caller [69]. The time to actually do j^{th} action is τ_j. In the case of caller, the action is more varied. It is not restricted to the movement of cursor on a computer screen. In this case I can apply the enhanced Fitts Law equation (eq. 19) to model the time spent in doing each action. So I express the total time from the caller side as:

$$\tau_{caller} = \sum_{i=1}^{n} \tau_i + a + \sum_{\substack{i=1\ to\ k \\ j=1\ to\ m}} \{\beta_{i,j} * \lambda_{i,j} * \alpha_{atomic} * log_2(\frac{2D_{i,j}}{W_{i,j}} + 1)\} \tag{25}$$

Where n is the number of questions answered, k is the number of actions the operator asks the caller to perform and m is the number of motions needed to perform each action.

The following are some the ways to reduce the time on caller's end:

- I_j is the time delay in answering questions due to cognitive impairment of the caller (ability to follow instructions). This can be caused by the medical condition of a loved one or the caller himself. The delay can be reduced by making the instructions from the operator simple enough that even the impaired caller can follow them without much delay. For example the instructions could be a sequence of arm movements to bring the smart phone camera closer to the victim, instead of one instruction. The ability of the operator to view all the actions on a video further helps in making the instructions simpler.
- Another important consideration to reduce the time is the ability to correctly answer questions from the operator, especially about the medical condition. The questions about the medical condition can be better answered by using smartphone sensors. CPR, blood pressure, breathing analysis can be done using the smartphone. An automatic transfer of certain vital signs from the victim not only improves the quality of response, but also reduces the time. It improves the diagnosis by reducing the possibility of giving wrong information to the operator. It reduces the need to possibly repeat the answers for medical information.

- Use of Remote Media Control frees up the caller from many tasks involving the phone. For example, the caller may not know how to zoom in the camera. With remote media control, the operator does this from the remote end.

7.2.3. Network Interface

In this section I briefly discuss the contribution of network delay towards the total time of a 9-1-1 call. This issue assumes importance in NG9-1-1 architecture because of the bandwidth requirement of multimedia calls. The advances in VoIP technology have enabled the availability of higher bandwidth over the network not only for landline calls, but also for cellular calls. Under normal circumstances, the bandwidth to support multi-media calls is available. In the case abnormal circumstances like natural disasters, even the voice calls may be impacted. In fact the VoIP architecture has enough redundancy built into the network that even in such case more calls will be completed as compared to the traditional PSTN networks. So in the model of the Human Computer Interface, I will not consider this factor for time of response analysis.

In the next section I provide the hardware and software details of the two applications I have developed to improve the Human Computer Interface during a multimedia 9-1-1 call.

7.3. Applications of HCI

Remote Media Control application allows a 9-1-1 operator take over the video controls of a caller's smartphone during a 9-1-1 call. During the call a caller may face problems of impairment. A simple instruction from an operator to zoom in the smartphone's video camera may be hard to execute. This may not only be due to impairment, but also the caller may not know which button to press for zoom in.

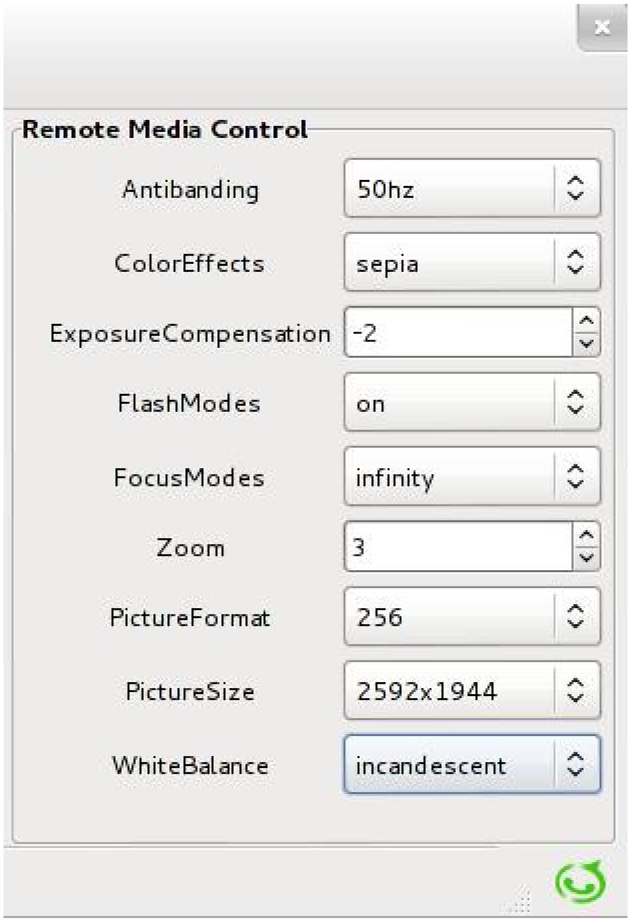
Text-to-Speech application will allow the 9-1-1 operator to send text to the caller, instead of actually speaking it. The text is converted to speech at the caller's end by the TTS engine in the smartphone. The application can be useful in several scenarios. The operator is freed from having to read or repeat certain standard questions or instructions. The smartphone's speech engine can be programmed to speak in an accent that the caller easily understands.

In the next subsections I list the requirements that I considered for developing the application. Then I describe the hardware and software resources needed to develop the applications. Finally I describe the software architecture of the applications.

7.3.1. Platform Requirements

Remote Media Control Application will attempt to control the media capabilities of caller's smartphone. At present there is no capability of controlling the media features from remote. The following are some of the requirements I considered in developing these application:

- There is a need to consider the privacy issues. Most people will not like to give up control of their smartphones. Any user of this application will have to download this application on the smartphone before the control can be given up. During a 9-1-1 call, the operator will send this application to the caller to download. In an emergency situation, when there is a question of life and death, the caller will most likely download the application and give up this control. After the call is complete, the application in the smartphone can be stopped and removed.
- There are several models of smartphones in the market made by different vendors. Not all the models support all the possible set of features. On the operator side, a new screen will be needed that shows the media features of the smartphone that can be controlled. For each media feature, the set values that can be changed will also be shown. Ideally, the operator's screen should show only those smartphone features that the phone supports. The application meets this requirement such that the smartphone will send a message to the operator side with a list of all the supported features and the set of values for each of those features. Figure 7.2 shows a screen shot of the Remote Media Control as seen on the operator's screen.
- The Text-to-Speech application is also downloadable on the caller's smartphone. When the application is downloaded the TTS engine is activated and it is ready to convert the received text messages into speech. The 9-1-1 operator's screen shot is



Antibanding	50hz
ColorEffects	sepia
ExposureCompensation	-2
FlashModes	on
FocusModes	infinity
Zoom	3
PictureFormat	256
PictureSize	2592x1944
WhiteBalance	incandescent

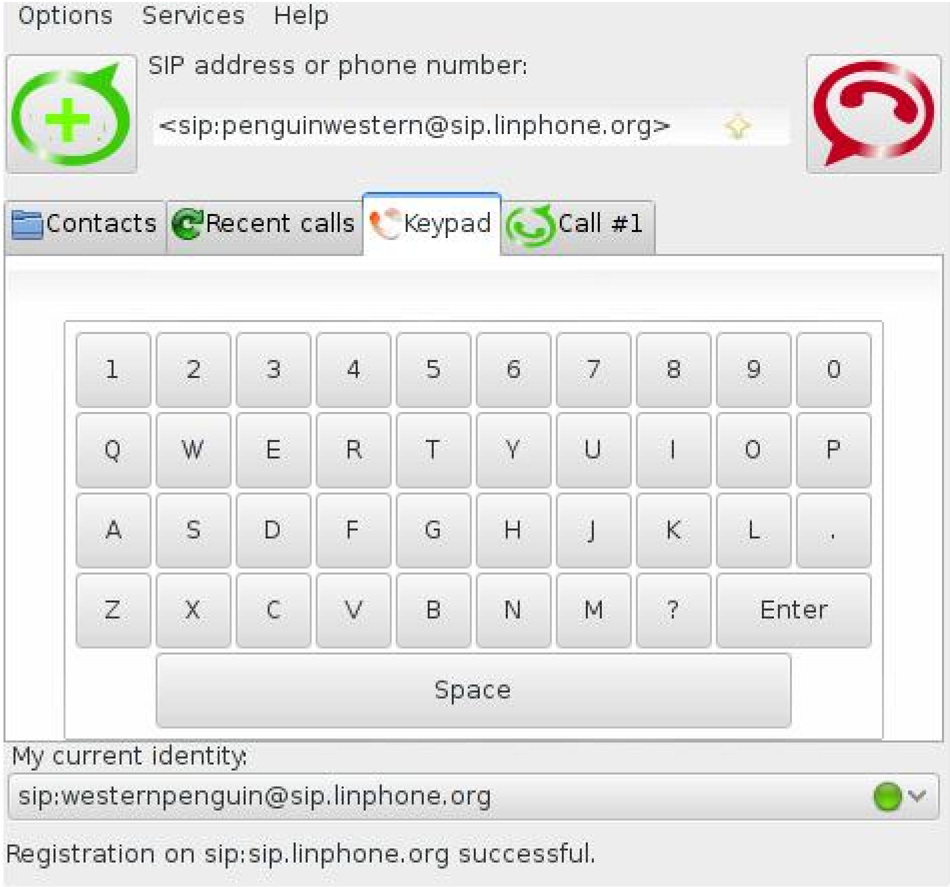
FIGURE 7.2. Remote media Control Screen shot as seen on the operator's screen.

shown in figure 7.3.

The hardware and software resources needed to develop these applications are discussed in the next subsections.

7.3.2. Hardware Resources

The hardware resources neded for these applications are rather simple. I need an android based smartphone used by the caller to make a call. The 9-1-1 operator has a large computer screen and a device to receive or make calls. A computer with a telecom application to make call would serve this need. The major effort in developing the two applications is on the software side. In the next subsection I describe the software needs and the architecture.



SIP address or phone number: <sip:penguinwestern@sip.linphone.org>

My current identity: sip:westernpenguin@sip.linphone.org

Registration on sip:sip.linphone.org successful.

FIGURE 7.3. TTS screen shot on the 9-1-1 operator's side.

7.3.3. Software Resources

The software resources to develop these applications are as follows:

- An opens source SIP software installed on a computer/laptop that can make and accept SIP Voice/Video calls. I need the source code for this client so that code changes can be made. The SIP client on the computer will simulate the 9-1-1 operator.
- Open source smartphone application software that can initiate SIP calls and also accept SIP call. In this case also I need the source code to make code changes. I would prefer the smartphone SIP software should have a common source code base with the computer based SIP software as that would make code changes easier. I would not need to understand the software architecture of two different products

and then make code changes to each of them.

- Any other software libraries or end point support needed to complete the calls. One of the end points needed to complete SIP calls is called a proxy server. The proxy server knows the IP address of all clients that register on it. It routes calls from an originating end point to a terminating end point, if the terminating end point had registered with that proxy.
- Development environment for client and the server side of the application. Ideally this development environment should be the same for client as well as the server. It should support debugging the application as well as download the code to the smartphone for testing.

In the next section I describe the software products that I selected to develop my application and meet the software requirements listed above.

7.3.4. Selection of Software Modules

There are several software products on the internet that are developed by open-source community. These software products are free to download along with their source code. Many of them have forums to discuss problems with the product and possible solutions to them. But there is no dedicated support. The forums and help on them is by volunteers. The answers to problems may not exist and the participants may not be able to readily answer all the questions in a timely manner.

7.3.4.1. *Selection of SIP Application Software*

As mentioned earlier, I wanted to search a SIP based product that has a common source code for operator side as well as the smartphone side of the application. A search on the internet revealed that there were several open source SIP clients that I could download and install on a computer. But I could only find two SIP based Android applications that would allow SIP calls to be completed to a smartphone:

- SipDroid Application.

- Linphone-Android Application.

7.3.4.1.1. Evaluation of SipDroid

The procedure to make a call is as follows:

- Download SipDroid application on the smart phone.
- Sipdroid recommends pbx.org as the proxy server. Set up an account on pbx.org
- Download a computer based Sip Client. There are several open source computer based sip clients available on the internet. I downloaded Ekiga.
- Register Ekiga on pbx.org, using a second account.
- Make a call from smart phone to Ekiga or from Ekiga to smart phone.

I made a Video call from Ekiga to SipDroid smart phone. The audio in the call worked, but the video did not work. Similarly, an attempt to make a video call from SipDroid smart phone to Ekiga also did not work. I downloaded some other Sip based computer clients, like Kphone, linphone etc. But the video call did not work on any of the clients.

The disadvantages of SipDroid are that it depends on the third party proxy servers like pbx.org. Similarly it does not have its own Sip based computer client, but depends on third party clients. In order to implement my project, I would need to make code changes to the Android based smartphone and also to the sip based computer client. If I use SipDroid, I will need to modify code in two entirely different platforms. Finally, the video call did not work on any of the tested computer clients.

7.3.4.1.2. Evaluation of Linphone:

The second Android based Sip Client for smartphones is called linphone-android. Linphone supports its own proxy server to route calls. The proxy server address is sip.linphone.org. Linphone also has its own computer based Sip client, called linphone. So I first attempted to make a video call between Linphone-android smartphone application on one end and the computer based sip client, linphone, at the other end. I registered two accounts with sip.linphone.org proxy server. The video call succeeded. Another advantage of linphone is that the code base is common for both ends of the call. So making code changes would be easier. For these reasons, I picked Linphone to develop the application. Linphone is supported on windows as well as on Linux. I selected Linux for the development environment as the code is more stable in Linux environment.

7.3.4.1.3. Selection of development Environment

The development environment I selected is called eclipse. It is an open source development environment. Linphone code base is also developed using eclipse. Finally, eclipse supports debugging and downloading of new applications on a smartphone. Eclipse emulates several features of smartphones so it is easy to debug smartphone applications in the eclipse environment itself. Eclipse is supported in windows as wells as linux. I developed my application using the linux operating system.

7.3.5. Installation Procedure

Installing linphone and linphone-android in Linux involves several steps. It also depends on the version and package of linux that has been installed. For example Fedora Linux may have one set of problems to resolve during installation, but Ubuntu Linux may have some different set of problems. For this project I had installed Fedora Linux on one system and also installed Ubuntu Linux in a different system.

7.3.5.1. ***Linphone-Android Installation***

The following procedure is followed to download and prepare the linphone-android code:

In the next section I describe the knowledge domains needed to develop this application and some examples of difficulties involved in working on an open source product.

7.3.6. Domains of knowledge

In order to complete the project, I need the knowledge in the following areas:

- C, C++, Java and JNI languages
- SIP protocol
- Knowledge Telecom areas like call processing, message coding and decoding, routing etc.
- Eclipse development environment.
- Android OS APIs.

7.3.7. Architecture of Linphone

Linphone is an open-source product. As such there is very limited support and documentation available to understand the software architecture of the product. So I first needed to focus on understanding the overall software architecture. Later on I studied the details of the software modules that I will need to modify for my applications. In this section I describe the overall architecture and then in the later section I describe the details of the software modules that I modify.

7.3.7.1. *Software Architecture*

Linphone-android is written in Java. It is supported in Windows as well as the linux environment. However developing in the windows environment involves installing a software on windows called mingw (minimalist GNU for windows). Mingw allows Unix like command line interface to develop and compile code. The rest of the code is written in c/c++. The code is compiled as libraries that are loaded during initialization of linphone-android. The largest library is the linphone library itself which consists of several packages including the Osip package. There does not exist a simple ability to interact between java and the native language (c/c++). It is not possible to directly call a native function from java or to call a java interface directly from the native language. JNI (Java Native Interface) is a language construct developed to provide the facility to interact between java and native language.

Figure 7.4 shows a block diagram for the different modules in the linphone architecture [1] A brief description of each module is:

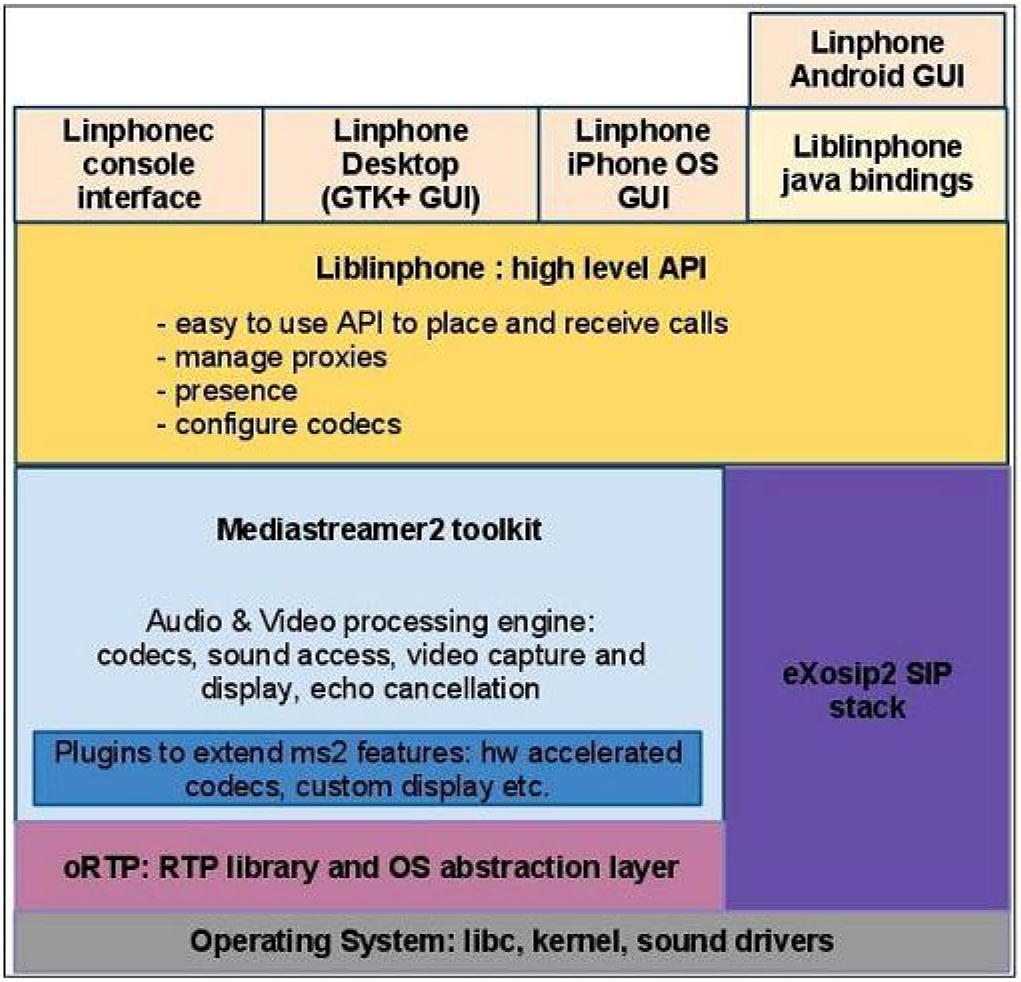


Figure 7.4. Block Diagram of Linphone Software modules

(1) The base layer consists of linux OS that comes with all the device drivers, including the audio device drivers.
(2) oRTP is the RTP stack for based on RFC 3550. It is available as open source software under Lesser Gnu Public License (LGPL).
(3) ExOsip2, extended open Sip, is the SIP stack used by linphone. It has a robust API and is used is many SIP based products. The development of eXosip2 started in the year 2000. Since then it has gone through several updates and revisions and has been extensively tested on several products.
(4) Mediaserver2 is the library that is responsible for all the receiving and sending of multimedia streams in linphone, including voice/video capture, encoding and

decoding, and rendering.

(5) LibLinphone is the layer that has the actual linphone code. This has APIs to initiate calls, among other APIs used for management of media resources including initialization of external libraries (SIP library, codecs etc).

(6) GTK provides the graphical user interface to linphone. This shows a phone like image and the user can click buttons to do various activities, including dialing the called party number or address.

(7) A text based user interface is also provided, called linphonec. This allows users to issue commands from console. The commands include making a phone call, answering incoming calls or disconnecting calls.

(8) Another thin layer on top of linphone is called linphone java bindings. This layer facilitates communication between the lower layers and the highest layer of Android OS.

(9) The top layer consists of the android OS and the application that makes possible the completion of sip calls to an android based smart phone. It is the layer where the Android based APIs are invoked to activate various services, activities and resources that are available on the Android platform.

The lower layers up until linphone API layer are programmed in C. Linphone itself is programmed in C and c++, and the Android module of linphone is programmed in Java. The interaction between the three languages is necessitated because the overall Linphone-android application is designed by combining various modules written in these programming languages. The SIP stack has been written in C, but the Android OS is written in Java. It is not feasible to re-write the SIP stack in Java. The interaction is made possible by a new language interface called JNI (Java Native Interface).

The low level software architecture focussing on the code changes is described in Appendix B.

CHAPTER 8

EMERGENCY DISPATCH PROTOCOLS FOR THE NEXT GENERATION 9-1-1 SERVICES

8.1. Introduction

The 9-1-1 emergency calling System has its origin in United States in 1958. Now, most advanced countries provide emergency response services using two key components. The dispatcher, a critical player in the 9-1-1 call center, takes information about the emergency from the caller and arranges to send adequate resources to handle the situation. The emergency dispatcher's role originated in the United States, but it has gained acceptance in all parts of the world [142, 196, 140, 18, 85]. Second, as the system has evolved, gathering information from callers to access the emergency situation has also been standardized with documents called Dispatch Protocols. The first use of standardized protocols was recorded in Arizona in 1975. In the US, these dispatch protocols are called the Medical Priority Dispatch System (MDPS) [86]. This system has about 37 cards and each card gives instructions to the dispatcher for a specific emergency type. A similar dispatch protocol, used by the state of New Jersey, is called Emergency Medical Dispatch Guidecards [89]. This protocol also uses a set of cards based on the type of emergency call to guide the dispatcher. The success of dispatch protocols can be easily gauged. Today, many developed countries have developed such protocols. The UK uses AMPDS [141], France uses SAMU [88].

8.1.1. Case for Next Generation Emergency Response System

Traditional phone subscribers use the Public Switched Telephone Network (PSTN). A more modern network, based on Voice over IP (VoIP) had approximately 80 million VoIP subscribers worldwide in 2007. Currently, 50 percent of global telecommunications traffic is handled over IP networks. Each year, about 200 million emergency calls are placed in the US, with about one third originating from mobile phones. Most of these emergency calls are based on the Public Switched Telephone Network (PSTN). Although at this time VoIP subscribers place a small percentage of emergency calls, we can expect the use to

Type of Emergency Call	Percentage of Total Calls
Medical Emergency	37
Fire	11
Vehicle/Accidents	10
Chemical Hazards	2
Floods/Water Damage	1
Electricity/Wire Down	1
Other	38

TABLE 8.1. Category of 9-1-1 Calls

increase, as old telecom networks are replaced by the newer VoIP based networks. Existing emergency calling systems must adapt to support IP-based emergency calls. To support IP-based emergency communications and the variety of new services that VoIP allows, a new architecture called Next Generation 9-1-1 (or NG-9-1-1) is developing. Like traditional 9-1-1 systems, future VoIP systems must process a wide variety of calls. Emergency calls are placed for a variety of reasons, ranging from medical emergencies to crime-related incidents. As many counties in the US publish data from their 9-1-1 call records, we are able to determine the types and frequencies of emergency calls. Table 8.1 shows the data for call categories received in percentage terms [60]. Medical emergencies account for the largest percentage of calls, followed by fire emergencies and vehicle accidents. Although the category "Other" has the largest number of calls, it includes unclassifiable calls. The "Other" category also includes non-emergency calls. Given the variety of calls, an important component of emergency response system is the dispatcher. As mentioned, currently the dispatcher determines the level of first response based on information gathered from the caller and using standard protocols that assume voice only telephone communication. The Next Generation 9-1-1 system, a communication system using multimedia services, will improve the quality of information available to the dispatcher; but, NG9-1-1 will also require a redesign of the protocols to take advantage of those multimedia functions.

8.1.2. Current Protocols

Current emergency dispatch protocols are designed assuming that 9-1-1 calls are voice calls. Dispatchers may not have direct access to affected persons, yet to elicit optimum information from a caller, they must interpret quickly the caller's communication skills. Because dispatchers must elicit information from excited or emotionally distraught callers, they rely on a well-tested procedure. The protocols, which function almost like an algorithm, consist of written, step-by-step instructions to the dispatcher on how to gather information about the emergency and then provide follow up instructions on what to do. The response may include giving comfort to the caller, if he or she is the affected person. The protocol may also include giving first-aid advice or instructions to the caller before the emergency help arrives. Typically, the time a dispatcher has to gather information is limited, and even with protocols, situations arise where reaching a decision takes more time than desired. An optimum response time to make a decision using the protocols is 60 seconds, also called the "Sixty second dilemma" [34]. However, this time was set arbitrarily. A more reasonable time is about 75 to 90 seconds. Those developing the NG-9-1-1 architecture expect that with multimedia calls, a time limit of 60 seconds may become realistic and may even be less than 60 seconds.

8.1.3. Issues and Challenges

Telecom networks are moving toward Voice over IP protocols. Over time, an increasing number of calls will be made over these networks as opposed to the legacy networks. Naturally, while these advances allow access to multimedia communications in everyday life, they will also raise several issues for emergency services that will need to be resolved. Specifically for 9-1-1 calls, network related issues, such as identification of caller location, arise [70, 139]. The research challenges for these issues include:

- Remote Media Control: Developing automatic remote control of cameras in mobiles to changes in focus, lighting, contrast, Codecs, bandwidth, etc., to help prepare the dispatcher to better respond to the emergency [123].

- Emergency Dispatch Protocols: Modifying Emergency Dispatch Protocols to take advantage of new technology so as to reduce, both, the number of questions the dispatcher asks and the number of instructions the dispatcher gives.
- High Availability: Designing Quality of Service and traffic management so that 9-1-1 calls are not disrupted. This has always been true, but with multimedia services this issue must continue to be addressed.
- Human Machine Interface (HMI): Designing a functional HMI that takes advantage of the new technologies by both the caller and the emergency service staff. For example, video screens at the call center will need a new design enabling multiple screens or multiple windows on one screen. Design of HMI includes requests, responses, and usability of screens on the dispatcher side and also design of controls on the caller side.
- Connection Management: Enhancing Connection management becomes important as several responders may be sharing video and audio streams [30].
- Security: Maintaining and enhancing security of the NG9-1-1- network [45].
- Privacy: Determining appropriate strategies for image distortion and masking of parts of video or images to protect privacy of callers.
- Social Networks as First Responders: Understanding the role of social networks and developing suitable protocols to incorporate such networks into an NG-9-1-1 system. Many times people call friends and family members first when faced with a problem. The use of social networks has made their role an important addition to emergency response system. This process can make friends and family first responders in an emergency situation.
- Medical Records: Providing an appropriate protocol to select which responder or responders will have access to medical or personal information of caller(s).

8.1.4. Problem Definition

This chapter focuses on enhancing emergency dispatch protocols. The dispatcher's role will undergo substantial change in the Next Generation 9-1-1 system. The dispatcher will have access to several sources of information to make a decision on a situation's severity and will need to respond accordingly. Preliminary work has found that continuously feeding a patient's vital signs to the first responders and to hospital staff is critical for a patient's survival. It is also important for the hospital receiving the patient to know as accurately as possible the time of the patient's arrival. The United Kingdom Department of Health has stated that wireless sensors and modern networks can help in communicating this information [141]. This can be achieved by the video streaming from a smartphone. One of video streaming's advantages is live information sharing amongst several people. For example the video stream from the scene may be seen simultaneously by the dispatcher, and the first responders, and hospital personnel. A study performed in Boston concluded that live video feed to responders and at the command center was useful in making the right decisions at critical times [81]. The conclusions of a similar study in Sweden were that video feedback from the incident site has positive contribution to performance and a proper understanding of the situation [23].

It is not inconceivable that immediately on answering a plea for assistance over an NG9-1-1 system a dispatcher may view real-time video along with sound while simultaneously receiving digitized data such as vital signs. Even after the first responders are on their way to the scene, the dispatcher will typically remain in constant touch with both the caller and the first responders to communicate and update information. In fact, in case of medical emergencies, the dispatcher may likely access and transmit patient records to the first responders. Given such a scenario, dispatch protocols will need to change to reflect the changes in technology. The next sections discuss the current dispatch protocols and the changes that may be made to them.

8.2. Relevant Work

Emergency Dispatch Protocols (designed by Dr. Jeff Clawson, who worked as a fire surgeon in the city's fire department) were first used in Salt Lake City in 1981. Initially these protocols were used as an experiment to study their effectiveness. The results of these experiments were published in Journal of Emergency Medical Services [33]. Existing protocols are based in legacy telecom networks where only voice calls are used. Those telecom networks are based on dedicated landlines over a call connection. Over the years, technology developed to accommodate wireless networks. Call connections, no longer based on dedicated landlines, are based on packet networks. The packet networks' bandwidths have increased to a point where multimedia services are available to the general public. However, emergency services have yet to take advantage of VoIP. Potentially, VoIP users will expect to access emergency services using all the multimedia features they now use. In such a scenario, a complete re-design of the 9-1-1 system is needed. Accompanying this development, the Dispatch Protocols must also change to take advantage of the multimedia services.

The architecture for Next Generation 9-1-1 (NG9-1-1) has been designed by the National Emergency Number Association (NENA). NENA first identified the need for an overhaul of the 9-1-1 system in 2000. NENA produced its first document describing the future path in 2001. By the end of 2003, the standards development activity had started [87]. Some documents have been completed. For example, NENA i3 Technical Requirements Document defines overall requirements [129]. NENA is developing additional documents necessary to implement the architecture.

8.3. Communications System

8.3.1. Architecture for Next Generation Communication System

The next generation of the emergency communication system will have the capability of multimedia transmission and of broadcasting several streams simultaneously [83, 138, 168, 136]. Figure 8.1 illustrates such a multimedia-based call scenario. As shown in Figure 8.1, a smartphone has several sensors and applications which allow a caller to transmit video, pictures and voice simultaneously. The emergency service has comparable capabilities to effectively use this incoming data. Since legacy networks and wireless networks will also be operational in several jurisdictions simultaneously, so a 9-1-1 call may go over one or more of these networks before reaching its destination Public Safety Answering Point (PSAP). For the next generation to work effectively, the network architecture has to consider not only the new VoIP scenarios but also needs to be backward compatible. A multimedia exchange between

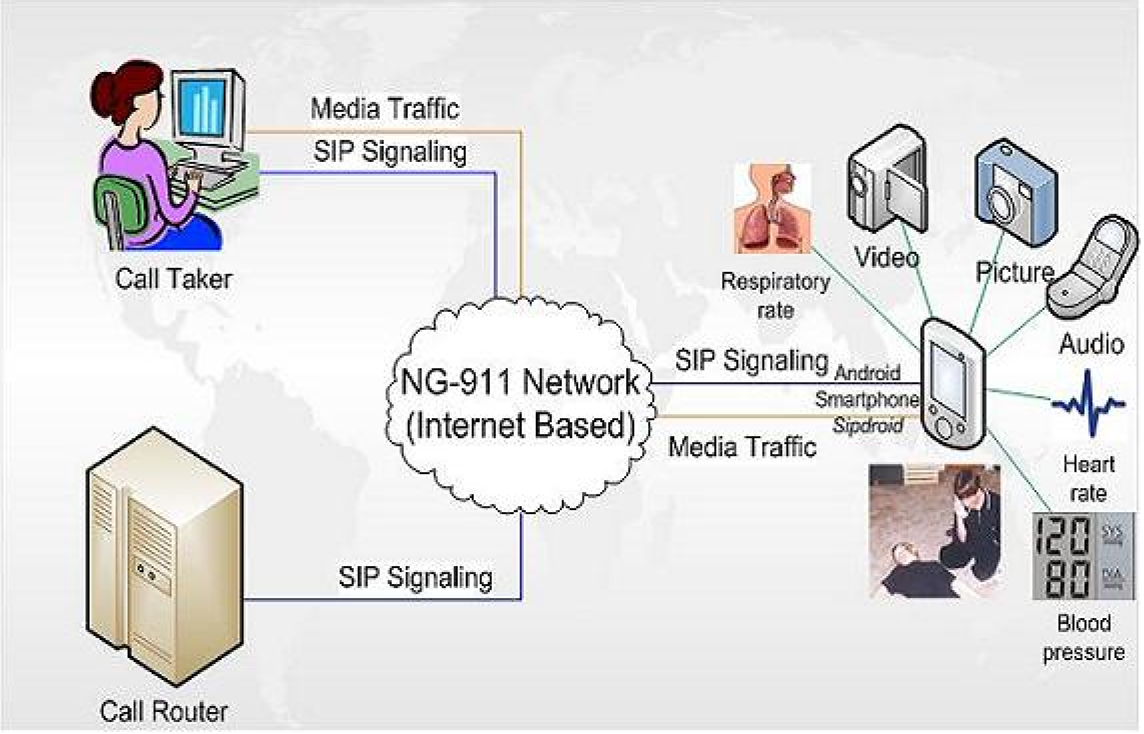


Figure 8.1. Multimedia based NG9-1-1 Call Scenario.

several sources also requires new kinds of display screens. Figure 8.2 shows a proposed screen layout in a PSAP where Next Generation 9-1-1 services are available. The screen receives multiple video streams. These streams may be coming from a caller, the dispatch team, a hospital, or other concerned parties. Similarly, the screen's image windows display simultaneously a patient's medical history as sent from a remote location. In addition, the system has the facility to display text and email messages. A part of the screen also displays a map of the location from where the 9-1-1 call is made. Figure 8.3 shows another screen showing the control of caller's camera by the dispatcher using remote media control feature. The screen shows the mobile phone features that can be controlled. Each feature also has a menu showing the possible value for the feature. In the figure the screen also shows the performance of CPR the depth and frequency of chest compressions. The call center may have four categories of calls for a given incident:

- Individual callers These scenarios are based on individuals calling 9-1-1 help. These individuals could range from children to the elderly, be English or non-English speak-

FIGURE 8.2. A sample screen for NG-9-1-1 based Display Layout at a PSAP. This screen shows the initial display when 9-1-1 call is received.

ers, be handicapped, be disoriented, or be barely alive. Individual callers may use a traditional landline phone, a mobile phone, or an IP phone. In the case of medical emergency, new technologies can provide the Public Safety Answering Point (PSAP) operator additional useful information to better handle the emergency. For example a caller can use the video camera on his smartphone to show the nature of the emergency. Instead of hearing a verbal description, the PSAP operator vi-

SIP address or phone number:
<sip:penguinwestern@sip.linphone.org>

Remote Media Control

Antibanding	auto
ColorEffects	none
ExposureCompensation	0
FlashModes	off
FocusModes	auto
Zoom	0
PictureFormat	256
PictureSize	2048x1536
WhiteBalance	auto

Vital Signs

CPR

Depth 2.12 inches

Frequency 84 comp/min

My current identity:
sip:westernpenguin@sip.linphone.org

Registration on sip:sip.linphone.org successful.

FIGURE 8.3. 9-1-1 Operator Screen Showing Remote Media Control. The smartphone Video/Audio Features can be Controlled by the Operator. Also the Sensor Information from the Remote Mobile is shown here - the CPR Compression Depth and Frequency

sually sees the problem. A caller who cannot speak can use text messaging or the smartphone camera (image or video) to show the problem. This can better assist in a two-way communication as the PSAP can visually see if the caller is following the instructions being given correctly and suggest alternatives, if necessary.

- Third Party Services These scenarios are based on calls made by services such as OnStar that monitor vehicle crashes; alarm companies that monitor break-ins, fires or other emergencies; home monitoring services of medical devices; and services that monitor infrastructures such as highways, bridges and water ways. These services depend on sensors alerting them about a problem. Many times, a sensor alert is followed by a call to a person to confirm an emergency exists. For example, a home-alarm service will call the home owner in case of a break-in alert. Once the emergency has been confirmed, the services call the appropriate 9-1-1 service. While these services reduce the number of false alarms, their procedure also causes a delay in handling the emergency. New technology can help to reduce the delay by routing a video camera's direct feed to the PSAP quickly.

- Calls from Emergency Response Units in the field These scenarios are based on situations where the units that respond to emergency require additional support. Medical personnel responding to an emergency may need support by law enforcement personnel if the situation turns dangerous. Fire station responders might discover illegal activities requiring police assistance. Police officers responding to a vehicle crash might require medical services. In any of these scenarios, when follow up units respond to a crisis, the PSAP operator can relay video images to all responding units, thus better coordinating the responses of individual units.
- The fourth category is automatic calls based on sensors. These are scenarios where a fusion of data from different sensors results in an automatic 9-1-1 call. For instance, sensors detect chemical spills and automatically notify emergency services. Another example could be vehicle sensors transmitting information about the state of a vehicle involved in an accident such as whether it rolled over [16].

8.3.2. Reducing Number of Instructions in a Dispatch Protocol

The PSAP operator uses dispatch protocols to decide the nature of emergency and to expeditiously determine an appropriate response. Timely response may be crucial to saving a life. Next Generation dispatch protocols would use several technologies to reduce the time a dispatcher takes to help and would also improve the quality of that help. Quality improvement is achieved by enabling better problem diagnosis which in turn allows hospital medical personnel to prepare to serve patients better while patients are being transported. This reduction in time will be possible by designing the protocols so that the operator needs to ask fewer questions. These protocols will also reduce the number of instructions given to the caller. Following the new protocols, a PSAP operator can observe the scene through a camera so he needs to ask fewer questions and can also observe if the directions are followed accurately.

The following is an example of questions asked by the dispatcher for a 9-1-1 call. The corresponding change in the protocol is also given at the same time. First, assume that the current 9-1-1 call occurs over a land line; thus, all communication is verbal. The caller in the modified version has called using a smartphone, which allows use of the smartphone's multimedia features. The caller explains the patient has complained of chest pains. The caller indicates possible heart problems. The first question the dispatcher asks is "Is the patient alert?" With current technology, the PSAP operator may have to expend time defining alert for the caller. A dispatcher using VoIP technology and a modified protocol would not need to do this if the smartphone has sensors which can relay this information directly to the PSAP. Given a video call, the dispatcher can also observe the patient's alertness directly by asking the caller to show the patient using camera. The follow-up question under old protocol is "Is the patient breathing normally?" Again, this question becomes redundant given the new technology. There are several sources through which the dispatcher can analyze breathing [68]. For instance, a smartphone accelerometer can determine the patient's breathing pattern. An audio transmission of breathing sounds can be used to draw conclusions about breathing quality. Thus, using a multimedia technology can reduce the dispatcher's reliance on an agitated caller's responses.

Table in appendix A provides a modification of the New Jersey Emergency Dispatch Protocol. The table has 5 columns. The first column identifies the protocol name, which relates to the emergency type. The second column states the question the operator asks based on the existing dispatch protocol. The third column indicates which smartphone sensor can assist in answering the question asked. The fourth column provides a modified question or action to be used when a caller is using a multimedia technology. The fifth column identifies what numeric data the smartphone sensor measures and transfers to the operator. The above example implies that the dispatcher will have input from several sources for a given call, thus, increasing the accuracy of the response.

8.4. Remote Measurements and control

On the one hand, an increase in bandwidth of telecommunications networks allows the possibility of several streams of data simultaneously transmitting information in real time [22]. On the other hand, the sensor technology has matured to a point where sensors can be embedded in smartphones and other devices. These developments make it possible to transmit information that sensors detect about a specific medical condition [49, 179, 5]. Certainly, such sensors may be used in dedicated medical devices that people wear on their person to help doctors to diagnose a specific medical condition [160, 195, 44]. For example, dedicated devices contain embedded sensors that track blood pressure. Or, sensors may be embedded in more general devices such as smartphones. In emergencies, the callers may be physically or cognitively impaired. Dedicated devices may not be readily available. In such situations, smartphone sensors can detect and transmit useful information to the PSAP operator. This section describes applications that enable measuring human vital signs. Although measurements using smartphone sensors do not replace more accurate medical devices found in hospitals, these ”in-the-field” devices can assist the dispatcher in making an accurate estimate of the nature and seriousness of a medical emergency and in relaying that information to first responder para-medical personnel [22].

8.4.1. Heart Rate

Heart rate (HR) is a vital sign of human health that the dispatchers can use when assessing a medical situation. Typically, measuring HR has required either a trained person who knows how to count the rate or a dedicated device placed at specific place on the body. Using smartphone to measure HR may initially seem difficult, but applications have been developed that help lay people to obtain reasonably accurate HR measurements [102, 41]. One of these applications, based on Photo Plethysmography (PPG), uses the camera and the LED flash available on most smartphones. Figure 8.4 shows how a smartphone camera lens can be used to take HR readings. The principle being used is that every heart beat results in pumping the blood through the blood vessels, including the capillaries in the finger tips. This movement of blood results in variations in light intensity as the blood passes through

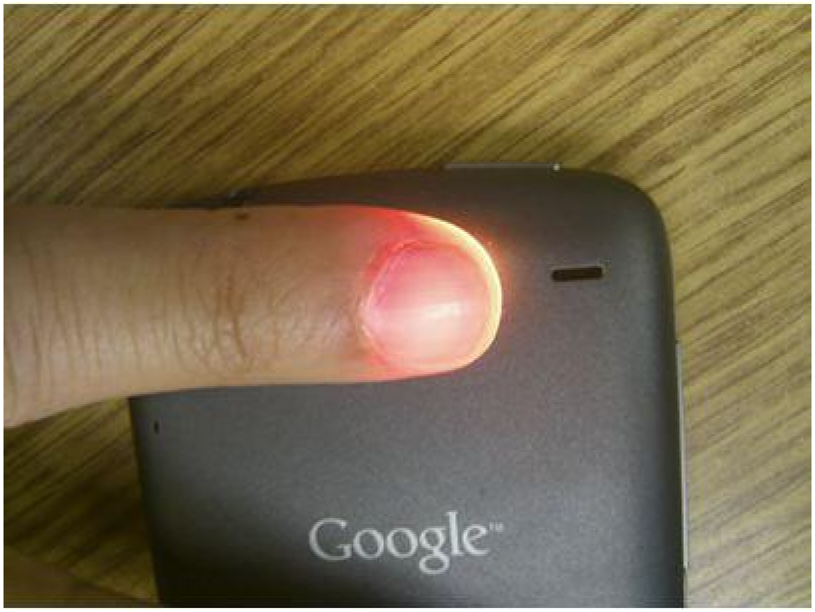


FIGURE 8.4. Using smartphone for Taking Reading for Heart Rate. The finger is placed on the mobile camera lens.

the finger tips. When a finger is placed on the camera lens, a video of the variation in light intensity is captured and can be analyzed. An analysis of the video to calculate changes in the pattern of this light intensity results in determination of heart rate with an accuracy of at least 95% [28]. Figure 8.5 shows the plot of results from video analysis for heart rate measurement. The heart rate is measured by calculating the number of peaks within a certain window frame and then using the equation:

$$HR = n * \frac{60}{Wt}$$

Where n is the number of peaks in the video frame and W and t is the length of the frame in seconds, and 60 is the number of seconds in a minute. The results were calibrated using a commercial heart-rate monitor. The HR was measured with an accuracy of more than 94%.

8.4.2. Respiration Rate (RR)

Respiration is another important vital sign dispatchers can use to determine an appropriate response during a medical emergency. An accelerometer in a smartphone can measure a person's respiration rate when medical devices are unavailable [173, 47, 122]. To achieve

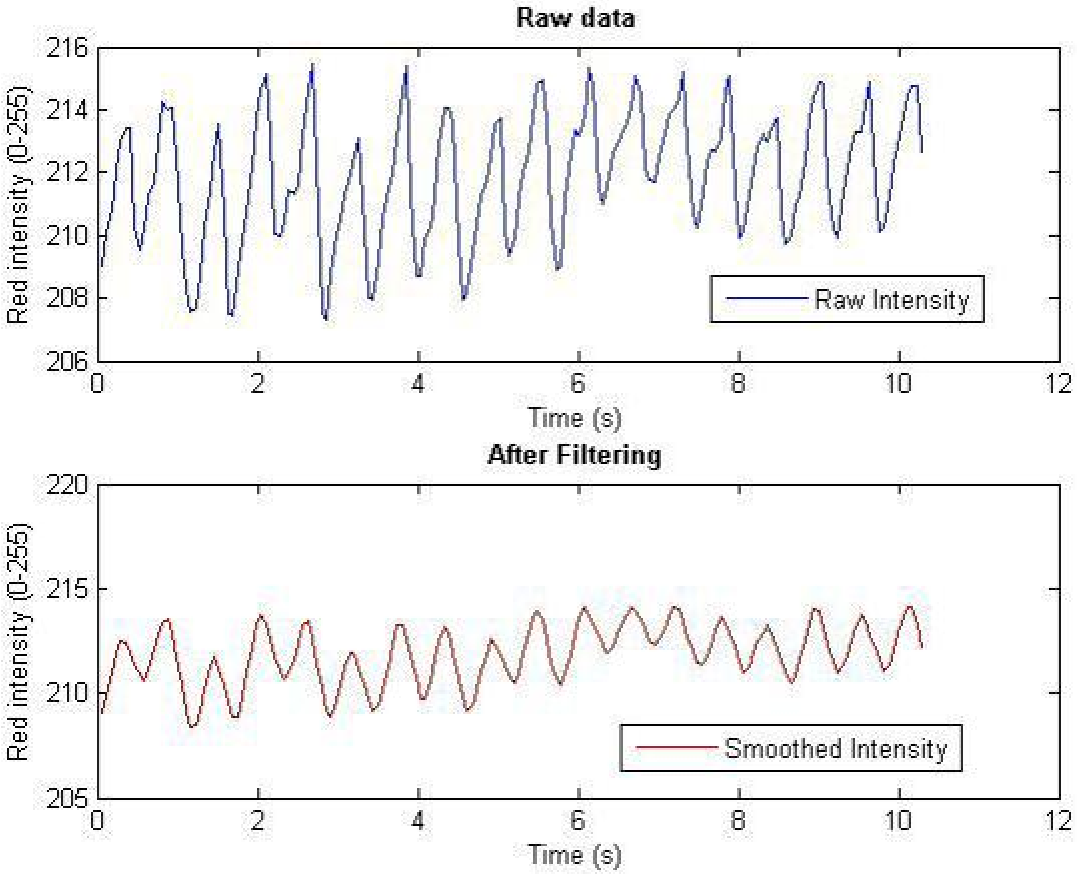


FIGURE 8.5. Heart Rate Measurement using smartphone [28]

the best breathing rate measurement, a smartphone is placed on the upper abdomen. Figure 8.6 and Figure 8.7 show examples of a smartphone placement. The smartphone's accelerometer records the measurement of acceleration approximately every 20 milliseconds. Figure 8.8 provides a plot of respiration as measured by an accelerometer. Respiration rate can be measured with an accuracy of 98% [68]. Another important measure of respiration is the patient's ease or difficulty of breathing. The accelerometer graph can also indicate uneven breathing. The smartphone's microphone captures the breathing sounds coming from the lungs if the smartphone is placed near the upper chest. To a dispatcher, such sound can indicate when the individual is having difficulty breathing, or the wheezing or guttural sounds coming from lungs during breathing. Figure 8.9 shows a pattern of irregular breathing where the person breathes slowly for period of time (about 15 times per minute) followed by fast

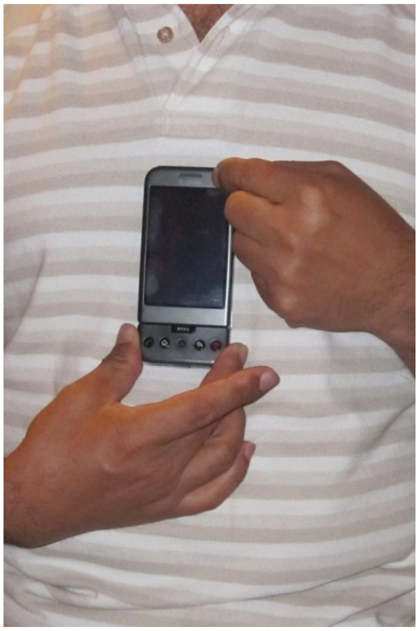


FIGURE 8.6. smartphone placement on Abdomen

FIGURE 8.7. smartphone placement on Chest

breathing for a period of time (about 45 times per minute).

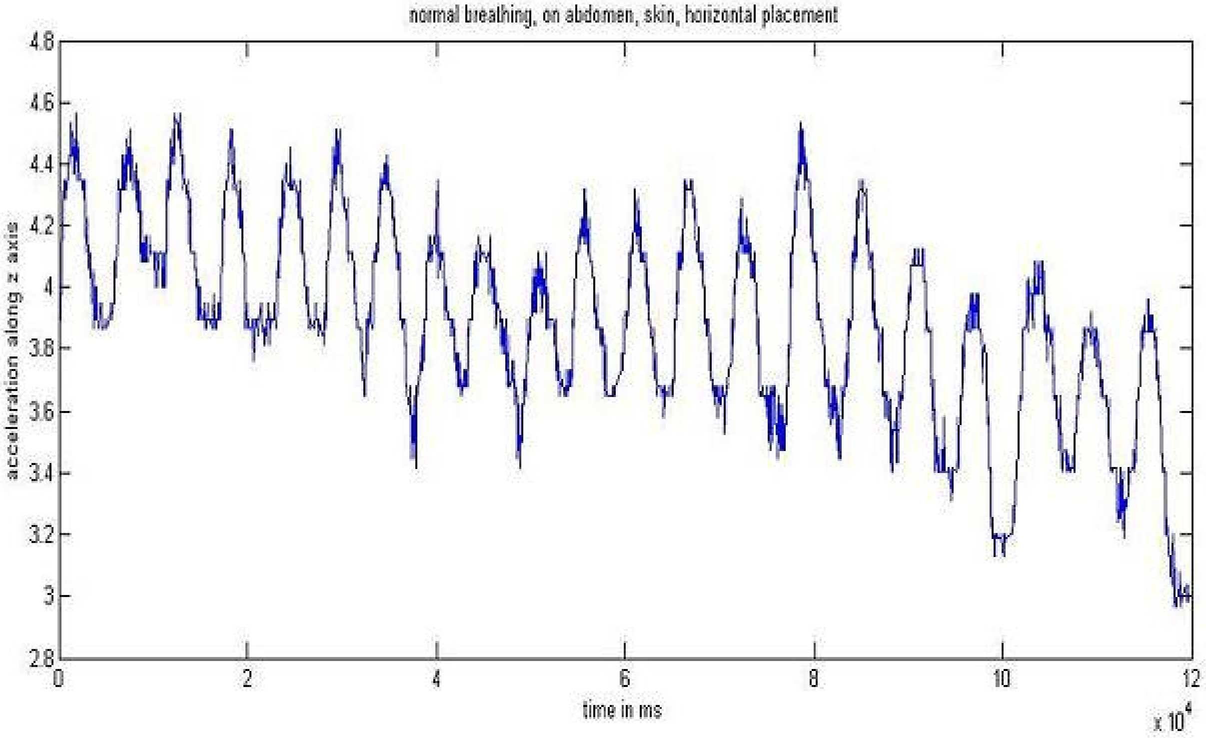


FIGURE 8.8. Respiration Rate plot as measured by accelerometer in smartphone.

8.4.3. CPR (Frequency of Chest Compression)

In case of medical emergencies where the patient has stopped breathing or has a heart problem, a timely and correct CPR can mean the difference between life and death. In the current 9-1-1 system, in such cases the 9-1-1 operator gives verbal instructions over the phone. CPR needs to be given as soon as possible [156, 12]. However, frequently the people with the patient may not know how to give or are nervous about giving CPR. While medical devices can help administer proper CPR, these devices are often not available or are not accessible in emergency situations at homes or public places. Here, again, a smartphone with an accelerometer can help [71].

An application within the accelerometer measures the frequency and depth of chest compressions. Such an application can then prompt the person giving CPR to change the frequency or depth of compression, as needed. In this instance, the smartphone can either be placed directly on the patient's chest or can be held in the patient's hand by wrapping a

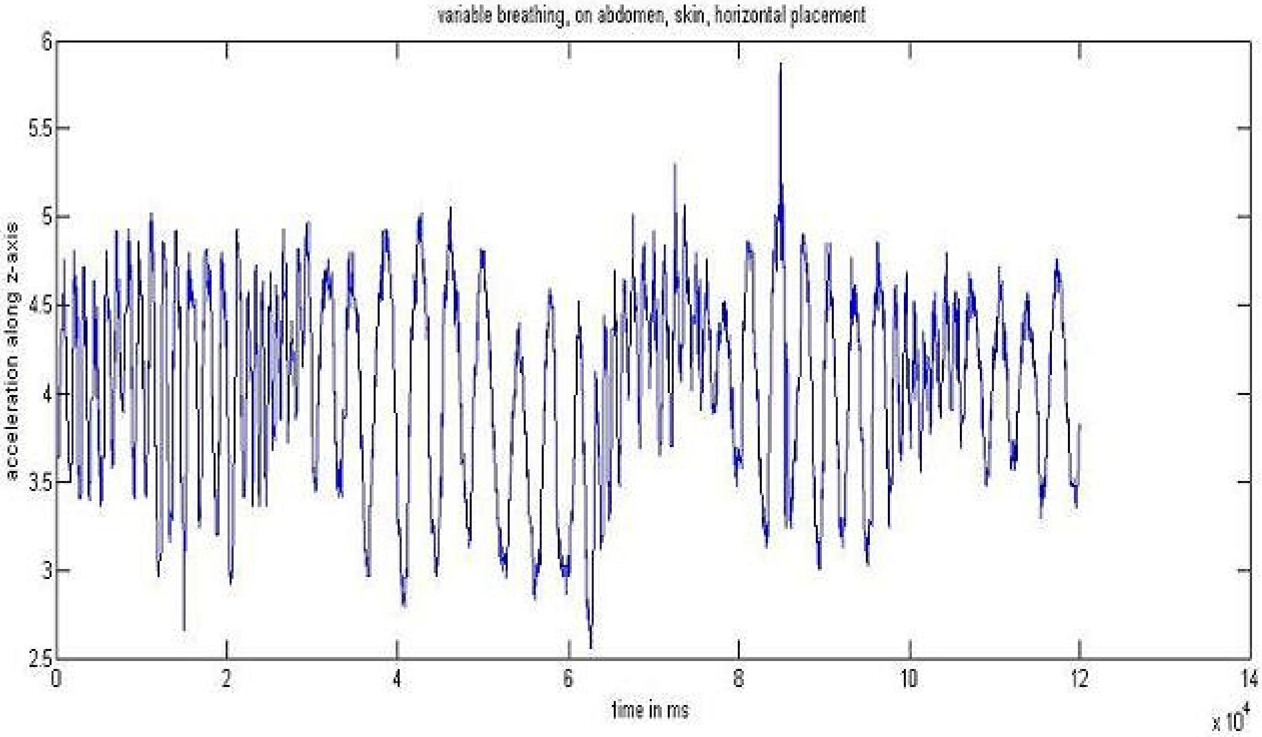


FIGURE 8.9. Irregular breathing Pattern as measured by accelerometer in smartphone. The figure shows fast breathing alternating with slow breathing.

FIGURE 8.10. CPR administered and the performance evaluated by measuring the compression depth, frequency and the Oxygen Saturation levels. The feedback is provided to the person giving the CPR.

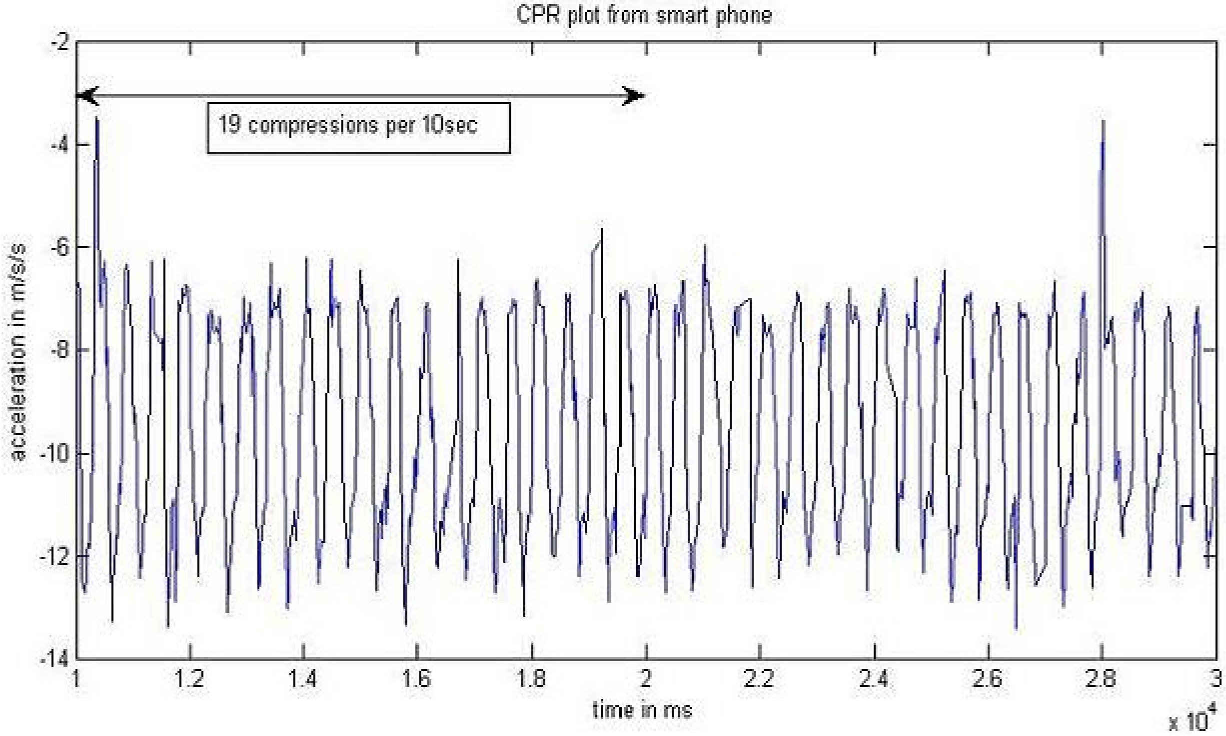


FIGURE 8.11. CPR Rate plot using data from accelerometer in a smartphone. The frequency of chest compression can be observed from the plot.

cloth around the hand and then placing the hand on the patient's chest (Figure 8.10). Then, the accelerometer calculates the frequency and depth of compressions and communicates to the first-aider giving CPR any necessary changes in technique. Figure 8.11 shows a sample of accelerometer data plot while doing a CPR. Figure 8.12 shows the plot of displacement during a CPR. The plot shows a regular pattern of chest compression during CPR. The calculation of displacement is done by a two-step procedure. The accelerometer provides raw data for an acceleration reading approximately every 10 milliseconds. The first step is to find the velocity by using the equation:

$$v_t = v_0 + v_d \tag{26}$$

where V_0 is the starting velocity and V_d is the change in velocity over a period of time and V_t is the velocity after time t

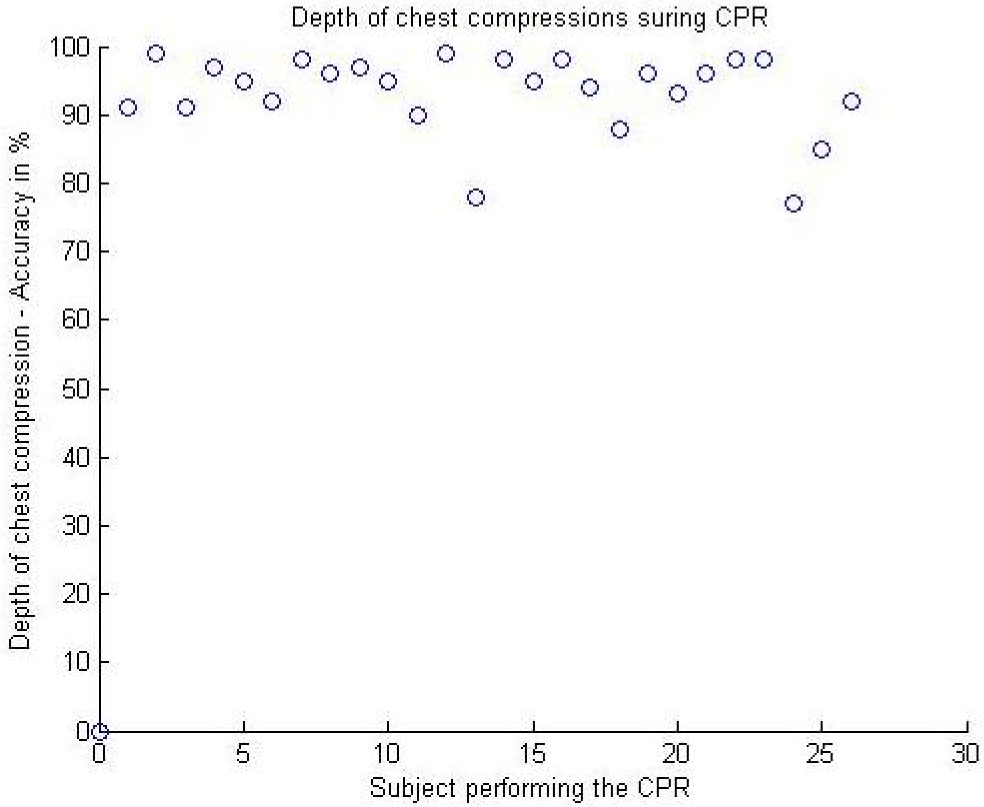


FIGURE 8.12. Scatter plot showing the Accuracy of depth of Chest compressions. The accuracy shows the depth calculated by the mobile phone application as compared to the actual depth of the chest compression [71].

The second step is to calculate the displacement from velocity using the equation:

$$Displacement = \frac{(v_0 + v_t)}{2} * t \tag{27}$$

where t is the time period.

The results for these experiments were evaluated after 30 subjects were asked to perform CPR on a manikin [71]. The application determined the frequency and depth of chest compression with an accuracy of more than 95%. Figure 8.12 shows a scatter plot of the accuracy of each of the subjects.

8.4.4. Blood Pressure

Blood pressure measures the amount of force applied to the arteries as blood is pumped through the body. The body tries to regulate human blood pressure. When the

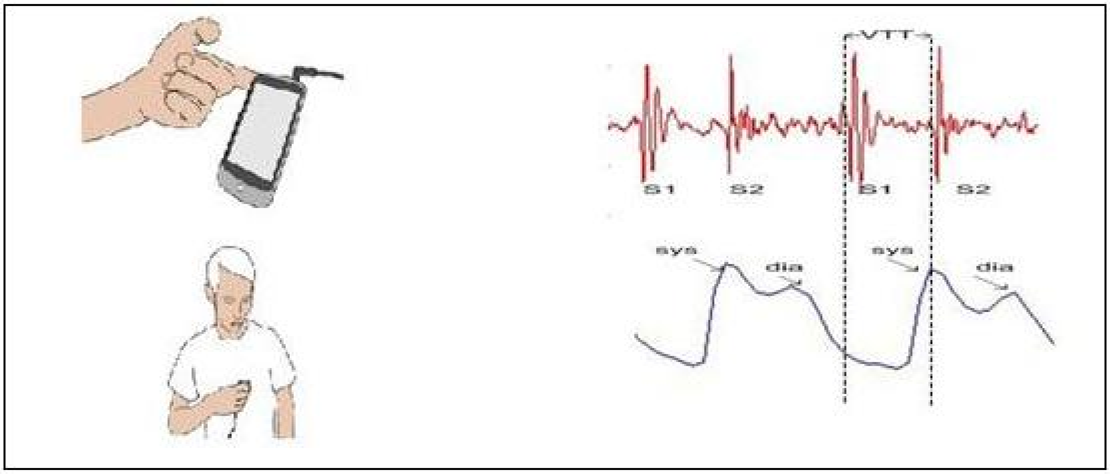


FIGURE 8.13. a: Blood pressure measurement. A finger placed on the mobile camera lens and a stethoscope placed on the chest. 8.13b: VTT Estimation.

pressure drops below normal, the heart rate increases and the arteries contract to increase the blood pressure. Medical devices that measure blood pressure are commonly available for household use. But, during emergency situations these devices may not be available. In such cases, it has been demonstrated that a smartphone can be used to measure blood pressure with an accuracy of more than 90% [28, 82]. The procedure uses two smartphones; one smartphone uses the camera and the LED flash by placing the index finger over the lens of the camera. The second smartphone records heart sounds when placed on the chest.

Figure 8.13a shows the setup of the procedure. Pulse signals over the finger are obtained using a video recording app with pixel intensity analysis. Heart sounds are obtained by passing the audio signal through a 15th order, low-pass Butterworth filter, (which allows only the frequencies between 10-250Hz.) The S1 (lub) and S2(dub) sounds are clearly distinguishable in the resulting audio signal. In Figure 8.13b, *sys* represents the systolic peak of the pulse, and *dia* represents the diastolic peak of the pulse. S1 and S2 are the first and second heart sounds respectively. Vascular transit time (VTT) is the time difference between the origination of S1 in the audio to the appearance of corresponding sys peak in video. The audio and video from the two smartphones is processed to give the blood pressure [28, 98]. The average accuracy of the calculated blood pressure is greater than 90 % when compared with commercial off-the-shelf blood pressure meters.

8.4.5. Motion/Movement detector

Another implication of placing sensors and obtaining automatic transmission of data from them is their potential use in homes of the elderly [143, 14, 163]. In such situations, there may be times when the elderly may be unable to call 9-1-1. However, an automatic motion detector or other similar sensor can analyze data it gathers and can call 9-1-1 when the sensor's application determines that an emergency situation may exist. Such devices are already in place in cars to call for help in case of an accident [103]. To study the feasibility of using such techniques in a facility, we have installed several VoIP-based cameras in our lab. The cameras detect motion on each frame and can independently initiate a VoIP call when decided by an algorithm embedded in the camera. The cameras also have remote controls to focus, zoom, pan or move the lens in different directions. These controls help the camera when analyzing the scene in a more detailed manner to make a decision about making the call.

8.4.6. Remote Control

On some occasions, callers may not be able to operate the sensors and feed the emergency dispatcher needed information. In time of panic, the caller may be unable to make accurate observations or answer the dispatcher's questions correctly. However, with the introduction of multimedia technology in NG9-1-1, the dispatcher will be able to extract the information about the scene by making observations and measurements remotely and will be able to instruct the caller accordingly (see camera features in Table 8.2). The dispatcher can remotely control camera features to get better view of the emergency scene [29]. This ability is useful when a caller is physically disabled or is cognitively impaired and cannot effectively follow verbal instructions.

smartphone cameras now have embedded sensors with controls to change their settings. For example, video cameras will have a setting for zooming, panning, or changing the picture resolution. These settings can be changed using a control button on the smartphone. Normally, the 9-1-1 operator will instruct the caller to change these settings, if needed. But, the technology allows the 9-1-1 operator to take control of the settings when necessary and

Feature	Range
Zoom	1-40
Brightness	0-10
Contrast	0-10
Sharpness	0-30
Saturation	0-10
Rotation	0-360

Table 8.2. Camera Features.

with the caller's permission (for example, when the caller is a young child or is physically or cognitively impaired). In these cases, the operator may choose to zoom in or pan out when he feels the need. Similarly, the volume audio controls may be controlled remotely to listen to a breathing sound. I have developed an application for android phone that allows the smartphone's camera features to be controlled by remote. Figure 8.3 shows a screen of the features that the 9-1-1 operator can remotely control. The application also has text to speech feature. Text to speech allows the 9-1-1 operator to send standard questions and instructions to the caller as a text; the android phone at the receiver end will convert the text into speech. The smartphone can be attuned to speak in an accent that the caller is most comfortable with.

8.4.7. Activity Detection

Many times, the callers/informants are unsure about the patient's state (due to panic/poor cognition). For example, the caller may believe the patient is not breathing but a video would reveal shallow breathing. It has been observed that every human activity has a direct impact on the change in bit rate associated with the frame in the video stream (Table 8.3). For example, in the absence of a user in the view port indicating a completely static scene, the bit rate maintains a very low value of 4 Kbps for every resolution. However, there is a change in bit rate when the scene includes a person even if the subject is completely at a standstill. The increase in the bit rate for different activities for the same

Activity	KB/s
No User	4.19
Eye Blink	24.57
Smile/Scream	.70
No Breathing	19.06
Normal Breathing	35.11
Heavy Breathing	62.39

Table 8.3. bit rates in a frame for Activity Detection.

resolution is due to the movement of exposed body parts involved in the activity. Hence, it can be concluded that bit rate increases even with a small amount of motion exerted by the human body without the user's knowledge. These changes are evident when a person is breathing normally and breathing heavily. It should be possible to detect even small changes in the scene, such as heavy breathing, screaming, and other body movements (using audio or video). One can extract this information in real-time without any complex image/video processing. This can help the dispatcher make an informed decision about the injured person's state. This is particularly useful in the case of a wall-mounted video camera detecting a person falling and automatically calling for help. The dispatchers can look at the person's state even when no one is around [82, 170].

8.5. performance issues

8.5.1. Metrics

The effectiveness of Next Generation Protocols can be measured by using several measures. This section discusses some of the metrics for the next generation Dispatch Protocols.

- Response time: One of the most important measures of the success would be the reduction in time it takes for a dispatcher to decide the level of seriousness of the incident and dispatch help.

- Number of Transactions: Many questions that an operator has to ask the caller during a voice call may become redundant in a multimedia call using video. So the number of questions eliminated is another measure of effectiveness.
- Bandwidth: Many of the vital signs may be measured by the smartphone sensors and can also be automatically transmitted. The amount of such data that can be automatically sent to the dispatcher would be another measure.
- Quality of Service: The quality of decision making at the dispatch center would also improve. This can be measured by several factors like reduction in number of un-needed dispatches, increase in number of lives saved.

8.5.2. Cost

The cost factor is important from the call center point of view. Currently, call centers are equipped for voice-only calls. A setup accepting multimedia calls will require substantial additional investment for call centers. This cost will include equipment costs as well as training costs [32].

8.5.3. Cognition and Anxiety of Callers

A 9-1-1 call may be made by the affected people themselves. Such people may be facing cognitive impairment or even physical impairment. PSAP dispatchers answering calls go through several steps during the call. During a voice call, the dispatcher depends on the caller to accurately describe the problem and answer all questions correctly [180]. The dispatcher may then have several instructions for the caller to follow until emergency personnel arrive at the scene. The operator, again, depends on the caller to follow the instructions. However, dispatcher cannot easily judge if the instructions are being followed accurately or if they are helping. But, in the case of a video call, the dispatcher can follow the caller much more easily, can see the scene, and can see if instructions are being followed. In situations where the caller is a close relative or friend of the affected person, the caller may have cognitive impairment. For example, a parent calling about a child's medical emergency may be hysterical and not in a position to listen and follow the dispatcher's instructions.

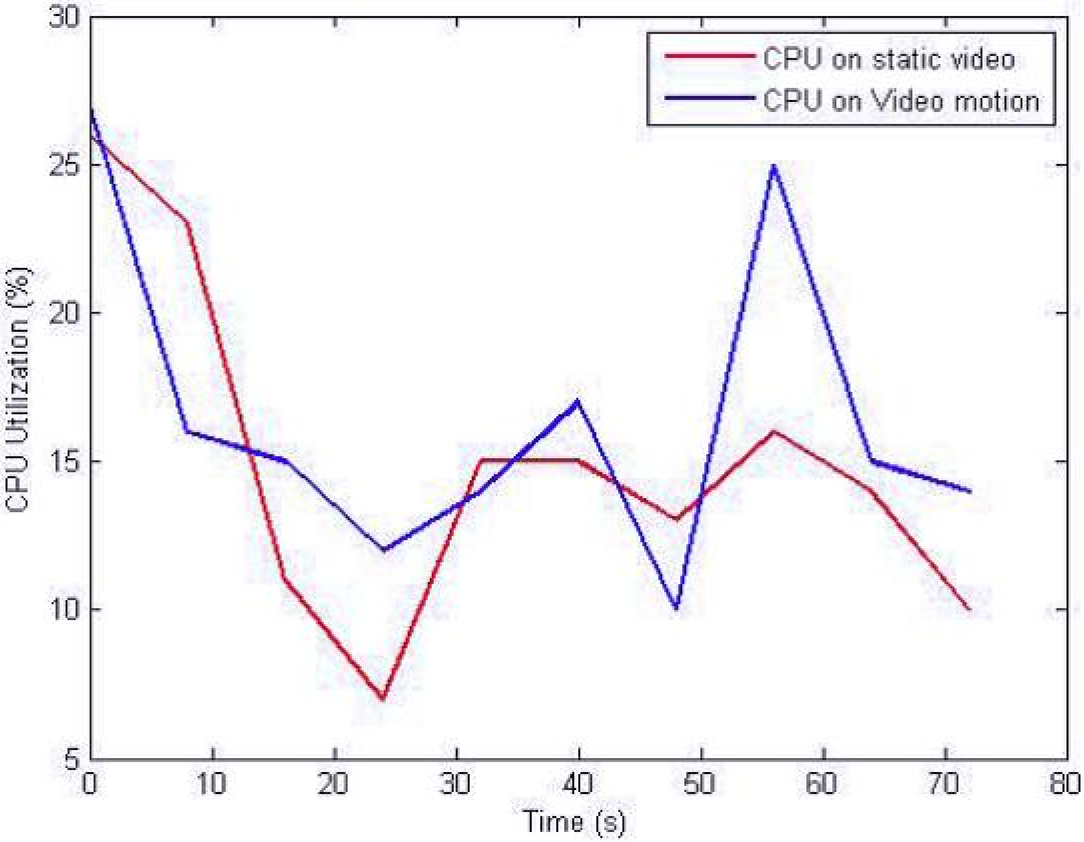


FIGURE 8.14. CPU Utilization of the process when Video is turned ON.

In these situations using a multimedia call, including the video, helps the operator to make better decisions. The dispatcher can actually see the scene as he guides the caller while the dispatch team is on its way.

8.5.4. Mobile Power Management

Power management may become an important issue during a multimedia phone call. During a call, when the video camera is switched on, the power consumption increases substantially. Figure-8.14 shows that the camera uses 25 % of the CPU which is a considerable amount of power for processing the video frames. During a 9-1-1 call the phone must not run out of battery. The resulting loss of connection can cost lives. This implies a prudent use of the video camera and other camera features that consume power. The operator has an important role to play in preserving power. The dispatcher must guide the caller about when to turn the camera on and off or remotely control features which consume large amounts of power.

8.6. Conclusion

There is tremendous scope for improvement in 9-1-1 Dispatch Protocols. Since the inception of such protocols in 1975, there is no question that 9-1-1 services have become an integral part of society. However, now, current protocols must evolve to take advantage of improved technologies. In this chapter I have described how the Next Generation 9-1-1 architecture improves responses to 9-1-1 emergency calls. The ideal will be for a response rate of 60 seconds for most protocols. For callers asking for emergency assistance, the new architecture makes possible the use of sensors embedded in mobile phones to evaluate the condition of an injured person [44]. Currently, these sensors can measure heart rate, blood pressure, and breathing rate; they can also easily transmit results to a 9-1-1 dispatcher. I have shown that the sensors can also be used by offsite dispatchers to evaluate and guide onsite personnel to give effective CPR.

We can expect that future mobile phones will be embedded with both more accurate sensors and with new types of sensors. Those improvements will require developing new applications that assist dispatchers in evaluating a person's condition. For example, sensors that can measure the temperature of a person or perform evaluation of oxygen saturation levels or blood glucose levels in a person may become available. Such applications will obviously not replace the more accurate devices available to medical personnel. But, they will assist 9-1-1 dispatchers in gathering relevant information which they can then relay to first responders and hospital personnel waiting to receive the injured person. When dispatchers can do this, lives can be saved. .

For 9-1-1 operators, the new architecture brings many changes. The visual screens the 9-1-1 dispatchers have before them will provide several streams of video from different sources, giving a more complete picture of an accident scene. Most dispatchers will not be trained to handle visual images of possible ghastly scenes from the accident. This training must be developed and provided. Also, dispatchers must learn to use the multiple levels of screens. When the call arrives, one screen will show the accident scene. A second screen may display video information relating to interactions with the caller. This screen may be providing at the same time information about the vital signs sent by the sensors from the mobile phone. We need to develop ways to assist dispatchers in using this technology. If we do, 9-1-1 operators can ask better, relevant questions of those in emergency situations and respond more quickly to the needs of those in distress.

The modified dispatch protocols will not only improve the questions that the dispatcher asks, but also will significantly modify the instructions that callers must answer in high-stress, oftentimes chaotic situations. For example, a situation may require that the injured person immediately receive CPR. However, CPR must be done correctly or the injured person may be further injured. A smartphone application can guide a bystander to give CPR by instructing him about the frequency and depth of chest compressions. The average accuracy calculation of depth of chest compression is more than 90%. But, there are situations when the accuracy is close to 80%. When callers are asked to give CPR, the dispatcher can monitor the CPR parameters in real time and provide the person giving CPR proper guidance. As more accurate sensors are used in the newer models of smartphones, the accuracy of these calculations will improve further, also enhancing the 9-1-1 operator's ability to give assistance. Another impact of the new Audi-Video technology on those calling for help will be a reduction in verbal responses they are required to make if the dispatcher is to correctly assess what help will be most beneficial. Callers may be confused, distraught, or incapacitated. With audio-only-Only technology, the dispatcher may have to use several seconds to calm callers to a point where they can coherently respond to questions. The caller may need to be calmed several times during the event. For many protocols, the dispatcher will see the actual scene on a video or receive data directly from a smartphone. The new technology will reduce both the number and type of questions that callers must answer, reducing their stress and enabling the dispatcher to make a diagnosis. These reductions in verbal interactions improve the response time, which is the overall goal. We can say that NG9-1-1 will not only improve the response time, but more importantly it will improve the quality of the response and, potentially, save more lives.

CHAPTER 9

CONCLUSIONS

In this dissertation I have focussed on the design of NG9-1-1 Emergecny Medical Disparch Protocols. I first presented the building blocks for a redesign of the Emergency Dispatch Protocols. The building blocks consisted of using technology at the caller's end (using smartphone) and also the developments in the telecom network to provide increased bandwidth for multimedia services. I have used applications that I have developed and others have developed using smartphone sensors to assist the injured person and improve the human computer interface between the 911 operator and his computer as well as the interface between the caller and his smartphone. I have developed an application to evaluate the breathing quality of a person; an application to assist and evaluate bystander given CPR; an application to remotely control the caller's smartphone media features; and an application that the converts text sent by the 9-1-1 operator into speech at the caller's end. Other applications I have documented include application to measure oxygen saturation level in the blood; an application to measure the blood pressure of a person; and an application to measure the heart rate of an injured person. Over time other applications will be developed. But the idea is that these applications can help people in medical emergencies when they call 9-1-1. I have presented mathematical model of cognitive impairment of individuals, which is useful to consider during the design of medical dispatch protocols. I have also extended Fitts law to analyze the human motions so that it can be used in emergency situations to design appropriate HCI for multiple joint movements. I, then present a sample of redesigned Dispatch Protocols. I used the existing New Jersey Dispatch protocols to modify them for the redesign.

9.1. Summary of Conclusions

In this section I detail the conclusions and contribution from each chapter.

In chapter 2, I have described the issues and challenges that face the NG9-1-1 deployment. The telecom network technology is rapidly changing, rendering the existing infrastructure obsolete. At the same time it also promises new opportunities to provide improved services to the community. From this study, I identified some of the issues for NG9-1-1 deployment that I focused on for further analysis and improvements. The biggest of these is the redesign of the Emergency Dispatch Protocols so that the PSAP operator can improve the quality and the time of response.

In chapter 3, I have discussed a way to help bystanders provide effective CPR in a non-clinical setting. The advantages of timely CPR have been well recognized in the medical community. There are programs in place to teach people how to administer effective CPR. But, in emergency situations, a trained person may not be available. At present CPR is an open loop procedure, i.e., there is no way to gauge its effectiveness. I have described a method of making the CPR procedure closed-loop so that there is a real time feedback about its effectiveness. The application uses a smartphone to evaluate the CPR being given and prompts the CPR giver in real time on when and how to adjust the frequency and depth of chest compressions to meet CPR guidelines. The experiments results show that the application can be used to effectively administer CPR, even by people who have not been trained to give CPR. Additionally, the smartphone sensors can measure oxygen decay to accurately determine the blood oxygen saturation level. The oxygen saturation level may offer a better indicator of CPR effectiveness than the depth or frequency of compressions. This also improves the CPR procedure for the trained people. They can determine when to provide mouth-to-mouth breathing.

In chapter 4, I described an application that evaluates the quality of breathing. I conducted experiments and the results show that the accelerometer sensor on the smartphone can actually help us determine the quality of breathing. I determined that the right placement of the smartphone on the body is important and the readings along the z axis of the accelerometer gave the best results. Also, while the readings from the placement on the chest were also accurate, the placement on the abdomen was better. It was also possible to accurately determine if the person was breathing slow or fast or if he had irregular breathing. Finally the accelerometer readings also gave a good indication of the effort used to breathe.

In chapter 5, I have used Fitts law to analyze the actions that a caller may be asked to perform by the 911 operator. Several studies have been done to confirm the validity of Fitts law for analyzing movement of joints. I wanted to study if I can use Fitts law to establish a correlation between different joint movements. The first goal was to define a mathematical relationship between different joint movements. Second, I wanted to confirm that the time it takes to move two or more joints is more than the sum of individual joint movements. Third, I wanted to create a model that would extend Fitts law to time the multiple-joint movements. The experiments confirmed that larger joints move more quickly than smaller joints. When I calculated the ratio of speeds of any two joints, the results indicated that the ratio for same joints was consistent across all participants. Based on these results, I have formulated a mathematical model of joint movements and have extended Fitts Law as given in Equation 19.

In chapter 6, I discuss transient cognitive impairment by simulating it by doing physical exercise, causing dizziness by spinning and by consumption of alcohol. The results consistently showed that the brain activity showed higher levels in Alpha and Beta waves. It also showed that more intense the exercise the higher the magnitude of power level of the waves. After the consumption of alcohol the EEG levels were higher as compared to the EEG levels before the consumption of alcohol.

In chapter 7, I present a mathematical model the HCI interfaces during a 9-1-1 call. The model utilizes the Fitts law equations I derived in chapter 5. An improved HCI can reduce the time to respond to 9-1-1 calls and also improve the quality of response. I describe two applications I have developed to improve the HCI at the caller end as well as the operator end of the 9-1-1 call. The remote control application successfully controls a caller's camera by the operator. Also the Text-to-Speech application successfully uses the TTS engine of the android smartphone to convert the text sent by a 9-1-1 opertor.

In chapter 8, I have present the case for redesign of Emergency Dispatch Protocols. The issues, applications etc. discussed and developed in previous chapters are integrated to design a new Protocols. The new protocols must evolve to take advantage of improved technologies and possible reach the ideal of a response time of 60 seconds for most protocols. For callers asking for emergency assistance, the new architecture makes possible the use of sensors embedded in mobile phones to evaluate the condition of an injured person [44]. Currently, these sensors can measure heart rate, blood pressure, and breathing rate; they can also easily transmit results to a 9-1-1 dispatcher. I have shown that the sensors can also be used by offsite dispatchers to evaluate and guide onsite personnel to give effective CPR. We can expect that future mobile phones will be embedded with both more accurate sensors and with new types of sensors. For example, sensors that can measure the temperature of a person or perform evaluation of oxygen saturation levels or blood glucose levels in a person may become available.

For 9-1-1 operators, the new architecture brings many changes. The visual screens the 9-1-1 dispatchers have before them will provide several streams of video from different sources, giving a more complete picture of an accident scene. Most dispatchers will not be trained to handle visual images of possible ghastly scenes from the accident. This training must be developed and provided. The modified dispatch protocols will not only improve the questions that the dispatcher asks, but also will significantly modify the instructions. Another impact of the new Audi-Video technology on those calling for help will be a reduction in verbal responses they are required to make if the dispatcher is to correctly assess what help will be most beneficial. These reductions in verbal interactions improve the response time, which is the overall goal. We can say that NG9-1-1 will not only improve the response time, but more importantly it will improve the quality of the response and, potentially, save more lives.

APPENDIX A

MODIFIED EMDP TABLE

Current Protocol Name Question in Protocol	Smart phone sensor used/ results	Modified question/action requested	Quantitative data
Bleeding/Laceration			
is the patient alert	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values 2. Zoom in, local/remote (N times) 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate of respiration 2. Volume control, local/remote
Where is the bleeding from?	Video images of moving eyes, or arms/hands, or legs. Changes in pixels can lead to conclusions about limb movements	Move camera to injury. Zoom in the camera to the injury (if not possible from remote).	1.Change in Pixels values 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is blood squirting out?	Video image of bleeding	redundant	

Bleeding - from where, How much, How long, Can it be controlled with pressure	Video image of bleeding	Zoom in the camera on the bleeding.	1.Change in Pixels values 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Can the patient answer your questions?	Use of video and audio enhances the interaction	Take the phone near the patient. Increase the volume of the microphone (if needed)	1. Volume Control, local/remote.

Eye Problems/Injuries

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Scan the camera over the patient. Zoom in or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer remotely. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
What caused the injury? Chemicals Foreign object Impaled object Direct blow Flying object Welding/near welder	Video images of the injury and the overall scene would provide a better diagnosis of the situation.	Focus the camera over the patients eyes. Zoom camera over the affected eye (if needed).	Change the resolution (if needed). 1. Zoom in, local/remote (N times). 2. Change resolution, local/remote.

Is eyeball cut open or leaking fluid?	Video image of the eyes. The zoom answers this question.	Zoom camera over the affected eye (if needed).	Change the resolution (if needed). 1. Zoom in the camera, local/remote (N times). 2. Change resolution, local/remote.
Are there any other injuries?	Video image of other injury, if any	Move the camera to any other injury	1. Zoom in the camera, local/remote (N times). 2. Change resolution, local/remote.

Fall Victim

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio used to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
What kind of surface did the patient land on?	Video image of the surface.	Move the camera over the surface where patient fell.	1. Zoom in the camera, local/remote (N times). 2. Change resolution, local/remote.

Are there any obvious injuries? What are they?	Video image of the injuries	Move the camera over the injury.	1.Zoom in the camera, local/remote (N times) 2. Change resolution, local/remote
Is the patient able to move their fingers and toes?	Video images of moving eyes, or arms/hands, or legs.	Move the camera over the hands and toes of the patient. Ask him to move them.	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Bleeding - from where, How much, How long, Can it be controlled with pressure?	Video images of moving eyes, or arms/hands, or legs.	Zoom in the camera on the bleeding.	1.Change in Pixels values 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote.

Heat/Cold Exposure

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote

Can the patient answer your questions?	Use of video and audio enhances the interaction	Take the phone near the patient.	Increase volume of the microphone if needed. 1. Control Volume of the microphone from local/remote.
If the patient is complaining of pain, where	Video images of pain area may help better diagnosis	Move the camera over the area of pain. Zoom over the pain area, if needed.	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Does the patient respond to you and follow simple commands?	Video/audio interaction. Operator interacts with the patient. Take the phone to the patient.	Change Microphone Volume, If needed.	1. Control Volume of the microphone local/remote.
Is the patient sweating profusely?	Video image of the patient and image analysis helps. Move the camera over the patients face. Zoom in, if needed	Change resolution, if needed.	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient dizzy, weak or feeling faint?	Video images and data from pressure sensor on screen.	Operator asks the patient to press on the camera touch screen to measure pressure.	1. Pressure change from touch screen.
Industrial Accidents			

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done. Move the camera over the patient.	Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
Is the patient able to move their fingers and toes?	Video images of moving eyes, or arms/hands, or legs.	Move the camera over the hands and toes of the patient. Ask him to move them.	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Bleeding - from where, How much, How long, Can it be controlled with pressure?	Video images of moving eyes, or arms/hands, or legs.	Zoom in the camera on the bleeding.	1.Change in Pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote.
Stabbing/ gunshot assault			

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
Is there more than one person injured?	Video images of the scene	Move the camera over the entire scene. Pan the camera, if needed	1. Pan the camera local/remote
Is there more than one wound? What part(s) of the body is/are injured?	Video images of the injuries Move the camera over all the injuries.	Zoom the camera, if needed	1.Zoom in local/remote (N times).
Bleeding - from where, How much, How long, Can it be controlled with pressure?	Video images of moving eyes, or arms/hands, or legs.	Zoom in the camera on the bleeding.	1. Change in Pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote.
Vehicular related injuries			

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
Are there any hazards present? (Is the scene safe), Fire, Water, HazMat, Wires down	Video image of the scene	Move the camera over the entire scene of the accident. Pan the camera over the entire scene.	1.Pan the camera
How many patients are injured? Are all of the patients free of the vehicle?	Video image of the scene.	How many patients are injured? Are all of the patients free of the vehicle?	
What types of vehicle(s) are involved?	Video image of the scene, focus on the vehicle	Move the camera over the vehicle	
Is anyone trapped in the vehicle?	Video image of the scene, focus on the injured	Is anyone trapped in the vehicle?	

Traumatic Injury

Is patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
Bleeding - from where, How much, How long, Can it be controlled? with pressure?	Video images of moving eyes, or arms/hands, or legs.	Zoom in the camera on the bleeding.	1. Change in Pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote.
Where is the patient injured?	Video images of the injury	Move the camera over the injury	1. Zoom in, local/remote (N times).

Abdominal Pain

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote

Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
How does the patient act when he/she sits up?	Make the person sit and observe on video Move the camera showing the patient.	Ask him to sit	
Has the Patient Vomited? If yes, what does vomit look like?	Video images of vomit can help. Number of pixels and color changes of pixels may lead to automatic conclusions.	Has the patient Vomited? If yes, Move the camera over the vomit.	1.Zoom in, local/remote (N times) 2. Change in Resolution, local/remote.

Allergies Stings

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote

Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
How does the patient act when he/she sits up?	Make the person sit and observe on video	Move the camera showing the patient. Ask him to sit.	
Does the patient have any rashes or hives?	Video image of bite area. Increased resolution and pixel analysis would show the seriousness of the rash	Move the camera over the rash area of his/her body. Increase the resolution, if needed. Zoom the camera over the rash, if needed	1. Zoom in, local/remote (N times). 2. Change in resolution local/remote.

Back Pain

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote

Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote

Breathing Problems

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
Is the patient able to speak in full sentences?	Video/Audio interaction with patient Take the phone to the patient.	Increase volume of the microphone if needed.	1. Volume control local/remote.

Is the patient drooling of having a hard time swallowing?	Video images of persons face. Pixel changes would lead to automatic conclusions about drooling and swallowing problems.	Move the camera over the patients mouth. Zoom in the camera, if needed Increase resolution, if needed.	1. Zoom in, local/remote (N times). 2. Change in resolution, local/remote

Chest Pain/Heart Problems

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
Is the patient nauseated or vomiting? Is the patient sweating profusely?	Video images of the person. Image analysis is done	Move the camera over the patients face. Zoom in, if needed. Increase the resolution, if needed.	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote

Is the patient experiencing rapid heart rate with chest pain?	Use smart phone sensors accelerometer, video, audio to determine heart rate	Turn on the accelerometer. Place the camera on the patients chest. Ask the patient to put finger on the camera lens.	1.Accelerometer data 2. change in Pixel intensity
Diabetic Problems			
Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/ remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
Is the patient sweating profusely?	Video image of the patient and image analysis helps.	Move the camera over the patients face. Zoom in, if needed Change resolution, if needed.	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Headache			

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote

OD/Poisonings/Ingestion

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote

Is the patient having difficulty swallowing?	Video images of the person. Number of pixel changes and the color changes of pixels would lead to automatic conclusion about swallowing problems.	Move the camera over the patients mouth. Zoom in the camera, if needed Increase resolution, if needed.	1. Zoom in, local/remote (N times). 2. Change in resolution, local/remote

Psychiatric/behavioral Problems

Is the patient alert?	Video images of moving eyes, or arms/hands, or legs. Image analysis is done.	Move the camera over the patient. Zoom or change resolution (if needed).	1. Change in pixels values. 2. Zoom in, local/remote (N times). 3. Resolution change, local/remote
Is the patient breathing normally?	1. Accelerometer data showing respiration rate. 2. Microphone audio to hear breathing sounds for wheezing etc.	Turn on the accelerometer. Place the phone on the patients upper abdomen.	1.Accelerometer data for rate or respiration 2. Volume control, local/remote
Can the patient answer your questions?	Use of video and audio enhances the interaction	Take the phone to the patient. Increase the volume of the microphone (if needed)	1. Control Volume, local/remote.

Table A.1: Typical dispatch protocol Questions

APPENDIX B

DETAILED SOFTWARE DESCRIPTION OF APPLICATIONS

B.1. Detailed Software Architecture of Linphone

In this section I describe a detailed architecture of the software modules. It is not possible to describe every detail of all the modules. I focus on the software modules and their code based on the scenarios that I will encounter for my applications. The project involves two applications:

- Text-to-speech application:

  In this application, a 9-1-1 operator can send text to the caller on his smartphone. The smartphone application will be able to convert the text into synthesized speech. This application is useful in sending standard instructions and the caller will be able to hear them as spoken word. Also, the instructions can be repeated as many times as needed without the involvement of the operator. The operator can use this time for some other activity in helping the caller.
- Remote Video control application:

  In this application the 9-1-1 operator can control the video camera of the caller's smartphone. For example, the operator can zoom in or zoom out by sending commands to the callers smart phone. Similarly, other camera controls can be changed by the 9-1-1 operator. This feature is useful in emergency scenarios where the caller is impaired and is not able to make these changes. However, the operator may find it useful to make the changes to camera controls to better view the situation. The complete list of features supported by a specific smartphone is sent by the phone in an INFO message. The values that each of these features support is also sent by the smartphone in the INFO message. Table B.1 gives a list of all the features that have been currently programmed and the corresponding DTMF digit.

The current implementation of SIP INFO message is based on RFC 2976. The header field, content-type, contains information about the body of the INFO message. The current

DTMF digit sent	Video Picture Feature	Description
1	AntiBanding	distortions of gradient steps between colors
2	color effect	changes color tint of pictures
3	increase exposure	increases the exposure lightens the pictures
4	decrease exposure	decreases the exposure darkens the picture
5	change flash mode	flash on or off or automatic
6	change focus	examples include auto focus, micro focus or distance
7	Zoom in	changes the camera to zoom in to the object
8	Zoom out	changes the camera to zoom out from the object
9	white balance	effect of natural colors white is really white
A	Scene Mode	examples include portrait, sports etc
B	Modify fps	changes the frames per second

Table B.1. List of camera features

code supports content-type of "application/dtmf-relay". The body of this content type contains a single DTMF digit. The existing content type does not allow a body of text message to be sent. For Text to Speech Application a new content type is created, called "application/info-tts". The info-tts portion of the content type is called "content-subtype".

B.2. Code modification

B.2.1. Initialization Scenario

Initialization scenario happens when the linphone application is launched. All Android applications have a file called AndroidManifest.xml. The file contains several specifications about the application. It has declarations for all the activities defined in the application. It indicates the main activity of the application which is launched when the application is started, i.e, when the application icon on the smart phone is pressed. For linphone-android, it starts with an activity called LinphoneLauncherActivity. The activity is defined in the file src/org/linphone/LinphoneLauncherActivity.java. The default function that is executed upon launch is called OnCreate(). The argument to OnCreate function is an instance of the activity, called Bundle. Initially this Bundle is NULL as the activity is just created, but after creation it is non-null. More details of the activity life-cycle can be found in Android developers documentation. In the next step it starts Linphone service, which executes OnCreate function. In this step the configuration files are read in and the application initializes the configuration related parameters. It then starts system related services like power management, phone vibrator, audio manager services and loads the linphone library. Since linphone library is written in C (native code), it uses JNI (Java Native Interface) to load the library. An example of c++ to Java interface is shown by the following steps in code:

(1) LinphoneCoreFactory.Instance() uses class.forname() call to return an instance of LinphoneCoreFactoryImpl, defined in file LinphoneCoreFactory.java.
(2) LinphoneCoreFactoryImpl.createLinphoneCore() is called to create an instance LinphoneCoreImpl and is defined in file LinphoneCoreFactoryImpl.java.
(3) LinphoneCoreImpl() calls newLinphoneCore() which creates and returns a pointer to a new linphone core and is defined in file LinphoneCoreImpl.java.
(4) NewLinphoneCore() uses the jni to return a pointer, called nativePtr to the c/c++ function in the linphone library and is defined in the file linphonecore_jni.cc. The resources with in linphone library are initialized. This includes the rtp stream, srtp stream, sound cards, video cards and various codecs etc.

For this project the initialization for android cameras is also important. The procedure uses jni to call Android API for camera from the native code (c/c++). The procedure is given below:

(1) video_capture_detect() function is called.
(2) ms_get_jni_env() gets a pointer, env, to the existing Java environment thread (Android).
(3) GetHelperClassGlobalRef() is called to get the pointer to the AndroidWrapper class based on the Android version.
(4) GetStaticMethodID is called to get a pointer to the Java Android method based on

class and the method id ”detectCameras”.

(5) CallStaticIntMethod is called to actually execute the java Android method ”detectCameras”.

(6) DetectCameras is defined in file AndroidVideoApi5JniWrapper.java. The Android Camera class APIs called to get number of cameras in the smart phone and various parameters of the Cameras.

The TTS engine must be initialized and started before a text will be converted into speech. In Andorid platform, this can be either achieved by creating an independent new activity for TTS, or it can be done as a part of another activity. A new activity in Android is created when there is a human interface involved. In a TTS application there is no human interface involved. In a smartphone it is used when a SIP INFO message requesting text to speech synthesis is received. A new activity for TTS is not needed. So I decided to initialize the TTS engine as a part of an existing activity. The Launcher activity is started when linphone is started. I decided to start the TTS engine also at the time linphone is launched. The file ”LinphoneLauncherActivity.java” is modified for TTS initialization.

Figure B.1 shows the UML diagram for the java class LinphoneLauncherActivity. There are four methods defined for the class as shown in the upper half of the box. The onCreate method is called when the linphone application is launched. In this method TTS related changes are made as shown in the control flow diagram in Figure B.2. The highlighted portion of the box shows the changes made. It creates intent to start the TTS engine. The result of the intent to create the TTS engine is available when the method onActivityResult is automatically invoked. Figure B.3 shows the control flow diagram for this method. If the TTS engine can be started, the onActivityResult method has a result of pass. In this case a new instance of TTS engine is created and assigned to a variable as shown in the box highlighted in red. After the instance is created the method ”onInit” is automatically called. But if the result shows a failure then a request is made to install the TTS engine as shown in the box highlighted in blue.The control flow for ”onInit” method is shown in Figure B.4. After successful completion of the TTS initialization, text to speech can be invoked any time

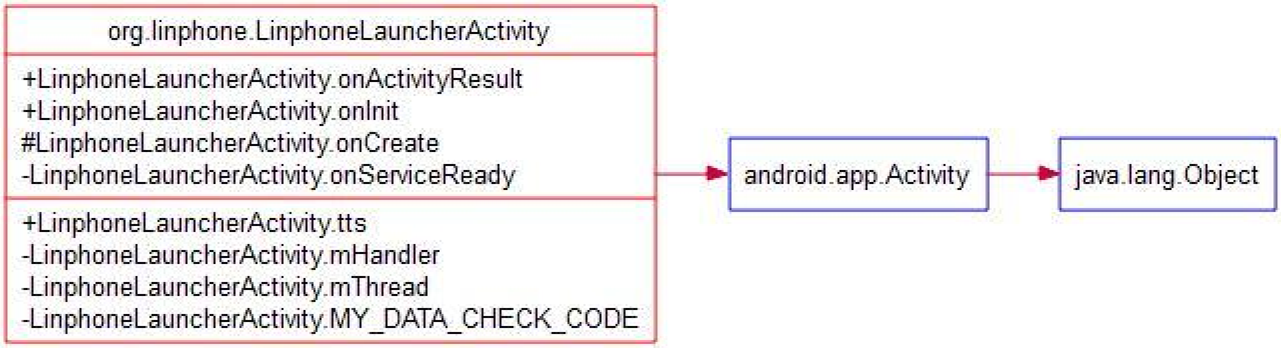
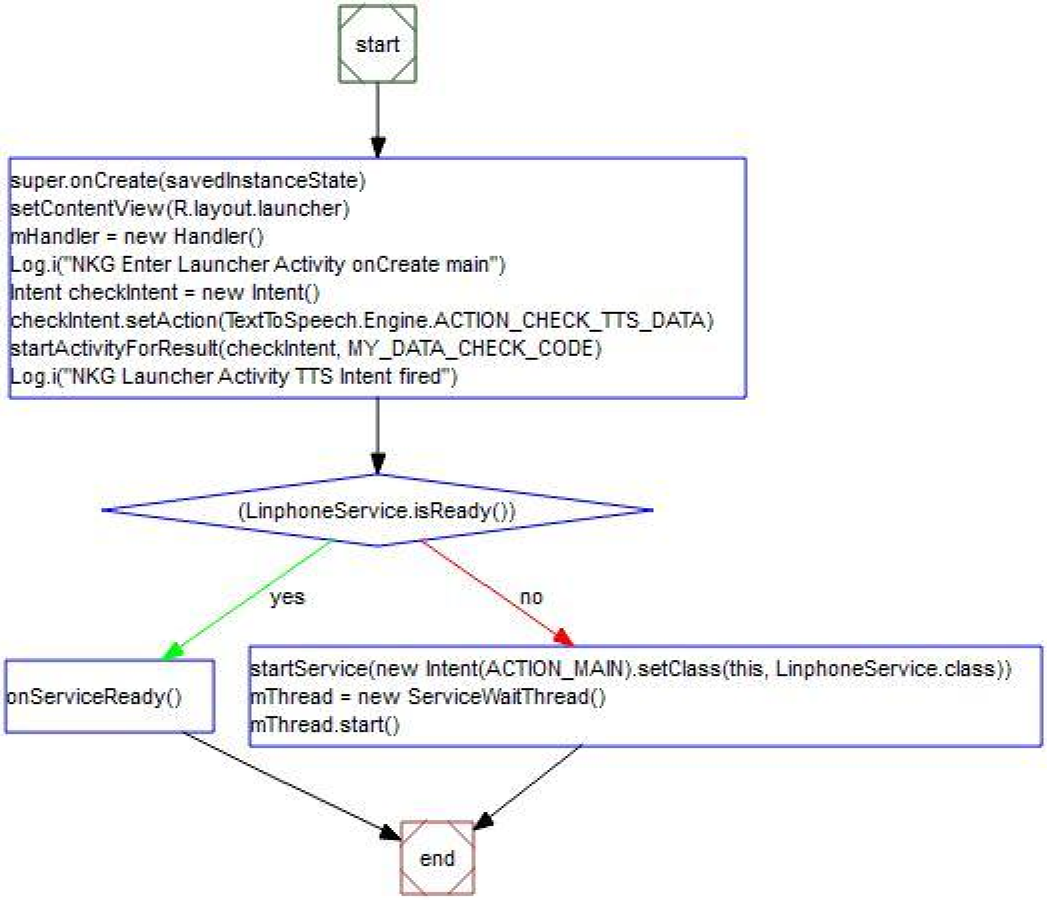


Figure B.1. UML Diagram for LauncherActivity



```
super.onCreate(savedInstanceState)
setContentView(R.layout.launcher)
mHandler = new Handler()
Log.i("NKG Enter Launcher Activity onCreate main")
Intent checkIntent = new Intent()
checkIntent.setAction(TextToSpeech.Engine.ACTION_CHECK_TTS_DATA)
startActivityForResult(checkIntent, MY_DATA_CHECK_CODE)
Log.i("NKG Launcher Activity TTS Intent fired")
```

```
(LinphoneService.isReady())
```

```
onServiceReady()
```

```
startService(new Intent(ACTION_MAIN).setClass(this, LinphoneService.class))
mThread = new ServiceWaitThread()
mThread.start()
```

Figure B.2. Control Flow for onCreate method

by using the variable assigned to the TTS instance (tts).

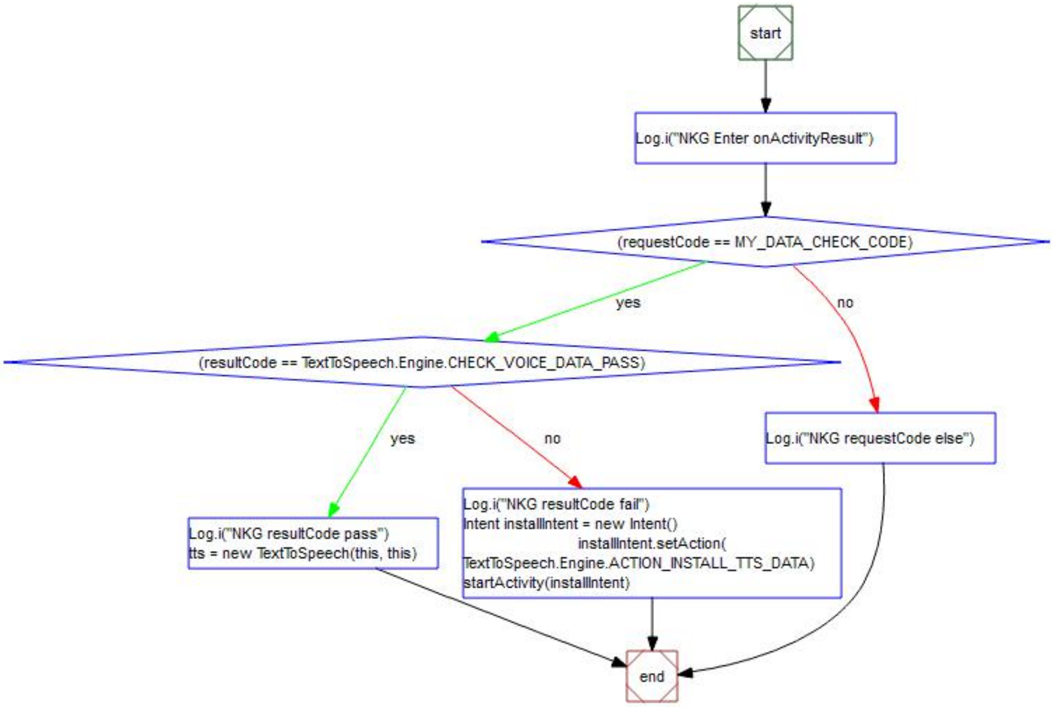


Figure B.3. Flow control for onActivityResult method

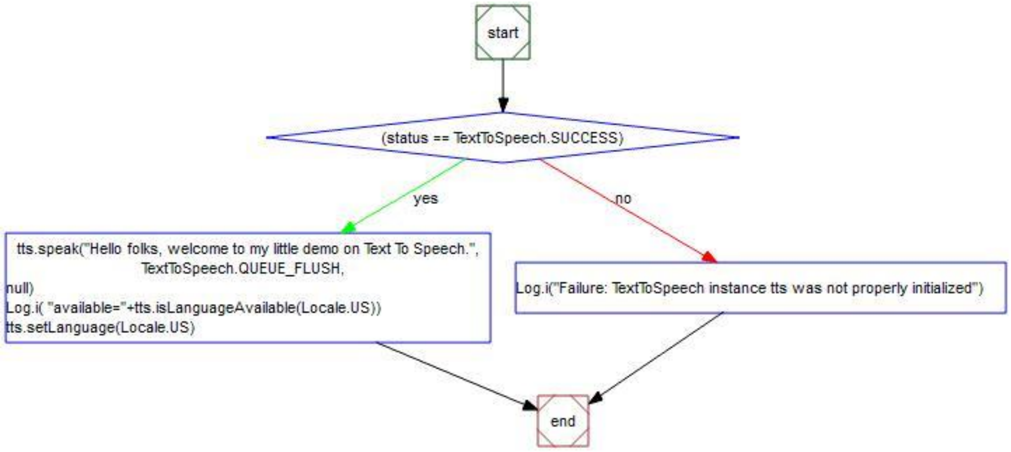


Figure B.4. Control Flow for method onInit.

B.2.2. SIP INFO Message trace

The text for TTS is sent and received using the SIP INFO message. Also the RMC messages are also sent using the INFO message. So understanding the software of INFO message trace is also important. Figure B.5 shows the call flow of INFO message. The Sip INFO message can be sent any time during the call. A Sip INFO message is always

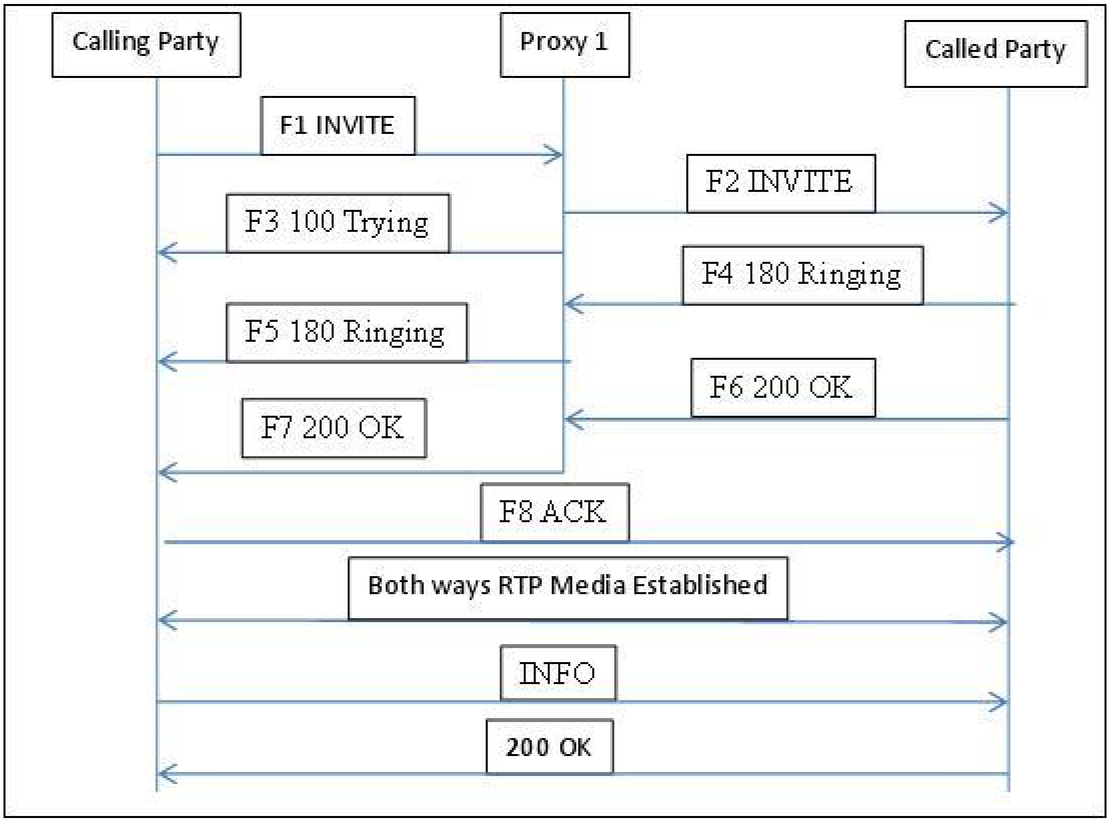


Figure B.5. SIP INFO message trace

acknowledged by returning a 200 OK response.

B.2.2.1. *Sending TTS*

Linphone client on the computer can be invoked using one of two interfaces a graphical interface and a console interface. So each time a text to speech based message is to be sent, the command is invoked, followed by the text to send. The new type of SIP INFO message is created and sent to the far side.

B.2.2.2. *Receiving TTS*

On the receiving side, each message is parsed and appropriate action is taken. Figure B.6 shows a high level flow diagram of how a message is processed. The function "process_event"

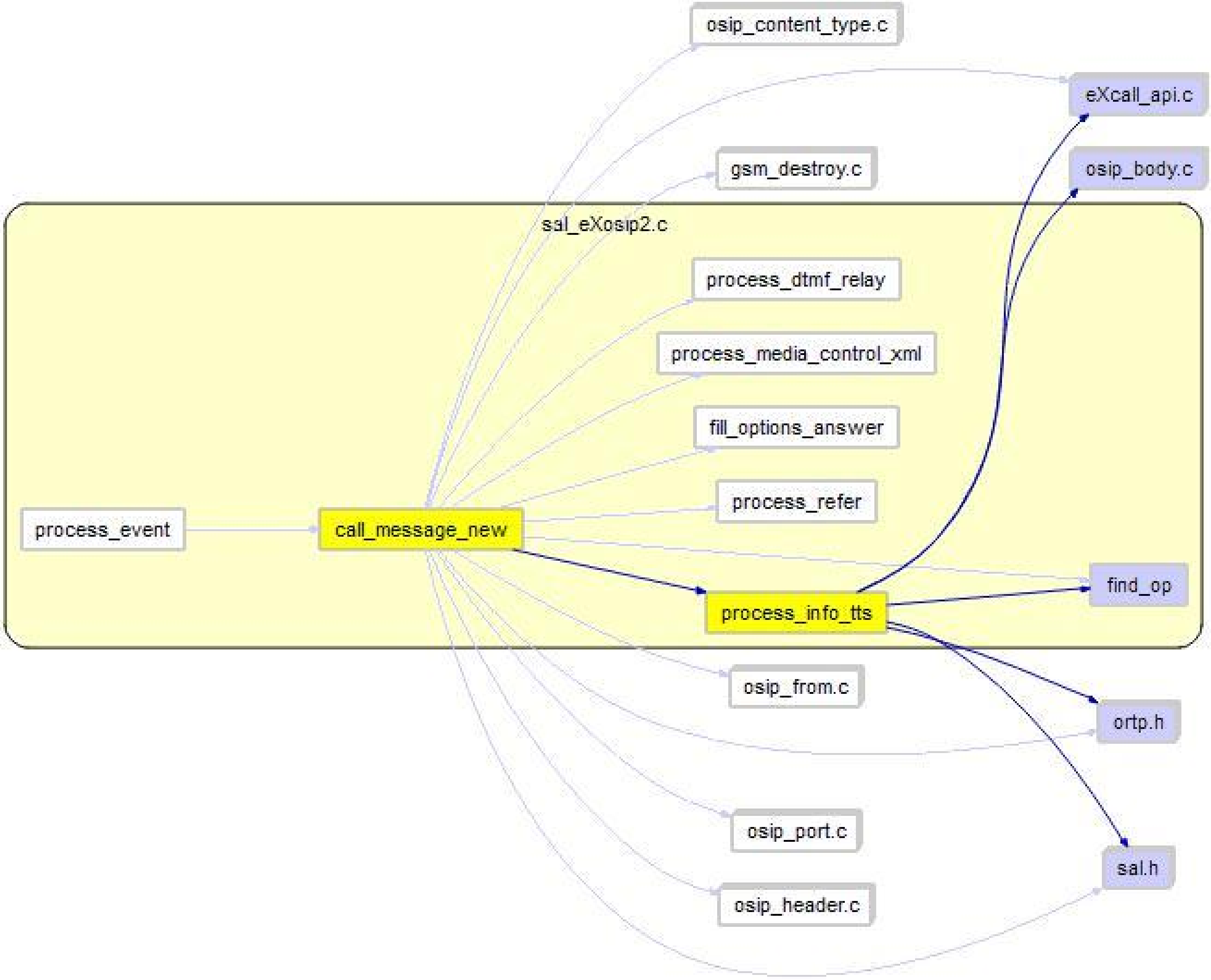


Figure B.6. incoming SIP message processing

waits for any event to occur, this could be a message coming in or it could be a timer event. The following files/functions are changed for this part of the application:

(1) Call_message_new()/Sal_eXosip2.c

In case it is a message coming in then the function "call_message_new" is called. The changes for TTS are made in this function and the control flow for the function is shown in figure B.7. It highlights the changes made for TTS functionality. If the message received is INFO message then the content-type and subcontent-type are checked. If the subcontent-type is tts-info then this is an invocation for text-to-

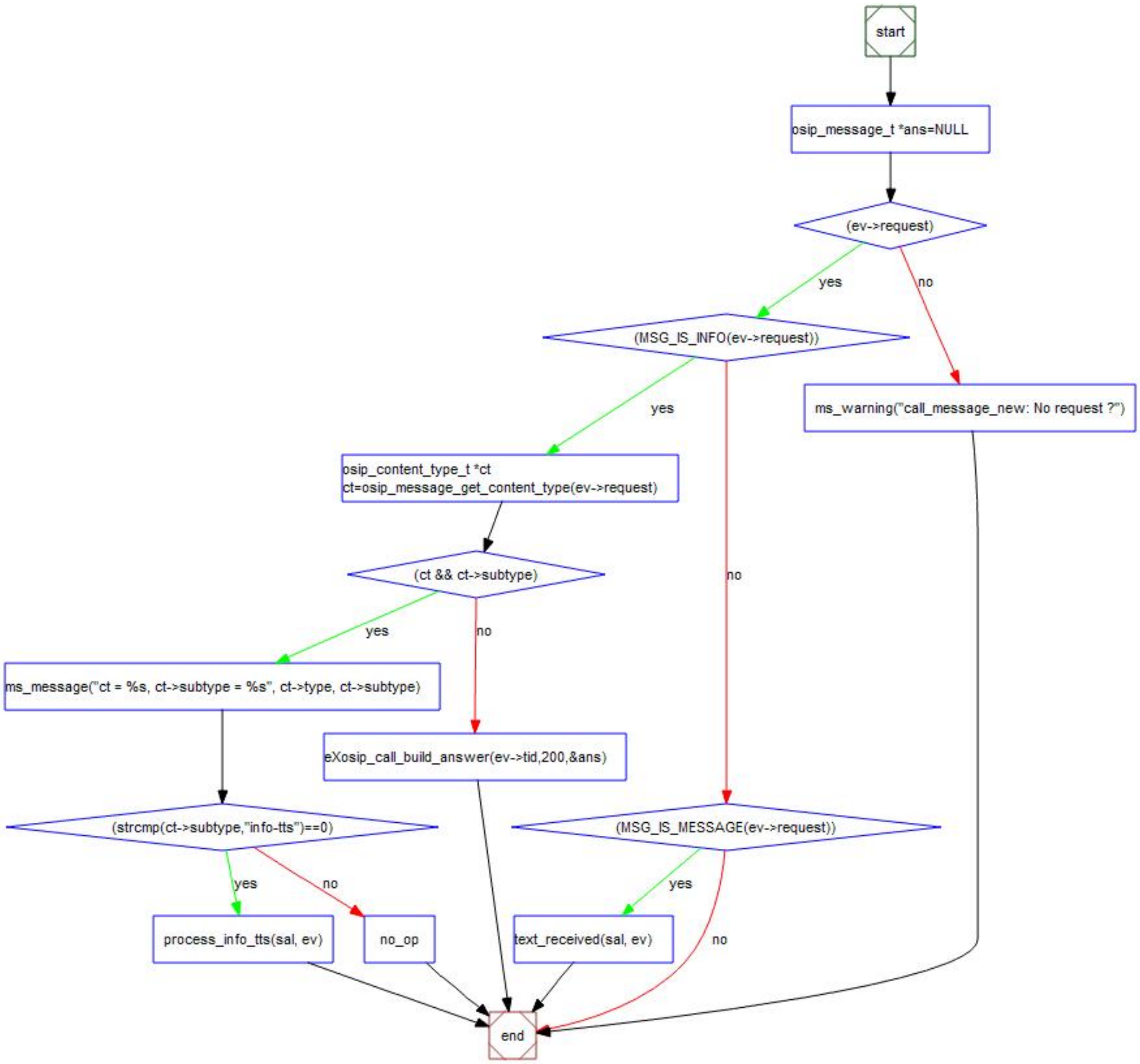


Figure B.7. Control flow of call_message_new()

speech.

(2) Process_tts_info()/Sal_eXosip2.c:

This is a new function added for TTS. In this function the body of the INFO message is recovered. The function also sends a 200 OK response to the INFO message. The callback function for TTS is tts_received(). The control flow for process_tts_info() is shown in figure B.8.

(3) tts_received()/callbacks.c:

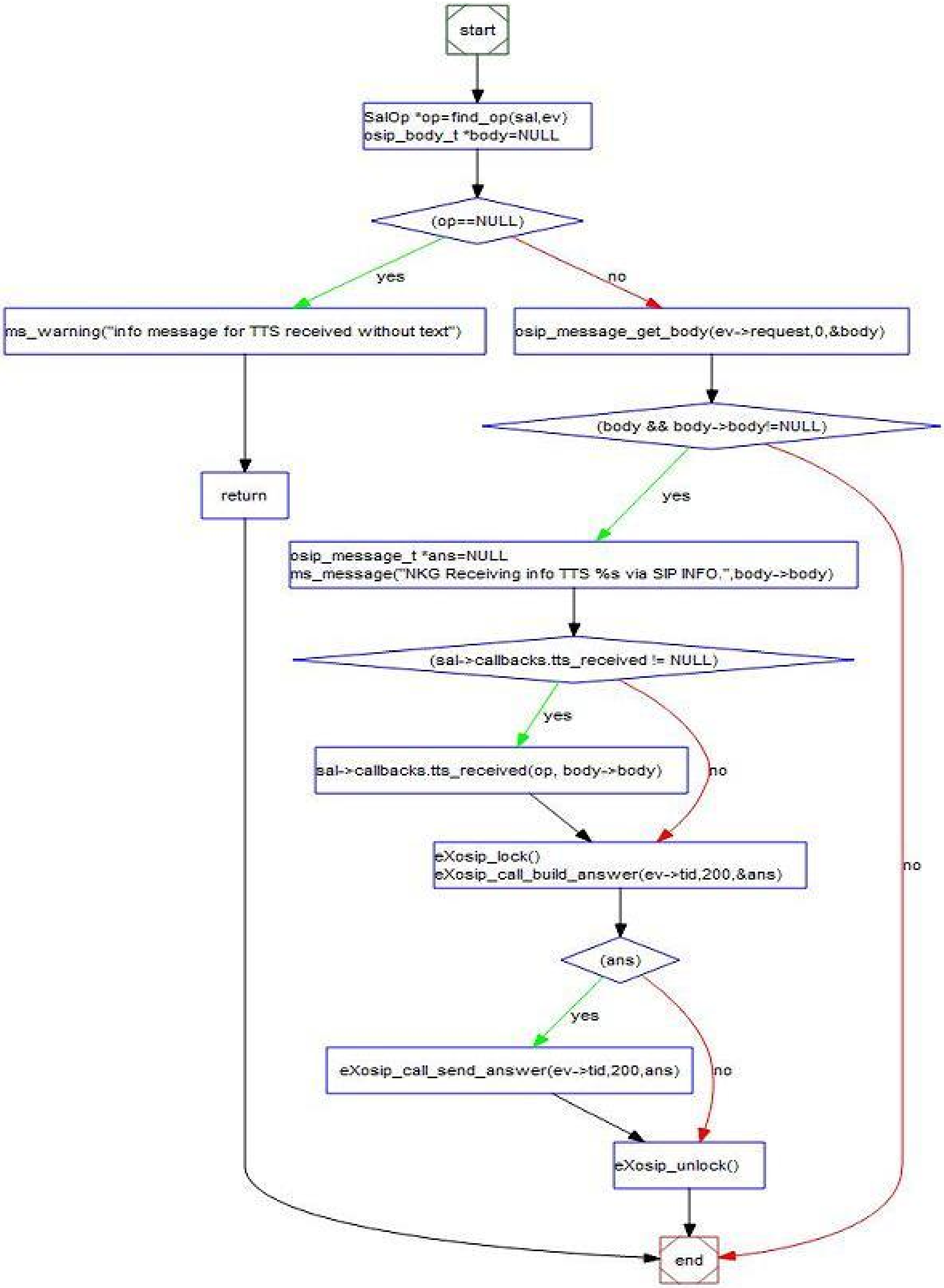
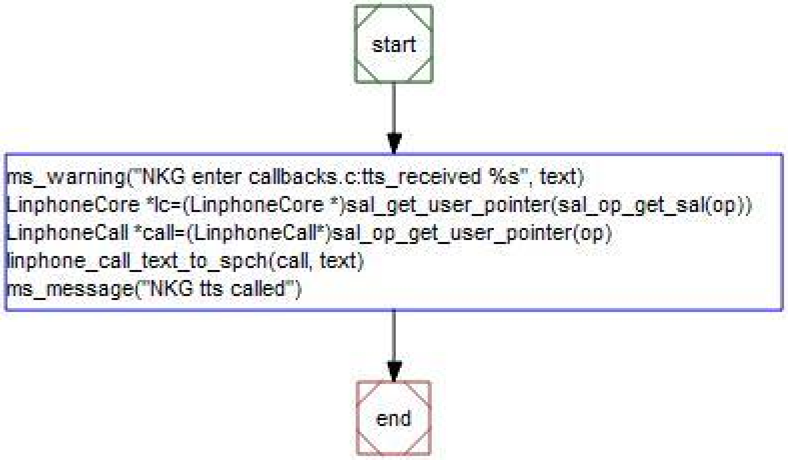


FIGURE B.8. Control flow for process_info_tts



```
ms_warning("NKG enter callbacks.c:tts_received %s", text)
LinphoneCore *lc=(LinphoneCore *)sal_get_user_pointer(sal_op_get_sal(op))
LinphoneCall *call=(LinphoneCall*)sal_op_get_user_pointer(op)
linphone_call_text_to_spch(call, text)
ms_message("NKG tts called")
```

Figure B.9. Control flow for tts_received()

The purpose of the callback functions is to move from one layer (stack) of code modules to different layers of code module. The callbacks make the code modular and it is easy to use the functionality of each stack by using these callback functions as interfaces. The control low of tts_received() is shown in figure B.9. The function is an intermediate layer as the tts text is moved to the final destination where the tts engine can be invoked to actually convert the text to speech.

The function gets the context for the current call.

(4) linphone_call_text_to_spch()/linphoneCall.c:

This function is used to call another function in a different layer (mediastreamer layer). The new function called is text_to_speech().

(5) text_to_speech()/msandroid.cpp

The function text_to_speech() uses the jni interface to call the methods defined in a java class. It finds a pointer to the java class where the final text_to_speech engine will be invoked. The java class used to finally convert text to speech is called LinphoneManager. The function also gets a pointer to the java method that we want to call. The java method is called text2Speechn(). The control flow is shown in figure B.10.

(6) text2Speechn()/LinphoneManager.java

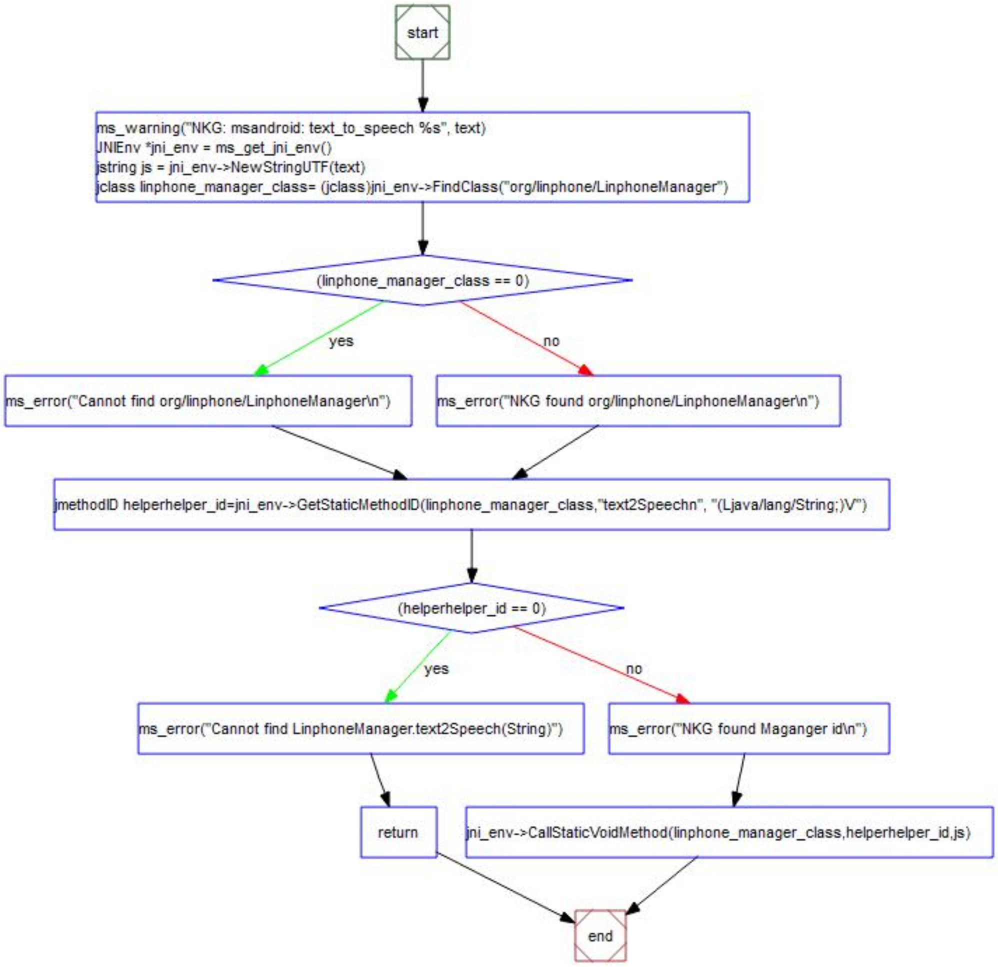


Figure B.10. Control flow for text_to_speech()

The method text2Speechn is defined in the LinphoneManager class. The function uses the reference to TTS engine to call the Android API to finally convert text to speech. The control flow is shown in figure B.11. The Android API is called speak.

B.2.3. Remote Control of Video Camera

The video camera of the caller is remotely controlled by sending commands using the SIP INFO method. The content type used is the dtmf-relay. Each digit will correspond to a command to change a specific camera feature. There is no change in the code for sending the DTMF digit. But on receiving the DTMF digit, the code changes so that each digit received is interpreted as a camera change command. The list of major files/functions changed is

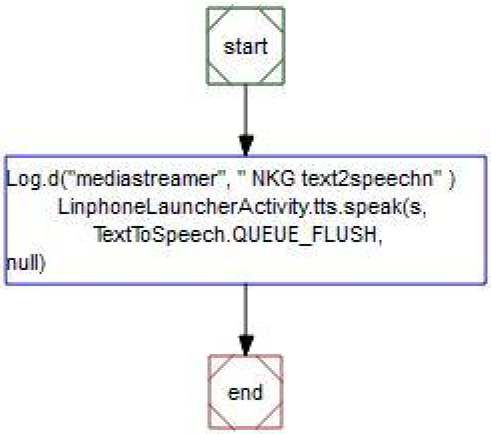


FIGURE B.11. Control flow for text2Speechn()

listed below along with the control flow.

(1) call_message_new()/Sal_eXosip2.c:

The control flow of this function is already shown in Figure B.7 above. The only change is that the case of content-subtype of dtmf-relay is checked. In case the SIP INFO message has this content-subtype then the function process_dtmf_relay() is called.

(2) process_dtmf_relay()/sal_eXosip2.c

This is an existing function and there is no change to this code. The callback function is dtmf_received(). This is an interface between the SIP stack and the linphone application code.

(3) dtmf_received()/callbacks.c

The function gets a reference to the linphone application and the current call. It then calls linphone_call_modify_media_streams(). This function provides the interface to the mediastreamer part of the code. Figure B.12 shows the call flow for all the functions.

(4) linphone_call_modify_media_streams()/linphonecall.c

The function calls video_stream_camera_control() if the current call is a video call, as shown in figure B.12.

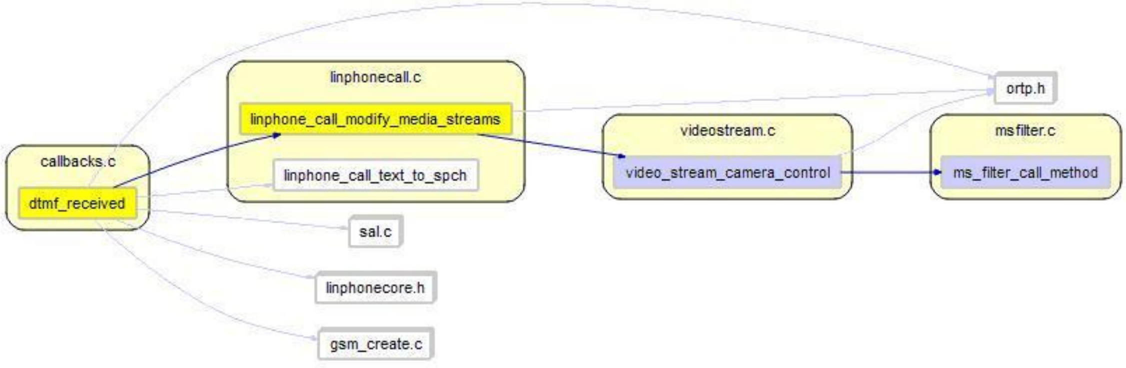


FIGURE B.12. Partial call flow for camera control application

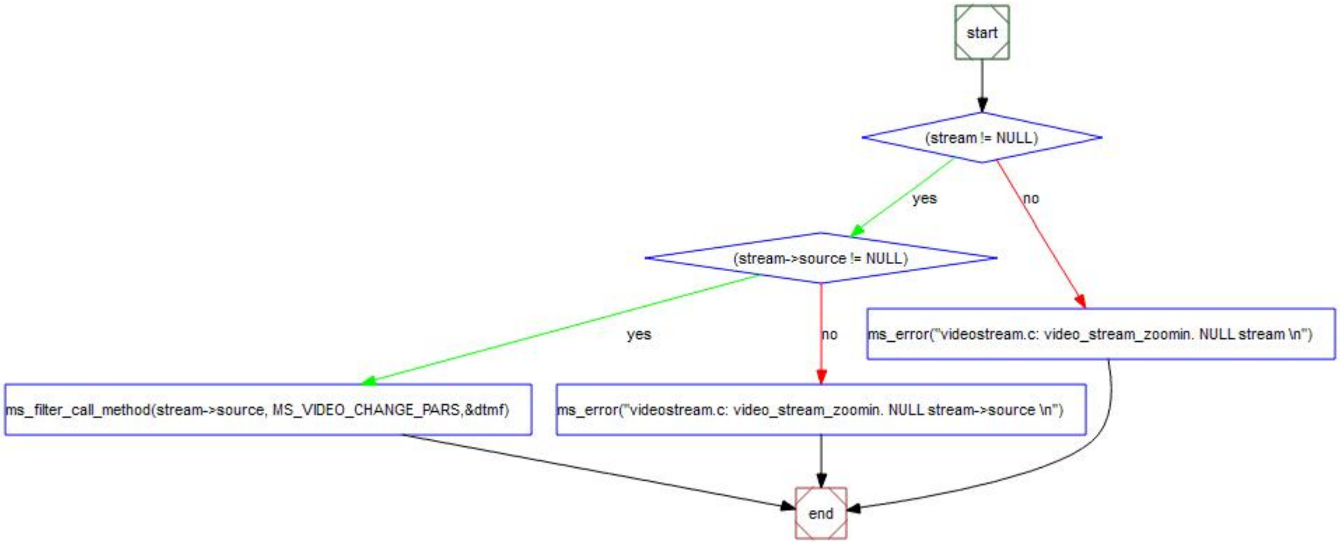


FIGURE B.13. Control flow for video_stream_camera_control()

(5) Video_stream_camera_control/videostream.c

The call flow for this function is shown in figure B.13. The function has defined an index, MS_VIDEO_CHANGE_PARS, into Video filter table to call the next function. The index maps to the function video_set_camera_control().

(6) video_set_camera_control/msandroidvideo.cpp

The function control flow is shown in Figure B.14. The function uses the jni interface functionality to call the method in Java class AndroidVideoApi9JniWrapper to actually call the Android APIs to modify the video camera parameter. The name of the function is modifyDisplay().

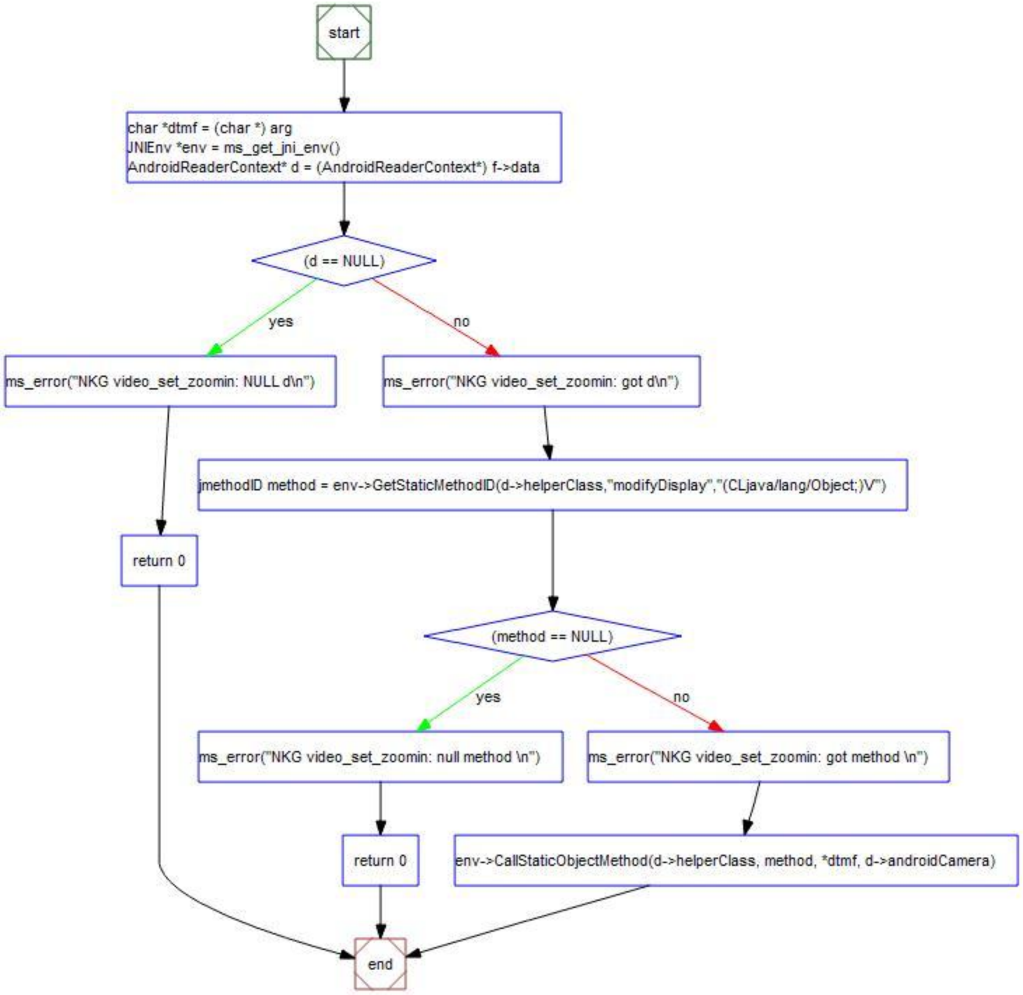
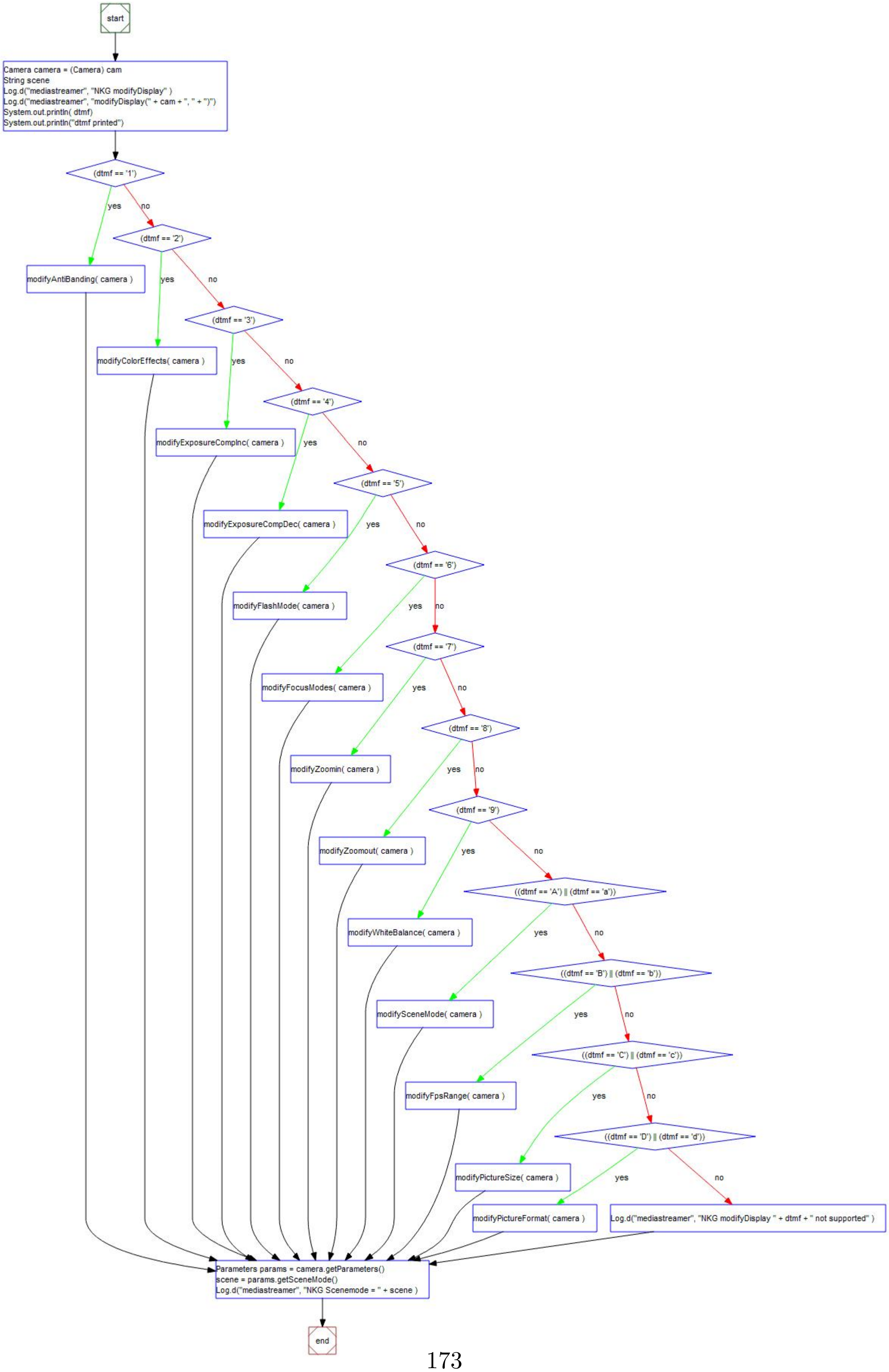


FIGURE B.14. Control flow for video_set_camera_control()

(7) modifyDisplay()/AndroidVideoApi9JniWrapper.java

The function call diagram is shown in figure B.15. It can be seen that the function has several function calls for each camera control. The list of functions is shown in the figure B.15. The specific function called is based on the dtmf digit. Figure B.16 shows a sample control flow for the function modifyColorEffect(). The modify function actually calls the Andorid API to modify the color effect. In this implementation I do the modification in a round robin fashion. So each time the same dtmf digit is reached the parameter value is changed to the next value. The other functions in the list have similar control flow.



```
Camera camera = (Camera) cam
String scene
Log.d("mediastreamer", "NKG modifyDisplay" )
Log.d("mediastreamer", "modifyDisplay(" + cam + ", " + ")")
System.out.println( dtmf)
System.out.println("dtmf printed")
```

```
Parameters params = camera.getParameters()
scene = params.getSceneMode()
Log.d("mediastreamer", "NKG Scenemode = " + scene )
```

Figure B.15. Control flow for modifyDisplay()

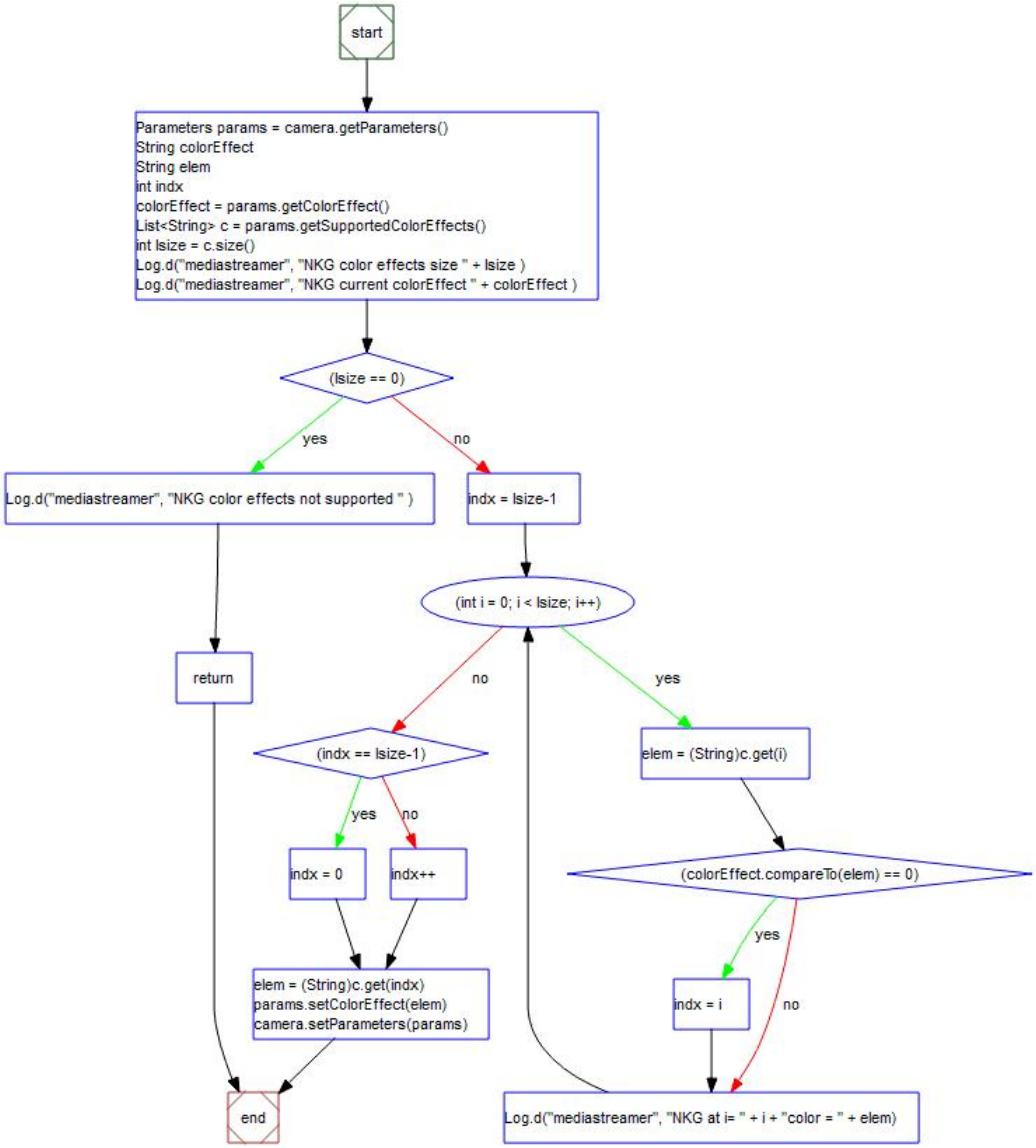


FIGURE B.16. control flow for modifyColorEffect()

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