博士論文　(要約)

Early Drowning Context Awareness Using Wearable Sensors

(ウェアラブルセンサを用いた早期溺れ検知)

Mohamed Kharrat

Drowning is among the main causes of accidental death in the world. Several of these incidents occur in sea or in a swimming pool even with the presence of professional lifeguards. Drowning is often described as a fast and silent death. In fact, in many cases victims are not able to call for help or even attract the attention of the swimmers swimming next to them. The victims main concern at that instant is to get a last breath once he reaches the surface of the water before getting submerged again. Observation among several victims who faced near drowning incidents has shown that they have particular physiological patterns in early drowning stage called Instinctive Drowning Response (IDR). In which, victims tend to panick and struggle vertically at the same location with an up and down motion. We took advantage of such an observation, to propose to use the recently available wearable MEMS sensors to automatically detect this kind of particular pattern. As it is difficult to get information from real drowning incidents, we asked professional lifeguards to infer near drowning pattern. We attach motion and pressure sensors at both the chest and head level of the lifeguards. The measured data shows a particular pattern from the head level pressure sensor and the chest level pressure sensors, accelerometer and gyroscope. We used a neural network to train and test the possibility to detect such a pattern automatically. We were able to detect near drowning patterns with a twenty-second time window from the head level pressure sensor and with twelve-second-time window from the chest level pressure and motion sensor data. In addition, victims who face drowning incident tend to get into a panic situation, which is usually associated with high heart rate activity. So we investigated the possibility to use Piezofilm sensor to monitor the heart activity of the swimmer. Piezofilm sensors are particularly lightweight and flexible so they can be attached to the swimming cap at the level of head's superficial temporal artery to monitor the swimmers heart activity. Our experimentation on Piezofilm sensor shows that the signal suffers from noises particularly in motion situation. Our pre-experimentation on Emipirical Mode Decomposition (EMD) signal processing method has shown encouraging results in processing the signal in both motion and motionless situations. So we decided to further investigate the performance of this method in non-motion situation, as it is easier to evaluate its performance. Our experimentation on EEMD has shown that it suffers from adaptively issue called mode mixing. So we proposed a new method, which we called Weight Factor Mode (WFM) to reduce this effect. The method has been tested in both Piezofilm data which we measured from our laboratory's subjects and ECG benchmarking databases. We succeed to obtain a good performance in reducing the mode-mixing effect. As the system we are proposing is based principally on an inferred data, it is difficult to ensure its performance. So we proposed another system based on counting the amount of time the swimmer spent underwater, which can be used in the case the previous early drowning detection system fails. The lapse time underwater is measured based on a pressure sensor attached at the swimmer's head level. So the system automatically distinguishes if the swimmer's head is submerged underwater or not. In addition the system can detect if the swimmer becomes motionless while underwater using accelerometer information. We made a prototype of this system using an android smartphone. We have also developed a waist airbag that can be automatically triggered if a drowning pattern is detected. Finally, in order to ensure a higher layer of safety, we proposed a cloud service, which can track the user's head position while swimming and automatically trigger an alert if an incident occurs with the information about the swimmers location. The proposed service can also be operated as a stand-alone system and by using this a new proposed cloud pulling method. In addition to the swimmer location the system can send periodical information about the swimmer's head depth, motion as well as mobile network signal and battery strength. The information is then sent to the cloud using a mobile network to detect if any abnormal behavior is detected. We believe that a combination of these different proposed wearable drowning prevention solutions which we call Hakim Drowning Prevention

System can considerably reduce drowning incidents.

Contents

1 Introduction **13**

1.1 Drowning 13

1.2 Defintion 13

1.2.1 Statistic About Drowning Incidents 13

1.2.2 Lifeguard Vigilance 14

1.2.2.1 At pool environment 14

1.2.2.2 At sea environment 15

1.2.3 Drowning Types 16

1.2.4 Response in Early Drowning 16

1.2.4.1 Active Drowning 16

1.2.4.2 Passive Drowning 17

1.3 Survey on Drowning Prevention Systems 18

1.3.1 Wearable Based Drowning Prevention Systems 18

1.3.1.1 Introduction 18

1.3.1.2 SenTag 18

1.3.1.3 Wahoo 19

1.3.1.4 Conclusion 20

1.3.2 Video Based Drowning Prevention System 22

1.3.2.1 Introduction 22

1.3.2.2 Vision-Based Approach to Early Detection of Drowning 22

1.3.2.3 Poseidon 22

1.3.2.4 Conclusion 23
1.4 Research Objective 23
1.5 Thesis Outline 24

2 Hakim-1 a Drowning Detection and Evacuation System 25
2.1 Introduction 26
2.2 Drowning Detection Based on Under Water Time Lapse . . . 31
2.3 Automatic Motionless Status Detection Using Accelerometer . 35
2.4 Android Smartphone Application 37
2.5 NFC based auto lunch application system 40
2.6 Airbag System 40
2.7 Conclusion 46

3 Hakim-2 an Early Drowning Detection Based on Motion Analysis 47
3.1 Introduction 48
3.2 Early Drowning Detection Based on Wearable Sensors 48
3.2.1 Physiological Changes in Near Drowning Situation . . 48
3.2.2 Experimentation Setting 49
3.3 Near Drowning Pattern Detection Using Neural Network and Pressure Information Measured at Swimmer's Head Level . . . 53
3.3.1 Head Level Pressure Measurement 53
3.3.2 Automatic Near Drowning Pattern Detection Using Neural Network 56
3.4 Near Drowning Pattern Recognition Using Neural Network and Wearable Pressure and Inertial Sensors Attached at Swimmer's Chest Level 58
3.4.1 Chest Level Pressure Measurement Analysis 58
3.4.2 Accelerometer 59
3.4.3 Gyroscope 62

3.4.4 Automatic Near Drowning Pattern Detection Using Neural Network 64
3.5 Conclusion 66

4 Hakim-3: Toward Next Generation Near Drowning Detection System Based on Heart Activity Analysis 68
4.1 Introduction 70
4.2 Physiological Data Analysis 71
4.2.1 Empirical Mode Decomposition 71
4.2.2 Ensemble Empirical Mode Decomposition 73
4.2.3 Proposed Weight Factor Mode (WFM) Method 73
4.3 Heart Rate Analysis Using Piezofilm Sensor and Ensemble Empirical Mode Decomposition 74
4.3.1 Experimentation setting 74
4.3.2 Results 77
4.4 Evaluation of the WFM based EEMD method using ECG Benchmarking Data Bases 83
4.4.1 MIT-BIH data set 83
4.4.2 Results 87
4.5 AAMI data set 87
4.6 Conclusion 90

5 Hakim-4 a Cloud Based Drowning Incident Detection and Notification 92
5.1 Introduction 92
5.2 Cloud Pulling Based Drowning Detection System 93
5.2.1 Web service description 93
5.2.2 Cloud computing use justification 93
5.2.3 Cloud based pulling system 95
5.3 Preliminary Implementation 96
5.4 Conclusion 97

6 General Conclusion **98**
6.1 Summary 98
6.2 Challenges and Future Work 99

List of Figures

1.1 Sentag wrist band [15] 19
1.2 Sentag Drowning Prevention [15] 19
1.4 Wahoo Drowning Detection System 20
1.3 Wahoo Head Band 20
1.5 Poseidon Drowning Prevention System [13] 23

2.1 Global Internet Device Sales [22] 27
2.2 Panasonic Eluga waterproof smartphone [23] 28
2.3 Sony Xperia scratch resistant, Waterproof and Dustproof model [24] 29
2.4 Example of Smartphone waterproof cases 30
2.5 Smartphone with waterproof case inserted in the swimming cap [19] 32
2.6 Pressure variation depending on the pressure sensor environment [19] 33
2.7 Pressure Fluctuation According to Water Depth [19] 35
2.8 Accelerometer measured information [19] 36
2.9 Smartphone Application [19] 38
2.10 Developed Sound Track 39
2.11 Motorcycle Airbag [29] 41
2.12 Waist Type Personal Floatation Device (PFD) [30] 41
2.13 CO2 compressed bottle with automatic deflation system [31] . 42

2.14 IOIO Board Protected With Epoxy 43
2.15 Developed Automatic Airbag System Before Waterproofing . 44
2.16 Servomotor Circuit Protection with Epoxy 44
2.17 Servomotor Gum Protection 45
2.18 Final Airbag System after Waterproofing [19] 45

3.1 Life Guard Wearing Sensor Units 50
3.2 Lifeguard imitating near drowning pattern [34] 51
3.3 Lifeguard imitating the near drowning behavior 52
3.4 Measured pressure information in three data set [34] 54
3.5 Measured pressure in near drowning scenario [34] 54
3.6 Measured Pressure Information in One Data Set [34] 55
3.7 Used Neural Network Architecture [34] 56
3.8 Neural Networks Confusion Matrix [34] 57
3.9 Pressure fluctuation measure from pressure sensor [33] 59
3.10 Measured pressure in near drowning imitating scenario [33] . . 60
3.11 Motion sensor logging unit and axis direction information [33] 60
3.12 Accelerometer information measured from X axis during near drowning mimic [33] 61
3.13 Logged accelerometer data measured from X axis [33] 62
3.14 Gyroscope information measured from Y axis during near drowning imitating scenario [33] 63
3.15 Logged gyroscope data measured from Y axis [33] 64
3.16 Used neural network architecture [33] 65
3.17 Chest Confusion Matrix [33] 66

4.1 Superficial Temporal Artery [36] 71
4.2 Heart Rate Analysis Using Piezofilm Sensor Attached at the Level of Superficial Temporal Artery 74

4.3 Experiment for Measuring Heart Rate Activity Through the radial artery using a Piezofilm sensor before applying the medical band [45] . . . 75
4.4 Case of signal not affected by motion noise artifact [47] 75
4.5 Signal B measured by the Piezo film sensor in motion situation [47] . . . 76
4.6 Experimentation Bloc Diagram [46] . . . 77
4.7 Obtained IMF components ci(1<=i<=9) by EEMD sifting process [47] . . . 78
4.8 c4+ c5 mode (Blue) compared to data 2 signal measured from Piezo film (Green) [47] . . . 79
4.9 c4+ c5 mode (Blue) compared to data 7 signal measured from Piezo film (Green) [47] . . . 81
4.10 WFM mode (Blue, Red) compared to data7 signal measured from Piezo film (Green) [47] . . . 82
4.11 Component c4 and c5 Used for Extracting Heart Activity [46] 84
4.12 ECG signal (Green) and WFM Obtained Signal (Blue) 84
4.13 ECG Signal (Green) and WFM Obtained Signal (Blue) . . . 85
4.14 Example from data 102 when in rare cases WFM could not detect successfully the heart some heart peaks [45] . . . 86
4.15 AAMI-3b ECG signal . . . 87
4.16 Decomposition of aami3-b into IMF components ci (1≤i ≤12) by EEMD sifting process [45] . . . 88
4.17 Heart peaks detected with delay in the case of AAMI-a signal [45] . . . 89
4.18 Difficulty in finding a suitable WFM mode in the case of AAMI-b signal [45] . . . 90

5.1 Near Drowning Alert Delivery System . . . 94
5.2 Smartphone Application Screen Capture . . . 96
5.3 Cloud Saved Data . . . 97

6.1 Hakim combined drowning prevention solution 101
6.2 Hakim System Actions 103
6.3 Concept Design Early Drowning Detection Cap 103

List of Tables

2.1 Comparision Between Smartphone and Customized Based Solution . . . 31
2.2 PRESSURE MEASURED FROM THE SYSTEM AT DIFFERENT DEPTH (avP) average atmospheric pressure [19] . . 34
2.3 Motion and Motionless Situation [19] . . . 37

4.1 MODE MIXING OBSERVED PROBLEM WITH DIFFERENT IMF MODE COMBINATION [47] . . . 80
4.2 EVALUATION OF WFM METHOD [46] . . . 85

Chapter 1

Introduction

1.1 Drowning

1.2 Defintion

Drowning is defined as “the process of experiencing respiratory impairment from submersion/immersion in liquid” [4]. Before that several drowning definition existed [1]. The old drowning definitions mainly associate drowning with death. While the incidents during in which the victim succeed to survive are called Near Drowning incidents. As in the previous drowning definition near drowning was not considered as a drowning incident. This lead to the lack of data about the victims who have faced a near drowning incident. As for the drowning process itself it is considered that it starts “at the point when persons are no longer able to keep their mouths above the surface of water” [4].

1.2.1 Statistic About Drowning Incidents

According to the World Health Organization (WHO) 2012 fact sheet [2], drowning is the third cause of unintentional injury death in the world. with a number of annual victims estimated to 388000 deaths, presenting 7% of the total related fatalities. According to the same source these numbers “may significantly underestimate the actual public health problem related to drowning”. In fact the number of victims who have been hospitalized for near drowning incidents is believed to be five time more frequent than the total number of drowning [3] . While victims who faced drowning incident and survived, called generally near drowning incident, “are estimated to be 500 to 600 times more common than their fatal counterpart” [3]. As result basing on the WHO 2012 statistics [2], we can estimate the number of hospitalized drowning victims in 2012 to reach 1.9 million and those who faced a near drowning incident to be about 200 millions.

1.2.2 Lifeguard Vigilance

1.2.2.1 At pool environment

Several of drowning incident occurs in public swimming pools stuffed with professional lifeguards. The drowning incident occurrence in the presence of lifeguards is due mainly to the three following factors [9].

1. Lifeguard distraction caused for example by talking with people.
2. Conducting other tasks in parallel such as pool maintenance activities.
3. The failure to detect the drowning pattern by the lifeguard.

The last factor might be due to the lack of lifeguard training to recognize victim at early drowning stages or just due to the lack of vigilance. A research conducted about lifeguards vigilance in swimming pools [11] showed that “Vigilance capacity cannot be maintained at an optimum level for more than 30 minutes”. The research also highlighted that the vigilance is affected by the monotony of the task. In addition a temperature as high as 30 degree Celcius can decline the lifeguard vigilance by about 45%. Thus the Red cross recommend lifeguard to have a 15 min break every hour. Another research by Billy Doyle highlighted by Pia in [9] mention the incapacity of 89% of in-experimented lifeguards to detect a drowning person in a video clip within less than 30 seconds. While 70% percent of the participant did not act on the first 2 minutes to see the progress of the situation and 30% of participants simply consider that no action is needed. This highlight how difficult is for a lifeguard to detect drowning incidents. Pia in [8] suggest that training lifeguard on detecting a particular pattern response called RID (which we will discuss in 1.2.3) observed among some victims in drowning situations can help reduce the failure of some lifeguards identifying them.

1.2.2.2 At sea environment

The mission of lifeguards in the sea is even more challenging than in a pool environment. In fact, the swimming area in the sea is theoretically illimited, thus the distance from the lifeguards position to the victim might be very large. Unlike swimming conditions in a pool, the conditions in the sea are different. As it depends on whether, conditions sometimes the sea can become agitated with high amplitude waves. In addition, the sea bottom sometimes has an irregular surface so the swimmer might find himself suddenly in a deep region which make a victim without a floatation capability in big trouble. In addition, some regions in the sea might contains RIP currents. Which is very dangerous for both people with or without swimming abilities. Generally people who are familiar with the region know about the dangerous area so they try to avoid it, which is not the case of many tourist. So every year many drowning incidents occurs among tourist who are ignorant about the danger of the swimming location they are visiting.

We also have to notice that whereas almost all public swimming pools are guarded. In the case of the sea, several of them are patrolled during a particular period of time or not patrolled at all. Thus the risk that the victim finds himself in trouble alone or if he is lucky enough for a person nearby to find him and try to come to his rescue. Which is a very dangerous act for someone who did not receive prior lifesaving training.

1.2.3 Drowning Types

We can distinguish two type of drowning.

1. **Active drowning** happens when the victim is conscious of the danger he is facing.

2. **Passive drowning** occurs when a bather is unconscious due for example to the suffering from a sudden illness such as a heart attack. It is important to distinguish between these two categories as their response toward a drowning incident are different.

1.2.4 Response in Early Drowning

1.2.4.1 Active Drowning

Unlike passive drowning during which victims do not react while facing the incident, in active drowning victims become distressed and fight for survival. This reaction might differs according to the swimming skills. In fact, we can distinguish two kind of active drowning victims.

1. **Non-Swimmers victims** are those who cannot float by themself in normal situation so they do not have swimming ability. These victims find themself incidentally in deep water so they get immediately panicked as they cannot float in water and start developing particular water crisis which Pia [32] calls Instinctive Drowning Response (IDR).

2. **Swimmers victims** are those who know how to swim. As result this category of victims have a self floating swimming capability. However, they can also be victims of a drowning incident when they get exhausted in deep water, get cached by rip current or just facing any other kind of

accident without loosing total consciousness. Such victims are generally able to float when the incident just occurs so they are generally able to call for help or show up by their hand. Nevertheless, with the time they will start getting exhausted and loosing their energy thus they can also start developing and Instinctive Drowning Response (IDR).

Instinctive Drowning Response IDR

Frank Pia used information about drowning rescue incidents gathered during a 21 year period at Orchard Beach, New York; where 40000 rescues occured to introduce Instinctive Drowning Response (IDR)[32]. He released a short movie in which he include IDR response from real drowning incidents [6].

Pia observed that during IDR victims have a particular pattern

- They tend to have a vertical body posture
- Move in an up and down motion
- The victims can struggle for a period as few as 20 second and as long as 60 second. While children tend to have a shorter period.

In addition victims facing an IDR response is generally unable to control his body so he might become very violent when some one approaches to save him.

1.2.4.2 Passive Drowning

Passive drowning victims are generally unconscious. As result they usually drown after loosing consciousness without a visible reaction. Moreover, more recent researh about drowning have shown that young children do not fight for survival when they get submerged in water, an example of such an incident can be found in this video link [10]. Thus this category of victims should also be included in the passive drowning category.

Unlike active drowning where the victim express an IDR reaction, in passive drowning the victim drown silently. So the victim can disappear underwater in less than one second The identification of passive drowning victim is extremely difficult especially in a crowded environment and a large swimming area.

1.3 Survey on Drowning Prevention Systems

There are basically two different approaches in a drowning prevention system. The first one is based on wearable devices while the second approach is camera based. We will discuss the advantages and disadvantages of each approach with examples of commercialized products.

1.3.1 Wearable Based Drowning Prevention Systems

Wearable computing based drowning prevention system. As its name suggests, requires the user to wear a special device. This device analyzes the victim pattern so if an early drowning scenario is detected an alarm is triggered. We will try to survey examples of the existing drowning prevention system commercialized in the market.

1.3.1.1 Introduction

1.3.1.2 SenTag

Sentag is a drowning detection system for swimming pool use. The system is composed mainly of three components.

1. Wrist band Fig. 1.1 which the user wears helping analysing his depth and motion in water.
2. Hydrophones 1.2 which is installed in the swimming pool to listen to any alarm signal received from the the wrist band.

3. System Unit which receive the information from the hydrophone and analyze it so if a drowning pattern is observed an alarm is sent to the lifeguard through a pager. Fig. 1.2

The wrist band will send a drowning alert if the victim is motionless under a preset depth and time period. By default, the depth is set to 70 cm and time period is 40 seconds. These parameter can be modified using another device.

Figure 1.1: Sentag wrist band [15]

Figure 1.2: Sentag Drowning Prevention [15]

1.3.1.3 Wahoo

The swimmer is requested to wear a head band which includes sensors in order to help identify his depth in water Fig.1.3. The head band will transmit a

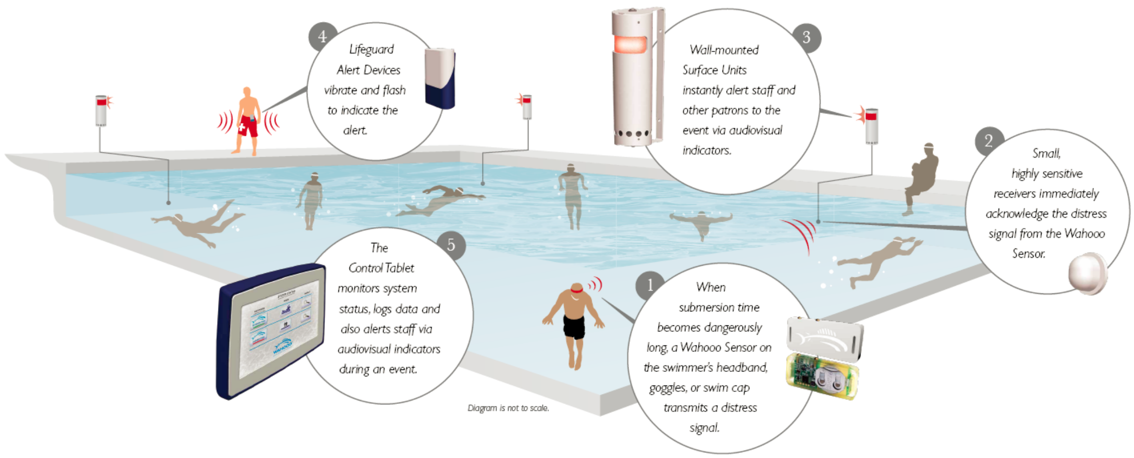

Figure 1.4: Wahoo Drowning Detection System

signal to the nearby hydrophone if the victim spends an abnormally long time underwater. In such a case an alert is triggered in the swimming area and a message is sent to the lifeguard Fig.1.4.

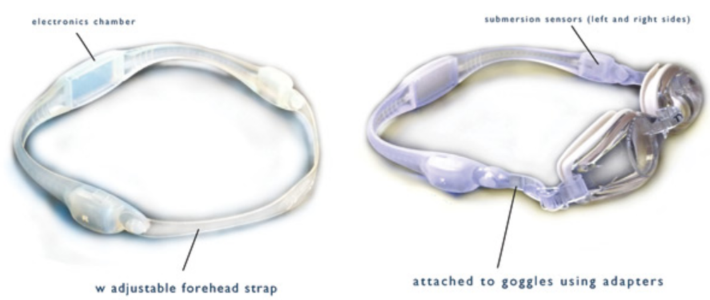

Figure 1.3: Wahoo Head Band

1.3.1.4 Conclusion

It is difficult to evaluate these two solutions without having access to a complete technical information. Most probably these solutions use a pressure sensor to measure the depth of the swimmer underwater and a motion sensor such as an accelerometer for motion detection in the case of Sentag. Based on the the presentation of these two products and the disclosed technical information. Most probably they cannot detect early drowning stages pattern as the main detected patterns is the time spent under water and includes motion. If we compare between the two systems the main difference is the location of the sensor. Whereas the Sentag sensor is attached at the hand level which is a very comfortable location for the swimmer. Wahoo sensor is attached at the head level which is less comfortable. However, Wahoo system can give precise information about the swimmer's head depth position in water. Thus it can calculate exactly the time the swimmer spent underwater without breathing. So the system triggers an alarm if the preset threshold is exceeded. Which is not the case of Sentag system, as the information about the hand's depth in water does not necessarily reflect the time the swimmer spent underwater. For example, someone might have his hand submerged about one meter underwater while his head is still above water. And similarly the swimmer might have his head and hand underwater at a half meter depth. So it is not possible to detect drowning pattern just based on the hand depth location. As a result in addition to the hand's depth position, Sentag system analyzes the hand motion. So if the victims hand's is motionless under a specific depth for period exceeding the preset threshold an alarm is triggered. The pattern detected by Sentag system might correspond to an advanced drowning stage when the victim is completely motionless and starts submerging to the water. So if some delay occurs the lifeguard reaches the victim too late. The last one might suffer from health complication which might lead to permanent brain damage or even death.

Finally, although we do not have the exact information about the pricing of these solution. But, we can expect that it is costly as several equipment have to be installed. So this solution is not suitable for private swimming pool and hotels with limited budget. These solutions can also be used only in a limited swimming area such as pools and it is difficult to expand their use to the sea.

1.3.2 Video Based Drowning Prevention System

1.3.2.1 Introduction

Video based approach relay on the processing of video captured from the camera attached above the swimming pool and sometimes even from underwater cameras. In this subsection we will first discuss some of the scientific published works about video based drowning prevention system and then present an example of a commercialized product.

1.3.2.2 Vision-Based Approach to Early Detection of Drowning

In [16], Wenmiao and How-Lung presented how they can detect early drowning pattern automatically from video captures. For this they used video measured from an imitation of drowning incidents. And developed a new method for early drowning detection composed of two components. The first one is called the vision component . Which consist mainly on detecting and tracking the swimmer for extracting motion and shape features. The second components is called event-inference. Which use a finite state machine composed of different stages observed during drowning incident using sequential change algorithm which parse the detected drowning features.

1.3.2.3 Poseidon

Use video images from camera placed over the pool and below the water Use Artificial intelligence To detect abnormal swimming behavior.

In their website they already mention that they installed 128 system in 11 countries.

We notice also that many of the installations have been conducted by large organization such as city office, universities and sport centers. However we could not find reference to installation for example done for hotels. In addition the installation have so far been done only in developed countries.

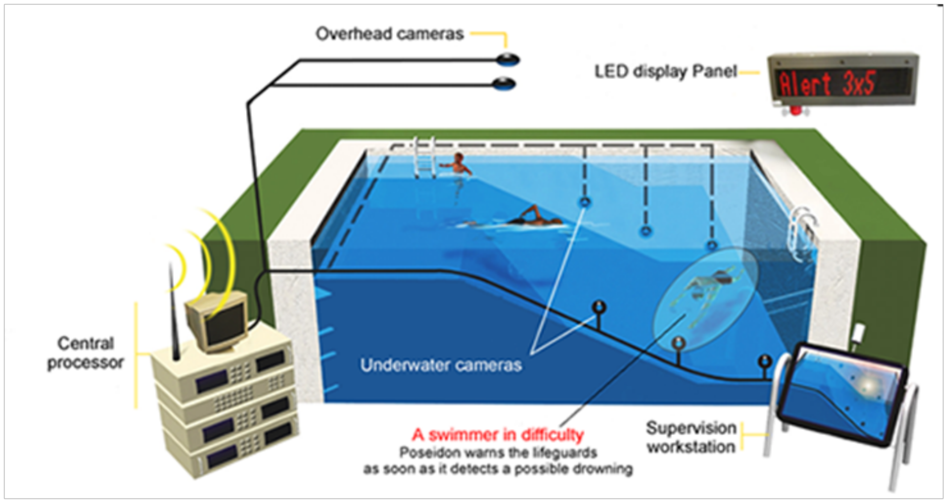

Figure 1.5: Poseidon Drowning Prevention System [13]

This can be explained by the expensive installation cost which is estimated according to [14] to 100 000 US$.

1.3.2.4 Conclusion

Unlike wearable computing based approach, the video based that one can bring a higher comfort to the user as he will not need to wear any additional devices. Thus we can find several scientific research [16, 18]. However other problems have to be investigated furthermore such the occlusion problem which might appear in the case of crowded swimming pool. Moreover, the video based approach cannot be also aplyed at the sea level.

1.4 Research Objective

The aim of this research is to create a drowning prevention platform. Which support the following features:

- Affordability so a large number of users can have access to it at any location in the world

- Availability for use not only in public swimming pool but also to the private one and can be used even at the sea
- Detection of victim facing advanced and early drowning stage
- Evacuating victim from water
- Alerting the rescuing unit and providing them information about the victim and his current location

1.5 Thesis Outline

This thesis is composed of six chapters.In the first one we already highlighted the need of a wearable drowning prevention system. In the second chapter, we propose a system to help detect victims facing advanced drowning stages using Smartphones as a platform connected to an airbag system which can help float the victim above water. However saving the victim after reaching an advanced drowning stage might lead to a dangerous consequences on the victim's health . Thus we propose in the third chapter to use information measured from pressure and inertial sensors to train neural network to detect early drowning pattern . For this we asked professional lifeguards to imitate the particular motions observed among drowning victims at the early stage. However, as the training data might not be large enough, it is difficult for system accuracy. So in chapter four we propose to analyze another different pattern observed in the early drowning stage, which is the panic reaction. For this we propose to use piezofilm sensor to analyze the sudden increase in the victim's heart rate. As Piezofilm sensor suffer from different kinds of noises, to reduce such a problem we propose to use new method called Weight Factor Mode (WFM) which is based on Ensemble Empirical Mode Decomposition (EEMD). In the last chapter, we propose a cloud drowning prevention platform. Which can log information about the swimmers location which can be used to rescue the victim.

Chapter 2

Hakim-1 a Drowning Detection and Evacuation System

Some of the illustration in this chapter appeared in the publication:"M. Kharrat, Y. Wakuda, N. Koshizuka, K. Sakamura "Automatic Waist Airbag Drowning Prevention System Based on Underwater Time-lapse and Motion Information Measured by Smartphone's Pressure Sensor and Accelerometer" 31st IEEE International Conference on Consumer Electronics (ICCE), January 2013"

2.1 Introduction

A normal person is able to spend as long as one minute underwater without breathing . Even though some professional swimmers can exceed such a time lapse. For normal people, if the forty seconds threshold is exceeded, we can assume that the person might be facing difficulties. Moreover, another abnormal behavior that can be considered is when a person is motionless for a long period while underwater. In this section we aim to detect such abnormal patterns using wearable sensors. Nowadays we witness rapid advancement in electronics with the introduction of MEMS sensor technology. MEMS sensors are particularly small so they can be used in embedded systems and especially wearable applications. An example of these sensors are accelerometers and pressure sensors. The pressure sensor can be used to analyze the swimmer's depth position in water. While the accelerometer can be used to analyze the swimmer motion.

From the other side, we recently we witness an important increase in the number of shipped Smartphone. Which expected to reach one billion unit by the end of 2013[22].

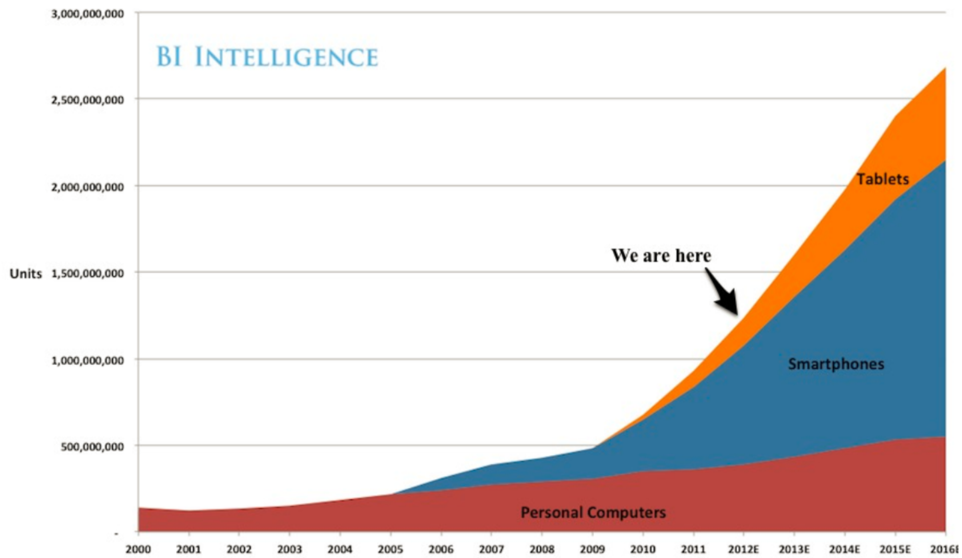

Figure 2.1: Global Internet Device Sales [22]

These Smartphones are mainly characterized by a large touch screen with an operating system (OS) open to Third-Party applications providers. Today one of the most popular Smartphone's OS is Android which has been adopted by most Smarphone makers. However, with the Smartphone shape makers have limited design options to differentiate their products. Thus, nowadays, the innovation in Smartphone industries nowadays moved towards the circuit integrated in the devices instead of shape. However another challenge appears again, classically in personal computer industry the hardware performance especially the CPU and GPU clock cycle were intensively advertised as the key performance factor to be considered by customers once purchasing a new hardware. However with the rise of the need of mobile electronic devices relying on batteries such as notebooks, hardware manufacturers understood the needs to opt toward a new strategy with a lower power consumption on the detriment of CPU and GPU performance. Similarly, today Smartphone manufacturers are even facing more challenging problem with a smaller device size and the consumer need for a longer battery running device. With the recent development of the tiny MEMS sensors , Smartphone makers identified this new opportunity to equip their devices with new features such as accelerometers which now has become a default feature in nearly all Smartphone. Also, MEMS sensors recently found their position in Smartphones such as Gyroscope and pressure sensors. In addition, System on Chip (SoC) development is helping a wider adoption of more communication protocol standards such Near Field Communication (NFC) with the recently announced SoC NFC chips produced by STmicroelectronics and Qualcomm. One other aspect some manufacturers are working on for differentiating their products is fortifying them against shock, dust and water. Recently, Panasonic released a general public Smartphone with principal feature to be waterproof Fig. 2.2.

Figure 2.2: Panasonic Eluga waterproof smartphone [23]

Soon after, Sony followed its competitor and proposed a scratch resistant dust and waterproof model Xperia Go 2.3 . Which has the main advantage to include a pressure sensor comparing to Panasonic Eluga.

Figure 2.3: Sony Xperia scratch resistant, Waterproof and Dustproof model [24]

We believe that in the future many other manufacturers will follow the trend in a way that a waterproof capability becomes part of the default features in all Smartphone similarely to what happened in the watch industry. In fact, waterproof Smartphone can avoid damage caused by liquid spill or rain. In addition today more and more users find the need to use their mobile in the sea for various reasons such answering phone calls, keeping connected to the Internet, listening to sound tracks or taking pictures and video. As result, today we can find many Third-Party Smartphone accessories manufacturers who provide waterproof protection cases. Some of these cases are general purpose and are compatible with most Smartphones in the market, however they are generally big and not good enough.

(a) General Purpose Waterproof Case

(b) Otterbox waterproof case for iPhone [26]

(c) iOttie Waterproof Skin Case Cover Pouch for Samsung Galaxy Nexus [27]

Figure 2.4: Example of Smartphone waterproof cases

Some other manifacturer provide cases which fit the shape of the Smatphone Fig. 2.4b in a manner it becomes difficult to distinguish from normal protection cases. Some disposable waterproof cases have even been recently released ensuring complete protection in keeping the original shape and size of the Smartphone unmodified Fig. 2.4c. The frequent need to remove the protection skin for Smartphone's cable connection purpose can be reduced by using a wireless charger and handsfree bluetooth kit. With all the presented accessories and recent effort of Smartphone and accessories makers', we believe that Smartphones will have more and more presence in water environment in the future. Thus in this chapter, we consider to use Smartphone as a platform to develop a drowning prevention system and taking profit of the different MEMS sensors embedded in the device. This has many advantages such as the possibility to make a solution available to a large population of users at very low cost comparing to the use of customized devices. Also, the user will not also need to handle an extra device with them to the water which can sometimes be embarrassing to the adult who does not know how to swim. In addition the user will not need to ensure the battery charging of an additional device neither the subscription to an additional internet plan for an alert transmission Fig. 2.1.

System	Customized	Smartphone
Package	Special System	Smartphone with application
Cost	-	+
Comfort	+	-
Availability	-	+
Battery	-	+
Communication Channel	-	+

Table 2.1: Comparision Between Smartphone and Customized Based Solution

2.2 Drowning Detection Based on Under Water Time Lapse

Drowning death is principally caused by the lack of oxygen in body due to the inaptitude to breath while underwater. The maximum time a person can spend underwater without breathing is estimated to be one minute. Thus, continuously monitoring the time spent by the person underwater can help avoiding drowning incidents. We suggest that using pressure sensor attached at the back of the swimmer head's might help monitor the head depth position in the water. To ensure that, we conducted a couple of experimentations using a Nexus Galaxy Smartphone as a platform which is among the first released devices to integrate a pressure sensor (Bosch BMP180). To use the Smartphone in water we used a waterproof case then we inserted it in the swimming cap Fig. 2.5.

Figure 2.5: Smartphone with waterproof case inserted in the swimming cap [19]

To analyze how these procedures affect the measured pressure. We analyze the pressure fluctuation before using the waterproof case and after. We found that the measured pressure decreased by about 60 Pascal. Again by inserting the protected Smartphone inside the swimming cap the pressure decreased by approximately 50 Pascal Fig.2.6. The overall pressure fluctuation is approximately 110 Pascal however in this case we consider the maximum measured fluctuation reaches 150 Pascal .

The reason why it is important to measure the pressure fluctuation is that we are using the pressure sensor to determine the swimmer position in the water. This can be better understood from the following experimentation where we are submerging the device in a water tank and measuring the pressure at different depth. In fact at the level of 1 inches the measured

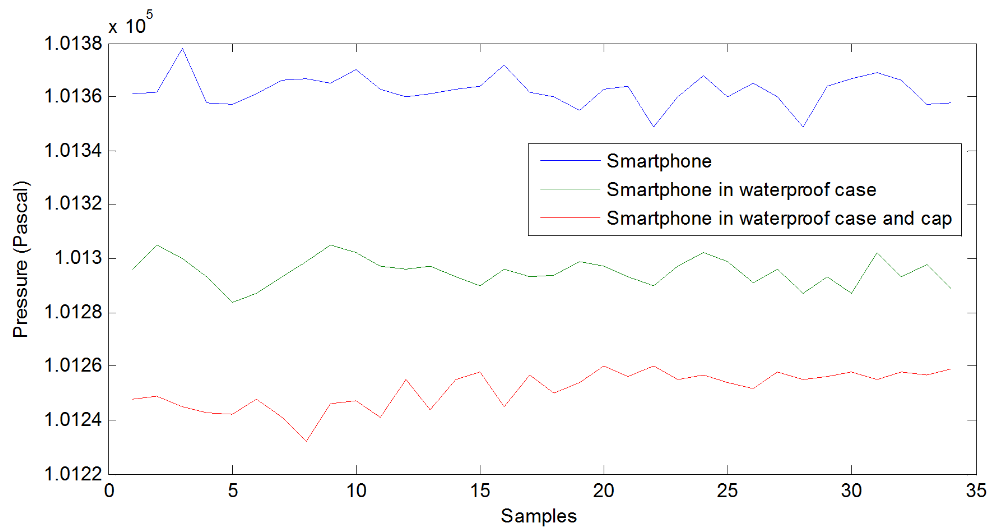

Figure 2.6: Pressure variation depending on the pressure sensor environment [19]

pressure increase by 133 Pascal. At the level of 2 inches the pressure increase up to 333 Pascal while at 3 inches we measured a pressure of 523 Pascal Fig. 2.2.

Depth (Inches)	Pressure (Pascal)	Pressure Differences In-Out Water
0(avP)	101247	
1	101380	133
2	101580	333
3	101770	523
4	101960	713
5	102440	1193
6	102790	1543
7	102950	1703
8	103090	1843
9	103320	2073
10	103345	2098
11	103720	2473
12	103930	2683

Table 2.2: PRESSURE MEASURED FROM THE SYSTEM AT DIFFERENT DEPTH (avP) average atmospheric pressure [19]

These experimentation shows that the pressure sensor (Bosch BMP180) has good precision so it can be used to analyze in real time the swimmer head's depth position Fig. 2.7.

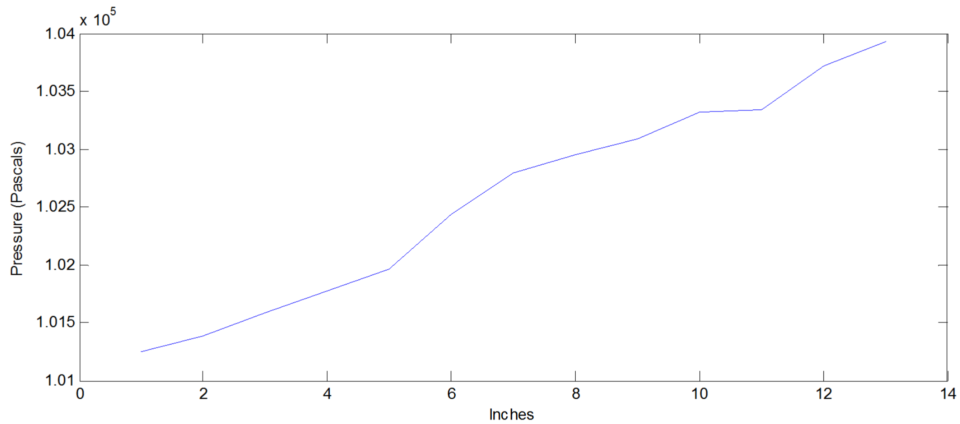

Figure 2.7: Pressure Fluctuation According to Water Depth [19]

2.3 Automatic Motionless Status Detection Using Accelerometer

We are considering using an accelerometer to analyze the swimmers motion in water. We will again use the Nexus Galaxy Smartphone as a platform for our experimentation which embed the invensense MPU-3050 all in one motion sensor including an accelerometer and gyroscope. We consider both situation in water motion and non motion. In the Fig. 2.8 the first and second time window (w) correspond to the motion situation while the last three time window correspond to the motionless situation.

To identify the person motion situation we calculate the acceleration square root accSQR as defined below

$$accSQR = \frac{x^2+y^2+z^2}{g^2}$$

By comparing accSQR to a predefined accSQR threshold (accSQRth) during a specific time window , we can determine if the swimmer is in motion or motionless. In the example below we set accSQRth= 1.25 m/s2 and the

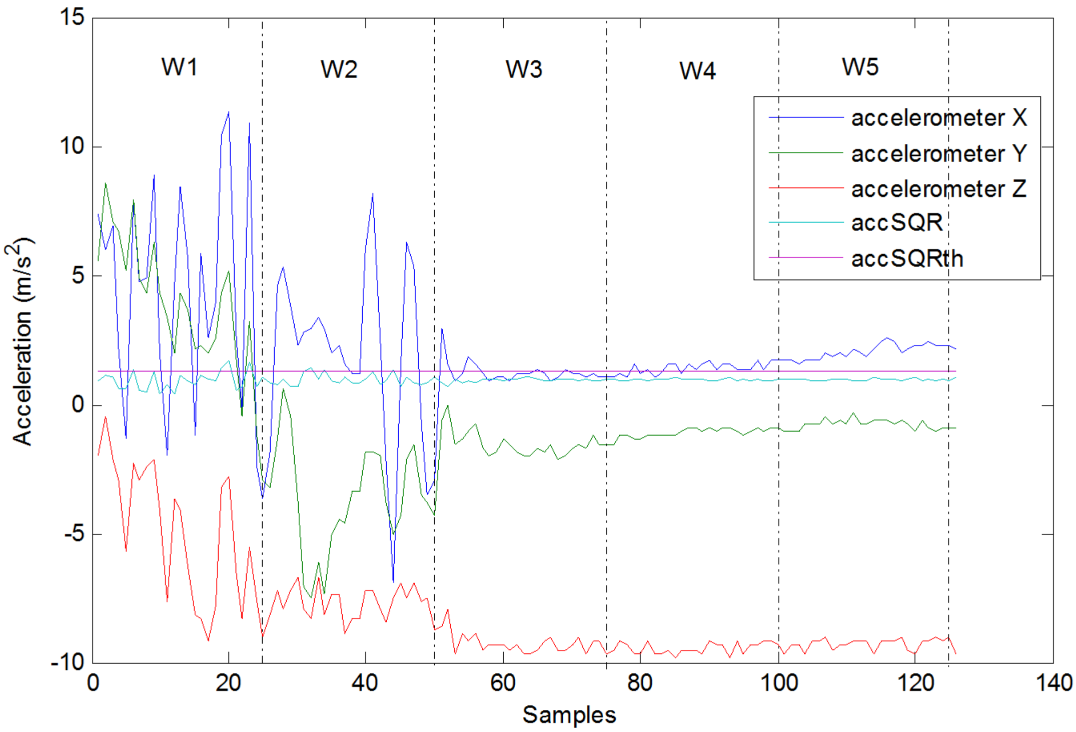

Figure 2.8: Accelerometer measured information [19]

Time Windows	W1	W2	W3	W4	W5
Max accSQR	1.699	1.385	1.026	1.041	1.036
Situation	Motion	Motion	Motionless	Motionless	Motionless

Table 2.3: Motion and Motionless Situation [19]

window size w= 5 second. So we were able to automatically detect the in motion and non motion situation Fig. 2.3.

2.4 Android Smartphone Application

Smartphones are getting popular nowadays with about one billion units shipped in 2012 [22]. With Android OS based devices being the most popular. Android OS comes with a good API facilitating the access and use of the Smartphone embedded sensors. In this section we propose an Android application in which the users set the maximum time he can spend underwater and in the case the maximum threshold is exceeded the device alarm is triggered. Once the application is started it takes the average of the first 50 measured pressure values corresponding to a five second period and sets the average value above water pressure reference which will be used later on to distinguish between above water and underwater user position. So if the user spends time underwater which exceeds the preset threshold the device alarm is triggered. However one important issue has to be considered in this case which is related to the pressure above water reference. In the case the user starts the application before inputting the device in the water proof case the preset threshold will change. In addition, the measured pressure will also be affected once the user inserts the protected device inside the swimming cap based on the previous experimentation conducted in Fig. 2.2 we show that the maximum pressure fluctuation that can have between non protected device and protected device inserted in the swimming cap is 150 Pascal Fig.2.6.

From the other side our experimentation in pressure measurement in water Fig. 2.2 show that at just a depth of two inches we can measure a pressure of about 333 Pascal which is more than twice the error risk of 150 Pascal which we might have in the case the user starts the application before using the waterproof case. Ideally the application should start measuring the above water pressure reference once the user inserts the protected device inside the swimming cap in the section 2.5 we will show how we can do that using NFC technology in section 2.5. A prototype of the proposed system has been developed Fig. 2.9.

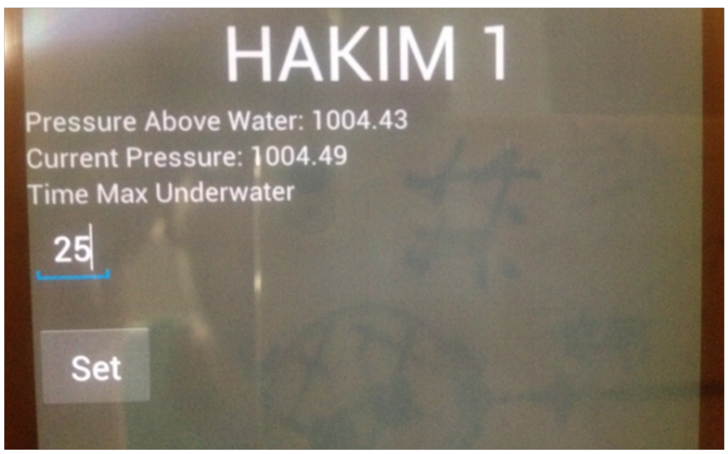

Figure 2.9: Smartphone Application [19]

In the case the underwater threshold is exceeded an on device alarm is triggered. However we noticed a problem in relation to the on device alarm. In fact, a normal alarm tone operates generally in a high frequency domain so it is highly attenuated by water. So it is difficult for people surrounding the user to hear the alarm. Instead, a tone operating in lower frequency has to be used. We experimented various sound frequencies trying to find the most optimal one. However it is difficule to find manually the optimal frequency. Upper the suggestion of Professor Mardi Hastings from Georgia Institute of Technology we used a sound tone with 500Hz frequency and 10 cycles Fig.

2.10.

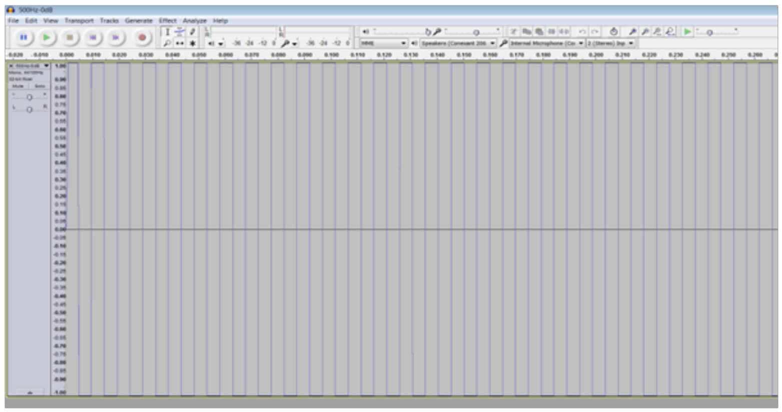

Figure 2.10: Developed Sound Track

We tested the alarm tone in a water tank and we succeed to achieve a fair result as the signal is slightly attenuated when the device is submerged in water. However when we tested the tone in a large swimming pool the signal completely absorbed. We are planning to keep investigating furthermore possibilities to develop the optimum alarm tone that can be apled on a Smartphone. However it is unlikely to come up with an alarm tone that can be heard in a large swimming pool. As the Smartphone speaker is designed to operate in a different environment. One other option we can consider is to build a customized speaker which can be integrated within the waterproof case or the swimming cap for higher efficiency. However we have to consider the alarm transmission problem is wider than that as the victim can find himself far away from any rescuer. Such a problem can appear for example when he is swimming alone in private swimming pool or swimming in the beach in a non patrolled area. This problem can be solved by using cloud computing based solution which we present in Fig. 5. One other approach we are considering in Fig. 2.6, is to use an airbag system and save the victim directly instead of just triggering an Alarm.

2.5 NFC based auto lunch application system

In the previous section Fig. 2.4 we highlighted that ideally, the Smartphone application should start measuring above water pressure once the user inserts the protected device inside the swimming cap as this can give a higher precision information about the swimmers head position is water. Another important issue we have to consider is in relation to the user behavior.Sometimes the user forgets to start the application or simply gets more confidence and gets lazy to start it. However, he might keep the interest to carry his device with him in the water for several reasons, such as replaying to the incoming phone calls, taking pictures or listening to sound tracks.

To solve these two problems, we propose to use NFC technology to execute the application automatically once the user inserts the device in the swimming cap. Recently many Smartphone integrate NFC reader with the principal aim to transform Smartphones into electronic wallets as well as using it for access control. The proposed system consists on providing the user an RFID label which he can attach permanently at the back level of the swimming cap. So once he insert the Smartphone to the swimming cap the Smartphone's NFC reader detect the RFID tag and launch automatically the application. The system have been successfully implemented on the android platform.

2.6 Airbag System

Recently airbags have become a default equipment in most commercial cars which helped reducing the number of death associates with crash incidents. In addition airbags have been recently applied to several others applications such as motorcycles Fig. 2.11 and horse riding.

Figure 2.11: Motorcycle Airbag [29]

Airbag is also used in water safety under the name Personal Flotation Devices (PFDs) Fig. 2.12. PFD is composed mainly of three parts.

- Nylon bag
- Small compressed Co2 bottle Fig. 2.13
- Deflation system

Figure 2.12: Waist Type Personal Floatation Device (PFD) [30]

This system comes in two varieties the first one is called manual. Once the user finds himself incidentally in deep water he just pulls up a cable so the nylon bag gets deflated. Due to its relatively compact size they are provided today to all the airlines passengers to be used in an emergency situation. The second variety is called automatic, it is used generally when someone falls accidently in water so the airbag deflates automatically. For this an additional component is used which reacts in the presence of water to deflates the system automatically Fig. 2.13.

Figure 2.13: CO2 compressed bottle with automatic deflation system [31]

However the main problem of the automatic system is not designed to be used by people who are located normally in water. So a more intelligent system needs to be designed. In this part we take profit of the previously developed Smartphone based drowning detection application to connect it with PFD system to transform it into an airbag which deflates automatically once the system detects an abnormal behavior. For this we use a manual commercial PFD version. As the automatic one deflates with the first contact with water so it is not suitable for our application. The manual PFD is deflated once the cable is pulled up. To make from the system automatic we use a high torque servo motor which we attach to PFD deflation system in order to replace the hand pulling action. In order to control the servomotor from the Smartphone, we use IOIO board Fig. 2.14.

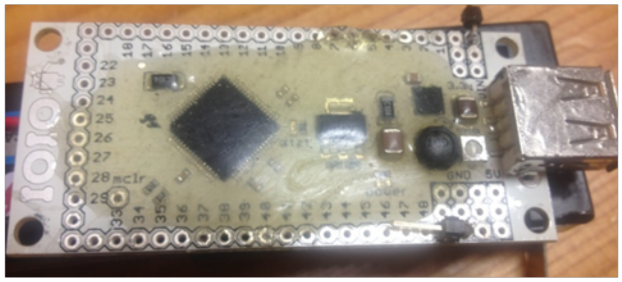

Figure 2.14: IOIO Board Protected With Epoxy

IOIO is a board which come with a PIC microcontroller, USB connectivity, analog and digital Input Output. The board also support Bluetooth connectivity through additional dongle connected in the USB port. The main advantage of IOIO board compared to for example others popular boards such Arduino, is that it come with Java library which can be added to previously developed Android application and used to control the IOIO board directly using the same Java code used in the application source code. This avoids the need to seperately develop the controlling board and ending up with two separate source code. We succeed to ensure the communication between our android application and the board to automatically deflate the PFD manual system and transform it to an automatic airbag Fig. 2.15.

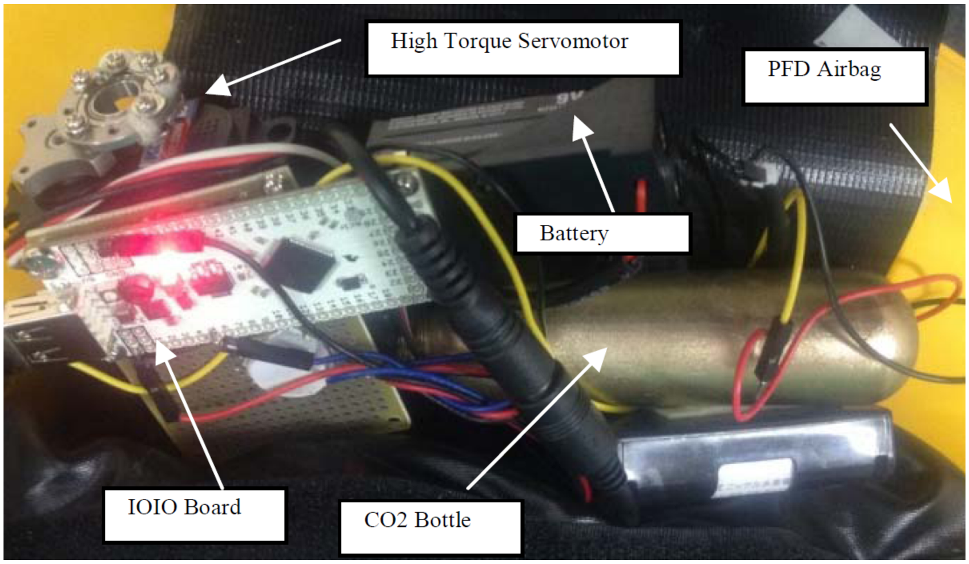

Figure 2.15: Developed Automatic Airbag System Before Waterproofing

However another issue has to be considered in the real use of the system, which is the waterproofing of the IOIO board, battery and the servomotor which itself contains an electronic control circuit needing to be protected. For this we use Epoxy potting usually used for protecting circuit which have the risk in getting damaged by water Fig. 2.14, Fig. 2.16.

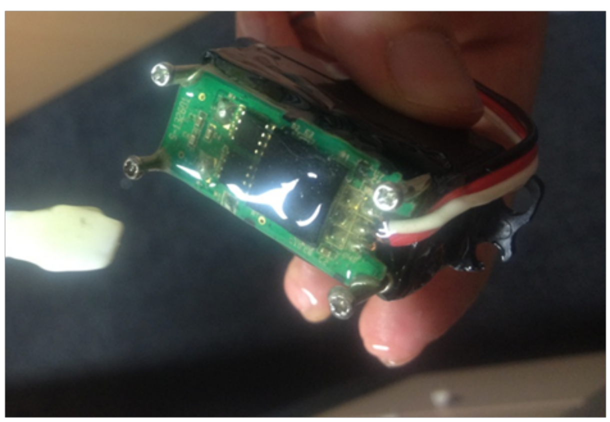

Figure 2.16: Servomotor Circuit Protection with Epoxy

For additional layer of protection we use gum doping Fig. **2.17.**

Figure 2.17: Servomotor Gum Protection

We finally package the airbag system in a protection case Fig. 2.18.

Figure 2.18: Final Airbag System after Waterproofing [19]

2.7 Conclusion

In this chapter we proposed a Smartphone based drowning prevention system which can detect victims who spend an abnormally long time underwater while motionless. For this we use pressure and accelerometer sensor embedded in the Smartphone. As on device alarm is difficult to propagate in water. We designed a waist type airbag which can be triggered by the application and evacuate the victim. In the system design we also took consideration of some users behavior toward the system, so we showed how we can use NFC technology to automatically start the system once it is inserted in its position. Which can help ensure a higher precision on measuring the head position in water.

Chapter 3

Hakim-2 an Early Drowning Detection Based on Motion Analysis

Some of the illustration and content in this chapter appeared in the publication:

"M. Kharrat, Y. Wakuda, N. Koshizuka, K. Sakamura " Near Drowning Pattern Detection Using Neural Network and Pressure Information Measured at Swimmer's Head Level " The Seventh ACM International Conference on Underwater Networks and Systems (WUWNet 2012)"

"M. Kharrat, Y. Wakuda, N. Koshizuka, K. Sakamura "Near Drowning Pattern Recognition Using Neural Network and Wearable Pressure and Motion Sensors Attached at Swimmer's Chest Level" IEEE,19th International Conference on Mechatronics and Machine Vision in Practice (M2VIP12), November 2012"

3.1 Introduction

In the previous chapter we proposed a system which can automatically detect victims who abnormally spend a long time under water while motionless. However, these syndromes are generally associated with victims who are facing advanced drowning stages. Survivals from such incidents migh suffer from permanent brain damage causing handicap. This problem might appear mainly in the case the victim did not wear the airbag system and victim find himself in non patrolled sea, where it might take a long time for the rescue team to reach the victim leading to a death risk. In this chapter, we instead aim to detect the victim at an early drowning stage so health complication can be avoided and longer time to rescue the victim becomes available. So we propose to use motion sensors as well as pressure sensors to analyse the victims motion in the water and to automatically identify abnormal behavior.

3.2 Early Drowning Detection Based on Wearable Sensors

3.2.1 Physiological Changes in Near Drowning Situation

Drowning pathology at early drowning stage differs between people who do not know how to swim called non-swimmer and people who have swimming knowledge. In fact, in the swimmers case as he know how to float he can better control himself in near drowning situations. So the victim can generally call for help to nearby people or at least show some signs with his hands. However, in the case of a non-swimmer, the victim immediately gets panicked when he faces a near drowning situations. As he is unable to float by himself, the victim will start fighting to get above the water following the Intrinsic Drowning Responce (IDR) pattern. In most situations, non-swimmers will not be able to call for help. Nevertheless when the swimmer gets completely exhausted and can not keep floating above the water any more he can express an IDR response. In the both previous situations we consider that the victim is aware of the drowning incident, so it is called active drowning. In the case the victim is at a very young age or an adult who faces a health problem leading to the loss of his consciousness, he won't be able to call for help and drown silently, in such a case the drowning is called passive drowning. In this research section we will focus only on active drowning as generally the victims express a particular IDR response.

3.2.2 Experimentation Setting

In this research we asked a professional lifeguard to imitate near drowning behavior. For this we used a wearable sensor logging unit which include 3 axis accelerometer, 3 axis gyroscope, pressure sensor we used also an external heart monitoring unit (Polar) Fig. 3.1.

The experimentation has been conducted in a professional diving swimming pool which we have rented especially as the University of Tokyo main swimming pool is just about 1.50 cm depth so it is not suitable for conducting such experimentation. In fact, to avoid drowning incident risks most public swimming pools in Japan are shallow. Even though we noticed the presence of three lifeguards at the university's pool which show that drowning incidents can occurs among adults even in shallow swimming pools. Renting a professional swimming pool in Japan is very costly which limited the number of experimentations we can conduct and thus the amount of data we can gather.

We have attached three of these units to the lifeguard at the level of his head, chest and hand and asked him to follow the scenario below:

- Swim for 30 second in place.
- Conduct free style swimming for 3 minutes.

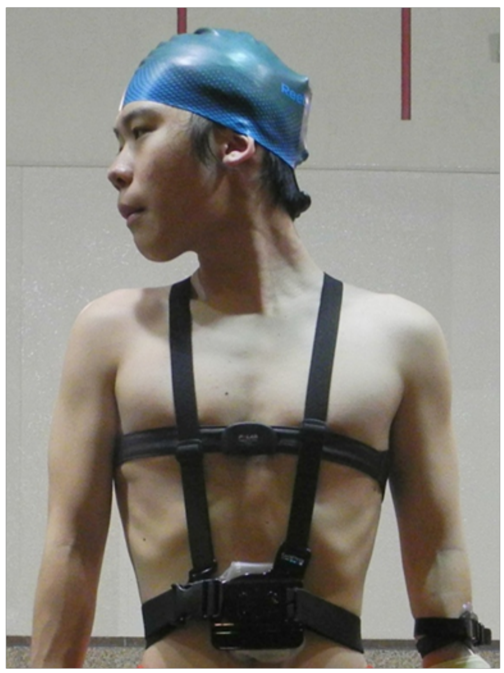

Figure 3.1: Life Guard Wearing Sensor Units

- Infer drowning pattern for 40 second.

The experimentation has been recorded using both above water camera and underwater camera for later data indexing.

Figure 3.2: Lifeguard imitating near drowning pattern [34]

(a) Underwater Video View Camera) [33]

(b) Upper Side Video View [33]

Figure 3.3: Lifeguard imitating the near drowning behavior

One of the most important study we has about victims behavior in near drowning situation, is the conducted by Frank Pia[32]. Who highlighted that a victim without swimming abilities when he faces a near-drowning situation tends to have a vertical body posture with up and down struggling. As the measured data that we have come from an imitation of drowning incidents, to minimize the associated inaccuracy risk, we decided to exclude the data measured at the hand level sensors unit as we do not have enough research references providing a precise description of victims arms motion in a panic situation. We have also excluded the accelerometer and gyroscope data measured at the head level for the same reason but we kept the pressure data as it is less prone to errors and can reflect the general body motion in water. We also decided to exclude the data measured from the heart monitoring system as we cannot imitate the physiological changes observed during a real panic reaction this topic will be discussed further more in Fig. 4. In the case of the data measured at the chest level we consider to using the three sensors measurements as we have access to detailed observations conducted by expert in the field[32]. Finally, ze studied the possibility to automatically detect near drowning patterns using a neural network.

3.3 Near Drowning Pattern Detection Using Neural Network and Pressure Information Measured at Swimmer's Head Level

3.3.1 Head Level Pressure Measurement

An analysis of the pressure information measured at the lifeguards head level in near drowning imitation scenario, shows a particular pattern compared to the one observed in a normal swimming status Fig. 3.6.

This pattern is particularly marked by the presence of multiple high amplitude low frequency fluctuation Fig. 3.5.

In fact, in the case of a normal swimming situation, the pattern is observed occasionally when for example the user jumps in to the water or changes the swimming style Fig. 3.6.

This particular pattern corresponds to the in water up and down struggling motion.

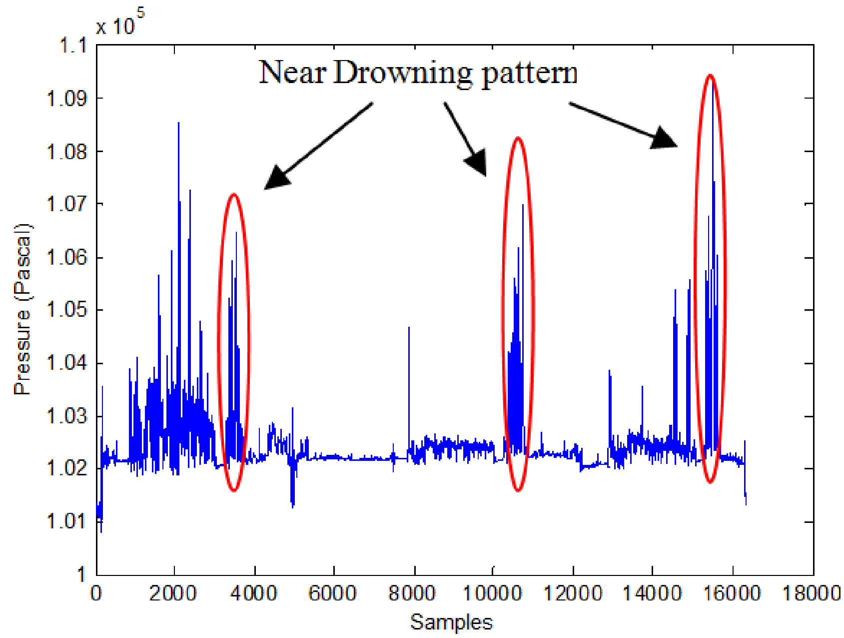

Figure 3.4: Measured pressure information in three data set [34]

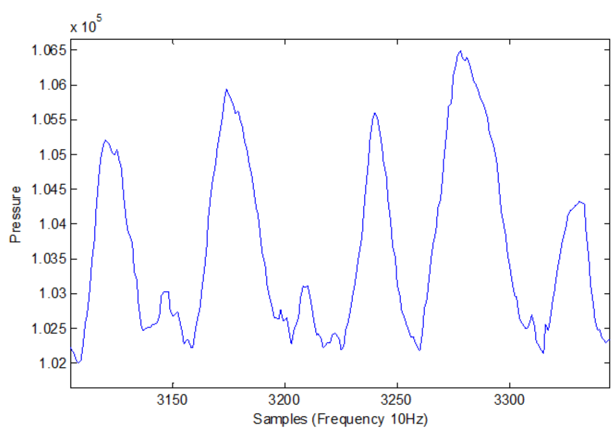

Figure 3.5: Measured pressure in near drowning scenario [34]

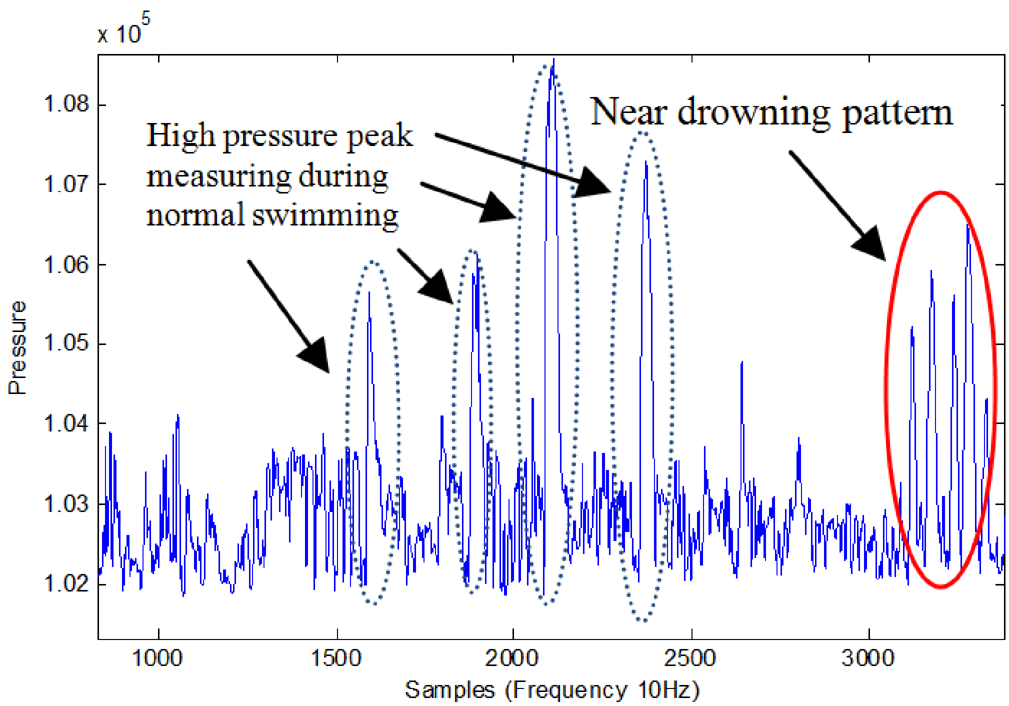

Figure 3.6: Measured Pressure Information in One Data Set [34]

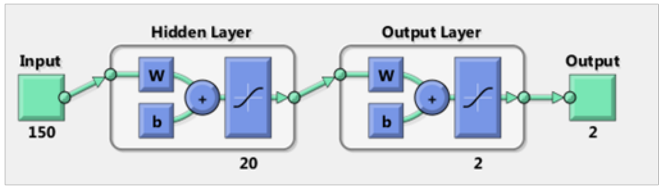

Figure 3.7: Used Neural Network Architecture [34]

3.3.2 Automatic Near Drowning Pattern Detection Using Neural Network

The main purpose of this research is to create a system which can automatically detect a near drowning pattern. For this we use a neural network pattern recognition tool box in Matlab. Pattern detection has to be conducted during a particular time window. thus, we split the measured sensor's data into vectors composed of 200 samples each. Which corresponds to a 20 second time window as our pressure sensor sampling frequency is 10Hz. With the support of the captured video, we manually classified the data into two categories, near drowning and normal swimming. We also kept the data measured out of the swimming pool and even the data when the user first jumps into the water with normal swimming circumstances, to ensure the robustness of the designed system$e$ against errors. Then, we split the dataset into 160 vectors each composed of 200 samples. Among the obtained data, we find 11 vectors corresponding to the near drowning situation and the rest to normal swimming situation. Finally, we use two layers of feed-foreword Neural Network, with sigmoid hidden and output neurons which we feed with the classified data set Fig. 3.7. 70% of the data (112 samples) have been dedicated for training while 15% of the data (24 samples) have been used for each validation and testing stages. The data has been divided randomly between the three different stages.

The trained Neural Network succeeded to achieve a 100% success rate in detecting near drowning patterns out from the overall data set Fig. 3.8.

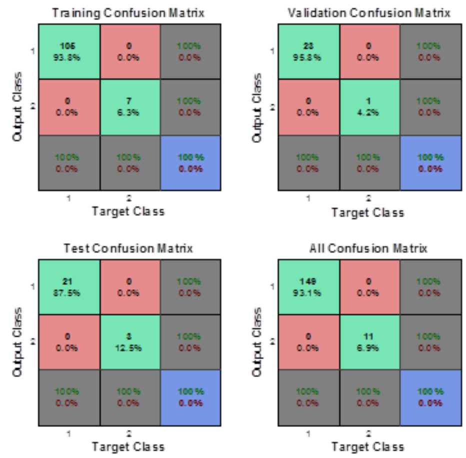

Figure 3.8: Neural Networks Confusion Matrix [34]

However, we have to take into consideration that this does not necessarily imply that the trained neural network will be able to ensure such a high performance with a dataset measured from a new user. This problem can be *reduced* by using a larger dataset gathered from different subjects. We also noticed some high pressure peaks during normal swimming periods when the head submerged underwater. So we have to further consider future scenario where the subject periodically follows a swimming style for a long period. Nevertheless, such a case is unlikely to occur among the main target users of this system who do not principally know how to swim.

3.4 Near Drowning Pattern Recognition Using Neural Network and Wearable Pressure and Inertial Sensors Attached at Swimmer's Chest Level

In the previous section we have showed how it is possible to automatically distinguish between near drowning and normal swimming patterns using a data measured from pressure sensors attached at the subject head level. In this section, we further investigate the possibility to automatically detect near drowning patterns from the chest level using an addition to pressure sensors, accelerometer and gyroscope.

3.4.1 Chest Level Pressure Measurement Analysis

The chest pressure measurement level show a multiple high amplitude low frequency fluctuation in near drowning situations similarly to the one measured at the head level Fig. 3.9.

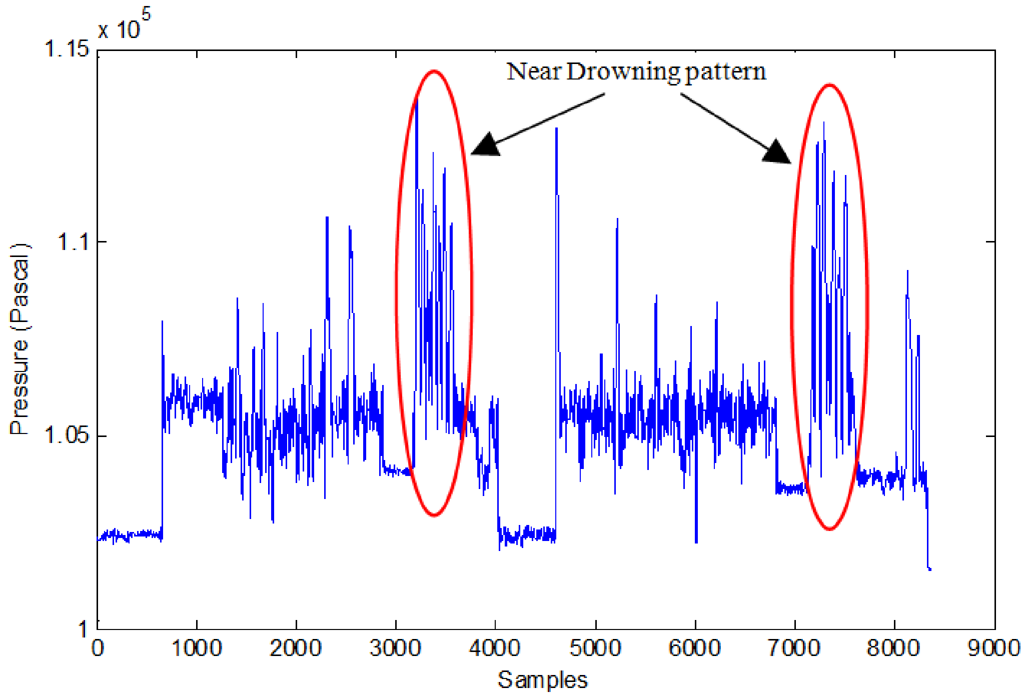

Figure 3.9: Pressure fluctuation measure from pressure sensor [33]

However, we noticed a difference in term of the variation between normal and near drowning patterns. Which is mainly due to the fact, the subject has always has his body submerged inside the water, unlike the situation when the pressure sensor is attached at the head level where the head reach often a low pressure level at the surface of the water. From the other side, the maximum measured pressure amplitude is higher in the chest measurement level rather in the case of head level. Which is normal as the sensor unit at the chest level is located at a deeper depth position leading to a higher pressure value.

3.4.2 Accelerometer

The accelerometer provides information about the vertical posture of the swimmer observed in near drowning situation. We use the data corresponding

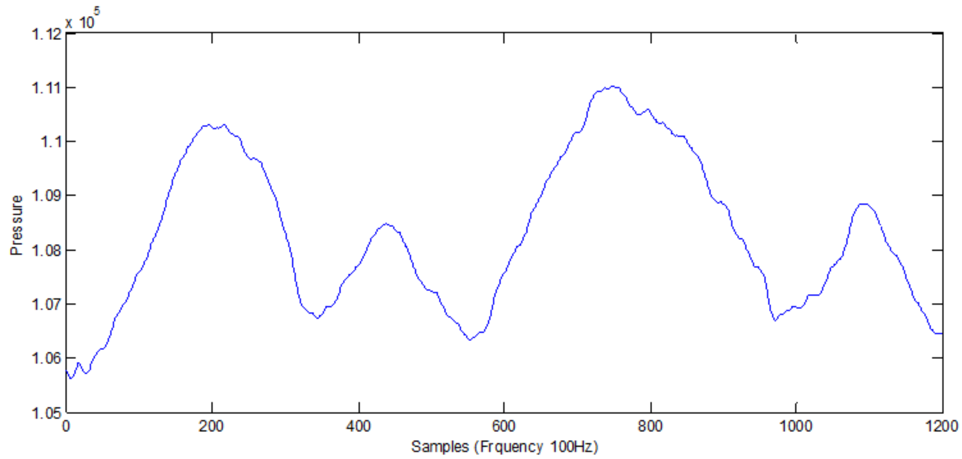

Figure 3.10: Measured pressure in near drowning imitating scenario [33]

to X axis only which corresponds to the vertical motion of the swimmer Fig. 3.11as we are looking to near drowning situations where victims tend to struggle up and down vertically.

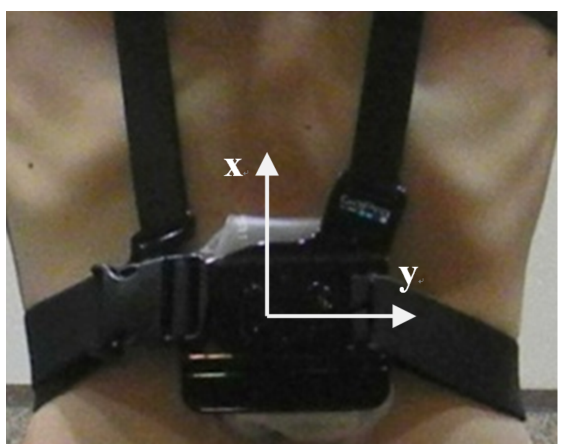

Figure 3.11: Motion sensor logging unit and axis direction information [33]

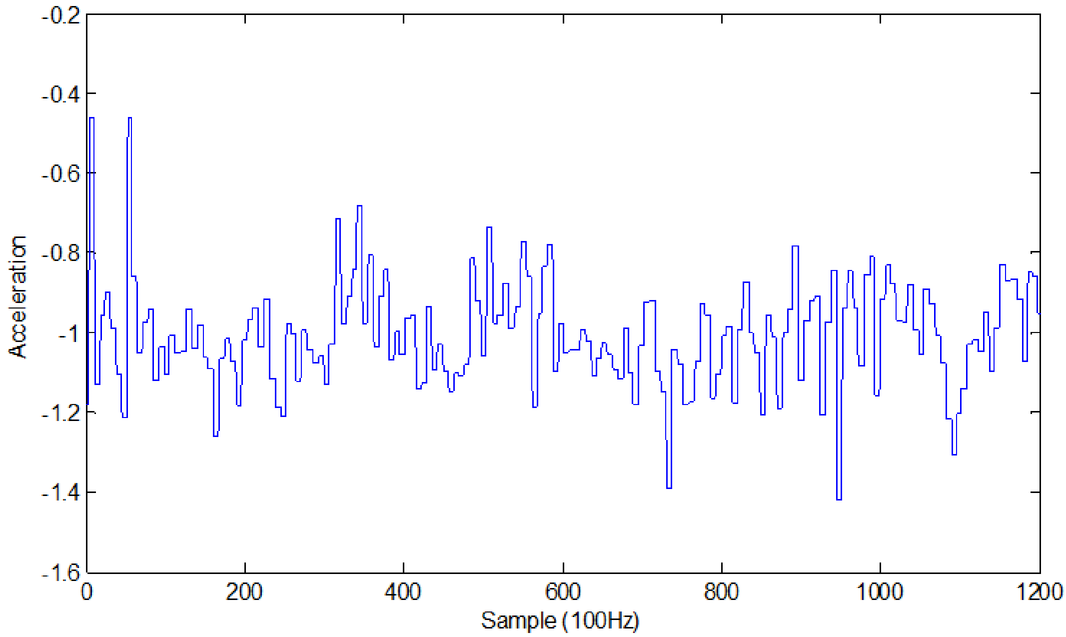

Figure 3.12: Accelerometer information measured from X axis during near drowning mimic [33]

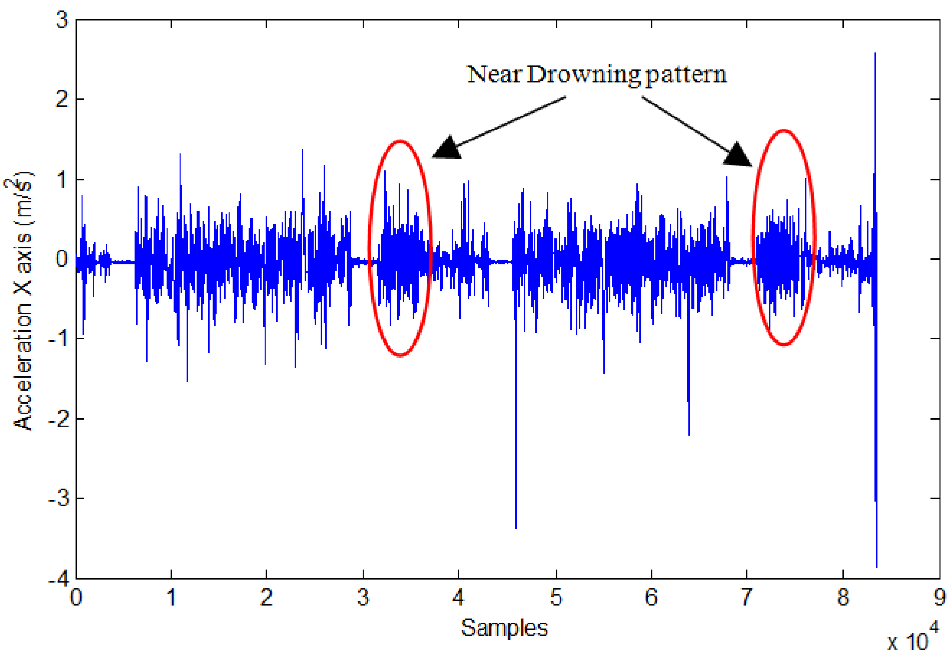

Figure 3.13: Logged accelerometer data measured from X axis [33]

3.4.3 Gyroscope

Gyroscope provides information about the swimmers angular orientation. As a victim in a near drowning situation tends to have a near vertical body posture. So we only use the Y gyroscope axis to analyze the swimmer angular posture Fig. 3.11.

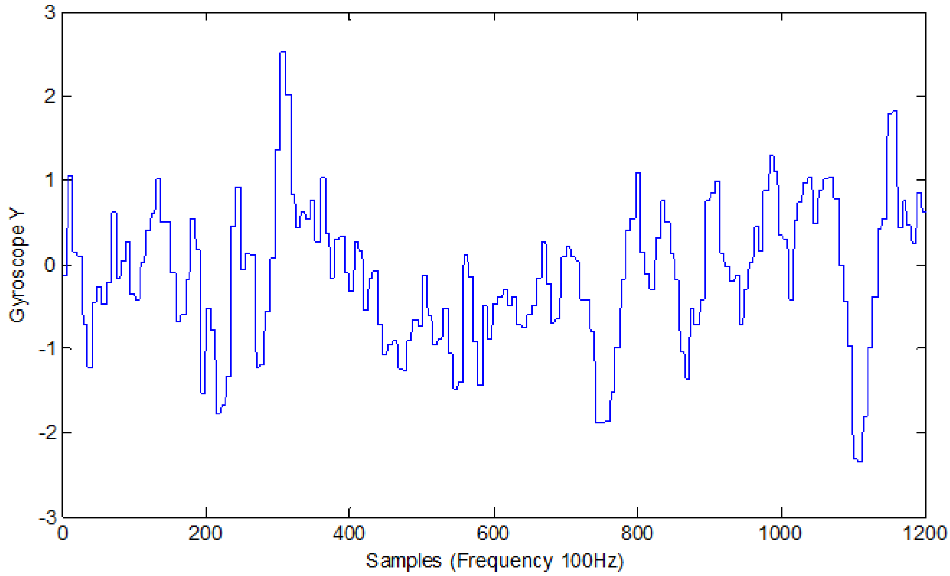

Figure 3.14: Gyroscope information measured from Y axis during near drowning imitating scenario [33]

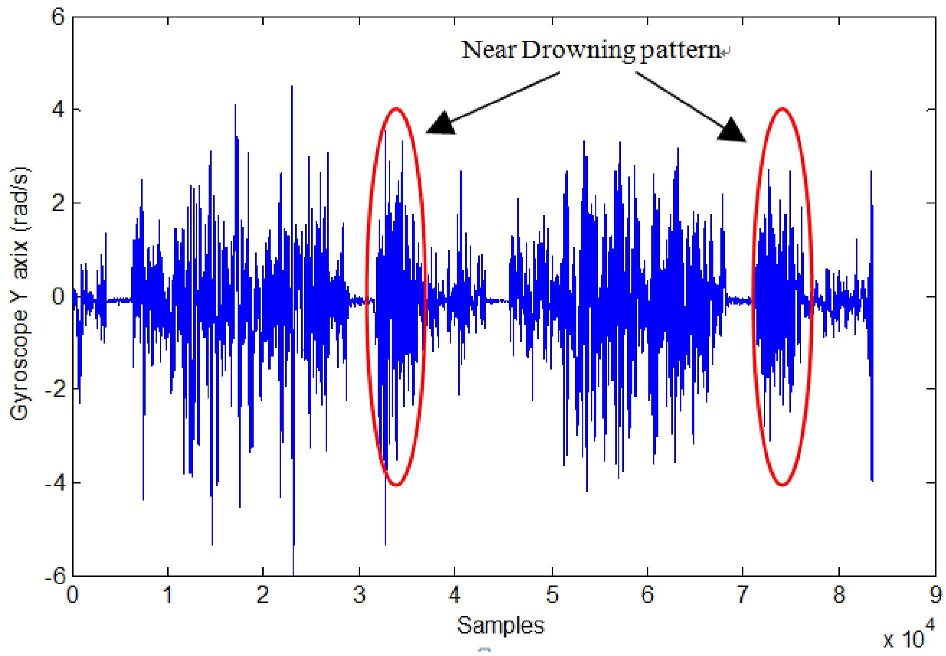

Figure 3.15: Logged gyroscope data measured from Y axis [33]

3.4.4 Automatic Near Drowning Pattern Detection Using Neural Network

We use the information measured from pressure sensor, accelerometer X axis and gyroscope Y axis to form a single vector to be used as an input for the Neural Network. The accelerometer and gyroscope information is logged at 100Hz frequency. However the pressure sensor logging frequency is 10Hz. So a frequency adjustment is necessary. We use interpolation function in Matlab to increase the pressure sensor frequency rate to 100Hz. We also reduce the time window size from 20 second to 12 second (1200 samples) compared to the previously used window size for the head level pressure analysis experimentation. This can help reducing the time required to detect near drowning pattern in real time system application. After the concatenation of the pressure, accelerometer and gyroscope data, we obtain a single vector composed of 3600 samples which we use as an input for the neural network . The total data set is composed of 202 vectors Fig. 3.16. We allocate a random 70% of the data (142 samples) for training, 15% (30 samples) for cross validation and similarly 15% for testing. We train 20 hidden neurons using scaled conjugate gradient back propagation algorithm.

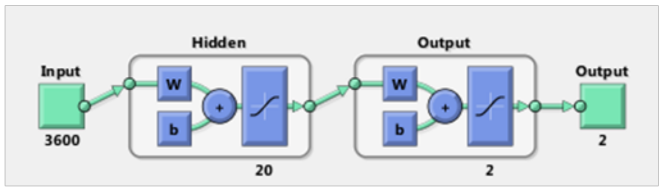

Figure 3.16: Used neural network architecture [33]

The trained neural network succeeds to achieve 100% success rate distinguishing between normal swimming situations and near drowning pattern Fig. 3.17 . In order to understand the contribution of each component to the detection of near drowning pattern. We tried to analyze the performance of motion sensors alone in time domain in detecting near drowning pattern however the performance was bad as none of the near drowning pattern has been detected. From the other side by using only the information measured from the pressure sensor we were able to achieve a 100% success rate. As a result we tried to transform the accelerometer and gyroscope data to the frequency domain and testing them one by one together as an input for the neural network. The performance has then consequently improved as we were able to detect near drowning pattern using only accelerometer and gyroscope data. However, 100% accuracy has not been achieved. From the other side we tried to analyze the performance of the pressure sensor in a frequency domain and we found that the performance slightly declined. Finally, when we combined the time domain pressure sensor information with frequency domain accelerometer and gyroscope information, we succeed to again achieve 100% detection rate Fig. 3.17.So at this level it is difficult to conclude whether only the information measured from pressure sensor is

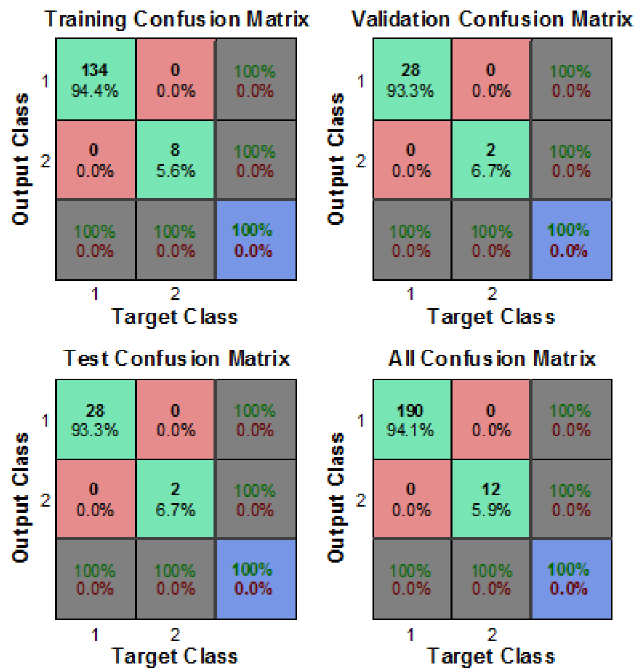

Figure 3.17: Chest Confusion Matrix [33]

enough for an accurate near drowning pattern detection or the frequency domain accelerometer and gyroscope information can help reduce the risk of a false positive scenario. Especially in the case that the trained neural network model is applied to a dataset measured from different subjects.

3.5 Conclusion

These experimentations can be considered as a proof of concept of an early drowning prevention system. Although it cannot be used as a stand-alone system. If combined with the system presented in the previous chapter 2 it can be used with a best effort service as a first layer of drowning prevention. So in the case that near drowning patterns is not detected, the second system operating in parallel can detect drowning incidents. This concept can help us gathering a real near drowning incident information which we can use in the future for the training of the Neural Network of the early drowning classification system in order to ensure a higher level of precision. However as the ultimate goal of this research is to save human life we have to define more than security layer with a higher maximum of performance. In the next chapter 4 we will investigate another approach

Chapter 5

Hakim-4 a Cloud Based Drowning Incident Detection and Notification

5.1 Introduction

Cloud computing based services are getting popular recently among the general public. This is mainly due to many people today own more than a single device connected to the internet. So it is not surprising to find someone in a developed country owning more than seven devices: such as a personal computer and Smart TV at home, net-book, laptop, tablet PC, e-book and Smartphone. Which created the need to access personal electronic information anywhere, anytime, separately or simultaneously from several devices. In addition we notice that in the last years an improvement in mobile internet bandwidth provided by the operator in the form of relatively affordable and unlimited internet package. This new ecosystem helped the rise of cloud computing services for the general public. In this chapter we present the concept of a new cloud service which can h::elp save victims who are facing drowning incidents. Similarly to Chapter 2, in this chapter we also consider the use of

Smartphones as a platform for the cloud drowning prevention system.

5.2 Cloud Pulling Based Drowning Detection System

5.2.1 Web service description

After installing the application, the user will have to create an account which includes information such as his name and e-mail address. This information will be saved in the cloud as well as on the user device's internal data base.

5.2.2 Cloud computing use justification

First In the previous chapter we discussed various techniques to detect victims at early drowning stages while in the second chapter we proposed various techniques showing how to detect a victim facing advanced drowning stages. We also showed how the in device local alarm might be inefficient in a large area and when a victim is far from rescuers. As a result we designed an airbag system which can be deflated in such a case and save the victim. However when the victim is evacuated above water by the airbag system he might be unconscious especially in the case the system detect him in an advanced drowning stage. Thus the need to send a message about the victim's GPS coordinate location to the nearest rescuing unit. The user can provide an e-mail address such as a friend or family member to which the message can be sent. However this may be sometimes inefficient for example when the friend cannot act in rapid and proper way or did not read the message immediately. To avoid such a problem we propose to update the user profile in the case he faces any trouble. And sending an alert message to the nearest rescuing organization from the victims location. The alert message might include further information about the victim such as age and profile picture t:o help identify the user. Second reason Even though the airbag based rescue system is an efficient way to rescue the victim. However we believe that many pople might not use it due to many reasons such as:

- The airbag purchasing associated cost
- Not willing to wear an extra device (even though we consider integrating the airbag in the swimming pants in the future)

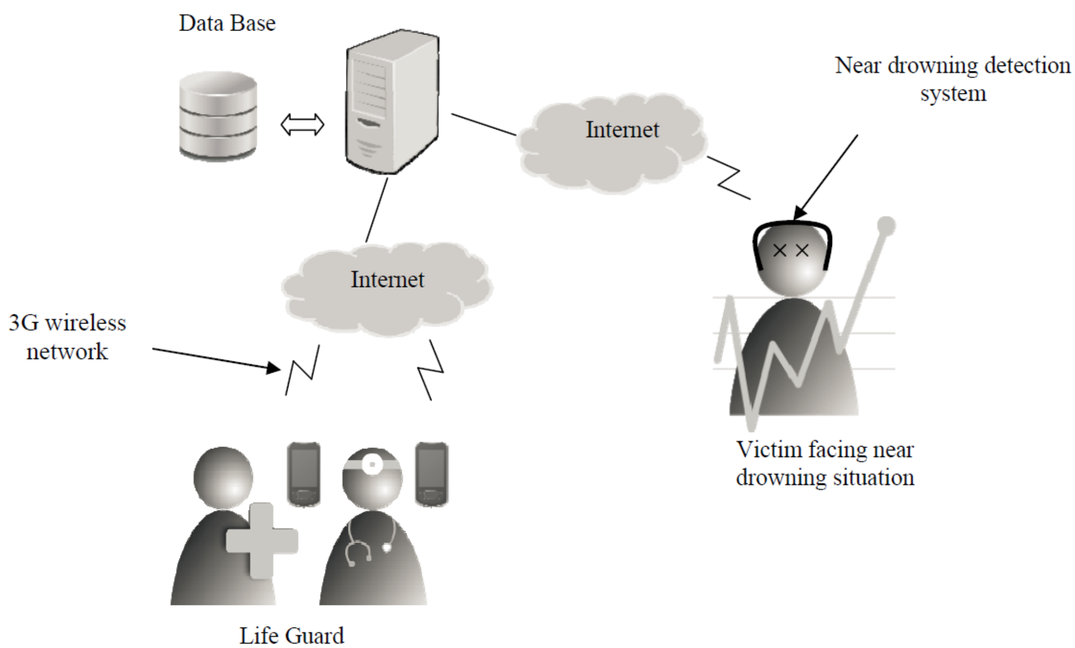

Figure 5.1: Near Drowning Alert Delivery System

So in the case the victim does not use the airbag a communication problem might appear. In fact, the communication between the victim and web service which is in charge of communicating the alert message is conducted over a mobile networks Fig. 5.1. Many of mobile network use high frequency bandwidth situated near 2GHz bandwidth. Which make from the communication signal highly subject to attenuation in water. As in advanced drowning stages the victim finds themself underwater, there is a high risk that system can fail to communicate the near drowning alert message. So a solution have to be found to this problem. In the opposite case,if our system is used whithout airbag it will not be operational.

5.2.3 Cloud based pulling system

We propose to periodically submit a packet to the cloud with information about the users location. So in the case that packets are not received for a long period of time, the server understand that the swimmer did not come out of the water. So if a certain threshold is exceeded without receiving any information from the user an alert can be sent to the rescuing authority. However some aspects has to be considered .

- The first issue, we consider is that most of the beaches are covered by mobile network, there will be a risk that the swimmer go far away in the water until the network covertures become very weak. In such a situation, the reason behind the non reception of the packet, will be the presence of the user in a non covered area by the mobile network.
- The second issue, is when the battery runs out of charge while the person is swimming.

The server in both previously mentioned cases might understand that the swimmer is drowning as it cannot receive packets from him anymore. To avoid such a scenario we propose to send periodically and extra information in the packet about the mobile network signal strength measured from the Smartphone as well as its battery level. So it becomes possible at the level of web service to distinguish these two different cases.

Figure 5.2: Smartphone Application Screen Capture

5.3 Preliminary Implementation

We implemented the remote server user registration and login password system. In addition to the remote server the information is also registered on the device local data base. This will avoid the user to retype his login information. The application cn now can also sense and display all the needed sensor information. In addition to real time processing of the above water pressure reference and motion detection Fig. 5.2.

The system can detect the swimmers location from GPS battery level and temperature as well as the mobile network signal strength level.

All these information are automatically sent to our remote MySQL data base using JSON format Fig. 5.3.

Email_	longitude_s	latitude_s	mStrength_s	battery_level_	battery_temperature_	PressureAboveWater_s	currentPressure_s	motion_s	created_at
ABC@abc.abc	139.759952891618	35.71101154200733	dddd	100	39.0		1012.88995	true	2012-09-26 01:29:48
ABC@abc.abc	139.759952891618	35.71101154200733	dddd	78	35.0		1016.58997	true	2012-09-26 07:36:25

Figure 5.3: Cloud Saved Data

5.4 Conclusion

In this chpter we present a new concept of cloud based drowning detection web service. Which can provide information about the victim location to a rescuing authority. A preimplementation of the system has been realised such smartphone application with on device and remote server login. We succeed also to log the data from the device to the cloud remote database using JSON format. In the future we are planing to complete the implementation of the system especially at the cloud side to automatically detect the drowning pattern.

Chapter 6

General Conclusion

6.1 Summary

In the previous chapter we described various methods which can help prevent drowning incidents. In the second chapter, we proposed a system which analyses time spent by the victim underwater and his motion so if a preset threshold is exceeded a wearable airbag is triggered on the victim. However the main drawback of this method that it does not detect the victim at early drowning stages. Moreover, in the case the airbag evacuation system is not used, an additional time delay has to be considered to rescue the victim. All this may cause a serious health problem to the victims which can lead to permanent brain damage or even death. As a result, we proposed another method based on wearable motion and pressure sensor to help identify the particular victim motion at early drowning stage called IDR. We then used Neural Network to automatically detect near drowning pattern. Nevertheless, the main problem with the method is that the system training data did not come from a real near drowning incident as we asked a professional lifeguard to imitate the near drowning incident. As a result, the proposed method at this time can be used only with best effort performance. So drowning detection methods are needed to ensure higher performance of the system. For this we again take of the description we have about real drowning incidents. In fact, victims who faces such an incident tend to get panick rapidly. Panic reaction is usually associated with high activity at the level of autonomic nervous system (ANS). This leads to the sudden increase of the victims heart rate activity. We took profit of this observation to propose to develop a new heart rate monitoring system which can be used in water and help detect panic reaction. For the heart rate monitoring applications, usually ECG and PPG are used. Besides, recently with the development in material science, new thin and flexible piezofim sensors have been released. On the other hand, a survey on wearable computing has shown that users are particularely concerned with the systems daily life use convenience and even look. In fact, ideally the system has to be invisible to the final user and completly embedded in the users clothes. This concern, encouraged us to opt for the use of the emerging piezofilm sensor based heart monitoring technology as the piezofim sensor can be integrated inside the swimming cap just at the level of superficial temporal artery to monitor the wimmers heart rate activity without the user notice the presence of the sensor. In fact the Piezo film sensor is thin and flexible enough to be invisible for the final user. However the use of Piezofilm sensor presents many challenges in term of signal processing and heart activity extraction as it suffer from many kinds of noises.

6.2 Challenges and Future Work

In the future we consider continuing working on Hakim-3 system by analyzing the heart rate activity of the swimmer in a motion situation. In the case of Hakim-2 we are planning to continue working on the real time side of the system. Finally for Hakim-4 web service, we are considering to finalize the server side to automatically detect the disappearing of the victim underwater.

As this project aim to save human life, we need to minimize any risk of failure detecting victims drowning. Our ultimate goal is to detect early drowning stage at the very beginning of panic reaction. Thus we proposed different methods for drowning detection. These methods accuracy and precision vary according to the techniques used. For example in Hakim-1, the bather underwater lapse time accuracy is high. While in the case of Hakim-2 we are using artificial intelligence to detect early drowning stage motion's with an imitated data. Thus the precision of the system is lower. As it is difficult to get a real data, it is better to operate such a system at the current stage with best effort service. To take profit of the strength of each techniques and avoid the risk of True-Negative scenario consisting of drowning incident occur without system reaction, we consider combining all the proposed systems in a single one as described in the figure below.

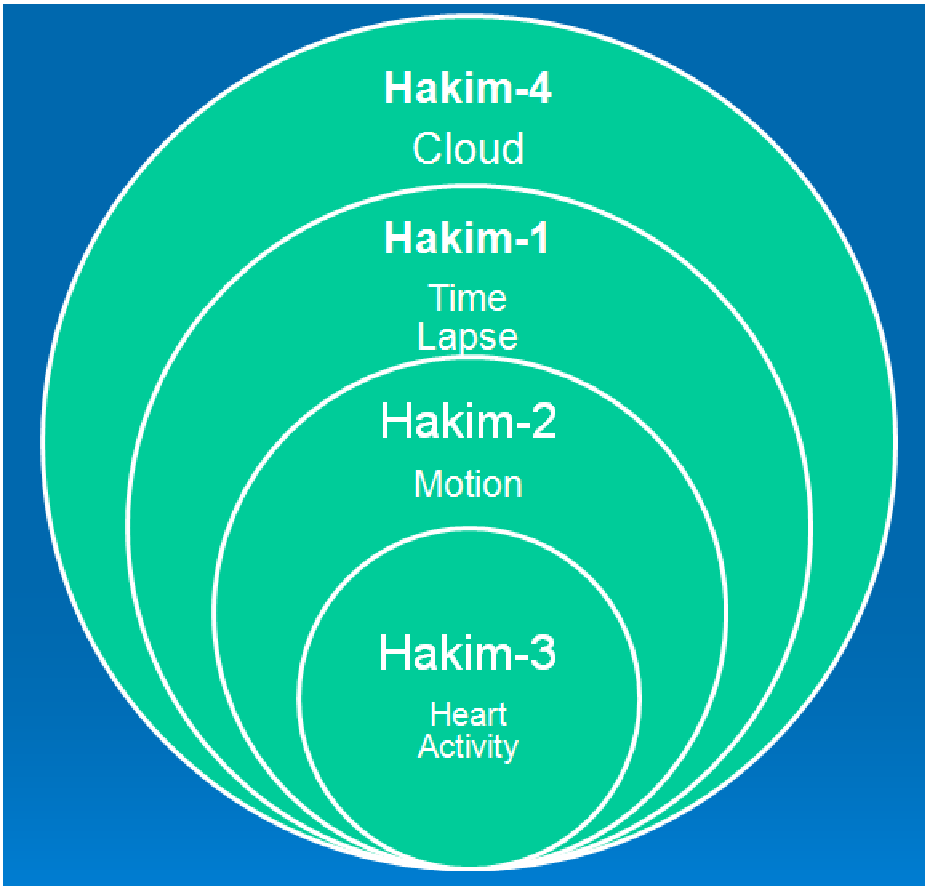

Figure 6.1: Hakim combined drowning prevention solution

When Hakim system is first starts, all its four subsystems Hakim-1 to Hakim-4 will operate in parallel. These subsystems are differentiated with their aptitude to detect drowning incidents at different stages and with different accuracy levels. The following example can better explain how Hakim system can behave in the case a drowning incident occurs.

First Hakim-3 analyze the heart rate activity of the victim in the case a sudden increase of the heart pulse rate is measured this might correspond to a distress situation so the system can act. Even in the case Hakim-3 fails, Hakim-2 which is analyzing the swimmer motion, can take action if an abnormal motion is measured. Hakim-3 and Hakim-2 use complex signal processing and machine learning methods respectively, these methods if particularly tuned in the way to minimize the risk of false alarms (False-Positive scenario), should be better considered to be operating with best effort service in real situations. Thus an additional layer of drowning detection with high accuracy is needed, this is the case of Hakim-1, which analyze the underwater lapse time spent by the swimmer. So if he spent an abnormally long time underwater it takes action. Ultimately a fourth layer of drowning detection can be used. Hakim-4, is a cloud web service which is continuously receiving information packets from the swimmer device. So if the web service suddenly no longer receives any information, it extracts the GPS coordinate from the bather's last received packet and sends it to the rescuing authority. We believe that the proposed combination can eliminate any risk of True-Negative scenario corresponding to the total failure of the system to detect a drowning incident. However, the risk of a False-Positive scenario which can be manifested with a false alarm remains possible especially if the system parameters are tuned towards high sensitivity. To minimize such a risk, we consider triggering first, an on device alert message which the user can deactivate Fig. 6.2. If the user fails to do so within for example 10 seconds, the system continue to take action by triggering on device Alarm, then airbag system and finally sending an alert rescue message to the nearest lifesaving unit.

The rescue organization can keep the option to call the victim on his device to ensure about his health conditions. If no response can be received, most probably the swimmer is facing an advanced drowning stage. So an immediate rescue action has to be conducted.

Finally in the future we aim to improve the design of the system by embedding it completely inside the swimming clothes in the way it becomes invisible for the final user. An example of such a concept design can be found in Fig 6.3 .

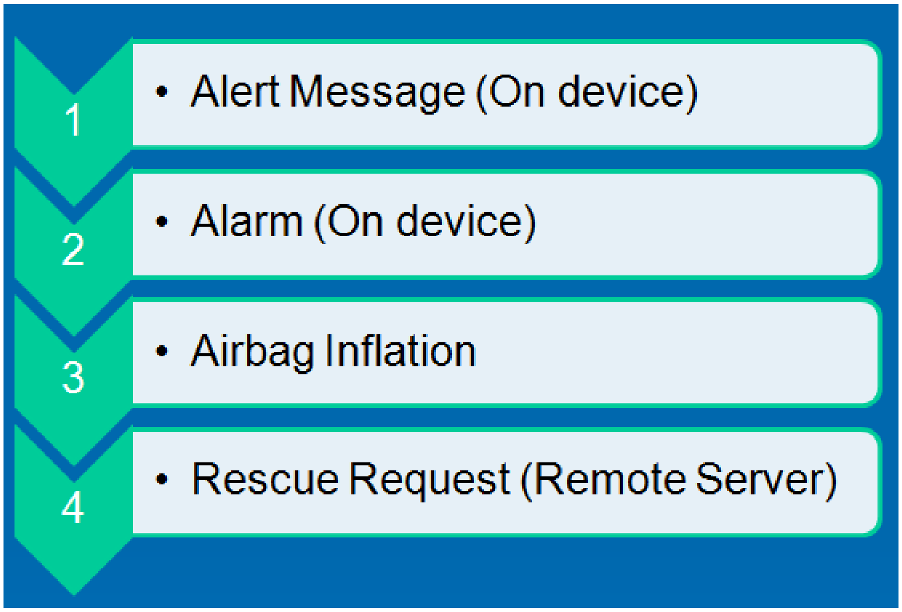

Figure 6.2: Hakim System Actions

Figure 6.3: Concept Design Early Drowning Detection Cap

Bibliography

[1] Linda Papa, Robyn Hoelle, Ahamed Idris, “Systematic review of definitions for drowning incidents”, Resuscitation, Volume 65, Issue 3, June 2005, Pages 255-264,

[2] World Health Organization, "Drowning Fact Sheet Nř347", October 2012.

[3] Orlowski, JP. Drowning, near-drowning and ice-water drowning. JAMA 1988; 260:390.

[4] van Beeck EF, Branche CM, Szpilman D, Modell JH, Bierens JJ. “A new definition of drowning: towards documentation and prevention of a global public health problem.” Bull World Health Organ. Nov 2005;83(11):853-6.

[5] Frank Pia, “The RID Factor As a Cause of Drowning”;

[6] Frank Pia, “On Drowning”, 2nd revised edition, Water Safety Films, Inc, Larchmont, NY.

[7] Example of active drowning video victim “http://www.youtube.com/watch?v=G4MeoO8MtTQ”, accessed December 2012

[8] Frank Pia, “Reflections on Lifeguard Surveillance Programs” CRC Press 1999

[9] Frank Pia, ”Guarding Against Misconceptions”, Aquatics International “http://www.aquaticsintl.com/”, May 2006

[10] Rescuing 3 Year Old Kid Drowning, “https://www.youtube.com/watch?v=KtesdQh0wvU”, accessed January 2013

[11] Applied Anthropology Institute ”The Bibliographic Study on Lifeguard Vigilance”, September 2001

[12] websters New Ninth Collegiate Dictionary, Merriam-Webster, Springfield, MA, 1991

[13] Computer aided drowning detection; www.poseidon.fr ,2010.

[14] ’Silent drowning’ pool girl saved by underwater cameras https://www.youtube.com/watch?v=qfKEBfPobmE, 2007

[15] SenTag pool safety, risk and drowning detection, www.sentag.com, 2010.

[16] Wenmiao Lu; Yap-Peng Tan; , "A vision-based approach to early detection of drowning incidents in swimming pools," Circuits and Systems for Video Technology, IEEE Transactions on , vol.14, no.2, pp. 159- 178, Feb. 2004.

[17] R. Picard, E. Vyzas, and J. Healey, “Toward machine emotional intelligence: Analysis of affective physiological state,” IEEE Trans. Pattern Anal. Machine Intell., vol. 23, pp. 1175–1191, Oct. 2001.

[18] How-Lung Eng; Kar-Ann Toh; Wei-Yun Yau; Junxian Wang; , "DEWS: A Live Visual Surveillance System for Early Drowning Detection at Pool," Circuits and Systems for Video Technology, IEEE Transactions on , vol.18, no.2, pp.196-210, Feb. 2008.

[19] ”M. Kharrat, Y. Wakuda, N. Koshizuka, K. Sakamura "Automatic Waist Airbag Drowning Prevention System Based on Underwater Time-lapse and Motion Information Measured by Smartphone’s Pressure Sensor and Accelerometer" 31st IEEE International Conference on Consumer Electronics (ICCE), January 2013.

[20] C. Edmonds, "Drowning Syndromes-The Mechanism", Forty-seventh Workshop of the Undersea and Hyperbaric Medical Society, 1997.

[21] **World Health Organization, "Drowning Fact Sheet** Nř347", November 2010.

[22] Gartner, IDC, Strategy Analytics, company filings, BI Intelligence estimates.

[23] Panasonic Eluga, “http://smartphones.panasonic.eu/en/”, accessed December 2012.

[24] Sony Xperia Go, “http://www.sonymobile.com/global-en/products/phones/xperia-go/”, accessed December 2012.

[25] iBdry Waterproof case ”http://www.newegg.com/Product/Product.aspx?Item=9SIA10208J5530”,accessed December 2012.

[26] Otterbox Waterproof case “http://www.otterbox.com/”.

[27] iOttie Waterproof Skin Case “http://www.iottie.com/Home/Index.aspx”, accessed December 2012.

[28] Liquipel Molecular Level Waterproofing “http://www.liquipel.com/”, accessed January 2012,

[29] Motoair, http://occforeclosure.net/with/with-the-new-jacket-with-integrated-airbags-motorcycle-showcase.htm”,accessed December 2012.

[30] Recreonics, “http://www.recreonics.com/life_vests.htm”, accessed December 2012.

[31] Boat store ”http://www.boatstore.com/onyx-rearming-kit-for-3200-a-m-inflatable-pfd.html”, accessed December 2012.

[32] F. Pia, "Observations on the Drowning of Nonswimmers", Journal of Physical Education, July, 1974.

[33] M. Kharrat, Y. Wakuda, N. Koshizuka, K. Sakamura “Near Drowning Pattern Recognition Using Neural Network and Wearable Pressure and Motion Sensors Attached at Swimmer’s Chest Level” IEEE, 19th International Conference on Mechatronics and Machine Vision in Practice (M2VIP12).

[34] M. Kharrat, Y. Wakuda, N. Koshizuka, K. Sakamura " Near Drowning Pattern Detection Using Neural Network and Pressure Information Measured at Swimmer’s Head Level " The Seventh ACM International Conference on Underwater Networks and Systems (WUWNet 2012).

[35] T. Martin, E. Jovanov, and D. Raskovic, Issues inWearable Computing for Medical Monitoring Applications: A Case Study of a Wearable ECG Monitoring Device, 2000.

[36] Uptodate Online, “www.uptodateonline.com”, accessed 2009.

[37] Karagiannis A., Constantinou P., “Comparative Study of Empirical Mode Decomposition Applied in Experimental Biosignals,” 8th IEEE International Conference on BioInformatics and BioEngineering, BIBE, Oct 2008.

[38] Ji, T.Y. Lu, Z. Wu, Q.H. Ji, Z., “Baseline Normalization of ECG signals using empirical mode decomposition and mathematical morphology,” Electronics letters, vol. 44, pp. 82-83, Jan 2008.

[39] Tang G., Qin A., “ECG De-noising Based On Empirical Mode Decomposition,” The 9th International Conference for Young Computer Scientists ICYCS, Nov 2008.

[40] Zhao Z. D., Chen Y. Q., “A New Method for Removal of Baseline Wander and Power Line Interference in ECG Signals,” International conference on Machine Learning and Cybernetics, Aug 2006.

[41] Wade D. Peterson, David A. Skramsted and Daniel E. Glumac, Phoenix Ambulatory Blood Pressure Monitor Project Sub-project: Piezo Film Pulse Sensor, 2004.

[42] Nan B., Naohiro U., Osamu F., “Monitoring of Respiration and Heartbeat during Sleep using a Flexible Piezoelectric Film Sensor and Empirical Mode Decomposition,” Conf Proc IEEE Eng Med Biol Soc EMBS, 1362-6. August 2007.

[43] Abdulhay E, Guméry P.Y, Fontecave J, Baconnier P. “Cardiogenic oscillations extraction in inductive plethysmography: Ensemble empirical mode decomposition," 31st Annual International Conference of the IEEE EMBS, Minneapolis, Minnesota, USA, (2009).

[44] Z. Wu, Research Center for Adaptive Data Analysis, [Online]. Available: http://rcada.ncu.edu.tw/research1_clip_program.htm, accessed (2012).

[45] M. Kharrat, Y. Wakuda, S. Kobayashi, N. Koshizuka, K. Sakamura "Evaluation of WFM based EEMD Method in Heart Activity Analysis" Journal of Medical Imaging and Health Informatics Vol. 2, 1–6, 2012 American Scientific Publisher (ASP 2012).

[46] M. Kharrat, Y. Wakuda, S. Kobayashi, N. Koshizuka, K. Sakamura, "Evaluation of Weight Factor Mode and EEMD Performance on Measuring Heart Rate Activity in the Presence of Cardiac Arrhythmia", In-

ternational Conference on Biomedical Engineering (ICoBE 2012), IEEE, Vol. B, P128, 28, February 2012.

[47] Mohamed Kharrat, Yuki Wakuda, Shinsuke Kobayashi, Noboru Koshizuka, Ken Sakamura, "Adaptive Radial Artery Pulse Rate Measurement using Piezo Film Sensor Based on Ensemble Empirical Mode Decomposition," The 10th IEEE International Conference on Information Technology and Applications in Biomedicine (ITAB 2010), November 2010.

[48] MIT-BIH Arrethmya Databnase [Online] Available “www.physionet.org/physiobank/database/mitdb/”.

[49] Measurement Specialities, “http://www.meas-spec.com/”, 2000.

[50] ANSI/AAMI EC57: Testing and reporting performance results of cardiac rhythm and ST segment measurement algorithms (AAMI Recommended Practice/American National Standard), 1998. Available: www.aami.org; Order Code: EC57-293.

[51] Huang N. E., Shen Z. Long S. R., Wu M. C., Shih H. H., Zheng Q., Yen N. C., Tung C. C., Liu H. H., "The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis." Proc. R. Soc. Lond. A, 454, 903–995, (1998).

[52] Norden E. Huang, Zheng Shen, and Steven R. Long,”A new view of nonlinear water waves : The Hilbert Spectrum,” Annual Review of Fluid Mechanics Vol. 31: 417-457, Jan 1999.

[53] Wu Z. and Huang N.E,” Ensemble Empirical Mode Decomposition: a noise-assisted data analysis method,” Advances in Adaptive Data Analysis, Vol. 1, No.1 1-41 ,2009.