Designing of Optical Devices for Biomedical Applications: A Study on IV Drip Rate Monitoring Device

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Designing of Optical Devices for Biomedical Applications: A Study on IV Drip Rate Monitoring Device

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by

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based on research carried out

under the supervision of

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and

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May, 2017

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Supervisor's Certificate

This is to certify that the work presented in the research project entitled "*Designing of Optical Devices for Biomedical Applications: A Study on IV Drip Rate Monitoring Device*"submitted by *Pratyush Kumar Patnaik*, Roll Number 215BM1255, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements of the degree of *Master of Technology* in *Biomedical Engineering*. Neither this thesis nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Kunal Pal

Dedication

This thesis is dedicated to my parents,

my brother and
my supervisor for making me who I am.

Signature

Declaration of Originality

I, *Pratyush Kumar Patnaik*, Roll Number *215BM1255* hereby declare that this dissertation entitled *Designing of Optical Devices for Biomedical Applications: A Study on IV Drip Rate Monitoring Device* presents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Reference" or "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

May 27, 2017
NIT Rourkela

Pratyush Kumar Patnaik

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ABSTRACT

Addition of biotelemetry in the field of bio-medical engineering is a useful method for improving the efficiency of the healthcare professionals. Thus it is necessary to develop devices that can improve the connectivity of the system. Optical devices have a huge application in this field. Simple optical devices can be used for the purpose of object detection, checking the optical density of samples. Intravenous infusion rate can be measured using drip rate monitorig device. A wireless drip rate monitoring device has been developed. This device incorporates the use of Light Emitting Diode (LED) and Light Dependant Resistor (LDR) to detect the drops. A mountable clasp system was used to mount the sensor on the drip chamber. Using microcontroller, the device calculates the drip rate and the Xbee communication module wirelessly notifies the centralized monitoring station whenever the drip rate crosses the desired range. A Network was developed using the Xbee Radio Modules to transmit the message to the central monitoring station. This adds feasibility and mobility in the system thus, increasing the efficiency of the healthcare professionals.
***Keywords*: *LED*; *LDR*; *Drip Rate*; *Arduino*; *Zigbee*.**

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Chapter 1

Introduction

1.1 Introduction

Currently there is a constant rise in the population of the world. It is quite evident that the shortage of required quantity of skilled healthcare professionals in the healthcare sector is one of the major problem faced by the current developing countries [1]. In such a scenario when demand for the skilled health care professionals cannot be met with their active numbers, it is necessary to maintain the patient's safety by use of automation in the healthcare industry. Addition of information technology in the medical field has greatly increased the efficiency of diagnosis and analysis done by the health care professionals.

With the advent of electronics technology, its use in the current-day life has become indispensable. This is also true for the healthcare sector. The use of electronic devices in the hospitals and the diagnostic centres is on a rapid rise. This has allowed a significant reduction in the work-load on healthcare givers, which is important because of the low healthcare giver to patient ratio across the globe. The electronic health monitoring devices allow monitoring of the patient health condition even when the movement of the patient is restricted to the bed. Many researchers and medical equipment companies have proposed transmission of signals via wireless technologies. This type of medical signal transmission is categorized as telemedicine.

The main aim of the World Health Organization (WHO) is to provide adequate and equal access of healthcare services to every person across the globe [2]. Extensive advancements made in the field of both telecommunication and healthcare technologies have made this possible. These advancements in the field of telemedicine has resulted in the wide application of the technology and have become an essential component in the healthcare delivery system [3].

Cheap and efficient networking of the devices have enabled the efficeint deployement of the human resourse across the theater of medical field. The present study proposes a device that can monitor the intravenpus (IV) drip rate automatically and wirelessly inform the monitoring station about any problems in the drip rate. A simple optical device was used for determinig the drip rate. As the detection system was made using LED and LDR, the system could be made at a very cheap cost.

1.2 Background

Intravenous infusion is a procedure used for providing blood or blood-based products, volume expanders, electrolytes and chemicals or drugs into the bloodstream by directly injecting these using needles. It is a very common procedure, yet very important. It takes approximately one minute for the blood to circulate through the entire body. So, IV therapy alters the physiological condition of the body quickly due to its capability of spreading rapidly throughout the body as compared to the drugs and compounds administered via other procedures. One such example of the rapid effect of IV therapy is the swift decrease in temperature of the body when saline is administered at a higher drip rate [4]. IV fluid overload has some dire effect for the critically ill patients [5]. Thus, it is necessary to continuously monitor and control the drip rate. Yet, it is very difficult to achieve this. There can be a variety of factors that can affect the flow of the IV fluids, for example, change in the posture of the body alters the pressure forces in the blood stream and so, can alter the drip rate [6]. A blockage in the IV tube or an empty fluid chamber will cause air bubbles to enter into the blood stream. This causes air embolism. Other complications that arise in this therapy are pain and hypothermia, and drug overdose.

The IV catheter consists of the drip chamber, IV tube, a roller clamp followed by a needle which can be inserted into the veins of the body. The purpose of the drip chamber is to prevent air embolism by making any air or gas bubbles trapped within the IV tube to rise and allow their accumulation in the drip chamber. The transparent nature of the drip chamber adds another purpose to the drip chamber, it enables the operator to check if the fluid from the fluid chamber is flowing or not. Counting the number of drops falling inside the drip chamber, the rate of flow of the IV fluid can be calculated. Observing the flow rate, the roller clamp can be manually controlled to alter the drip rate. The roller clamp squeezes the IV tube, restricting the flow of the IV fluid, thus, giving an appropriate drip rates at different positions of the roller constrictor. If the drip rate is not being monitored continuously, any sudden change in the drip rate cna't be detected. Further, there is absolutely no mechanism to inform the operators about any flow related anamolies. A human operator has to periodically monitor the fluid chamber and the drip chamber to to detect such conditions. Maintaining a constant vigil by a human to constantly monitor these problems is near impossible. In such a scenario, inclusion of biotelemetry will increase the efficiency of the medical attention to the patients, thus ensuring the safety of the patients.

Taking note of the aforementioned facts, an automated device can be made for the continuous monitoring and control of the IV infusion drip rate. The system consists of a Light Emitting Diode (LED) as the light source and a Light Dependant Resistor (LDR) as a photodetector. An Arduino Uno microcontroller (Arduino, Italy) was used for calculating and the displaying of the drip rate. It is also necessary for making the logical decisions necessary for the notification at the central monitoring station and the control of the drip rate. A Liquid Crystal Display (LCD) was used for displaying various instructions, drip rate and the state of the device. The Arduino microcontroller alerted and informed the central monitoring station if there was a case of any deviation in the IV drip. The device wirelessly transferred information using a Zigbee communication protocol.

Chapter 2

Literature Review

In order to calculate the drip rate, the operator counts the number of drops for a set period of time, and by devide the number of drops by time taken for them to fall. This is possible due to the transparent nature of the Drip Chamber. It is quite evident that this method is very inaccurate, and one person can't simply continuously count the drops to determine the change in the drip rate. To automatically determine the drip rate, the drop inside the drip chamber needs to be detected.

2.1 Related Work

Various methods have been discussed by different researchers for the determination of the IV drip rate [6–11]. The falling of the drop causes some change in the physical parameters of the drip chamber. these parameters could be change in the optical density or change in the dielectric constant of the drip chamber. Using these changes, sensors are used to generate electrical outputs that can be used to count the number of drops by use of a microcontroller or a digital counter. The drip rate gets calculated from the number of drops and the total time required for a set number of drops.

2.1.1 Capacitance Based Drip Rate Monitoring

Capacitance probes were used for sensing the presence of drops by Sethi et al. (2006) and Ogawa et al. (2010) [9, 10]. Capacitive sensors made sure that the surrounding ambient light did not affect the drop sensing mechanism. Sethi et al. (2006) developed a capacitance probe to detect the saline drop. This probe had a clasp for holding two copper plates [9].The change in the dielectric constant caused by the falling of the drop changes the capacitance across the probe. This probe was a part of a square wave generator. A decrease in the frequency of the square wave was observed when a drop fell in the chamber. The microcontroller detected the fall in frequency which was used to count the number of drops. The paper discussed that one of the greatest problems faced by the capacitive sensors are the parasitic capacitances and the interferences from other devices.

Ogawa et al. (2010) also used a capacitive probe arrangement made up of three electrodes for the determining the saline drop and the free flow condition [10]. The capacitance across them changed with the falling of the drop between them, ultimately causing a change in the impedance across them. An impedance converter was used by the microcontroller and the waveform was isolated enabling the detection of a drop. After counting the time taken for two consecutive drops, the microcontroller calculates the drip rate. A handy phone system was employed for notifying the hospital staaf, if there was a free flow situation.

2.1.2 Optical sensor Based Drip Rate Monitoring

An optical detection system was employed by Yang and Kim, (1998), Kamble et al., (2001) and Vasuki et al, (2011) [6, 8, 12]. There are patents that have discussed optical sensors in details [13, 14]. The devices made by these researchers used the transparent nature of the drip chamber to develop an optical drop detection mechanism. The system consists of a light source and a sensor. The light falling on the sensor gets interrupted by a saline drop while fallin. This changes the electrical parameter of the photo-sensor. Using this the drops falling within the drip chamber are detected and drip rate is calculated.

Yang and Kim (1998) used a fuzzy-based detection algorithm to determine the drip rate [7]. The paper discussed the use of an infrared sensor for the detection of the IV drop. The response of the optical sensor corresponding to the fall of a single fluid drop in the drip chamber has been explained (Figure 2.1).

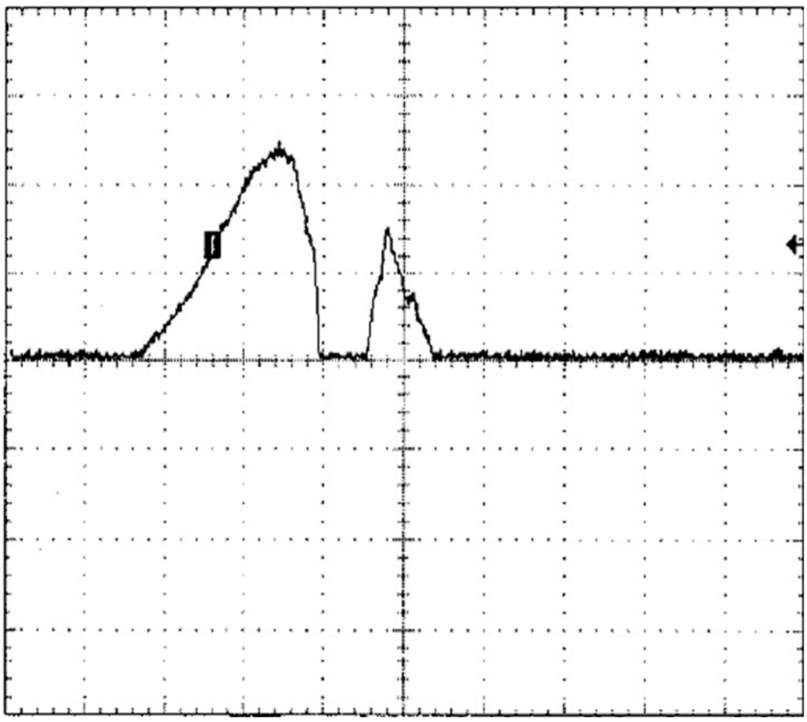

Figure 2.1: Light Scattering pattern of a single drip [7]

It was explained that the larger part of the drop is due to the scattering of maximum light by the lower part of the drop. Similar effects were observed at a decreased scale when the upper part of the drop scattered some more light. A variety of advantages of the optical sensing mechanism over the capacitive sensing mechanism have been discussed. One of the major disadvantages of the capacitive sensors are that they are prone to electrical interferences from the power supply to the other equipment in the hospital. The optical system is uneffected by electrical interferences. The infusion rate was determined by the dividing the drip rate by the drop factor 2.1. The drip rate was displayed in an LCD panel. With the push of a button the drip rate was displayed in either drops per minute or volume infused per minute.

$$VolumeInfusedRate(mL/min) = \frac{DripRate(drops/min)}{DropFactor(drops/mL)} \quad (2.1)$$

An infrared LED and a photodiode pair was used by Kamble et al. (2001) to sense the falling of a drop inside the drip chamber [8]. The photodiode output was provided to a comparator circuit. Thus, falling of a drop caused a high signal to be sent out by the comparator circuit. Thus, a pulse gets gnerated when a drop fell in between the LED and the photodiode pair. This was used by the microcontroller to detect a drop. The microcontroller counted the time between two simultaneous drops using a counter. This time period value was used by the microcontroller to calculate the drip rate. A seven segment display was used for displaying the current drip rate. One of the problems with the optical drop detection technique was the interference caused due to the external light.

Vasuki et al. (2011) developed a device that consisted of an LED, receiver, and an amplifier circuit [6]. Amplifier was used to amplify the signal from photo receiver. This signal was given to a digital counter, which counted the number of drops that fell inside the drip chamber. Using a seven segment display the total number of drops were diplayed.

If by any chance the drip chamber was not perfectly vertical, there was a probability that the droplet will not intersect the light beam and so won't be detected. This was solved in the patent 5439442 August 8, 1995 [14]. Here the sensor was inserted in a gripper that held the drip chamber. The gripper had multiple reflex reflectors that reflected the light beam multiple times before it reached the sensor. This increased the probability of the droplet to intersect the light beam.

2.2 Currently Used Wireless Protocols

Lee et al. (2007) and Sidhu et al. (2007) performed a comparative analysis of different wireless network protocols that are currently used [15, 16]. The comparative study of different wireless protocols has been given in the following table.

Zigbee protocol is one such protocol that can be used for the wireless communication if the device. It is a protocol that makes use of small digital radios which consume significantly

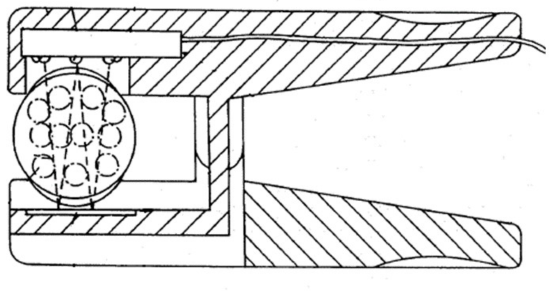

Figure 2.2: Clamp showing reflectors being used to increase the coverage area of the beam [14]

Table 2.1: Comparison of different Wireless Protocols [15]

Standard	Bluetooth	UWB	Zigbee	Wi-Fi
IEEE Standard	802.15.1	802.15.3a*	802.15.4	802.1 1a/b/g
Frequency Band	2.4 GHz	3.1-10.6 GHz	868/915 MHz; 2.4 GHz	2.4 GHz; 5 GHz
Max signal rate	1 Mb/s	1 10 Mb/s	250 Kb/s	54 Mb/s
Nominal range	10m	10 m	10 - 100 m	100 m
Coexistence mechanism	Adaptive freq. hopping	Adaptive freq. hopping	Dynamic freq. selection	Dynamic freq. selection
Basic cell	Pico-net	Pico-net	Star	Basic Service Set
Extension of the basic cell	Scatter-net	Peer-to-peer	Cluster tree, Mesh	Extended Service Set
Max number of cell nodes	8	8	>65000	2007

low power. Compared to other WPAN, it is simple and cheap. The main selling point of the Zigbee is its low power consumption and maximum number of cell nodes that can be attached to a single communication unit which is overwhelmingly huge compared to other protocols. A property necessary for the efficient functioning of the sensor network is the ability to create large device arrays. Since Zigbee can create arrays with huge number of peripheral nodes [15], it is very much usefull in creating such networks. The Zigbee can be explained with the help of three architecture layers [16]. Network an application support layer has been developed and designed such that the network can grow without much increase in the power consumption level of the network. it helps in the matching and discovery of other networks sharing the same PAN ID. The physical layer is the actual IEEE 802.15.4 protocol. It is responsible for a high level integration which enables simple and cheap implementation along with analog circuits. The media access control layer enables the implementation of several topologies with large number of devices without increasing the complexity of the network system. It can be applied for the networks where there is a periodic, repetitive and low latency data flow. Thus, it is most suitable for the application where there are huge number of network nodes with a low data transfer rate and it is a necessity for the network nodes to have minimum power consumption.

There are various research works that have incorporated wireless technologies in the applications of biomedical field. Rashid et al. (2008) devised a system for the home healthcare using a wireless biomedical sensor network (WBSN) [17]. This network is a collection of low powered biosensors and wireless networks, integrated with each other via

Table 2.2: Current consumption of chipset of each protocol [15]

Standard	**Bluetooth**	**UWB**	**Zigbee**	**Wi-Fi**
Chipset	Blue core 2	XS 110	CC2430	CX53111
Vdd (Volts)	1.8	3.3	3	3.3
TX current (mA)	57	227.3	24.7	219
RX current (mA)	47	227.3	27	215

of sensors, microcontrollers, and radio network terminals. The system worked by collecting disease-specific metrics from the bio-medical sensors attached to the patient. The data from these readings were then transferred to servers for storage and analysis by the healthcare professionals. This data gets stored in the permanent medical record of the patient for the future reference of the healthcare professionals. Yuce (2010) reported the development of a wireless body area network (WBAN) system for healthcare applications [12]. The wireless systems add mobility and location based adaptability to any device, making it more efficient by giving it the ability of rapid deployment. The paper discussed incorporation of Bluetooth, Zigbee, and the Wi-Fi protocols into the wireless systems in healthcare facilities. Different wireless protocols helped to increase the efficiency and the robustness of the network. This also helps in creating a backup network in situation of failure of one wireless system. The WBAN directly sends the data and readings from body by use of wearable technology based sensors. Various scenarios were explained for the data transfer between the biomedical sensors and the central monitoring and control station. Kioumars and Tang (2011) developed a wireless system to monitor the heart rate and the temperature of the patient [18]. Pulse oxymetry was used to measure the heart rate and the TMP36 temperature sensor was used to measure the body temperature. Zigbee protocol was used to transfer the data. The framework of basic wireless network for biomedical application was explained in this paper.

Zulkifli et al. (2012) used a Garmin heart rate strap incorporated with Zigbee technology for monitoring the heart rate of a number of athletes simultaneously [19]. The strap was interfaced with an Arduino Nano and a Zigbee module to make the system wireless. The paper discussed the use of arduino programming to create a network key for separating the signals from various athletes. Each Arduino on the athletes was given a code that was sent with each message making, the signal identification easier for the main coordinator Zigbee. We came across only manuscripts which employed the wireless technology in IV drip rate monitoring systems [11]. The device proposed by them used Zigbee communication protocol in peer to peer topology for sending the desired data from the saline flow measurement device to the monitoring station. However, simultaneous monitoring of the drip rate from multiple devices at the monitoring station was not implemented.

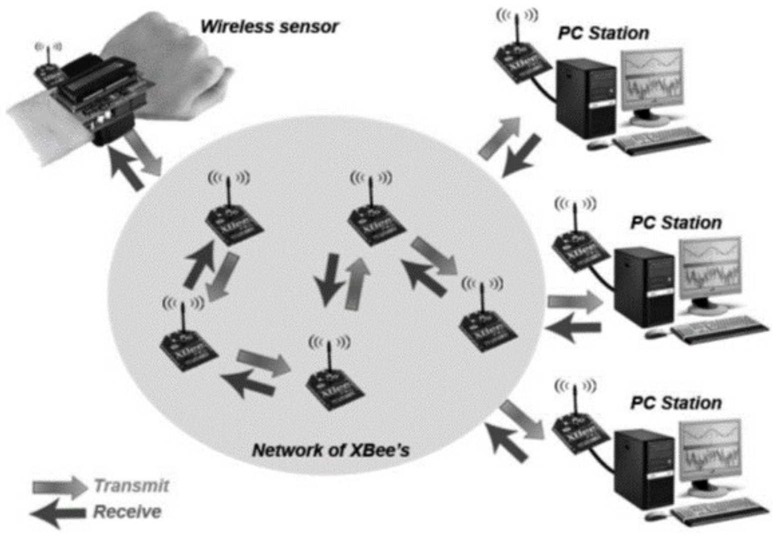

Figure 2.3: Frame work of basic wireless biomedical system using Zigbee [18]

2.3 Wireless Network Topologies

Various topologies (e.g. star, bus and mesh) are available for the networking of a system [20, 21]. There are many topologies in which the Zigbee wireless network can be used (Figure 2.4).

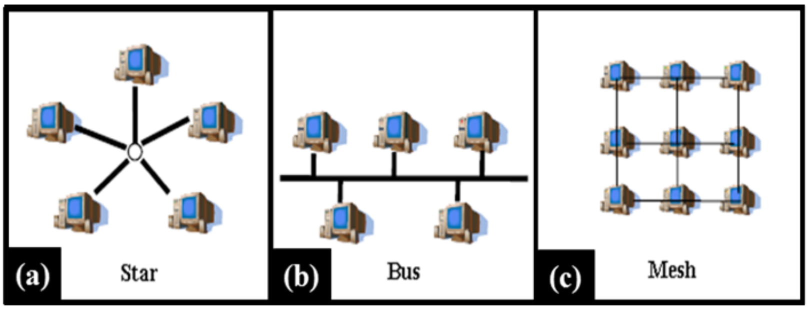

Figure 2.4: Different topologies: (a) Star Topology, (b) Bus Topology, (c) Mesh Topology [22]

Star topology is essentially a many to one, peer to peer communication. The device nodes communicate with one centralized sink node. Sink node is the node that receives data from other nodes. For our application the sink node will be connected to the computer at the central monitoring station. Star topology is thus, generally not used for applications where relocating of the device nodes is essential. This is because the nodes may go out of range of the sink node if they are in motion. In the drip rate monitoring application, the patients may be displaced from one place to another while still attached to the IV tube and the drip rate monitoring device during treatment. Star topology is not suitable. The bus topology is basically a series of receiver nodes placed and programmed such that it can receive message from any node but it can transmit only to a particular node. This node will transmit the message to the next receiver in a bus like fashion. In simple words the messages are directed to the sink node via a single predefined path. This topology also comes with an inherent problem, even a single node failure in the main bus pathway can cause the network to stop functioning.

The mesh topology is the interconnection of various transmission nodes which can send message to any nodes in their vicinity. This allows the mesh topology network to heal itself in the case of failure of a transmission node by rerouting the traffic through the other nodes in the network. Due to this nature of the topology, any node can easilyenter or leave the network without causing problem to the network. These properties make the mesh topology a better candidate for wireless networking of drip rate monitoring devices. Any device node can be detected by the main sink node if it is in range of any transmission node of the network.

Since the transmission nodes in mesh topology are connected to all the nodes in its vicinity, it is necessary to maintain the network traffic for the sake of energy saving, preventing latency, and delivering the message in the fastest and the most efficient method. Flooding protocol is a method by which the data gets delivered without the need of any hopping maintenance as all the nodes are in broadcast mode. Thus, the nodes transfer the data to all of the neighbouring nodes, and the message gets retransmitted till it eventually reaches the sink node or the maximum number of hops have been reached by the message. This causes problems like error due to excess copies of data received by the sink. A gradient routing technique with virtual geographical coordinate has been proposed by T. Watteyne (2011) for optimum performance [23].

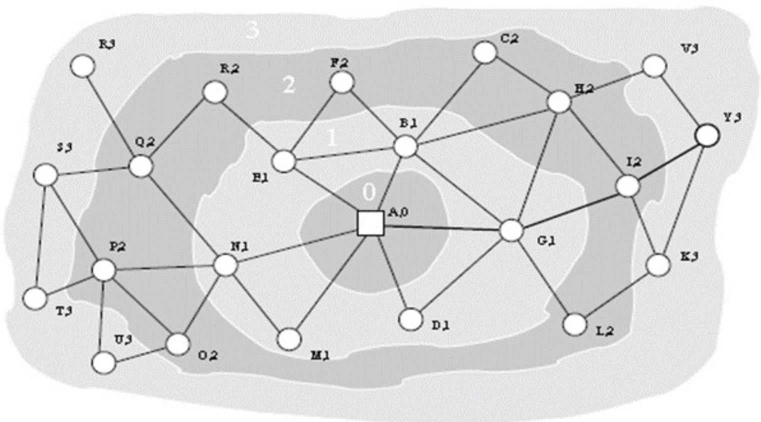

Figure 2.5: Mesh network with virtual coordinates applying gradient routing [23]

The re-transmission by the transmission node requires decision making algorithm and the ability to distinguish messages from different devices and nodes. The nodes detect the message and based on the contents of the message, they make decision to if forward the message or stop it. Thus, standardization of the message is necessary for proper transmission of the information [22].

2.4 Drip Rate Control

The IV Infusion Rate Monitoring and Control device has been conceived since a long while. But as the technology improves, the methods used to make this device change and make this device much more portable, compact user friendly and reliable. This can be observed by the change in the techniques used in this device from 1980s to the 2000s [13, 14, 24, 25]. The core of the device remains same, i.e. to determine the drip rate of the IV infusion therapy as accurately as possible.

One of the first patents that described such a device, a drop rate controller. Peristaltic action based pumps were already present during this time. Use of peristaltic motion on the IV tube caused the IV fluid to flow into the veins. Though this technique is simple, it is mostly criticized for its effects on the human body. Gravity feed drip rate is advised to decrease such effects due to their safety and reliability. The above mentioned patent describes a device that detects the number of drops by use of an optical sensor. It then generated a frequency of drips by use of counters and mathematical circuits [24]. A desired drip rate is given by use of a thumb wheel switch. This generated the desired frequency. These frequencies are then compared in a subtraction circuit, and the output is used to control a solenoid plunger. This plunger squeezes the IV tube to restrict the flow of the fluid. If the drip rate was less than the desired drip rate, the plunger released the IV tube and thus more fluid could flow through the tube. Unlike the devices of today, a microcontroller was not used for this device.

The next patent 4493710, the electronic circuitry was replaced by the use of a CMOS microcontroller to perform all the calculations. Though a novel form of controlling structure was also developed and explained. The IV tube is made of plasticized vinyl. Earlier the use of solenoid plunger caused the IV tube to be kinked at the site at which the plunger was used. This caused cold flow and eventually caused restriction in fluid flow, even though the pressure from the tube was removed [13]. The novel constriction mechanism applied tension on the tube instead of pressure on a particular location. The increased tension on the tube caused it narrow down. This in turn reduces the flow of the fluid. If more fluid is needed to be passed, the tension was simply decreased.

Using a motor attached to a decentralized wheel, pressure can be applied on the plates that can compress the IV tube and control the flow rate. The flow will depend on the design of the constrictor and the applied force.

2.5 Objectives

The prime aim of the present study is to develop a low cost prototype for the monitoring and controlling of the IV drip rate.

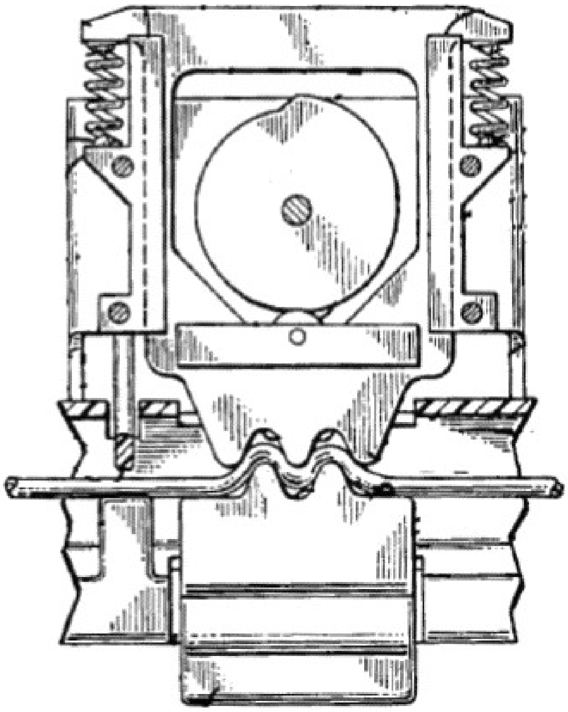

Figure 2.6: Constriction mechanism for controlling the fluid flow [13]

- Development of a LED based drip rate monitoring system.
- Development of a wireless system for wirelessly notifying the central monitoring station.
- Development of a wireless network for the transmission of the wireless messages to the central monitoring station.
- Design and development of a GUI for alerting the central monitoring station in case of any discrepancies in the drip rate.
- Development of a control mechanism for the control of the drip rate.

Chapter 3

Development of Intravenous Drip Rate Monitoring and Control Device

3.1 Components

Arduino Uno and Arduino 1.0.5 IDE (Arduino, Italy)

Arduino is an open source electronics platform for making easy to use hardware and software. Being inexpensive and open source, it is the choice for many projects based on microcontroller. It is used for many educational programs, mostly by designers and technitians, because it is easy to create a prototype using Arduino without any prior understanding of electronics. The Arduino Uno is a microcontroller development board made using ATmega328P microcontroller. It was released with the Arduino Integrated Development Environment (IDE), is the first microcontroller development board in the series of USB enabled microcontrollers.

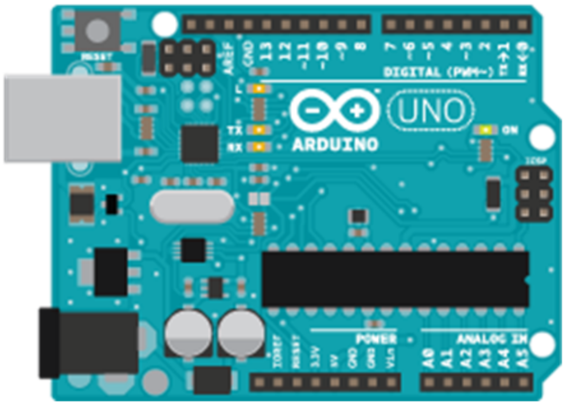

Figure 3.1: Pictograph of Arduino Uno [26]

The board contains a USB to Serial converter for USB based programming. The Arduino microcontrollers are preloaded with boot loaders that enable easy upload of programs on the flash memory present on the chip. Containing 14 digital pins, out of which 6 can be used as pulse width modulated (PWM) output, and 6 analog pins, an analog to digital convertor, 16

Mhz quartz based crystal oscillator is very versatile in handling the needs of many control system projects.

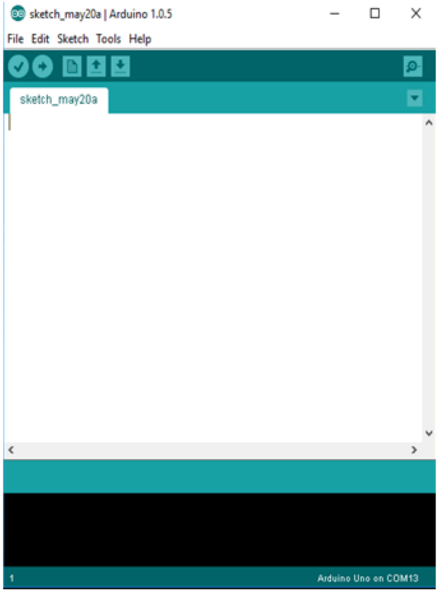

Figure 3.2: Arduino IDE Environment

The Software Programs are called Sketches. These are created using the Arduino IDE. The IDE copiles the sketch written in it and uploads it in the Arduino using Serial Communication via USB Communication Port. This Sketch governs the behaviour of the Arduino.

16x2 Liquid Crystal Display (LCD)

LCD are important for displaying the status of device. It can also be used to display various instructions for the device. It consists of 16 pins Which can be configured to display appropriate message on the LCD. The characters are pre-loaded in the LCD in the form of ASCII values. The microcontroller sends the objects to be ”printed” on the LCD by sending the ASCII code of the corresponding characters. The Arduino is pre-loaded with a Library Function that can be used for controlling the LCD using simple commands (witout doing the conversion from any data type to character type then the ASCII equivalent). The LCD pin configuration and their connection to the Arduino have been show in table 3.1

Figure 3.3: 16x2 LCD [27]

Table 3.1: Pin Configuration of 16 x 2 LCD & Arduino Interface [28]

LCD Pin Number	Functions	Arduino Pin
1	GND	GND
2	+5V or Vdd	5V
3	Vo for Contrast	—
4	RS	12
5	R/W	GND
6	E	11
7	D0	—
8	D1	—
9	D2	—
10	D3	—
11	D4	5
12	D5	4
13	D6	3
14	D7	2
15	LED Anode	—
16	LED Cathode	—

5mm Round White LED

These LEDs have a very high luminous power. The blue light from the InGaN chip is converted to near flawless white by filling the reflectors with yellow phosphor. When provided with a constant flow of current, will provide same intensity of current without any disturbance in the output intensity of the LED. While handling the LED care must be taken to avoid overflow of current. Figure 3.4 (b) gives the response of LED output intensity with respect to current passing through it.

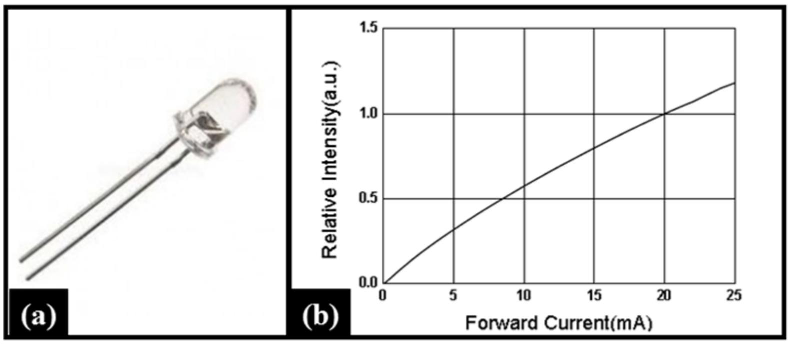

Figure 3.4: a) White LED, (b) Intensity Response of the LED with respect to current passing through it [29]

Light Dependant Resistor (10KΩ)

The Light dependant resistor is a simple component whose resistance decrease with the increase in the intensity of light falling on it. Applications include smoke detection, automatic lighting control, batch counting and burglar alarm systems. The batch counting application of the LDR is used for the counting of the number of drops. The LDR simply cannot be used for detection purpose. It has to be attached to another resistor forming a Voltage Divider Circuit to read the change in resistance by measuring the voltage across it.

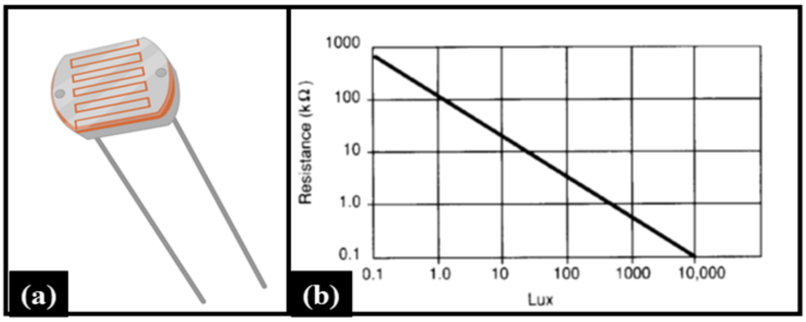

Figure 3.5: (a) LDR, (b) Characteristic response of the LDR with respect to Light intensity [30]

LabVIEW 13.0

Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is a visual programming language developed by national instruments (USA). The execution of the program depends on the visual structure in which the functional locks have been arranged. Thus unlike the code based languages, execution in LabVIEW program occurs in parallel. It has an extensive support to integrate devices like DAQ, camera and other devices via USB serial communication.

Multisim 13.0 (National Instruments, USA)

NI Multisim is an electronic circuit schematic and simulation software. Along with NI Ultiboard, it can be used for the development of schematic for developing PCB of any circuit. The Multisim uses standard circuit diagram to create the circuit. This circuit schematic is transferred to Ultiboard for creating a printed circuit board (PCB) layout. The layout is designed by placing the virtual lookalike of the components and interconnecting them using connecting wires. The circuit can then be manufactured on a PCB using surface etching method.

USB 6008 (National Instruments, USA)

USB 6008 is a multifunctional, low cost USB based data acquisition system. Used along with LabVIEW it can measure analog and digital values as well as generate analog signals.

Figure 3.6: NI USB 6008 [31]

Xbee Series-1 and X-CTU (Digi International, USA)

Xbee Series-1 is a radio module based on Zigbee communication protocol (IEEE 802.15.4). Xbee modes AT mode and API mode. The Series-1 always works in AT mode (also known as the transparent mode). In this mode, communication is done through the Xbee without any communication with the Xbee. Basically the device will directly send the data through the Xbee. This is done by directly sending the data to the Xbee shield using serial communication.

Figure 3.7: . Xbee Series-1 Radio Module [32]

X-CTU is a serial programing freeware developed by Digi. It is a GUI developed specifically for setting configuration of the Xbee radio module.

Xbee Adaptor Board with USB interface.

The header pins connected to the Xbee communication module has smaller gaps and can neither be attached to a bread board or connected via jumper wires. The USB interfaced adaptor will be necessary for communication with the arduino and the personal computer.

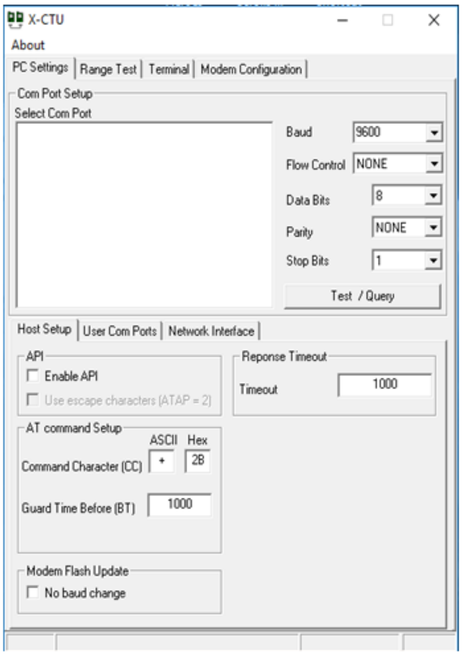

Figure 3.8: X-CTU Environment for Xbee Configuration

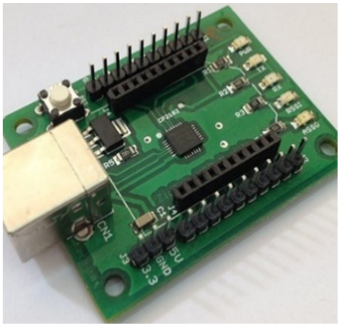

Figure 3.9: Xbee adaptor chip with USB [33]

MATLAB

Graphical User Interface (GUI) provide point and select option in various software. These are developed for the users who do not know the use of programming language and thus can directly select the required options to get the desired outcomes. The MATLAB's GUI Development Environment is an excellent tool for the development of custom user interface for the required application.

The GUIDE layout editor can be used to place the various components of the GUI. The MATLAB code is then used to govern the behaviour of each component.

Tower pro MG996r

The tower pro MG996r is a stepper motor that can provide torque up to 9.4 Kgfcm when supplied with the power source of 4.8 V. This can be increased to 11 Kgfcm with use of a 6V power source. Stepper motors are very accurate when it comes to providing the required

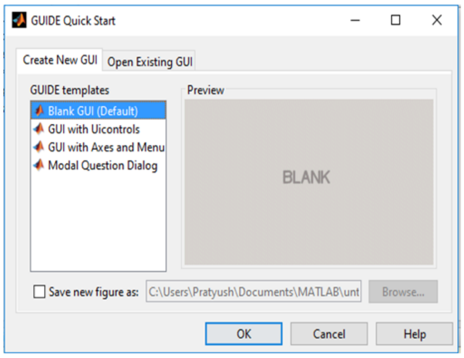

Figure 3.10: MATLAB GUI development Environment (GUIDE)

angle of rotation. The PWM input of the motor when connected to the PWM output of the Arduino, the motor shaft can be rotated to any angle between 0 to 180 degrees.

Figure 3.11: Tower pro MG996r [34]

Solid Works

Solid works is a CAD software by Dassault. It is mostly used for designing and modelling of various components before being manufactured. It is a great simulation tool as well. The software was used to design the part files use for the 3D printing of the constrictor JAWS.

Acrylic Sheets

Acrylic Sheets are made of polymers of Acrylonitrile. It is an organic compound that can be cut using simple cutting tools. These can be attached to each other by fusing their edges using Chloroform. Chloroform dissolves the sheets to a semi-solid consistency that can be used to fuse two sheets together.

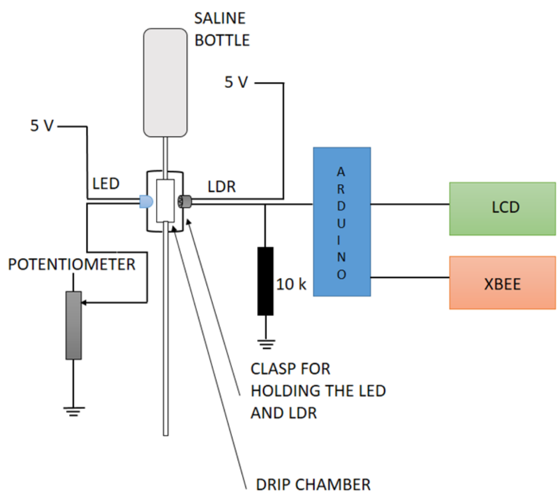

Figure 3.12: Diagrammatic representation of the Entire Monitoring system

3.2 Methodology

Design of sensor clasp

The clasp isolated the drip chamber from ambient light. In absence of a fluid drop, the constant ligt from the LED, gave a constant resistance across the LDR. Falling of a drop in the drip chamber caused a shadow to be formed on the LDR. The decrease in the intensity on the intensity of light on the LDR due to the shadow of the drop resulted in the increase in the resistance of the LDR. The LDR was connected in series with a 10 kΩ resistor to form a voltage divider circuit to which a 5V DC power supply was given to the LDR to drive the circuit. The junction between the LDR and the 10 kΩ. resistor was taken as the output. The voltage at this junction followed the voltage division rule (3.1), where R_{LDR} is the resistance of the LDR in kΩ.

$$V_{out} = 5V \times \frac{10}{10 + R_{LDR}} \tag{3.1}$$

In order to get the exact waveform of the response of the LDR circuit during the event of falling of a drop, the LDR circuit was analyzed using data acquisition program made in LabVIEW (13.0, National Instruments, USA).

The waveform obtained was used for the making of the algorithm for drop detection and eventual calculation of drip rate.

Programming

The use of Arduino Uno enabled simplicity. Since, it has an analog to digital converter, directly giving the input from the voltage devider circuit will enable it to read the analog value. The ADC is a 10 bit ADC, thus the voltage values get mapped according to the

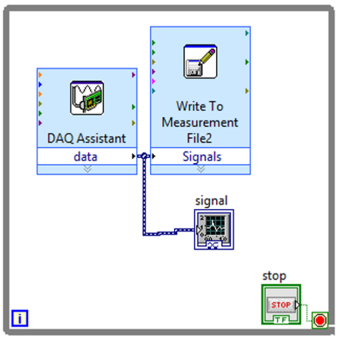

Figure 3.13: LabVIEW program for Sensor Analysis

following formula (3.2).

$$Value = \frac{Voltage}{5} \times 1023 \tag{3.2}$$

An algorithm was developed for programing the Arduino for drip rate monitoring and decision making.

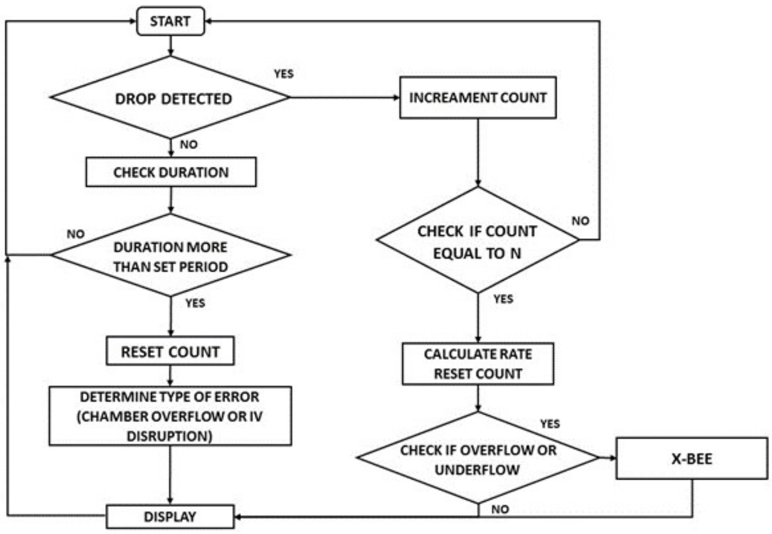

Figure 3.14: Algorithm for drip rate measurement

The Arduino acknoledged the presence of drop only when the voltage level crossed and went below a set threshold value. This event incremented the counter, which gave the total number of drops. When the drop counter counted N drops, the time required for N drops to fall gets measured and using equation 3.3 the Drip rate gets calculated. Multiplication of the value of 60,000 in the Equation was done to convert the unit of time from msec to min. After N drops were counted, the counter was reset to acquire a fresh drip rate.

$$Rate(Drops/Minute) = \frac{N}{Time\ Taken\ For\ N\ Drops} \times 60000 \tag{3.3}$$

The microcontroller monitored if the drip went beyond the range of the desired drip rate. Alarm signal is sent when the drip rate goes beyond the desired range of the drip rate. The alrm signal is basically a message that gets sent by the device that will notify the healthcareprofessionals about the change in the drip conditions of the patient. Thus, they can rush to the patients site as soon as possible.

If the voltage stayed above the hreshold value for the set time, a ”DROP DISRUPTION” gets displayed. If the Voltage Value stayed below the threshold value, ”FREE FLOW”. When the drip rate is in the desired range, normal drip rate along with the total volume infused gets displayed in the LCD.

In case of any problems the Zigbee was used to send a message to the central monitoring station informing about the problem. A GUI in the monitor of the central monitoring station helped in proper sorting and display of devices facing the problem.

Since a network was to be developed, it was necessary to standardise the message tht gets sent in case of emergency situations. This message will help it in the navigation of the mesh network till it can eventually reach the sink node.

After multiple trial and error, the message was standardised to have 7 bytes of information. VC1 and VC2 are the two virtual coordinated of the sender node. If sent from the device node, their value will be 99 suggesting the other nodes that the message is from the device. when re-transmitted, the value of these two variable will change and the sender will replace the previous values with its own virtual coordinate. PN1 and PN2 are the patient number and remain constant. This will be used to identify the patient whose device is facing problems. PR1 and PR2 are the code for the problem faced by the device. The legend for the problem code has been shown in table 3.2.

Table 3.2: Message code for various problems

PR1	**PR2**	**Problem**
0	1	DROP DISRUPTION
0	2	FREE FLOW
0	3	OVERFLOW RATE
0	4	UNDERFLOW RATE
0	0	SITUATION NORMAL

The PRI variable holds the priority status. This is ususlly 0 but if the sender doesn’t receive any acknoledgement that the message was received by the node of higher hierarchy, it will resend the message to all nodes with pririty status being one in broadcast mode. This way the message will be rerouted by other nodes.

Networking

Xbee is a wireless microcontroller which can automatically connect with the Zigbee network if the PAN ID of the Xbee matches that of the network. All the Arduinos were connected to Xbee Series-1 Communication modules via Serial Communication. The standardized message was used along with the the decision making logic loaded on the Arduino to transmit the message to the nodes having a hierarchy higher than the sender. Acknowlegement message is sent by the rceiver when it receives the message. If the sender node doesn't receive the acknowledgement message, the sender node will send a priority message in broadcast mode. This message gets delivered to all the nodes in the vicinity.

The Arduino at the sink extracted the data from the essage and sends it to the PC via serial communication. MATLAB was used for developing a GUI to extract and decode and finally display the information in the monitor.

GUI development

The Sink node's Arduino wasn't directly controlled by MATLAB. This shouldn't be done as the MATLAB cannot operate the Xbee communication module. The Arduino had its own program which received the messages from the Xbee network and simultaneously processed the message and sent it to the PC via serial comunication of USB. These processed messages were vasically codes stripped of their address and the priority status. Thus they contained only the patient number and the error code. This was decoded by the MATLAB and the GUI displayed the patient number and the status of the device. The GUI was developed using the guide tool of MATLAB. The GUIDE layout operator was used to arrange all the components of the GUI (buttons, status bars). This was saved as a MATLAB fig file. The behaviour of these components was set using MATLAB programming. The GUI was programmed such that, it displayed the patient number along with the problem that the device is facing. When the problem is solved the GUI will show status OK in the text box.

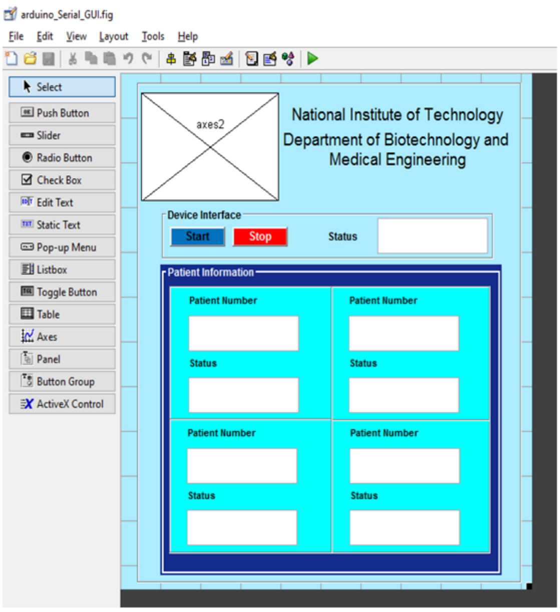

Figure 3.15: Arrangement of various components of GUI using the GUIDE layout editor.

Development of Control Mechanism

In order to develop a drip rate control mechanism, a separate device was made. The previous device only had the capabilities of monitoring the drip rate and notifying the central monitoring station via Zigbee. No User Interface was added to the system, the device initialization was done wirelessly. The message for initialization was standardised (Figure 3.16).

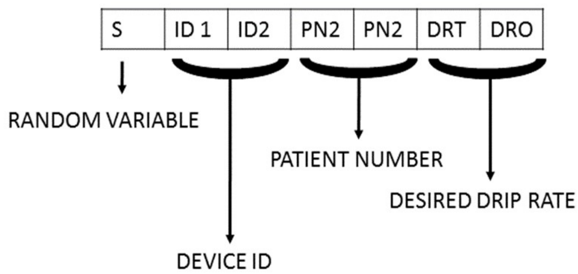

Figure 3.16: Message to be sent for wireless initialization of the device

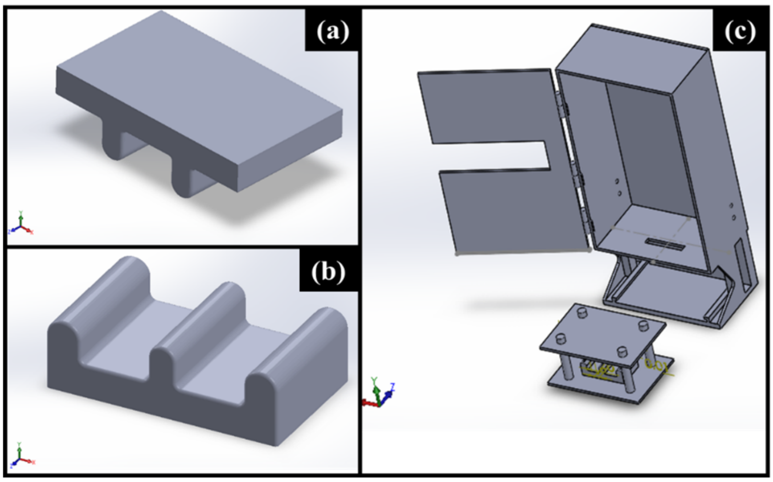

Figure 3.17: Solid works model of (a) Upper JAW, (b) Lower JAW, (c) Entire Casing

The message contained the Device ID, Patient number and the desired drip rate. The device ID was displayed on the LCD screen. This device ID was used for the authentication of the message. The device was initialized only after the ID of the device and the ID in the message matched with each other. The patient ID and the desired drip rate in the message was used for initializing the device.

The casing and constrictor JAWS were first designed in Solid Works. The JAWS after being designed with appropriate dimensions were saved as stl file. These stl files were used to 3D print the JAWS. The Rapid prototyping machine used Acrylonitrile butadiene styrene (ABS) for 3D printing the constrictor JAWS. The rest of the casing was developed using Acrylic sheets. These are polymers of Acrylonitrile, that can be attached with each

Figure 3.18: Pictograph of the casing and the constrictor mechanism.

other by application of Chloroform. The chloroform temporarily breaks the polymer bonds. Attaching the acrylic sheets with each other during this period will fuse them with each other. The motor was fixed at the bottom of the casing. A decentralized wheel was attached to the motor shaft (Figure3.18). Increasing the angle of the motor will put pressure on the plates on which the JAWS are attached.

A pillar like structures were added to the plates holding the JAWS. These served for guiding the path of the JAWS, and held springs that pushed the Upper JAW back to its original position when there was no force applied.

Two Arduinos were used for the control of the drip rate. The master arduino calculated the drip rate and found the difference between the drip rate and the set drip rate. Based on the difference between the measured drip rate and the set drip rate, the master arduino instructed the controller arduino via serial communication. The controller arduino rotated the motor to give appropriate pressure on the tube. Increasing the angle of the motor shaft, applied pressure on the IV tube. The algorithm has been shown in fig. 3.19.

The Arduino draws a lot of current when constant torque gets applied by the motor. For this reason, an external power supply was given to the Arduino, using a 5V DC power jack. This enabled non stop supply of current for maintaining the motor torque. The Master microcontroller sends characters to the controller. This character when detected, was used for setting the angle of the motor. The Master microcontroller sends '+' for increasing motor angle and '-' for decreasing the motor angle.

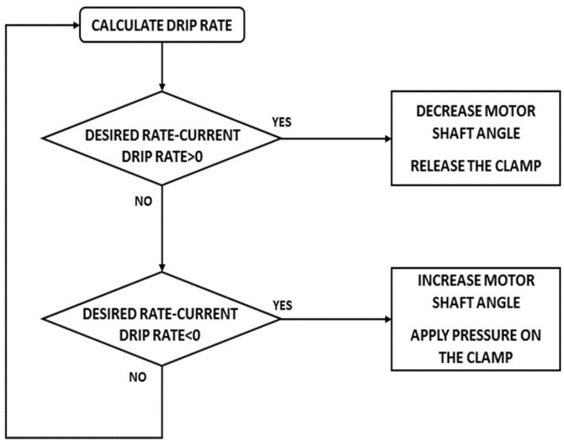

Figure 3.19: Control mechanism algorithm

Chapter 4

Results and Discussion

To check the waveform response of the clasp in correspondence to the falling of drop and various other conditions the clasp was mounted on the drip chamber. The clasp completely isolated the drip chamber from the ambient light and thus it could not effect the LDR response.

Figure 4.1: Sensor Clasp

The waveform representation across the LDR, was obtained using the NI USB 6009 data acquisition system and an in-lab developed LabVIEW program. Fig. 4.2 shows the voltage response observed across the resistor, when there was a drop present in the drip chamber.

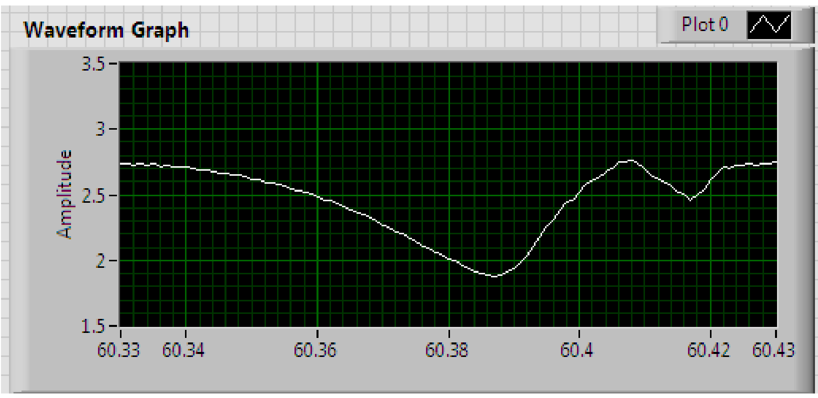

Figure 4.2: Waveform response for a single drop

In Figure 4.2 the first trough was obtained when the shadow of the bottom of the IV fluid drop fell on the LDR. The decrease in the intensity decreased the voltage across the resistor because of the voltage divider circuit used for the detemination of the voltage. The shadow of the uper edge of the drop created the second trough. The crest is obtained due to the center of the circular drop acting as a convex lens. Yang & Kim (1998) reported a similar observation [7]. The hight of the crest depended on the shape of the fluid drop.

As the sensor was not affected by the ambient light, the offset removal circuit should not be used. Removal of the offset will make the waveform response to decrese to zero when there is no drop. This will also be the same for the case of free flow. The microcontroller wont be able to detect the free flow and drop disruption conditions.

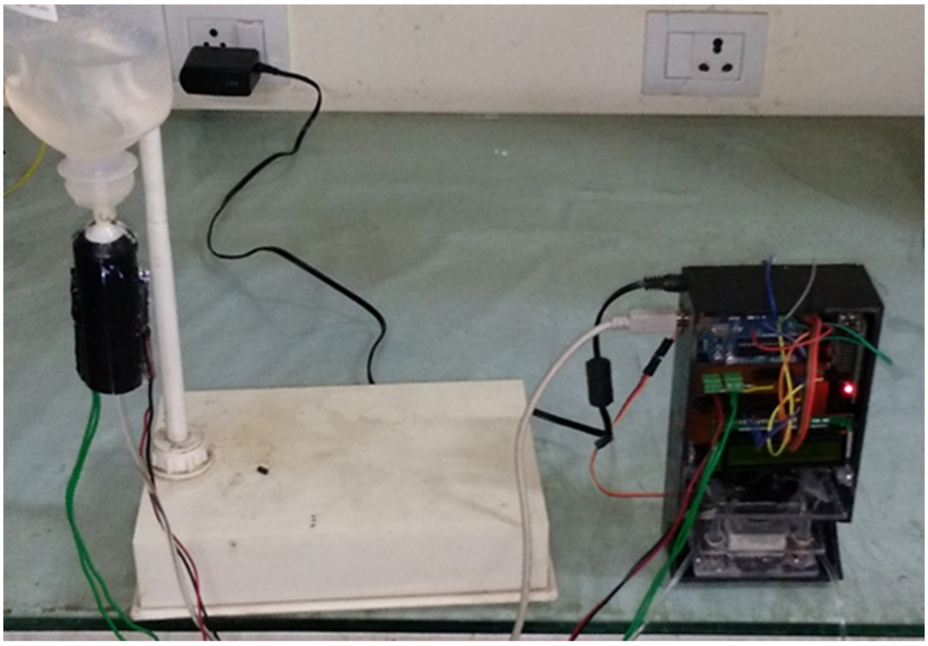

Figure 4.3: Pictograph showing the Entire Setup

Using this response, a threshold value was set in the Arduino. The the microcontroller increamented the drop counter only if the voltage value crossed the threshold value while decreasing. The Arduino always measured the time taken for N drops to fall and using Equation 3.3, the drip rate was calculated. The drop factor of the IV tube was calculated by measuring the volume of fluid infused for twenty drops. It was observed that the average volume of twenty drops was $1.093 \pm 0.08ml$. The calculated drop factor was 18.383 ± 1.293. The IV infusion tube came with a label suggesting its drop factor was 20 ± 0.1 drops/ml. But we observed that this wasn't mostly accurate. Using equation 2.1, the total volume infused was calculated, and displayed on the LCD.

Instantaneous drip rate was displayed on the LCD. Viewing this value, the operator can change the position of the roller clamp and change the infusion flow rate. If there were no drops for more than 10 seconds, ”DROP DISRUPTION” gets displayed in the LCD. If free flow occured, ”FREE FLOW” was after 1 second of this condition. In case the drip rate went beyond the desired Drip rate, ”OVERFLOW” or ”UNDERFLOW” gets displayed.

Figure 4.4 (a, b, c, d, and e) display the zoomed view of the LCD during different conditions.

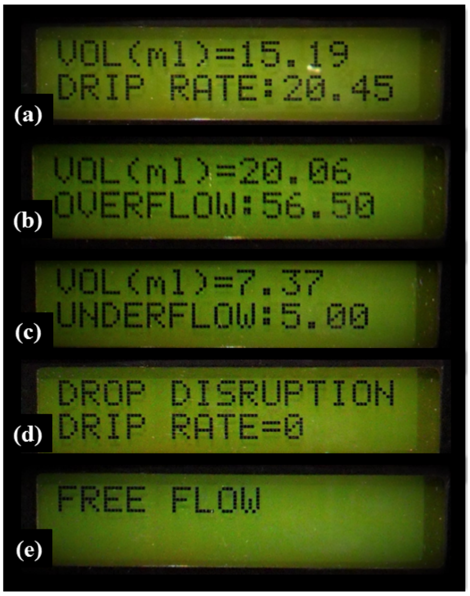

Figure 4.4: (a) Normal drip rate along with total volume infused, (b) Overflow drip rate, (c) Underflow drip rate, (d) Drop disruption, (e) Free flow condition

The wireless message was transfered using Xbee. The sink node received the message from the network. The Arduino extracts the message and sends this message to the PC via serial communication. This is used by the GUI to display the status of the patients.

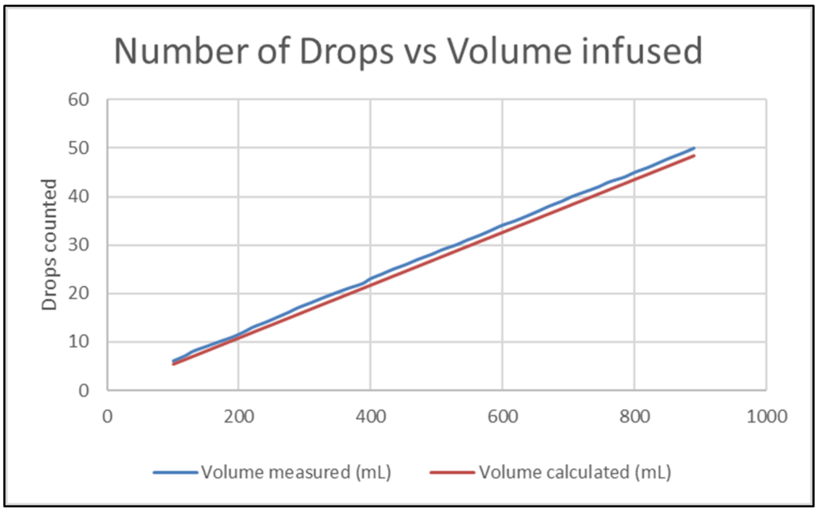

Figure 4.5: Number of Drops Vs Volume Infused

Figure 4.5 shows the graph with plot of the calculated volume infusd and the actual measured volume. The device calculated the total infused volume with an error of 5.6 %.

Figure 4.6 shows the GUI developed for receiving and displaying message from the network.

The GUI at the beginning will ask the operator to start the GUI enabling the serial communication between the Arduino Sink and the PC COM port. When a message reaches the sink node, the information is extracted and sent to the MATLAB GUI. Here the patient information gets displayed and the colour of the status bar becomes red. When the problem is fixed, the device will send an all clear message and the status will display OK in the background of green colour.

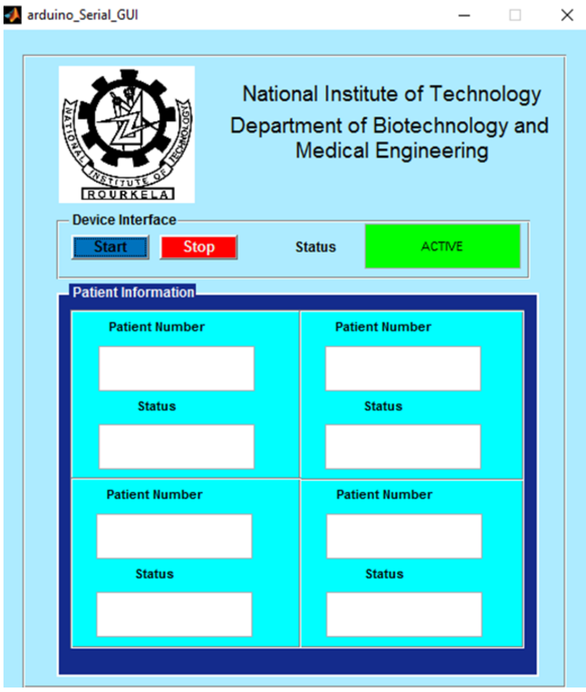

Figure 4.6: GUI made for showing problem statement

Since there were no User Interface added to the device as there were no buttons attached, the initialization of the device was done purely by means of wireless communication. When the device was initialised, the LCD showed the Device ID and instructed to configure the patient ID and the drip rate. To this instruction were purely sent via X-CTU terminal connected to a Xbee Series-1 sharing the same PAN ID as the device Xbee.

The message to be sent contained the device ID, the patient ID and the set drip rate. The reason, devcie ID was sent in the message was to prevent this message from interfering with other device if they are getting initialised.

After the device was initialised, it started counting the drops and calculating the drip rate. As per the algorithm if the difference between the desired drip rate and the present drip rate was positive, the pressure on the clamp containing the JAW was decreased by decreasing the angle of the shaft. Otherwise if the difference was negative, pressure was increased with increasing the angle of the motor shaft. At first when the motor was connected to the master Arduino itself, the sudden surge in current due to the requirements of the motor caused fluctuations in the intensity of the LED thus creating erroneous drop counting and giving wrong drip rate. For this reason, second arduino was used for the control of the drip rate. Though the motor responded appropriately by changing the shaft angle with respect to the drip rate, the device couldn't control the drip rate. The motor even after reaching its maximum position while compressing the IV tube, wasn't able to fully constrict the flow of the fluid. At full constriction the device still read a drip rate of 60 drops per minute. It was clear that the JAWS weren't efficient for constricting the IV tube. It was also observed that the motor required a lot of current for maintaining the desired angle when reverse pressure from the IV tube was also present. A better Constriction mechanism needs to be developed which can efficiently control the flow of the IV fluid.

Chapter 5

Conclusion

LED and LDR were used for making cheap alternatives of some very costly instruments. The operator has to take care of the alignment of the device while setting up the drip rate monitoring device. Improvement in the clasp can be done for covering more areas with light beam so that alignment is not the issue [14]. The novel thing about this device is that it incorporates wireless technology for better and efficient communication with the healthcare givers. Zigbee wireless communication enabled rapid transmission of messages across to the central monitoring station thus enabling rapid deployment of forces in the medical field. Such an arrangement can help the healthcare givers to act accordingly to situations they will get more time and information to deal with a particular situation. The GUI can be further developed so that it can send commands to the device as well. Achieving this will make the system completely automated, the operator at the central monitoring staion will be able to directly control the drip rate of teh device. It is feasible for deploying this system in hospitals.

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