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Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

DESIGN AND DEVELOPMENT OF IoT INTRAVENOUS BAG MONITORING AND ALERT SYSTEM IN RWANDA

By: UWIMANA Gerardine
Reference Number: 222000954

A Dissertation Submitted to the Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE), University of Rwanda as partial fulfilment of the requirements for the Master's Degree in Biomedical Engineering.

Supervised by: Dr. Moussa HAKIZIMANA
Dr. Peace BAMURIGIRE

DECLARATION

I, **UWIMANA Gerardine**, declare that this dissertation entitled "**Design and Development of IoT Intravenous Bag Monitoring and Alert system in Rwanda**" is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

Student Name:

UWIMANA Gerardine

Student Reference Number: **222000954**

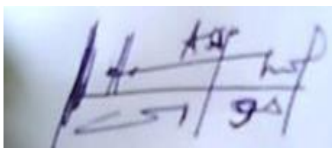
Student Signature: ____________________________

Date: ______________________________

CERTIFICATE

This is to certify that the project entitled "**Design and Development of IoT Intravenous Bag Monitoring and Alert system in Rwanda**" is a record of original work done by UWIMANA Gerardine (Reference number: 222000954), a MSc. Degree student in Biomedical Engineering.
This work has been submitted under the guidance of Dr. Moussa HAKIZIMANA and Dr. Peace BAMURIGIRE.

Main Supervisor: **Co-Supervisor:**



Dr. Moussa HAKIZIMANA **Dr. Peace BAMURIGIRE**

Biomedical Engineering Master's Program Coordinator

Dr. Gerard Rushingabigwi

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ABSTRACT

Under our current medical care system, monitoring patients on a daily basis at a hospital is a difficult chore especially in developing countries because of the lack of needed medical equipment which can help healthcare providers to monitor patients.

The development and assessment of a system that employs Internet of Things (IoT) technology to monitor intravenous bags and notify medical personnel as soon as an issue arises are the main objectives of this study

Traditional manual IV bag monitoring is prone to human error and slow to recognize life-or death situations. These problems are addressed by the IoT IV bag monitoring and alarm system, which makes use of IoT gadgets with sensors to gather data in real-time on important variables including fluid level. Then, for processing and analysis, this data is wirelessly transferred to a thingspeak. The system architecture includes ThingSpeak, IoT devices, wireless communication protocols, and computation. Appropriate sensor technologies and wireless communication protocols are found through a thorough analysis of analysis of the literature and included into the system design.

Thingspeak receives data securely from the Intravenous bag sensors, where it is processed and analyzed in real-time. In order to enable the system to generate alerts and notifications, sophisticated algorithms are used to detect abnormal circumstances or Fluid level of IV bags. Thingspeak allows medical personnel to view historical data, track the status of IV bags, simultaneously displayed on LCD display.

Through studies and comparisons with manual monitoring techniques, the system's performance, accuracy, and dependability are assessed. Patient safety, proactive intervention, and increased workflow effectiveness in healthcare environments are all significantly enhanced by the IoT IV bag monitoring and alert system. It improves all aspects of patient care while minimizing hazards related to manual monitoring and speeding up reaction to life-threatening circumstances

Keywords: IoT, IV bag monitoring, real-time alerts, patient safety, healthcare technology

LIST OF ACRONYMS

IV: Intravenous
LCD: Liquid Crystal Display
LED: Light Emitting Diode
IR: infrared

FIGURES

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CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

The number of patients requiring hospitalization increased considerably as the COVID-19 and some other pandemic like Cholera spread across the world. This increased medical staff workloads dramatically, leading to increased distress [1]. Most inpatients are treated with intravenous (IV) infusion. Infusion conditions should be checked once or twice per hour to ensure that they are stable [2], this is because abnormal IV infusion can cause severe complications. In hospitals, small errors can lead to severe patient outcomes. A report published by the National Confidential Enquiry into perioperative Deaths highlighted the significance of IV fluid monitoring, noting the deaths of numerous hospitalized patients due to excessive or inadequate infusion of fluid [3]. Therefore, it is crucial to monitor every patient's IV infusion rate and residual fluid to help both patients and medical staff.

The IoT IV bag monitoring and alert system is a technological solution to enhance the safety and efficiency of intravenous (IV) fluid administration in healthcare settings. It leverages the Internet of Things (IoT) technology to continuously monitor and track the status of IV bags, providing real time data and timely alerts to healthcare professionals.

The IoT based IV bag monitoring system will help in rehydration therapy to replace lost fluids and electrolytes using intravenous fluid depending on the severity of dehydration during pandemic disease like cholera [4].

The benefits of implementing an IoT IV bag monitoring and alert system are manifold. It helps prevent medication errors by providing accurate and up to date information about IV bag status. Healthcare professionals can proactively address any issues or risks, such as preventing the IV bag from running dry or adjusting the flow rate if necessary. This enhances patient safety and reduces the chances of adverse events and also prevent the spread of infection or disease to the hospital caregivers [5]

1.2 Problem statement

Manually monitoring IV bags is a complex and time-consuming task that is prone to human error. Clinicians must regularly check IV bags to ensure that they are functioning properly and that patients are receiving the correct amount of fluids and medications.

However, it can be difficult to keep up with the demands of manually monitoring IV bags, especially in busy healthcare settings

Manual monitoring of intravenous (IV) bags presents several challenges including human error, such as accidental disconnection or failure to notice low fluid levels, delays in problem detection due to time consuming checks, increased staff workload leading to fatigue and stress, and potential negative impacts on patient safety and satisfaction. These issues can result in dehydration risks and patient dissatisfaction. To mitigate these challenges, automated IoT based IV bag monitoring and alert solutions offer real time alerts, reduce workload, improve accuracy and enhance overall healthcare efficiency.

1.3 Research Questions (Hypotheses)

1. Which are the existing systems used to monitor intravenous bags?
2. What are the most effective and user-friendly technological solutions for real-time monitoring of intravenous (IV) bags, and how do these systems impact clinicians' ability to optimize patient care, reduce errors, and enhance workflow efficiency in a healthcare setting specifically in rural areas where there is no other device which can help them?"
3. Is there an architecture for integration of IoT with existing intravenous bag monitoring?
4. Which tools can be used for prototyping a real time intravenous bag monitoring system so that can be used in developing countries

1.4. Objectives

1.4.1 General Objective

To Design and prototype an IoT Intravenous bag monitoring and alert system will improve the safety and quality of patient care.

1.4.2 Specific Objectives

1. To develop a system that can monitor multiple IV bags simultaneously.
2. To develop a system that can provide real-time alerts to healthcare staff
3. To Test the functionality of the system by prototyping

1.5 Study Scope

This study is done with much focus on rural areas specifically in health centers, some clinics, and some district hospitals where there aren't equipment's or devices for injecting the intravenous fluid like infusion pump or syringe pump, Data are corrected from conveniently selected rural healthcare facilities.

1.6 Significance of the Study

IoT-based intravenous (IV) bag monitoring and alert systems are significant in healthcare for several reasons. They improve patient safety by providing real-time alerts to clinicians if there is a problem with an IV bag, such as a low fluid level or a blocked line. This technology also reduces the workload on clinicians, freeing them from the need to manually monitor IV bags and allowing them to focus on other important tasks, such as providing direct patient care. Additionally, the use of sensors to collect data and algorithms to analyze the data improves accuracy. Enhanced healthcare efficiency is another benefit, as these systems reduce the amount of time clinicians spend on monitoring IV bags, leading to better patient outcomes and lower costs. Furthermore, IoT-based IV bag monitoring and alert systems can address specific challenges in healthcare, such as improving the safety of IV therapy in patients at high risk of complications and improving the efficiency of IV therapy in busy healthcare settings.

1.7 Organization

The remaining part of this thesis is organized as follows. In Chapter 2, the literature review is

explored covering the previously related research done about IoT Intravenous Bag Monitoring and Alert system. In Chapter 3, the methodology used for achieving the specific objectives, explains the data collection from questionnaire about monitoring intravenous bags, the proposed system, the hardware and software used to build the system. Chapter 4, is devoted for the system analysis and design taking into account the simulation model and system flow chart. In Chapter 5, the result and the analysis of the project are presented together with discussion. In Chapter 6, the overall conclusion of the project is drawn and future recommendations that can be done to improve this project are presented.
research study.

CHAPTER 2. RELATED LITERATURE

2.1 Literature Review

In emergency, outpatient, long term, home healthcare, and acute care settings numerous drugs are continuously infused intravenously. Every person who administers intravenous medications is concerned about medication errors; these errors may have extremely detrimental effects [6]. Many hospitalized patients are given medication through an IV, which causes a state of increased disquiet and pain. Make sure the infusion is functioning normally by checking it every hour or so to be stable, although improper IV infusion administration could have serious negative effects. Small errors shouldn't be ignored in a healthcare setting. According to the newest report from the National Confidential Enquiry, perioperative deaths brought to light the need of IV fluid management. Numerous patients have needed to be hospitalized as a result of excessive or insufficient fluid infusion [7].

A retrofittable IV drip monitoring device that updates data to medical staff through WSN is described in the paper" Design, Fabrication, and Testing of an Internet Connected Intravenous Drip Monitoring Device" the article highlights this system's benefits and drawbacks, including the necessity of defining the manufacturing materials utilized, the unreliability of measurements for changes in drip chambers, and the requirement to manually set drip values every time [2].

Yang Zhang developed "A wireless sensor network (WSN) as a method of monitoring intravenous infusion.'' Slot-coupled infrared emitting diodes (IREDs) are used in the research as sensors, and Zigbee communication is used for data transmission. Although the research emphasizes the use of LED sensors for IV monitoring, it points out that sensing errors may occur when the flow rate fluctuates, which could lead to misidentification and failures in the warning system [8].

R. Shelishiyah, S. Suma, and R. M. R. Jacob, the article'' A System to Prevent Blood Backflow in Intravenous Infusions" describes a system that is an effective way to monitor and prevent blood backflow in IV tubes, particularly for use in neonatal sections. It is also safe and reasonably priced. That system cannot simultaneously inform the nursing stations [9].

Kumar et al. (2015) developed "ZigBee technology-based wireless intravenous monitoring" the design and execution of a wireless intravenous monitoring system using ZigBee technology are presented in this paper. The technology can keep track of the infusion's flow rate, look for any irregularities, and send up to three notifications to medical professionals as needed [10]

Autor [11] developed “A Remote Drip Infusion Monitoring System Employing Bluetooth” the infusion monitoring device employing a Bluetooth module that can detect the drip infusion rate and an empty infusion solution bag. The use of Bluetooth is inefficient because of the limited range of area. The healthcare provider can’t monitor the intravenous bag at long distance.

Work done in [12], presented a system that comprises a sensor that acts as a weight sensor for monitoring the critical level of the saline in the saline bottle. Whenever the level of the saline reaches the predefined critical level, then the nurses, caretakers, and doctors are alerted through the buzzer and an indicator will glow to alert the nurses, caretakers, doctors that there is a need for replacement of the saline bottle. The proposed system is built using Radio frequency (RF) transceiver platform. The work done in [13], presented research that had designed and developed a low-cost remote infusion monitoring system. The SWOT analysis is used to determine the features of the system. Some important features have been implemented, such as reporting the important information to the nurses ‘station; realization of the monitoring system in the patient room and nurses’ station using wireless technology.

The work done in [14], presented the system that uses a “LED photodiode-based system” to monitor the saline bottle using Arduino Uno which performs the logical operation and connects the system to blink or serial monitor terminal application. Blynk is an IoT platform that deals with software, and other technologies to connect and exchange data with other devices and systems over the internet. Whenever the level of the saline reaches the pre-defined critical level, then the nurses, doctors will be alerted through the message and an indicator will glow to alert the nurse station as well as clamps the saline bottle without any further delay. The major difficulties faced in this project is the clamping circuit mechanism of the saline tube and testing of different sensors.

The work done in [15], presented a design study that proposed a system made by electromechanical components. In this design spring acts as a weight sensor for monitoring the saline solution.

In [16], IR based sensor is used in which output voltage changes when IV is below some threshold, comparator then compares the output with a predefined threshold. Work done in [17], presented the system that the drip rate is being measured with the use of an optical sensor, a motor, and an actuator to clamp the tube. The firm called shiflabs has developed a device named ‘drip assist infusion rate monitor’ wherein it counts drops flowing through the IV tube and is attached to the cannula.

For the interests of low-cost systems and high efficiency to monitor intravenous bags, we developed the IoT intravenous bag monitoring and alert system in Rwanda that is composed of a weight sensor which is low cost, low power requirement, simple circuitry, their portable features, more accurate and sensitive to the environment. It detects the fluid level in the bag and the ESP 32 processes it at the same time sends data to the Thing Speak cloud. Thing speak cloud is used as a web application that stores, analyzes, and visualizes data from sensors. It helps the nurses, caretaker and doctors to find the level of the fluid remaining in the bag. Though this work exists elsewhere, it is new in Rwanda.

2.2 Gap

The main gaps in the field of monitoring intravenous (IV) bags without using IoT-based IV bag monitoring and alert systems include the lack of low-cost, reliable, and easy-to-use devices, as well as the absence of integrated solutions capable of monitoring multiple IV bags simultaneously and providing real-time alerts to healthcare staff. These deficiencies make it challenging for many healthcare settings, especially in low-resource countries, to effectively monitor IV bags.

CHAPTER 3. METHODOLOGY

This chapter concerns the methodology used to achieve the objectives of an IoT intravenous bag monitoring and alert system in Rwanda.

3.1 The data analysis from research questionnaires

The survey was conducted in a hospital or clinical environment where intravenous is commonly administered. And also, in home healthcare settings for patients who receive intravenous therapy at home. We used random sampling where we selected healthcare facilities and caretakers of patients at home to participate in this study randomly.
We worked on a sample of 30 healthcare providers including 14 nurses, 5 physicians and 11 home healthcare from different healthcare settings. We asked them the questions about monitoring intravenous bag in healthcare settings, before involving the participants in this study they are informed about the purpose of this study and there data are protected, the analysis of data collected was done using excel, according to the data coming from the survey done, I developed the system called IoT intravenous bag monitoring and alert system in Rwanda especially in healthcare settings like clinics, hospitals, home healthcare that will solve all problems seen in the tables which are in appendix facing the monitoring of intravenous bag in healthcare settings.

3.2 Proposed System diagram

The system diagram of proposed system is shown in Figure 3.1 below, the system consists of intravenous bag or saline bottle which is connected to Loadcell or weight sensor. That weight sensor will record the flow of intravenous which are in the bag, the weight sensor is also used to measure the weight of the empty IV bag at first, it keeps on dripping until the fluid runs out.

The weight sensor or Loadcell is connected to the HX711 Amplifier, that Amplifier is a load cell amplifier breakout board for the HX711 IC that allows you to easily read load cells
to measure weight. This module uses 24 high precision A/D converter chip HX711. It is specially designed for the high precision electronic scale design, with two analog input channels, the internal integration of 128 times the programmable gain amplifier. The load cell value is constantly transmitted to ESP 32 microcontroller, the controller constantly processes this data and processes it. The current level of IV bag is parallelly displayed on a LCD display, also this data is transmitted on thing speak via Wi-Fi Module. As soon as the level of IV bag falls below certain level LCD display as well as bag empty, or if there is a clogged line at the same time the buzzer is ringing for notifying healthcare provider (Nurse, doctor of Relative).

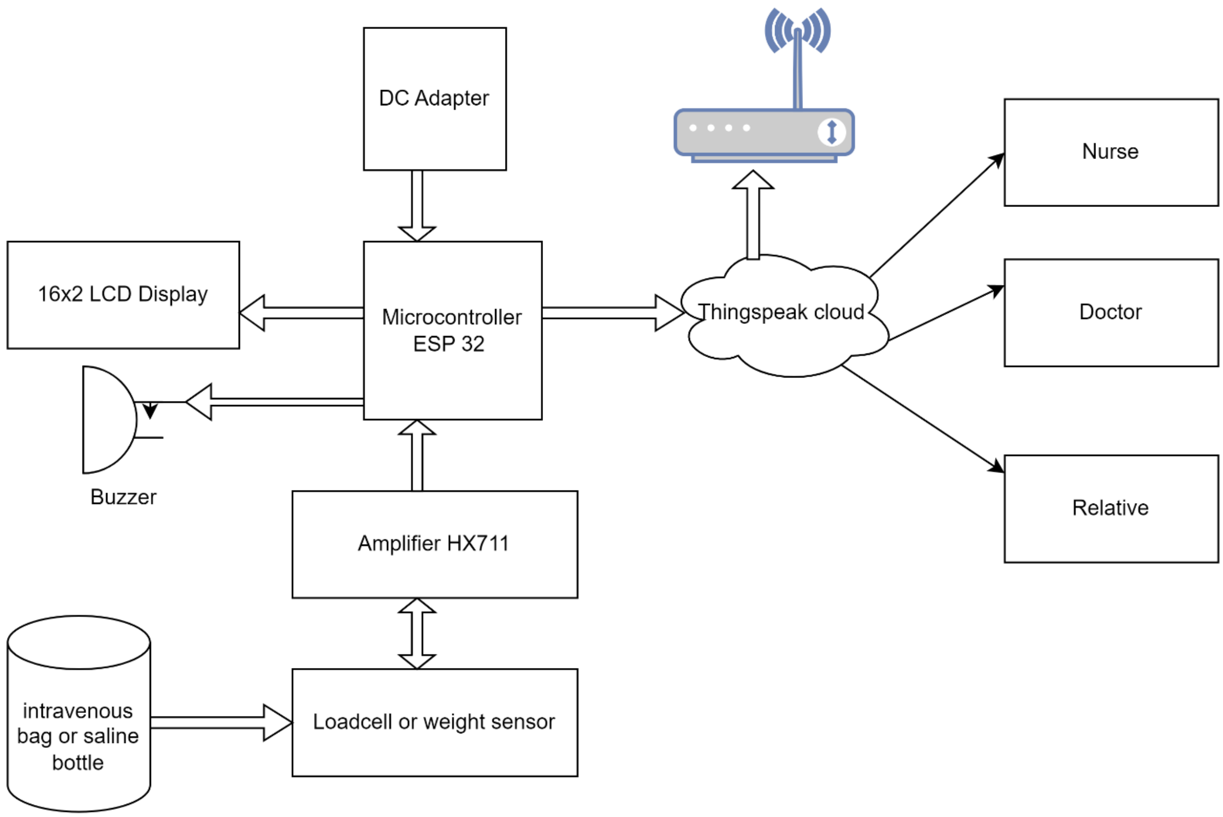

Figure 3. 1: IoT intravenous bag monitoring and alert system architecture

3.3. HARDWARE AND SOFTWARE COMPONENTS USED IN THIS PROJECT

3.3.1. Hardware Components

3.3.1.1. Microcontroller ESP32

ESP32 is a powerful, low-cost system-on-chip (SoC) microcontroller that combines Wi-Fi and Bluetooth capabilities. It is designed and manufactured by Department of Electronics and Communication Engineering 7 by Espressif Systems; a Chinese company known for creating cutting-edge IoT solutions. The ESP32 is the successor to the ESP8266, offering improved performance and added features [18].

Figure 3. 2: Microcontroller ESP32

3.3.1.2. Load Cell or Weight Sensor

The load cell is used in this work as a weight sensor. The rated load of this load cell is 5 kg with working voltage 2.6 volt. It is placed on the medical Intravenous. The intravenous bottle is suspended on the load cell. This strain-gauge load cell converts the intravenous weight into electrical signals and then sends to the weight sensor amplifier module (HX711) before going to the microcontroller [19]

Figure 3. 3: Weight Sensor

3.3.1.3. LCD display

The LCD is a small low-cost display. It is easy to interface with a microcontroller because of an embedded controller. This controller is standard across many displays which means many micro-controllers have libraries that make displaying messages as easy as a single line of code.

Figure 3. 4: LCD display

3.3.1.4. Buzzer

A buzzer or beeper is an audio signaling device, which may be mechanical, electromechanical, or piezoelectric (piezo for short). Typical uses of buzzers and beepers include alarm devices, timers, trains and confirmation of user input such as a mouse click or keystroke.

Figure 3. 5: Buzzer

3.3.1.5. LED (Light Emitting Diode)

A light-emitting diode (LED) is a semiconductor light source that emits light when current flows through it. It has two pins such as a cathode which is flat (negative) pin and anode which is longer (positive).

Figure 3. 6: LED diode

3.3.1.6. USB Cable

A Universal Serial Bus (USB) is a common interface that enables communication between devices and a host controller such as a personal computer (PC) or smartphone. It connects peripheral devices such as digital cameras, mice, keyboards, printers, scanners, media devices, external hard drives and flash drives. It used to connect any board with a personal computer (pc).

Figure 3. 7: USB cable

3.3.1.6. HX711 AMPLIFIER

HX711 module is a Load Cell Amplifier breakout board for the HX711 IC that allows you to easily read load cells to measure weight. This module uses 24 high precision A/D converter chip HX711. It is specially designed for the high precision electronic scale design, with two analog input channels, the internal integration of 128 times the programmable gain amplifier [18].

Figure 3. 8: HX711 AMPLIFIER

3.3.2. Software used

3.3.2.1. Arduino Software (IDE)

The Arduino Integrated Development Environment or Arduino Software (IDE) is open source and to write the codes in Arduino IDE is easy and upload it to the board. It is easy to use for beginners, yet flexible enough for advanced users to take advantage of. It runs on Windows, Mac OS X and Linux. It is published as open-source tools, available for extension by experienced programmers. The Arduino IDE supports the languages C and C++ using special rules of code structuring. The Arduino IDE supplies a software library from the Wiring project, which provides many common input and output procedures [20]

3.3.2.2. Thing speak cloud platform

Thing speak is an open source IOT platform where anyone can visualize and analyze live data from their sensor devices. Also, we can perform data analysis on data posted by remote devices with MATLAB code in Thing speak [21]

3.4 System Prototype

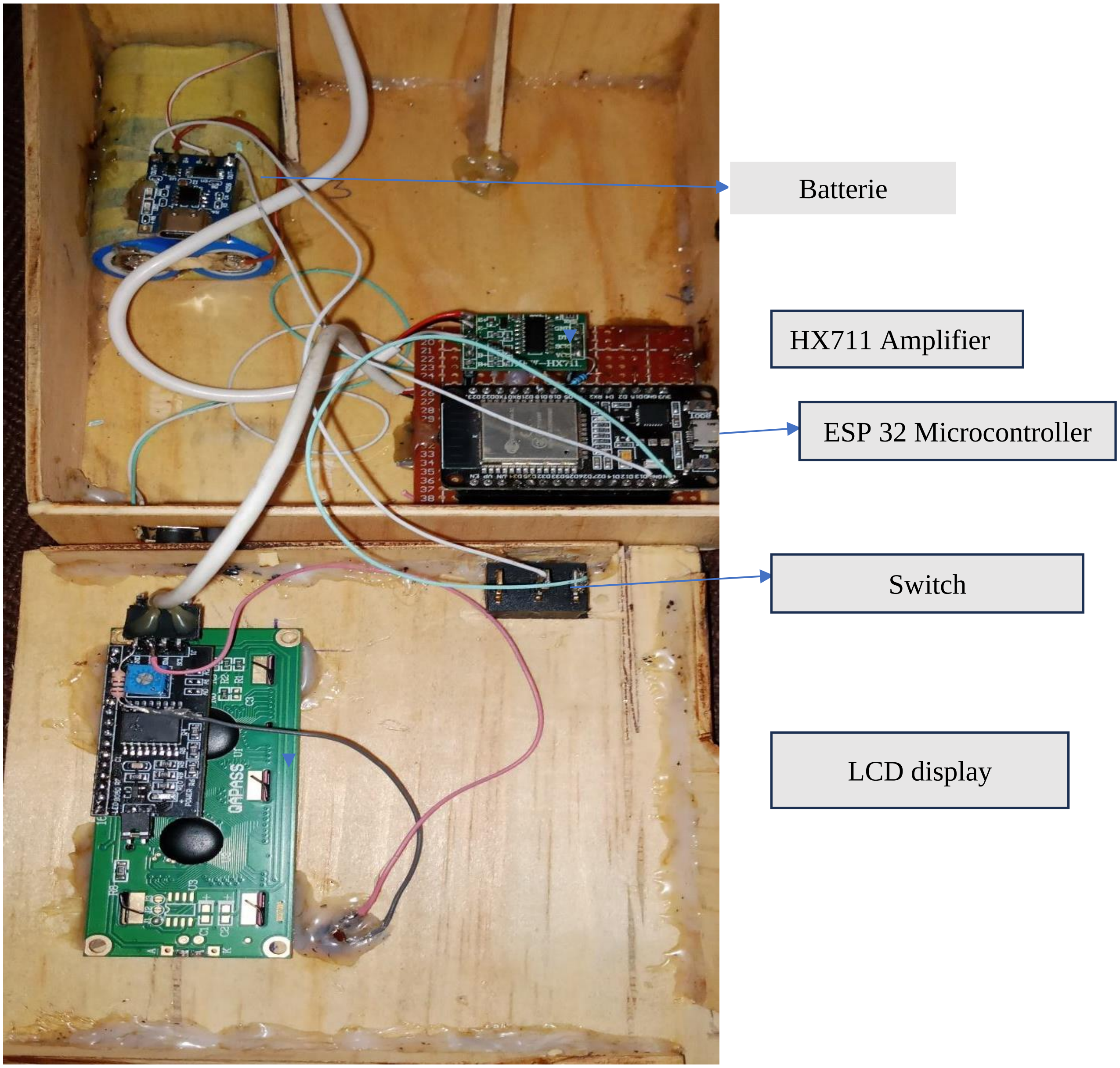

Figure 3. 9: internal of system circuit

Figure 3. 10: the whole system circuit

CHAPTER 4. SYSTEM ANALYSIS AND DESIGN

4.1. Circuit Diagram of the System

The figure 4.1 shows the designed circuit of the system, firstly The ESP 32 is first powered up with 5 volt DC power adapter and connected to a PC or laptop via a USB connection and turn on the switch, once turned on the ESP Module is connected to a registered Wireless Network (Wi-Fi), when connection is successful the ESP 32 shows that the weight is 0 which means there is no weight on Load cell which is displayed through the LCD display connected to the ESP processor. Once an intravenous bag is positioned on the load cell, its weight is measured and shown on the LCD. It is also uploaded to the cloud and viewed on the ThingSpeak platform. The ThingSpeak website allows for live monitoring of the bag's weight. If the weight or liquid level of the bag falls below a certain threshold, there is a message on the LCD display to refill at the same time the buzzer is ringing.

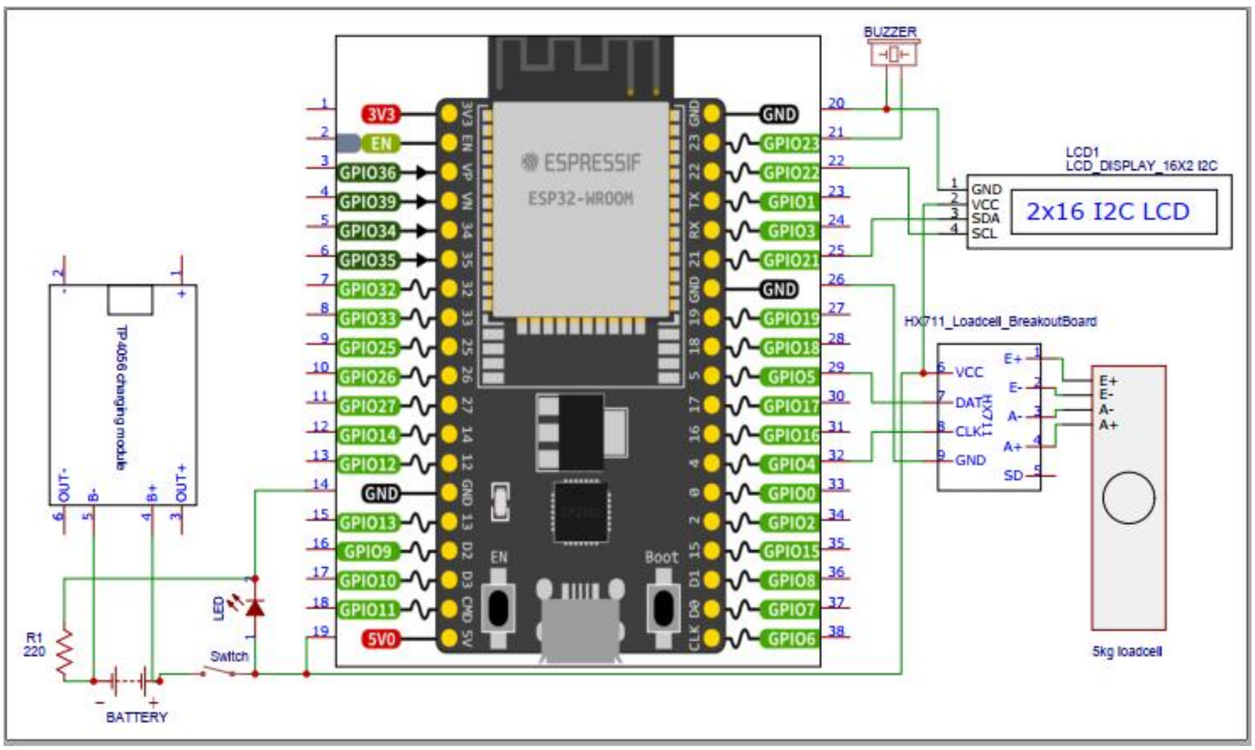

Figure 4. 1: the designed circuit of the system

4.2. IoT intravenous bag monitoring and alarm system flowchart

A patient is receiving IV therapy in a hospital room or at home. The patient's IV bag is connected to an IoT-based IV bag monitoring and alert system. The system is monitoring the fluid level in the IV bag and the flow rate of the IV fluid. If the fluid level in the IV bag gets low, or there is clogged line which means the fluid is stopped to flow the system will generate a ringtone using a buzzer and at the same time display it on LCD display. The nurse or healthcare provider will also use Thingspeak on their smartphone or tablet to see the left weight of intravenous fluid. The nurse or healthcare provider will go to the patient's room to refill the IV bag or to see if there is a clogged line.

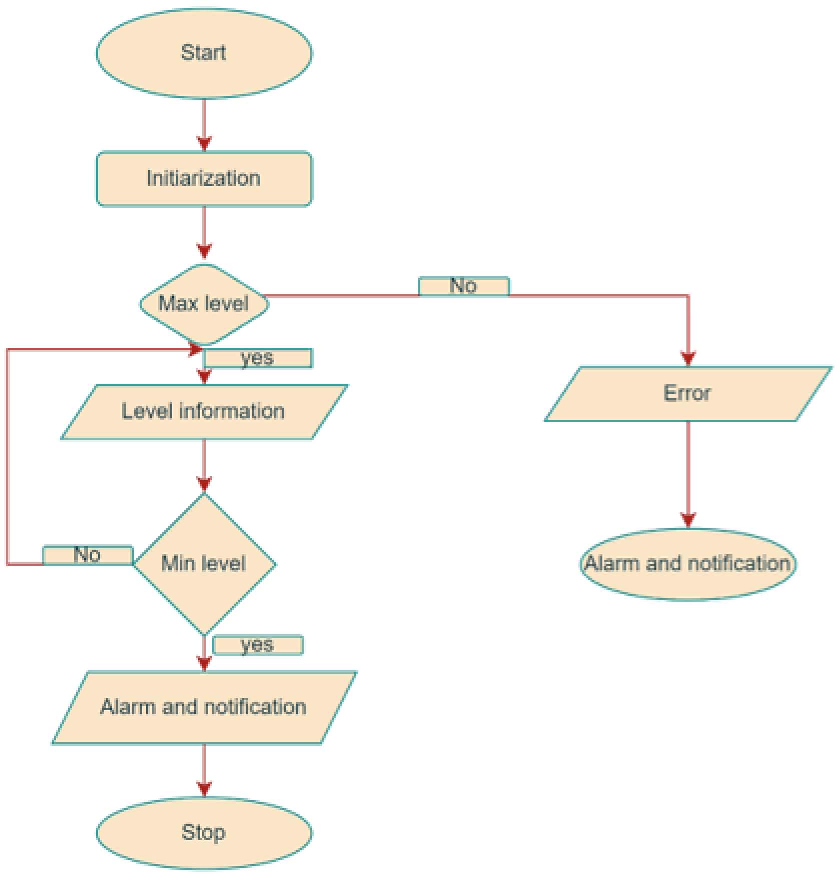

Figure 4. 2: IoT intravenous bag monitoring and alarm system flowchart

CHAPTER 5. PROJECT RESULTS

5.1 Results from Survey

After doing the survey the tables below show the result obtained.

Q1. What is your role in healthcare?

Table 5. 1 the role of the responder in healthcare setting

Responses	**Frequency**	**Percentage**
Nurse	14	46.7
Physicians	5	16.7
Home healthcare	11	36.7
Administrator	0	0
Total	30	100

This table shows that 46.7% responders are nurse of different healthcare settings including health centers, hospitals and clinics. 16.7% responders are physicians from different healthcare settings, and 36.7% responders are home healthcare who use the intravenous bag to treat their patients at home.

Q2. Which technology are you using to monitor intravenous bag or saline in your healthcare settings?

Table 5. 2 technology which are used to monitor intravenous bag in healthcare settings

Responses	**Frequency**	**Percentage**
Manually monitoring	25	83.33
infusion pump	4	13.33
syringe pump	1	3.33
IoT intravenous bag monitoring	0	0
Total	30	100

This table 5.2 shows that 83.33% of the responders (nurses, physicians and home healthcare) use manually monitoring technology to monitor intravenous bags, 13.33% of the responders use infusion pumps to monitor intravenous bags, and 3.33% of the responders use syringe pumps.
In summary, according to these responses manually monitoring technology of IV bags is more used than other technology.

Q3. In your experience, what are the biggest challenges associated with monitoring IV fluids and administering intravenous therapy?

Table 5. 3 the biggest challenges associated with monitoring intravenous fluids and administering intravenous therapy

Responses	**Frequency**	**Percentage**
Difficulty in manually monitoring IV fluid levels	8	26.7
Difficulty in documenting and tracking IV fluid intake	2	6.7
All of the above	17	56.7
None of the above	3	10
Total	30	100

This table 5.3 shows 56.7% of the responders have the biggest challenges in both manually monitoring intravenous fluid levels and in documenting and tracking intravenous fluid intake, 26.7% responders have the challenges in manually monitoring IV fluid levels, 6.7% responders have challenges in documenting and tracking IV fluid intake and 10% of the responders don’t have any challenges.

Q4. Have you ever encountered issues or concerns regarding the monitoring and management of IV fluid bags in healthcare settings? Answer Yes/No

Table 5. 4 Have you ever encountered issues or concerns regarding the monitoring and management of IV fluid bags in healthcare settings? Answer Yes/No

Responses	**Frequency**	**Percentage**
Yes	24	80
No	6	20
Total	30	100

This table 5.4 shows that 80% responders gave the responses Yes, which means that there are issues in monitoring and management of IV fluid bags in healthcare settings. 20%

responders gave the responses No which means there are no issues in monitoring and management of IV fluid bags in healthcare settings.

Q5. Do you believe that implementing the IoT IV bag monitoring and alert system can contribute to a reduction in medical errors and adverse events related to IV fluid administration? Answer Yes/No or May be

Table 5. 5 Contribution of implementing IoT IV bag monitoring and alert system in a reduction of medical errors related to IV fluid administration.

Responses	Frequency	Percentage
Yes	27	90
No	0	0
May be	3	10
Total	30	100

The table 5.5 shows that 90% responders gave the response Yes which means that implementing the IoT IV bag monitoring and alert system will contribute in a reduction of medical error related to IV fluid administration. 10% of responders don't know if implementing the IoT IV bag monitoring and alert system will contribute to a reduction of medical error.

Q6. How important do you believe real-time monitoring and alerting for IV bag contents are in enhancing patient safety and healthcare efficiency?

Table 5. 6 how it is important for real-time monitoring and alerting for intravenous bag in enhancing patient safety and healthcare efficiency.

Responses	Frequency	Percentage
Extremely important	22	73.3
Very important	8	26.7
Moderately important	0	0
Slightly important	0	0
Not important at all	0	0
Total	30	100

The table 5.6 shows that 73.3% responders believe that real -time monitoring and alerting for intravenous bags will be extremely important in enhancing patient safety and healthcare efficiency, 26.7% responders gave a response of very important.

Q7. Have you ever used or worked with IoT medical devices before? Answer Yes/No

Table 5. 7 Have you ever used or worked with IoT medical devices before? Answer Yes/No

Responses	Frequency	Percentage
Yes	4	13.3
No	26	86.7
Total	30	100

The table 5.7 shows that 86.7% responders gave the responses No, which means they don't know about IoT medical devices in healthcare settings, if this IoT IV bag is implemented it will be helpful and innovative. 13.3% responders gave the responses Yes which means they know about IoT medical devices.

Q8. In what healthcare settings do you believe IoT intravenous bag monitoring systems would be most beneficial?

Table 5. 8 where IoT intravenous bag monitoring system is most beneficial

Responses	Frequency	Percentage
Hospitals	0	0
Clinics	4	13.3
Home healthcare	3	10
All of the above	23	76.7
Total	30	100

Table 5.8 shows that 76.7% responders agree that IoT intravenous bag monitoring will be helpful or beneficial in all healthcare settings like hospitals, clinics and home healthcare. 13.3% responders show that the system will be mostly beneficial in clinics. And 10% responders shows that it will be helpful in-home healthcare

Q9. In your opinion, what is the biggest potential benefit of using an IoT-based intravenous bag monitoring system?

Table 5. 9 the biggest potential benefit of using an IoT based intravenous bag monitoring system

Responses	Frequency	Percentage
Improved patient safety	1	3.3
Increased staff efficiency	3	10
Reduced costs	1	3.3
Improved data collection and analysis	0	0
All of the above	25	83.3

Total	30	100

Table 5.9 shows that 83.3% responders say that the IoT intravenous bag monitoring system will have the potential benefit of improving patient safety, increasing staff efficiency, reducing costs and improving data collection and analysis. 10% responders show that the system will have the potential benefit of increasing staff efficiency only, 3.3% responders show that the system will have the potential benefit of improving patient safety only and other 3.3% responders show that the system will have the potential benefit of Reducing cost only.

Q10. Which of the following functionalities would be most valuable in an intravenous bag monitoring system?

Table 5. 10 the functionalities which will be most valuable in an intravenous bag monitoring system

Responses	**Frequency**	**Percentage**
Real-time fluid level monitoring	2	6.7
Low fluid level alerts	2	6.7
Remote access for healthcare providers	0	0
All of the above	26	86.7
Total	30	100

Table 5.10 shows that 86.7 responders highlighted the functionalities of the system I must consider which are real-time fluid level monitoring, low fluid level alerts and remote access for healthcare providers. 6.7% responders responded that I must consider Real-time fluid level monitoring only and other 6.7% responders responded that I must consider Low fluid only.

Responses	**Frequency**	**Percentage**
Nurse	14	46.7
Physicians	5	16.7
Home healthcare	11	36.7
Administrator	0	0
Total	30	100

This table shows that 46.7% responders are nurses of different healthcare settings including health centers, hospitals and clinics. 16.7% responders are physicians from different healthcare settings, and 36.7% responders are home healthcare who use the intravenous bag to treat their patients at home.

5.2 Results from Implementation

Once the system is turned on using a switch, the system waits for the right Wi-Fi to be connected and then on LCD there is 0 weight and 0 percentage which means there is no intravenous bag on the weight sensor. Once a weight is placed the weight sensor calibrates the weight of the intravenous bag and sends the measured data to the cloud Thingspeak, the preset threshold values are also simultaneously checked by the system. If the measured weight is less than or equal threshold value (below 100 g), then the message to refill is displayed on LCD at the same time the buzzer is ringing. Or if there is a clogged line also the message of warning is displayed on the LCD display.

If the weight of the measured bag is above the threshold value (above 100g), then no alert from the buzzer the weight of the intravenous bag placed is continuously monitored and is kept updated via the IoT server through cloud. The Weight can be seen by both LCD display or via Thingspeak cloud.

Figure 5. 1 : the System wait for the right Wi-Fi to be connected

Figure 5. 2: the system is connected to registered Wi-Fi network


Weight Percent
249 g 49

Figure 5. 3: the weight of IV bag is displayed on LCD display

Figure 5. 4: the weight of the IV bag is seen also on ThingSpeak

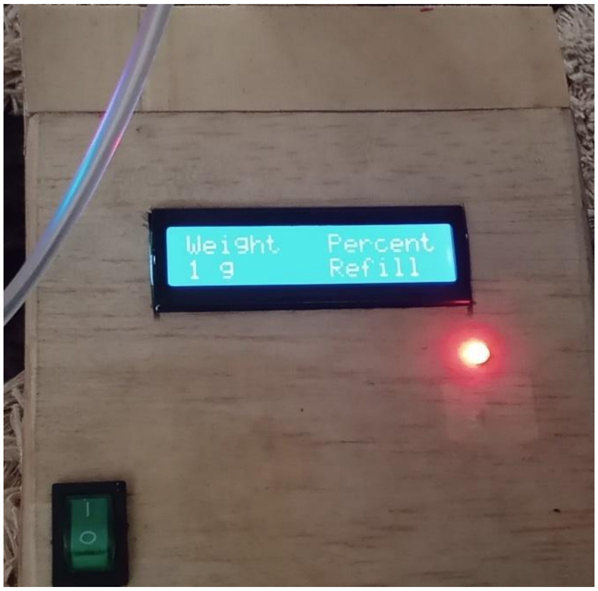

Figure 5. 5: shows when weight of IV bag is below the threshold value the LCD display the remaining weight and remind you to refill

Figure 5. 6: the weight of the remaining intravenous are updated on the graph


Weight Percent
249 g 49

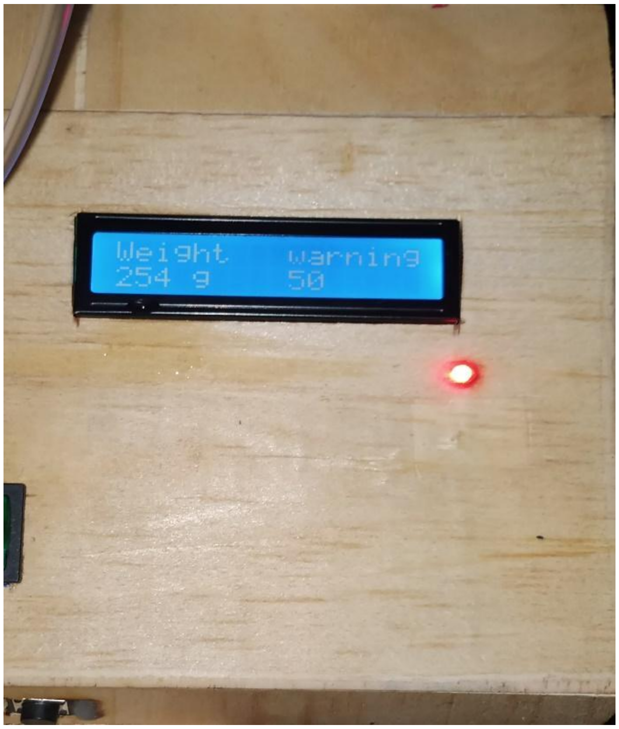

Figure 5. 7: this figure show when there is normal weight of IV bag but there is clogged line LCD display warning

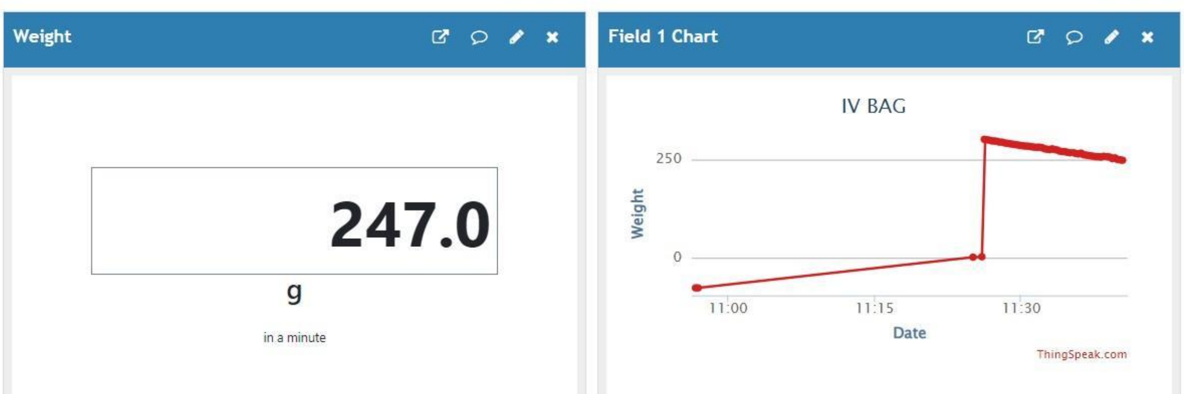

Figure 5. 8: the weight of intravenous bag is updated on the graph

When there is a clogged line or the intravenous fluid is not flowing, on the ThingSpeak also the weight is stopped to be updated.

According to my specific objectives all are achieved by designing and developing the system of IoT intravenous bag monitoring and alert system.

- The First specific objective was to develop a system that can monitor multiple IV bags simultaneously; this was achieved by integrating ThingSpeak with IoT devices such as weight sensors attached to each intravenous bag. After that you can create separate ThingSpeak channels for each intravenous bag that needs to be monitored. ThingSpeak channels act as data repositories where sensor data can be sent and stored.
- The Second specific objective was to develop a system that can provide real-time alerts to healthcare staff. This was achieved also by using ThingSpeak which allows me to set up alerts based on predefined conditions and display it on LCD display with the ringing of the buzzer.
- The Third specific objective was to Test the system by prototyping and this was done by using Hardware's devices including (weight sensor, ESP 32 microcontroller, LCD display) and software including (Arduino IDE, ThingSpeak).

5.3 Comparison between using Existing system to new IoT intravenous bag monitoring and alert system

The comparison facts of existing system and new IoT intravenous bag monitoring and alert system are huge but for the current concern, one can list in the following table

Difference between existing system and new IoT IV bag monitoring and alert system	
Using Existing system	**Using new IoT IV bag monitoring and alert system**
1.Existing IV bag monitoring technologies may not be connected to the internet and might rely on local monitoring systems or manual checks.	IoT IV bag monitoring systems are connected to the internet, allowing for remote monitoring and data access from anywhere with an internet connection.
2.Existing IV bag monitoring may not offer real time monitoring capabilities leading to delays in detecting problems.	Using the new system provides real-time data on various parameters, enabling healthcare providers to respond promptly to any issues or anomalies.
3.Existing technologies may rely on visual inspections or manual checks, lacking automated alert systems	Using the new technologies can trigger alerts or notifications in real-time when predefined

	thresholds are exceeded or abnormalities are detected
Similarities of both existing system and new IoT IV bag monitoring and alert system	
Existing system	**New system**
1.Existing system focus on monitoring parameters such as fluid level to ensure administration of IV fluids	New system also focuses on monitoring parameters such as fluid level to ensure administration of IV fluids
2.Exisisting system aims to enhance patient safety by providing accurate and timely information about IV fluid administration, helping to prevent complications such as overhydration or underhydration	New system also aims to enhance patient safety by providing accurate and timely information about IV fluid administration, helping to prevent complications such as overhydration or underhydration

Table 5. 11 comparisons between existing system and new IoT intravenous bag monitoring and alert system

CHAPTER 5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the implementation of a wireless IV bag monitoring and alert system offers significant benefits in healthcare settings. This system provides real-time monitoring and notifications regarding the status of IV bags, improving patient safety and reducing the risk of medication errors.

5.2 Recommendations

The intravenous bag monitoring system has a bright future because of developments in technology and the healthcare sector. The following are some possible directions for iv bag monitoring system development and expansion. The use of Artificial intelligence (AI) and machine learning to analyze data from Intravenous bag monitoring systems to predict potential complications such as blockages or air bubbles, and provide alerts to healthcare professionals.

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APPENDICES

Appendix 1: Questionnaire used

Intravenous Bag or Saline Monitoring System in Rwanda

I am Gerardine UWIMANA, a postgraduate student in the Center of Excellence in Biomedical Engineering, University of Rwanda (UR). I am doing research on how to improve monitoring intravenous bag or saline using IoT (Internet of Things) technology in healthcare settings where there is not enough equipment for monitoring intravenous bag. I would like to know about existing technology used to monitor intravenous bags.
Please help me to complete this survey, your responses are anonymous and will be used only for academic purpose

The questions and analyses are in the following tables.

Q1. What is your role in healthcare?

Table 3. 1 the role of the responder in healthcare setting

Responses	**Frequency**	**Percentage**
Nurse	14	46.7
Physicians	5	16.7
Home healthcare	11	36.7
Administrator	0	0
Total	30	100

This table shows that 46.7% responders are nurse of different healthcare settings including health centers, hospitals and clinics. 16.7% responders are physicians from different healthcare settings, and 36.7% responders are home healthcare who use the intravenous bag to treat their patients at home.

Q2. Which technology are you using to monitor intravenous bag or saline in your healthcare settings?

Table 3. 2 technology which are used to monitor intravenous bag in healthcare settings

Responses	Frequency	Percentage
Manually monitoring	25	83.33
infusion pump	4	13.33
syringe pump	1	3.33
IoT intravenous bag monitoring	0	0
Total	30	100

This table 3.2 shows that 83.33% of the responders (nurses, physicians and home healthcare) use manually monitoring technology to monitor intravenous bags, 13.33% of the responders use infusion pumps to monitor intravenous bags, and 3.33% of the responders use syringe pumps.

In summary, according to these responses manually monitoring technology of IV bags is more used than other technology.

Q3. In your experience, what are the biggest challenges associated with monitoring IV fluids and administering intravenous therapy?

Table 3. 3 the biggest challenges associated with monitoring intravenous fluids and administering intravenous therapy

Responses	Frequency	Percentage
Difficulty in manually monitoring IV fluid levels	8	26.7
Difficulty in documenting and tracking IV fluid intake	2	6.7
All of the above	17	56.7
None of the above	3	10
Total	30	100

This table 3.3 shows 56.7% of the responders have the biggest challenges in both manually monitoring intravenous fluid levels and in documenting and tracking intravenous fluid intake, 26.7% responders have the challenges in manually monitoring IV fluid levels, 6.7% responders have challenges in documenting and tracking IV fluid intake and 10% of the responders don't have any challenges.

Q4. Have you ever encountered issues or concerns regarding the monitoring and management of IV fluid bags in healthcare settings? Answer Yes/No

Table 3. 4 Have you ever encountered issues or concerns regarding the monitoring and management of IV fluid bags in healthcare settings? Answer Yes/No

Responses	Frequency	Percentage
Yes	24	80
No	6	20
Total	30	100

This table 3.4 shows that 80% responders gave the responses Yes, which means that there are issues in monitoring and management of IV fluid bags in healthcare settings. 20% responders gave the responses No which means there are no issues in monitoring and management of IV fluid bags in healthcare settings.

Q5. Do you believe that implementing the IoT IV bag monitoring and alert system can contribute to a reduction in medical errors and adverse events related to IV fluid administration? Answer Yes/No or May be

Table 3. 5 Contribution of implementing IoT IV bag monitoring and alert system in a reduction of medical errors related to IV fluid administration.

Responses	Frequency	Percentage
Yes	27	90
No	0	0
May be	3	10
Total	30	100

The table 3.5 shows that 90% responders gave the response Yes which means that implementing the IoT IV bag monitoring and alert system will contribute in a reduction of medical error related to IV fluid administration. 10% of responders don't know if implementing the IoT IV bag monitoring and alert system will contribute to a reduction of medical error.

Q6. How important do you believe real-time monitoring and alerting for IV bag contents are in enhancing patient safety and healthcare efficiency?

Table 3. 6 how it is important for real-time monitoring and alerting for intravenous bag in enhancing patient safety and healthcare efficiency.

Responses	Frequency	Percentage
Extremely important	22	73.3
Very important	8	26.7
Moderately important	0	0
Slightly important	0	0
Not important at all	0	0

Total	30	100

The table 3.6 shows that 73.3% responders believe that real -time monitoring and alerting for intravenous bags will be extremely important in enhancing patient safety and healthcare efficiency, 26.7% responders gave a response of very important.

Q7. Have you ever used or worked with IoT medical devices before? Answer Yes/No

Table 3. 7 Have you ever used or worked with IoT medical devices before? Answer Yes/No

Responses	**Frequency**	**Percentage**
Yes	4	13.3
No	26	86.7
Total	30	100

The table 3.7 shows that 86.7% responders gave the responses No, which means they don't know about IoT medical devices in healthcare settings. If this IoT IV bag is implemented it will be helpful and innovative. 13.3% responders gave the responses Yes which means they know about IoT medical devices.

Q8. In what healthcare settings do you believe IoT intravenous bag monitoring systems would be most beneficial?

Table 3. 8 where IoT intravenous bag monitoring system is most beneficial

Responses	**Frequency**	**Percentage**
Hospitals	0	0
Clinics	4	13.3
Home healthcare	3	10
All of the above	23	76.7
Total	30	100

Table 3.8 shows that 76.7% responders agree that IoT intravenous bag monitoring will be helpful or beneficial in all healthcare settings like hospitals, clinics and home healthcare. 13.3% responders show that the system will be mostly beneficial in clinics. And 10% responders shows that it will be helpful in-home healthcare

Q9. In your opinion, what is the biggest potential benefit of using an IoT-based intravenous bag monitoring system?

Table 3. 9 the biggest potential benefit of using an IoT based intravenous bag monitoring system

Responses	**Frequency**	**Percentage**
Improved patient safety	1	3.3
Increased staff efficiency	3	10
Reduced costs	1	3.3
Improved data collection and analysis	0	0
All of the above	25	83.3
Total	30	100

Table 3.9 shows that 83.3% responders respond that IoT intravenous bag monitoring system will have the potential benefit of improving patient safety, increase staff efficiency, reduce costs and improve data collection and analysis. 10% responders show that system will have the potential benefit of increasing staff efficiency only, 3.3% responders show that system will have the potential benefit of improving patient safety only and other 3.3% responders show that system will have the potential benefit of Reducing cost only.

Q10. Which of the following functionalities would be most valuable in an intravenous bag monitoring system?

Table 3. 10 the functionalities which will be most valuable in an intravenous bag monitoring system

Responses	**Frequency**	**Percentage**
Real-time fluid level monitoring	2	6.7
Low fluid level alerts	2	6.7
Remote access for healthcare providers	0	0
All of the above	26	86.7
Total	30	100

Table 3.10 shows that 86.7 responders highlighted the functionalities of the system I must consider which are real-time fluid level monitoring, low fluid level alerts and remote access for healthcare providers. 6.7% responders responded that I must consider Real-time fluid level monitoring only and other 6.7% responders responded that I must consider Low fluid only.

Appendix 2: The Utilized Codes

```
#include "HX711.h"
```

```
#include <LCD_I2C.h>
#include <WiFi.h>

#include "ThingSpeak.h"
const char* ssid = "Gera";
const char* password = "Amabilis@123";
WiFiClient client;
unsigned long myChannelNumber = 2417091;
const char* myWriteAPIKey = "DBAL65ZG6FPO5P7R";
unsigned long lastTime = 0;
unsigned long timerDelay = 1000;
HX711 scale;
LCD_I2C lcd(0x27, 16, 2);
int led = 34;
float weight;
int percentage;
float calibration_factor = 423500;
int buzzer = 23;
int button = 19;
int buttonstate;

unsigned long previousMillis = 0;  // Variable to store the previous time
const long interval = 5000;

unsigned long lastChangeTime = 0;  // Variable to store the time when the
value last changed
unsigned long currentTime = 0;     // Variable to store the current time
unsigned long elapsed_time = 0;
int oldValue = 0;

void setup() {
  Serial.begin(115200);
  lcd.begin();
  lcd.backlight();
  lcd.print("  IV BAG");
  lcd.setCursor(0, 1);
  lcd.print("  Connecting.....");
  WiFi.mode(WIFI_STA);
  ThingSpeak.begin(client);

  if (WiFi.status() != WL_CONNECTED) {
    Serial.print("Attempting to connect");
    while (WiFi.status() != WL_CONNECTED) {
      WiFi.begin(ssid, password);
      delay(2000);
    }
    Serial.println("\nConnected.");
  }
  pinMode(button, INPUT);
  pinMode(buzzer, OUTPUT);
  pinMode(led, OUTPUT);
```

```
  scale.begin(5, 4);  // Begin the HX711 library with the correct pins
  scale.set_scale(calibration_factor);
  scale.tare();  // Reset the scale to 0
  long zero_factor = scale.read_average();
  // put your setup code here, to run once:
}

void loop() {

  weight = scale.get_units(5);
  int weightg = weight * 1000;
  buttonstate = digitalRead(button);
  percentage = map(weightg, 0, 500, 0, 100);
  // float percentage = map(weight, input_min * 1000, input_max * 1000,
output_min * 1000, output_max * 1000) / 1000.0;
  if (percentage > 100) {
    percentage = 100;
  }
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Weight");
  lcd.setCursor(0, 1);
  lcd.print(weightg);
  lcd.print(" g  ");
  lcd.setCursor(9, 0);
  lcd.print("Percent");
  lcd.setCursor(9, 1);
  lcd.print(percentage);

  if ((weightg < 101) && (weightg != 0)) {
    lcd.setCursor(9, 1);
    lcd.print("Refill");
    tone(23, 20, 1000);
  } else {
    noTone(23);
    // digitalWrite(buzzer, LOW);
  }
  Serial.println(buttonstate);
  Serial.println();
  unsigned long currentMillis = millis();
  if ((currentMillis - previousMillis >= interval) && (weightg != 0)) {
    // Save the last time data was sent
    previousMillis = currentMillis;
    if (weightg < 500) {
      data();
    }
  }
  if ((weightg != oldValue)) {
    lastChangeTime = millis();  // Update the last change time
    oldValue = weightg;         // Update the old value
  }
```

```
  currentTime = millis();
  elapsed_time = currentTime - lastChangeTime;

  Serial.println(elapsed_time);
  if ((elapsed_time > 30000) && (weightg != 0)) {
    Serial.print("YAKWAMYE");
    digitalWrite(buzzer, HIGH);
    lcd.setCursor(9, 0);
    lcd.print("warning!");
  } else {
    digitalWrite(buzzer, LOW);
  }
  delay(100);  // Adjust the delay as needed
}
void data() {
  int weightg = weight * 1000;
  ThingSpeak.setField(1, weightg);
  int x = ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);

  if (x == 200) {
    Serial.println("Channel update successful.");
  } else {
   Serial.println("Problem updating channel. HTTP error code " + String(x));
  }
}
```