ASHESI UNIVERSITY

DESIGN AND FABRICATION OF A LOW-COST SYSTEM FOR VITALS MONITORING OF HOSPITALIZED PATIENTS

CAPSTONE PROJECT

B.Sc. Electrical & Electronic Engineering

Prince Mark Coffie

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical & Electronic Engineering.

DECLARATION

I hereby declare that this capstone is the result of my original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate’s Signature:

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Candidate’s Name: Prince Mark Coffie

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Date: April 22, 2021

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I hereby declare that the preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature:

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Supervisor's Name:

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To my lovely Mum, Juliana Coffie , I love you and thank you for all the support. To the best and greatest person, I know, my Father, Vincent Coffie who is the reason I am working on this project. Till we meet again in heaven may your impactful and perfect soul rest in peace. I cannot forget to thank and praise God for bringing me this far.

Abstract

Internet of things (IoT) is a quickly growing field that centers around giving savvy and smart solutions that could be incorporated in many fields to solve everyday problems. Further exploration in this field zeros in on the most proficient and often low-cost method to make things and activities smart, continuously monitor and observe changes that occur in environments and may more.

One crucial aspect in the healthcare industry is the treatment and monitoring of hospitalized patients which is a factor that speak volumes to the survival rate of the hospitalized patients. However, in many developing countries, patient monitoring structures in hospitals are scarce, which in fact contributes to the alarming deathrates and loss of loved ones in our hospitals. Thus, considering this and the many opportunities IoT presents in conjunction with remote monitoring and data collection system, this Applied Capstone report focuses on how to continuously monitor the vitals of hospitalised patients, use the data collected to present meaningful information to users and other parties anywhere they did themselves via a web application interface. The vitals monitoring system for hospitalised patients is built with the ATMEGA328p as its core processor, it takes information about the patient via the some sensors, stores the data into a database where it can be read at anytime and remotely via a web application.

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Chapter 1: Introduction

1.1 Background

The healthcare system in many third world countries is a developing one; One yet to be fully-fledged and equipped with all the necessary paraphernalia that would help drastically reduce the death rate in hospitals. As at 2012, a staggering 6000 patients died annually due to poor monitoring in the UK [1]. Hospitals are to be safe havens where the health and recovery of admitted patients are assured. However, in Ghana and other developing countries, only a few are assured of this also, evidence is emerging that despite the expanding health care coverage in these countries, better outcomes are still low [2]. This could be mainly ascribed to the limited vital monitors available and the costly nature of having every hospitalized patient or those in critical condition hooked up to vital monitors. Medical personnel have then resorted to spot-checking, which is not the best approach, since anomalies in patients' vital signs cannot be easily noticed.

1.2 Problem Definition

Considering the unreliable approaches (like spot-checking) used in monitoring the recovery trends of hospitalized patients in many third world public and private hospitals, there is a need for an effective low-cost and efficient monitoring system, since the acquisition of already existing ones are not only expensive but difficult to repair. The system to be developed is to help improve the monitoring of the vitals of hospitalized patients at a reduced cost. Since these vital signs are the main indicators of one's health status. This would in a long run enhance the services rendered at all health centres.

1.3 Motivation

Medical equipment is often expensive for people in low-income countries hence, these medical devices are not readily available to hospitalized patients. Medical personnel have resorted to unreliable and less smart means of recording patients' vitals such as recording of vitals on sheets of papers. Also, having witnessed this with my dad who passed away without any proper monitoring in the hospital, passing away minutes after my mother noticed his temperature was high. Furthermore, according to the 2013 annual report from the most equipped hospital in Ghana, Korle-Bu has only 17 vital monitors matched against the 138 patients admitted a day. This further shows only 12% of the admitted patients can get access to these monitors provided they can afford them. This and many other preventable deaths are the motivating factors for this project.

1.4 Objective of the project

The project is aimed at designing a low cost, proficient and reliable vitals monitoring system. With this system in place, there would be continuous monitoring of patients body temperature, blood pressure, oxygen concentration and breathing rate throughout the hospital. Also, patients will be able to rest and get well with fewer interruptions as compared to spot-checking, keeping the patients on a smooth recovery path and possibly lessen their length of stay. The system will further help prioritize the efforts of the medical personnel to concentrate on those patients whose condition is most in need of intervention since there will be an alarm system that will go off when anomalies are spotted in the vitals of the patients.

It must be noted that people in rural areas are mostly below the poverty bracket. The World Bank defines poverty as individuals who cannot afford $1.9 per day[3]. As such, the fundamental design goal is to achieve high efficiency at a low cost. This project further aims to fulfil one of the Sustainable Development Goals (SDG's), to ensure healthy lives and promote well-being for all at all ages SDG 3 [4].

The system should be able to:

- Sense and record vital signals of the hospitalized patient
- Remove unwanted components from recorded signals

- Transmit patients vital signals to a database
- Segregate recorded patient vitals and make data presentable
- Provide patient vitals to health personnel in the hospital on a smart device
- Activate an alarm system when there is an anomaly in patients' vitals

In summary, this project would result in a reduced need for rescues, intensive care unit transfers and prevent avoidable deaths.

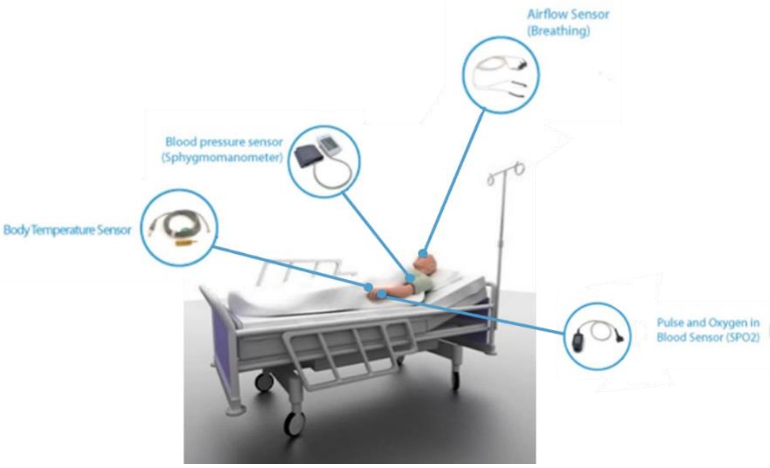


Figure 1.4.1 shows a patient whose vital signs are been recorded and would be further analysed

1.5 Use Case

For this project, the *police hospital* at Cantonment-Accra with coordinates 5 degrees, 34 minutes, 6.4 seconds north; zero degrees, 10 minutes, 54.2 seconds west (5°34'06.4"N 0°10'54.2"W) will be considered as a use case. Hence, designs, decisions and consideration will be done with this at the back of our minds.

Figure 1.5.1 shows a satellite view of the police hospital

Chapter 2: Literature review

2.1 History

The earliest written account pertinent to the historical backdrop of patient monitoring is contained in the papyrus found by Ebers,1875 [5]. This document, written in 1550 BC, stated that ancient Egyptian physicians knew about the way that the peripheral pulse could be associated with the heartbeat. Subsequent contribution was made after some 3000 years when Galileo found the principle of the pendulum in 1658 and utilized it to quantify the pulse rate. This was arguably the first example of clinical measurement [6]. A breakthrough was made when Seymour B. London, an American physician constructed the first automatic blood pressure monitor [7]. The designed prototype proved to be quite accurate after it was tested on 400 doctors at a 1965 American Medical Association convention [7]. Henceforth, complex vital monitors have been built to measure various physiological or vital signals.

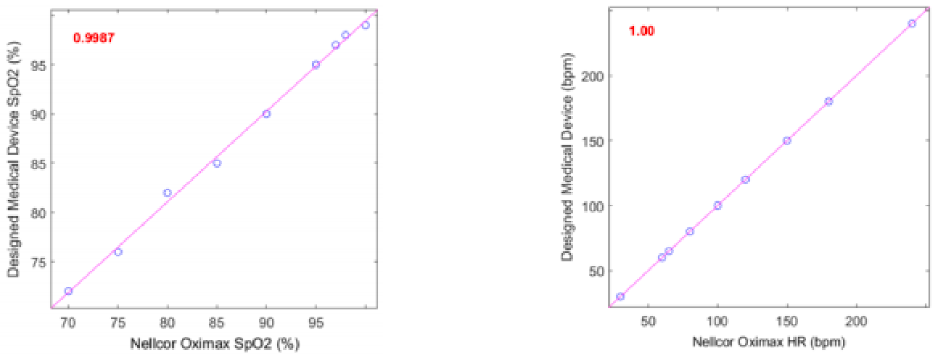
Vitals monitors have been designed and developed by many researchers, Shnayder in his paper designed a wearable medical system for monitoring vital signs for the next generation triage system [8]. Vitals measured include, electrocardiogram ECG, SpO2 and systolic blood pressure. The project sought to continually monitor the triage levels, physiological status, and location of the patients and automatically distribute patient data in real-time to response team members both on and off the disaster site. To carry this out, an Advanced Health and Disaster Aid Network (AID-N) was designed, which included an electronic triage and sensing systems that contain low power embedded devices. The data transmission framework was mainly built on a publish/subscribe routing architecture, permitting various sensor devices to send data to all receivers that have registered an interest in that data. This mock-up certainly meets the needs of medical purposes where some medical staff may be interested in sensor data from overlapping groups of patients.

The system also helps address and replace the colour coded paper tags deployed to determine the severity of the patient's injury, further helping responders focus on patients who need special attention. One amazing feature of Shnayder's design is how the communication layer of the monitoring system is made to be mobile when establishing routing paths. That is, the system keeps monitoring in the medical scenarios where patients are ambulatory and transferred between wards. The main drawback in this architecture is the cost involved in the purchase of the many sensors, communication devices and the use of wireless sensors which mainly resulted in the loss of data. This could however be mitigated by the redundant transmission of data, which on the other hand burdens the bandwidth. Also, the developed system was quite complex to operate. To borrow some features from this paper, the output of the developed system could be validated by comparing it with the existing vital monitors.

Niswar et al. [9] present a low-cost wearable medical device to measure vital signs of a patient including heart rate, blood oxygen saturation level (SpO2) and respiratory rate. The wearable medical device mainly consists of a microcontroller and two biomedical sensors including an airflow thermal sensor to measure respiratory rate and a pulse oximeter sensor to measure SpO2 and heart rate. In the paper, the vital signs are monitored from a smartphone using a web browser through IEEE802.11 wireless connectivity to the wearable medical device. From the paper, the IEEE802.11 (Wi-Fi) wireless connectivity was used as an improvement or replacement on previous designs where Bluetooth and Zigbee were used. This was mainly done to enable easy connectivity to the Internet. This is however needless since the previous model/design could be IP-enabled by simply adding another layer (IP layer), to the Zigbee protocol. The system had two output units, i.e., a 1.3 inches OLED display and three LED indicators. The OLED shows SpO2 and heart rate status of a patient. The three LEDs displayed three stages of patients' severity condition.

Figure 2.1.1: Prototype of the designed vital monitor [9]

Finally, a performance test was then conducted to compare the results from the developed system shown in Figure **2.1.1** to a standard biomedical system. Hence, they used the Pearson correlation coefficient statistical analysis to describe the correlation between the designed medical device and standard biomedical system. The performance evaluation results shown in Figure **2.1.2** depicted a strong correlation between the designed medical device and the chosen standard medical system (Nellcor OxiMax). In the paper, Niswar failed to show the design process/criteria used for the selection of devices used.



(a) (b)

Figure 2.1.2 Correlation between designed medical device and Nellcor OxiMax SpO2, (a) Oxygen saturation, (b) Heart rate [9]

Ortiz et.al [10] mainly describes how IoT with remote information gathering, can be used by healthcare professionals to diagnose, evaluate, and treat patients in remote locations using telecommunications technology. With the architecture shown in Fig **2.1.3**, the authors built a small-scale electrocardiogram (ECG) monitoring device that will determine pulses and waveforms and curate data using a Wi-Fi module to a database and a web server. The ECG device was made using a single-lead heart rate monitor sensor and an Arduino. The obtained data were analysed and uploaded using MATLAB and C# programs. Rapid Application Technology (RAD) was used to rapidly design the system. Then the hardware and software systems went through a prototyping cycle. Both systems were put together to construct a complete IoT-based ECG monitoring system. The designed system was examined using a t-test, with $\alpha = 0.05$ and a sample size of 18. The result showed t-test values remained in the non-critical zone for all ECG parameters, purporting that the gathered data has no significant difference. The device’s per cent reliability in spotting ECG conditions was 83.33% with the per cent difference for the heart rate being 0.35 %, which falls within the accepted medical standard of 99% accuracy [11]. Hence, the device was deemed functional and reliable.

Figure 2.1.3 Proposed Architecture of the ECG Monitoring System

Furthermore, Abo-Zahhad et.al. [12], in their examination embraces a framework that incorporates continuous assortment and assessment of various indispensable signs, long haul medical services, and a cellular connection to a medical centre in cases of crisis and it moves all obtained crude information by the web in ordinary cases. The proposed system can continuously measure four distinct physiological signs, for example, SpO2, temperature, ECG and blood pressure and additionally send them to a smart data analysis algorithm to diagnose irregular pulses for discovering prospective diseases. The recommended system also has a user-friendly web-based portal for medical staff to see instantaneous pulse signals for remote analysis and medication if possible. Abo-Zahhad uses a smart method to reduce the cost of using a GPRS network for transmission, by sending only abnormal readings. The designed system uses dual transmission modes, store-and-forward mode and real-time mode. In the store-and-forward mode, the unit reads and sends out patient's vitals to the server using the internet. However, when an abnormal sign that calls for the attention of the doctor is detected, the monitoring unit transmits it to the server via a GPRS network in real-time to the doctor and a family member's mobile. This transmission architecture shown in Figure **2.1.3** could be said to be event-driven since the vitals sign is sent based on the occurrence of an event.

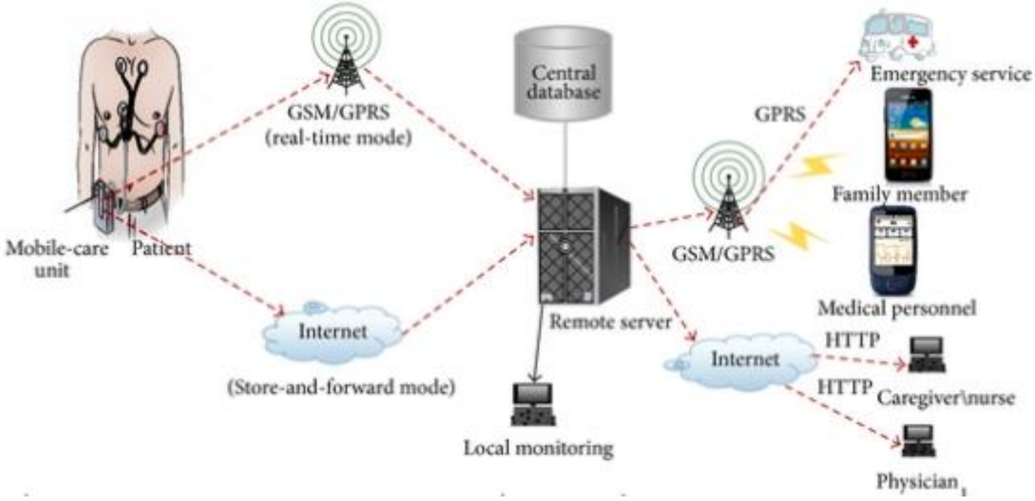


Figure 2.1.4 The architecture of the proposed system [12]

Hence, the purpose of this capstone is to meet a healthcare need of poor monitoring of hospitalised patients in developing countries (Police Hospital, Ghana), through the design of a low-cost vital signs monitor. Based on the gross research done to stand on the shoulders of giants, the review helps shape up certain aspects of the project for example it helped inform some sensor selection, the kind of architecture to use (Client-server), statistical evaluation methods to accredit the efficiency of some sensors and which communication module to use and why.

2.2 Market Research

From research, the global market for advanced Patient Monitoring Systems has a projected Compounded Annual Growth Rate (CAGR) of 7 % mainly contributed by the First-world countries Table 2.2.1 [13].

The Global Market for Advanced Patient Monitoring Systems (2012-2021) in millions USD		
Year	**Revenues**	**Per cent Change**
2012	$ 28,289	-
2013	$ 29,261	5.20%
2014	$ 31,665	6.40%
2015	$ 33,794	6.70%
2016	$ 35,204	4.20%
2017	$ 37,157	5.50%
2018	$ 39,435	6.1%
2019	$ 42,161	6.90%
2020	$45,620	8.20%
2021	$ 49,440	8.40%
Period	**CAGR**	
2012-2016	5.60%	
2016-2021	7.00%	
2012-2021	6.40%	

Table 2.2.0.1 Tabulated Data of Global Market Growth [13]

This market is largely dominated by biomedical giants such as GE Healthcare, Johnson & Johnson, Medtronic, Boston Scientific, Roche and so on. However, the advanced Patient Monitoring Systems provided by these companies are expensive averaging about $ 2, 167 which makes them quite unaffordable for many third-world countries.

Chapter 3: Design Requirements and Criteria

This chapter establishes the desired user requirements, technical specifications, as well as the entire proposed system. Based on the user and system requirements obtained from secondary research, various design considerations, including material selection, selecting the right dimensions and configuration will be introduced to achieve the desired goal.

3.1 Design Proposal

The objective of this project is to build a prototype of a low-cost vitals monitor, that is, a vital monitor to help continuous monitoring of hospitalised patients in Ghanaian hospitals. To achieve this, the vitals monitor, with its calculated dimensions, was designed and simulated in fritzing. After which the prototype was fabricated. The functional block diagram of the system is shown in Figure **3.1.1**

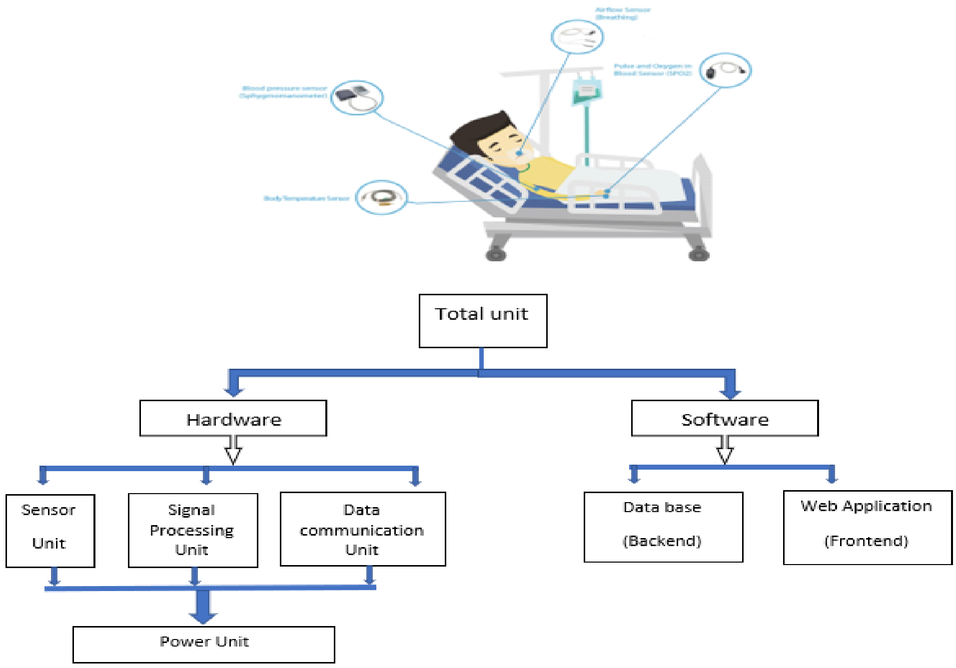


Figure 3.1.1 Functional block diagram of proposed vitals monitor

3.2 Requirements

The requirements outlined include requirements from the user's perspective, as well as the system requirements based on its functionalities. These requirements were obtained mainly through literature reviews and user interviews. With the help of these requirements listed, the system was designed according to the user's preferences. The users of this system include people hospitalized patients and health personnel (doctors and nurses). The user and system requirements are listed in table **3.2.1 and 3.2.2** respectively**.**

Criteria	**User Requirement**	**Design Specification**	**Justification**
Functionality	Record vitals with high precision and accuracy	Filters and amplifiers would be used to remove all unwanted components	Accuracy is very important in biomedical devices; hence the designed device needs to have small margins of error.
User friendly	Transferred vitals/data should be easily readable and presentable to medical personnel, the device should be easy to use		
Low Cost	Affordable for all (hospitals in third-world countries) Device Cost < $200	Components and materials used should be cheap but should do the job well	The designed system mainly targets hospitalized patients in third-world countries, hence should be affordable
Portable	Less cumbersome and lightweight	A suite would be designed to house the system	
Highly responsive	The alarm system should be highly responsive and audible		

Table 3.2.0.1: User Requirements

*Accuracy is based on per cent error from a commercial biometric device. It is calculated using:
Accuracy (1-%error) = $1 - \frac{[Commercial\ Reading - Experimental\ Reading]}{Commercial\ Reading}\ x\ 100$

Criteria	**System Requirement**	**Design Specification**	**Justification**

Functionality (Sensitivity)	Record vitals with high precision and accuracy (95% Accuracy*)	Filters and amplifiers would be used to remove all unwanted components	Accuracy is very important in biomedical devices; hence the designed device needs to have small margins of error.
User-friendly/ Safety	The designed system should not be harmful to the user/environment	low carbon footprint components and skin-friendly materials will be used	The system is designed to save lives, hence it's a priority to users are not exposed to harmful things
Low power consumption	Affordable for all (hospitals in third-world countries)	Components and materials used should consume less power but should do the job well e.g., Access technologies used should consume less power	The designed system mainly targets hospitalized patients in third-world countries, hence should consume less power and last long
Highly responsive	The alarm system should be highly responsive and audible	The system would be designed to respond quickly to any anomalies in the vitals of the patient	This is a very essential feature since the life of the hospitalized patient depends on it

Table 3.2.0.2 System Requirements

3.3 Design Criteria and Decision Matrix

To achieve the goals of this system, a design criterion was set, and a decision/Pugh matrix was created to evaluate specific aspects of the system. A Pugh matrix was constructed for various aspect of the system. A Pugh matrix uses selection criteria i.e., (user and system requirements), and supplementary research data to assess a choice of component or material using a scoring matrix. With weights assigned to each criterion, every positive means better than, negative means worse than and zero for equal weight among choices.

3.3.1 Medical Sensors Overview

Body Temperature: The normal body temperature recorded at skin level is about 36.5ºC for grown-ups and 37.0ºC for infants and kids [14]. A value between 36.5ºC and 37.5ºC is normal for adults. Irregularities occur when the value is above 37.5ºC indicating fever or hyperthermia and called hyperpyrexia when the value is above 40ºC. The reverse of the previous condition is hypothermia which indicates a temperature value below 36ºC. These conditions could be life-threatening and usually denotes infections or illness, hence should be addressed as a real medical emergency. There are various body temperature measuring sensors, to narrow down on one for the patient monitoring system a sensor pugh matrix was used considering certain user and system requirements (Table **3.3.1**). The criteria were weighted based on its importance and the requirements of the project.

		Temperature Sensors						
		Alternatives						
	Weights	DS18B20	TMP35A	DHT 22/11	LM 35	MAX 30205	Totals	Rank
Accuracy & Precision	4	**0**	–	–	**0**	+	-1	3rd
Low Power	3	**0**	+	**0**	+	**0**	2	1st
Availability	5	+	**0**	+	+	–	2	1st
User friendly/Safety	5	+	–	**0**	–	+	0	2nd
Low Cost	4	–	**0**	–	–	**0**	-3	4th
	Total	1	-1	-1	0	1		
	Rank	1st	3rd	3rd	2nd	1st		

Table 3.3.0.1 Pugh Matrix for Body Temperature Sensors

Among all the temperature sensors, the MAX30205 and the DS18B20 sensor had the highest rating. However, the DS18B20 temperature sensor shown in figure **3.3.1** will be used mainly due to its availability. Some technical details of this sensor are as follows, Usable temperature range: -55 to 125°C (-67°F to +257°F), ±0.5°C accuracy from -10°C to +85°C, temperature-limit alarm system, 9 to 12-bit selectable resolution, usable with 3.0V to 5.5V power/data [15].

Figure 3.3.1 DS18B20 temperature sensor

Pulse Oximeter: Pulse oximetry has been used as a clinical diagnostic technique since its development in the early 1970s [15]. It is a non-invasive device used to measure human haemoglobin saturation (SpO_2)and heart rate through the finger. A healthy adult at rest has a heart rate between 60 and 100 BPM (Beats per Minute) and Oxygen concentration between 95 and 100 % [16]. Conversely, tachycardia is a condition where the beats per minute (BPM) is greater than 100, and bradycardia is when the beats per minute is less than 60. Though these conditions may somethings be normal, they may also be indicators of some underlying ailments. Table **3.3.2** shows a pugh matrix for the selection of a pulse sensor from the available ones.

		Pulse Sensors			
		Alternatives			
	Weights	SEN-11574	MAX 30102	Totals	Rank
Accuracy & Precision	4	–	+	0	3rd
Low Power	3	+	+	2	1st
User friendly/Safety	4	+	–	1	2nd
Availability	5	+	**0**	1	2nd
Low Cost	4	–	+	0	3rd
	Totals	1	2		
	Rank	2nd	1st		

Table 3.3.0.2 Pugh Matrix for Pulse Oximeters

From the above comparison, the MAX 30102 sensor shown in figure **3.3.2** had the highest rating hence it will be used for measuring pulse and oxygen concentration in the system. Some technical specifications of this sensor are as follows: Low-Power Heart-Rate Monitor (< 1mW), Supply Voltage between 3.3 and 5 V, uses I2C Interface and so on.

Figure 3.3.2 MAX 30102 pulse & O2 Concentration sensor

3.4 Communication Technology

The means for the transmission of data could either be wired or wireless, long or short-range, high or low power consumption, however, for this project long-range, wireless mode of communication will be considered. Some available options for communication include but are not exclusive to Global System for Mobile communication (GSM) module and the Wi-Fi Module. The Wi-Fi Module is relatively low cost, with an indoor scope of 30 m up to 100 m outdoor range [17]. Wi-Fi networks use radio technologies IEEE 802.11x standard, which is a standard that utilizes the 2.4 GHz and 5 GHz bands, to send and receive the wireless data. The GSM module is a mobile telephone system mainly meant for voice and data, To communicate it needs a comparatively expensive dedicated regional frequency.

Figure3.4.1 GSM Module

		Communication Modules					
		Alternatives					
	Weights	GSM Module	Wi-Fi Module	LTE-M	LORA	Totals	Rank
Transmission Speed	3	0	+	+	0	2	1st
Power Consumption	3	–	–	+	+	0	2nd
Availability	5	+	0	–	0	0	2nd
User friendly/Safety	5	+	0	–	–	-1	3rd
Low Cost	4	–	0	–	–	-3	4th
Total		0	0	-1	-1		
Rank		1st	1st	2nd	2nd		

Table 3.4.0.1 Pugh matrix for Communication module

The above pugh chart shows the most suitable communication modules are the GSM and Wi-Fi module. However, though transmission speed ranked first, criteria such as availability and user-friendliness would be most preferred hence, the GSM module shown in figure **3.4.1** will be used as means for sending data.

3.5 Microcontroller or processor

For the processing unit of the low-cost vitals monitor, there is a huge array of available alternatives for microcontrollers or processors, but considered options include Atmega 328p, Frdm kl25z and Raspberry pi. The raspberry pi is more of a microcomputer hence, it possesses high processing speed, and it is easy to use, but it consumes a lot of power and quite costly. The freedom board kl25z easy to use and, possess flexible power options however, it is relatively expensive and consumes more power than the Atmega 328p.

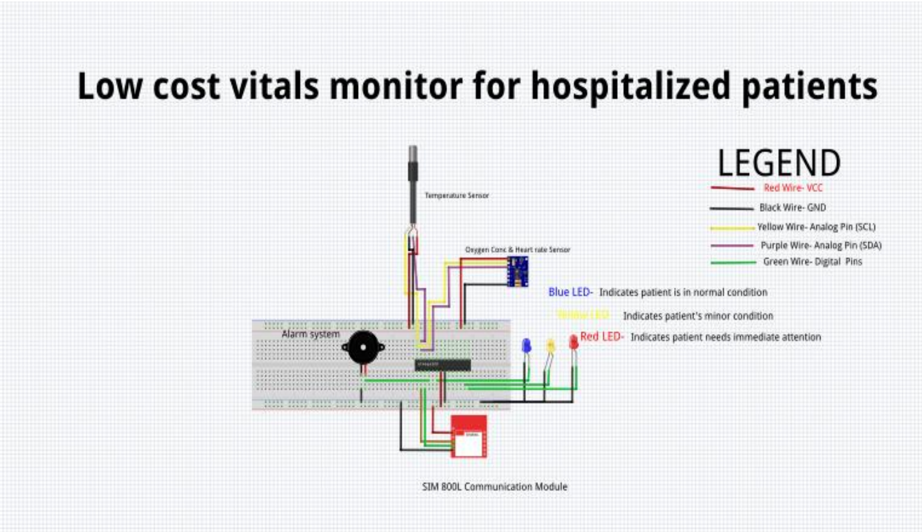
		Microcontroller or processor				
		Alternatives				
	Weights	Atmega 328p	Raspberry Pi	Frdm-kl25z	Totals	Rank
Processing Speed	**3**	−	+	0	**0**	**3rd**
Power Consumption	**3**	+	−	0	**0**	**3rd**
Availability	**5**	+	**0**	**0**	**1**	**2nd**
User friendly/Safety	**5**	0	+	+	**2**	**1st**
Low Cost	**4**	+	−	**0**	**0**	**4th**
	Total	**2**	**0**	**1**		
	Rank	**1st**	**3rd**	**2nd**		

Table 3.5.0.1 Pugh matrix for Microcontroller & processor

The Atmega 328p chip shown in figure **3.5.1** is picked for the low-cost vitals monitor despite its relatively low processing speed and since it also helps create a cost-effective solution with low power consumption rates.

Figure 3.5.1 ATMEGA 328p

Hardware Breadboard Design using Fritzing



3.6 Software Architecture

The framework is typically web-based that has many highlights and parts. The backend of the system can be developed using various backend scripting frameworks such as JavaScript, Java, PHP, Python, among others. For the frontend development available frameworks such as the JavaScript frameworks (React, Vue, or Angular), HTML/CSS and flutter can be used. A database is also needed to hoard the user data hence, SQL will be used. From the array of options presented PHP will be used for backend development, and HTML/CSS/SASS will be implemented for the frontend.

3.6.1 System Flow

The system flow describes how users and the system intermingle with each other and conditions that influence the output. The flow of the system (Web page for vitals monitoring) is represented in the flow chart diagram in figure **3.6.1**.

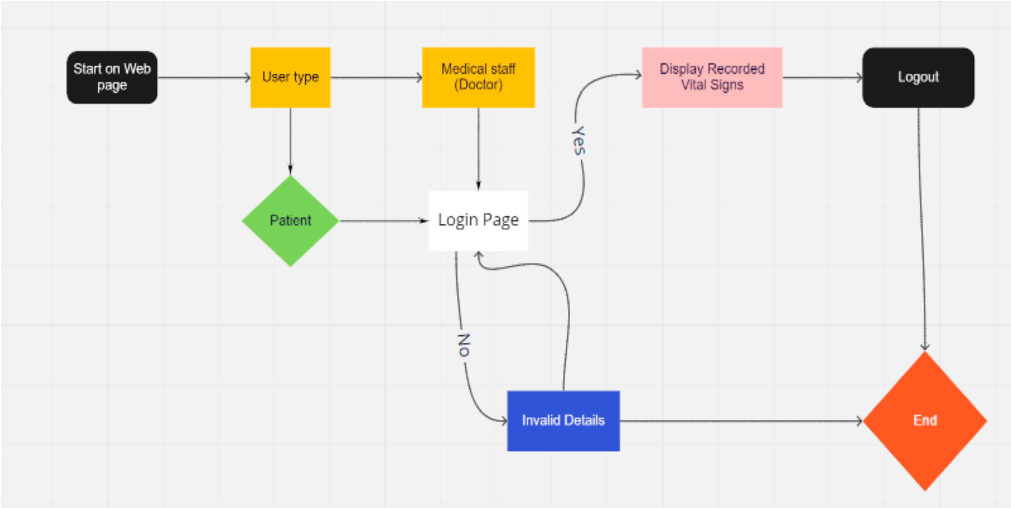


Figure 3.6.1 User Flow chart diagram on the Web page

3.6.2 Client-server architecture

The client-server architecture exhibits the system interaction with the user. The system is hosted on a server and connected to the database with a client making a request through the Internet. The users interact with the portal (Website), to send requests to the server which in turn connects to the database to retrieve the data to be presented to the client. This architecture is shown in figure **3.6.2**.

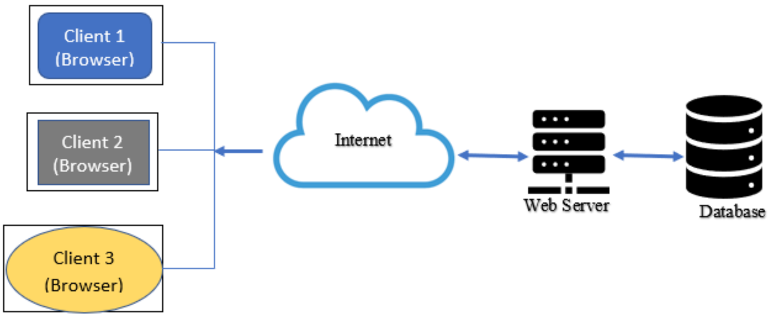


Figure 3.6.2 Client-server architecture

3.7 System Users

The system is designed for medical personnel (Doctors) in Ghana mainly focusing on the Police hospital. However, the vital signs of hospitalized patients may not only be of importance to the doctors but to the patients and family members as well. Below are some key clients that directly interact with the system**:**

a. **Medical Staff:** The designed system mainly serves as a remote platform for doctors to view and monitor some vital signs of hospitalised patients from their smart devices. With their details, the doctors are registered onto the platform, to ensure some level of authenticity and security.

b. **Patients:** These are hospitalized patients whose vital signs are measured and displayed on the web platform. They are registered onto the platform as well, hence can login into the system with their details to see their own recorded vital signs.

3.8 Power Requirements

Components	Voltage (V)	Current (mA)
ATMEGA 328p	5	16
GSM Module	5	2000
MAX 30102	1.8 - 5	0.6
DS18B20	3.3 - 5	1
Buzzer	3.3-5	30
LED's (Red, Yellow, Blue)	3.3-5	30

Table 3.8.0.1 Power requirements for each component

From the power requirement table above, the total voltage which will be required by the system is between five to nine volts. Taking into consideration some user requirement like portability, it is more feasible to use a rechargeable battery which can meet the power requirement of the system.

3.9 Non-Functional Requirements

Security: The designed system will be carrying patients' vital signs which is sensitive data. It is therefore paramount to protect the system from attacks. To meet this requirement the following measures were considered. All data on the system will use POST requests to prevent easy access. Patient and doctor password is encrypted before being saved on the database. However, more security and data protection schemes will be explored in the future.

Home Page for designed web app

Chapter 4: Implementation

This chapter illustrates the implementation of the low-cost vitals monitoring system with regards to the software frameworks (database, web development) and hardware programming such as sensor programming and integration of the various facets of the entire system.

4.1 Power Supply

Majority of the component used in the design of the low-cost vitals monitor, require voltages ranging between 3.3 and 5 V DC. Hence, a constant 5 V power supply was designed using the following modules:

- 9V battery or Rechargeable Battery (Power Bank)
- **LM7805** (a linear voltage regulator)
- Capacitors (10 uf Electrolytic and 0.1uf Ceramic)
- 1 Resistor 330 ohm & Red LED

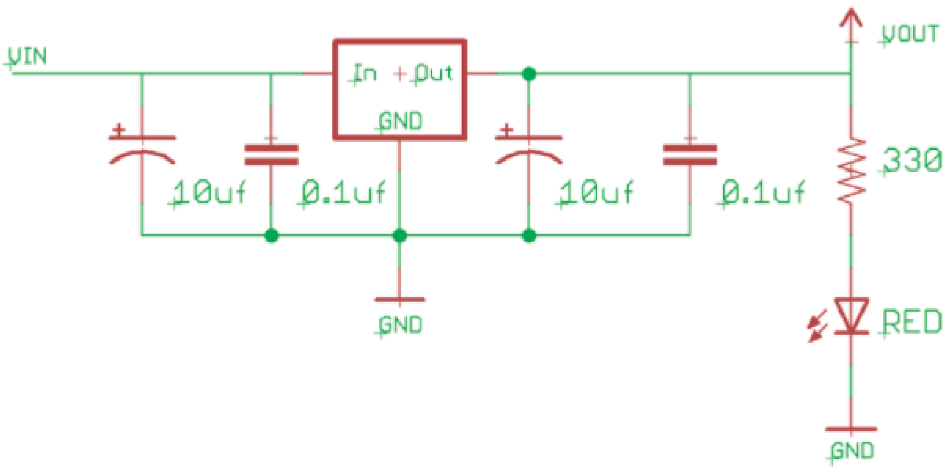


Figure 4.1.1 shows the power supply for low-cost vitals monitor

The 9V battery serves as the input voltage (Vin) and the capacitor combination at both the input and output end helps filter out noise from the circuit. The choice of capacitors values was informed from consulting datasheets of the voltage regulator and research. The 330 ohm resistor was chosen to help reduce the voltage to meet the voltage and current requirement of the LED. The LED has a voltage drop of 3.3 V and draws 20 mA maximum brightness. This implies approximately 1.7 V needs to be lost across the resistor.

$V = IR$; $\frac{5-3.3}{0.02} = 85\ ohm,$ however, a 330 ohm resistor was used instead since I could not acquire an 85 ohm resistor. This choice of the resistor would result in a dimmer LED and save battery power.

4.2 Web Application

The construct of the web application required a few web innovations to make it run, hosted and accessed by users. The transmission of the sensor information from the detecting gadget to the far off data set required facilitating the web application on a remote server in light of the fact that a privately hosted web application must be accessible by users on the same server. In any case, for this situation, a remote global server was needed to host the application so that data generated by detecting devices can be accessed remotely via the Internet.

The primary language used for developing the frontend is the Cascading Style Sheet (CSS), Hyper-Text Markup Language (HTML) and Syntactically Awesome Style Sheets (SASS) whiles PHP Hypertext Preprocessor was used for the backend or server side development. This framework will be used together with a bootstrap framework. The database of choice is MySQL for its flexibility in development and other relational features. The microprocessor will be programmed using C, which is the language for AVR Atmel chips. The tools used during the development process are Sublime Text Editor, GitHub, and Arduino IDE.

4.2.1 Frontend and Backend Development

PHP was chosen for backend framework development because it is an open-source scripting language with many advantages: support for different database types, high performance, has many built-in functions for performing many useful web-related and has wide support and documentation due to its wide usage and popularity [18]. The backend is responsible for processing and storing information input into the system from the frontend into the database, MySQL, and vice versa. A snippet of the backend code is shown below:

```
        <?php include_once('includes/header.php');?>
        <?php include_once('includes/sidebar.php');?>
        <div class="page-wrapper">
            <div class="content">
                <div class="row">
                    <div class="col-sm-12">
                        <h4 class="page-title">B/W Dates Report of Body Temperature</h4>
                    </div>
                </div>
                <div class="row">
                    <div class="col-lg-12">
                        <div class="card-box">
                            <h4 class="card-title">B/W Dates Report of Body Temperature</h4>
                            <form method="post" action="bt-bwdates-reports-details.php">

                                <div class="form-group">
                                    <label>From Date:</label>
                                    <div class="col-md-12 cal-icon">
                                        <input type="text" class="form-control datetimepicker" value="" name="fromdate" required="true">
                                    </div>
                                </div>
                                <div class="form-group">
                                    <label>To Date:</label>
                                    <div class="col-md-12 cal-icon">
                                        <input type="text" class="form-control datetimepicker" value="" name="todate" required="true">
                                    </div>
                                </div>
                                <div class="form-group">
                                    <label>Reg User</label>
                                    <div class="col-md-12">
                                        <select type="text" name="reguser" id="reguser" value="" class="form-control" required="true"
                                        onChange="getmem(this.value)">
<option value="">Choose Reg Users</option>
                                                <?php

$sql2 = "SELECT * from   tbluser ";
$query2 = $dbh -> prepare($sql2);
$query2->execute();
$result2=$query2->fetchAll(PDO::FETCH_OBJ);

foreach($result2 as $row)
{
    ?>
<option value="<?php echo htmlentities($row->ID);?>"><?php echo htmlentities($row->FullName);?></option>
 <?php } ?>
```

Figure 4.2.1 Code Snippet PHP code interacting with the database

The Frontend forms one of the most important aspects of the web application. This is where both doctors and patients register unto the system to observe measured vital signs and other statistics. The web application is to be used by both the doctors and patients but each with different dashboards upon login shown in the figure below:

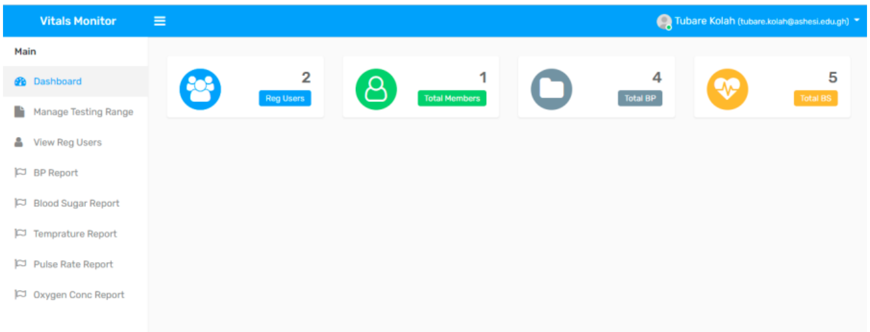


Figure 4.2.2 Doctor's Dashboard

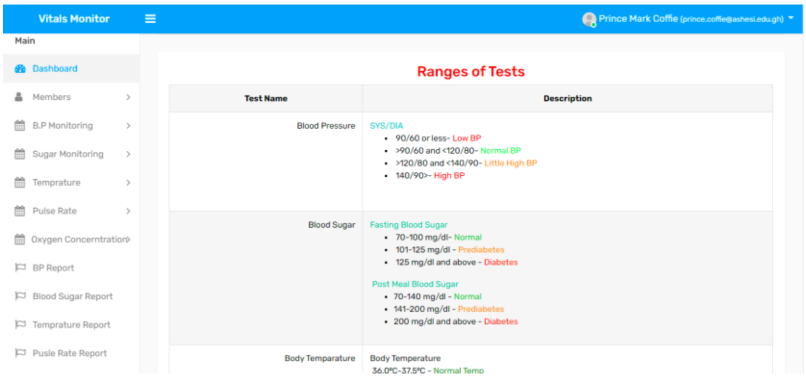


Figure 4.2.3 Patient's Dashboard

4.3 Hardware

4.3.1 Communication module for Data Transmission

Since the ATMEGA 328p microprocessor has no inbuilt server service system, hence it is required that the client's measured data is sent via a communication medium to the database on a remote server in order for patient data to be visible on the web application. The SIM 800L GSM module is used as means of communication shown in Figure **4.3.1**. Therefore, when the vitals of the hospitalised patient are being measured, an HTTP client on the microprocessor through the GSM module is used to access the remote database using the website's HTTP link address. This allows newly measured data to be sent to the remote database using the user's login details.

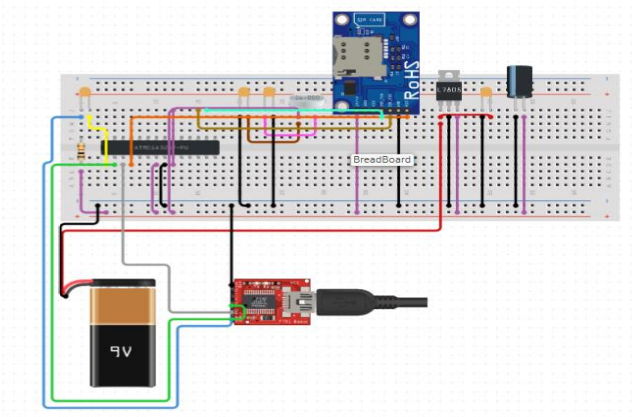


Figure 4.3.1 GSM module connection with ATMEGA328p

4.3.2 Sensing Devices

The main sensing devices used here are the MAX 30102 and DS18B20 which measure pulse rate, oxygen concentration and body temperature.

The DS18B20 temperature sensor is a digital thermometer that provides 9 to 12-bit resolution (configurable) to show the temperature of an object. It communicates over a 1-Wire bus hence needs a single information line and ground (GND) for communication with a chip.

Its main usefulness is its direct to digital temperature sensor making it easy to interact and share information with a computer. The working principle of the DS18B20 sensor is attached in appendix A. The script to read and write the content of these sensors is written in C programming language, in the Arduino IDE. The temperature sensor (DS18B20) will be placed in the axilla of the hospitalised patient to read the body temperature and the MAX 30102 sensor will be placed on the finger to measure the remaining vital parameters. Since the safety of the patient is key, an alarm system with a couple of LEDs is used to indicate the health status of the patient. The alarm goes off and the red LED comes on whenever the recorded temperature, pulse rate and oxygen concentration of the patient does not fall within the set range of the doctor. The sensor recordings are taken every minute. All measured data will be sent via the GSM module to the database on the remote server.

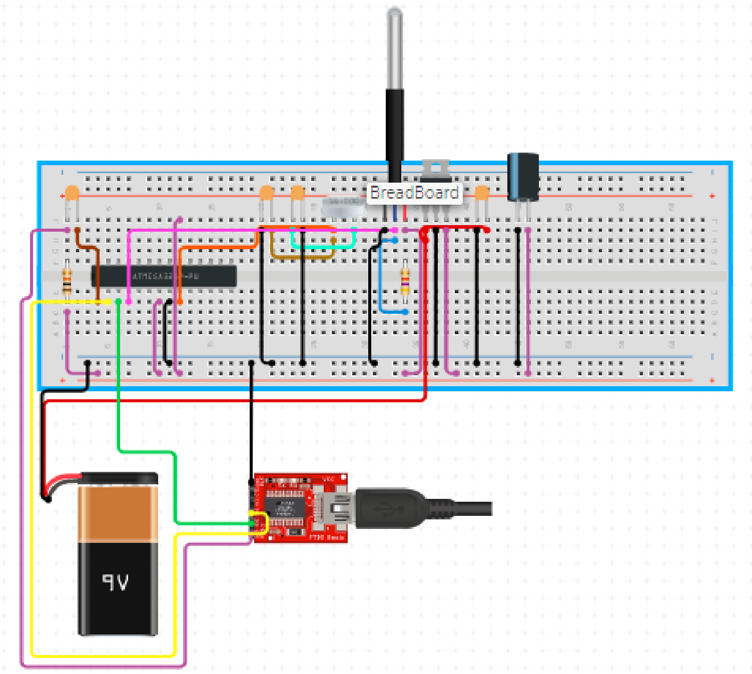


Figure 4.3.2 DS18B20 temperature sensor connection with ATMEGA328p

4.4 Database Development

MySQL is an open-source relational database management system (RDBMS) that operates using the client-server model and Structured Query Language (SQL). MySQL is said to be most suitable for database-driven web applications, logging applications and many more [19]. It is a widely used database because of its robust data segregation scheme of breaking down data into multiple separate storage areas called tables shown in Figure **4.4.1**. The nature of this structure makes it more expressive and powerful for the manipulating of data in the database making it simple, flexible and user friendly.

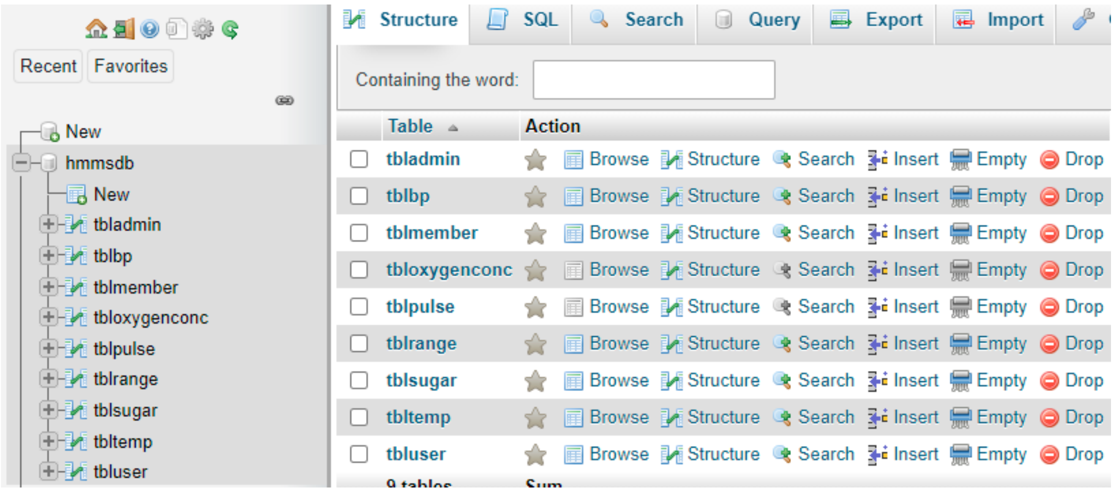


Figure 4.4.1 shows created tables for the database of the vitals monitor

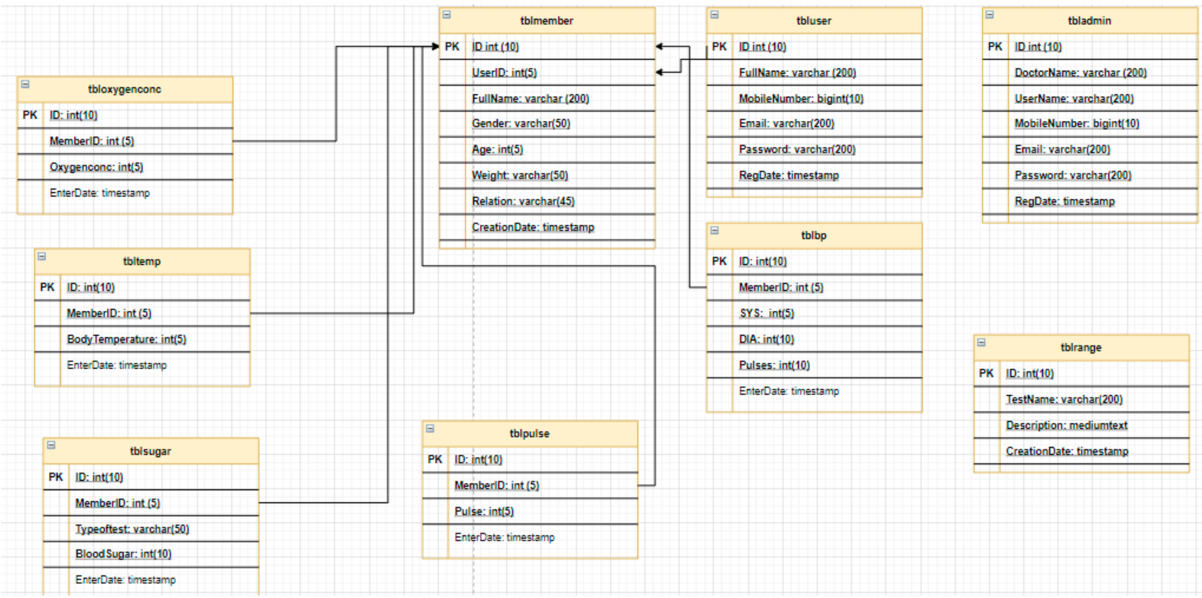


Figure 4.4.2 : Entity relation diagram

Chapter 5: Results and Analysis

5.1 Physical Systems

5.1.1 Power Supply System

The two 5V power supply system were designed shown in Figure 5.1.1 , one to supply power to the ATMEGA 328p processor, sensors, LED'S, buzzer and the other powers the SIM 800l module which consumes about 2A during transmission burst. Using the digilent waveforms oscilloscope the output and the input voltage were measured shown in figure 5.1.2

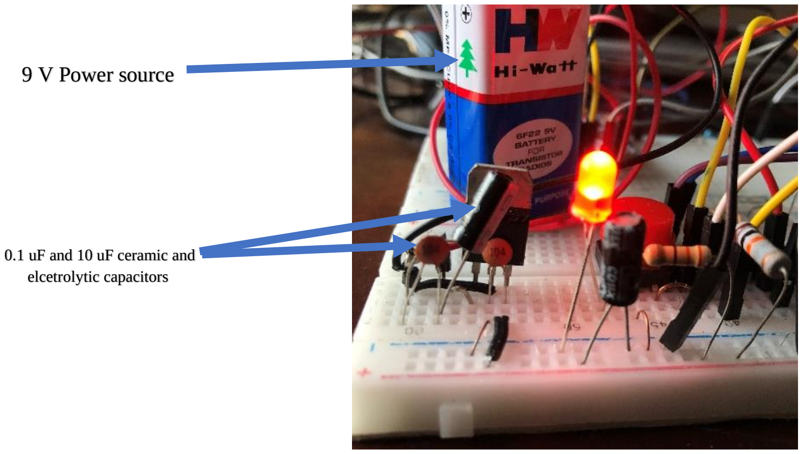


Figure 3 Hardware for designed 5 V power circuit

Figure 4 The digilent waveforms oscilloscope window showing the output and the input voltage

5.1.2 Sensing devices

The sensing devices deployed for this project measured body temperature, pulse rate and oxygen concentration, however the result from the DS18B20 sensor is extensively discussed in this section. This sensor will be placed in the axillary of the hospitalised patient to record body temperature every minute. The recorded temperature value is compared to the set threshold often between 35.5 °C and 37.5ºC (95.9 °F - 99.5 °F) and in the event the threshold is exceeded, the red LED comes on along with a buzzer to drawn attention of the medical staff to the patient who needs to be treated and green LED remains on as long as temperature value of patient remains within the set range. However, the average of three samples are taken before sending to the database.

To record the temperature values using the DS18B20 temperature sensor I used my self as the test subject shown in **figure 5.1.3** and compared the recorded values to a K3 Infrared thermometer which is now used in many hospitals, the following procedures were followed. Three sets of data were sampled, data in the morning, afternoon and evening. Morning data was taken from 8:00 am to 9:06 am, April 22, 2021, with data recorded every minute. The sampled data represented the temperature values of a healthy, hyperthermic and hypothermic person. The last two instances were simulated as follows: a fixed volume of water was either warmed or chilled to a particular temperature. I plunged my hand in the water for 8 to 10 seconds and recorded the temperature values after removing my hand. Ten to twelve samples were collected for each instance i.e. (10-13 Healthy, 10-13 Hyperthermic and 10-13 Hypothermic), however, a total of 37 body temperature values were collected in the morning. This same process was repeated for afternoon and evening, respectively to give data shown in Figure 5.1.7 . Furthermore, the K3 infrared thermometer was subjected to the same process to acquire temperature values as well on April 22, 2021.

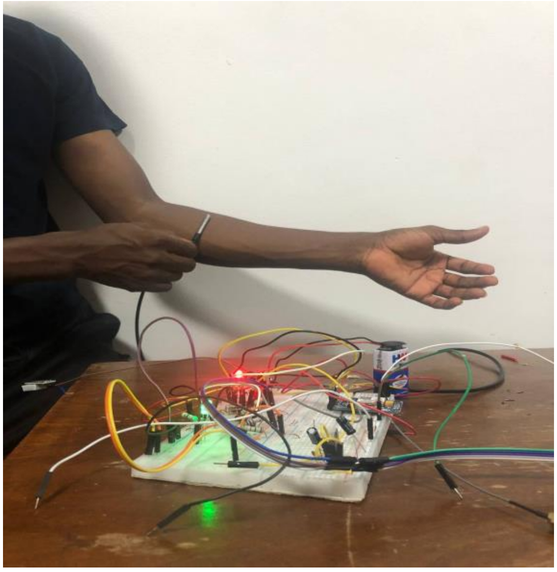


Figure 5 DS18B20 temperature sensor used on test subject

Figure 6 a) K3 Infrared thermometer & b) Location where body temperature values were recorded

To ensure minimum errors and differences in the sampled data, the following measures were considered:

- The DS18B20 sensor was thoroughly wiped after each reading.
- Body temperature values were recorded at a fixed location (Ashesi University, 2nd Lobby)
- All body temperature readings were taking on the hand.

- 10 minutes interval was observed between recording healthy, hyperthermic and hypothermic body temperature values.
- A minimum of 35 samples were taken to ensure that collected data satisfied the Central Limit theorem. This theorem states that the sampling distribution of the sample means looms towards a normal distribution (bell shaped curve) as the sample size gets bigger. This often stands for sample sizes greater than 30 [20].
- Times for reading body temperature was the same for the DS18B20 sensor and the K3 infrared thermometer. Morning (8:00 am - 9:06 am), afternoon (12:30 pm – 1:40pm) and evening (8:30 pm – 9:50 pm). This measure was taken into account based on the assumption that weather and ambient temperature conditions will be the same.
- All activities during the process were timed to ensure consistency.

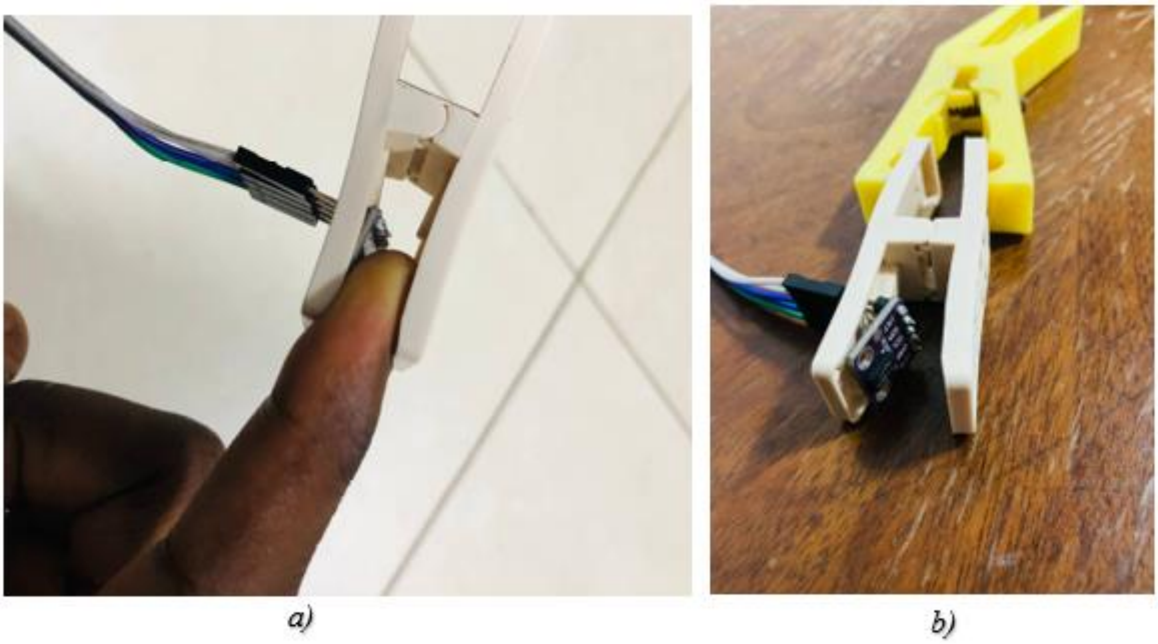


Figure 7 a) MAX 30102 Pulse oximeter with finger inserted & b) MAX30102 Pulse oximeter without finger

Hospital Temperature Sensor K3 Infrared Thermometer			DSB18B20		
Morning_K3Temp	Afternoon_K3Temp	Evening_K3Temp	Morning_DSB18B20	Afternoon_DSB18B20	Evening_DSB18B20
36.5	36.7	35.8	36	35.8	35
36.2	36.7	36.4	36.1	36.4	35.6
36.7	36.8	36.5	35.7	36.5	35.7
36.4	36.7	37.2	35.6	37.2	35.4
36.7	36.7	37.3	36.1	37.3	37.2
36.3	36.8	37.5	35.6	37.5	37.4
36.5	36.7	36.5	35.7	36.5	37.1
36.5	36.8	36.8	35.4	36.8	36.9
36.3	36.8	36.5	34	36.5	35.1
36.6	36.8	36.6	35.8	36.6	35.7
36.4	36.8	36.6	36.7	36.6	36.3
38.1	36.7	36.6	36.6	36.6	35.9
38.3	37.1	38.6	38.3	38.6	35.5
38.7	38	38.7	37.8	38.7	35.9
38.2	38.9	38.2	38	38.2	38.4
38.1	39	37.8	37.8	37.8	40.2
37.8	37.9	37.8	40.1	37.8	40.3
37.6	38.1	38.1	37.6	38.1	39.5
37.8	38.2	37.8	37.8	37.8	38.8
37.9	38.1	38	38.2	38	38.7
37.9	37.8	37.8	39	37.8	38.5
38.5	37.8	37.9	39.5	37.9	39.1
34	37.9	37.8	39.3	37.8	39.9
34.3	38.5	37.7	39.4	37.7	38.9
34.6	34.8	38.2	34.6	38.2	37.9
34.1	34.3	34.5	34.1	34.5	40.1
34	34.6	34.1	34	34.1	39.4
34.2	34	34.2	34.6	34.2	34.4

Figure8: Body temperature data for K3 Infrared Thermometer & DS18B20

5.2 Statistical Analysis & Performance Evaluation

The body temperature values of the DS18B20 sensor were compared to that of the K3 infrared thermometer using the following statistics concepts.

5.2.1 Pearson's Correlation

This is a statistical test that measures the statistical connection, or association, between two continuous variables and assesses whether there is statistical proof for a linear relationship among the variables [21]. It further highlights the extent of the correlation, and the direction of the relationship.

The Pearson's correlation test was conducted on the sampled body temperature values of both temperature sensors. This is to see the kind of correlation the DS18B20 sensor exhibits towards the medically used thermometer (K3 infrared thermometer). However, the test focused on showing the correlation that existed among dataset collected at different times of the day (e.g., what is the correlation between data collected by the DS18B20 sensor and K3 infrared thermometer in the evening).

Starting with the null hypothesis (H_o) that: There is no correlation between body temperature values recorded by K3 infrared thermometer and DS18B20 sensor in the morning (H_0: $\rho \leq 0$). Alternative hypothesis (H_1) : There is a correlation between body temperature values recorded by K3 infrared thermometer and DS18B20 sensor in the morning (H_1: $\rho > 0$).

Performing a two-tailed test with a 95% confidence interval ($\alpha = 0.05$) and degree of freedom ($df = n - 2$) , where 'n' is the sample size,

$$df = 37 - 2 = 35$$

Consulting the Critical Values for Pearson's Correlation Coefficient table in appendix B to find the (r_{critical}),

$$r_{\text{critical}} = +0.3246 \text{ or } - 0.3246$$

Therefore, the null hypothesis is rejected if $r_{\text{observed}} > r_{\text{critical}}$. Using excel the following results were achieved.

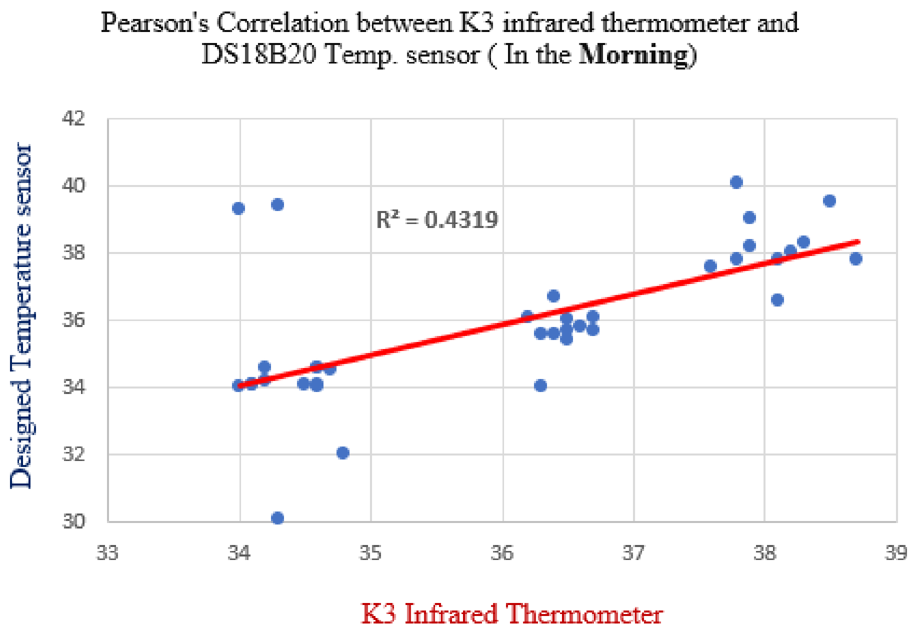


Figure 5.9.1: Scatter plot to show the linear correlation between DS18B20 & K3 infrared thermometer

Pearson's coefficient (r) of the above correlation is shown as follows:

$$r_{\text{observed}} = \sqrt{R^2} \text{ .... Eqn 5.2.1}$$

$$r_{\text{observed}} = \sqrt{0.4319} = 0.657$$

Therefore, from the calculated Pearson's coefficient (r_{observed}) which is positive, greater than 0.5 and greater than r_{critical} the null hypothesis (H_0) is rejected. This implies that there is a considerably strong and positive correlation between temperature values recorded by the K3 infrared thermometer and the DS18B20 sensor in the morning. Hence, an increase in body temperature values of the K3 infrared thermometer tends to cause an increase in the values of the DS18B20 sensor as well.

	1.	*2.*	*3.*	*4.*	*5.*	*6.*
1. Morning_K3 Temp	---					
2. Afternoon_K3 Temp	0.77	---				
3. Evening_K3 Temp	0.75	0.87	---			
4. Morning_DS18B20	**0.64**	0.85	0.80	---		
5. Afternoon_DS18B20	0.75	**0.87**	1.00	0.80	---	
6. Evening_DS18B20	0.32	0.60	**0.57**	0.64	0.57	---

Note: **Bold** *and* red *coefficients are the main/key coefficients of interest*

Table 5.2.1 Pearson's Coefficients of all variables under study

Further comparing the result from equation 5.2.1 to the tabulated results of Table 5.2.1, it is clearly seen that there is some small differences. This is mainly caused by some truncations or rounding effect applied whiles generating the correlation table in excel. For example, the Pearson correlation coefficient between morning K3 infrared values and morning DS18B20 sensor values is **0.657** for calculated and **0.64** for tabulated. Finally, since the null hypothesis has been rejected in all the cases ($r_{\text{observed}} > r_{\text{critical}}$.) it can be concluded that the DS18B20 sensor can used in the hospital to measure the body temperature of hospitalized patients.

5.3 Cost Analysis

This section focuses on discussing the financial cost involved in the deployment of the project. Further comparison is made to know by how much the designed system varies from the available vital signs monitors.

Cost Breakdown

DS18B20 Temperature sensor = $ 5

MAX30102 Pulse and oxygen concentration sensor = $ 5

GSM Module (SIM 800L) = $ 20

Battery (2x) = $ 6

ATMEGA328p = $ 3

Consumables (Resistors, LED’s, Capacitors, jumper wires, breadboards, voltage regulators, and so on = $ 25

Shipping and Transportation = $ 60

The total cost for the manufacturing of a single low-cost vitals monitor is estimated at $ 124 which about 717 Ghana cedis. Though this system may not be as efficient as the available vitals monitor, it can still serve a great purpose by sensing patients vital signs, displaying the measured data via a web application and with its alarm system draw the attention of medical officials whenever needed. The analysis finally highlights that the designed vitals monitor is far cheaper the available vital signs monitor.

CHAPTER 6 : Conclusion

The IoT vitals monitoring system for hospitals in developing countries (e.g., Police hospital, Ghana) illustrates how IoT can be integrated in the healthcare industry. The vitals monitoring Web Application provides flexibility and adaptability for any type of hospital in Ghana and Africa at large. A doctor and hospitalized patient can register via the web page and in conjunction with the hardware, the vital signs (Body temperature, Pulse rate, and oxygen concertation) can be monitored. The web application (database) has made room for other vital signs such as blood pressure and blood sugar that hasn't been incorporated to the hardware aspect of the vitals monitor. With this smart system also, the medical staff do not have to use spot-checking to record patient vital signs which is very unreliable; since everything is being continuously monitored and displayed on the web application. The vitals monitor will help save lives and go on to reduce the deathrates in our hospitals and healthcare industry.

The DS18B20 temperature sensor gave accurate body temperature results based on its statistical comparison (Pearson's correlation)with the K3 infrared thermometer, however how it will behave after a long time is quite problematic. Since from research it starts to record slightly wrong values after some time of usage (i.e. 18 to 24 months).

6.1 Limitations

- The DS18B20 temperature sensor was tested on simulated hyperthermic and hypothermic conditions which might not be the same as a human being in such conditions.
- 9 V batteries, which was used as a power source drained quickly, hence getting a strong rechargeable battery is essential.
- Data on the web page is displayed in tabular format which makes it quite difficult to comprehend and much meaning cannot be deduced from it.

❖ The designed system was deployed in a breadboard which exposes the circuitry to all sort of unhelpful conditions and might affect the effectiveness of the system in a long run.

6.2 Future works

❖ The system should be tried on real life scenarios to help show the effectiveness of the system.

❖ The web application should display patient’s data in a graphical format for easy comprehension and analysis.

❖ The system should be able to send an SMS to a loved one and the doctor when an abnormal vital sign persists.

References

[1] “Poor monitoring is behind most preventable hospital deaths | News | Pharmaceutical Journal.” https://www.pharmaceutical-journal.com/news-and-analysis/poor-monitoring-is-behind-most-preventable-hospital-deaths/11104270.article (accessed Jan. 03, 2021).

[2] T. Powell-Jackson, S. Mazumdar, and A. Mills, “Financial incentives in health: New evidence from India’s Janani Suraksha Yojana,” *J. Health Econ.*, vol. 43, pp. 154–169, Sep. 2015, doi: 10.1016/j.jhealeco.2015.07.001.

[3] “Poverty Overview.” https://www.worldbank.org/en/topic/poverty/overview (accessed Jan. 04, 2021).

[4] P. Howden-Chapman, J. Siri, E. Chisholm, R. Chapman, C. N. H. Doll, and A. Capon, “SDG 3 ENSURE HEALTHY LIVES AND PROMOTE WELL-BEING FOR ALL AT ALL AGES.”

[5] A. Hallmann-Mikołajczak, “Ebers Papyrus. The book of medical knowledge of the 16th century B.C. Egyptians,” *Arch. Hist. Filoz. Med.*, vol. 67, no. 1, pp. 5–14, 2004, Accessed: Jan. 01, 2021. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/15586450/.

[6] H. Graham, “Surgeons all. By Harvey Graham. With a Foreword by Oliver St. John Gogarty. 9 × 6 in. Pp. 426, with 24 Plates. 1939. London: Rich & Cowan Ltd. 18s. net,” *Br. J. Surg.*, vol. 27, no. 105, pp. 206–207, Jul. 1939, doi:

10.1002/bjs.18002710552.

[7] B. L. Steinberg and S. B. London, “Automated blood pressure monitoring during surgical anesthesia.,” *Anesthesiology*, vol. 27, no. 6, pp. 861–863, Nov. 1966, doi: 10.1097/00000542-196611000-00024.

[8] C. Shnayder *et al.*, “Sensor Networks for Medical Care.” Accessed: Dec. 19, 2020. [Online]. Available: https://dash.harvard.edu/handle/1/24829604.

[9] M. Niswar, M. Nur, A. A. Ilham, and I. Mappangara, “A low cost wearable medical device for vital signs monitoring in low-resource settings,” *Int. J. Electr. Comput. Eng.*, vol. 9, no. 4, pp. 2321–2327, 2019, doi: 10.11591/ijece.v9i4.pp2321-2327.

[10] K. J. P. Ortiz, J. P. O. Davalos, E. S. Eusebio, and D. M. Tucay, “IoT: Electrocardiogram (ECG) monitoring system,” *Indones. J. Electr. Eng. Comput. Sci.*, vol. 10, no. 2, pp. 480–489, May 2018, doi: 10.11591/ijeecs.v10.i2.pp480-489.

[11] T. M. Chen, C. H. Huang, E. S. C. Shih, Y. F. Hu, and M. J. Hwang, “Detection and Classification of Cardiac Arrhythmias by a Challenge-Best Deep Learning Neural Network Model,” *iScience*, vol. 23, no. 3, p. 100886, Mar. 2020, doi: 10.1016/j.isci.2020.100886.

[12] M. Abo-Zahhad, S. M. Ahmed, and O. Elnahas, “A wireless emergency telemedicine system for patients monitoring and diagnosis,” *Int. J. Telemed. Appl.*, 2014, doi: 10.1155/2014/380787.

[13] S. P. Clarke and N. E. Donaldson, *Nurse Staffing and Patient Care Quality and Safety*. Agency for Healthcare Research and Quality (US), 2008.

[14] F. G. Benedict, W. R. Miles, and A. Johnson, “THE TEMPERATURE OF THE HUMAN SKIN.”

[15] J. E. Sinex, “Pulse oximetry: Principles and limitations,” *American Journal of Emergency Medicine*, vol. 17, no. 1. W.B. Saunders, pp. 59–66, Jan. 01, 1999, doi: 10.1016/S0735-6757(99)90019-0.

[16] E. P. Rivers, D. S. Ander, and D. Powell, “Central venous oxygen saturation monitoring in the critically ill patient,” *Current Opinion in Critical Care*, vol. 7, no. 3. Curr Opin Crit Care, pp. 204–211, 2001, doi: 10.1097/00075198-200106000-00011.

[17] R. Singh Ȧ, P. Singh Ȧ, and K. Yadav Ḃ Ȧ, “Wireless Communications Enlargement: A Review of Advancement in Technologies,” 2014. Accessed: Apr. 05, 2021. [Online]. Available: http://inpressco.com/category/ijcet.

[18] C. Supaartagorn, “PHP Framework for Database Management Based on MVC Pattern,” *Int. J. Comput. Sci. Inf. Technol.*, vol. 3, no. 2, pp. 251–258, Apr. 2011, doi: 10.5121/ijcsit.2011.3219.

[19] M. Kofler and M. Kofler, “What Is MySQL?,” in *MySQL*, Apress, 2001, pp. 3–19.

[20] C. C. Heyde, “Central Limit Theorem,” in *Wiley StatsRef: Statistics Reference Online*,

Chichester, UK: John Wiley & Sons, Ltd, 2014.

[21] M. M. Mukaka, “Statistics Corner: A guide to appropriate use of Correlation coefficient in medical research,” 2012. Accessed: Apr. 27, 2021. [Online]. Available: www.mmj.medcol.mw.

Appendix A

1-Wire Signaling

The DS18B20 uses a strict 1-Wire communication protocol to ensure data integrity. Several signal types are defined by this protocol: reset pulse, presence pulse, write 0, write 1, read 0, and read 1. The bus master initiates all these signals, with the exception of the presence pulse.

Initialization Procedure—Reset And Presence Pulses

All communication with the DS18B20 begins with an initialization sequence that consists of a reset pulse from the master followed by a presence pulse from the DS18B20. When the DS18B20 sends the presence pulse in response to the reset, it is indicating to the master that it is on the bus and ready to operate.

During the initialization sequence the bus master transmits (Tx) the reset pulse by pulling the 1-Wire bus low for a minimum of 480µs. The bus master then releases the bus and goes into receive mode (Rx). When the bus is released, the 5kΩ pullup resistor pulls the 1-Wire bus high. When the DS18B20 detects this rising edge, it waits 15µs to 60µs and then transmits a presence pulse by pulling the 1-Wire bus low for 60µs to 240µs.

Read/Write Time Slots

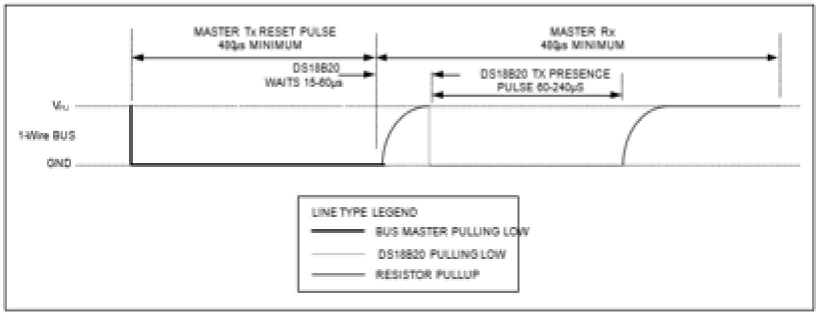
The bus master writes data to the DS18B20 during write time slots and reads data from the DS18B20 during read time slots. One bit of data is transmitted over the 1-Wire bus per time slot.

Write Time Slots

There ar two types of write time slots: "Write 1" time slots and "Write 0" time slots. The bus master uses a Write 1 time slot to write a logic 1 to the DS18B20 and a Write 0 time slot to write a logic 0 to the DS18B20. All write time slots must be a minimum of 60µs in duration with a minimum of a 1µs recovery time between individual write slots. Both types of write time slots are initiated by the master pulling the 1-Wire bus low.

To generate a Write 1 time slot, after pulling the 1-Wire bus low, the bus master must release the 1-Wire bus within 15µs. When the bus is released, the 5kΩ pullup resistor will pull the bus high. To generate a Write 0 time slot, after pulling the 1-Wire bus low, the bus master must continue to hold the bus low for the duration of the time slot (at least 60µs).

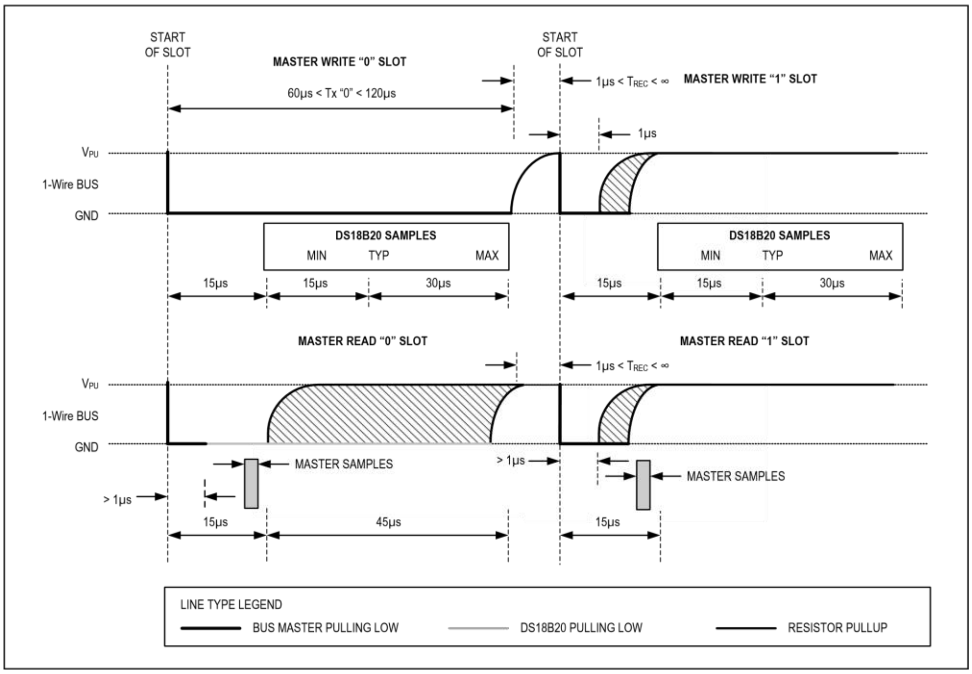
The DS18B20 samples the 1-Wire bus during a window that lasts from 15µs to 60µs after the master initiates the write time slot. If the bus is high during the sampling window, a 1 is written to the DS18B20. If the line is low, a 0 is written to the DS18B20.



Read Time Slots

The DS18B20 can only transmit data to the master when the master issues read time slots. Therefore, the master must generate read time slots immediately after issuing a Read Scratchpad [BEh] or Read Power Supply [B4h] command, so that the DS18B20 can provide the requested data. In addition, the master can generate read time slots after issuing Convert T [44h] or Recall E2 [B8h] commands to find out the status of the operation as explained in the DS18B20 Function Commands section.

All read time slots must be a minimum of 60µs in duration with a minimum of a 1µs recovery time between slots. A read time slot is initiated by the master device pulling the 1-Wire bus low for a minimum of 1µs and then releasing the bus. After the master initiates the read time slot, the DS18B20 will begin transmitting a 1 or 0 on bus. The DS18B20 transmits a 1 by leaving the bus high and transmits a 0 by pulling the bus low. When transmitting a 0, the DS18B20 will release the bus by the end of the time slot, and the bus will be pulled back to its high idle state by the pullup resister. Output data from the DS18B20 is valid for 15µs after the falling edge that initiated the read time slot. Therefore, the master must release the bus and then sample the bus state within 15µs from the start of the slot.

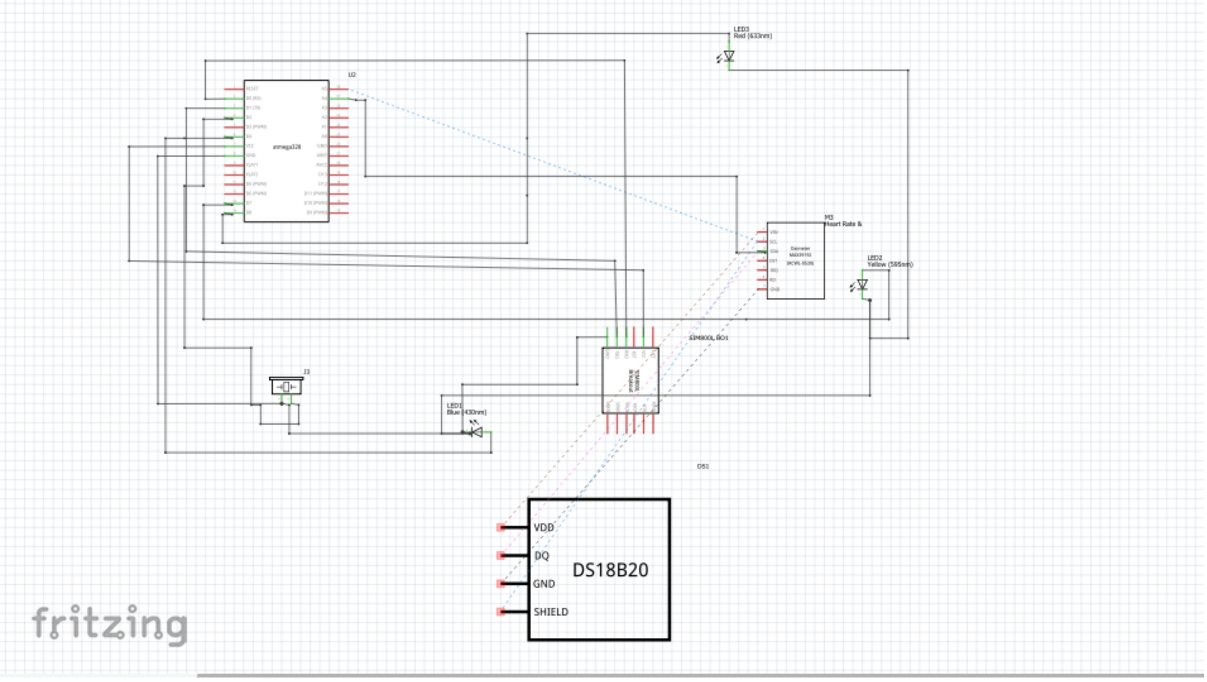

START OF SLOT
MASTER WRITE "0" SLOT
60µs < Tx "0" < 120µs
START OF SLOT
1µs < TREC < ∞
MASTER WRITE "1" SLOT
1µs
VPU
1-Wire BUS
GND
DS18B20 SAMPLES
MIN
TYP
MAX
15µs
15µs
30µs
MASTER READ "0" SLOT
MASTER READ "1" SLOT
MASTER SAMPLES
> 1µs
45µs
LINE TYPE LEGEND
BUS MASTER PULLING LOW
DS18B20 PULLING LOW
RESISTOR PULLUP

Appendix B

Critical Values for Pearson's Correlation Coefficient

	Level of Significance of a One-Tailed or Directional Test					
	H_0: $\rho \leq 0$ or H_0: $\rho \geq 0$					
	$\alpha = 0.1$	$\alpha = 0.05$	$\alpha = 0.025$	$\alpha = 0.01$	$\alpha = 0.005$	$\alpha = 0.0005$
	Level of Significance of a Two-Tailed or Nondirectional Test					
	H_0: $\rho = 0$					
df	$\alpha = 0.2$	$\alpha = 0.1$	$\alpha = 0.05$	$\alpha = 0.02$	$\alpha = 0.01$	$\alpha = 0.001$
1	0.9511	0.9877	0.9969	0.9995	0.9999	0.9999
2	0.8000	0.9000	0.9500	0.9800	0.9900	0.9990
3	0.6870	0.8054	0.8783	0.9343	0.9587	0.9911
4	0.6084	0.7293	0.8114	0.8822	0.9172	0.9741
5	0.5509	0.6694	0.7545	0.8329	0.8745	0.9509
6	0.5067	0.6215	0.7067	0.7887	0.8343	0.9249
7	0.4716	0.5822	0.6664	0.7498	0.7977	0.8983
8	0.4428	0.5494	0.6319	0.7155	0.7646	0.8721
9	0.4187	0.5214	0.6021	0.6851	0.7348	0.8470
10	0.3981	0.4973	0.5760	0.6581	0.7079	0.8233
11	0.3802	0.4762	0.5529	0.6339	0.6835	0.8010
12	0.3646	0.4575	0.5324	0.6120	0.6614	0.7800
13	0.3507	0.4409	0.5140	0.5923	0.6411	0.7604
14	0.3383	0.4259	0.4973	0.5742	0.6226	0.7419
15	0.3271	0.4124	0.4821	0.5577	0.6055	0.7247
16	0.3170	0.4000	0.4683	0.5425	0.5897	0.7084
17	0.3077	0.3887	0.4555	0.5285	0.5751	0.6932
18	0.2992	0.3783	0.4438	0.5155	0.5614	0.6788
19	0.2914	0.3687	0.4329	0.5034	0.5487	0.6652
20	0.2841	0.3598	0.4227	0.4921	0.5368	0.6524
21	0.2774	0.3515	0.4132	0.4815	0.5256	0.6402
22	0.2711	0.3438	0.4044	0.4716	0.5151	0.6287
23	0.2653	0.3365	0.3961	0.4622	0.5052	0.6178
24	0.2598	0.3297	0.3882	0.4534	0.4958	0.6074
25	0.2546	0.3233	0.3809	0.4451	0.4869	0.5974
30	0.2327	0.2960	0.3494	0.4093	0.4487	0.5541
35	0.2156	0.2746	0.3246	0.3810	0.4182	0.5189
40	0.2018	0.2573	0.3044	0.3578	0.3932	0.4896
50	0.1806	0.2306	0.2732	0.3218	0.3542	0.4432
60	0.1650	0.2108	0.2500	0.2948	0.3248	0.4079
70	0.1528	0.1954	0.2319	0.2737	0.3017	0.3798
80	0.1430	0.1829	0.2172	0.2565	0.2830	0.3568
90	0.1348	0.1726	0.2050	0.2422	0.2673	0.3375
100	0.1279	0.1638	0.1946	0.2301	0.2540	0.3211
150	0.1045	0.1339	0.1593	0.1886	0.2084	0.2643
300	0.0740	0.0948	0.1129	0.1338	0.1480	0.1884
500	0.0573	0.0735	0.0875	0.1038	0.1149	0.1464
1000	0.0405	0.0520	0.0619	0.0735	0.0813	0.1038

Appendix C



Appendix D