UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

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

Design and Development of an IoT-Based Automatic Monitoring and Early Warning System for Low Back Pain

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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:

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and
Dr. Nuhu ASSUMANI

DECLARATION

I, KALISA Jean Bosco, declare that this dissertation entitled "Design and Development of an IoT-Based Automatic Monitoring and Early Warning System for Low Back Pain" is my original work based on research and Design and has not been submitted for any other degree or professional qualification.

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CERTIFICATE

This is to certify that the project entitled "Design and Development of an IoT-Based Automatic Monitoring and Early Warning System for Low Back Pain" is a record of original work done by 222000945, a MSc. Degree student in Biomedical Engineering.

This work has been submitted under the guidance of Dr. Emmy MUGISHA and Dr. Nuhu ASSUMANI.

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ABSTRACT

Worldwide, people struggle with low back pain. Monitoring the factors contributing to this pain is crucial to avoid such a medical disorder. Traditional methods consist of unreliable evaluations or delayed clinical tests to monitor and identify this health issue. At home, the patient is unable to determine the cause of the pain he/she is experiencing at the low back. A human-centered data collection was conducted at Rwamagana level-II teaching hospital and at RP/IPRC Gishari with the purpose of getting insights on prevalence of low back pain among employees and the key factors associated with this issue. The results from this survey showed that low back discomfort is more prevalent for nurses than the other employees asked with 30% and 16.7% respectively and this is explained by the fact that nurses are mostly engaged in activities that affect their low back. Existing solutions to this problem focused on gauging the muscle activity but did not consider that the pain at the low back can be caused by the bad posture of the low back. In this study, the IoT-based automatic monitoring and early warning system was designed and developed to address this gap. It is based on the principle of detecting the posture of the low back using an accelerometer sensor connected to the Node MCU which acts as the heart of the entire system. The posture data are sent into the database and accessed by the user through a web page. When the bad posture is detected for at least 30min the system warns the user to change that position and thus avoid the pain that may result. Circuit design in Proteus Software as well as prototype development are the approaches used to get the intended solution.

Keywords: Low back pain, Real-time monitoring, Early warning, Posture monitoring.

LIST OF ACRONYMS

AC :Alternating Current

ADS :Advanced Design System

CEBE :Center of Excellence in Biomedical Engineering and E-Health

CHUK :Centre Hospitalier Universitaire de Kigali

CLBP :Chronic Low Back Pain

CMHS :College of Medicine and Health Sciences

CT :Computed Tomography

EIM :Electrical Impedance Myography

EMG :Electromyography

ESP :Espressif modules

FSR :Force-Sensitive Resistor

GSM :Global System for Mobile Communication

IoT :Internet of Things

IPRC :Integrated Polytechnic Regional College

IRB :Institutional Review Board

LBP :Low Back Pain

MAV :Mean Absolute Value

MCU :Microcontroller Unit

MMG :Mechanomyographic

MNF :Mean Frequency

MRI :Magnetic Resonance Imaging

MSc :Master of Science

MVC :Maximal Voluntary Contraction

NMES :Neuromuscular Electrical Stimulation

PC :Personal Computer

RF :Radio Frequency

RMS :Root Mean Square

RP :Rwanda Polytechnic

SCI :Spinal Cord Injury

UR :University of Rwanda

FIGURES

TABLES

TABLE OF CONTENTS

CHAPTER 1 : GENERAL INTRODUCTION

1.1. Introduction

1.1.1. Definition of key terms and concepts

Low back pain refers to the discomfort felt between the buttocks and the lower edge of the ribcage. Approximately 70% to 80% of people will experience low back discomfort at some point in their life, making it one of the most prevalent medical complaints worldwide [1]. Acute low back pain lasts less than six weeks, subacute pain lasts between six and twelve weeks, and chronic low back pain lasts longer than twelve weeks. It could be a sign of discomfort to one or both lower limbs [2].

Real-time monitoring refers to the provision of continually updated data concerning systems, procedures, or events. Data collection and analysis happen with the least amount of delay possible thanks to this kind of monitoring, which streams information at zero or low latency. It makes it possible to find abnormalities, problems with performance, and important events quickly[3].

Many energy sources, including mechanical vibrations, electromagnetic fields, light, sound, airflow, heat, and temperature fluctuations, can be harvested for energy. The process of converting ambient energy into electrical energy that can be used is known as energy harvesting or energy scavenging. In contrast to energy contained in typical storage components like batteries, capacitors, and the like, accessible energy from the environment is comparatively boundless [4]. As systems get smaller, there is less energy accessible on board, which results in shorter battery life or shorter run times for devices. Researchers are still working on creating high-energy density batteries, but the systems' lifetime is constrained by the batteries' low and limited energy availability. Among all other forms of ambient energy, such as solar, water, wind, thermal, etc., radiofrequency energy is more abundant. Scavenging radio frequency (RF) power from surrounding areas such as cellular base stations, Wi-Fi access points, and television and radio broadcast stations is a simple and constant process. Only a little amount of power is received by the receiver's antenna from these sources, even though their transmissions are quite powerful (in the KW range). Thus, it is possible to capture lost energy and use it to create electricity, which powers low-power gadgets[5].

1.1.2. Background

One of the most prevalent health issues, low back pain, has a significant impact on people's lives, communities, and economies around the world. According to a comprehensive analysis of the prevalence of low back pain worldwide, women and people between the ages of 40 and 80 are the populations most likely to experience it [1].

Trustworthiness of self-reporting, accurate diagnosis, determining the appropriate period for reassessment, and adherence to interventions and recommendations are the main problems in the therapy of back pain. In the controlled setting of a clinic visit, the severity of BP impact on physiological and social functioning is observed at a specific point in time [3][6].

The most common cause of years spent disabled worldwide is low back pain. The World Health Organization was urged by an international working group to focus more on the prevalence of low back pain and the need to steer clear of too medical treatments in 2018. In fact, many individuals with low back pain today require little to no formal treatment, according to major worldwide professional standards. When therapy is necessary, it is advised to promote physical and psychological therapies rather than the use of painkillers, steroid injections, and spinal surgery. A lot of health systems are not built to accommodate this method [7].

The number of years lost to disability due to low back pain is increasing globally, and this problem is becoming more prevalent as the population ages. The consequences will likely be more severe in low-income and middle-income nations because these demographic changes are occurring more quickly there, where there may not be the resources to address the issue. As the majority of low back pain is unconnected to particular, recognizable spinal anomalies, our viewpoint, the third item in the Lancet Series, is a call to action about this widespread issue [8].

Various research papers highlighted the low back pain as a global issue that requires every ones ’attention. Solutions for wearable body monitoring devices have been facilitated by recent developments in sensor technology, low power electronics, power delivery, data transmission, security measures, and information processing methodologies. The design of a reliable IoT-Based monitoring system for real-time assessment of the low back health condition is done in this research project. It is able to alert users whenever the sensor data are below or above threshold values and thus avoid regular visits to the hospital for physical checkups that are costly and time consuming.

1.2. Problem statement

People experience low back discomfort in a variety of ways. It may result in pain and discomfort, making it challenging to work, attend school, or engage in other activities. Additionally, it may cause muscle stiffness, weakness, and restricted range of motion. Low back pain can occasionally be so bad that it renders a person disabled. Heavy lifting, bending, twisting, and prolonged standing are jobs that increase the chance of developing low back discomfort. Nurses, construction workers, drivers, and industrial employees are people mostly exposed to low back disorders.

The recent study conducted in CHUK revealed that 70% of nurses are suffering from low back problems. It was shown that the department of Internal Medicine had the highest percentage of nurses who experienced LBP. Another research study[9], was conducted to 122 nurses at Kanombe Militaly Hospital. The results revealed the prevalence of low back pain among nurses at 78%. Physical activity and low back pain did not significantly correlate, according to the data, which also revealed that job-related physical activity accounted for the majority of physical activity (83.6%) and leisure-time physical activity (4.9%). The study came to the conclusion that there might be more variables that influence low back pain in nurses than only their physical activity levels and demographic traits. These include biological and environmental obstacles (financial limitations, infrastructure, emotional behaviors, work- or personal-related stress, and cultural limits), as well as psycho-social elements (biomechanics of the body).

A research study[10], was conducted to 144 selected bank staff in Kigali City and it has shown that the prevalence of low back pain among them is at 45.8%. Their research study came to the conclusion that, at the reduced model of multivariable analysis, elements like sitting with the back twisted or curved, as well as not taking breaks while work, were linked to back discomfort. L. Morris et al [11] presented the results of an updated review of the literature on the prevalence of LBP in African countries and draw attention to the particular difficulties in locating epidemiological data throughout the continent. A large portion of the research was done in South Africa (n = 16;25%) as well as Nigeria (n = 31;47%). According to this assessment, the lifetime, yearly, and point prevalence of LBP in African countries was generally significantly greater than the stated global LBP prevalence estimates. G. Ogunsanya et [12], conducted a research with the purpose of finding out the prevalence of LBP and related variables in a Nigerian metropolitan community. With one instance, yearly, and lifelong incidence of 31.2%, 61.1%, and 70.6%, respectively, LBP is prevalent among people in the research area. Strategies aiming at preventing low back pain (LBP) should focus on improving recognized modifiable related variables, such as bad posture, inactivity, and a lack of knowledge about LBP. B. Naude [13], conducted a research in a district hospital from South Africa. The purpose of that study was to identify the factors that influence low back pain in employees. According to the findings, 47% of people reported having low back pain at some point. The majority of the staff members were female nurses, with ages ranging from 26 to 40. Among the staff at Tshwane District Hospital, low back discomfort was quite common. While group exercise lowers the risk of low back pain, female gender and a high degree of perceived stress raise the risk of low back pain.

Multiple trips to the doctor or a specialist are necessary for current monitoring techniques. Particularly for people who reside in rural areas or do not have adequate health insurance, this is costly and time-consuming. Although X-rays, CT scans, and MRIs are common traditional diagnostic methods, which provide the information about the structure, they may not fully reveal functional problems or pain. Since most diagnostic techniques mainly depend on the presence of signs, disorders that do not manifest with severe pain or discomfort until later stages, might remain undiscovered. Current diagnostic techniques offer Images of the state of a patient at a certain period. The proposed project will offer real-time low back health monitoring, providing early warning for abnormal conditions thus guiding proper decisions and further treatments.

1.3. Research Questions

The following questions are the baselines, which guided this study:

1. What are the major causes and prevalence of low back pain in various demographic groups?
2. In what ways can low back pain risky conditions be identified and predicted based on reliable data?
3. How users can be assisted in self-monitoring and tracking of the factors that cause low back pain?
4. How can an integrated system to address the causes of low back pain be developed and tested to determine its efficacy and usability?

1.4. Objectives

1.4.1. General Objective

The general objective of this research project is to develop an IoT-based automatic monitoring and early warning system for low back pain.

1.4.2 Specific Objectives

The following are the specific objectives of this project:

- To assess the prevalence of low back pain among different individuals and its main cause.
- To design an embedded system to monitor the identified cause and alert users for risky conditions.
- To create a user-friendly web application for data visualization thus allow users to easily access data about their low back status.
- To make a prototype for the entire system and test it.

1.5. Study Scope

Through early detection and warning, this technology assists users live better lives by empowering them to take preventative steps and avoiding pain breakouts. It operates by monitoring low back posture that could be causing low back discomfort by using appropriate sensor. The data from the sensor are used to spot trends and patterns that point to a potential pain flare-up. The user receives a notification from the system warning to take precautions if it notices an elevated risk of a pain flare-up. To enable remote access to sensor data from any location, the system relates to a web application. As internet connection may be challenging in some regions, a GSM-based communication facility is used to let the users get informed whenever any abnormal case occurs.

1.6. Significance of the study

The system was designed to help people find the cause of their suffering. A customized treatment plan that can assist to lessen pain and enhance quality of life can be created using the information generated by this system. It gives data on posture of the body part of interest, which can assist users in avoiding uncomfortable or hazardous behaviors. By avoiding problems and lowering the need for hospitalization, the system will assist in lowering healthcare expenditures. This system will minimize the possibility for people to be disabled and enable them to work or engage in other economic activities. It will contribute to a better understanding of the cause of low back discomfort, which might result in new and better treatments.

1.7. Organization of the study

This thesis report consists of five chapters. Chapter one gives the general introduction about the project. Chapter two discusses the recently related literature. In chapter three, the research methodology is described. Chapter four talks about the project results from the survey and implementation. Finally, chapter five discusses the conclusion and recommendations from the study.

1.8. Summary

This chapter discusses low back discomfort, a common problem that has major negative effects on one's health and finances. It describes the incidence and consequences of low back pain to the individual and the society. The creation of a more proactive strategy is motivated by the shortcomings of existing low back pain management techniques. Current approaches frequently concentrate on treating pain after it happens. An early warning system is necessary to either prevent or lessen the extent of pain. The next chapter will discuss on the recent body of research on low back discomfort detection.

CHAPTER 2 : STATE OF THE ART (RECENTLY RELATED LITERATURE)

2.1. Literature Review

Low back pain (LBP) is a major cause of musculoskeletal injury globally. The most overburdened sector is healthcare, where nurses in particular are particularly vulnerable to LBP [2]. Wearable technology has the ability to solve problems like monitoring LBP-causing postures and raising people's awareness of movements and postures at work. Ferrone, A. et al [14], conducted a research to learn how workers perceived LBP and whether they would think about utilizing wearable monitoring devices to lower the risk of injuries. To collect data from a chosen population of nurses, they conducted a cross-sectional survey. The poll was completed by 64 people, and machine learning techniques were used to analyze the results.

The results of this study showed that the 64 nurses who participated in the survey are interested in these novel methods of tracking posture and mobility at work. They found that the wearable sensors-based technology may alter how ergonomic recommendations are applied to this population.

All medical professionals are now forced to reevaluate their procedures for treating spinal pain as a result of the current era of evidence-based medicine. Strength, endurance, fitness, and functional capacity training have traditionally been the main focus of many exercise programs for patients with spinal pain. These general programs are beneficial for the deconditioned patient and for boosting the overall muscular support of the spine in late stages of rehabilitation. According to recent studies, the muscle system's primary weakness is not just one of strength but also of motor control [15]. Such deficiencies are thought to require special attention prior to, or at the very least in conjunction with, more general exercises recommended for people with low back pain. When measuring the risk of injury for nurses, focus needs to be made on patient care and other tasks in addition to lifts and transfers, according to an analysis of posture over the whole working shift [16].

Chronic low back pain (CLBP) is a primary contributor to disability and has huge financial expenses as well as negative psychological and social outcomes. A. Chhikara et al [3], conducted a research Project named In-House Monitoring of Low Back-Pain Related Disability (IMPAIRED). Its goal was to design and develop a multi-sensor wearable prototype to monitor movement of the lumbar spine and pelvis, sleep disturbance (circadian rhythm), as well as muscle fatigue and activity pattern. They have analyzed the usefulness of inertial sensors to monitor the anticipated range of movement, selected pertinent movements linked to LBP impairment, and presented a sensor placement plan.

Myography, an interface between machine hardware and human wetware that allows for direct and natural control of electronic peripherals, records the signals from muscle actions. The standard myographic detectors are still unable to produce the requisite high resolution and non-invasive recording, despite recent considerable advancements. The modern wearable sensing technologies that record deeper muscle activity with great spatial resolution, or "super resolution," were critically examined [17]. In this article authors provided a critical analysis of modern wearable sensing technological advances, or "super-resolution," that record deeper muscle activity with great spatial resolution.

R. Uwamahoro et al, demonstrated that mechanomyographic (MMG) signals can be employed to gauge muscle activity [18]. In clinical and experimental contexts when voluntary contraction fails to stimulate muscles, it has been established important to stimulate the lost physiological functions of a muscle via an electrical signal. The results of this work highlight standardized electromyostimulation and MMG characteristics from several experimental protocols and show that MMG with neuromuscular electrical stimulation (NMES) provides feature factors for muscle activity evaluation. Despite the use of mathematical methods to quantify MMG and NMES, the technique is susceptible to inaccuracies due to the need for rapid processing and the fluctuation of MMG signals. Even though machine learning was not the main topic of their study, a few studies have used it to evaluate muscle fatigue, torque, and force in place of statistical analysis.

D. Esposito Et al presented a new, straightforward, non-invasive sensor based on a force-sensitive resistor (FSR) that can quantify muscle contraction [19]. The sensor, which is attached to the skin through a hard dome, detects the mechanical force generated by the muscles beneath the skin as they contract. Even though FSR creep results in output drift, it has been discovered that using the right FSR conditioning can minimize this drift by stabilizing the voltage across the FSR and producing voltage output that is proportionate to force. The sensor was able to pick up the mechanomyogram (MMG), or the tiny vibrations that take place during muscle contraction, in addition to the bigger contraction signal. It was discovered that the FSR sensor's frequency response was sufficient to accurately measure the MMG.

C. Ngo, C. Munoz, M. Lueken et al, developed a tool that concurrently performs EMG and Electrical Impedance Myography, EIM for a more accurate measurement of muscular states that are susceptible to artifacts [20]. The EMG, EIM, microcontroller, and communication modules are stacked and joined via connections in the lightweight, wireless, wearable device's modular architecture. The bioimpedance was therefore measured by the EIM module between 20 and 200 W. The communication and microcontroller module created an ARM-Cortex M3 microcontroller that reads and sends the collected data every 1 ms over RF (868 Mhz) with a baud rate of 500 kbps to a receptor connected to a PC. Initial tests on a volunteer during sit-to-stand, walking, and leg extension demonstrated the system's potential to study muscle activity by integrating simultaneous EMG and EIM.

A. Bawa, K. Banitsas, Conducted a study whose objective was to compare their low-cost sensor design to a well-known commercial device for determining muscle activity and weariness [21]. Several dynamic activities carried out by volunteers were used to evaluate the suggested system. On the vastus lateralis muscle, their inexpensive EMG sensor and a commercially available system were applied to simultaneously capture the signal during a maximal voluntary contraction (MVC). On the SPSS 26.0 version, the signal analysis was conducted using two validation indicators: Spearman's correlation and intra-class cross correlation. The root mean square (RMS), mean absolute value (MAV), and mean frequency (MNF) indices were utilized to quantify muscular exhaustion. Findings showed a good to outstanding agreement between the two systems and supported the robustness of their design. The inexpensive sensor additionally demonstrated its suitability for determining muscle activity.

E. Gulbandilar et al [22], offered an unbiased technique that might be applied to adjust the degree of low back pain. The purpose of this study was to determine whether it is possible to objectively determine the LBP's intensity level. A total of 169 participants, including 110 patients with LBP and 59 healthy volunteers as the control group, took part in the study. Every subject has had their skin resistance and visual analog scale (VAS) values tested. The established fuzzy logic method used these values as input variables. In addition to current unbiased methodologies, it was discovered that the fuzzy logic algorithm distinguishing the healthy and LBP participants by evaluating the level of the LBP was advantageous.

S. Shesham et al, developed a data acquisition model with a NodeMCU microcontroller, vibration actuators, tactile pressure sensors, a computational interface, and an office chair for an ergonomic workstation. Pressure sensor mats were strategically positioned on the seat surface and backrest of their smart chair prototype. These tactile pressure sensor mats, which are composed of polyester, cotton, stainless steel microfibers, and polyethylene tissue, can be used to track users' sitting habits. Without compromising the user experience, each sensor mat has the appearance of a soft fabric piece with great flexibility and extensibility. The data acquisition module contains a NodeMCU microcontroller, which could be used to gather signals from sensors, communicate with vibration actuators, store the data in the cloud server, and wirelessly send it to a mobile app. Conducting fibers in the fabric enable measuring pressure distribution on uneven surfaces [23].

Table 2.1: Summary of related works reviewed

Authors	**Contribution**	**Existing gap**	**Expected solution**
A. Chhikara et al [3]	Design and development of a multi-sensor wearable prototype to monitor the movement of the lumbar spine and pelvis, sleep disturbance (circadian rhythm), as well as muscle fatigue and activity pattern	Low back posture not taken into consideration while it is one of the factors that contribute to the low back pain	Using accelerometer sensor with the Node MCU to detect low back posture and alert users in case of risky conditions to avoid the occurrence of the pain.
R. Uwamahoro et al [18]	Muscle activity evaluation using Mechanomyographic (MMG) signals	No detection of Low back posture	
D. Esposito Et al [19]	Straightforward, non-invasive sensor based on a force-sensitive resistor (FSR) to quantify muscle contraction	Low back posture not detected	
C. Ngo, C. Munoz, M. Lueken et al [20]	Developed a tool that concurrently performs EMG and Electrical Impedance Myography, EIM for a more accurate measurement of muscular states	No detection of low back posture	
A. Bawa, K. Banitsas [21]	Developed a low-cost EMG sensor for determining muscle activity	No detection of Low back posture	
E. Gulbandilar et al [22]	Offered an unbiased technique applied to adjust	No detection of Low back posture	

	the degree of low back pain using fuzzy logic with skin resistance and visual analog scale (VAS) values as inputs		
S. Shesham et al [23]	Developed an IoT Based smart chair to help for Back pain. It consists of a data acquisition model with a NodeMCU microcontroller, vibration actuators, tactile pressure sensors, a computational interface, and an office chair for an ergonomic workstation.	No detection of Low back posture	

CHAPTER 3 : RESEARCH METHODOLOGY

The prototyping method was used in this research project. This is a hands-on approach that consists of building an early version of a product in order to test and eventually improve its design. The high-fidelity form of prototype was chosen for this project as it is a realistic and detailed model that closely resembles the finished product.

A survey was conducted to nurses from Rwamagana level II Teaching hospital and the employees of RP/IPRC Gishari to have an understanding of factors that contribute to low back pain and the prevalence of this health issue in those employees. Having the information from the review of existing related works and the survey, the selection of materials to be used in the design and development of the proposed system was conducted. These include sensor, the microcontroller, GSM module and End user devices (Smartphone/PC). Components were interconnected in Proteus software, the program codes were written and the prototype was developed and tested. The test results are presented and discussed in chapter four.

3.1. Research Process

3.1.1. Sample Size

A human-centered data collection with the purpose of getting insights on the prevalence of low back pain among employees of Rwamagana Level II teaching hospital and RP/IPRC Gishari staff as well as the factors contributing to low back pain. By Random sampling, 50 employees participated in this research. They include 20 nurses from Rwamagana Level II teaching hospital as well as 30 staff from RP/IPRC Gishari. This sampling method was used because these employees have the same life condition at work and they share the same facilities thus any one can represent the group. The choice of such population was informed by the review of various articles on the factors that influence the occurrence of low back pain namely the daily activities people are engaged in and the bad posture of the low back among others.

3.1.2. Research Instruments and Procedures

The research instrument consisted of a dichotomous questionnaire since the respondent had to answer either by Yes or by No. There was no consent form signed, the respondents were explained the objectives of the project and how the collected data will be kept. The Ethical clearance was also presented and they willingly participated in the survey. The copy of this questionnaire is appended on this thesis report. Respondents were free to reply to the survey questions to the best of what they knew and had experienced because questionnaires were anonymous. This helped to get extra details, and it is certain that the data provided accurately depicts the real status of low back pain among employees. Before providing their answers, respondents were given clear explanations on the purpose of the survey and the use of the data they are asked to give.

3.1.3. Data Analysis

The results obtained from the data collected have shown that low back pain is more prevalent for nurses compared to other employees with 30% and 16.7% respectively. The data were presented and analyzed using MS Excel tools. It has been noted that most of the employees with low back pain do not consult the doctors; this is a big problem since this issue may cause serious problems like being disabled when it is not treated in its early stages. Respondents agreed that low back bad posture cause low back discomfort with 75% and 86.7% for nurses and IPRC Gishari respectively. As per the feedback from survey participants an IoT-based automatic monitoring and early warning system can be a viable solution for low back pain monitoring with 90% and 86.7% for nurses and the other staff asked respectively who replied by “Yes” for the question related to the adoption of a such a system.

3.1.4 Problems and Limitations

Due to their busy schedules, nurses and staff have little time to complete questionnaires. Both sample size and generalization were challenged by the limited data collection period and the lack of incentives to survey participants.

3.1.5 Ethical Considerations

This research project was approved by the UR/ CMHS IRB Board, and this assured that this research complies with ethical guidelines. The goals of the study and the procedures used to gather the data were explained to the respondents in a clear and simple manner. The technique used to obtain the data was simple to comprehend and required little time from the participants. Only the information required on the research question was gathered. No personal information was asked. Anonymization was applied to the data.

3.2. Research Design Method

3.2.1. Blockdiagram of the system and its working principle

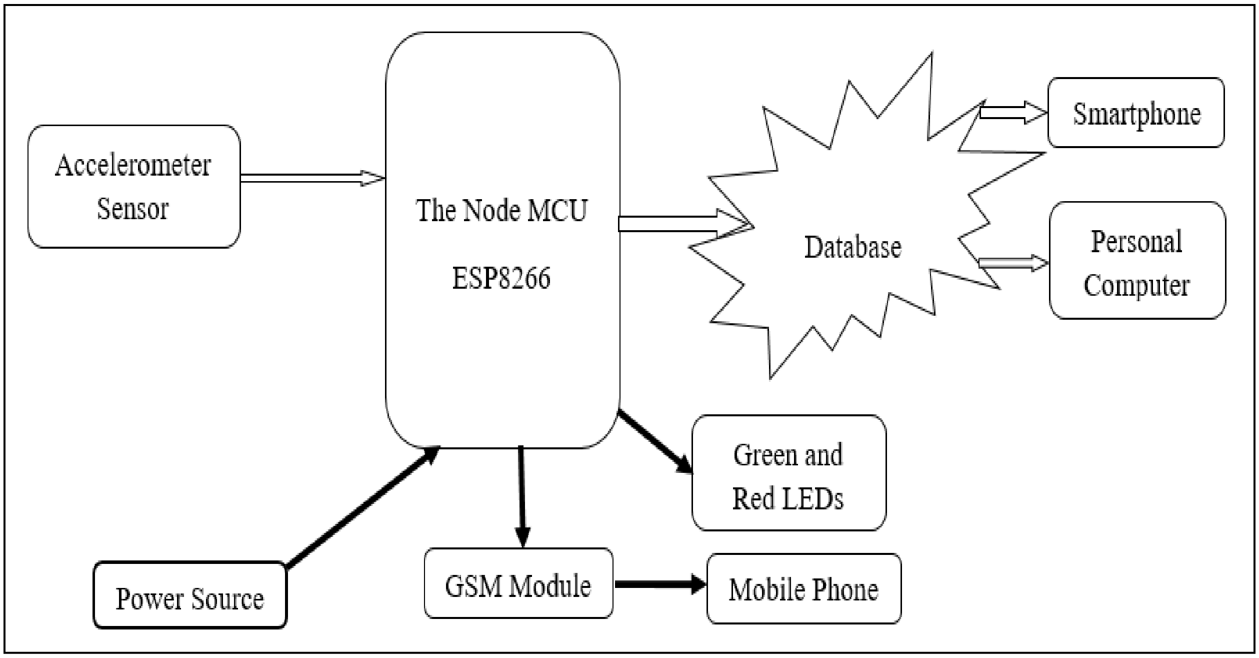

Figure 3.1: The system block diagram

The system block diagram consists of the sensing and control parts, the communication, the storage as well as the end user subsystems. The sensing part involves the accelerometer sensor used to collect data and send them to the microcontroller unit which has built-in WiFi capabilities. The microcontroller processes these data, sends them into the database for storage and provides alerts to the users' mobile phone via a GSM module. The Green and Red LEDs are used as indicators to show that the data from sensors are within the normal range or not, thus preventive measures can be taken accordingly. The normal range consists of low back posture data between 0 and 2.5 while values above 2.5 put the low back under risk of pain. Users can access their low back posture values and status data from a web page. Users will utilize the smart phone or a personal computer to access their data.

3.2.2. The system components

Table 3.1: Description of system components

S/N	Name	Description	Usage in the system
1	Accelerometer Sensor	A compact, thin, low-power, three-axis accelerometer with 13 bits of high resolution. Suitable for measuring both the dynamic acceleration brought on by motion	To monitor posture and movement of the body. The data from this sensor are

		or shock and the static acceleration of gravity in tilt-sensing systems. Permits inclination changes of less than 1.0° to be measured. ±3 g is the full scale range. Low power: 350 µA on average 10,000 g shock resistance outstanding stability of temperature 	used to examine patterns of movement connected to low back pain.
2	The Node MCU ESP8266	RISC CPU Tensilica Xtensa LX106, 32-bit Wi-Fi connectivity built-in 16 General Purpose Pins for input and output One pin of the analog-to-digital converter (ADC) RAM: 128 KB 4 MB of flash memory Voltage required for operation: 3.3V 	Receives and processes data from sensors thereafter sends them into the database for storage and provides alerts to the users.
3	GSM Module	Able to send and receive SMS texts offers extensive regional coverage Universal Asynchronous Receiver Transmitter with SIM Card Slot	Used to send alert messages to the user

			
4	Green and Red LEDs	Long lifespan, low energy consumption, and environmental friendliness 	Green LED for indicating that the sensed data are in the normal range while the red LED will indicate that the data exceed the threshold values
5	Jumper Wires	Insulated wires Male-to-Male Male-to-Female Female-to-Female 	To interconnect circuit components

3.2.3. Circuit diagram

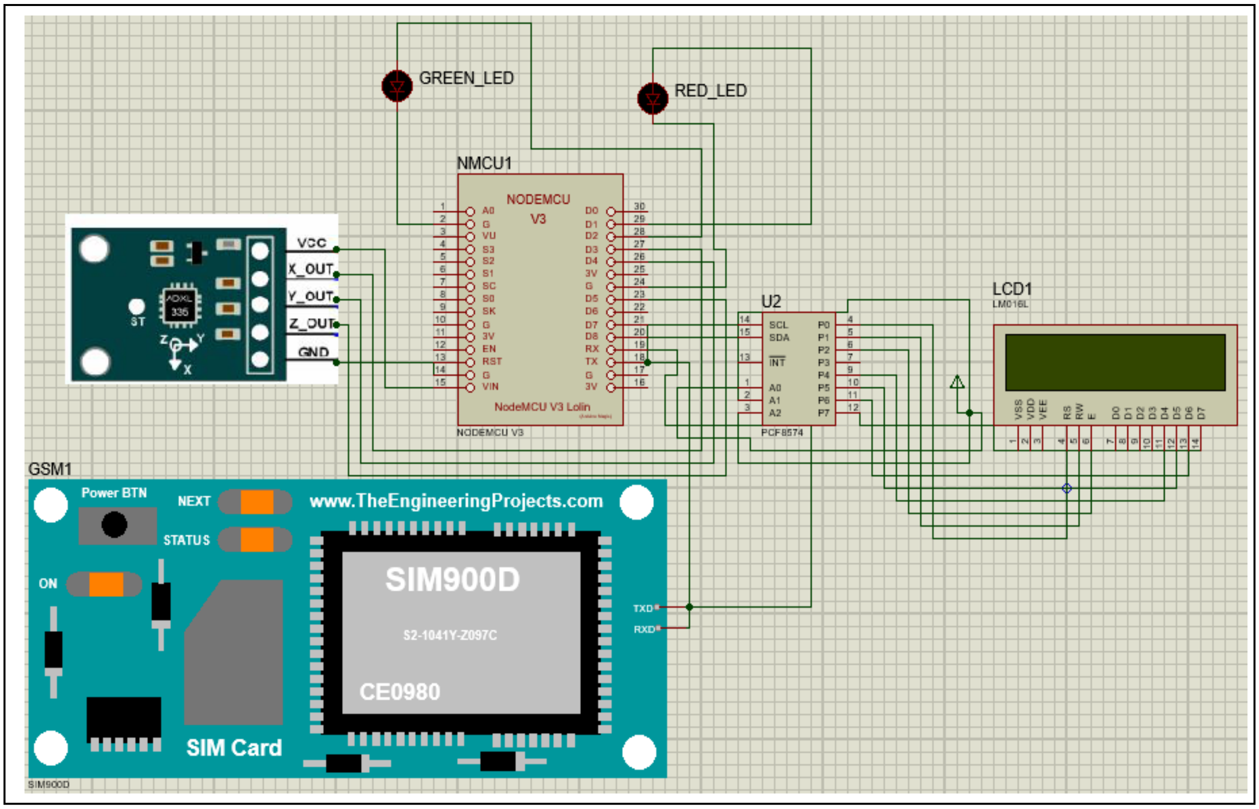

Figure 3.2: Circuit diagram designed in Proteus software

Proteus software was used to design the circuit for the entire system. All connections made between individual components are shown. It is observed that the Accelerometer sensor, the GSM module, the LEDs and the LCD display are all connected to the Node MCU, the central controller of the whole system.

3.2.4 Design of the data storage platform

Data storage was designed in xampp server running the PHP code for inserting the data into the table. The table was created from database called "kalisa " using mysql. To get data from hardware system into the table, the user has to activate apache and mysql of xammp server and run the browser in computer.

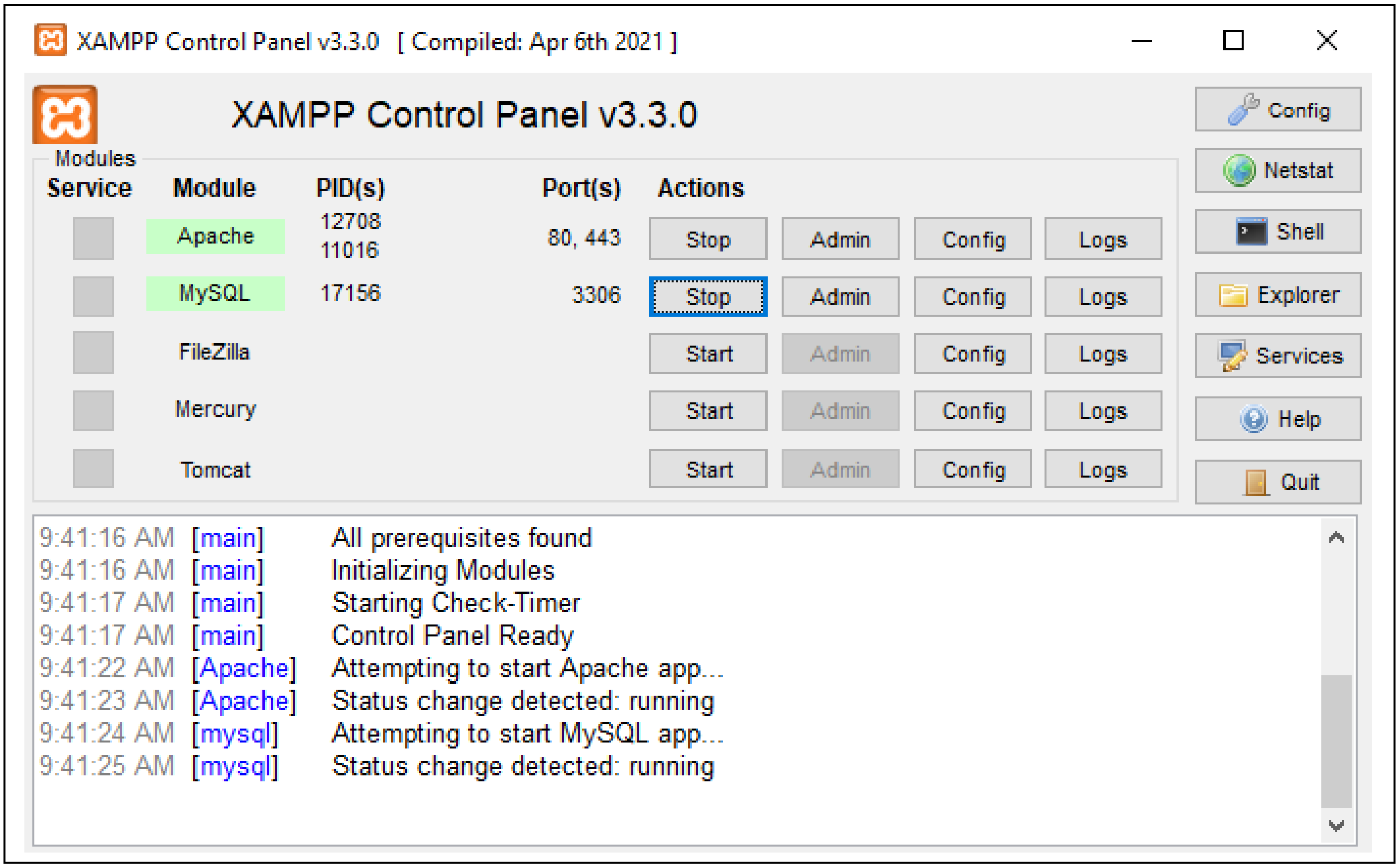

Figure 3.3: XAMPP Control Panel with both Apache and MySQL activated

After running Apache and MySQL, data was inserted into the table if there is any measurement done with 2 seconds delay.

Table 3.2: The table created in a database containing data from sensors

Server: 127.0.0.1 » Database: kalisa » Table: lbdata

Browse | Structure | SQL | Search | Insert | Export | Import

				id	system	posture	postureresults ▲ 1	time
☐	Edit	Copy	Delete	560	1	2.80	BAD POSTURE	2024-08-11 20:14:35
☐	Edit	Copy	Delete	561	1	4.46	BAD POSTURE	2024-08-11 20:14:43
☐	Edit	Copy	Delete	543	1	0.99	GOOD POSTURE	2024-08-11 20:13:55
☐	Edit	Copy	Delete	544	1	0.99	GOOD POSTURE	2024-08-11 20:13:57
☐	Edit	Copy	Delete	545	1	0.99	GOOD POSTURE	2024-08-11 20:13:59
☐	Edit	Copy	Delete	546	1	0.99	GOOD POSTURE	2024-08-11 20:14:01
☐	Edit	Copy	Delete	547	1	0.99	GOOD POSTURE	2024-08-11 20:14:03
☐	Edit	Copy	Delete	548	1	0.99	GOOD POSTURE	2024-08-11 20:14:05
☐	Edit	Copy	Delete	549	1	0.99	GOOD POSTURE	2024-08-11 20:14:07
☐	Edit	Copy	Delete	550	1	1.66	GOOD POSTURE	2024-08-11 20:14:09
☐	Edit	Copy	Delete	551	1	1.83	GOOD POSTURE	2024-08-11 20:14:12
☐	Edit	Copy	Delete	552	1	1.83	GOOD POSTURE	2024-08-11 20:14:13
☐	Edit	Copy	Delete	553	1	1.83	GOOD POSTURE	2024-08-11 20:14:15
☐	Edit	Copy	Delete	554	1	1.83	GOOD POSTURE	2024-08-11 20:14:17
☐	Edit	Copy	Delete	555	1	1.83	GOOD POSTURE	2024-08-11 20:14:19
☐	Edit	Copy	Delete	556	1	1.83	GOOD POSTURE	2024-08-11 20:14:21
☐	Edit	Copy	Delete	557	1	1.83	GOOD POSTURE	2024-08-11 20:14:23
☐	Edit	Copy	Delete	558	1	1.83	GOOD POSTURE	2024-08-11 20:14:25

CHAPTER 4 : PROJECT RESULTS FROM THE SURVEY AND IMPLEMENTATION

4.1. Results from the survey

Results obtained from nurses at Rwamagana level II teaching hospital

S/N	QUESTIONS ASKED	The number of nurses whose answer was “YES”	The number of nurses whose answer was “NO”	Percentage(%) for YES	Percentage(%) for NO
1	Have you ever felt a low back pain?	6	14	30	70
2	If you once experienced low back pain, Have you taken a step to know the reason behind that issue?	4	16	20	80
3	Do you think long time bad posture of the low back can contribute to low back pain?	15	5	75	25
4	Have you met a doctor for low back pain consultation and/or treatment?	3	17	15	85
5	Were you given a schedule for regular visits to hospital due to your law back issues?	2	18	10	90
6	Is there any means you use to automatically detect your low back status?	0	20	0	100
7	Do you think an automatic system for low back pain monitoring can be useful	6	14	30	70

	for you?				
8	Do you have a relative/friend with low pack discomfort?	9	11	45	55
9	Can you recommend your relatives/friends with low back issues to use automatic monitoring systems?	18	2	90	10

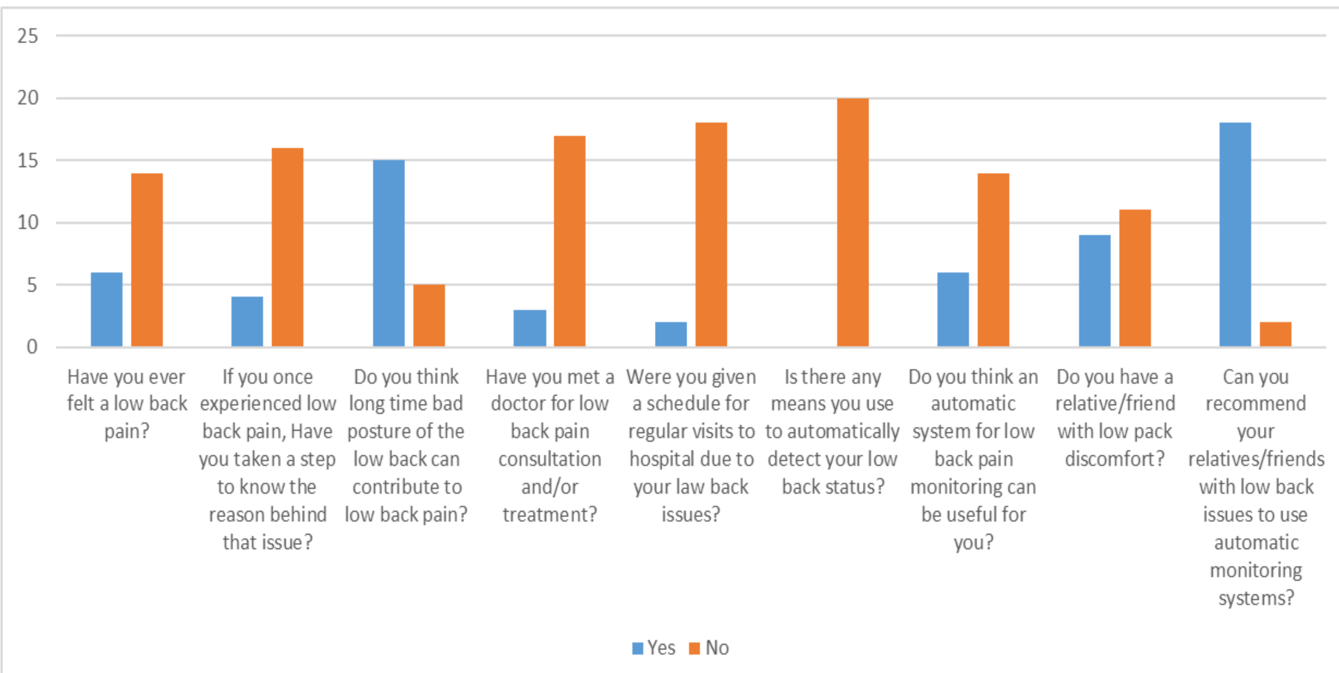

Figure 4.1: Analysis chart for data collected from nurses

A considerable prevalence of low back pain was found in the survey of nurses, which also identified probable causes and treatments. Notably, 30% of the nurses who responded to the study said they had low back pain. This suggests that a significant segment of the nursing workforce is impacted by this problem. The majority of nurses (75%) said that their low back bad posture was the cause of their low back pain. This implies that treating postural problems may be a crucial tactic for lowering low back pain in nurses. About thirty percent of the nurses said they would be interested in treating their low back pain with an automated monitoring system. This suggests that there is a need for this technology among nurses.

Results of the survey conducted to IPRC Gishari Staff

S/N	**QUESTIONS ASKED**	**The number of nurses whose answer was “YES”**	**The number of nurses whose answer was “NO”**	**Percentage(%) for YES**	**Percentage(%) for NO**
1	Have you ever felt a low back pain?	5	25	16.7	83.3
2	If you once experienced low back pain, Have you taken a step to know the reason behind that issue?	3	27	10	90
3	Do you think long time bad posture of the low back can contribute to low back pain?	26	4	86.7	13.3
4	Have you met a doctor for low back pain consultation and/or treatment?	2	28	6.7	93.3
5	Were you given a schedule for regular visits to hospital due to your law back issues?	2	28	6.7	93.3
6	Is there any means you use to automatically detect your low back status?	0	30	0	100
7	Do you think an automatic system for low back pain monitoring can be useful for you?	5	25	16.7	83.3

8	Do you have a relative/friend with low pack discomfort?	7	23	23.3	76.7
9	Can you recommend your relatives/friends with low back issues to use automatic monitoring systems?	26	4	86.7	13.3

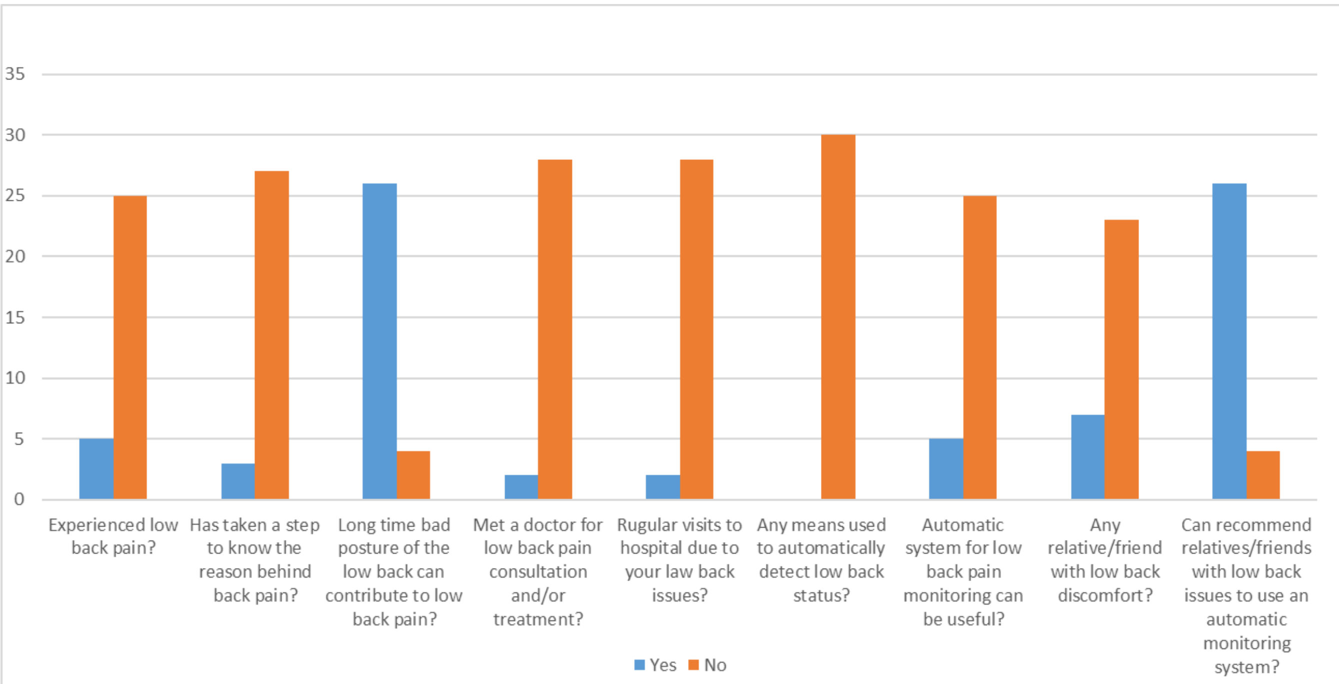

Figure 4.2: Analysis chart for the data collected from the staff of IPRC Gishari

Compared to nurses, IPRC Gishari staff members were less likely to report having low back pain, while the underlying reasons and potential treatments seem to be the same. Compared to nurses, just 16.7% of academic staff members reported having low back pain, indicating a decreased prevalence of this problem among them. Bad low back posture was the main cause of low back pain among academic personnel, despite the lower total prevalence, suggesting a connection between the two occupations. Staff from IPRC Gishari expressed interest in the possible advantages of adopting automatic monitoring systems to treat low back pain, much like nurses do.

4.2. Results from Implementation

Results were obtained from the developed system whereby the posture data of the Low back was taken using accelerometer sensor. The Node MCU was also utilized to achieve a communication between the measured sensor data and the xampp server on the side of the database. The data saved or stored in database consists of all detected values from Low back postures. Moreover, the data is stored in databases with the purpose of sending the status to the user. Status indicates whether the person is under risk or normal and therefore, when the person is at under risk, the GSM module sends the message to the person under test.

Table 4.1: Low back Posture data taken from accelerometer.

Time in seconds	**Posture data**	**Status**
1	2.8	Bad Posture
3	4.46	Bad Posture
5	0.99	Good Posture
7	0.99	Good Posture
9	0.99	Good Posture
11	0.99	Good Posture
13	0.99	Good Posture
15	0.99	Good Posture
17	0.99	Good Posture
19	1.66	Good Posture
21	1.83	Good Posture
23	1.83	Good Posture
25	1.83	Good Posture
27	1.83	Good Posture
29	1.83	Good Posture
31	1.83	Good Posture
33	1.83	Good Posture

As per system running, the accelerometer sensor reads the posture values between 0 and 2.5 when the person’s low back is in a good posture and it reads beyond 2.5 when it is in a bad posture. The data was taken several times to analyze the functionality and accuracy of the system. For all tests the results were similar.

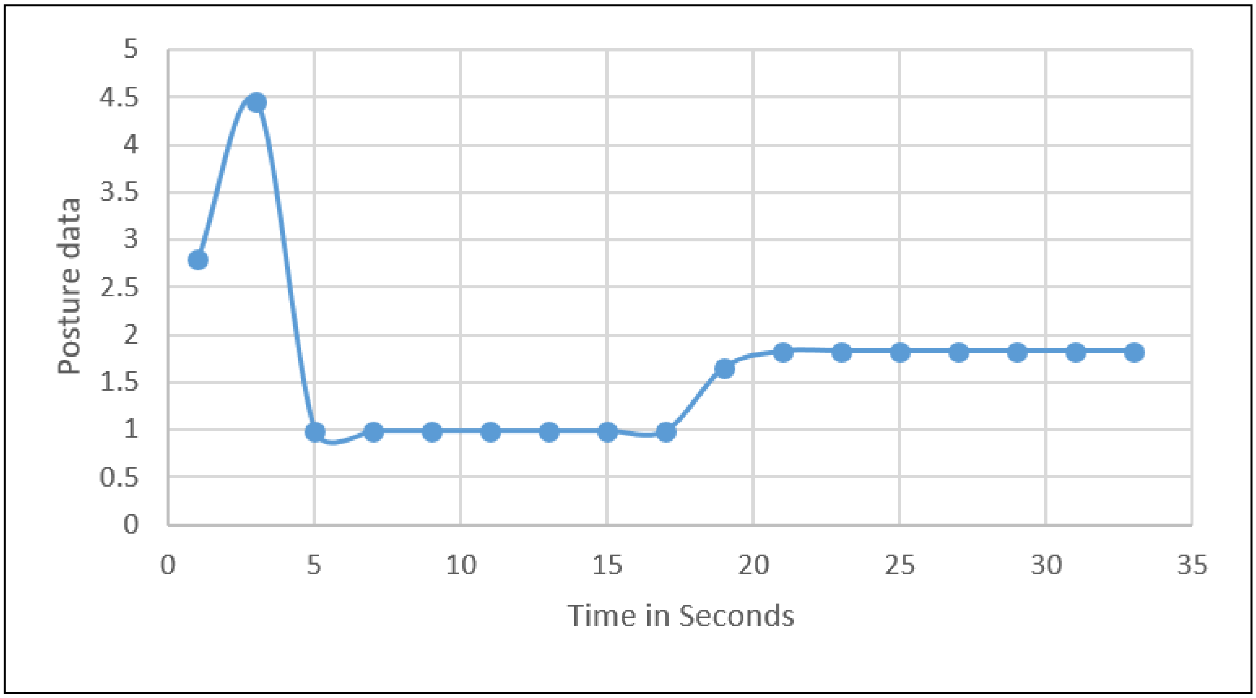

Figure 4.3: Low back posture data versus time

The Figure 4.3. Shows the variation of the low back posture data with time. Under risky condition, the GSM module alerts the person by providing the reading on the low back status through SMS. The system also advises the user to change the low back posture. The figure 4.4 shows the message sent to the person/user once the sensors detected that he/she is at risk of low back pain.

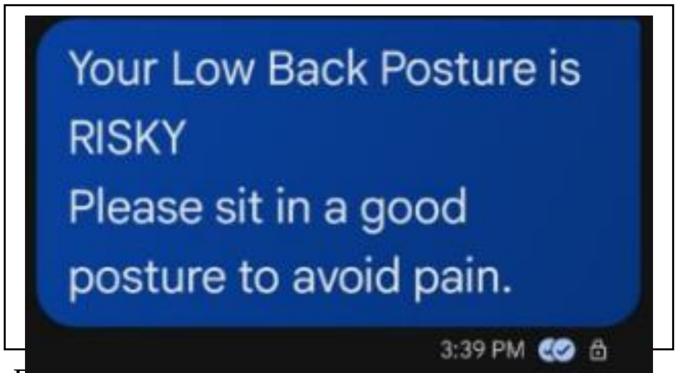

Figure 4.4: SMS alert for a potential low back pain

The figure 4.5. shows pictures of the prototype developed being enclosed. The LCD is displaying data about the low back status for both normal and abnormal cases. The values for low back posture and are shown.

Figure 4.5: The pictures of the developed prototype during testing

In contrast to the bad low back posture, which included back bending, difficulty breathing, fatigue, and pain, the good low back posture was characterized by little discomfort, easy breathing, and stability.

ID	posture	postureresults
543	0.99	GOOD POSTURE
544	0.99	GOOD POSTURE
545	0.99	GOOD POSTURE
546	0.99	GOOD POSTURE
547	0.99	GOOD POSTURE
548	0.99	GOOD POSTURE
549	0.99	GOOD POSTURE
550	1.66	GOOD POSTURE
551	1.83	GOOD POSTURE
552	1.83	GOOD POSTURE
553	1.83	GOOD POSTURE
554	1.83	GOOD POSTURE

Figure 4.6: Dynamic data on the user's web page from the database

The Figure 4.6 shows the screenshot of how the user is viewing the data about his/her low back posture data via a web page. At any time, the user can open the web page and see which posture he/she is taking thus decide to keep it or not depending to the results. The bad low back posture and pain can therefore be avoided by keeping posture values less than 2.5.

4.3. Performance Evaluation

The developed system includes the accelerometer sensor data to deliver real-time insights about low back posture. It allows individuals to monitor their posture and receive notifications for unhealthy circumstances. Additionally, a web page for users provides data visualization. It provides accurate and precise readings of posture values over time. Changes in posture that can indicate the potentials risks for low back discomfort can be easily detected which explains the high sensitivity of the sensors used in this system.

Compared to other systems consulted which mainly rely on evaluating the muscle activity, this system can accurately recognize normal postures, prevent false alarms, and offer accurate posture measurements without any unexpected delays.

4.4. Results Discussion

There is a link between posture and the likelihood of developing low back discomfort. The low back posture is classified as good by the system when the posture values are less than or equal to 2.5. The system signals a dangerous low back condition when posture values are greater than 2.5. These findings offer important new information about the risk factors for low back pain. An important first step toward early intervention and prevention is the system's capacity to recognize possible hazards based on posture data. Through the system's flagging of risky low back statuses, users can be made aware of possible problems before they become chronic discomfort. It is crucial to maintain good posture to avoid discomfort.

CHAPTER 5 : CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This research project was successfully conducted as expected. The results obtained from the survey have shown that the low back pain is a more prevalent threat for nurses than other employees asked. Different solutions were implemented to monitor the factors that contribute to low back pain but they present gaps in monitoring the low back posture, movement patterns and temperature. The system developed in this study using the accelerometer sensor, the temperature sensor, the Node MCU and communication modules is a viable solution to address the stated gap.

5.2. Recommendations

Low back pain should be taken as a big health issue and more emphasis should be put in technology-based monitoring techniques for early detection and treatment.

Awareness should be increased among people as it was seen that some individuals do not consult doctors, while untreated low back discomfort may result into more effects that are dangerous.

Researchers should work on how to involve more advanced technologies like machine learning in low back pain monitoring as it may lead to more accurate results.

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APPENDICES

Appendix 1: The Questionnaire used for data collection

UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

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

RESEARCH PROJECT FOR THE MASTER'S PROGRAMME

THE QUESTIONNAIRE FOR COLLECTING DATA

The purpose of this questionnaire is to gather information on the prevalence of low back pain among employees. With this information, an IoT-based automatic monitoring and early warning system will be designed and it will provide data on posture and temperature on the low back, which can assist users in avoiding uncomfortable or hazardous behaviors thus assist in lowering healthcare expenditures. The system will aid in improving patient care decisions by giving healthcare professionals real-time data and insights.

Instructions:

Kindly take a moment and respond to these questions. Add any extra details or explanations in the space provided in comments column. Write "Not Applicable" with N/A if you do not have an information to give. Remember to specify your Job title and workplace.

Job title and workplace: …………………………………………………………………………

S/N	QUESTIONS	YES	NO	COMMENTS
1	Have you ever felt a low back pain?			
2	If you once experienced low back pain, Have you taken a step to know the reason behind that issue?			
3	Do you think that the bad posture of the low back can contribute to low back pain?			

4	Have you met a doctor for low back pain consultation and/or treatment?			
5	Were you given a schedule for regular visits to hospital due to your law back issues?			
6	Is there any means you use to automatically detect your low back posture?			
7	Do you think an automatic system for low back posture monitoring can be useful for you?			
8	Do you have a relative/friend with low pack discomfort?			
9	Can you recommend your relatives/friends with low back issues to use automatic monitoring systems?			

Please fill out this field with any additional details you feel might be useful for this study.

………………………………………………………………………………………………………

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Date: ………………………………..

Signature: …………………………….

Appendix 2: Ethical Clearance from CMHS Institutional Review Board

UNIVERSITY of RWANDA

COLLEGE OF MEDICINE AND HEALTH SCIENCES

DIRECTORATE OF RESEARCH & INNOVATION

CMHS INSTITUTIONAL REVIEW BOARD (IRB)

Kigali, 27th/12/2023
Ref: CMHS/IRB/**559**/2023

KALISA Jean Bosco (Ref. No. 222000945)

MSc. Degree Student in Biomedical Engineering

Centre of Excellence in Biomedical Engineering and E-Health (CEBE), CST, UR

Dear KALISA Jean Bosco

RE: ETHICAL CLEARANCE

Reference is made to your application for ethical clearance for the study entitled ***"Design of an IoT-Based Automatic Monitoring and Early Warning System for Low Back Pain"***

Having reviewed your application and been satisfied with your protocol, your study is hereby granted ethical clearance. The ethical clearance is valid for one year starting from the date it is issued and shall be renewed on request. You will be required to submit the progress report and any major changes made in the proposal during the implementation stage. In addition, at the end, the IRB shall need to be given the final report of your study.

We wish you success in this important study.

Assoc. Prof. Stefan Jansen (PhD)
Acting Chairperson Institutional Review Board,
College of Medicine and Health Sciences, UR

Cc:

- Principal College of Medicine and Health Sciences, UR
- University Director of Research and Postgraduate studies, UR

Appendix 3: The Program Codes Used

```
#ifdef ESP32
  #include <WiFi.h>
  #include <HTTPClient.h>
#else
  #include <ESP8266WiFi.h>
  #include <ESP8266HTTPClient.h>
  #include <WiFiClient.h>
#endif
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <SoftwareSerial.h>
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
Adafruit_MPU6050 mpu;
SoftwareSerial mySerial(D5, D6); //A6 Tx & Rx is connected to Arduino #3 & #2
LiquidCrystal_I2C lcd(0x27,20,4);  // set the LCD address to 0x27 for a 16 chars and 2 line
display
int ledred=D7;
int ledblue=D8;
int buzzer=D4;
WiFiClient espclient;
const char* ssid     = "GC ROOM3";
const char* password = "GC@12345@";
const char* serverName = "http://10.10.0.30/kalisa/post-kalisa.php";
String api_Key_Value = "0784030462";
String status1 ="BAD POSTURE";
String status2 ="GOOD POSTURE";
String system1 ="1";
float posture=10.2;
float back;
void setup(void) {
   lcd.init();                      // initialize the lcd
```

```
 lcd.init();
 // Print a message to the LCD.
 lcd.backlight();
 lcd.setCursor(3,0);
 lcd.print("LOW BACK POSTURE ");
 lcd.setCursor(2,1);
 lcd.print("   MONITORING ");
  lcd.setCursor(0,2);
 lcd.print("   SYSTEM ");
delay(3000);
Serial.begin(9600);
mySerial.begin(9600);
 Serial.println("Initializing...");
 delay(1000);
lcd.clear();
 pinMode(ledred,OUTPUT);
   pinMode(ledblue,OUTPUT);
   pinMode(buzzer,OUTPUT);
 while (!Serial)
   delay(10); // will pause Zero, Leonardo, etc until serial console opens

 Serial.println("Adafruit MPU6050 test!");

 // Try to initialize!
 if (!mpu.begin()) {
   Serial.println("Failed to find MPU6050 chip");
   while (1) {
     delay(10);
   }
 }
 Serial.println("MPU6050 Found!");

 //setupt motion detection
```

```
  mpu.setHighPassFilter(MPU6050_HIGHPASS_0_63_HZ);
  mpu.setMotionDetectionThreshold(1);
  mpu.setMotionDetectionDuration(20);
  mpu.setInterruptPinLatch(true); // Keep it latched.  Will turn off when reinitialized.
  mpu.setInterruptPinPolarity(true);
  mpu.setMotionInterrupt(true);

  Serial.println("");
  delay(100);
  WiFi.begin(ssid, password);
  Serial.println("Connecting");
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("");
  Serial.print("Connected to WiFi network with IP Address: ");
  Serial.println(WiFi.localIP());
  Serial.println("");
  delay(100);

}

void loop() {
 lcd.setCursor(0,0);
  lcd.print("LOWBACK POSTURE DATA ");
  if(mpu.getMotionInterruptStatus()) {
    /* Get new sensor events with the readings */

    sensors_event_t a, g, temp;
    mpu.getEvent(&a, &g, &temp);
 back=(posture+(a.acceleration.x));
    /* Print out the values */
```

```
   Serial.print("AccelX:");
   Serial.print(a.acceleration.x);

   Serial.println("");
   if(back>=2.5){
     digitalWrite(buzzer,HIGH);
     digitalWrite(ledred,HIGH);
      digitalWrite(ledblue,LOW);
        lcd.setCursor(2,1);
  lcd.print("POSTURE:");
  lcd.print(back);
  lcd.print(" ");
   lcd.setCursor(2,2);
  lcd.print("STATUS:BAD POSTURE  ");
   delay(500);
    digitalWrite(buzzer,LOW);
      delay(500);
      digitalWrite(buzzer,HIGH);
      delay(500);
       digitalWrite(buzzer,LOW);
       sms();
       delay(500);
       if(WiFi.status() == WL_CONNECTED) {
    HTTPClient http;
    http.begin(espclient,serverName);
http.addHeader("Content-Type", "application/x-www-form-urlencoded");
    //http.addHeader("Content-Type", "text/plain");
     String httpRequestData;

    httpRequestData = "api_key=" + api_Key_Value+ "&system=" +system1 + "&posture="
+back+ "&postureresults=" +status1 + "";
    Serial.print("httpRequestData: ");
    Serial.println(httpRequestData);
```

```
  int httpResponseCode = http.POST(httpRequestData);
//timersensor();
  if (httpResponseCode > 0) {
    Serial.print("HTTP Response code: ");
    Serial.println(httpResponseCode);
  }
  else {
    Serial.print("Error code: ");
    Serial.println(httpResponseCode);
  }

  http.end();
 }
else {
  Serial.println("WiFi Disconnected");
 }
 delay(1500);
 }
  }
  else{
      digitalWrite(buzzer,LOW);
     digitalWrite(ledred,LOW);
     digitalWrite(ledblue,HIGH);
       lcd.setCursor(2,1);
 lcd.print("POSTURE:");
 lcd.print(back);
 lcd.print(" ");
 lcd.setCursor(2,2);
 lcd.print("STATUS:GOOD POSTURE   ");
 delay(100);
  if(WiFi.status() == WL_CONNECTED) {
  HTTPClient http;
```

```
    http.begin(espclient,serverName);
http.addHeader("Content-Type", "application/x-www-form-urlencoded");
    //http.addHeader("Content-Type", "text/plain");
     String httpRequestData;

    httpRequestData = "api_key=" + api_Key_Value+ "&system=" +system1 + "&posture=" +back+ "&postureresults=" +status2 + "";
    Serial.print("httpRequestData: ");
    Serial.println(httpRequestData);

    int httpResponseCode = http.POST(httpRequestData);
 //timersensor();
    if (httpResponseCode > 0) {
      Serial.print("HTTP Response code: ");
      Serial.println(httpResponseCode);
    }
    else {
      Serial.print("Error code: ");
      Serial.println(httpResponseCode);
    }

    http.end();
  }
 else {
    Serial.println("WiFi Disconnected");
  }
  delay(1500);
  }

  delay(100);
}
void sms(){
  updateSerial();
```

```
  mySerial.println("AT"); //Once the handshake test is successful, it will back to OK
  updateSerial();
  mySerial.println("AT+CMGF=1"); // Configuring TEXT mode
  updateSerial();
   mySerial.println("AT+CMGS=\"+250788517643\"");//change ZZ with country code and xxxxxxxxxxx with phone number to sms
  updateSerial();
  mySerial.print("Your Low Back Posture is "); //text content
  updateSerial();
   mySerial.print("RISKY");
   updateSerial();
   mySerial.println(" Change the posture "); //text content
    updateSerial();

  mySerial.write(26);
  updateSerial();
}
void updateSerial()
{
  delay(500);
  while (Serial.available())
  {
    mySerial.write(Serial.read());//Forward what Serial received to Software Serial Port
  }
  while(mySerial.available())
  {
    Serial.write(mySerial.read());//Forward what Software Serial received to Serial Port
  }
}
```