DESIGN AND IMPLEMENTATION OF WEARABLE SENSOR BELT FOR GAIT ANALYSIS

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15CJ02873

A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE BACHELOR OF ENGINEERING DEGREE IN COMPUTER ENGINEERING SUPERVISED

SUPERVISED BY

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JULY, 2020

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DECLARATION

I hereby declare that the work detailed in this report was completed by me under the supervision of Engr. Omoruyi Osemwegie in the Department of Electrical and Information Engineering, Covenant University. Also, I affirm that as far as I could possibly know, no piece of the report has been submitted here or somewhere else in an earlier application for the honor of a degree. All sources of information utilized thus have been properly recognized.

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CERTIFICATION

This is to certify that the project titled "Design and Implementation of a Wearable Sensor Belt for Gait Analysis" by OWOLABI IFEOLUWA ANUOLUWA, meets the requirements and regulations governing the award of the Bachelor of Engineering, B.Eng. (Computer Engineering) degree of Covenant University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I thank my Almighty Father, God, who has been my help all through these five years of study and for the enablement and grace that he has given me to finsh this project effectively. I dedicate this project to my family for their continuous care, belief, reassurance, and love throughout my course in Covenant University. Finally, I dedicate this project to the final year students of computer engineering in class 2020.

ACKNOWLEDGEMENT

I hereby acknowledge the College of Engineering for the knowledge they have impacted me with all through my stay at Covenant University. I acknowledge my supervisor, Engr. Omoruyi Osemwegie for his great support, assistance, guidance, and his ideas of improvement in nurturing this project. I acknowledge my family for their continual backing. I also want to recognize all my lecturers in the Department of Electrical and Information Engineering for the knowledge they have imparted in me throughout my stay at Covenant University

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ABSTRACT

Ongoing advancements in wearable sensor innovations can help make a convenient home care services condition effortlessly, permitting patients to have their physiological signs observed while remaining at home. This paper depicts a continuous task on the design and working of a wearable sensor belt to procure information concerning physical fitness of an individual needing clinical consideration. A waist mounted triaxial accelerometer and gyroscope unit is utilized to record human developments. The acquired information was sent utilizing a RF Transmitter to the data unit and went to a PC for analysis.

The data was normalized using zero normalization technique and filterd using the complementary filtering method. The result showed the difference between a normal gait and an abnormal gait pattern

The the model execution, and testing of the system are also discussed in this paper.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND STUDY

Gait can simply be defined as the way people walk or walking patterns from one point to another. Gait often rely on some part of your body, including the brain, eye, ears, muscles, etc.

A lot of information regarding gait can be collected by observing or analyzing and proper interpretation of people's motion[1].

Gait analysis is the study of the movement. It is an essential tool that helps analyze and understand unique information (usually signals) collected or observed from a person walking pattern.

For proper diagnosis of patients with irregular gait patterns, the study of gait analysis is essential as it helps to determine the gait functionalities and irregularities. Gait analysis can be either kinematics or kinetic. The kinematic analysis uses trajectory, position, the motion of the person to describe the pattern of movement, while kinetic analysis uses mass and force for its review. There is also Inverse dynamic analysis uses kinematic data to get kinetic information like muscle force and joint contact force [2].

A total gait cycle is a development from one-foot strike to the progressive foot strike on a similar side [3]. The Gait phase describes the entire walking period of a person. Gait Cycle is made up of the stance and swing phase.

- The **stance phase** is the point at which the foot is on the ground, that is, the point at which the body is balanced on the two feet.

    - The swing stage is. One foot is on the floor while the other is noticeable all around.

- The **swing phase** is the point at which the foot is in in-flight. One foot is on the floor while the other is in suspended in the air.

Gait Analysis technique is the method used for the collection of gait data. They include

1. **Image Processing**: - this is the use of cameras (digital or analog) for collection of gait data
2. **Floor sensors**: - this technique is carried out by placing sensors on the floor(walkway) where gait can be measured by the pressure or floor sensors. They can be either force platforms and pressure measurement systems [4].
3. **Wearable sensors**: - this is the placement of sensors at a different part of the body including leg, waist, knee, etc. to get data for gait analysis

1.2 PROBLEM DEFINITION

Gait analysis is fundamental in properly analyzing human walking patterns as it also helps to diagnose different illnesses that affect human locomotion. It also plays a crucial role in athlete training as it helps to observe their practice, therefore improve their performances. Gait analysis is also essential for restoration activities and planning human stride, exoskeletal frameworks, and prosthetic appendages [2].

1.3 MOTIVATION OF STUDY

Health care centers are flooded with patients suffering from gait-related problems ranging from the elderly to children and the disabled. With the proper understanding of gait and close monitoring of their gait patterns at a very affordable rate, it will help early detection of symptoms and improve their chances of adequate treatment.

The development of this project will be beneficial not only to the elderly or the sick but to everyone because of the constant monitoring of the Gait pattern helps monitor the health status of individuals.

1.4 SCOPE OF STUDY

The wearable sensor belt will include:

1. A transmitter connected to the belt to transmit the signal received
2. A receiver connected to the computer to receive the message from the transmitter
3. Computer Application to display the result obtained from the receiver for analysis

1.5 AIMS AND OBJECTIVES

This project aims to design a wearable belt sensor that helps collects gait data for proper analysis of gait patterns.

The objectives include

1. The design of a cost-effective wearable sensor belt for gait analysis
2. To communicate in real-time sensor information to a computer application.
3. To analyze gait patterns using the computer application.

1.6 METHODOLOGY

Gait analysis can be actualized utilizing distinctive sort of movement sensors. Accelerometer, gyroscope,flexible goniometer, magnetoresistive sensors, sensing fabric, force sensor, electromyography (EMG) sensors, electromagnetic global positioning framework (ETS), are a wide range of movement sensors that can be utilized for Gait investigation [4]. In this project, we will be making use of an accelerometer, and the process includes:

1. Design of a comfortable waist belt
2. The coupling of the accelerometer and transceiver to a microcontroller device to be used to transmit the generated gait data
3. The connection of a microcontroller device and a transceiver to receive and display the collected data.
4. To process the received data by normalizing and filtering using Arduino IDE
5. To generate graphs for each subject received from the microcontroller device.

1.7 APPLICATION

Gait analysis can be applied to different areas, including:

1. Developmental Disabilities in children with complex gait analysis
2. Amputations: Gait analysis can be really helpful for patients with lower and upper extremity
3. Sports Medicine: Gait analysis can be very helpful for athletes to monitor their progress and improve performance.
4. Orthopedics: Gait analysis can be very helpful in monitoring patient healing progress
5. Biomedical Engineering: Gait analysis is the most used tool for characterizing human locomotion.

1.8 PROJECT ORGANIZATION

Chapter one introduces gait, gait analysis, gait phase. The motivation for the study, aim and objectives are also discussed. **Chapter two** gives an in-depth explanation of gait analysis, gait cycle, gait phase. It also presents the method of gait analysis and the different sensors used. Reviews of related works as regards gait analysis are discussed. This chapter also showcases the uniqueness of this project that makes it stand out from previous projects. **Chapter three** focuses on the method of design for this project. It gives a detailed insight into the system design, the system requirement, and cost, as well as the software aspect(programming), involved in the execution of this project.

Chapter four describes the system construction, testing and result obtained in the project. It also shows the challenges encountered and solutions used to overcome the difficulties.

Chapter five is the concluding chapter. This chapter highlights the knowledge gained throughout the project and determines whether or not the aim and objectives were met. This chapter also includes further recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1. INTRODUCTION

Gait is simply the pattern of movement of an individual. The analysis is a detailed examination of an element. So, therefore, Gait analysis is the comprehensive examination of the human propulsion. During gait analysis, data on the motion of the hip, knee, ankle are collected for observation and analysis to detect any underlying condition that might affect the nature of the movement of an individual.

2.1.1 GAIT CYCLE

Gait cycle is the period from one-foot contact with the ground till the same foot contacts the ground again. One gait cycle is a Stride. Human walking consists of a repetitive pattern of movement of the limbs, also known as the gait phase [5].

A whole gait cycle contains the stance and swing phase.

1. The stance phase consists of the entire period the foot makes contact with the ground, and it lasts for about 62% of the cycle. The stance phase is divided into three segments
    i. initial double stance
    ii. single-limb stance
    iii. terminal double limb stance.
2. The swing phase is the entire period the foot is off the ground (in the air); it lasts for the final 38% of the cycle.

The gait phase is divided into initial contact, loading response, midstance, terminal stance, pre-swing, initial swing, mid-swing, and terminal swing[6].

(1) **Initial contact**: This stage involves the instant when the foot contacts the ground. The joint stances introduced now decide the appendage's stacking reaction design [4, 6].

(2) **Loading response (Foot Flat)**: The phase starts once the foot contacts the ground until the contrary foot is lifted along these lines, moving the weight to the next leg [2].

(3**) Midstance**: Midstance starts when the opposite foot is raised up until the weight is on the forefoot. This involves the balancing of body weight on the opposite foot [2].

(4) **Terminal stance**: The phase starts with the lifting of the heel landing of the opposite foot on the floor. The stage begins with the lifting of the impact point (heel) arriving on the contrary foot on the floor. The impact point rises, and the appendage moves to precede the forefoot rocker [2].

(5) **Pre-swing (Toe-off)**: This is the last stage of the stance and the beginning of the swing phase in the gait cycle. The foot is flexed and lifted off of the floor. The target of this stage is to situate the appendage for swing [2].

(6) **Initial swing**: This stage makes up 33% of the swing time frame. Here, the hip, knee, and lower leg are flexed to start the progress ahead of the appendages and make freedom of the foot over the ground.

(7) **Mid-swing**: The appendage advancement keeps making the thigh arrive at its pinnacle progression. The knee is permitted to increment in response to gravity, while the lower leg proceeds with dorsiflexion to neural [2].

(8) **Terminal swing**: In this stage, the last progression of the appendage happens, situating the foot for the next foot contact to start the next gait cycle.

Other terminologies include

1. **Single support**: This is the time in which one of the foot is on the floor. In single support, there are two different periods, namely, the left stance and the right stance, respectively.
2. **Double support**: Here, both feet are on the floor. This happens when the first limb ends its stance phase, and the second limb begins its stance phase.

- **Step Length**: This is characterized as the separation between the impact point contact of the essential foot to that of the subsequent foot. In a typical stride, the right step length is equivalent to left step length
- **Stride Length**: This is the separation between two impact point contacts of a similar foot. Usually,the stride length is twofold the step length.
- **Walking Base or Stride Width**: This is characterized as the side-to-side separation between the line of steps of two feet.
- **Cadence**: This is also known as rhythm. It is characterized as the number of steps per unit time. Usually, rhythm is about 100–115 steps per minute. The cadence of an individual is dependent upon various variables.

- **Comfortable Walking Speed**: This is an average speed at which there is the least vitality utilization per unit separation. This is around 80 meters for every moment in a typical gait.

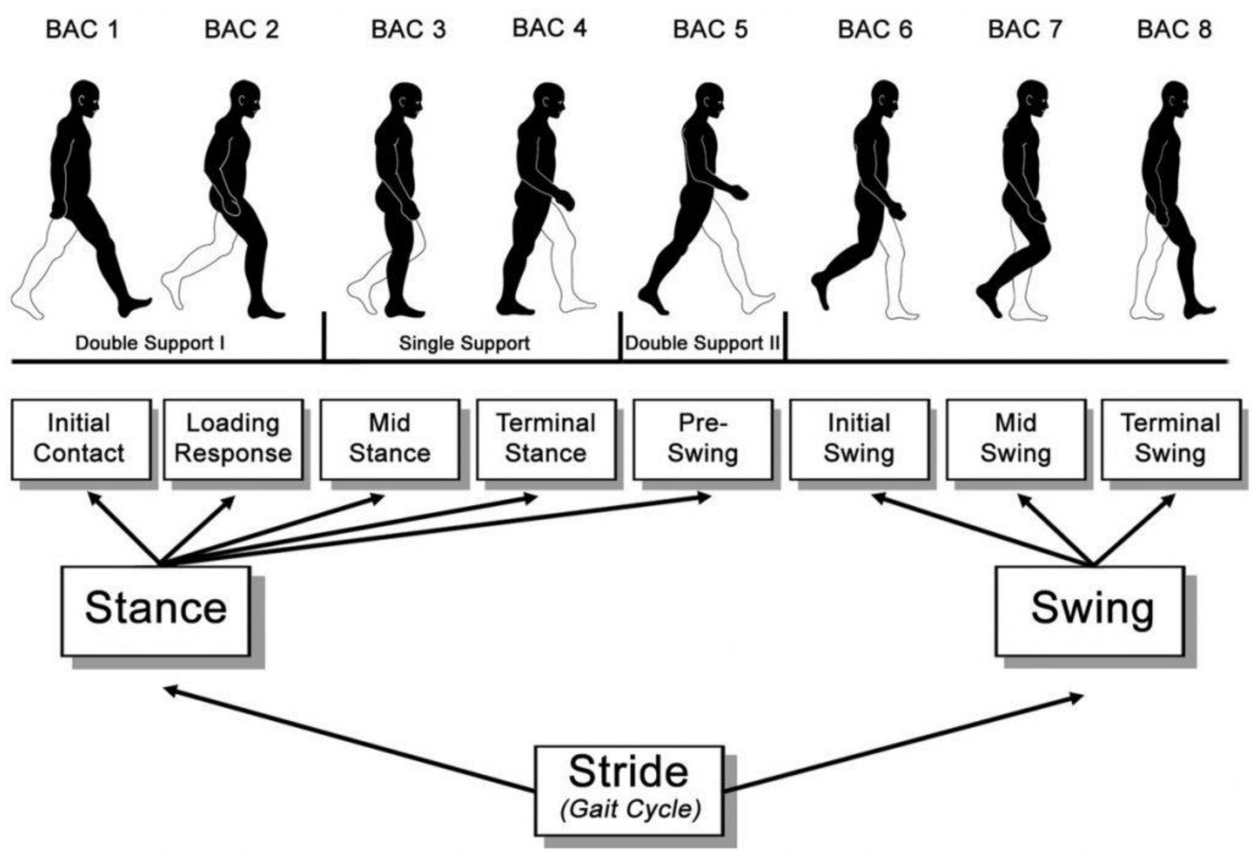

FIGURE 2.1 REPRESENTATION OF GAIT CYCLE

2.2. GAIT ABNORMALITIES

Abnormal gait is when the part of the body in control of the movement does not function properly. Different factors that can affect one's gait include; age, sex, weight, body proportion, footwear, or diseases, injury, genetic factor, etc. Pathology in gait can be observed to be either musculoskeletal or neuromuscular.

Under the musculoskeletal pathologies, we have

1) Hip pathology

2) The knee pathology

3) Foot/ ankle pathology

4) Length discrepancy.

Under the neuromuscular pathologies, we have

1. Hemi-paretic gait

2. The spastic gait

3. The parkinsonian

THE KNEE PATHOLOGY:

The knee, which is the largest joint in the body, is often called a complicated joint. This is because it imitates the movement of a door hinge. It allows for bending movement, which in turn makes bending, squatting, jumping, and running possible. It is made up of four (4) different components, namely

1. The bones

2. The cartilage Page

3. The ligaments

4. The tendons

The femur, which can also be called the thighbone, can be found at the upper part of the knee joint. The tibia is found at the lower part of the knee joint, while the knee cap is found in between the tibia and the femur. It acts as the coverage point for the two bones. The cartilage is a tissue, it cushions the bones of the knee joint, and it also helps the ligaments slide over the bones very easily. The tendons connect various muscles supporting the bones and knee joints together. Knee pathology occurs as a result of knee injuries.

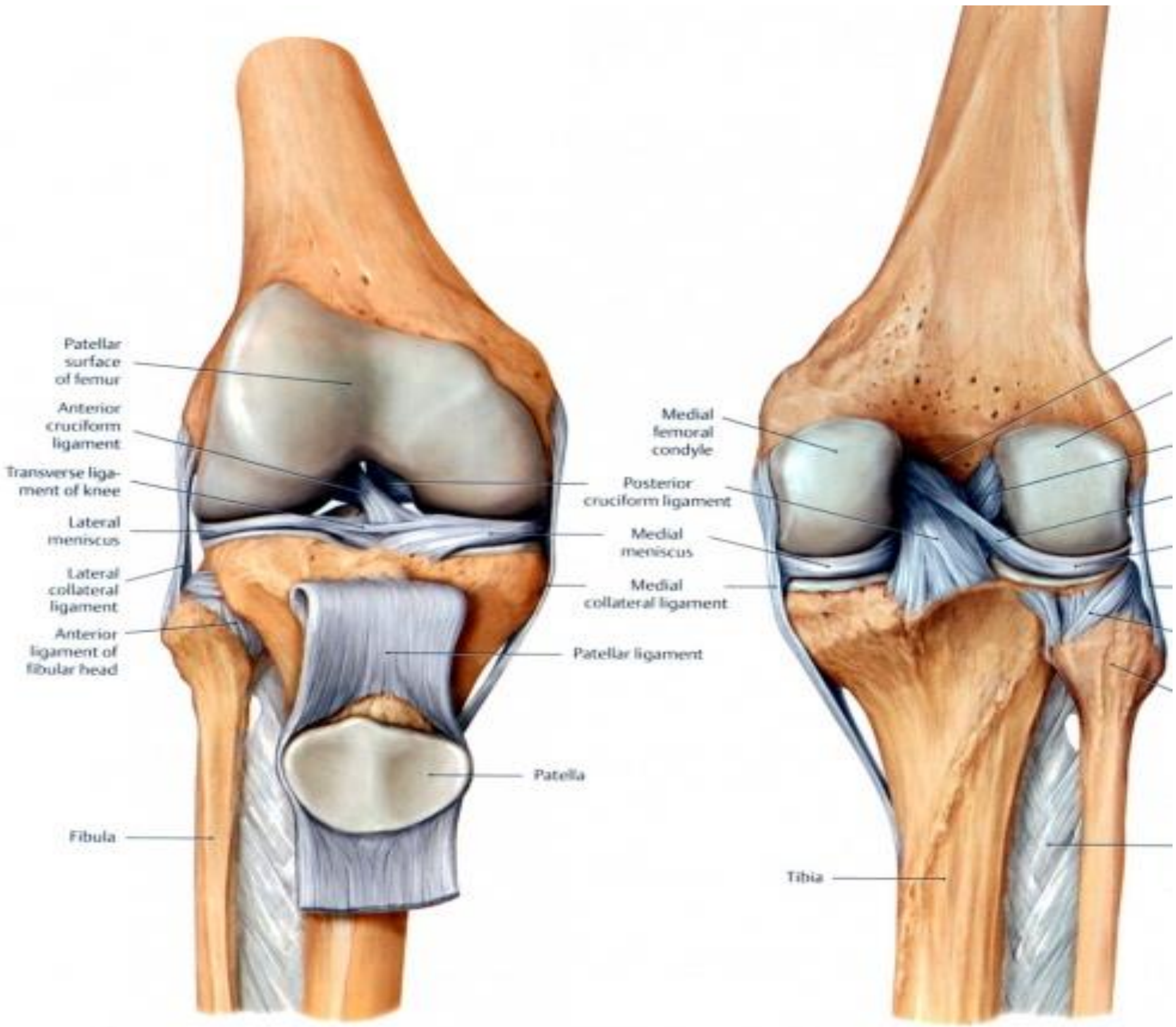

FIGURE 2.2 THE KNEE AND IT VARIOUS COMPONENTS

There are different types of knee injuries, the most common ones are

1. Fractures

2. Dislocations

3. Tendon tears

4. Collateral ligament injuries

5. Tendonitis

6. Iliotibial band syndrome

7. Posterior cruciate ligament injury etc.

Any of these injuries cases pathology to the knee, and hence the gait of a person is altered. In most cases, there is a noticeable difference in the walking pattern of the person. Everyday wearing and tearing, recreational activities and sport also could lead to knee pathologies.

2.3. GAIT CAPTURING TECHNIQUES

Motion Capture Camera

This is a commonly used technique for gait analysis. For examination, the joint positions, joint movement directions, and joint point varieties are detected during walking. In contrast to different advancements, this method does not require the connection of any material on the body. This method can be utilized both for 2D or 3D investigation of the human step.

For 2D analysis. A single camera is usually used to get information. The camera is set in corresponding with the subject's plane of movement of interest. The significant restriction of this strategy is the out-of-plane development that drives the investigation to unordinary yields.

For 3D examination, more than one camera is required with a perplexing arrangement, as the perception should concentrate on all planes of developments [2].

Optoelectronic system

This procedure utilizes dynamic or uninvolved markers that are connected to the focal point of the human body. The optoelectronic framework follows these marker focuses and changes over the produced or reflected light signals from the markers into electrical signs, which is then used to build models for walk examination [2].

Inertial system

The inertial framework utilizes accelerometers and gyroscopes together and takes a shot at the rule of inertial estimations. Acceleration and Orientation information of the connected point are given by the Accelerometer and Gyroscope through which gait analysis can be achieved. The weakness of utilizing this framework is the skin development antiques which can affect the perusing of acceleration and gyration[2].

Electrogoniometer

Electrogoniometer (EGM) is an electro-mechanical instrument that is utilized to gauge points of joint movements and furthermore utilized in gait investigation. [2].

Gait mat/pressure mat

Gait mat is an extraordinary sort of rug that contains an arrangement of embedded sensors. The geometry of the carpet is pre-decided, and the sensors of the mat can detect the foot contact and GRF while walking[2].

Force Shoes

Force sensors are organized in the bottom of shoes so that the conveyed foot weight can be estimated [2].

2.4. GAIT CAPTURING DEVICES

Gait analysis has utilized various sorts of movement sensors and frameworks, for example, the accelerometer, gyroscope, magnetoresistive sensors, adaptable goniometer, electromagnetic global positioning framework, force sensor, and sensors for electromyography (EMG)

Accelerometer

An accelerometer is a kind of inertial sensor that can gauge both static (e.g., gravity) and dynamic (e.g., vibration) acceleration, both including the consistently present gravitational acceleration g. In the event that the angle of the sensor as for the vertical is known, the gravity component will be displaced, and speed and position will be dictated by numerical integration. There are three principle sorts of accelerometers. Piezoresistive and capacitive accelerometers can give double acceleration segments and have higher stability. In this way, these kinds of accelerometers are reasonable for estimating the movement status in the human stride. The increasing speed can be determined by appending the accelerometer to a body part, typically knee, feet, or abdomen[1][2].

Gyroscope

This is a precise angular`speed sensor. It gauges the movement and stance of the human body in gait analysis by estimating the specific angular rate. This device depends on the idea of assessing the Coriolis force (an outward force corresponding to the precise angular velocity of rotation in a pivoting reference outline). The angular rate can be gotten by the integration of the gyroscopic signal [2].

Magnetoresistive sensor

Magnetoresistive sensors depend on the magnetoresistive impact. That is, the magnetoresistive effect alludes to the adjustment in the resistivity of a current-conveying ferromagnetic material coming about because of a magnetic field, with the opposition change corresponding to the tilt point with respect to the magnetic field direction. In light of this magnetoresistive impact, magnetoresistive sensors will assess changes within the body orientation in regard toward the north or the vertical pivot in the

in the gait analysis [2].

Flexible Goniometer

An adaptable goniometer quantifies the relative pivot between two human body fragments by estimating the longitudinal displacement of two parallel wires twisted in the plane of rotation, which is shown by determining the knee joint during human strolling [2].

The electromagnetic tracking

This is a sort of 3D estimation gadget dependent on Faraday's law of magnetic induction. In the ETS, the controlled magnetic fields are produced by a fixed transmitter and identified by the receivers fixed on the moving object. Along these lines, the positions and directions of the item according to the transmitter can be determined [2].

Force Sensors

Force sensors can be implanted in footwear to acknowledge mobile estimations of GRF during the stride. This GRF is a 3D vector, with the definite direction contingent upon the type of the interface between the foot and the ground [2].

2.5. GAIT ANALYSIS APPROACHES

Different factors come to play to determine the approach to be used in the analysis of the gait. Generally, there are two distinct approaches used to analyze gait. They are

1. **THE OBSERVATIONAL APPROACH**

In this method, the walking pattern of the subject is critically analyzed by an observer. Here, different aspects of a person's walking style are observed (pace, duration, walking stride, etc.) Also, in this method, phases like fast, poor, slow, smooth, etc. are also considered. The observer also puts into consideration the different standing views of the subject also. (Front, back, side, etc.). However, this method has proved highly

ineffective and unreliable.

2. **THE QUANTITATIVE APPROACH**

In this method, biomechanics serves as an effective tool for analysis. It gives a better understanding of human motion, which in turn allows for a more objective evaluation of the accuracy and effectiveness of different rehabilitation treatments for the improvement of gait pathologies. It is divided into two namely;

a) Kinematic data approach

b) Kinetic approach

2.5.1 KINEMATIC DATA APPROACH

This involves the measurement of the motion in the joint. The measurement can be gotten using various sensors or camera system techniques[4]. The extent, direction, and speed of the movements of joints and segments are considered. The center of gravity (COG) and the center of mass (COM) are considered as they help in the generation of parameters for the analysis. They also act as forces that aid the

movement and balance of motion. The part of the body where the total mass of the body is distributed evenly is the COM. It has been proven over time as an effective means of analysis for gait pathologies.

2.5.1 KINETIC DATA APPROACH

This centers around the forces and moments that make walking conceivable and are evaluated in the human body portions (Joint reaction, gravity, etc.). It also includes the measurement of GRF and kinetic analysis. It is assessed from the force that responds when the foot contacts the ground and relies upon the utilization of versatile force sensors [4].

The quantitative analysis of gait deals majorly with the detection of changes in the gait of a person. These changes occur mostly due to specific medical interventions such as surgery or therapy. This method has proved very suitable as it has the ability to directly and quantitatively compare an entire gait waveform, and at the same time, also pinpoint the similarities and differences between them.

2.6 Time and Frequency Signal Analysis

The time-domain represents signals as an element of time while the frequency domain characterizes signals by a magnitude and phase as a component of time. The time domain is a plot of a signal with one of the axes as time which is an independent variable and the other which is the reliant variable is typically the amplitude. The time-domain gives a time-amplitude depiction of the signal. This depiction isn't generally the best portrayal of the sign for most sign handling related applications

Transforms are applied to signals in order to acquire additional data from that signal that isn't promptly accessible in the crude signal. The crude signal is a signal that is in the time domain. Fourier transforms are applied to a signal to change it into the frequency domain, which gives more information on the signal as it uncovers the characteristic frequency substance. The" frequency" of a thing includes the pace of progress of that thing. Along these lines, one 18 can say if a variable changes quickly, it is of high frequency. If this variable changes gradually, one can say that it is of low frequency and If the variable doesn't change by any stretch of the imagination, at that point, it has no frequency. As a rule, the most recognized data in a signal is covered up in the frequency substance of the signal. Classic frequency investigation applies the Fourier Transforms (FT) a Short-Time Fourier Transforms(STFT).

These transforms separate a signal into constituent sinusoids of various frequencies and equivalent coefficients mirror the magnitude of those frequencies. The Fourier transforms an amazing analytic tool that finds the leading frequency of a signal. Its shortcoming is that it doesn't give localized information concerning when a specific dominant frequency occurs. The Short-Time Fourier transforms attempts to beat this shortcoming by windowing the region of interest; however, resolution issues are then experienced a lot like focusing in on a low resolution picture. The wavelet transforms is a moderately new numerical tool that can be applied in handling signals, giving striking data about both the time and frequency content of the signal. The wavelet transforms a waveform pattern of a constrained span that has a standard estimation of zero rather than a sine wave, which has a great length. The Wavelet analysis comprises taking a waveform, for example, the daubechies wavelet, moving it through the degree of the sign.

As the waveform is loosened up and scaled, coefficients are created as a component of both scale and location

2.7. APPLICATIONS OF GAIT ANALYSIS

Sports: Gait analysis can be utilized during sports drills for investigation and improvement of an athlete's execution. The performance of the athlete can be perceived and further adjusted if there is a flaw by the walking stride examination. This sort of investigation advances execution improvement [4]

Rehabilitation: Gait analysis is a viable clinical instrument for treatment, arranging, result appraisal, and longitudinal surveys on the upkeep and progress of patients. Movement investigation can be applied as a clinical apparatus of the lower limbs during stride in pre-usable planning for patients with cerebral paralysis, which can change the careful dynamic.

In specific fields like joint arthroplasty, gait analysis utilizing wearable sensors is used to gather clinical and instrumental.

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2.8 REVIEW OF RELATED WORKS

Skevin et al. [7] examined the gait estimation with a wearable sensor for three people with and without multiple sclerosis (an interminable provocative infection of the focal sensory system) each. The framework comprises of the primary sensor hub and three other installations. Every sensor hub consists of a three-axis accelerometer and a two-axis gyroscope. Cross-correlation examination with the walk signal was applied

Liu [2] built up a wearable sensor for quantitative gait analysis utilizing three gyroscopes to quantify the precise speeds of the shank, foot, and knee and two accelerometers to gauge the position and swing period of various individuals. The information gathered was spared in a pocket information recorder that was in the sent into a PC. The information was processed on MATLAB utilizing direct integration to evaluate the direction of the three-leg sections

Agostini et al. [8] compared two techniques for a wearable sensor for the computation of gait analysis.MIMUs framework and the highest quality level electro-mechanical framework. The first involved seven sensor units, each containing a gyroscope, accelerometer, and magnetometer, while the other utilized stage 32 system, which depends on foot-switches, timing foot-floor contact events, and electrogoniometers. Three foot-switches are put under each sole, underneath the back segment of the impact points, while Three electro-goniometers are put in correspondence of lower leg, knee, and hip joints, in every limb. The two techniques were utilized to gather information from sound volunteers with no physical incapacity history, and the outcomes, in spite of the fact that Mimus estimations on the knee and hip joints are clinically adequate, they are not as dependable for the lower leg joint like the stage 32 framework.

Chen et al. [9], structured a midsection mounted triaxial accelerometer unit to record human developments. The framework comprises of two units, a wearable sensor unit, and the data logger unit. The wearable sensor unit, which contains an accelerometer and a microcontroller, is worn by the volunteer. The information is sampled utilizing ADC(analog-to-computerized converter) and the output is fed into a microcontroller. The sampled data are then communicated remotely to the data logger unit. The data logger is fixed close to a network power source. Through cable connection, the sampled information is downloaded and investigated to PC utilizing programming programs.

Samer et al. [5] designed a wearable in-shoe pressure-based mapping framework. It is otherwise called a F scan wireless in-shoe pressure mapping system. The system gathers pressure and force estimation remotely utilizing a segmentation approach. The segmentation approach comprises of modeling each section by a regression model and using the logistic function to model the transition between segments. The remote unit was connected to the midsection of the subject, and pressure and force information are sent from a paper-slim in-shoe sensor progressively to the PC. The investigation required five trial of complete phase cycles as the data were recovered. The paper harped more on the recognition of the primary attributes of the stride cycle.

Biagetti et al. [10], structured a remote wearable surface electromyography (sEMG) and accelerometer to gain both sEMG and movement-related signals utilizing ultralight. The proposed structure is comprised of four base stations and a few wearable detecting hubs that remotely communicate the natural and accelerometer signals to the base stations using a custom convention. The sEMG/inertial detecting hubs can obtain, intensify, digitize, and send the signals to at least one base station through a 2.4 GHz radio connection utilizing a custom made communication protocol designed on top of the IEEE 802.15.4 physical layers. An external power supply was used to control the base station. Additionally, the USB interface containing the RF transceiver for the remote association with the versatile hubs is utilized to control the framework at the same time energizing six mobiles hubs, and a 32-piece microcontroller. The UI programming recorded and broke down the information taken care of from the base station through a USB to the control PC.

Moon et al. [11], structured a framework for three-dimensional gait examination utilizing wearable sensors and quaternion computations. The framework comprised of Seven sensor units, each consisting of tri-axial accelerometer and gyro sensors, which was then fixed to the lower appendages. A calculation dependent on quaternion computation was executed for the direct estimation of the sensor units. The directions of the sensor units were converted to the orientation of the body sections by segments by a rotation matrix obtained from a calibration trial.

2.9 CONCLUSION

Numerous researchers have taken interest and studied different approaches to obtain the best and most efficient result for proper gait analysis. Gait analysis is useful in various fields ranging from clinical practice to biomechanical research. The method used determines the level of accuracy be expected. With video cameras, the accuracy of gait analysis improved as cross-examination was used to ensure accuracy. Additionally, the utilization of wearable sensors for gait investigation gives quantitative and repeatable outcomes over broadened timespans with minimal effort and high compactness, indicating better possibilities and gaining incredible ground as of late.

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CHAPTER THREE

DESIGN METHODOLOGY

3.1 INTRODUCTION

This chapter breaks down the design process adopted for the execution of the project. This chapter also defines and describes the design model used and applied in the development of the

Wearable sensor.

The goal of this project is to design a wearable sensor belt prototype that can acquire data concerning the locomotion of an individual for gait analysis. Also, the prototype should be able to effectively show in a graphical illustration a person with a normal gait or abnormal gait. The data collected should be comprehensive enough for processing and proper diagnostics. The proposed system should be as light as possible for ease of movement.

3.2 SYSTEM DESIGN

This describes the different units that make up the entire design and working of the system. The system design consists of two central units: the wearable sensor unit(hardware) and the data logger unit (software).

3.2.1 Wearable Sensor Unit (Hardware)

This is the hardware part of the project. This unit comprises the different components that make the wearable sensor. The components include an accelerometer, a gyroscope, a microcontroller (Arduino

Uno). These components are fixed to a wearable belt that will be worn around the waist of a person to collect gait data to be analyzed.

3.2.2 Data Logger Unit

This is the software aspect of the project. This unit has to do with the analysis of the data collected from the wearable sensors. It makes use of a microcontroller (Arduino nano), a transceiver, and a Personal Computer, which contains the software that will be used to carry out the analysis.

3.3 Components

1. Accelerometer

They are fit for estimating static and dynamic acceleration, both including gravitational acceleration g. In the event that the angle of the sensor as for the vertical is known, the gravity part can be expelled, and speed and position can be dictated by numerical integration. Movement in three dimensions can be calculated using accelerometer estimations over three orthogonal axes (X, Y, Z) [9]. An accelerometer was picked for this task in light of its low value, minimized size, and simplicity of integration.

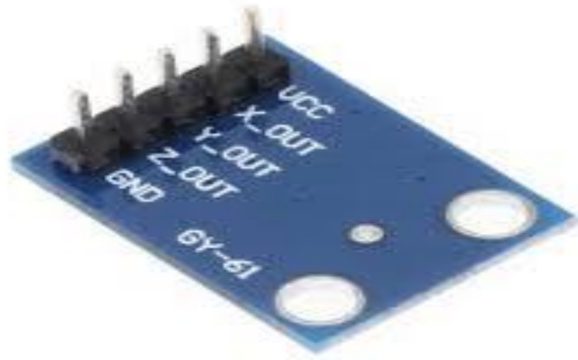

FIGURE 3.1 ACCELEROMETER

2. Gyroscope

They are used to measure angular velocity. In the event that the underlying angle is known, integration over time gives the adjustment in angle.

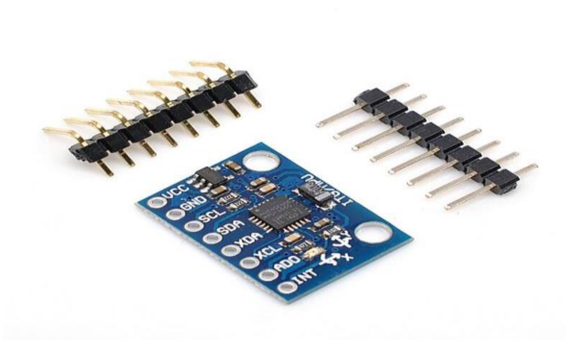

FIGURE 3.2 GYROSCOPE

3. Arduino

This device comprises of two separate parts namely;

i. The IDE (integrated development environment) or software. This is where the code is written (programmed) to run on the system, then uploaded to run on the physical board.

ii. The physical programmable circuit board.

Arduino is an effective and easy means for programming in circuits as it does not require other hardware. Just a piece of cable is used for the programming. It also serves as a medium for the housing of other components. For this project, the Arduino was used for the installation and programming of different components for the gait analysis. Arduino Gemini pro and the Arduino Uno were utilized for actualizing the project.

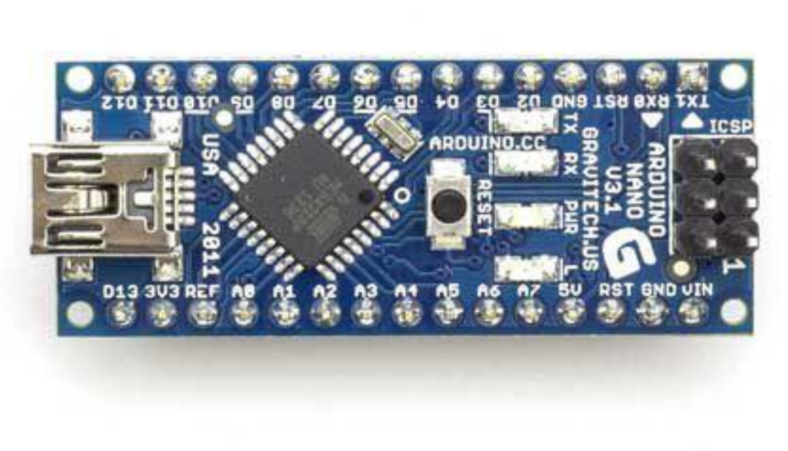

FIGURE 3.3 ARDUINO GEMIMI

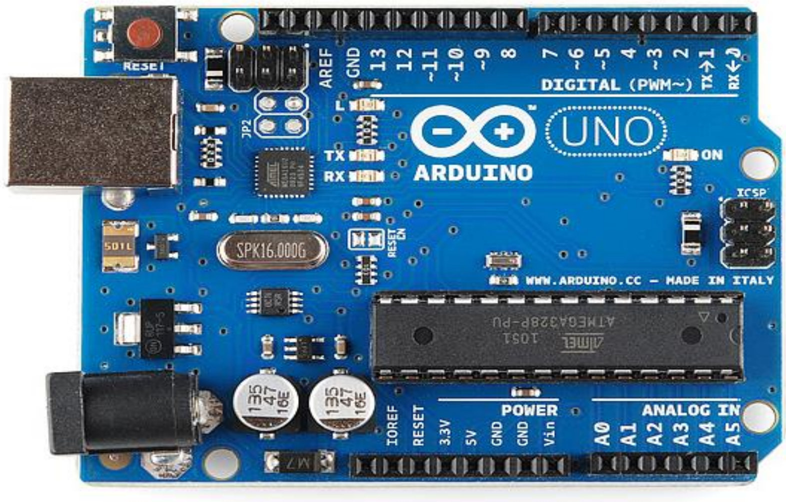

FIGURE 3.4 ARDUINO UNO

IDE (integrated development environment) or software

During configuration, the Arduino displays a programmable interface. This interface acts as a collector of instructions. This is where the code is written(programmed) then the programed message is then carried out by the device.

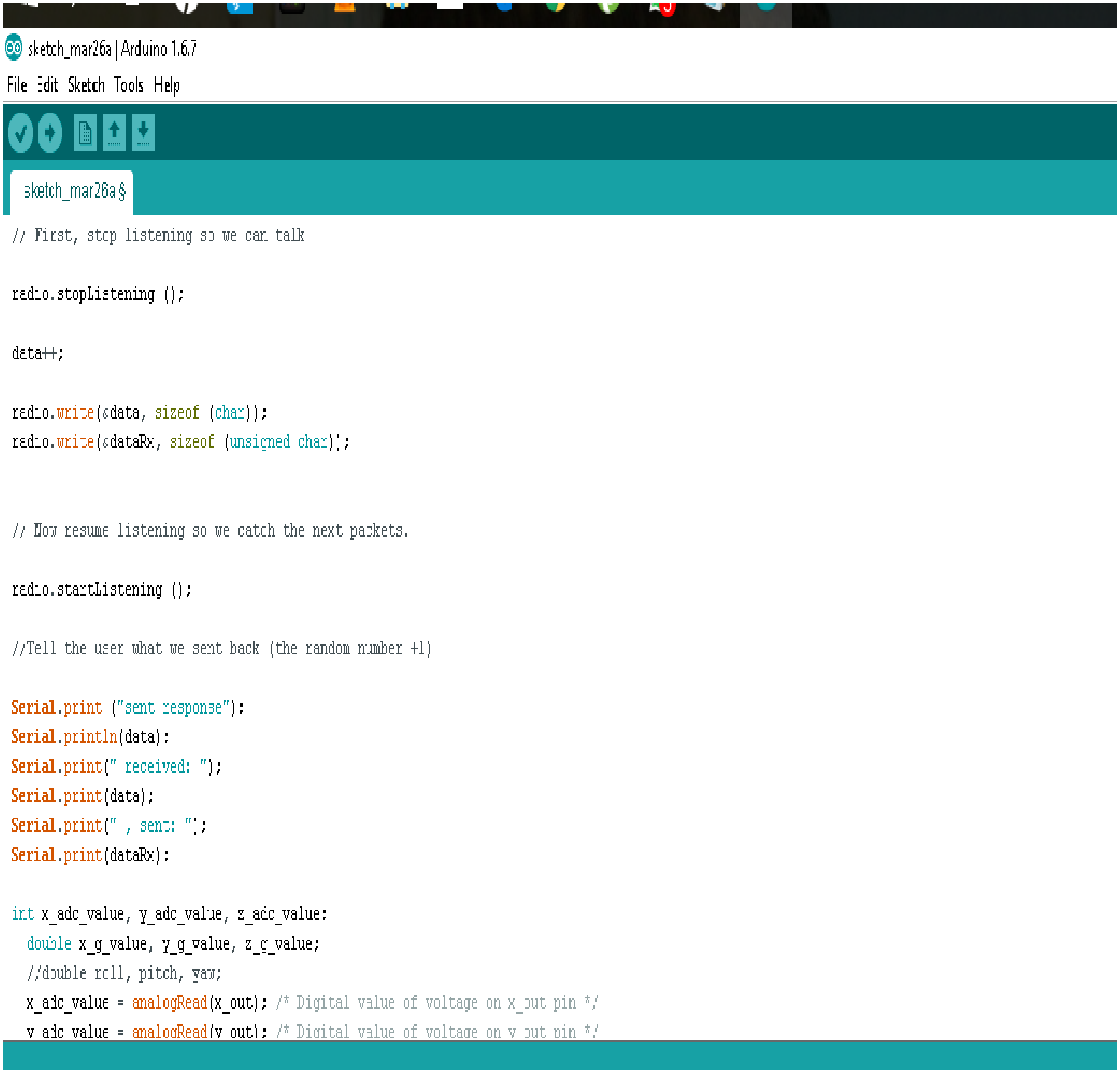

FIGURE 3.5 ARDUINO INTERFACE DURING CONFIGURATION.

4. **Transceiver**

This is a device that comprises of both a transmitter and a receiver. The device has the ability to transmit signals as well as receive signals. When transmitting occurs, the receiver is made dormant, and when receiving occurs, the transmitter is likewise made inactive also. This project harnessed the ability to make and establish a connection between the transmitting and receiving end of the wearable sensor. The wearable sensor belt had a transceiver connected to the Arduino. The Arduino acts as both the processor and circuit board where the connection takes place, which then transmitted the data collected by the accelerometer during the analysis.

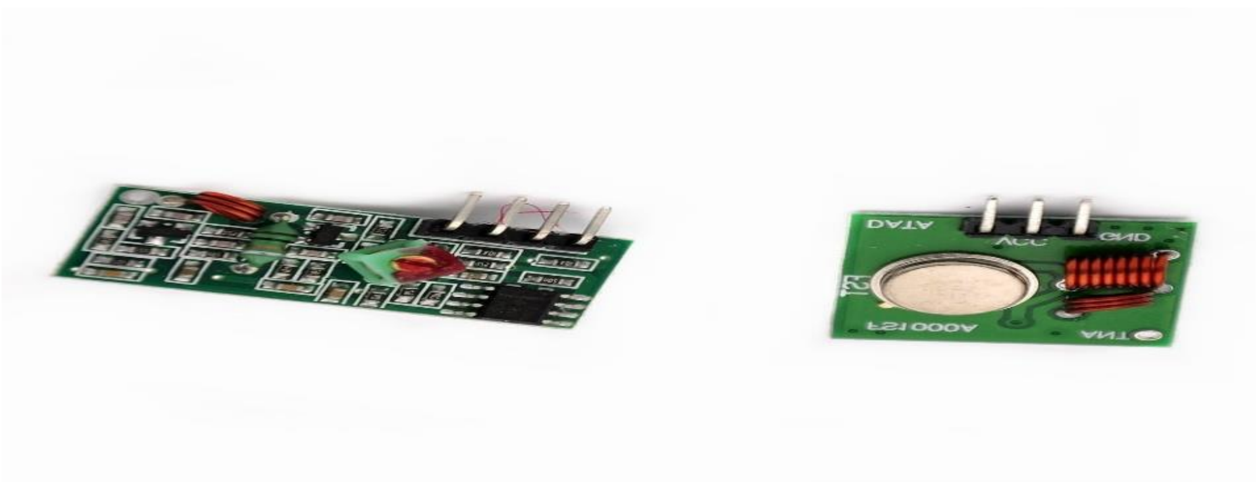

FIGURE 3.6 TRANSCEIVERS

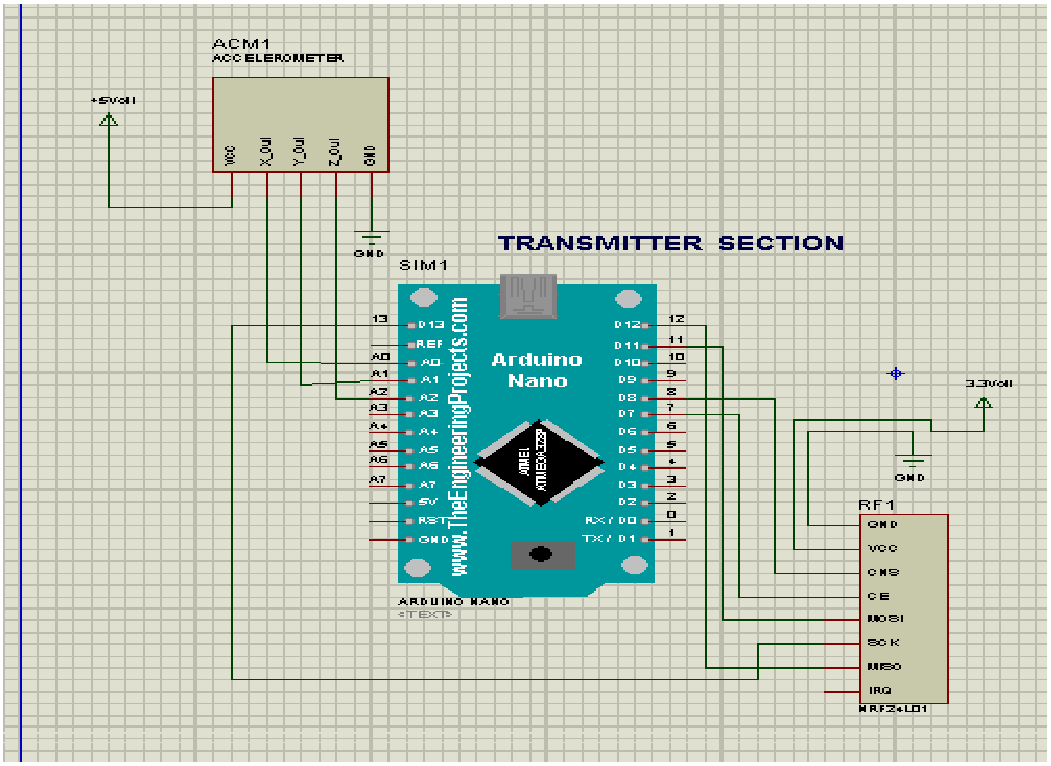

FIGURE 3.7 CIRCUIT DIAGRAM OF TRANSMITTING END OF THE WEARABLE SENSOR

On the receiver's end, the arduino is connected to the other transceiver. The transceiver acts as the receiver, it takes the generated values obtained with the aid of the accelerometer for the generation of graphs for each subject.

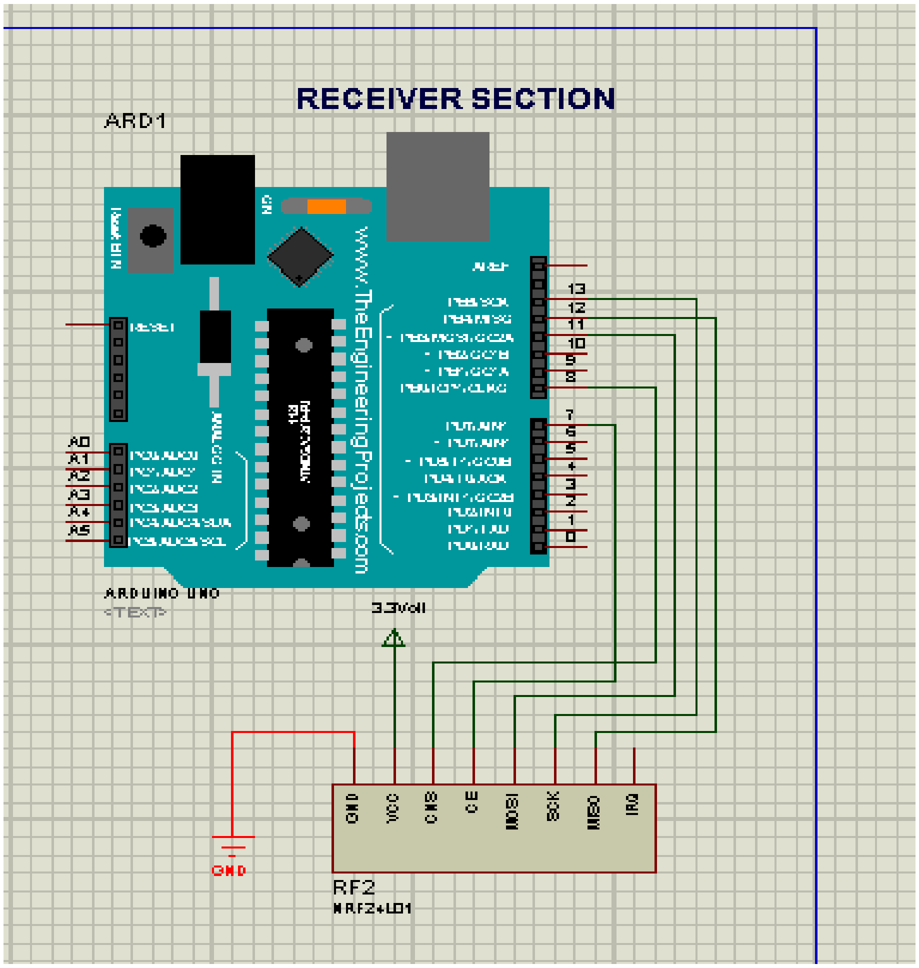

FIGURE 3.8 CIRCUIT DIAGRAM SHOWING THE RECEIVING END

For proper analysis to be carried out, the link between the transmitting and the receiving end must be established. After the connection is established, signals are then transmitted from the transmitting end of the wearable sensor to the receiving end. The transceiver on the transmitting end, which acts as the transmitter, only transmits to the other transceiver on the receiving end, which serves as the receiver only, thereby creating a communication link.

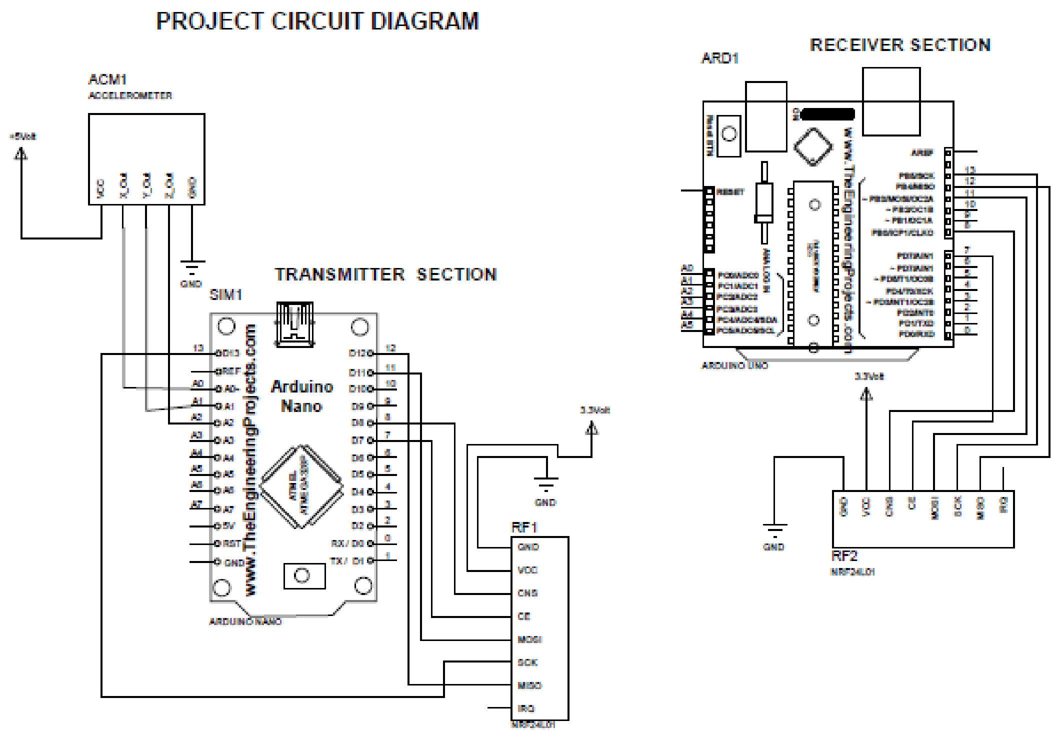

FIGURE 3.9 THE FULL SYSTEM CIRCUIT DIAGRAM

3.3 SYSTEM PROCEDURE

The system procedure describes the different stages the system undergoes to accomplish the task.

The System procedure is described in the flowchart below

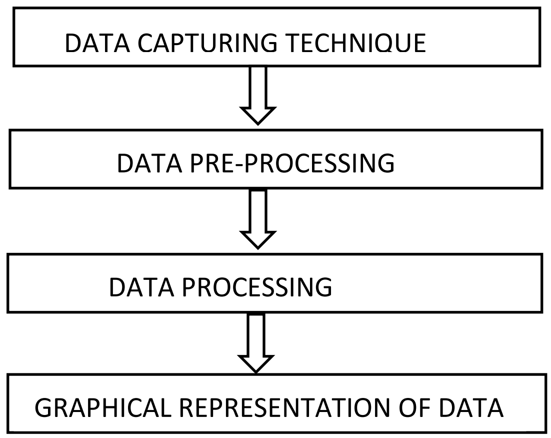

FIGURE 3.10 FLOWCHART OF SYSTEM DESIGN

3.3.1 DATA CAPTURING TECHNIQUE

The technique utilized for the capturing of gait data was the accelerometer for static acceleration data and gyroscope for angular velocity. That was attached to the waist of the participant. A population of six random participants, each wearing the waistband, was used to obtain the required data.

3.3.2 DATA PROCESSING

Data normalization is a vital part of the pre-processing stage in gait analysis. The technique involves the removal of some variables like physical characteristics like weight and then group the data into a defined format for a more effective clinical comparison of different body mass.

Filtering: Often, in kinematics, there are errors associated with the measurements referred to as noise. Noise is the unwanted part of signals. These unwanted signals can be eradicated using a process called filtering. Digital filtering is used to attenuate noise while leaving the useful signal untouched. Noise usually are of low frequencies, and low pass filter are used for the filtering [12].

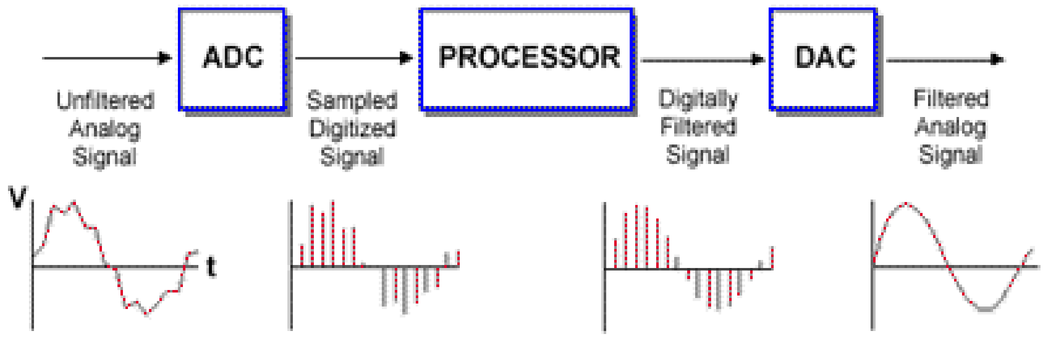

FIGURE 3.11 BASIC FILTERING PROCESSES

3..5 CONCLUSION

The design process is the most important part of any work. The chapter breaks down the step by step procedure of how the project is meant to operate . it also talk about the method to be used to accomplish the goal of the project .

CHAPTER 4

CONSTRUCTION, TESTING, AND RESULT

4.1 INTRODUCTION

This chapter describes the implementation of the project. The testing of the prototype is discussed as well as the results. Also, this chapter analyses the different walking patterns acquired in an attempt to distinguish normal from abnormal gait.

4.2 PROJECT COSTING

The entire bill of engineering, showing the cost and quantity of each component used in the achievement of this project is stated and analyzed in the table below.

TABLE 4.1 BILL OF ENGINEERING MEASUREMENT AND EVALUATION

S/N	ITEM DESCRIPTION	QUANTITY	RATE	TOTAL
1	ARDUINO UNO	1	₦3,000.00	₦3,000.00
2	RF transmitters and receiver	1	₦900.00	₦2000.00
3	65pcs breadboard connectors and jumpers	1	₦1,500.00	₦1,500.00
4	vero board small size stripped	1	₦150.00	₦150.00
5	ADXL335 3 axis accelerometer	1	₦3,000.00	₦3,000.00
6	100Ω 2W resistor	1	₦150.00	₦150.00

7	5mm LED blue	1	₦100.00	₦100.00
8	2200UF 63V electrolytic capacitor	1	₦500.00	₦500.00
9	MPU6050 GYROSCOPE	1	₦2500.00	₦2500.00
10	BELT	1	₦2000.00	₦2000.00
11	ARDUINO NANO	1	₦8000.00	₦8000.00
12	BATTERY	1	₦2500.00	₦2500.00
	TOTAL			₦25,400.00

4.3 SYSTEM IMPLEMENTATION

The wearable sensor was attached to the waist of the 3 participants of varying ages and weight. They were required to walk 2 meters distances for the data acquisition. ADXL335 3 axis accelerometer was the sensor used to obtain the gait data. The acquired information was then transmitted by the RF transmitter to the Arduino Uno. The Arduino was able to receive the data via the RF receiver attached to it. The received data was then normalized using a zero normalization method.

The data were normalized by subtracting a constant number to ensure balance in the actual output being transmitted by the accelerometer. This was achieved by taking the Y data and subtracting from the corresponding value to give us the value of G. (-1g,) thereby eliminating the gravity component. This makes the actualization of a zero-value possible. The same process was then also carried out on the X and Z values, respectively, and they were both equated to zero. This is because gravity had no effect on them. This is because the accelerometer was not in motion yet.

The accelerometer measures the acceleration (g's) in three dimensions (X, Y, Z), and the data are analog. For easy processing, the data need to be converted to digital format. To convert the analog readings into degrees, the formula below is applied:

$$AccVal = AccADC - AccZero$$

Where $AccVal$ is the analog reading, and $AccZero$ is the value when it reads $0g$

The normalized data need to be filtered because although the gyroscope is very precise, it tends to drift while The accelerometer can become unstable after some time but does not drift. The data, therefore, needs to be low pass filtered to calculate the precise data using the complementary filter. The processed data can now be used for proper gait analysis.

4.3.1 COMPLEMENTARY FILTER (CF)

The complementary filter is a compelling yet simple approach for the data fusion of different types of information, which are integral in a frequency domain [13].

For each signal $P(s)$ and transfer function $W(s)$, we can say:

$P(s)W(s) + P(s)\big(1 - W(s)\big) = P(s)$ ………………………………………. Equation 1

If $W(s)$ has the characteristics of low-pass, the complementary high pass characteristics will be

$1 - W(s)$ therefore, by filtering two complementary data, it is possible to get an estimate of the signal P:

$P_{low}W_{PB} + P_{lowhigh}\,(1 - W_{PB}) = P$ …………………………………………………. equation 2

where P_{low} = low-frequency approximation of P and P_{high} = high-frequency approximation of P, respectively.

Most times, we can derive the high-frequency approximation by the integration of a velocity signal received by the gyroscope, which shows a low-frequency drift phenomenon. Therefore, we can rewrite Equation 2 as:

$P_{low}\ W_{PB} + \frac{V_{high}}{s}\ (1 - \ W_{PB}) = P$……………………………………………….. equation 3

If we start from the low-pass filter, we can get an easier implementation of the CF as:

$W_{PB} = \frac{1}{\mathrm{T}_p \mathrm{S} + 1}$………………………………………………………. Equation 4

this means Equation 2 can be realized as:

$\left(P_{low} + \ \mathrm{T}_p V_{high}\right) W_{PB} = P$………………………………………. Equation 5

For this project, the approximation of the position is gotten from the data provided by accelerometers (P_{low}) and gyroscopes (V_{high}). Certainly, accelerometers provides precise data at a low frequency; but, gyroscopes tends to drift in the same frequency band; therefore, they are useful at higher frequencies [13].

4.4 SYSTEM TESTING

Unit testing was completed to guarantee that each phase of the structure work appropriately. Unit testing was first completed of every part to ensure usefulness. An integration testing was then completed. This is to guarantee every segment in the framework had the option to impart and work together effectively. Finally, the functionality test was done. This is to ensure that the wearable gait sensor belt was in impeccable condition and ready to communicate the information of the different subjects to the receiver's end for a legitimate investigation

This ensures that the wearable sensor works according to earlier stated specified requirements. The belt was tested to ensure it was light enough for the participant but firm enough to hold the component and acquire relevant information.

The receiving end of the component was tested to ensure that it received the appropriate data. The code was carefully scrutinized to prevent the wrong interpretation of the information.

4.5 RESULT AND DISCUSSION

While the belt is strapped on each participant, the gait data was processed, and the graphs below show filtered and non-filtered gait data in X, Y, and Z direction (forward movement, upward/downward movement and sideways movement) respectively for each subject. The aim of this project is to be able to properly distinguish between normal and abnormal gait. In the graph generated for a subject with a normal gait, we can distinctively observe a set of repetitive cycles, while in subjects with noticeable gait pathology, there was no distinctive repetitive pattern due to inconsistence and abnormality in the walking pattern

```
X = -0.93        Y = -0.99        Z = -1.30
X = -0.53        Y = -0.98        Z = -1.40
X = -0.98        Y = -1.08        Z = -1.46
X = -0.55        Y = -0.74        Z = -1.28
X = -0.90        Y = -1.02        Z = -1.40
X = -0.62        Y = -0.81        Z = -1.30
X = -0.27        Y = -0.58        Z = -1.15
X = -0.83        Y = -0.84        Z = -1.24
X = -0.53        Y = -0.75        Z = -1.22
X = -0.69        Y = -0.78        Z = -1.22
X = -0.84        Y = -0.90        Z = -1.30
X = -0.89        Y = -1.12        Z = -1.47
X = -0.75        Y = -0.93        Z = -1.40
X = -0.58        Y = -0.69        Z = -1.22
X = -0.66        Y = -0.81        Z = -1.25
X = -0.62        Y = -0.69        Z = -1.18
X = -0.49        Y = -0.58        Z = -1.07
X = -0.93        Y = -0.95        Z = -1.28
X = -0.95        Y = -0.98        Z = -1.36
X = -0.66        Y = -0.77        Z = -1.25
X = -0.56        Y = -0.55        Z = -1.07
X = -0.55        Y = -0.68        Z = -1.13
X = -0.72        Y = -0.66        Z = -1.10
X = -0.55        Y = -0.40        Z = -0.93
X = -0.15        Y = -0.28        Z = -0.05
```

FIGURE 4.1 THE X, Y, Z FILTERED RESULTS

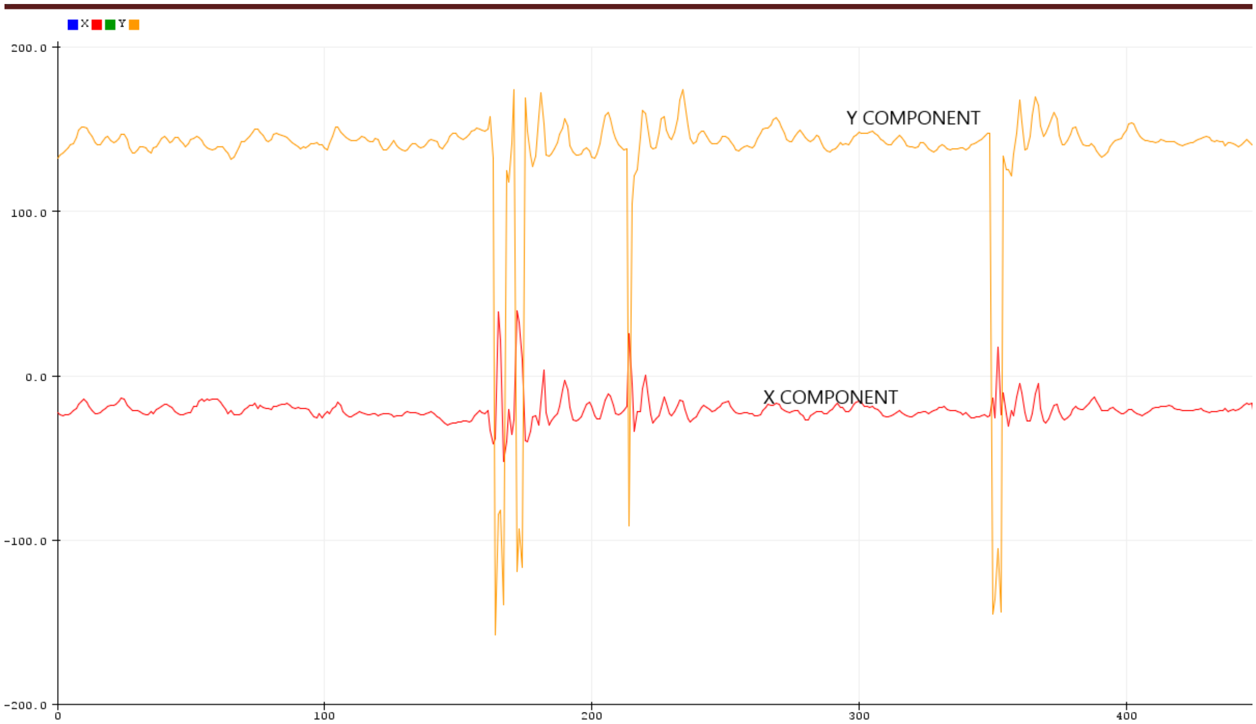

FIGURE 4.2 A NORMAL GAIT

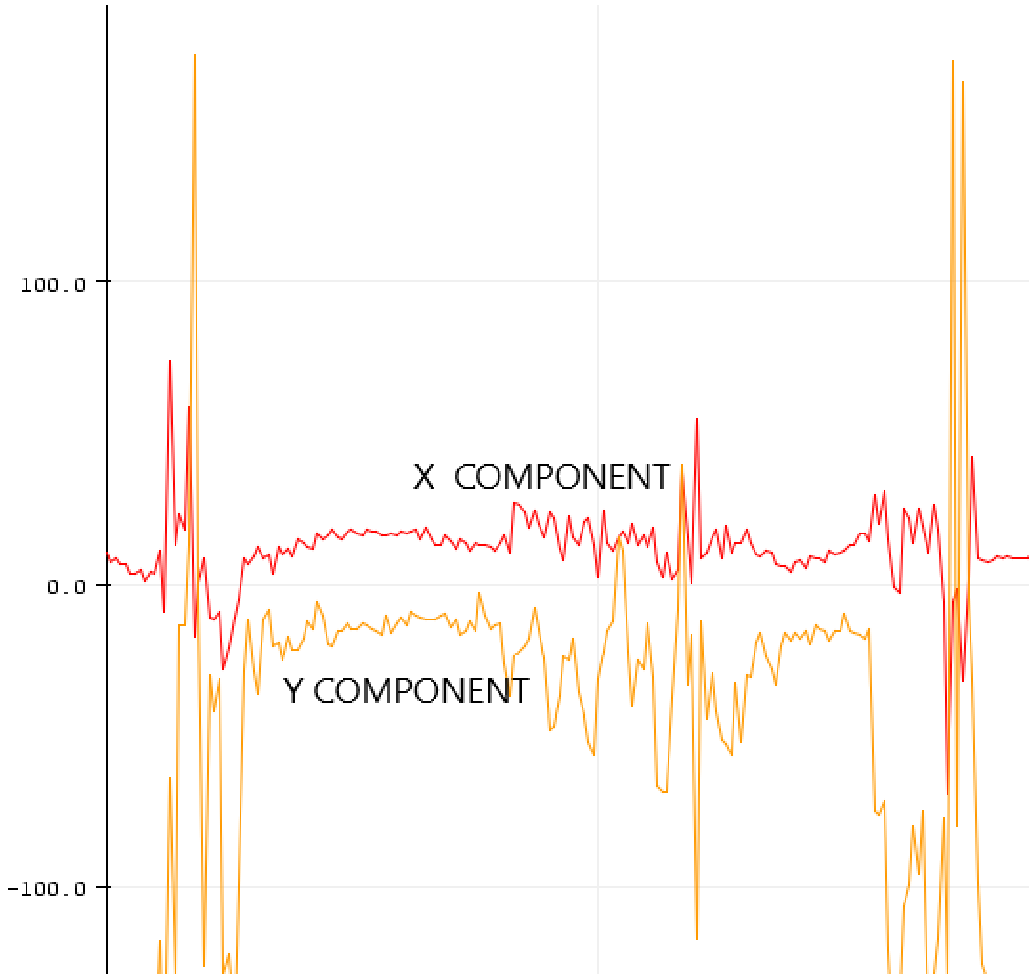

FIGURE 4.3 ABNORMAL GAIT

The red line signifies the X-axis and the brown Y-axis. The graph shows the filtered results of both axes. As shown in the graph generated, there is a clear distinction between normal and abnormal gait. For a subject with a normal gait, we can distinctively observe a set of repetitive cycles, while in subjects with noticeable gait pathology, there was no distinctive repetitive pattern due to inconsistence and abnormality in the walking pattern.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1. PROJECT SUMMARY

In this report, the design of a wearable sensor belt for the capturing of gait data to distinguish between normal and abnormal gait. This project provided a systematic and detailed review of gait with the aid of wearable sensors. After the introduction to the gait phase, the different methods of analysis for gait was analyzed and explained. The features and applications of gait were also discussed. I went further to explain the various gait pathologies. The design, which involves the use of an accelerometer and gyroscope, was described in detail. The major setback of both components was explored and corrected for the generation of an accurate result. Also, normalization and filtering were introduced as an essential part of the processing stage so as to generate a better result. The participant with normal and abnormal gait were required to walk a two-meter distance for the extraction of gait data. The gait data then underwent the processing stage to generate graphs. The results from the graph help show a repetitive pattern in participants with normal gait while there are inconsistencies in participants with an abnormal gait. The design analysis shows a cheap, energy-efficient, and convenient way to monitor and detect gait abnormalities.

5.2 CHALLENGES

During the entire course of the project, different challenges were encountered

1. Getting a belt with a material thin enough to maintain contact with the body at the same time strong enough to hold and house the sensors for the analysis.

2. Getting the written code to function was also a challenge. The errors in the code had to be corrected to get the code to operate.

3. Assembling and testing of the components to function correctly was tricky

3. Figuring out the filtering method that best suits the project and how to implement it in the code was challenging.

4. During configuration and programming, the radio was not found. Troubleshooting was carried out to resolve the issue.

5. There was a noise interference with some components leading to improper data generation but was resolved by implementing the right filtering method.

6. This type of project requires time for implementation. Therefore, it became a problem when such a project was to be completed under a limited period of time.

5.3 RECOMMENDATIONS

Due to the fact that this project interacts with everyday activities, especially locomotion and movement, this project can be applied to solving motion-related problems. Although this paper focused mainly on the center of mass, I strongly recommend a system that also takes into consideration the force from the ground, reacting to the foot coupled with the center of mass (COM) data of the subjects to create a more efficient system. I also strongly recommend further work be done on the sensor belt to make it possible for the sensor to be remotely controlled.

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APPENDIX

APPENDIX A

CODE FOR RF TRANSMITTER AND RECEIVER

```
#include<SPI.h>

#include<RF24.h>

RF24 radio (7,8);

const byte addresses [][6] = {"1NODE", "2NODE"};

void setup(){

Serial.begin(9600);

delay(1000);

Serial.println("THIS IS THE TRANSMITTER CODE YOU NEED THE OTHER ARDUINO TO SEND
BACK");

radio.begin();

radio.setChannel(124);

radio.setPALevel(RF24_PA_MIN);

radio.setDataRate(RF24_250KBPS);

radio.openWritingPipe(addresses[1]);

radio.openReadingPipe(1,addresses[0]);

radio.stopListening();
```

```
randomSeed(analogRead(A0));
}
void loop(){
  unsigned char data = ( x_out, y_out, z_out);
if (! radio.write( &data, sizeof(unsigned char))){
Serial.println("No acknowledgement of transmission receiving radio device");
delay(5);
}
radio.startListening();
unsigned long started_waiting_at = millis();
while (! radio.available()){
if (millis() - started_waiting_at>200){
Serial.println("No response received - timeout!");
return;
  }
}
unsigned char dataRx;
```

```
}

radio.read(&dataRx, sizeof(unsigned char));

Serial.print(" sent: ");

Serial.print(data);

Serial.print(" , received: ");

Serial.print(dataRx);
```

APPENDIX B

```
const int x_out = A1;

const int y_out = A2;

const int z_out = A3;

void setup(){

Serial.begin(9600);

delay(1000);

Serial.println("THIS IS THE RECEIVED DATA");

 Serial.print("NORMALIZED DATA");

 Serial.print("\t");

}
```

```
void loop(){

  unsigned char data = ( x_out, y_out, z_out);
 int x_digital, y_ digital, z_ digital;
  double x_g_ digital, y_g_ digital, z_g_ digital;
  double roll1, pitch1, yaw1;
  // for (int i = 0; i <= 10; i++) {
  x_ digital = analogRead(x_out);
  y_ digital = analogRead(y_out);
  z_ digital = analogRead(z_out);
/*  Serial.print(  "    x = ");
  Serial.print(x_ digital);
  Serial.print("\t\t");
  Serial.print("y = ");
  Serial.print(y_ digital);
  Serial.print("\t\t");
  Serial.print("z = ");
  Serial.print(z_ digital);
```

```
  Serial.print("\t\t");

  //delay(1000);

  */

  x_g_ digital = ( ( ( (double)(x_ digital * 5 ) / 1024) - 1.65 ) / 0.330 );

  y_g_ digital = ( ( ( (double)(y_ digital * 5 ) / 1024) - 1.65 ) / 0.330 );

  z_g_ digital = ( ( ( (double)(z_ digital * 5  ) / 1024) - 1.80 ) / 0.330 );



 //Serial.print("\n\n");

 // delay(1000);

  double roll1  = atan2 ( y_g_ digital, z_g_ digital) * RAD_TO_DEG;

  double pitch1 = atan ( -x_g_ digital / sqrt( y_g_ digital * y_g_ digital + z_g_ digital * z_g_ digital)) *
RAD_TO_DEG;

#else

  double pitch  = atan2(-x_g_ digital, z_g_ digital) * RAD_TO_DEG;

  double roll = atan(y_g_ digital / sqrt(x_g_ digital * x_g_ digital +z_g_ digital * z_g_ digital)) *
RAD_TO_DEG;

#endif

double accXangle = roll1;

 double accYangle = pitch1 ;
```

```
 double CAngleX = roll1;

  double CAngleY = pitch1;



  timer = micros();



  double accXrate = x_g_value / 131.0;

  double accYrate = y_g_value / 131.0;



  double dt = (double)(micros() - timer) / 1000000;

  timer = micros();

//COMPLEMENTARY FILTER

  CAngleX = 0.93 * (CX + accXrate * dt) + 0.07 * roll1;

  CAngleY = 0.93 * (CAngleY + accYrate * dt) + 0.07 * pitch1;

Serial.print("X = ");

Serial.print(x_g_value); Serial.print("\t");

Serial.print("Y = ");

Serial.print( y_g_value); Serial.print("\t");

Serial.print("Z = ");
```

```
 Serial.print(z_g_value); Serial.print("\t");

 Serial.print("\n");


// Serial.print(roll); Serial.print("\t");


//Serial.print("NON FILTERED Y = ");

//Serial.print(accYangle); Serial.print("\t");

//Serial.print("NON FILTERED X = ");

//Serial.print(accXangle); Serial.print("\t");



//  Serial.print("FILTERED Y = ");

 //Serial.print(compAngleY); Serial.print("\t");

//  Serial.print("FILTERED X = ");

// Serial.println(compAngleX); Serial.print("\t");


//  Serial.print("\n");
```

```
 // Serial.print(pitch); Serial.print("\t");

;



 // Serial.print("\n\n");

  delay(200);



}
```