

KNEE BRACE FOR OSTEOARTHRITIS

Submitted in partial fulfillment of the requirements for the award of

Master of Technology degree in Medical Instrumentation

by

Babisha.J (41440004)



DEPARTMENT OF BIOMEDICAL ENGINEERING

SCHOOL OF BIO AND CHEMICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with Grade “A” by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project report is the bonafide work of **Babisha.J** (Reg. No. 41440004) who carried out the project entitled "Knee Brace for Osteoarthritis" under our supervision from November 2022 to April 2023.

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I, Babisha.j (Reg. No. 41440004) hereby declare that the Project report entitled "Knee brace for osteoarthritis" done by me under the guidance of Ms. Sindu Divakaran, Department of Biomedical Engineering is submitted in partial fulfillment of the requirements for the award of **Master of Technology** degree in **Medical Instrumentation**.

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ABSTRACT

The knee joint carries majority of the human body's weight and the heaviest pressure loads while allowing for flexible movement; it is the body portion that is most at risk for developing osteoarthritis. In the early stages of exercise treatment, which run for about six weeks, the patient meets with the physical therapist many times per week. After that, instructions are given to the patient on how to continue rehabilitation exercises at home on their own. Patients with knee osteoarthritis can monitor their own rehabilitation progress by employing a method that uses three wearable sensors mounted on the chest, ankle, and knee working leg during rehabilitation exercises. Motion sensor signals are utilised to characterise the workout type and determine whether or not the exercisers' postures are correct using time-domain, frequency-domain, and angle information. When an angle range falls inside the level, it advances to the next stage; if it does not, buzzer is activated. By gathering information from the patient, the device is utilised to track the patient's knee status based on daily/weekly measures. As part of their daily regimen, the patient is expected to bring reading from home. Then, the measured data are sent to the patient's mobile application.

Keywords: Osteoarthritis, Time-domain, Rehabilitation Exercise, Frequency-domain, Angle information, Mobile Application.

CHAPTER	TITLE	PAGE NO.
	ABSTRACT	i
	LIST OF ABBREVIATION	iv
	LIST OF FIGURES	vi
1	INTRODUCTION	1
2	LITERATURE SURVEY	8
3	AIM AND SCOPE	11
	3.1. ADVANTAGE	11
	3.2.DISADVANTAGE	12
4	METHODS AND MATERIALS	14
	4.1 MPU6050	14
	4.1.1.GENERAL PIN FUNCTION OF MPU6050	15
	4.1.2.SPECIAL PIN FUNCTION OF MPU6050	16
	4.1.3.SPECIFICATION OF MPU6050	16
	4.2.ESP32	17
	4.2.1.SPECIFICATION OF MICROCONTROLLER	18
	4.2.2.GENERAL PIN FUNCTION	18
	4.2.3.SPECIAL PIN FUNCTION	19
	4.2.4.SPECIFICATION OF ESP32	20
	4.2.5.FEATURES OF ESP32	20
	4.3.AMS117	21

	4.3.1.SPECIFICATION OF AMS117	22
	4.4.5V SMPS	23
	4.4.1.BASIC COMPONENTS	23
	4.4.2.STAGES OF 5V SMPS	24
	4.4.3.SPECIFICATION OF 5V SMPS	24
	4.5.METHODS	25
	4.5.1.DATA ACQUISTION	25
	4.5.2.FEATURE EXTRACTION	26
	4.5.3.CLASSIFIER	26
	4.5.4.ARUDINO IOT CLOUD APP	27
	4.5.5.SOFTWARE	28
5	RESULTS AND DISCUSSIONS	29
6	CONCLUSION AND FUTURE SCOPE	33
	REFERENCES	34

LIST OF ABBREVIATIONS

ADO	Active Data Object
ADC	Analog Digital Converter
BLE	Bluetooth Low Energy
CPU	Central Processing Unit
CKC	Closed Kinetic Chain
CAN	Controller Area Network
DPS	Degree Per Second
DMP	Digital Motion Processor
DIP	Dual Inline Package
EDR	Endpoint Detection and Response
FCC	Federal Communications Commission
GPIO	General Process Input/output
GPIO	General Purpose Input/output
GND	Ground
IMU	Inertial Measurement Units
IDC	Integrated Development Environment
I2C	Inter Integrated Circuit
I2C	Inter Integrated Circuit
IOT	Internet Of Things
INT	Interrupt Pin
LED	Light Emitting Diode
MPU	Magnetic Pickup Unit
MEMS	Micro Electro Mechanical system
MMC	Modular Multilevel Converter
MSD	Moisture Sensitive Device
OA	Osteo Arthritis
OKC	Open Kinetic Chain
PTOA	Post Traumatic Knee Osteoarthritis
PS	Power Supply
PROM	Programmable Read Only Memory
PWM	Pulse Width Modulation
PWM	Pulse Width Modulation

RBF	Radial Basis Function
ROM	Random Access Memory
ROHS	Restriction Of Hazardous Substances
RPM	Revolution Per Minute
SD	Secure Digital
SDIO	Secure Digital Input Output
SDIO	Secure Digital input/output
SCL	Serial Clock Pin
SDA	Serial Data
SPI	Serial Peripheral Interface
SPI	Serial Peripheral Interface
SOT	Small Outline Transistor
SRAM	Static Random Access Memory
SMPS	Switch Mode Power Supply
SOC	System On Chip
TKA	Total Knee Arthroplasty
UART	Universal Asynchronous Transmitter
VCC	Voltage Common Collector
VSS	Voltage Source Supply
XCL	Xoops Cube Legacy
XDA	Xtreme Development Of Arudino

LIST OF FIGURES

FIGURE NO.	DESCRIPTION	PAGE NO.
3.1	BLOCK DIAGRAM OF THE PROJECT	11
4.1	MPU6050	14
4.2	MPU6050 PIN CONFIGURATION	15
4.3	ESP32 WIFI MODULE	17
4.4	GENERAL PIN CONFIGURATION	18
4.5	AMS117	21
4.6	CIRCUIT DIAGRAM OF AMS117	22
4.7	5VSMPS	23
5.1	PLACEMENT OF SENSORS	29
5.2	TEST 1	30
5.3	TEST 1 RESULT	30
5.4	TEST 1 RESULT	30
5.5	TEST 2	31
5.6	TEST 2 RESULT	31
5.7	TEST 2 RESULT	32

CHAPTER-1

INTRODUCTION

1.1. OUTLINE OF THE PROJECT:

A novel method to track and measure the physical activity of patients with knee osteoarthritis throughout their rehabilitation exercises is wearable sensor-based rehabilitation exercise evaluation. Millions of individuals worldwide suffer from knee osteoarthritis, a degenerative joint disease that causes pain, stiffness, and reduced mobility. The patient's body can be fitted with wearable sensors, such as accelerometers and gyroscopes, to detect their exercise posture and provide real-time feedback Bellitti, Paolo et.al (2022). Utilizing this technology, it is possible to evaluate the efficacy of therapeutic exercises and track the patient's development over time. The advantages of exercise evaluation and therapy for osteoarthritis of the knee are numerous Bolam et.al (2021). According to their specific requirements, patients can receive individualised workout regimens and feedback, which can increase their adherence to the rehabilitation programme. The information produced by these sensors can also be used by medical practitioners to monitor patient progress and choose the best course of action Büttner et.al (2021). Overall, rehabilitation exercise evaluation for osteoarthritis of the knee is a promising strategy that has the potential to enhance both patient results and the standard of care given by medical professionals.

1.2. OSTEOARTHRITIS

Osteoarthritis is a multifactorial, degenerative joint disease that causes loss of articular cartilage, enlargement of the bone around the joint, subchondral sclerosis, and a variety of biochemical and morphological changes to the synovial membrane and also affects any joint in the body, but it most frequently affects the knees, hips, hands, and spine Calliess et.al (2014). The protective cartilage that cushions the ends of bones breaks down over time, which causes pain, stiffness, and limited movement. Pain is a common clinical symptom, especially after heavy lifting and continuous exertion; stiffness is a symptom of inactivity. It most likely

consists of a number of illnesses that together cause joint failure rather than being a single disease. Degenerative arthritis is another name for it, and it typically affects the hands, feet, spine, and large weight-bearing joints like the hips and knees. The three main forms of treatment for knee OA are drugs, physical therapy, and surgery Cao et.al (2022). It is called as degenerative condition. Age, heredity, obesity, joint traumas, and repetitive stress on the joints are some of the risk factors for osteoarthritis. Although there is no known cure for osteoarthritis, there are a number of therapies that can help to reduce symptoms and enhance quality of life. Painkillers, physical therapy, exercise, weight loss, and occasionally surgery are among them. A healthy weight, avoiding recurrent joint stress, and engaging in low-impact physical activity are additional lifestyle changes that can help stop the condition from progressing. In general, osteoarthritis is a prevalent and crippling ailment that can greatly affect a person's quality of life Chen et.al (2015). But many people with osteoarthritis are able to keep an active and rewarding lifestyle with the right care and management. The most crucial interventional therapy for mild to intermediate stages of knee OA is exercise therapy. Exercise therapy does not lessen the knee adduction moment, a crucial factor, even though it may relieve symptoms indication of the development of OA. Through a variety of rehabilitation programs, patients with knee OA receive exercise therapy that is good for joint mobility and body metabolism. The patient meets with the physical therapist multiple times each week during the first six weeks of early therapy. After that, the patient is given directions on how to continue exercising at home Chen et.al (2022).

The most frequent joint disease, with a prevalence of 22% to 39% in India, is osteoarthritis, the second most prevalent rheumatologic condition. Women are more likely than men to have OA, although as people get older, their frequency rises significantly. Nearly 45% of women over the age of 65 have symptoms, while 70% of those over 65 have radiological evidence. OA of the knee, especially in women, is a significant factor in reduced mobility. According to estimates, OA is the tenth most common reason for nonfatal burden. The majority of primary OA cases are those with no recognised underlying conditions Chiang et.al (2017). The main cause of primary osteoarthritis is ageing. It might manifest as erosive OA, generalised OA, or localised OA. Another illness or condition is the primary cause

of secondary osteoarthritis. In the study presented by Taylor, the scientists employed a peak detection technique to split signals into time segments. From each time segment, they then extracted features from the frequency and time domains to identify inappropriate motions using a classification system. The participant carried out each exercise throughout its initial set according to their interpretation of the directions. For offline labelling data, the video was recorded. The expert was tasked with rating the labels for the activities based on the frequency of the errors in real-world observations and their seriousness. Both a high incidence and severe movement were used to construct the labels for incorrect movement. The remaining information was labelled by a non-expert with the expert's advice Grimm et.al (2016).

1.2.1. Types of knee osteoarthritis:

Medical compartment knee osteoarthritis: The middle chamber Knee osteoarthritis is a kind of knee osteoarthritis that affects the medial compartment, or inner side, of the knee joint. The most prevalent kind of knee osteoarthritis, this condition is frequently attributed to the joint wear and tear that comes with ageing. The medial femoral condyle, which is located at the base of the thigh bone, and the medial tibial plateau make up the medial compartment. (The top of the shin bone). The cartilage in this region rapidly deteriorates with age in knee osteoarthritis, causing the bones to scrape against one another. This may cause the knee joint to experience discomfort, edema, stiffness, and a reduction in range of motion. Age, obesity, past knee injuries, and heredity are all risk factors for medial compartment knee osteoarthritis. Physical therapy, drugs, injections, and surgery (such as knee replacement surgery) are all possible forms of treatment Harper et.al (2020).

Lateral compartment knee osteoarthritis: laterally contained Knee osteoarthritis is a kind of knee osteoarthritis that affects the lateral compartment, or outer side, of the knee joint. Although less frequent than medial compartment knee OA, this type of OA can nonetheless be very painful and uncomfortable. The lateral femoral condyle (the bottom of the thigh bone) and the lateral tibial plateau make up the lateral compartment (the top of the shin bone).

Patellofemoral knee osteoarthritis: The patella (kneecap) and femur (thigh bone), which meet at the knee joint, are both affected by patellofemoral knee

osteoarthritis. The front of the knee may hurt with this kind of OA, especially when bending or ascending stairs. The patella moves in a groove on the end of the femur and is maintained in place by tendons and ligaments. The cartilage in this region rapidly deteriorates with age in knee osteoarthritis, causing the bones to scrape against one another. This may cause the knee joint to experience discomfort, edema, stiffness, and a reduction in range of motion. Age, past knee injuries, overuse of the knee joint, and heredity are all risk factors for developing patellofemoral knee osteoarthritis Taylor et.al (2018).

Bilateral knee osteoarthritis: A form of knee osteoarthritis known as bilateral knee osteoarthritis affects both knees simultaneously. This very common ailment can lead to severe discomfort, stiffness, and mobility restrictions. Osteoarthritis of the knees, which affects both knees, normally worsens over time as the cartilage in the knee joints starts to erode. As a result, there may be bone-on-bone contact and the development of bone spurs, both of which can worsen symptoms. Age, obesity, heredity, previous knee injuries, and overuse of the knees are risk factors for bilateral knee osteoarthritis. The most common course of treatment for bilateral knee osteoarthritis is a mix of non-pharmacologic and pharmaceutical measures. Physical therapy, exercise, weight loss, and the usage of aids like knee braces are a few examples of non-pharmacologic therapies. Over-the-counter painkillers, prescription painkillers, and injections of corticosteroids or hyaluronic acid are examples of pharmacologic therapies. Surgery, such as knee replacement surgery, may be advised in extreme circumstances. The degree of discomfort and disability, as well as the person's general health and capacity for surgery and recovery, will all play a role in the choice to undertake surgery Reichenbach et.al (2020).

Post-traumatic knee osteoarthritis: A kind of knee osteoarthritis called post-traumatic knee osteoarthritis (PTOA) occurs when the knee sustains a traumatic injury. A number of knee injuries, including ligament tears, meniscus tears, fractures, and dislocations, can lead to PTOA. Osteoarthritis, a condition where the cartilage that cushions the joint breaks down and causes pain, stiffness, and swelling, can be brought on by the knee injury. Pain, edema, stiffness, and a restricted range of motion in the knee joint are all possible signs of PTOA. When moving the knee joint, people with PTOA can hear a clicking or popping sound.

Treatment options for PTOA may combine non-surgical measures such as pain management, physical therapy, and lifestyle changes. Surgery, such as knee replacement surgery, may be required in rare circumstances. It's crucial for people with PTOA to collaborate closely with their medical professionals to create a treatment strategy that takes into account their particular requirements and circumstances Jung et.al (2019).

1.2.2. Classifications of knee osteoarthritis:

Primary and Secondary osteoarthritis: Primary osteoarthritis is a degenerative joint condition brought on by ageing and gradual damage to the knee joint. The majority of persons who develop this form of osteoarthritis are over 50. Primary osteoarthritis may run in families and can also be brought on by hereditary factors. On the other hand, underlying conditions or injuries that impact the knee joint can result in secondary osteoarthritis. This may include past knee injuries like fractures or ligament tears, as well as other illnesses like rheumatoid arthritis, gout, or infections that have an impact on the knee joint. Osteoarthritis secondary to primary can develop at any age and can advance more quickly. Primary and secondary osteoarthritis share many of the same symptoms, such as pain, stiffness, swelling, and a reduction in the range of motion in the knee joint. Treatment for both types of osteoarthritis may combine non-surgical interventions like pain management, physical therapy, and lifestyle changes. In severe cases, surgical interventions like knee replacement surgery may be required Thomas et.al (2012).

Symptomatic and Asymptomatic osteoarthritis: Osteoarthritis with symptoms, such as pain, stiffness, edema, and a restricted range of motion in the knee joint, is known as symptomatic osteoarthritis. Osteoarthritis symptoms frequently cause discomfort and functional restrictions in sufferers, which can lower their quality of life. A mix of non-surgical therapies, including pain management, physical therapy, and lifestyle changes, may be used to treat symptomatic osteoarthritis. Surgery, such as knee replacement surgery, may be required in extreme circumstances. On the other side, asymptomatic osteoarthritis is distinguished by the lack of symptoms. Asymptomatic osteoarthritis patients do not have pain, stiffness, or other symptoms of the condition despite the possibility of radiographic evidence of

joint destruction and degeneration. When imaging tests or X-rays are done for other reasons, it's common for asymptomatic osteoarthritis to be found by accident.

Unilateral and Bilateral osteoarthritis: Osteoarthritis can affect either one knee joint unilaterally or both knee joints bilaterally. Bilateral osteoarthritis can be brought on by genetic causes or systemic disorders that affect both joints, while unilateral osteoarthritis might be brought on by trauma or normal wear and tear on one knee. Similar signs and symptoms of unilateral and bilateral osteoarthritis can include knee pain, stiffness, edema, and a restricted range of motion.(s). A mix of non-surgical therapies, such as pain management, physical therapy, and lifestyle changes, may be used to treat both forms of osteoarthritis. Surgery, such as knee replacement surgery, may be required in extreme circumstances Karpiński et.al (2022).

1.2.3. Symptoms of knee osteoarthritis

Knee osteoarthritis is a degenerative joint condition that affects the bones, cartilage, and other knee joint tissues. Individuals may have different symptoms of knee osteoarthritis, which can include:

Pain: Knee joint pain is the most prevalent sign of knee osteoarthritis. It may be dull or sharp, and activity or extended sitting or standing may make it worse.

Stiffness: Another typical sign of knee osteoarthritis is stiffness in the knee joint, especially after prolonged sitting or lying down.

Swelling: An accumulation of fluid in the knee joint can cause swelling and inflammation.

Limited range of motion: People who have knee osteoarthritis may only have a small range of motion in their knee joint, which can make it challenging to carry out some tasks.

Popping or crackling noises: Some people with knee osteoarthritis may hear popping or crackling noises when they move their knee joint.

Joint instability: Severe knee osteoarthritis can cause buckling and instability in the afflicted joint, making it difficult to bear weight on the knee.

The severity of knee osteoarthritis symptoms can significantly affect a person's quality of life over time. It is crucial to consult a healthcare provider if you are experiencing any of these symptoms in order to receive a precise diagnosis and treatment strategy.

Exercise for osteoarthritis: The treatment for knee osteoarthritis includes exercise as a key element. Exercise can help reduce pain and stiffness, increase joint function overall, and enhance joint flexibility. Before beginning any workout program, it's crucial to speak with a healthcare provider, especially if you have advanced osteoarthritis of the knee or other medical issues.

Range of motion exercise: Exercises that increase joint flexibility and decrease stiffness Knee bends, straight leg rises, and ankle pumps are a few examples.

Strengthening exercises: By increasing muscular strength surrounding the knee joint, strengthening exercises can lessen the strain on the joint. Leg presses, squats, and step-ups are a few examples.

Aerobic Exercise: Low-impact aerobic activities like swimming, cycling, and walking can help lower knee joint stress by promoting weight loss and cardiovascular health.

Balance and stability: Exercises for balance and stability can aid with joint stability and lower the chance of falling. A balancing board or stability ball can also be used, as well as walking heel to toe Luan et.al (2020).

CHAPTER-2

LITERATURE SURVEY

Robert Karpinski et.al (2022) was proposed the patellofemoral joint examination and acquisition in order to find the optimum examination protocol for the best diagnostic outcomes. Prior to surgery, VAG acquisition was completed, and cartilage status was assessed as a benchmark during the procedure. During VAG, both closed (CKC) and open (OKC) kinetic chains were evaluated. The neighbourhood component analysis (NCA) algorithm was used to choose the best signal measurements. Multilayer perceptron (MLP) and radial basis function (RBF) neural networks were used to do the categorization. Three versions underwent classification using artificial neural networks: I. start the kinetic chain; II. Kinetic chain that is closed, and III. kinetic chain that is both open and closed. For the majority of the investigated variations, a classification accuracy of >95% was attained.

Hyunsuk Jung, et.al (2019) developed a wearable sensor system that tracks different movements by fastening it to the body has drawn a lot of interest. Strain sensors based on cracks are more sensitive than other types of sensors. These sensors have been studied for sensing tiny skin deformations because of their great sensitivity. For example, pulse the PS and SE processes to overcome the issues with crack-based sensors, such as low sensitivity at low strain, nonlinearity, and hysteresis. This finding demonstrates the great sensitivity with which minor, repeating deformations, like a pulse, can be detected.

Sang Jun Song, MD, et.al (2018) discuss noise characteristics and according to sound nature and onset, as well as parameters for differentiating between normal and pathological noises. Additionally, the management of knee noise is discussed, along with the origins of the physiological and pathological noises. Pain, an injury history, effusion, edema and pathological noise are all present in conjunction. It's critical to distinguish between physiological and pathological noise, a healthy individuals who are suffering physiological noise should be treated, whereas certain patients should receive diagnostic

procedures for pathological noise. Patients can receive help by carefully assessing noise characteristics and differentiating between normal and pathological noises and giving patients the right information regarding physiological noise will lower the likelihood of pathological noise and avoidable worry, which will lead to satisfied patients. By adopt by avoiding surgical errors, patellar crepitus and clunk should be prevented in TKA.

Oscar Kuang-Sheng Lee et.al (2022) developed a wearable motion sensor technology in conjunction with interactive mobile apps is promising in the post-TKA telerehabilitation situation and it can be utilised to trace the knee angular motion with sufficient reliability. This model assists patients who have undergone TKA in overcoming significant challenges in home-based physical therapy, demonstrating the viability of MSD in telerehabilitation and having significant consequences for patients and healthcare systems. To show the MSD's practicality in real-world settings, more studies on its usability, cost-effectiveness, and therapeutic success in telerehabilitation in large patient cohorts are required. However, as the technology is polished, it is anticipated that the MSD will be widely used in telerehabilitation for a variety of musculoskeletal illnesses.

Sara E. Harpe et.al (2020) developed a non-invasive wearable system to investigate tendon loading patterns during outdoor locomotion on diverse terrain. The device makes use of shear wave-tensiometry, a novel method for determining tendon load by monitoring the speed of waves within the tissue. With the help of a battery-operated piezoelectric actuator, our wearable-tensiometry system causes micron-scale shear waves in a tendon. Two tiny accelerometers put on the skin above the tendon are collected by a data recorder to track wave propagation.

Scott M. Bolam 1,2, et.al(2021) designed the feasibility of a remote patient monitoring (RPM) workflow. This workflow makes use of ankle-worn IMUs that measure impact load, limb impact load asymmetry, and knee range of motion .They present an innovative RPM system that offers a dependable and low-maintenance workflow for remote post-operative monitoring of patients

undergoing knee arthroplasty. Commercially available IMU sensors can be used to generate IMU outputs related to mobility (Bone Stimulus and Impact Load), impact load asymmetry, and range of motion. A more precise picture of the patient's recovery following knee arthroplasty surgery can be established by merging IMU data with existing PROMs. Even though these results are encouraging, more study is necessary to directly link the outputs of the IMU sensor with patient outcomes.

Grimm, Bernd, Stijn Bolin (2016) developed a wearable sensor technology with clinical applications for geriatric orthopaedic patients. The wearable sensor technology refers to algorithms and parameters used to analyse functional test results or activity monitoring data. Numerous orthopaedic investigations, especially those involving elderly patients, have used wearable sensor motion analysis and activity monitors. Many criteria for assessments of gait, sit-stand, stair or step-up tests have been validated for single or multiple IMUs and utilised in clinical trials for the routine objective assessment of physical functions. Future wearable sensor assessments of function and activity will combine to the extent that technology permits, taking into account patient compliance as well as the context necessary to derive trustworthy functional parameters.

Portia E. Taylor, et.al (2018) designed a home-based workout programme that can help knee discomfort sufferers perform better. An easy exercise regimen done at home can greatly alleviate knee pain. The absence of progress in patients who just had telephone contact with the therapist implies that benefits are not solely attributable to the psychosocial impacts of that communication.

CHAPTER-3

AIM AND SCOPE

3.1. AIM

The aim of this project is to assist physiotherapists in providing treatment to injured leg patients. It uses an MPU6050 sensor to obtain tilt angles in one direction. The device checks the angle to determine if a patient is performing the exercise correctly. If the angle is within a certain range, the device advances to the next step in the exercise. If the angle values are not within the expected range, an error message is displayed on your mobile via arduino iot cloud app.

3.2. BLOCK DIAGRAM

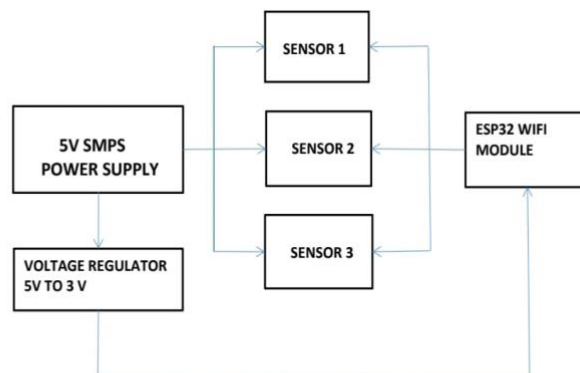


Fig.3.1: Block Diagram of the Project

3.2.1 Advantage:

- Personalized treatment
- Continuous monitoring
- Feedback and motivation
- Objective measurement
- Cost-effective

- Remote monitoring

3.2.2 Disadvantage:

- Technical limitations
- User discomfort
- Technology dependence
- Lack of human interaction
- Ethical concerns

3.3. SCOPE

The scope of brace for knee osteoarthritis is broad, as it has the potential to impact various aspects of the rehabilitation process. Here are some of the areas where wearable sensors can be used in the rehabilitation of knee osteoarthritis.

Objective assessment of exercise performance: Wearable sensors can provide objective measurements of exercise performance, such as range of motion, joint angles, and muscle activation. This information can be used to ensure that the patient is performing the exercises correctly and to track their progress over time.

Personalized exercise prescriptions: By monitoring the patient's movement patterns, wearable sensors can provide personalized exercise prescriptions tailored to the patient's specific needs. This can help ensure that the patient is performing exercises that are appropriate for their condition and they are exercising at the appropriate intensity.

Real-time feedback: Wearable sensors can provide real-time feedback to the patient and healthcare provider during exercise sessions. This feedback can be used to adjust the exercise program on the spot and to ensure that the patient is performing exercises correctly.

Remote monitoring: Wearable sensors can be used to remotely monitor the patient's progress, allowing healthcare providers to track the patient's rehabilitation program even when they are not physically present.

Data analytics: Wearable sensor data can be analysed to gain insights into the patient's movement patterns and to identify areas for improvement. This can help healthcare providers develop more effective rehabilitation programs and can lead to improved patient outcomes.

CHAPTER-4

MATERIALS AND METHOD

4.1. MPU6050

The MPU6050 sensor is a 6-axis Motion Tracking device developed by InvenSense that combines a 3-axis gyroscope and a 3-axis accelerometer in a single package. It is commonly used in applications that require motion tracking, such as robotics, drones, and gaming devices. The MPU6050 sensor uses MEMS (Micro-Electro-Mechanical System) technology to measure changes in velocity and orientation. The 3-axis gyroscope measures angular velocity, or how quickly the device is rotating around each axis, while the 3-axis accelerometer measures linear acceleration, or how quickly the device is accelerating or decelerating along each axis.

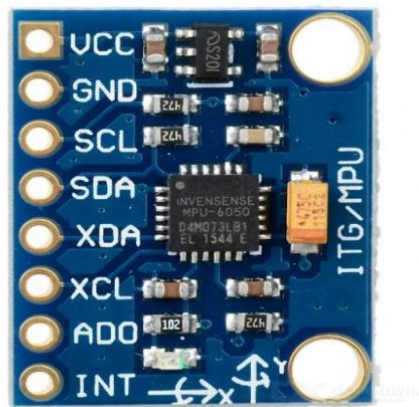


Fig 4.1: MPU6050

The sensor is capable of measuring changes in motion with high accuracy and can detect movements as small as 0.01° per second. It also includes a built-in temperature sensor, which can be used to compensate for changes in the sensor's readings due to temperature fluctuations. The MPU6050 sensor communicates with a microcontroller or other device using the I2C interface, which allows for easy integration into a wide range of applications. It can be configured to provide data at different sampling rates and with different levels of filtering to suit the specific requirements of the application. Overall, the MPU6050 sensor is a

versatile and reliable motion tracking device that is widely used in a variety of applications Song et.al (2018).

4.1.1 General pin function

The MPU6050 sensor has a standard 0.1-inch (2.54mm) pitch 8-pin DIP (Dual Inline Package) package. Here is a breakdown of the pin specification:

- VCC: This is the power supply pin for the MPU6050 sensor. It can be powered with a voltage between 3.3V to 5V.
- GND: This is the ground pin for the MPU6050 sensor.
- SDA: This is the data pin used for I2C communication. It is connected to the microcontroller's SDA pin.
- SCL: This is the clock pin used for I2C communication. It is connected to the microcontroller's SCL pin.
- XDA: This is an auxiliary data output pin that can be used for external devices, such as a magnetometer or a temperature sensor.
- XCL: This is an auxiliary clock output pin that can be used for external devices, such as a magnetometer or a temperature sensor.
- AD0: This is an address selection pin that can be used to change the I2C address of the MPU6050 sensor
- INT: This is the interrupt output pin, which can be used to alert the microcontroller when a specific event occurs, such as motion detection or data ready.
- Note that the XDA, XCL, and AD0 pins are optional and can be left unconnected if not needed in the application.

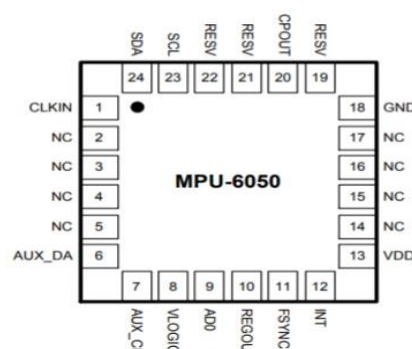


Fig 4.2: pin configuration

4.1.2. Special pin function

The MPU6050 sensor has a few special pin functions that can be useful in some applications. Here are the special pin functions of the MPU6050:

- **AD0 Pin:** The AD0 pin is used to set the I2C address of the MPU6050 sensor. When the AD0 pin is connected to GND, the I2C address of the sensor is 0x68. When the AD0 pin is connected to VCC, the I2C address of the sensor is 0x69.
- **INT Pin:** The INT pin is an interrupt output that can be used to indicate various events such as data ready or motion detection. The microcontroller can be configured to respond to these events by triggering an interrupt routine. The INT pin can be configured to operate in active-low or active-high mode by setting the appropriate register in the MPU6050 sensor.
- **Auxiliary I2C Pins:** The XDA and XCL pins are auxiliary I2C pins that can be used to interface with external sensors such as a magnetometer or a temperature sensor. These pins are not used in the basic operation of the MPU6050 sensor and are optional.
- **VLOGIC Pin:** The VLOGIC pin is used to set the logic voltage level for the MPU6050 sensor's I2C interface. The VLOGIC pin can be connected to the same voltage level as the microcontroller's logic voltage level or to a different voltage level. This can be useful in applications where the MPU6050 sensor is used with microcontrollers that operate at different voltage levels.

Overall, these special pin functions can be useful in some applications and can help to extend the capabilities of the MPU6050 sensor beyond its basic operation.

4.1.3. Specification

- Gyroscope range: ± 250 , ± 500 , ± 1000 , or ± 2000 degrees per second (dps)
- Accelerometer range: $\pm 2g$, $\pm 4g$, $\pm 8g$, or $\pm 16g$
- Operating voltage: 2.3V - 3.4V
- Interface: I2C (Inter-Integrated Circuit) protocol

- Maximum output data rate: 8kHz for the gyroscope, 1kHz for the accelerometer
- Built-in temperature sensor with a range of -40°C to +85°C
- DMP (Digital Motion Processor) engine for advanced motion processing capabilities
- Onboard 16-bit analog-to-digital converter (ADC) for accurate sensor data conversion
- Low power consumption: typically 3.9mA in full operating mode and 5µA in standby mode
- Small form factor: 4mm x 4mm QFN package

4.2. ESP32 WIFI MODULE

ESP32 is a powerful microcontroller and system on a chip (SoC) designed by Espressif Systems. It is a successor to the ESP8266 chip and is widely used for Internet of Things (IoT) applications, robotics, and other embedded projects. ESP32 comes with a dual-core processor, built-in Wi-Fi, Bluetooth, and a variety of input/output interfaces such as UART, SPI, I2C, ADC, and more. It has a low-power consumption mode and supports a wide range of operating voltages, making it suitable for battery-powered devices. ESP32 can be programmed using various programming languages and tools, including C/C++, Python, Arduino IDE, and Micro Python. Its rich feature set, low cost, and versatility have made it a popular choice among developers and hobbyists. The ESP32 is a popular Wi-Fi and Bluetooth-enabled microcontroller module that is used in a variety of applications, including home automation, IoT devices, robotics, and more. It is developed by Espressif Systems, and is based on the Xtensa LX6 microprocessor. The ESP32 module has a built-in Wi-Fi radio that supports 802.11b/g/n wireless standards, as well as Bluetooth 4.2 and Bluetooth Low Energy (BLE) protocols. It can function as a Wi-Fi access point or a client, and supports various encryption standards such as WPA/WPA2, WEP, and AES. In addition to its wireless capabilities, the ESP32 module has a dual-core processor that can run at up to 240 MHz, and features 512KB of RAM and 4MB of flash memory.



Fig 4.3: ESP32

It also has a variety of built-in peripherals, including multiple ADC channels, PWM outputs, and various interfaces such as UART, SPI, I2C, and more. The ESP32 module can be programmed using a variety of programming languages, including C++, Micro Python, and JavaScript. It is compatible with various development environments, including the Arduino IDE, Espressif's own ESP-IDF, and the Platform IDE.

4.2.1. Specification OF ESP32 Microcontroller

- Processor: Dual-core Xtensa LX6 32-bit processors, operating at up to 240 MHz
- Memory: 520 KB SRAM, 448 KB ROM, and 4 MB Flash
- Connectivity: Wi-Fi 802.11 b/g/n/e/i, Bluetooth v4.2 BR/EDR and BLE, and Ethernet (with external hardware)
- Input/output interfaces: 34x GPIO pins, 18x ADC channels, 2x DAC channels, 2x I2S interfaces, 2x UART, 2x SPI, 1x I2C, 1x SD/SDIO/MMC host controller, 1x IR (TX/RX), and 1x capacitive touch sensor
- Operating Voltage: 2.2V to 3.6V
- Operating Current: up to 160 mA in active mode, and less than 5 μ A in deep sleep mode
- Operating temperature: -40°C to 85°C

4.2.2. General pin function

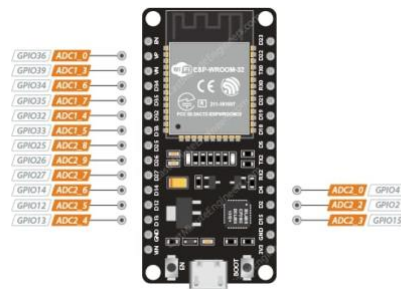


Fig 4.4: Pin Configuration

- General Purpose Input/output (GPIO) Pins: The ESP32 has 36 GPIO pins that can be used for digital input/output, PWM output, and other purposes.
- Analog Input Pins: The ESP32 has 18 analog input pins, which can be used to measure voltage levels.
- Serial Communication Interface Pins: The ESP32 has multiple pins that can be used for serial communication interfaces, including UART, SPI, and I2C.
- Pulse-Width Modulation (PWM) Output Pins: The ESP32 has 16 PWM output pins, which can be used to generate variable voltage levels for tasks such as dimming LEDs or controlling motor speed.
- External Interrupt Pins: The ESP32 has several pins that can be used for external interrupts, allowing the microcontroller to respond to external events.
- Touch Sensor Pins: The ESP32 has 10 touch sensor pins that can be used to detect touch inputs.
- Other Pins: The ESP32 also has additional pins for various purposes, including the boot mode selection pin, the reset pin, and the power supply pins.

4.2.3. Special pin function

In addition to the general pin configuration, the ESP32 also has some special pins with specific functionalities. Here are some examples:

- SPI Flash Pins: The ESP32 has dedicated pins for connecting external SPI flash memory. These pins are used for storing program code and other data.

- I2S Pins: The ESP32 has dedicated pins for connecting to I2S devices, which are used for digital audio data transmission.
- SD Card Pins: The ESP32 has dedicated pins for connecting to an SD card, which can be used for storing data and program code.
- Ethernet Pins: Some ESP32 development boards have dedicated pins for connecting to an Ethernet port, which allows the microcontroller to connect to a local network and access the internet.
- CAN Pins: The ESP32 has dedicated pins for connecting to a Controller Area Network (CAN) bus, which is commonly used in automotive and industrial applications.
- JTAG Pins: The ESP32 has dedicated pins for connecting to a JTAG interface, which is used for debugging and programming the microcontroller.

It's important to note that not all ESP32 modules and development boards will have all of these special pins, and the specific pin layout may vary depending on the device being used. It's important to refer to the pin out diagram and documentation for the specific device being used to understand the available pins and their functionalities.

4.2.4. Specification

- CPU: Dual-core Ten silica LX6 32-bit microprocessor, operating at up to 240 MHz
- Wi-Fi: 802.11 b/g/n/e/i (2.4 GHz) and 802.11 a/n/ac (5 GHz)
- Bluetooth: Bluetooth v4.2 BR/EDR and BLE (Bluetooth Low Energy)
- RAM: 520KB SRAM
- Flash memory: 4MB or 8MB depending on the model
- GPIO: 34 pins, which can be configured as digital input/output, analog input, PWM, or capacitive touch sensor
- ADC: 12-bit SAR ADC up to 18 channels
- DAC: 8-bit DAC output on two channels
- I/O interfaces: I2C, SPI, UART, I2S, RMII, PWM, IR, and more
- Operating voltage: 2.2V to 3.6V
- Operating temperature: -40°C to +125°C

- Power consumption: varies depending on usage, but can be as low as 5µA in deep sleep mode
- Security: Supports SSL/TLS, WPA/WPA2/WPA3, and AES encryption for secure communications

4.2.5. Features

- Dual-Core Processor: The ESP32 has two Xtensa LX6 32-bit processors, which can run at up to 240 MHz. The dual-core architecture allows for more efficient multitasking and improves overall performance.
- Wireless Connectivity: The ESP32 has built-in Wi-Fi 802.11 b/g/n/e/i, Bluetooth v4.2 BR/EDR and BLE, and Ethernet (with external hardware). This makes it easy to connect to the internet or other devices, and enables communication with other devices and cloud services.
- Low Power Consumption: The ESP32 has a low-power mode, which reduces power consumption to less than 5 µA, making it suitable for battery-powered devices.
- Rich Input/output Interfaces: The ESP32 has a wide range of input/output interfaces, including 34x GPIO pins, 18x ADC channels, 2x DAC channels, 2x I2S interfaces, 2x UART, 2x SPI, 1x I2C, 1x SD/SDIO/MMC host controller, 1x IR (TX/RX), and 1x capacitive touch sensor. These interfaces make it easy to connect to various sensors, displays, and other devices.
- Large Memory: The ESP32 has 520 KB of SRAM, 448 KB of ROM, and 4 MB of flash memory. This allows for more complex programs and data storage.
- Security Features: The ESP32 has built-in support for secure boot, flash encryption, and SSL/TLS protocols, providing a high level of security for IoT applications.
- Easy to Program: The ESP32 can be programmed using various programming languages and tools, including C/C++, Python, Arduino IDE, and Micro Python. This makes it easy for developers and hobbyists to get started with the ESP32 and build their own projects.

4.3. AMS1117

The AMS1117 is a low-dropout voltage regulator that is commonly used in electronic circuits to regulate voltage levels. It is a linear voltage regulator, which means that it regulates the output voltage by dissipating excess power as heat. The AMS1117 is available in various output voltage options, ranging from 1.2V to 5.0V. It has a maximum input voltage rating of 15V, and can regulate output current up to 1A, depending on the specific variant used. The AMS1117 has a low dropout voltage, which means that it can regulate voltage levels even when the input voltage is only slightly higher than the desired output voltage.



Fig 4.5:AMS111

This makes it well-suited for battery-powered applications, where the input voltage may fluctuate over time. The AMS1117 is available in a variety of packages, including TO-252, TO-263, and SOT-223, among others. It also has various features such as thermal shutdown protection and short-circuits current limiting to protect the device and the circuit it is used in, it is a popular and widely used voltage regulator due to its low dropout voltage, high efficiency, and availability in various output voltage options and package types. It is commonly used in a wide range of applications, including power supplies, battery chargers, and various electronic circuits.

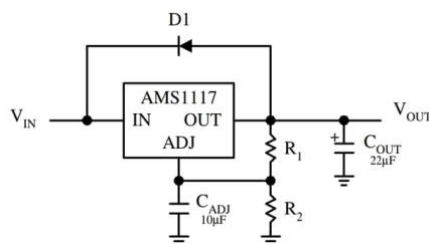


Fig 4.6: Circuit Diagram

4.3.1. Specification

- Input voltage range: The AMS1117 can operate with an input voltage range of 4.5V to 15V.
- Output voltage: The output voltage is fixed and is available in a variety of options, such as 3.3V, 5V, 1.8V, etc.
- Dropout voltage: The dropout voltage of the AMS1117 is typically 1.3V at full load.
- Quiescent current: The quiescent current of the AMS1117 is typically 5mA.
- Line regulation: The line regulation is typically 0.2% of output voltage for a change in input voltage of 1V.
- Load regulation: The load regulation is typically 0.4% of output voltage for a change in load current of 1mA to 1A.
- Thermal protection: The AMS1117 has built-in thermal protection that limits the junction temperature to a safe level.
- Package type: The AMS1117 is available in various package types, including TO-220, SOT-223, and SOT-89.

4.4.5V SMPS

A 5V SMPS (Switched-Mode Power Supply) is a type of power supply that is designed to convert an input voltage to a stable output voltage of 5 volts DC. SMPS is a modern type of power supply that uses a switching regulator to convert electrical power efficiently. The 5V SMPS is commonly used in electronic devices such as microcontrollers, sensors, and other low-power devices, and it is found in various products like USB chargers, power banks, and other portable devices due to its small size and high efficiency. The 5V SMPS can be designed using a variety of topologies such as fly back, buck, and boost, depending on the input voltage, output voltage, and load requirements. These topologies involve the use of various components like transformers, capacitors, diodes, transistors, and integrated circuits to regulate and convert the voltage.



Fig 4.7:5VSMPS

Compared to traditional linear power supplies, 5V SMPS have the advantage of high efficiency, small size, and low heat dissipation. They operate at high frequencies, which allows for smaller transformers and capacitors, making them more compact and lightweight. Additionally, they produce less heat than linear regulators, which continuously dissipate power as heat Zeng, et.al (2021).

4.4.1. Basic components of 5v smps

- Transformer: A transformer is used to step down the input AC voltage to a lower AC voltage level.
- Rectifier: A rectifier circuit is used to convert the AC voltage to a pulsating DC voltage.
- Filter: A filter circuit is used to smooth out the pulsating DC voltage and produce a stable DC voltage.
- Switching regulator: A switching regulator is used to convert the stable DC voltage to a high-frequency AC voltage.
- Output rectifier: An output rectifier is used to convert the high-frequency AC voltage to a stable DC voltage.
- Output filter: An output filter is used to smooth out any remaining ripple in the output DC voltage.

4.4.2. Stages of 5vsmps

- Input Stage: In this stage, the input AC voltage is first rectified by a bridge rectifier and then filtered by a capacitor to produce a pulsating DC voltage.

The AC voltage can be either from the mains power supply or a transformer depending on the application.

- **High-Frequency Stage:** The pulsating DC voltage is then fed into a high-frequency oscillator circuit that generates a high-frequency AC voltage. The oscillator frequency is usually in the range of 50 kHz to several hundred kHz.
- **Power Conversion Stage:** The high-frequency AC voltage is then fed into a switching regulator circuit that converts the voltage to a stable DC voltage. This circuit usually consists of a power transistor that switches on and off at a high frequency, a diode that acts as a rectifier, and an output capacitor that filters the output voltage.
- **Output Stage:** The output DC voltage is then filtered by another output capacitor to remove any remaining ripple or noise. The output voltage is then regulated to ensure that it remains stable and within the specified range.

4.4.3. Specification

- **Input Voltage:** The range of input voltage that the SMPS can handle, typically from 90V AC to 264V AC or from 120V DC to 370V DC.
- **Output Voltage:** The output voltage of the SMPS is 5V, which is regulated and stable.
- **Output Current:** The maximum amount of current that the SMPS can provide at the 5V output, usually expressed in Amperes (A).
- **Efficiency:** The efficiency of the SMPS, which is the ratio of the output power to the input power, typically greater than 80% for a well-designed 5V SMPS.
- **Ripple and Noise:** The amount of voltage ripple and noise present on the output of the SMPS, typically expressed in millivolts (mV) or percentage of the output voltage.
- **Protection Features:** The SMPS may have built-in protection features such as overvoltage protection, overcurrent protection, short circuit protection, and over-temperature protection.

- **Dimensions and Form Factor:** The physical size and form factor of the SMPS, such as the length, width, height, and mounting options.
- **Certification and Compliance:** The SMPS may need to comply with various safety and regulatory standards, such as UL, CE, FCC, and RoHS.

4.5. METHODS

4.5.1. Data acquisition

Sensor placement: The wearable sensors are placed on the patient's knee joint or surrounding muscles, depending on the specific parameters that need to be measured.

Data collection: The sensors collect data on various parameters, such as joint angles, muscle activity, and balance, during rehabilitation exercises or daily activities. The sensors may use different types of sensors, such as accelerometers, gyroscopes.

Data transmission: The collected data is transmitted wirelessly from the sensors to a data logger or a mobile device, such as a smartphone or tablet, using Bluetooth or other wireless technologies.

Data processing: The collected data is processed and analyzed using algorithms and software tools to extract meaningful information about the patient's movement patterns and progress. The data processing may involve techniques such as signal processing, machine learning, and statistical analysis.

Feedback and visualization: The processed data is presented to the patient and healthcare professionals in a user-friendly format, such as visualizations, to provide real-time feedback and motivation during rehabilitation exercises.

Storage and analysis: The collected data is stored in a database or a cloud platform for further analysis and long-term monitoring of the patient's progress.

4.5.2. Feature extraction

Signal processing: The raw data collected by the wearable sensors may contain noise or other artifacts that can interfere with the feature extraction process. Signal processing techniques, such as filtering or smoothing, may be used to remove these unwanted components.

Feature selection: The most relevant features for a particular rehabilitation task or exercise need to be selected. This can involve domain knowledge or statistical methods, such as principal component analysis or feature ranking algorithms.

Feature extraction: Once the relevant features have been identified, they need to be extracted from the sensor data. This can involve time or frequency domain analysis, such as calculating the maximum knee flexion angle or the spectral content of the knee joint acceleration signal.

Feature representation: The extracted features may need to be transformed or represented in a suitable format for use in the mathematical model or algorithm. This can involve normalizing or scaling the features, or combining them into higher-level features or descriptors.

Validation: The extracted features need to be validated to ensure that they are meaningful and relevant for the rehabilitation task or exercise being performed. This can involve comparing the features to ground truth data or using statistical methods to assess their correlation with the patient's knee joint movement.

4.5.3. Classifier

The first step is to gather a dataset of examples of extension flexion and seated marching exercises. This dataset should include labelled examples of each exercise, with features that can be used to distinguish between them. Some potential features for classification could include joint angles, muscle activation patterns, or movement velocity. Once I have a set of labelled examples with appropriate features, then split the dataset into training and testing sets. I can use a machine learning algorithm to train a classifier on the training set, using the labelled examples and features as inputs. After training, you can evaluate the classifier on the testing set to measure its accuracy and performance. Finally, I

use the trained classifier to predict the exercise type of new examples based on their features. With a well-trained and accurate classifier, you can automate the task of distinguishing between extension and flexion and seated marching exercises, which could be useful for exercise tracking and monitoring in rehabilitation context.

4.5.4 Arudino IOT Cloud App

Arduino IoT Cloud can be a useful tool in rehabilitation applications to monitor and track patient progress. By using Arduino boards equipped with sensors, you can measure various aspects of the rehabilitation process such as joint range of motion, muscle strength, and movement patterns.

To develop an Arduino IoT Cloud app for rehabilitation, you can follow these steps:

Identify the specific parameters you want to measure during the rehabilitation process. This could include joint angles, muscle activation, or movement speed.

Choose the appropriate sensors to measure these parameters. Depending on the specific parameters, you may need to use sensors such as accelerometers, gyroscopes, or flex sensors.

Connect the sensors to an Arduino board, and write a code to collect and process the data from the sensors.

Create an IoT Cloud account and set up a new IoT Cloud project.

Add your Arduino board to the IoT Cloud project and create a device on the dashboard.

Configure the device on the IoT Cloud dashboard to receive data from the Arduino board, and create widgets to visualize the data in real-time.

Integrate the IoT Cloud app into the rehabilitation process, such as by having patients wear sensors during exercises or using sensors to measure progress during physical therapy sessions.

4.5.5 Software

C Programming:

C is a popular language for system programming, as it allows low-level access to memory and hardware. It is also widely used in application programming, particularly for developing operating systems, compilers, and embedded systems.

Simple syntax: C has a relatively simple syntax compared to other programming languages, which makes it easy to learn and use.

Portability: C code can be compiled to run on a variety of platforms, including Windows, Linux, and macOS.

Efficiency: C code can be very efficient, as it allows low-level access to hardware and memory.

Modularity: C programs are typically organized into separate functions or modules, which can be compiled independently and linked together to create the final program.

CHAPTER-5

RESULT AND DISCUSSION

These sensors can track various parameters such as range of motion, muscle activity, and gait analysis, providing valuable data for clinicians and researchers to evaluate the effectiveness of rehabilitation programs. The MPU6050 sensor provides precise measurement of angular velocity and acceleration in three dimensions. It has a digital output interface and supports SPI communication protocols, making it easy to interface with a microcontroller. The hardware setup has ESP32 Microcontroller with Wi-Fi module, 5V SMPS, AMS1117 Voltage Regulator, three MPU6050 sensors, Female connector and some wires. The MPU6050 sensor is placed on the ankle, knee, and chest to measure the range of angle. An AMS1117 voltage regulator is used to step down the voltage from 5V to 3V, the sensors can be powered at a suitable voltage level without requiring additional circuitry to be added to the sensor design, it can help minimize the overall size and weight of the system, making it more comfortable for the user to wear for extended periods of time. A 5V SMPS adapter is used for the power supply. An Arduino IOT cloud app is used to check the posture correction.



Fig.5.1.Placement of sensor

Fig 5.1 shows the placement of sensor on chest, knee, and ankle. Patients are advised to ON the arduino iot mobile app before starting the exercise.

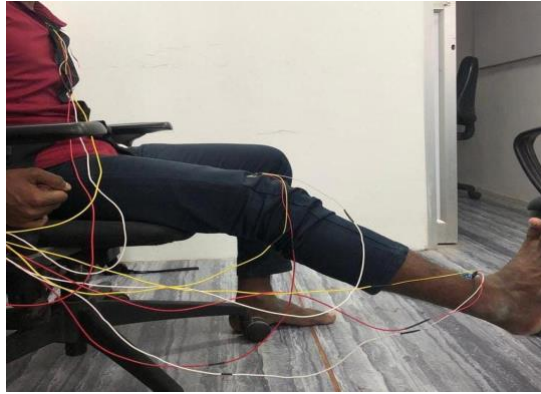


Fig.5.2.Test 1

Fig 5.2 shows the knee extension and flexion exercise. Normal range of motion of a knee flexion is 135 degree (fully bent) and knee extension is 0 degree (fully straight).

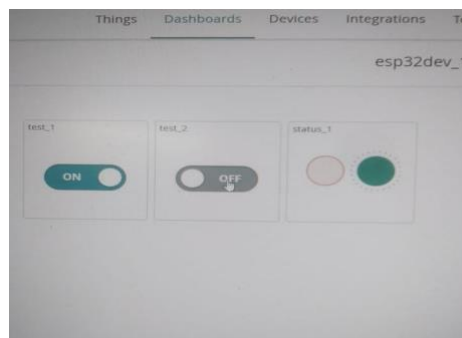


Fig.5.3.Test 1 Result

Fig 5.3 shows the result of test 1 exercise, which is within the range of motion, so green light is glowing. Fig 5.4 shows the range of motion is above the limit, so red light is glowing, then the buzzer starts beep, from this the patient can recognize that the exercise posture is wrong.

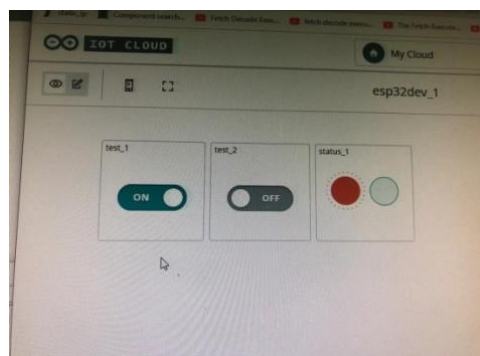


Fig.5.4.Test 1 Result

Fig 5.5 shows the test 2 seated marching exercise, sit upright in a chair; one leg is in the range of motion 0 to 140 degree and raises another leg from the floor.



Fig.5.5: Test 2

Fig 5.5 shows the arduino iot cloud app test 2 switch is ON; the range of motion is within the range so the green light is glowing. The posture of this exercise is correct.

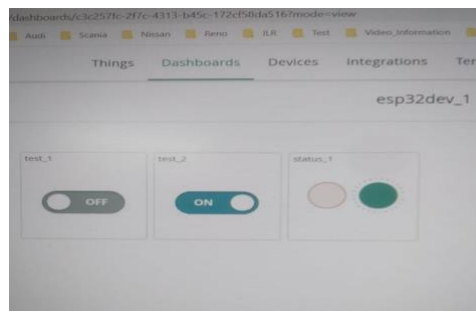


Fig.5.6: Test Result 2

Fig 5.7 shows the arduino iot cloud app test 2 switch is ON, the range of motion is above the range so the red light is glowing and the buzzer starts beep .The posture of this exercise is correct.

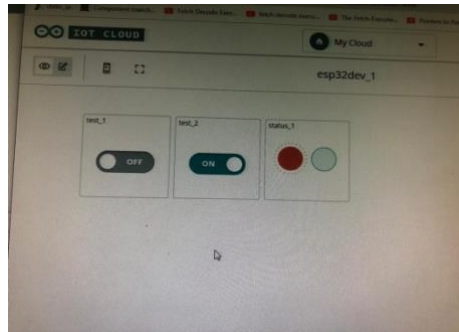


Fig 5.7: Test 2 Result

CHAPTER-6

CONCLUSION AND FUTURE SCOPE

Rehabilitation systems have shown great potential in the management and treatment of knee osteoarthritis. The systems use wearable sensors to capture the patient's knee joint movement data, which can be analysed and interpreted to develop personalized rehabilitation programs and track patient progress over time. The advantages of this system for knee osteoarthritis include increased patient engagement, improved rehabilitation outcomes, and the ability to collect objective and quantitative data. Additionally, the systems have the potential to reduce healthcare costs by providing a more efficient and effective rehabilitation process. However, there are also some challenges associated with wearable sensor-based rehabilitation systems, such as data processing and analysis, sensor accuracy, and patient adherence. Further research is needed to address these challenges and improve the effectiveness of the systems. In conclusion, knee brace for osteoarthritis systems have the potential to revolutionize the management and treatment of knee osteoarthritis. With continued advancements in technology and research, these systems may become an increasingly important tool for healthcare professionals in the management of knee osteoarthritis and other conditions.

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