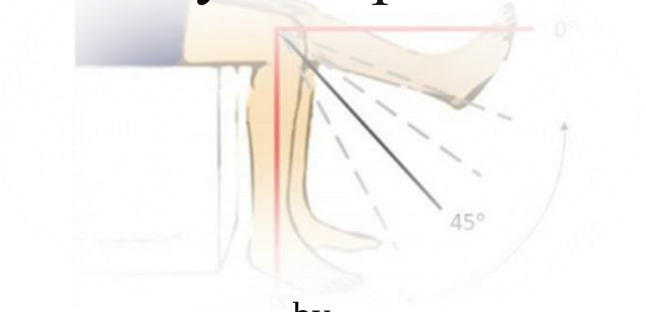
Smart Knee Brace

“Raspberry Pi and MPU6050 Gyroscope for Knee Angle Measurement”



by
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Submitted to
Professor: Dr. T Kishore Kumar

AIM

- Our task is to develop a wearable system for measuring the knee angle with respect to time using a Raspberry Pi interfaced with a gyroscope sensor (MPU6050).

MOTIVATION

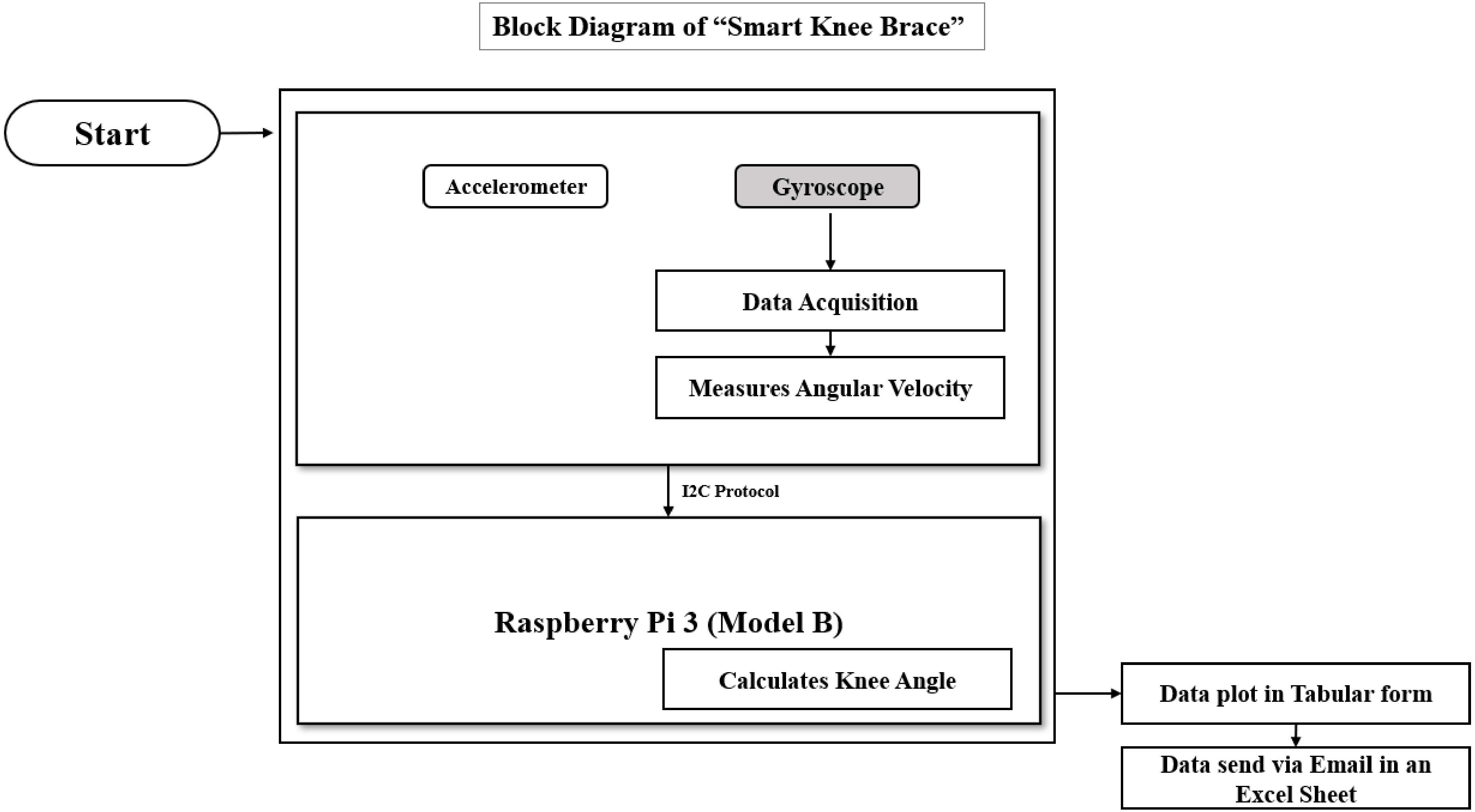
<u>“A Compassionate Journey into Joint Health Innovation”</u>

- We're addressing a variety of common and critical problems in society related to joint health.
- Many individuals, particularly the Spinal Cord Injury (SCI) patients and elderly face challenges associated with musculoskeletal issues, including knee pain and limited mobility.
- Our project is all about helping people with common joint problems, especially those related to knees.
- We're trying to give people an easy-to-use tool to keep track of their joint health and catch any issues early on.
- Our hope is that this approach can make it easier for everyone to take care of their joint health and stay healthy.

OBJECTIVES

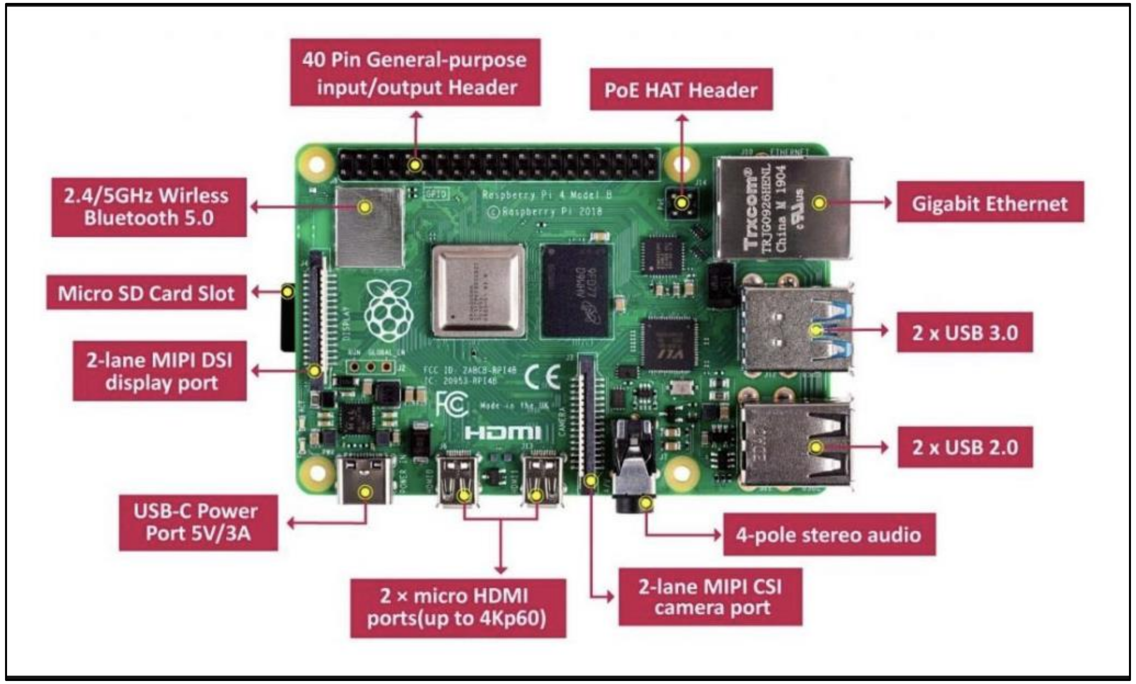
- To measure knee joint angles during various activities (Sitting).
- To track knee flexion and extension range of motion.
- To send measured data periodically via email for remote monitoring and analysis in an excel sheet in tabular form.

Block Diagram



Raspberry Pi

- Raspberry Pi is a series of small, affordable single board computers developed by Raspberry Pi foundation , a UK based charity organization.
- Similar to a traditional desktop CPU, the Raspberry Pi functions as a mini computer, carrying out tasks that are typically handled by a central processing unit (CPU).
- It is with built-in RAM and ROM components, the Raspberry Pi operates much like a standard desktop computer, executing functions analogous to those performed by a CPU.



Fig(a)

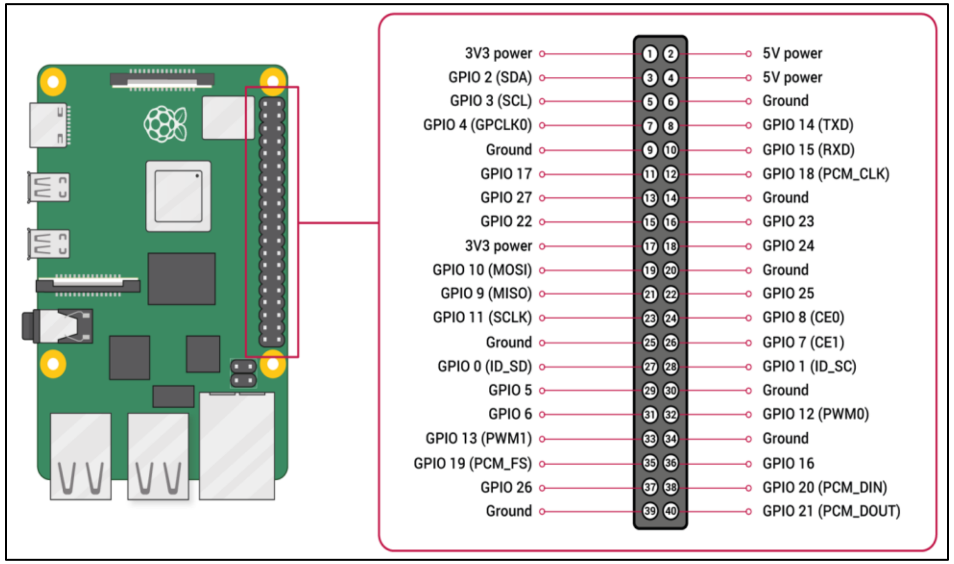
Hardware Description

Raspberry Pi

- The Raspberry Pi is a very cheap computer that runs Linux, but it also provides a set of GPIO (general purpose input/output) pins, allowing you to control electronic components for physical computing and explore the Internet of Things (IoT).

- The Raspberry Pi board has 40 pins (Power Supply(5V): 2 pins, Power Supply(3.3V): 2 pins, Power Supply(Ground): 8 pins, GPIOs: 26 pins, I2C IDS: 2 pins.

- It has USB Ports, Display Ports, Camera Ports, Audio Ports, Micro SD Port and it has Networks like Ethernet, WIFI and Bluetooth.



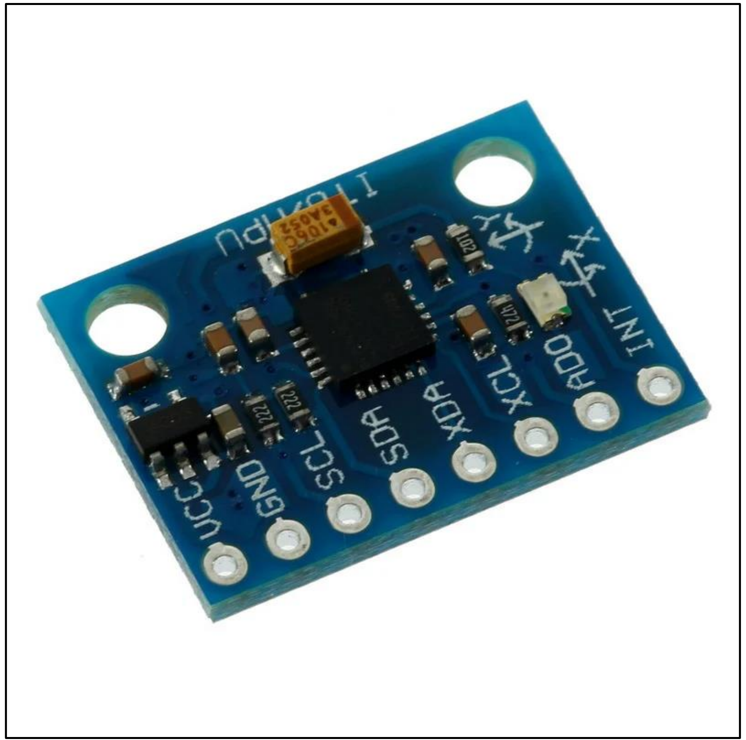
Fig(b)

Advantages:

Affordability, Compact Size, Low Power Consumption, Versatility, Expandability

MPU6050 Module

- **Sensor Integration:**
  The MPU-6050 integrates multiple sensors, including a 3-axis accelerometer, a 3-axis gyroscope. This combination of sensors allows for comprehensive motion sensing capabilities.
- **Communication Interface:**
  The module typically communicates with microcontrollers or single-board computers like the Raspberry Pi through I2C (Inter-Integrated Circuit) communication protocols.
- **Gyroscope:**
  The 3-axis gyroscope measures angular velocity, providing information about the rate of rotation around each axis.
- **Accelerometer:**
  The 3-axis accelerometer measures linear acceleration, allowing the detection of changes in velocity and tilt.

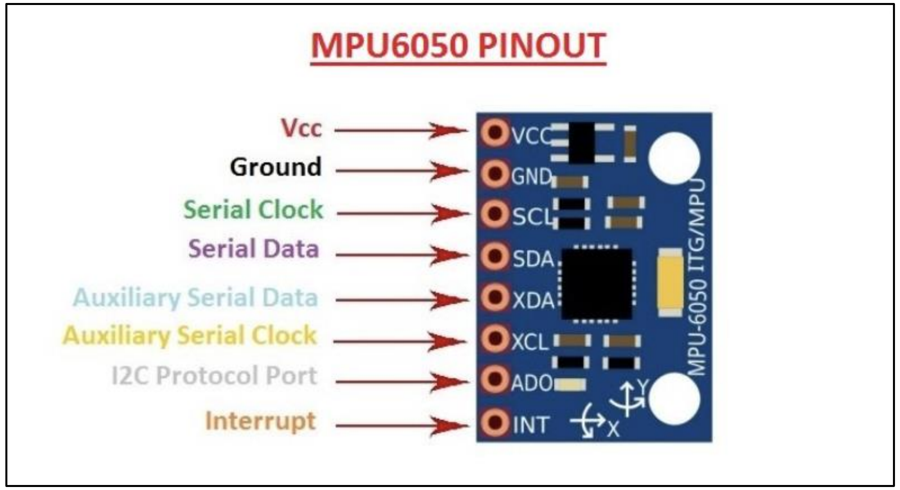


Fig(c)

MPU6050 Module

Pin Classification:

1. **VCC:**
   This pin is connected to the power supply voltage (VCC), typically ranging from 2.4V to 3.6V.
2. **GND:**
   Ground pin for the module, connected to the ground of the system.
3. **SDA (Serial Data):**
   SDA is the data line for I2C communication. It is used for bidirectional data transfer between the MPU-9250 and the microcontroller.
4. **SCL (Serial Clock):**
   SCL is the clock line for I2C communication. It synchronizes the data transfer between the MPU-6050 and the microcontroller.



Fig(d)

MPU6050 Module

Pin Classification:

5. **AD0/SDO (Address Select/Serial Data Output):**
   This pin allows you to change the I2C address of the MPU-6050. It can be connected to VCC or GND to set the least significant bit (LSB) of the I2C address.
6. **INT (Interrupt):**
   The INT pin is used for interrupt generation. It can be configured to generate interrupts based on specific events, such as motion detection or data ready.
7. ECL (Auxiliary I2C Clock):
   This pin outputs the I2C clock signal needed for communication with auxiliary sensors connected to the MPU6050.
8. EDA (Auxiliary I2C Data):
   This pin transmits and receives I2C data between the MPU6050 and the auxiliary sensors.

How the Raspberry Pi and gyroscope sensor play vital roles in the functionality of a "Smart Knee Brace“?

Gyroscope Sensor:

- **Measures of Angular Velocity**

- **Input to Raspberry Pi**

Raspberry Pi:

- **Data Processing**

- **Signal Processing Module**

- **Data Storage**

Hardware Setup

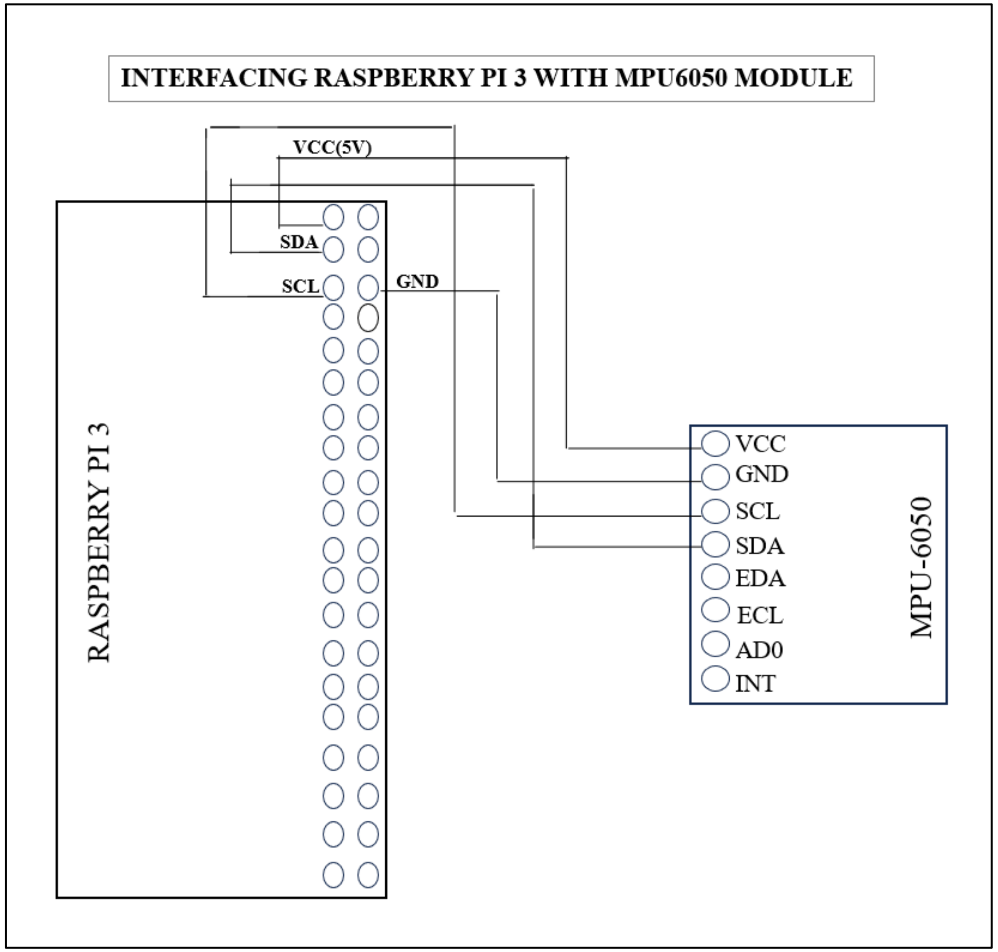
Interfacing **Gyroscope Sensor(MPU6050) with Raspberry Pi**

To connect a Raspberry Pi and an MPU-6050 gyroscope sensor, you need to make the appropriate physical connections and then enable the necessary software support.

Follow these steps::

- **Power Connections:**
  1. Connect the VCC (power) pin of the MPU-6050 to the 5V pin on the Raspberry Pi.
  2. Connect the GND (ground) pin of the MPU-6050 to any ground pin on the Raspberry Pi.

- **I2C Connections:**
  1. Connect the SDA (data) pin of the MPU-6050 to the SDA pin on the Raspberry Pi (GPIO2).
  2. Connect the SCL (clock) pin of the MPU-6050 to the SCL pin on the Raspberry Pi (GPIO3).



Fig(e)

Software Implementation

Step 1:

Installation of Raspbian OS on a Raspberry Pi

Requirements:

- Raspberry Pi Board
- USB Charging adapter
- USB Cable
- HDMI to VGA Converter
- Micro SD card
- Card reader

Fig(f)

Software Implementation

Step 1:

Installation of Raspbian OS on a Raspberry Pi

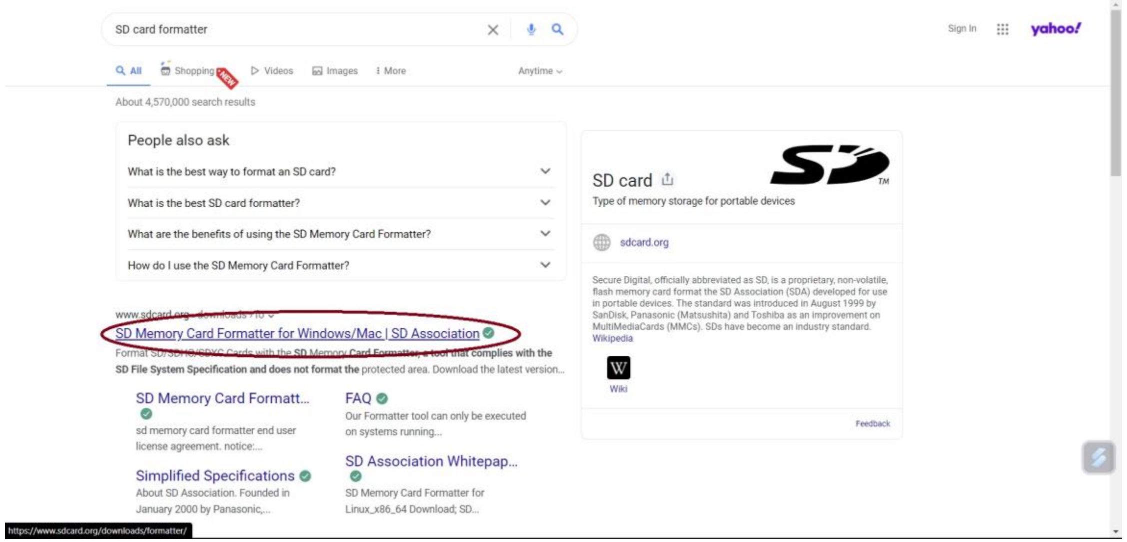
Steps:

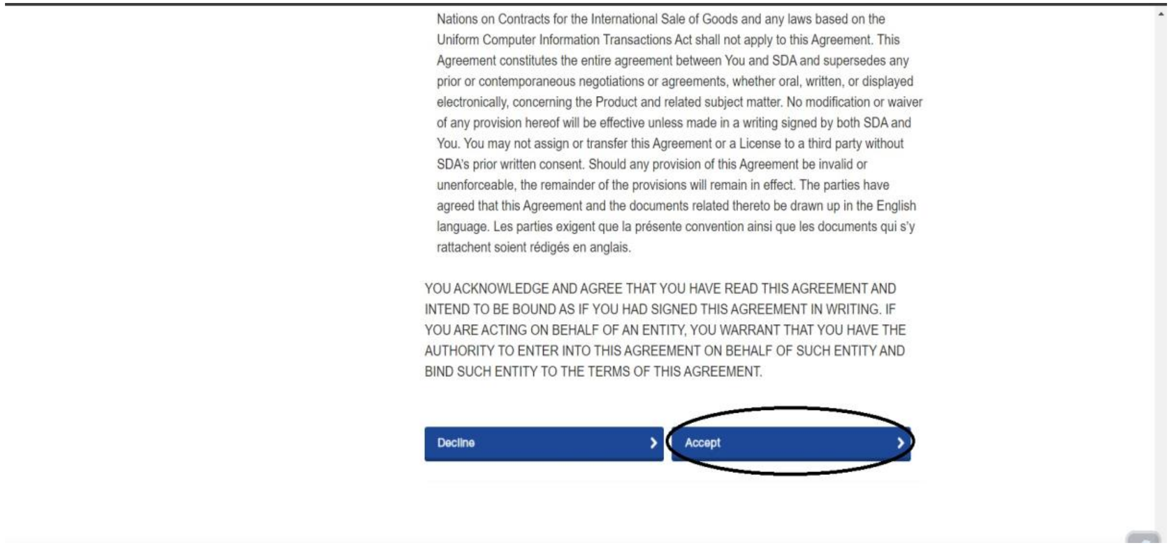
1. To install Raspbian OS on a Raspberry Pi, first install Raspbian OS on SD Card.
2. Open a browser tab, search for an SD Card formatter, click on the first link, and download the formatter suitable for your operating system (Windows/Mac).
3. In another browser tab, search for "etcher.io," and download the Etcher software for Windows or Mac.
4. Open a separate tab, visit the official Raspberry Pi website, navigate to the "Download" section, and select Raspbian. Download the ZIP file for Raspbian with Desktop.
5. Install the SD Card formatter and the Etcher software on your computer. Extract the contents of the downloaded Raspbian ZIP file.
6. Open the SD Card formatter, select your SD card, and format it.
7. Launch Etcher, choose the extracted Raspbian file, ensuring you select the correct SD card, and initiate the flashing process.
8. Upon completion of the flashing process, safely remove the SD card from your computer.
9. Insert the SD card into the Raspberry Pi board to initiate the Raspbian OS installation process.

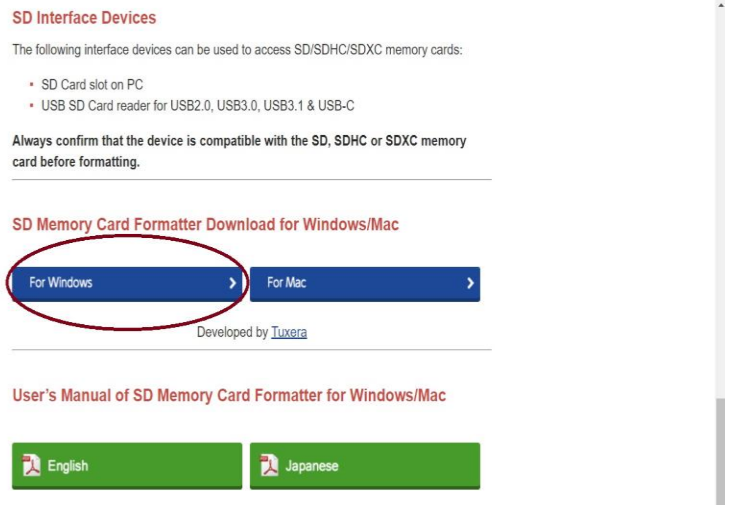
Step 1:

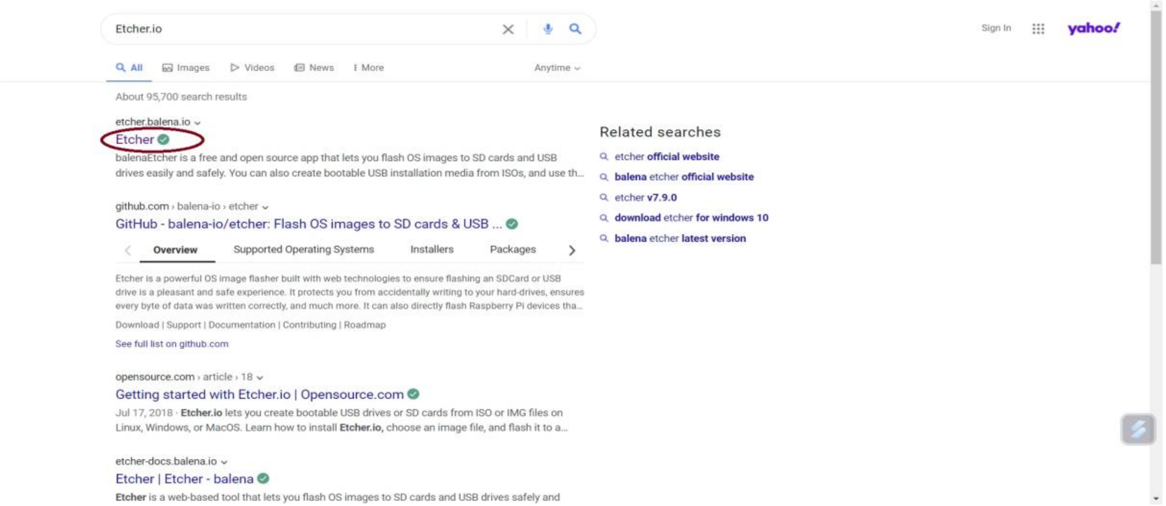
Software Implementation

Installation of Raspbian OS on a Raspberry Pi









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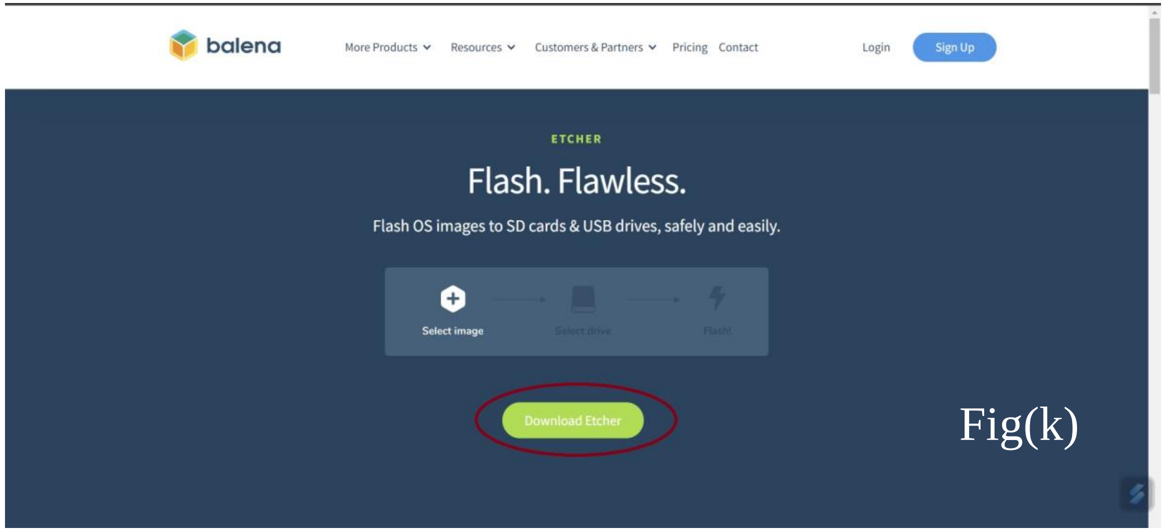
Software Implementation

Installation of Raspbian OS on a Raspberry Pi



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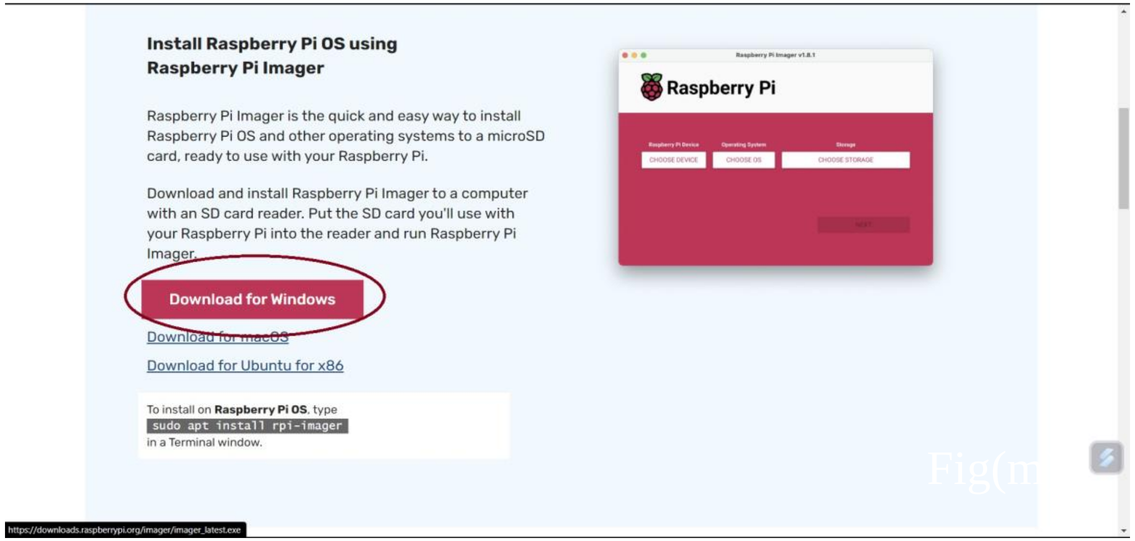
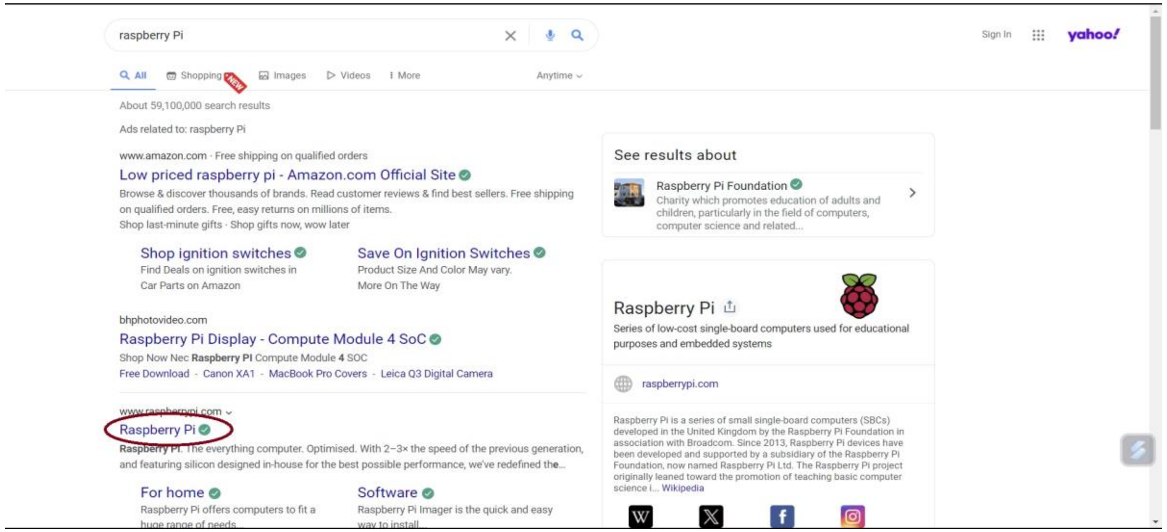
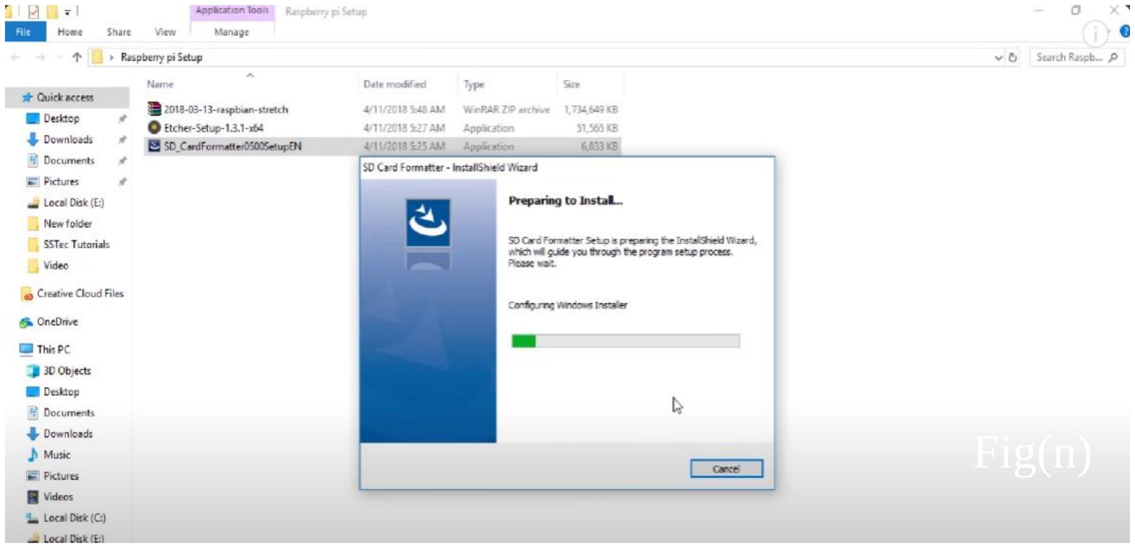


Fig(m



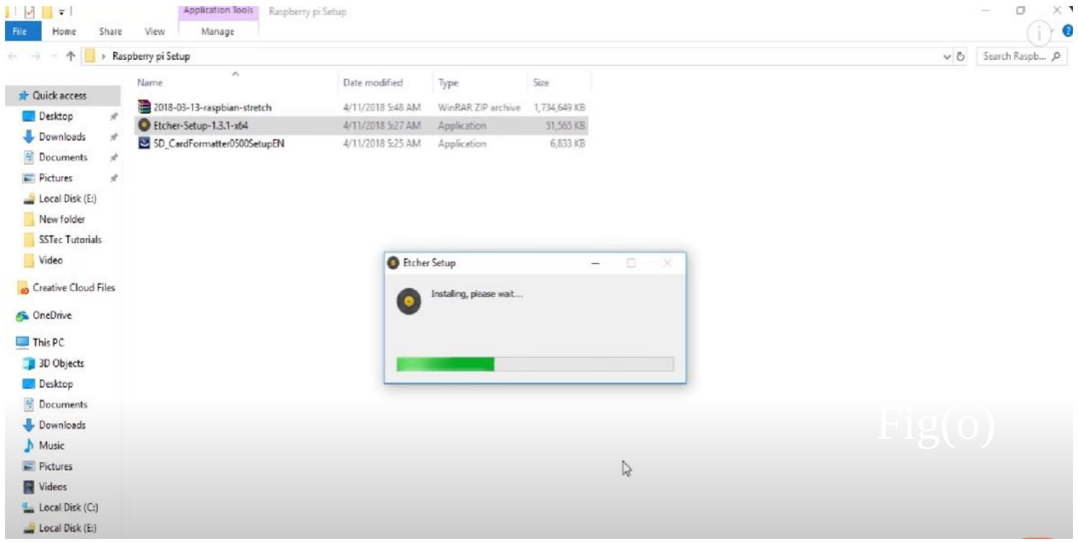


Fig(n)

Software Implementation

Step 1:

Installation of Raspbian OS on a Raspberry Pi



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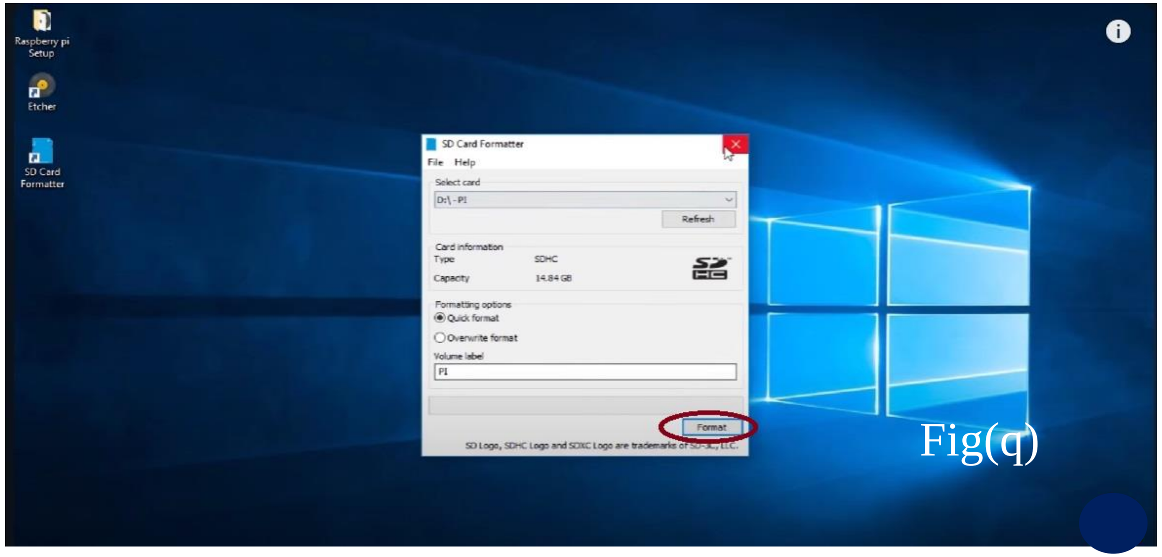

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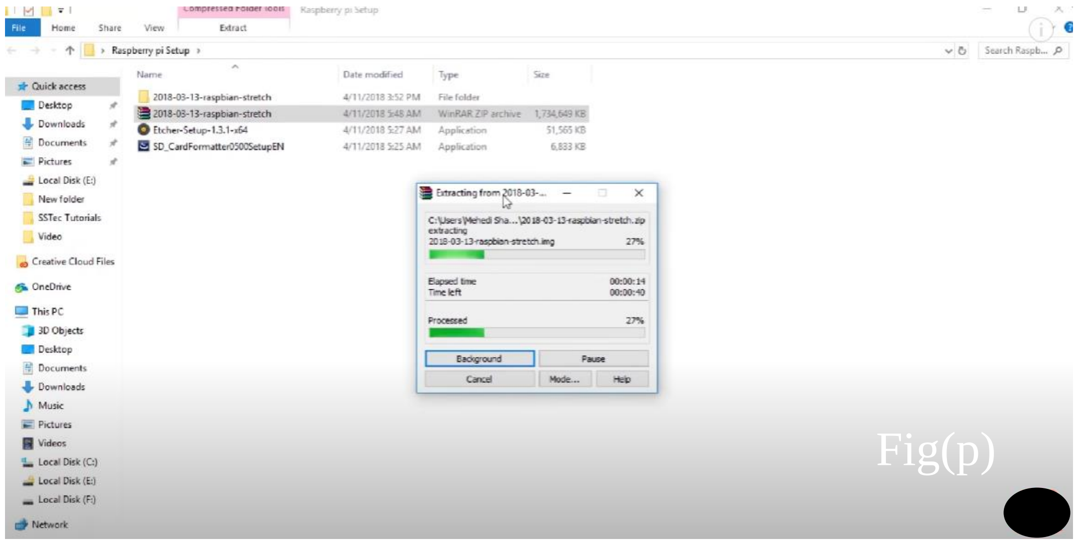

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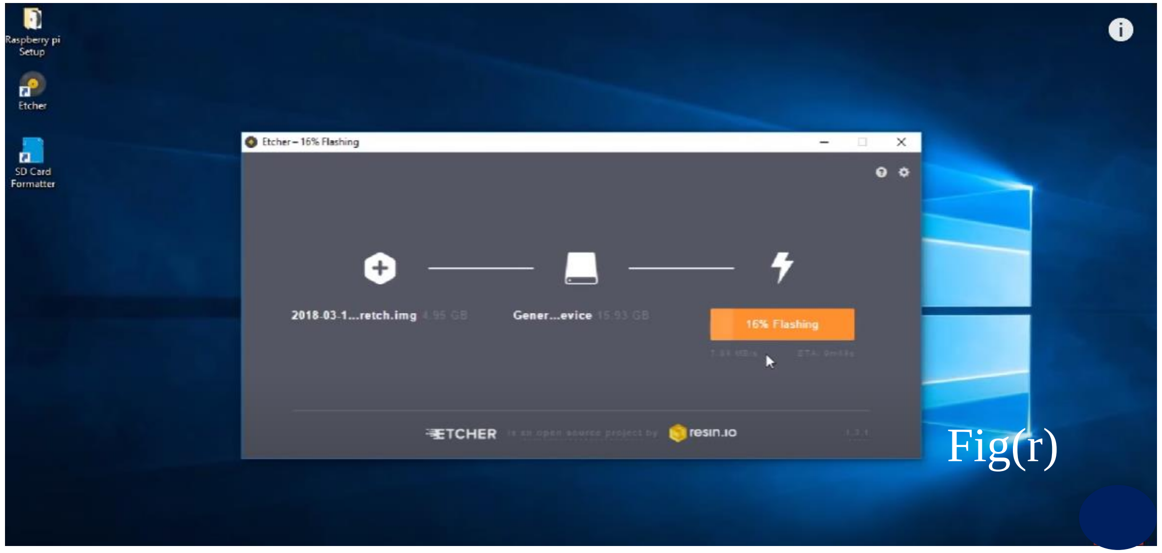


Fig(r)

Software Implementation

Step 2:

Python Script for Knee Angle Measurement (Programming Language: Python)

- Write a Python Script:

  Create a Python script that reads data from the gyroscope, processes it on raspberry pi and calculate the knee angle, and stores it in a data structure (e.g., a list).

- Save Data to CSV(Comma-separated Values):

  Periodically save knee angle data to a CSV file. Use the 'CSV' module for this purpose.

  CSV is a simple file format used to store tabular data, where each row of the file represents a record, and the values within a row are separated by commas.

Step 3:

Excel Automation

- Install pandas Library:

  Install the 'Pandas' library to facilitate working with data frames and Excel files.

- Modify Python Script to Save to Excel:

  Adjust your Python script to convert the knee angle data to a pandas Data Frame and save it to an Excel file.

Software Implementation

Step 4:

Email Automation

- Install smtplib Library:
  Install 'smtplib' library for sending emails.

- Configure Email Settings:
  Set up an email account to be used for sending emails. Obtain the SMTP server details, username, and password.

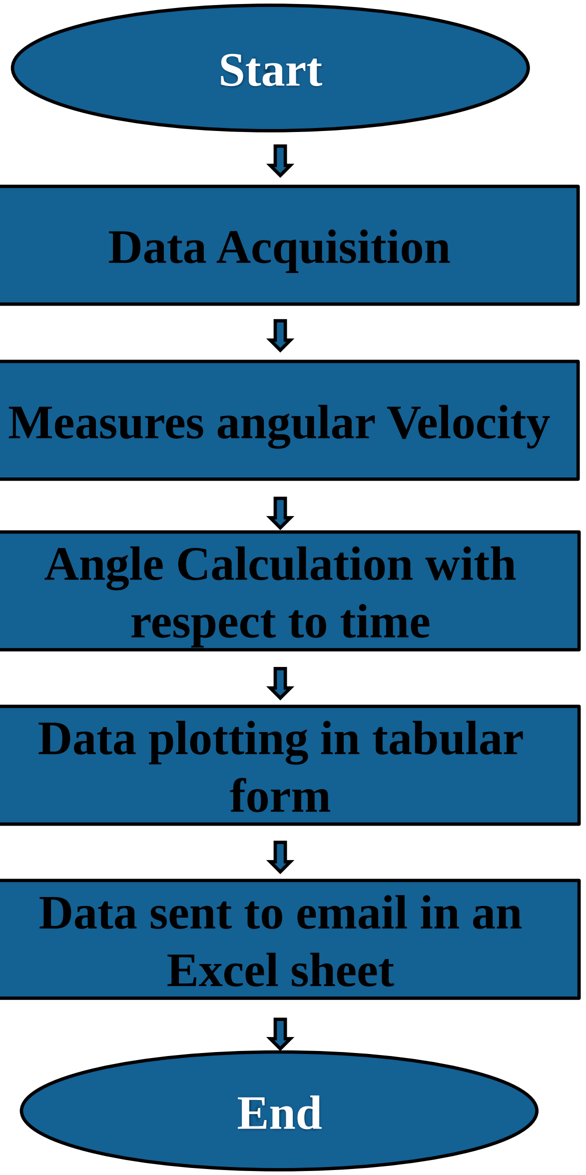
- Modify Python Script to Send Email:
  Modify your Python script to send an email with the Excel file attached.

Algorithm for calculation of Knee Angle:

- To get an appropriate output from the sensor that suits the application to measure the knee joint movement, sensor placement is very important. The sensor must be positioned at the point where it can capture even a small changes of movement.

Flow of system operation:

- The flowchart shows the flow of the system operation which involves the process of data acquisition, measures angular velocity, calculation of angle from angular velocity with respect to time, data plotting in CSV format, data sent to designated email in an excel sheet in a tabular form.



Algorithm for calculation of Knee Angle:

Data Acquisition & Measurement of Angular Velocity

Physical System (Movement of Knee) → **Coriolis Effect** → **Vibrating Structure** → **Capacitive Detection** → **Signal Processing** → **Angular Velocity**

- When an object (gyroscope) moves in a rotating system which is attached to knee, it experience a force perpendicular to the direction of motion and the axis of rotation. This phenomenon is known as the "Coriolis Effect".

- The Coriolis effect causes vibrating the structure (tuning fork or proof mass) to deflect.

- The deflection of the vibrating structure is detected capacitively, as the structure moves, the capacitance between different parts of the sensor changes. This change in capacitance is measured and converted into an electrical signal.

- The electrical signal is then processed by MPU6050 Module to convert it into angular velocity (Analog to digital transmission). This involves using calibration parameters and algorithms to account for sensor specific characteristics and errors.

Algorithm for calculation of Knee Angle:

- The formula to calculate angular velocity (ω) from the sensor output is given by:

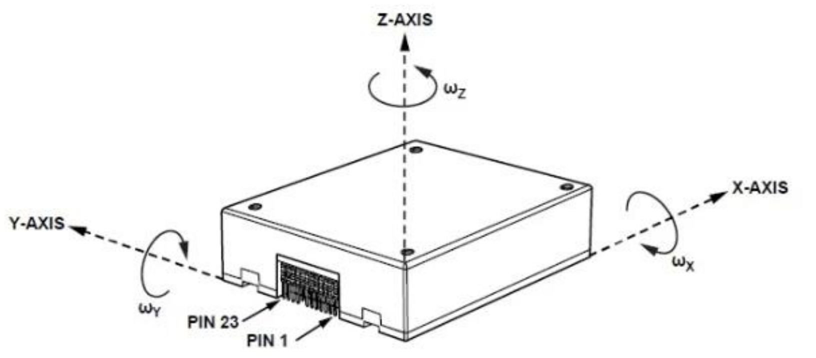
$$\boldsymbol{\omega} = \textbf{(Sensor output – Zero Rate output) / Sensitivity}$$

Where , Sensor output means raw output from the gyroscope sensor
Zero-Rate output means output when there is no angular velocity (sensor at rest)
Sensitivity means the sensitivity of the gyroscope typically specified in units of angular velocity per unit of sensor output.

- A Gyroscope in the MPU6050 is indeed a 3- axis device , meaning it can measure angular velocity along three axes (usually labelled as X, Y, Z).

- Mathematically representation of Angular Velocity (ω) is

$$\omega = \frac{d\theta}{dt}$$



Fig(s)

Algorithm for calculation of Knee Angle:

Sampling rate

- Sampling rate refers to how frequently the gyroscope takes measurements over times, it is typically expressed in (hertz) and represents no of samples taken per second.

- A higher sampling rate provides more data points but may also increase power consumption and processing requirements.

- We take sampling rate of 2KHz, it means the gyroscope provides 2000 samples per second for each axis.

Sampling time

- The Sampling time (period) is the inverse of the sampling rate and represents the time between consecutive measurements.

- The sampling rate is f Hz, the sampling time is T is given by

  $T = 1/f$

- With a Sampling rate of 2000Hz, the sampling time is $T = 1/2000$. It is 0.0005 seconds.

Algorithm for calculation of Knee Angle:

Calculation of Knee Angle

- By interfacing Raspberry pi with MPU6050 module, Raspberry pi can read data (Angular Velocity) from the gyroscope using I2C protocol (Inter- Integrated Circuit). Libraries such as "smbus" can be used for I2C communication.

- Formula to calculate angle from angular velocity by Raspberry pi
  Angle += Gyro _x * Elapsed _ time

Where,

- Angle is the variable represents the accumulated or integrated angle. It starts with an initial value (presumably 0) and gets updated over time.
- Gyro _ x is the variable represents the angular velocity around the X-axis. The gyroscope sensor provides this value in degrees per second (deg/s) or radians per second (rad/s), depending on the sensor configuration.
- Elapsed _ time is the variable represents the time elapsed since the last iteration of the loop. It's calculated as the difference between the current time and the previous time.

Algorithm for calculation of Knee Angle:

Calculation of Knee Angle

- The angular displacement (θ) can be obtained by integrating the angular velocity (ω) with respect to time (t).

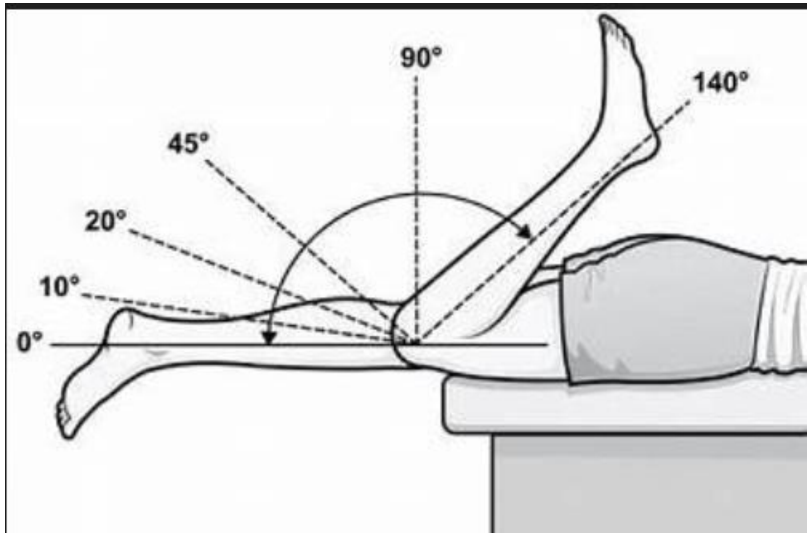
- This is mathematically represented as:

Numerical Integration:

$$\boldsymbol{\theta(t) = \int_{t_0}^{t} \omega(t)\, dt}$$

A. Experimental Setup

- Performance of the developed “Smart Knee Brace” was evaluated on knee swing movement, where a subject was set to be in sitting position.
- Maximum angle of movement and minimum angle of movement was observed for each person.
- For normal person the minimum angle of movement is 0° and the maximum angle of movement is 140°.



B. Representation of Data in tabular format

- For Person 1

Time(sec)	Angular Velocity(deg/sec)	Angle(deg)
0.1	3	15°
0.3	6	20°
0.5	9	45°
0.7	12	60°
0.9	15	90°
1	18	100°

Analysis

1. Maximum angle of movement =100°
2. Minimum angle of movement = 15°

Result and Discussion

➢ For Person 2

Time(sec)	Angular Velocity(deg/sec)	Angle(deg)
0	0	0°
0.2	5	20°
0.4	10	45°
0.6	15	60°
0.8	20	90°
1	25	140°

Analysis

1. Maximum angle of movement =140°
2. Minimum angle of movement = 0°

➢ For Person 3, person 4……so on.

Applications

1. Rehabilitation Monitoring

Use Case: Individuals undergoing knee rehabilitation can wear the device to track their knee movement.
Benefit: Physical therapists and healthcare providers can remotely monitor progress and adjust rehabilitation plans accordingly.

2. Athletic Performance Tracking

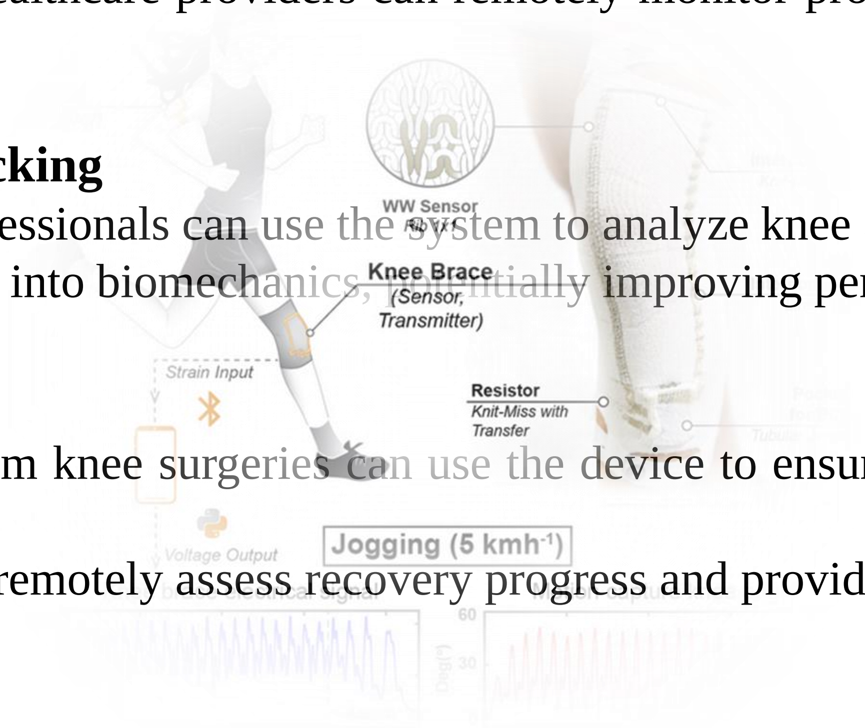
Use Case: Athletes and sports professionals can use the system to analyze knee angles during training sessions.
Benefit: Coaches can gain insights into biomechanics, potentially improving performance and preventing injuries.

3. Post-Surgery Monitoring

Use Case: Patients recovering from knee surgeries can use the device to ensure they follow prescribed movement patterns.
Benefit: Healthcare providers can remotely assess recovery progress and provide guidance as needed.

4. Elderly Care

Use Case: Elderly individuals prone to knee issues can wear the device to monitor their daily activities.
Benefit: Caregivers or family members can receive updates on movement patterns, helping ensure the well-being of the elderly.



Applications

5. Sports Science Research

Use Case: Researchers in sports science can collect real-time knee movement data during various activities.
Benefit: This data can contribute to studies on biomechanics, injury prevention, and performance optimization.

6. Remote Physical Therapy

Use Case: Patients in remote locations can benefit from virtual physical therapy sessions using the knee angle monitoring system.
Benefit: Enables access to rehabilitation services for individuals who may not have easy access to healthcare facilities.

7. **Fitness Tracking**

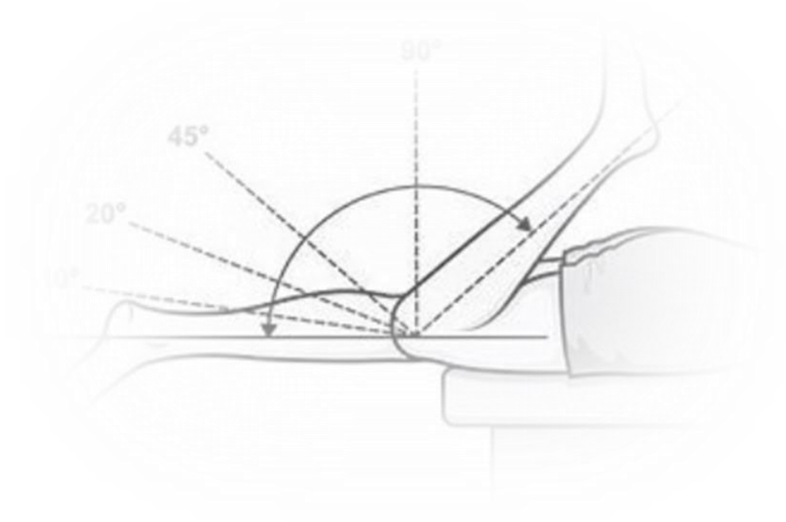
Use Case: Fitness enthusiasts can monitor their knee movements during workouts.
Benefit: Provides users with detailed insights into exercise effectiveness and helps in refining workout routines.

8. Wearable Technology Integration

Use Case: Integration with wearable technology like activity trackers.
Benefit: Enhances the capabilities of existing wearable devices by adding a more specific and accurate measurement of knee movement

Conclusion

- In summary, our “Smart Knee Brace” is a user-friendly tool designed to help people, especially the elderly, manage common joint issues. By combining technology and innovation, we offer an easy way for individuals to monitor their knee health in real-time. The project aims to catch potential problems early and promote a proactive approach to joint care. Through collaboration and education, we hope to make a positive impact on the well-being of those dealing with musculoskeletal challenges. Ultimately, our goal is to provide a simple yet effective solution for enhancing joint health and maintaining an active lifestyle.



Fig(t)

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