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# Wearable IOT System for Monitoring Knee Angle and Plantar Force for Early Detection of Knee Osteoarthritis

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**Abstract—**
Knee Osteoarthritis (KOA) is a progressive degenerative joint disorder that significantly affects mobility and quality of life. Early detection and continuous monitoring of knee joint movement are essential to prevent severe joint damage. Conventional diagnostic techniques such as X-ray and Magnetic Resonance Imaging (MRI) provide structural information but are expensive and not suitable for continuous monitoring. This paper proposes an Internet of Things (IoT)-based wearable system for monitoring knee angle and plantar force to support early detection of KOA. The system integrates an ESP32 microcontroller, MPU6050 inertial measurement unit, and a plantar force sensor to measure knee movement and foot pressure during walking. Sensor data are transmitted via Wi-Fi to the Blynk IoT platform for real-time monitoring. Experimental results indicate that normal knee movement produces flexion angles between 53°–72°, while reduced angles of 20°–30° may indicate possible KOA conditions.

**Keywords—** IoT, Knee Osteoarthritis, ESP32, MPU6050, Plantar Force Sensor, Wearable Healthcare, Blynk IoT.

## I. INTRODUCTION

Human mobility plays a vital role in maintaining independence and overall quality of life. Among the joints in the human body, the knee joint is one of the most important weight-bearing structures, enabling activities such as walking, running, standing, and climbing stairs. Due to continuous mechanical loading during daily activities, the knee joint is highly susceptible to degenerative disorders. Knee Osteoarthritis (KOA) is one of the most common musculoskeletal diseases worldwide and is characterized by the progressive degradation of cartilage in the knee joint, resulting in pain, stiffness, inflammation, and reduced mobility [1]. Factors such as aging, obesity, previous injuries, and excessive joint stress significantly increase the risk of developing KOA [2].

Early detection of knee abnormalities is essential to prevent severe joint deterioration. Conventional diagnostic techniques such as X-ray imaging and Magnetic Resonance Imaging (MRI) mainly detect structural changes in the joint

[3]. However, these methods are expensive and unsuitable for continuous monitoring. In many cases, structural damage becomes visible only in later stages, while functional changes in gait patterns may appear earlier.

Monitoring knee movement during walking can provide valuable insights into joint health. Individuals with knee osteoarthritis often exhibit reduced knee flexion and uneven weight distribution during gait [4]. Recent advances in wearable technology and Internet of Things (IoT) systems enable continuous monitoring of human motion using sensors such as inertial measurement units (IMUs) and pressure sensors [5].

This study proposes an IoT-based wearable system for monitoring knee angle and plantar force to support early detection of knee osteoarthritis. The system integrates an MPU6050 motion sensor and a plantar force sensor with an ESP32 microcontroller, and the collected data are transmitted to the Blynk IoT platform for real-time monitoring. The objective of this research is to develop a portable and low-cost wearable system capable of identifying abnormal knee movement patterns and supporting rehabilitation monitoring.

## II. LITERATURE REVIEW

Recent advancements in wearable sensor technology have enabled new approaches for monitoring human motion and detecting musculoskeletal disorders. Wearable devices equipped with inertial sensors, pressure sensors, and intelligent data processing techniques can capture continuous biomechanical data during daily activities, supporting early detection of joint abnormalities and rehabilitation monitoring.

Inertial Measurement Units (IMUs), which include accelerometers and gyroscopes, are widely used to measure joint angles and analyze gait patterns. Studies have shown that IMU-based systems can effectively estimate knee flexion angles and detect abnormal movement patterns associated with knee disorders [1], [2]. Compared with traditional motion capture systems, wearable IMU sensors offer a portable and cost-effective solution for real-time monitoring of joint motion.

Plantar pressure monitoring has also been extensively studied for gait analysis. Pressure sensors embedded in shoe insoles measure force distribution during walking and can reveal asymmetrical weight distribution, which is often observed in individuals with knee osteoarthritis [3], [4]. Several researchers have developed integrated wearable systems that combine motion sensors and pressure sensors to improve gait analysis accuracy [5], [6]. Additionally, machine learning techniques have been explored to classify gait abnormalities using wearable sensor data [7].

With the advancement of Internet of Things (IoT) technology, wearable healthcare devices can transmit sensor data wirelessly to cloud platforms or mobile applications for remote monitoring [8], [9]. However, many existing systems rely on expensive hardware or complex sensor configurations and often focus on either motion analysis or plantar pressure individually.

Therefore, a low-cost and integrated wearable system capable of monitoring both knee movement and plantar force is needed. The proposed IoT-based system addresses this gap by integrating an MPU6050 sensor and a plantar force sensor with an ESP32 microcontroller to provide real-time monitoring of knee biomechanics.

## III. METHODOLOGY

The proposed methodology focuses on developing a wearable system capable of monitoring knee joint motion and plantar force during walking. The system integrates motion sensing, force measurement, data processing, and wireless communication to enable continuous monitoring of knee biomechanics. The aim is to provide a portable and low-cost solution for early detection of Knee Osteoarthritis (KOA).

The workflow of the proposed system consists of four main stages: sensor data acquisition, signal processing, wireless data transmission, and real-time monitoring.

### A. Sensor Data Acquisition

In the first stage, biomechanical data related to knee movement and foot pressure are collected using wearable sensors.

An MPU6050 inertial measurement unit (IMU) is placed near the knee joint to capture motion data during walking. The sensor contains a three-axis accelerometer and a three-axis gyroscope capable of measuring motion along the X, Y, and Z axes. The accelerometer readings are used to estimate the knee flexion–extension angle during gait.

At the same time, a plantar force sensor embedded inside footwear measures the pressure applied by the foot while walking. This sensor provides information about weight distribution and loading patterns during gait cycles.

### B. Data Processing Unit

The ESP32 microcontroller acts as the central processing unit of the system. It collects raw sensor data from the MPU6050 sensor and the plantar force sensor. The microcontroller processes these signals by applying mathematical calculations to determine the knee flexion angle and plantar force values.

The ESP32 was selected due to its high processing capability, low power consumption, and built-in Wi-Fi module, which simplifies wireless communication and IoT integration.

### C. Wireless Data Transmission

After processing the sensor data, the ESP32 transmits the information wirelessly using its integrated Wi-Fi module. The sensor readings are sent to the Blynk IoT platform, which acts as a cloud-based monitoring interface.

This wireless communication allows remote access to the measured biomechanical parameters without requiring direct physical connection to the device.

### D. Real-Time Monitoring and Visualization

The Blynk IoT platform displays the received data in real time using graphical widgets on a smartphone dashboard. The monitoring interface provides:

- Knee flexion angle values
- Plantar force measurements
- Real-time motion graphs
- Indicators of abnormal movement patterns

These visualizations allow users and healthcare professionals to observe gait behaviour and identify abnormal readings that may indicate knee joint disorders.

## IV. System Architecture

The proposed system architecture integrates motion sensing, force measurement, data processing, and wireless communication to monitor knee biomechanics during walking.

The system consists of the following main components:

- ESP32 Microcontroller
- MPU6050 Inertial Measurement Unit (IMU)
- Plantar Force Sensor
- Wi-Fi Communication Module
- Blynk IoT Monitoring Platform

The wearable device collects biomechanical data from the knee joint and foot during walking. The acquired sensor data is processed by the microcontroller and transmitted wirelessly to the monitoring platform for visualization and analysis.

### A. Motion Sensing Unit

The MPU6050 sensor measures knee joint motion during walking. The accelerometer records acceleration along three axes (X, Y, and Z), which are used to estimate knee joint orientation. Continuous monitoring of knee movement helps detect abnormal motion patterns that may indicate joint dysfunction.

### B. Plantar Force Measurement

The plantar force sensor measures the pressure exerted by the foot during walking. Under normal conditions, body weight is distributed evenly between both legs. However, individuals experiencing knee pain may shift their weight to the opposite leg to reduce discomfort, resulting in uneven force distribution.

### C. Data Processing and Communication

The ESP32 microcontroller processes the sensor signals and converts them into meaningful parameters such as knee angle and plantar force values. The processed data are then transmitted to the Blynk IoT platform via Wi-Fi for real-time monitoring.

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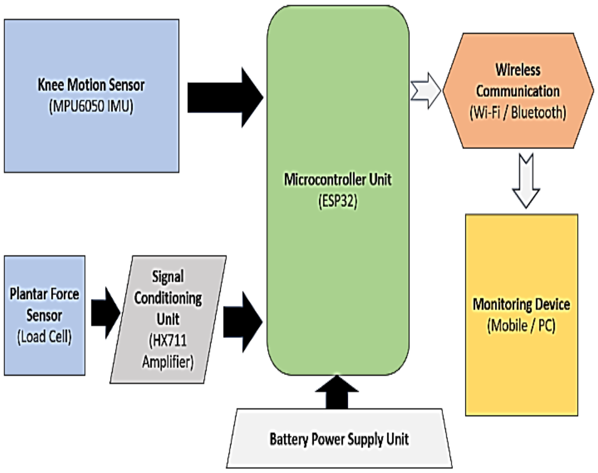


Fig.1. Block Diagram of Proposed System

## V. Mathematical Model

The mathematical model converts raw sensor readings into meaningful biomechanical parameters that describe knee movement and load distribution.

### A. Knee Angle Calculation

The knee flexion–extension angle is calculated using the acceleration values obtained from the MPU6050 accelerometer.

The knee joint angle $\theta$ is calculated using the following trigonometric relationship:

$$\theta = \tan^{-1}\left(\frac{a_x}{\sqrt{a_y^2 + a_z^2}}\right) \qquad (1)$$

Where:

- $\theta$= Knee flexion angle
- $a_x, a_y, a_z$= accelerometer readings along respective axes

This equation determines the orientation of the sensor relative to gravity. Continuous calculation of this angle allows monitoring of knee movement during walking.

### B. Plantar Force Calculation

The plantar force applied to the sensor is calculated using the relationship between mass and gravitational acceleration:

$$F = m \times g \qquad (2)$$

Where:

- $F$= Force (Newton)
- $m$= Mass applied on the sensor (kg)
- $g$= Gravitational acceleration (9.81 m/s²)

The sensor output is converted into digital values using the ESP32 microcontroller. A calibration factor is applied to obtain accurate force measurements.

### C. Sensor Data Processing

The ESP32 continuously reads sensor values from the MPU6050 and the plantar force sensor. The raw signals are filtered and processed to reduce noise and improve measurement accuracy. The calculated knee angle and plantar force values are then transmitted to the monitoring platform.

By combining both parameters, the system can simultaneously analyze joint movement and load distribution. Reduced knee flexion angle together with abnormal plantar force patterns may indicate potential knee joint abnormalities associated with Knee Osteoarthritis.

## VI. RESULTS AND DISCUSSION

The proposed IoT-based wearable system was implemented and tested to monitor knee joint movement and plantar force during walking. The experimental setup consisted of an ESP32 microcontroller, an MPU6050 inertial measurement unit, and a plantar force sensor integrated into a wearable configuration. Sensor data collected from the wearable device were transmitted to the Blynk IoT platform via Wi-Fi for real-time monitoring and visualization.

### A. Knee Angle Monitoring

The MPU6050 sensor measured acceleration along three axes during knee movement. These acceleration values were processed using the proposed mathematical model to calculate the knee flexion–extension angle. The calculated knee angle values were displayed on the Blynk IoT dashboard in real time.

Under normal walking conditions, the measured knee flexion angle ranged between **53° and 72°**, which corresponds to typical knee flexion during the gait cycle.

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When the knee was fully extended, the angle was approximately **2°**, representing a straight-leg position.

In simulated conditions representing possible knee osteoarthritis, the knee flexion angle decreased to **21°–30°**, indicating restricted joint movement. Reduced knee flexion is commonly associated with joint stiffness, pain, and limited mobility in patients suffering from knee osteoarthritis.

**Table 1** summarizes the observed knee angle values under different movement conditions.

Table 1. OBSERVED KNEE ANGLE VALUES

| Condition | Knee Angle (°) | Observation |
|---|---|---|
| Knee Extension | ~2° | Straight-leg support |
| Normal Walking | 53° – 72° | Normal knee flexion |
| Restricted Movement | 21° – 30° | Possible KOA indication |

## B. Plantar Force Monitoring

The plantar force sensor embedded inside the footwear measured the pressure exerted by the foot during walking. The sensor readings were converted into force values and displayed on the monitoring interface.

Under normal walking conditions, plantar force values ranged between 1.5 kg and 1.6 kg, indicating balanced load distribution during gait. In conditions representing knee discomfort or abnormal gait patterns, the plantar force values decreased due to uneven weight distribution.

Individuals experiencing knee pain often shift their body weight toward the opposite leg to reduce stress on the affected joint. This behavior leads to variations in plantar force distribution, which can be used as an indicator of potential knee abnormalities.

**Table 2** presents the measured plantar force values under different walking conditions.

Table 2. OBSERVED PLANTAR FORCE VALUES

| Condition | Plantar Force (kg) | Observation |
|---|---|---|
| Normal Walking | 1.5 – 1.6 kg | Balanced weight distribution |
| Abnormal Gait | ~0.9 kg | Uneven load distribution |

## C. Real-Time Monitoring

The ESP32 microcontroller successfully transmitted processed sensor data to the Blynk IoT platform through Wi-Fi. The mobile dashboard displayed real-time values of knee angle and plantar force along with graphical trends.

The monitoring interface enabled continuous observation of knee movement and load distribution during walking. The real-time visualization allows users and healthcare professionals to identify abnormal readings and movement patterns associated with knee osteoarthritis.

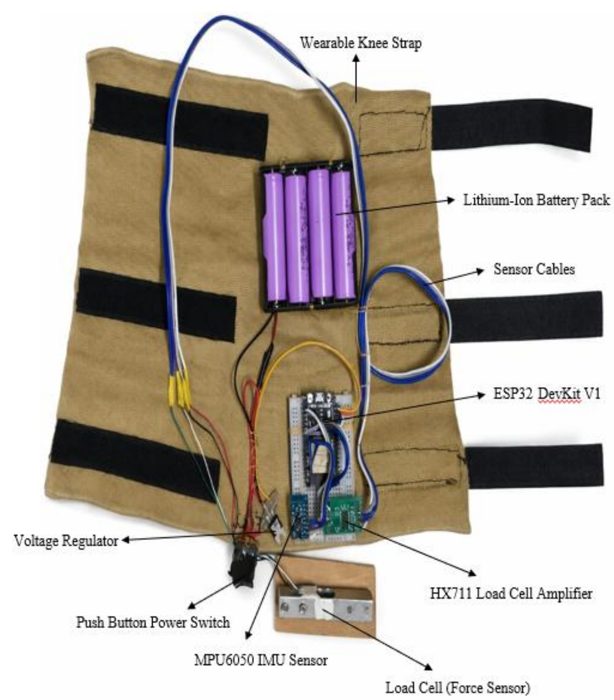


Fig.2. Real-time Hardware Implementation

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Fig.3. Blynk interface showing possible KOA condition

**D. Discussion**

The experimental results demonstrate that the proposed wearable system can effectively monitor knee flexion angles and plantar force simultaneously. The measured values are consistent with findings reported in previous studies on gait analysis and knee biomechanics. Reduced knee flexion angles combined with uneven plantar force distribution can indicate potential abnormalities in knee joint movement.

Compared with traditional clinical diagnostic techniques such as X-ray or MRI, the proposed system provides a portable, low-cost, and real-time monitoring solution. The wearable design enables continuous monitoring during daily activities, which may help detect early functional changes in knee movement before severe structural damage occurs.

Therefore, the proposed IoT-based wearable system has the potential to support early screening, rehabilitation monitoring, and remote healthcare applications for individuals at risk of knee osteoarthritis.

## VII. CONCLUSION

The proposed system integrates an ESP32 microcontroller, an MPU6050 inertial measurement unit, and a plantar force sensor to measure knee movement and foot pressure during walking. Sensor data are processed by the microcontroller and transmitted wirelessly to the Blynk IoT platform, enabling real-time monitoring and visualization.

Experimental results demonstrate that the system can effectively measure knee flexion angles and plantar force values during different walking conditions. Normal knee movement produced flexion angles between 53° and 72°, while reduced angles of 20°–30° indicated restricted knee motion that may be associated with early KOA symptoms. Plantar force measurements also revealed variations in weight distribution during gait, which may reflect joint discomfort or abnormal movement patterns.

The proposed wearable device offers a low-cost, portable, and real-time solution for continuous monitoring of knee biomechanics. This approach can support early detection of knee abnormalities and assist in rehabilitation monitoring. Future work may focus on integrating multiple sensors, applying machine learning algorithms for automated gait analysis, and conducting large-scale clinical testing to improve diagnostic accuracy.

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