DEVELOPMENT OF AN IoT-BASED KNEE EXOSKELETON DEVICE FOR REHABILITATION THERAPY MONITORING

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ABSTRACT: The COVID-19 pandemic has presented a multitude of challenges pertaining to medical treatments and patient care, creating a pressing need for innovative solutions. Constrained outdoor activities have hindered patients' ability to access essential healthcare, while healthcare professionals encounter difficulties in remotely monitoring and administering treatments. This study aims to address these pressing issues by proposing an Internet of Things (IoT)-based exoskeleton system designed for the monitoring of knee rehabilitation therapy. Through the utilization of the IoT platform ThingSpeak, this developed system enables patients to remotely monitor the status of their knee recovery from the comfort of their homes. The collected data is securely stored and made accessible to healthcare professionals, facilitating remote analysis and the formulation of treatment recommendations. This pioneering solution amalgamates advancements in exoskeleton technology with seamless IoT integration, establishing a dependable and easily accessible framework for the monitoring of knee rehabilitation. By empowering patients to actively participate in their own recovery process and enabling remote monitoring by healthcare providers, this system effectively surmounts the limitations imposed by the pandemic and financial constraints. The proposed IoT-based exoskeleton system possesses the potential to revolutionize knee rehabilitation therapy, thereby enhancing patient engagement, optimizing treatment outcomes, and circumventing traditional healthcare barriers.

KEYWORDS: *Knee rehabilitation therapy; IoT-based exoskeleton; Remote monitoring*

1.0 INTRODUCTION

The knee is a highly intricate joint composed of interconnected skeletal structures, supported by ligaments and surrounded by muscles [1]. Its vital role lies in facilitating movement and providing stability to the lower extremities. Ligaments play a crucial role in stabilizing the knee, preventing excessive front-to-back movement and restricting sideways sliding [1]. Knee injuries are common, and they can cause significant impairments and pain. Knee sprains, strains, inflammation, and medical conditions like osteoarthritis are frequently observed [2]. Doctors often encounter difficulties to remotely monitor and administer treatments when patients are not presence.

The integration of IoT technology in the knee rehabilitation monitoring device offers several advantages [3]. Patients can track their progress through a graphical representation, thus adjusting their rehabilitation efforts accordingly [4], [5]–[8]. This real-time monitoring empowers patients by providing immediate visual feedback on their recovery status [4]. Moreover, healthcare professionals can access patient data from other places, eliminating the need for frequent in-person visits and facilitating timely interventions and personalized care [4].

Security and privacy are important in protecting patient data and ensuring the integrity of the monitoring system [9]. Robust security measures, including encryption and authentication protocols, must be implemented to safeguard transmitted data and prevent unauthorized access [9]. These measures establish a secure and efficient platform for the IoT-based knee rehabilitation device, enabling effective monitoring and improved patient outcomes [10]–[12].

As such, the development and evaluation of an IoT-based knee rehabilitation monitoring device has been suggested. The device allows real-time monitoring of knee recovery status, providing visual feedback to patients and enabling healthcare professionals to monitor and deliver personalized care remotely [4],[6], [13], [14].

This paper explores the development and evaluation of an IoT-based knee exoskeleton rehabilitation monitoring device [7], [8], [15]–[17]. The knee complex structure and susceptibility to injuries make it an essential focus area [1], [18]. The device provides real-time monitoring of knee recovery, empowering patients and remote personalized care [4].

2.0 METHODOLOGY

The methodology section presents the approach and procedures followed in the development and implementation of the knee rehabilitation monitoring device. This section provides an overview of the device components, operating procedures, implementation, programming, and application. The device integrates the NodeMCU microcontroller, the MPU6050 sensor, and the ThingSpeak IoT platform to enable real-time monitoring of knee movement and recovery progress [19]. The methodology outlines the steps involved in using the device, including data collection, storage, and visualization through the ThingView application. Additionally, it highlights the programming tools utilized and emphasizes the simplicity and effectiveness of the device in achieving its objectives.

2.1 Device Overview

Prior to assembling and testing the actual knee rehabilitation monitoring device, a simulation circuit as in Figure 1 is built to simulate its workability. After that, the monitoring device is developed utilizing the same components in the simulation circuit and assembled as depicted in Figure 2. The NodeMCU microcontroller is programmed to control the IoT device and transmit data to cloud storage through the ESP8266 WiFi module. The MPU6050 sensor is employed to sense knee rotational movement along the x-axis and provide its movement data. This data offers insights into the recovery progress of the knee from injuries. The data collected is stored in ThingSpeak cloud storage, allowing for future utilization. Users can access the data at any time and view it through the ThingView application on their smartphone, enabling them to monitor movement and view graphs.

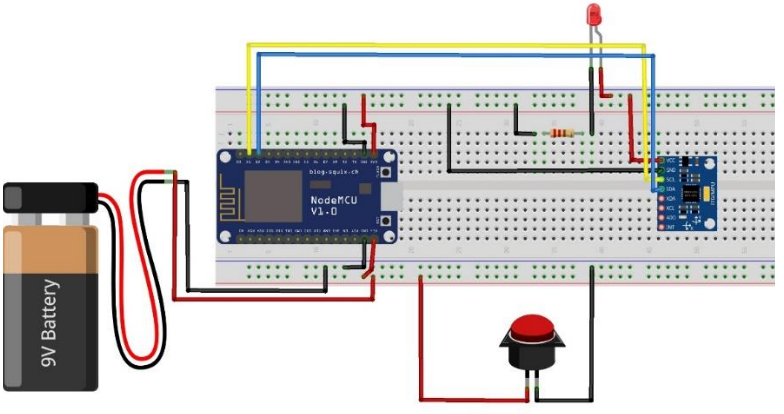

Figure 1: Simulation circuit

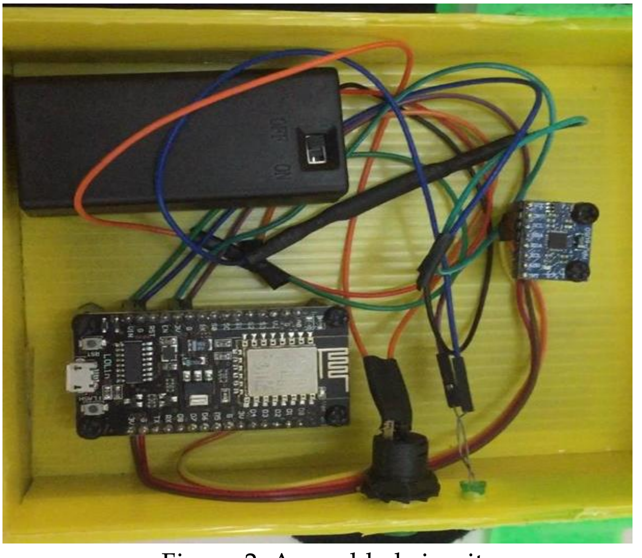

Figure 2: Assembled circuit

2.2 Operating Procedures

The following steps outline the operating procedures for the knee rehabilitation monitoring device:

a) Activate the power supply switch to provide power to the NodeMCU.

b) The MPU6050 sensor detects knee movement along the x-axis and converts it into a signal, which is then processed by the NodeMCU to generate meaningful data.

c) The device transmits the data to the ThingSpeak IoT platform via a WiFi connection, where it is displayed as a continuous real-time graph.

d) Users can access the same data through the ThingView application on their smartphones.

e) The ThingView application presents the data in numerical form, allowing users to monitor their knee movement conveniently.

f) Data received by the ThingSpeak platform can be downloaded in MS Excel format for further analysis or future reference.

2.3 Implementation

The knee rehabilitation monitoring device is designed to cater to IoT applications, encompassing both hardware and software components. The implementation process involves:

a) Utilizing the Arduino IDE to update or add program codes, which can be uploaded to the NodeMCU controller via a USB cable.

b) Connecting the NodeMCU to the ThingSpeak IoT platform, enabling the monitoring and storage of knee angle data in real-time.

c) The ThingView application offers a real-time display of the rotational angle value obtained from ThingSpeak. It presents the instantaneous knee movement as a gauge, facilitating easy monitoring without the need for graph representation.

2.4 Programming The Device

The device programming is executed with a simple interface and essential algorithms to achieve the intended objectives and meet the its requirements. The Arduino IDE, supporting the C++ programming language, is employed to program the NodeMCU controller and establish connectivity with the ThingSpeak platform. Additionally, the NodeMCU controller can be easily integrated with other devices or microcontrollers using a straightforward program. The value that is received from the MPU6050 is in radian. To create a graph in desired IOT platforms, the values must be converted into unit of degrees. Equation 2.1 allows the radian value to be converted into degree and incorporated in the program.

$$1\ radian = \frac{180^o}{\pi} \tag{2.1}$$

2.5 Applying The Device

The user needs to wear the knee support strap on the injured knee and turn on the device. Once the strap is placed, the user can start turning on the device and the WiFi to connect to the device. Once it is connected the user can start to monitor their movement by putting their knee in its initial position. Then, the user simply needs to move the knee in flexion and extension movements, shown in Figure 3.

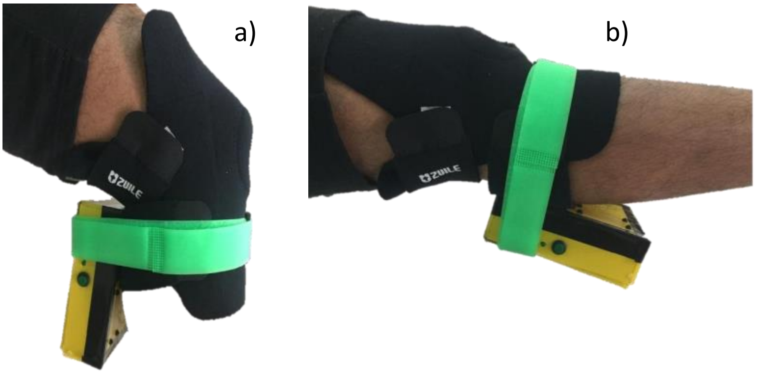

Figure 3: Knee movements with monitoring device attached a) Knee flexion b) Knee extension

The knee movement is detected by the sensor as rotational data along the x-axis movement and directed to the device controller. The IoT platform will start to receive and collect the knee movement data from the device and start plotting a graph. Figure 4 shows the overall procedure for the device application as explained in 2.2.

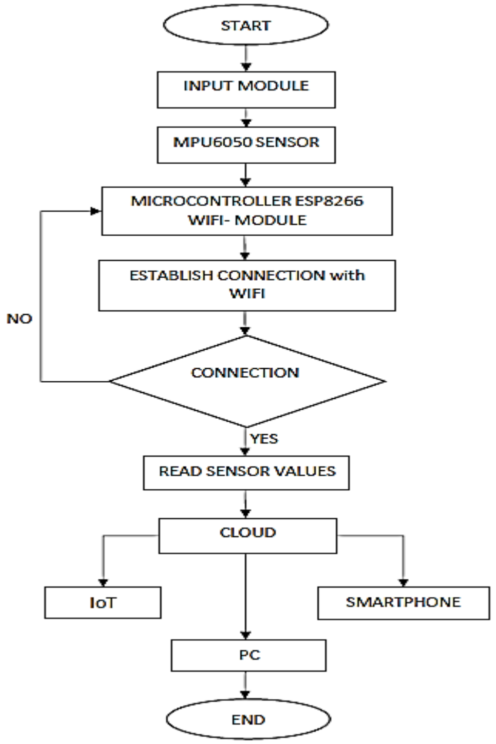

Figure 4: Device application procedure

3.0 RESULTS AND DISCUSSION

A knee rehabilitation monitoring device has been successfully developed for tracking knee recovery status. The device collected knee movement data, and displayed it on ThingSpeak's ThingView app in smartphone. The ThingSpeak smartphone app interface is as shown in Figure 5. The gauge in the application allows the user to quickly monitor the data by showing the exact current knee angle value without graph. Users could also assess the knee improvement graph through ThingSpeak web using computer as shown in Figure 6. The graph in both methods can be updated automatically or manually through web or smartphones. The collected data can then be downloaded in MS Excel format and stored for future use.

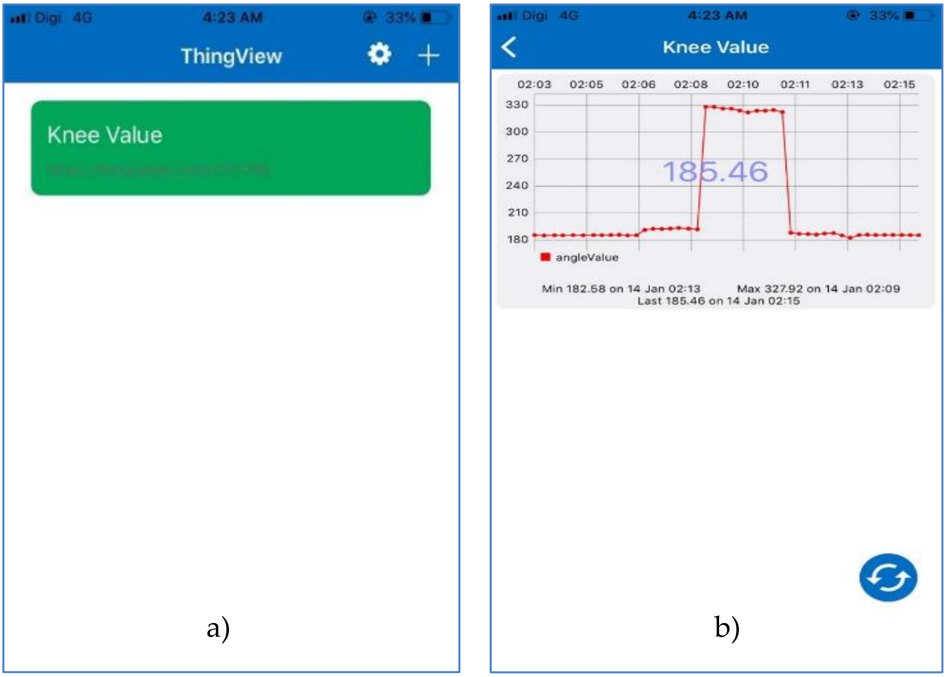

Figure 5: a) ThingView first screen b) ThingView graph display

Data collection on the knee movement angle occurred continuously, with updates at every 15 seconds. Users could monitor their knee recovery status for approximately 10 minutes in a single session. The graph on the IoT platform provided a visual representation of the knee movement data, enabling real-time assessment and comparison.

Figure 6: Knee movement graph in ThingSpeak

The device usability is enhanced by the option to download the graph as an MS Excel file for further analysis and future reference. This feature allowed users to track changes in their knee recovery over time and make informed decisions about their rehabilitation progress.

4.0 CONCLUSION

A knee rehabilitation monitoring device that allows the patient to view knee recovery status and the doctor to track the data remotely has been developed. Moreover, it has been developed by combining the features of the components with IoT. The device has been successfully tested for various angles in many situations and its data visualized as graph on the ThingSpeak IoT platform, provided a clear and measurable representation of the knee's improvement over time. The real-time monitoring of the knee angle and its progression enables personalized care and tailored rehabilitation efforts, allowing patients to adjust their exercises based on the immediate feedback provided by the graph.

In conclusion, the developed device tracks the knee's movement angle and recovery progress over time. By attaching the device to their knee, patients can undergo real-time monitoring of knee flexion and extension movements. The real-time graph visualization and data storage capabilities provided valuable insights for users to track and evaluate their knee rehabilitation progress. The knee rehabilitation monitoring device, utilizing the NodeMCU microcontroller, MPU6050 sensor, and ThingSpeak IoT platform, offered an effective solution for monitoring knee recovery. In the future, the device can be integrated into a modular knee exoskeleton, thus contributing to effective self-monitoring for knee rehabilitation therapy.

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