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Design and Experimental Prototyping of an ESP32-Based Instrumentation Device for Digital Data Acquisition and Wireless Monitoring of Foot Pronation Process

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ABSTRACT

This paper presents a new instrumentation device for digital data acquisition and monitoring of the human foot pronation process. It consists of a few hardware parts including pronation sensor socks, ESP32 microcontroller and a smartphone monitoring target. During the design steps, the block diagram and flowchart are presented. During experimental studies, the local instrumentation software is developed under Arduino IDE-C+ framework. Then it is compiled and uploaded into ESP32 application program memory, for digital acquisition and wireless transmission of pronation data. Furthermore, the involved mobile application, is preinstalled into a target smartphone, to be appropriately conFigd and activated for virtual monitoring the incoming foot pronation data. A number of experimental results presented and discussed in this paper, show the great technical relevance and the high ergonomic nature of the proposed digital instrumentation device for the human being foot pronation process

Key words: Instrumentation device, ESP32, Foot Pronation, Data Acquisition, Wireless Smartphone Monitoring

INTRODUCTION

Pronation is a natural movement of the foot that occurs during foot landing while running or walking. It should not occur past the latter stages of mid-stance, as the normal foot should then supinate in preparation for toe-off [1]. It involves three cardinal plane components: subtalar eversion, ankle dorsiflexion and forefoot abduction [2, 3]. These three distinct motions of the foot occur simultaneously during the pronation phase [4]. Abnormal pronation occurs when a foot pronates it should supinate, or over-pronates during a normal pronation period of the gait cycle. Approximately four degrees of pronation and supination are necessary to enable the foot to propel forward properly. In the neutral position, the foot is neither pronating nor supinating. If the foot is pronating or supinating during the stance phase of the gait cycle when it ought to be in the neutral position, a biomechanical problem may exist [4]. Pronation is a normal, desirable and necessary component of the gait cycle [5].

Pronation is also the first half of the stance phase, whereas supination starts the propulsive phase as the heel begins to lift the ground [6, 7]. Although varying definitions exist as described by Horwood and Chockalingam in [8] for choosing appropriate footwear, pronation could be described in three simple terms: neutral pronation, over-pronation, and under-pronation [9, 10].

A few promotion acquisition systems are available in the literature [11, 12]. In [11], an input sock system with 5 embedded FSRs (Force Sensing Resistors) is used, however no details are given about the acquisition interface. In [12], a sock system with 8 input FSRs is connected to a F031K6-based acquisition device. Unfortunately, the whole acquisition system involves a great complexity, and there is a significant lack of information, about how the so-called smart technology is implemented for possible wireless transmission and monitoring of pronation data. Given these weaknesses arising from a few existing pronation instrumentation systems, the relevant goal of this paper is to present the design and a prototyping realization, of a new type of ESP32-based instrumentation device for acquisition with wireless monitoring foot pronation data on a smartphone.

TOOLS AND METHODS

The block diagram of the proposed pronation instrumentation device is shown in Fig. 1. It consists of a few relevant parts, i.e. sensorized socks, ESP32 microcontroller, smartphone and a Laptop.

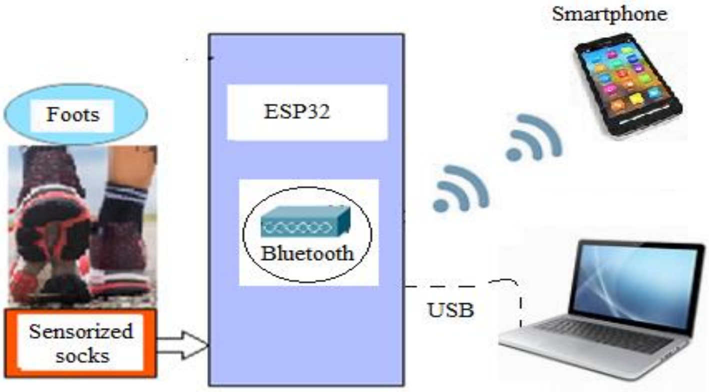

Fig. 1 Block diagram of the hand-luggage pronation system

Table 1 shows the technical specifications of hardware tools used to build the proposed pronation control device. The required relevant criteria of hardware parts are: availability in the local electronic market, reliability, sufficient operating range, low weight and cost, etc.

Table 1: Technical specifications of hardware tools

S/N	Hardware Tool	Specifications
1	FSR 402	• Actuation Force as low as 0.1N and sensitivity range to 10 N. • Easily customizable to a wide range of sizes • Highly Repeatable Force Reading; As low as 2% of initial reading with repeatable actuation system • Cost effective • Ultra-thin; 0.45mm • Robust; up to 10M actuations • Simple and easy to integrate
2	Textile material	Socks (Cotton)
3	ESP32 Module	• ESP32-WROOM-32 • 448KB of ROM, • 520KB of on-chip SRAM, • 8 KB of SRAM in RTC FAST, • 8KB of SRAM in RTC SLOW, • 1Kbit of eFuse, • CPU instruction memory 11 MB + 248KB • Data Memory 4MB • In-Built Bluetooth and BLE
4	Smartphone	Android smartphone with Serial Bluetooth Terminal Application installed.

The hardware wiring was designed in Proteus ISIS following the various positions of foot pronation. Fig. 2 shows the placement of sensors for a smart sock.

Fig. 1 Placement of sensors for a smart sock [11]

Fig. 3 shows the electronic diagram of the ESP32-based acquisition system. When the heel strike pattern is present (in walking or running), because the first to hit the ground is the heel, Sensor 5 is first activated, reaching the maximum value (minimum resistance in FSR 402) before the sensors placed in the front part of the foot (Sensors 1 and 2). When another type of strike pattern is used when running, Sensor 5 will reach its maximum value later or at the same time as the other sensors. When sensors 3 and 4 are activated without any other sensor(s) being activated it is considered a Neutral position for the foot. These considerations were taken into account in order to develop an algorithm for distinguishing heel strike and non-heel strike walking and running modes. The above design was used for detecting excessive pronation and supination gait conditions that may lead to injuries, both when walking and running.

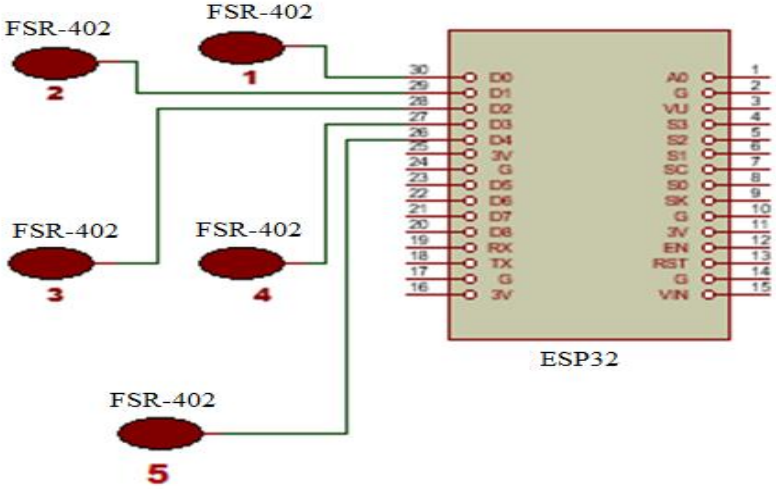

Fig. 2 Electronic diagram of the ESP32-based acquisition system

In the schematic above, the ESP32 module contains an in-built Bluetooth module which will be used to communicate with the companion mobile device, which is a smartphone.

The main instrumentation hardware components in this project is the Force Sensitive Resistors (FSR 402) and the ESP32 microcontroller module. An auxiliary hardware is included which is the companion device (an android device, e.g., a smartphone). It is necessary to have at this point to have a better understanding of the FSR 402 technology.

For the FSR 402 case, it is worth noting that the operating principle and input-output characteristics of each FSR (force sensing Resistor) used as sensor in the smart sock, are depicted on Fig. 4. In Fig. 4a, Rf stands for the electric resistance of the FSR due the associated active force on the FSR, V_{FSR}(Rf) being the incurred voltage across the FSR. The overall input-output characteristics of an FSR due to the input force are provided in Fig. 4b.

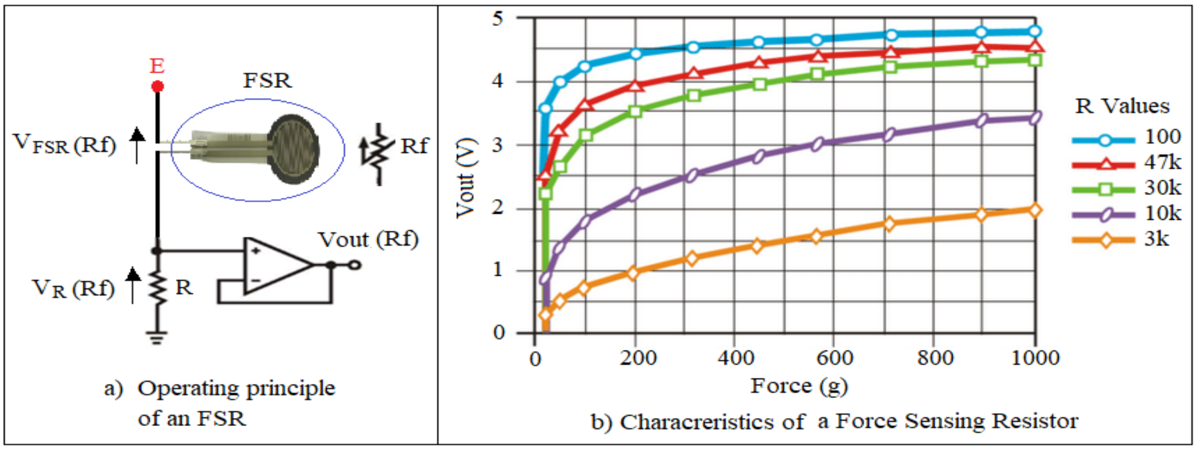

Fig. 3 Input-output operating principle and characteristics of an FSR [13]

The behavior of the circuit in Fig. 4a is described by the set of equations (1a, 1b), where (1) the marginal input-output characteristic of the FSR, whereas (1b) is overall input-output behavior involving the output voltage V_{out} (Rf (ψ)) to be connected to an analog input pin of a downstream processor.

$$\begin{cases} V_R(R_f(\psi)) = \dfrac{R}{R + R_{FSR}(R_f(\psi))}\,E & \text{(a)} \\ V_{out}(R_f(\psi)) = V_R(R_f(\psi)) = \dfrac{R}{R + R_{FSR}(R_f(\psi)}\,E & \text{(b)} \end{cases} \qquad (1)$$

As a technical implication, since Vout implicitly depends on Rf which in turn also depends on the input force ψ, then without lost of generality, given a N-size sample of known weights or forces { ψ1, ψ2, …, ψN}, simple experimental tests can be conducted in other to outline the sample of Vout (ψ,, n) given known sample of {ψ(n)}. Then, using optimal experimental estimation techniques, an overall operating behavior given by equation (2) can be provided. Following our reasoning, the basic procedure to built the types of overall characteristics as depicted on Fig. 4.b, becomes obvious.

$$V_{out}(\psi) = f(\psi, R) \qquad (2)$$

In the shown configuration, the output voltage increases with increasing force. The physical appearance of the FSR 402 is depicted in Fig. 5.

Fig. 4 FSR 402 physical appearance

The physical appearance and input/output pins of the ESP32-WROOM-32 module is shown in Fig. 6. It offers 32 reconfigurable input-output multipurpose pins, and an embedded ESP32 module. It is one of the best low-cost and flexible microchips available in today for ambitious IoT projects.

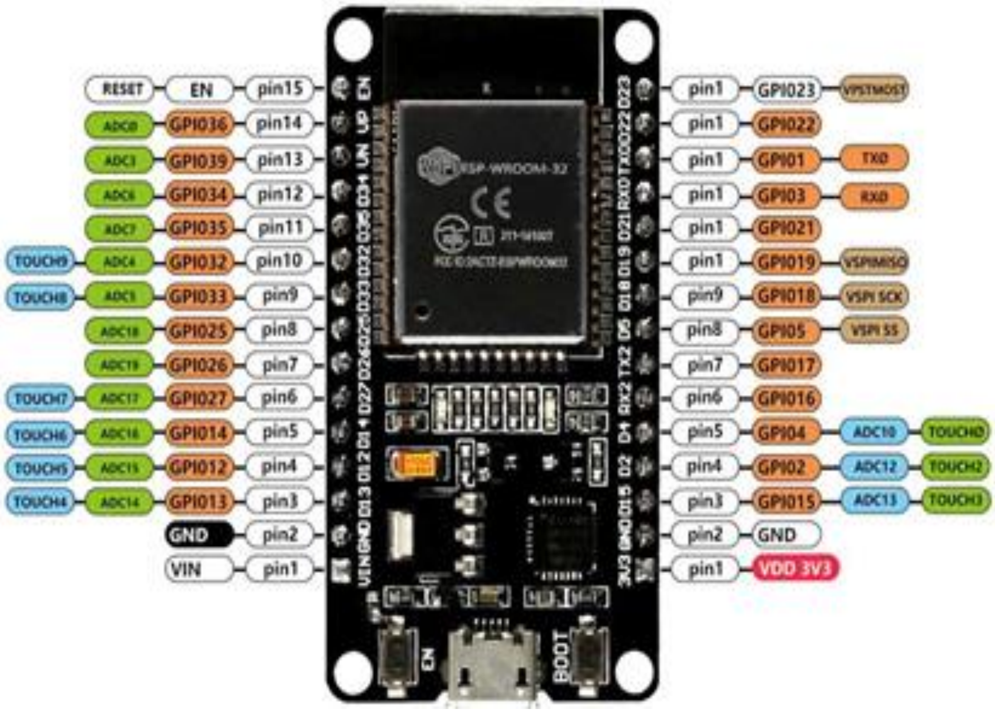

Fig. 5 Physical appearance and pins of the ESP32-WROOM-32 module

The required software tool for this paper is presented in Table 2. In addition, the main operating software is organizing into processing subroutines modules, and is written in Arduino IDE C++ according to the flowchart logic to be outlined in the next section.

Table 2: Technical specifications of software tools

S/N	Software	Specifications
1	ESP32 driver for windows	CP210x USB to UART bridge
2	Arduino C++ IDE	1.8.12 version
3	Bluethooth Library	BluetoothSerial.h
4	Serial Bluetooth Terminal	Last version for Smartphone

A digital system involving 5 input variable with binary states {High ≡ H, Low ≡ L), leads to a theoretical total of $N = 2^5 = 32$ different states, i.e. {0, 1, …, n, …, 31}. However, only a few number of these states are holder of significant pronation effects to be acquired from the sock wearer. Under these assumptions, Fig. 7 shows the flowchart of the decision process retained for the development of the Arduino application program.
It is worth noting at this step that the flowchart presented in Fig. 7, has been implemented under Arduino IDE-C++, equipped with heading ESP32 libraries required for pronation both data acquisition and Bluetooth-based wireless transmission of pronation processing outcomes. Table 3 shows suitable operating conditions of useful ESP32 pins.

Table 3: Operating conditions of ESP32 pins for correct functionality

S/N	Software tool condition	Output
1	All the 5 sensors activated in the order 5, 4, 3, 2, 1.	Neutral foot position in the forward movement
2	All the 5 sensors activated in the order 1, 2, 3, 4, 5.	Neutral foot position in the backward movement
3	Only sensors 2 and 3 activated.	Under-pronation
4	Only sensors 1 and 4 activated.	Over-pronation
5	Else Switch or Error Message	Please install the system on a human foot and retry

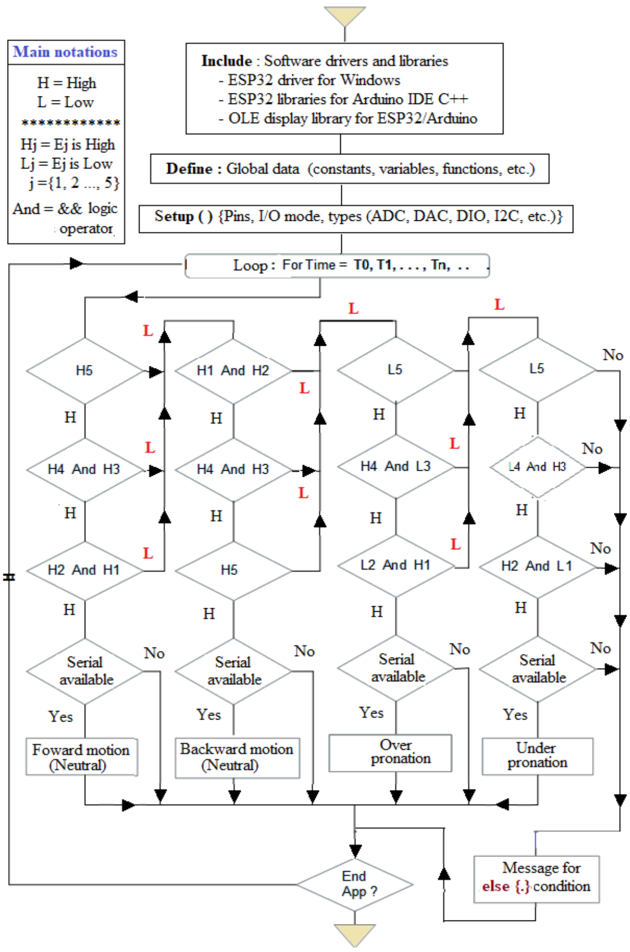

Fig 6: Flowchart of the application program for an ESP32 target

RESULTS AND DISCUSSIONS

An image of the experimental setup used to test the proposed ESP32-based pronation instrumentation device is presented in Fig. 8. In addition, a smartphone with a preinstalled Serial Bluetooth Terminal application, is used to test the overall instrumentation pronation system.

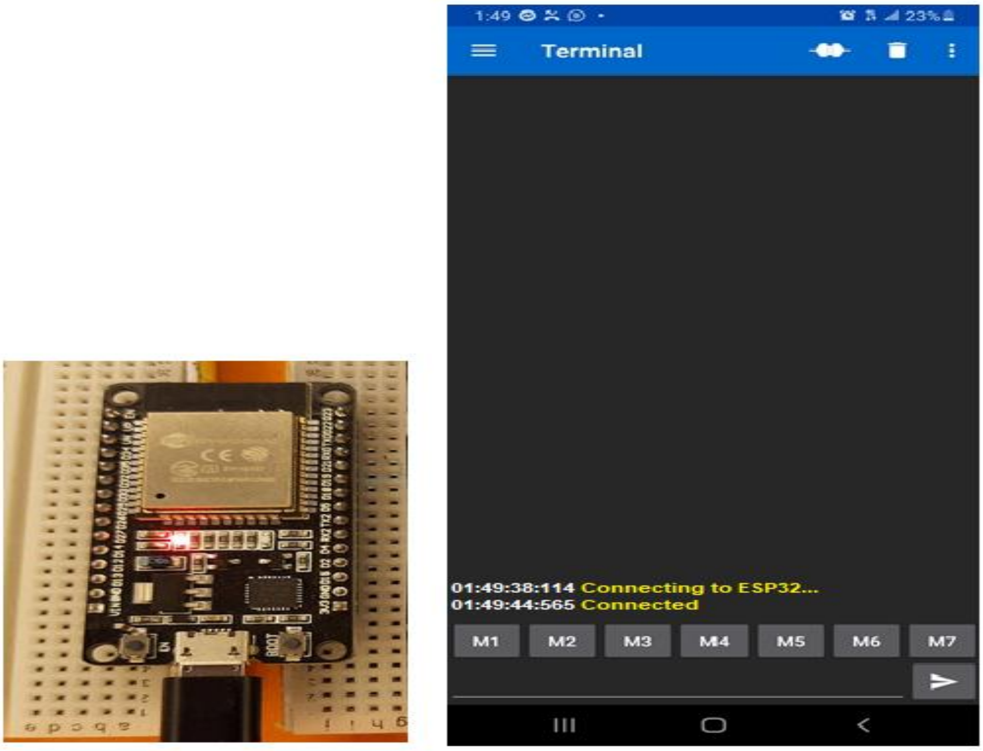

Fig. 8 Experiment setup for real time tests

When a subject (person) with normal movement or no pronation feet is detected, the output message displayed on the screen of the phone through serial Bluetooth Terminal application is "Neutral". Furthermore, the subject might either be moving forward or backwards. Thus, the application can also detect backward and forward movement for a Neutral position as seen in the screenshot in Fig. 9.

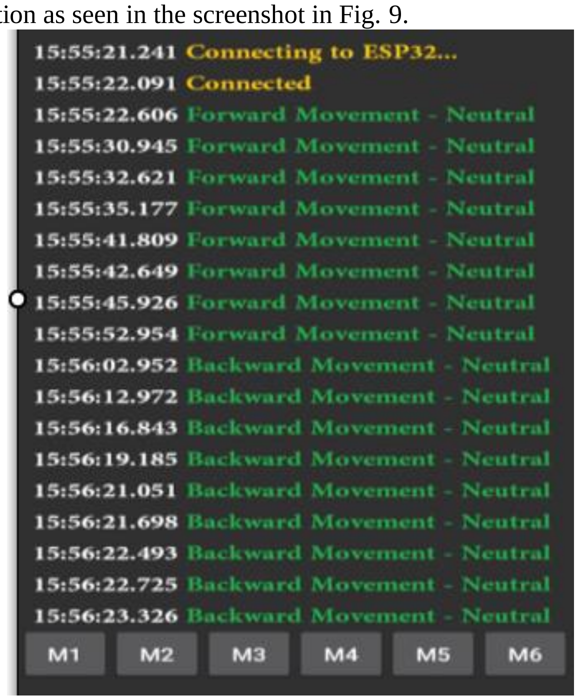

Fig. 9 Serial Bluetooth Terminal Pronation Testing for Neutral (Normal) Feet

For a subject (person) suffering from under-pronation feet, the output message displayed on the screen of the phone through serial Bluetooth Terminal application is "Under-Pronation". It does not matter whether the person is moving forward or backwards. Thus, the application can detect under-pronation in both backward and forward movements for a given subject and the result will be displayed as seen in the screenshot in Fig 10.

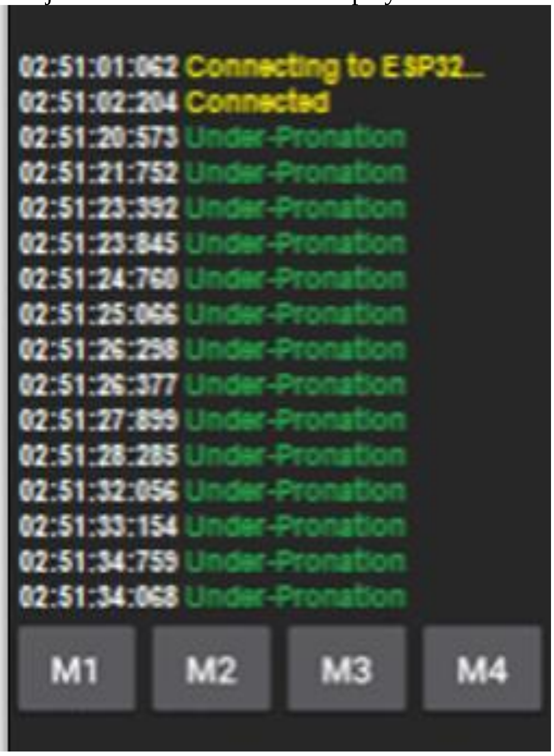

Fig. 10 Serial Bluetooth Terminal Pronation Testing for Under-Pronated Feet

For a subject (person) suffering from over-pronation feet, the output message displayed on the screen of the phone through serial Bluetooth Terminal application is "Over-Pronation". It does not matter whether the person is moving forward or backwards. Thus, the application can detect over-pronation in both backward and forward movements for a given subject and the result is displayed as seen in Fig 11.

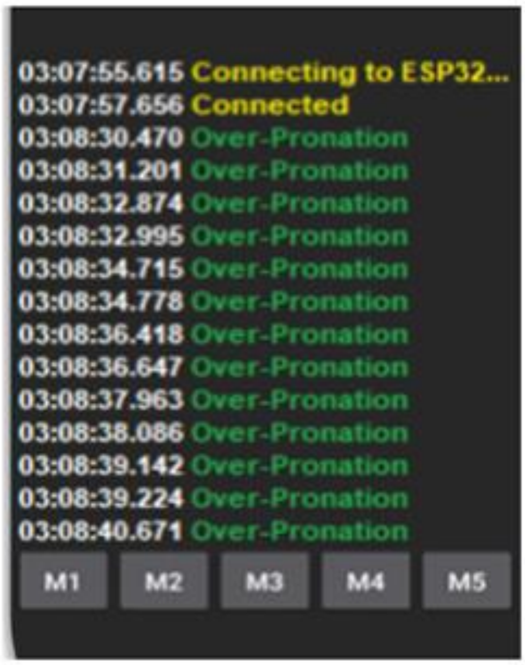

Fig. 11 Serial Bluetooth Terminal Pronation testing for over-pronated Feet

It is possible also to capture for display needs, an error message which comes up when the system is not actually installed on a human foot. Under such abnormal operating conditions, the target to be displayed the smartphone monitor as shown in Fig. 12, is "Please install the system on a human foot and retry". This error message will keep repeating until the system is properly installed on a human foot or is switched off if needed.

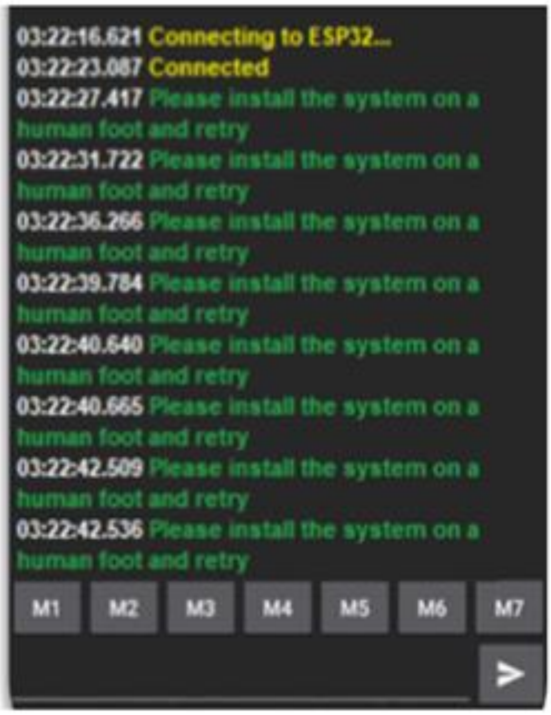

Fig. 12 A screenshot of the error message

The software code is locked to unidirectional transition of information from the ESP32 to the companion devices and not vice versa. This is to avoid interruptions from users and also get precise and accurate information on the state of the foot pronation. As seen above, in Fig. 9 the subject has no pronation defects (Neutral), in Fig. 10 the subject is suffering from under-pronation while in Fig 11 the subject is suffering from over-pronation. Fig. 12 presents a situation where the system is not properly installed on the human foot and other circumstances which may give undesired results; in which case an error message is sent to the user for rectification.

CONCLUSION

In this paper, we have presented a new ESP32-based smart digital device, for acquisition and wireless monitoring on smartphone of human foot pronation data. Here, the designed system responds by detecting the positioning of the foot during movement and sending accurate data to the companion mobile devices (smartphone or Tablet). The pronation system was designed to improve non-invasive data collection on the pronation state of the foot at the user's convenience by allowing the user to check the message queue in the companion devices as he or she moves or runs. Another efficient system function is that when a user tries to interact with the system, there are no interruptions to the information being sent to the companion device. Now the user can get information on whether his or her foot is undergoing some pronation or not. However, several unsolved problems remains, e.g., lack of optional Bluetooth/BLE transmission of pronation data, and a study in death of the device precision born. These unsolved problems will be investigated in future research works.

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