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Design and Development of Insole Monitoring System for Runner

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Abstract*: Nowadays, running is said to be one of the common activities that be practiced by various people especially athletes. Back then, there were some researchers report that most of the injuries among athletes involves lower hip bodies. It is due to some factors such as body and foot posture during running activity, selection shoe and style of running. Hence, this research is about to design and develop an insole monitoring system using ESP 32 development board and FSR sensor for the purpose of force distribution detection on runner's foot. The development of smart insole is to countermeasure the risk of injury to the athletes. This system includes (ESP 32) development board which act as a microcontroller that interfaced with a wifi module and force sensing resistance (FSR) sensor to detect the force distribution of runner's foot in (kg) unit. The system able to detect the foot force distribution acts by the runner and transmits the output data of the FSR sensor through the application which called Blynk. The experiments had done through two methods which are jogging and running. The force monitoring data was obtained through the Blynk Application via Wi-fi.The design and development of insole monitoring system has successfully done and implemented on the runner.

***Index Terms*: Sports injuries, microcontroller, force distribution, Blynk application, monitoring system.**

I. INTRODUCTION

In this paper will be discussed about the development of smart insole monitoring system for runner. Previously, the smart insole system had been created to monitoring the gait analysis. Gait is the individualistic manner of moving the body from one place to another through alternately and repetitively changing the location of the feet [1].

Therefore, developing smart insole was been primary goal of clinicians and rehabilitators to investigate gait of an individual with walking in abnormality before proposing the correct remedy of it [2].

In this case, the study focuses on gait kinetic on runner that mainly relates to force measurement under foot while running [2]. Based on study, Kyongchul deployed air bladder and air pressure sensor assembly [3], HuiYu choose strain gauges [4], M. Saito was used conductive rubber sensor [5], while A. Faivre experimented with custom made dynamometric rings [6]. Each of the sensors that were used by them had highlighted it own benefits. However, research study that many researchers refer to used force sensitive resistor (FSR) sensor to investigate the normal or abnormal gait due to easy used and set up based on real walking and running scenario.

Gait cycle contain two phase that are stance phase and swing phase. The stance phase can be defined as an interval of foot as the person walk on the ground that involves a lower limb and constitute about 60 percent of the gait cycle [7]. The stance phase started with initial contact, known as 'heel strike', followed by 'loading response' and 'mid stance' where the forefoot contacts on the ground. On this period, other side leg swings forward for initial contact cause the weight on same side leg shift from the heel to- wards toe hence raising the heel that known as 'heel off'. The 'terminal stance' from here starts and end with 'pressing' when heel strike on other side of the leg. Swing phase is a part of the gait cycle where it covers the remaining gait cycle. This phase is an interval or period of foot that not in contact with the ground about forty percent of the gait cycle [8]. The separation of toes from the ground marks the beginning of swing phase which involves the following sub phases initial swing, mid swing and terminal swing [9]. This gait cycle can be used in investigate the acting force on foot while running.

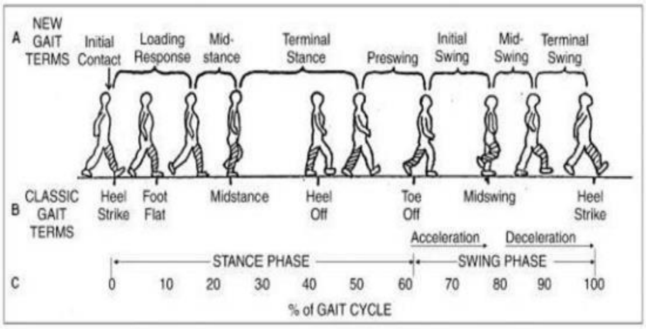

Fig 1 : Gait Cycle

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A lot of studies use force platforms in investigate running biomechanics [10]. However, the measurement was taken to a particular location and it often makes it inside the laboratory. There are using the instrumented treadmills in order to run the experiment. Besides that, based on studies, the set-up measurement of the experiment only for single foot contact at a time [10] and this show the system versatility was limited. Furthermore, the building of the gait lab was expensive, and it takes more than 300 k dollar to set up the facilities or equipment without consideration [11].

Even though a lot of research has been done, there was no evidence that said the rate of related running injury incidences was decreasing. Thus, ten force sensitive resistor (FSR) sensors are install on the insole for both side of the shoes where each in- sole consist of five FSR sensors that are used in this experiment. In this work, the FSR sensor will measure the force distribution change of the runner foot based on the weight applied during running. The focus in this work is to focus more on the forefoot strike (FFS) and rear foot strike (RFS) as it play an important role in running process as it measures the force loading rate at foot. Different kind of foot positioning during impact or landing can be used in classify type running style that are “toe-heel-toe” running or forefoot strike (FFS), “flat-footed” running with a mid-foot strike (M FS), or “heel-toe” running with a rear foot strike (RFS)[12].

In this research, smart insole had been developed to design newly type of smart insole using wireless microcontroller and FSR sensor to detect force distribution on footprint runner. Then, to integrate style and characteristic of running based on foot force of runner and to test the smart insole with real time data analysis are compulsory in reduce the rate of related running injury among runner.

II. SYSTEM DEVELOPMENT

A. Hardware

The insole monitoring system consists only two main components that were ESP32 Development Board also force sensitive resistor (FSR) sensor to run the system. The FSR sensor is the sensor that is used to sense the pressure applied by foot runner during running. The system consists of total ten FSR sensors where each insole left and right consists of five FSR sensors. The F SR sensor with a round 1.27 cm, sensing area consists of two membranes which separated by thin air gap. Rigidity of the membrane and spacer around its edges are maintained by air gap. It also had two set integrated fingers which electrically separated from each other, where each set is connecting to one track on the tail. Moreover, the other side of membrane is coated with FSR carbon-based ink. The sensor will operate as the force increase the resistance will decrease and voltage will pass through. If there is no force applied to FSR its resistance will be larger than 1M ohm. In this system, the analog voltage reading range from microcontroller is 0 to4095.

Another hardware used was ESP 32 Development Board. This development board had ESP-WROOM -32 module attached on it that boasts Wifi, Bluetooth, Ethernet and low power support. Its microcontroller was Tensilica 32-bit Single-/Dual-core CPU Xtensa LX6 and the operating voltage was only 3.3V. It also consists 25 digital I/O pins (DIO), 6 analog input pins (ADC) and 2 analog outputs pins (DAC). This development board also have 4MB flash memory, 240 M hz clock speed with IEEE 802.11 b/g/n/e/I of Wi-fimesia access control (M AC). In this system the ESP32 Development Board can be supply at range below than 12V. In this work, one ESP32 Development Board is need on each insole where each of the board is connected with 5 FSR sensors through wiring connection. The FSR sensor needs to connect on ESP 32 Development Board analog to digital converter (ADC) pin in order to read analog reading value

B. Software

Arduino IDE software is used to create the algorithm of the system. All the parameter, formula and flow process of the system need to be set systematically before the system could be operated. The programming code needs to be uploaded first through Arduino IDE to the ESP 32 Development Board before the system could operate. Since the ESP 32 Development support Wi-fi connection in transmit the data, the system become more reliable as the system could track runner foot force distribution reading live based on real time. The insole monitoring system will operate through Blynk Application that can be downloaded on Google Play connected via Wi-fi. Blynk is a platform with iOS and Android apps to control Arduino, Raspberry Pi and the likes over the Internet. It's a digital dashboard where user can build a graphic interface for making project by simply dragging and dropping widgets. Thus, the stable Wi-fi connection is needed to operate the system. All the reading will display live on the Blynk Application.

C. System Design

The system set up must be manage in correct way to ensure the functionality and performance of the insole monitoring system. Point location of runner foot force distribution need to be analyze in order to get proper data based on the impact of the foot during running. The implementation is based on the gait cycle of human walking but in running it will focus on forefoot strike (FFS), mid- foot strike (M FS) and rear foot strike (RFS). Each insole consist of 5 FSR sensor where FSR sensor 1,2 and 3 cover the forefoot strike, FSR sensor 4 cover mid foot strike while FSR sensor 5 cover the rear foot strike. Figure 2 indicates the point configuration of FSR sensor implement on the insole.

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Fig 2 : Point Configuration of FSR Sensor

Table 1 : FSR Sensor Location

No.	Sensor
1.	FSR sensor 1 (Right)
2.	FSR sensor 2 (Right)
3.	FSR sensor 3 (Right)
4.	FSR sensor 4 (Right)
5.	FSR sensor 5 (Right)
6.	FSR sensor 1 (Left)
7.	FSR sensor 2 (Left)
8.	FSR sensor 3 (Left)
9.	FSR sensor 4 (Left)
10.	FSR sensor 5 (Left)

The system uses two type of battery that were 3.7V lithium polymer battery and 9V of alkaline battery for each insole. The 3.7V lithium polymer battery use to supply power on ESP 32 while 9V of alkaline battery use to give power on the FSR sensor. The FSR sensor only needed 5V power supply to operate. Thus, 5V regulator needed to step down the power from 9V to 5V. All the connection will be connected with jumper wire and all components will be assemble together inside a mini box to be attached on the ankle except for FSR sensor.

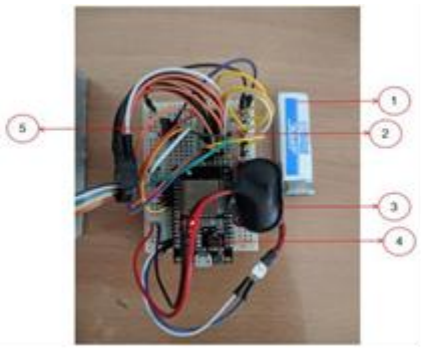


Fig 3 : Component Inside the Mini Box Case

Table 2 : T able of Component

No.	Component
1.	3.7V Lithium Polymer Battery
2.	Resistor 1k ohm
3.	9V Alkaline Battery
4.	ESP 32 Development Board
5.	5V Regulator 7805

D. Experimental Setup

Figure 4 shows the algorithm of the insole monitoring system. The system starts off by connecting the microcontroller which is ESP32 Development Board to the internet via Wi-fi connection. After getting the internet connection, the ESP32 will connect to the Blynk Application server. Once the server connection is online, the application can receive data obtain from the FSR sensor and display it inside the mobile phone. Each insole consists of 5 FSR sensor and connected to one ESP 32 Development Board and each FSR sensor will sense the force based on runner weight at every 0.1 second to the ESP 32.

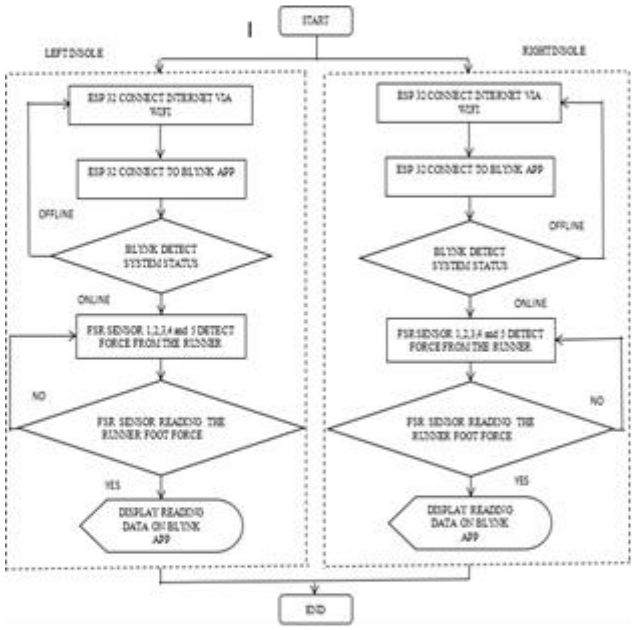


Fig 4 : Algorithm of Insole Monitoring System

The experiment was took place on the open space area. The runner need to take on two type of experiment where the first one was jogging and the second one was running. The experiment will monitor the runner performance on pressure act on the runner foot. The runner need to run and jogging total 5 meter on each experiment to obtain the result. All the system had set up on the runner as shown in Figure 5, 6 and 7.

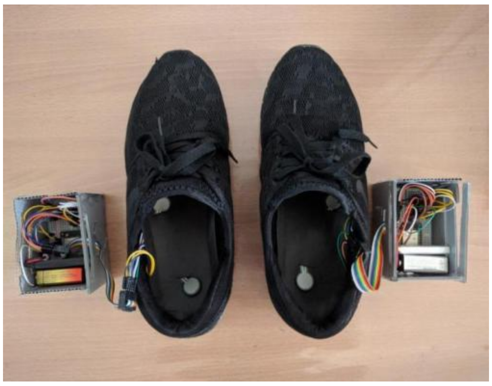


Fig 5 : Insole Monitoring System Set up Inside Both Shoes

Fig 6 : Insole Monitoring System Set up on Runner

Fig 7 : Experiment Set up for Running and Jogging

E. Blynk Application & User Interface

All monitoring data will be obtained in term of graph inside the Blynk Application. Each experiment had total 5 graphs and each graph consist of data on right and left insole. Figure 8 show the interface of Blynk Application on insole monitoring system

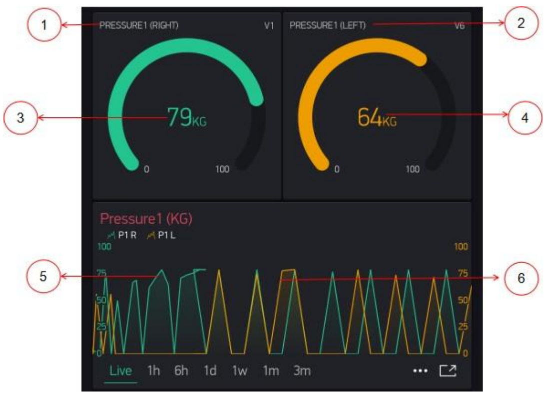


Fig 8 : Design Interface in Blynk Application

Table 3 : Table of Interface Blynk Application Description

No.	Description
1.	FSR sensor 1 (Right Insole)
2.	FSR sensor 1 (Left Insole)
3.	FSR sensor 1 (Right Insole) Gauge Display
4.	FSR sensor 1 (Left Insole) Gauge Display
5.	FSR sensor 1 (Right Insole) Graph Reanding Display (Green)
6.	FSR sensor 1 (Left Insole) Graph Reanding Display (Yellow)

III. MATHEMATICAL MODEL

The data analysis was taken during running. The system maybe varies depend on the type of the shoes use and type of field. Thus, in this paper, the experiment is done on the grassy field with standard sport shoes. All the data taken will be transmits live directly on Blynk Application via Wi-fi. The final data reading is in kilogram. There are some calculations needed to be through after getting the result. The insole monitoring system need to be calibrated first before can be used by using 200-gram weight.

Table 4 : Analog Reading data based on 0.2 kg weight

At-tempt	Analog Reading (Max 4095)								Aver-age
1st	24	32	32	32	32	36	32	21	30.125
2nd	32	21	32	32	32	40	38	32	32.375
3rd	40	38	32	4	32	36	32	26	30

200 gram = 0.2 kg

Average analog reading 0.2 kg = 30.833

Table 4 show the analog reading from the ADC pin based on the weight apply on the center of the FSR sensor. Each weight take three attempt and the value is take based on average of the data. A formula is created in order to get the value in kg. Average analog reading 30.833 was used and take maximum weight of the athlete in Malaysia as maximum value of force distribution reading.

Actual Weight(kg) = analog reading x (χ)
0.2 = 30.833 x (χ)
χ = 6.667 x 10^-3

M ax value analog reading = 4095 M ax weight could be achieved:

M ax weight = max analog reading x (χ)
= 4095 x (6.667 x 10^-3)
= 27.30 kg

To make experimental weight need to make ratio of the weight. Maximum weight of the athlete in Malaysia was 80kg thus the system will read the pressure max at 80 kg.

Assume Y = ratio increasing weight of the system to 80kg

Y = 80 ÷ 27.30
Y = 2.93

Thus,

27.30 x 2.93 = 80 kg (M ax FSR sensor reading-Experimental Weight)

All the data obtain is in unit kg

Experimental weight = Actual Weight x Y

= 0.2 x 2.93
= 0.586kg

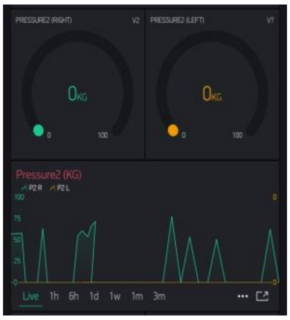
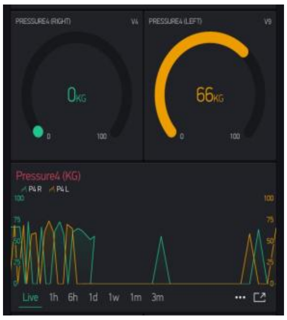
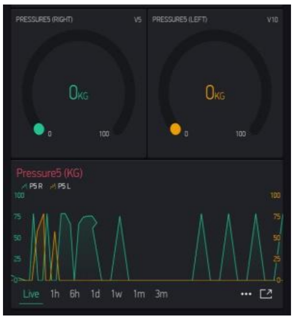
Thus, for actual weight of 0.2kg data is same as experimental weight of 0.586kg in the experiment. The reading of force distribution of system is equal to the experimental weight. Then the error reading was taken after the calculation process. Compare the value of weight get from the insole with the actual runner weight.

IV. RESULTS & DISCUSSION

During the experiment jogging, the graph obtains more data than the running because in experiment 1 run more slowly compare to experiment 2 as the runner need to run. For experiment 2, the data show less as the runner only took a few steps only as the runner only need to run through the 5-meter distance. Based on the both graphs, it can be shown the running or jogging will start with the forefoot strike (FFS) and end with rearfoot strike (RFS) through the experiment process. Furthermore, based on the both experiments, the runner shows different behavior during his running and jogging style. This can be proved through the data obtain on FSR sensor 3 on both experiments. The runner tends to put a lot of force on left side of the foot when running and jogging on point allocated at FSR sensor 3 while the right side of the foot force is maintained below the 50kg. Meanwhile, for pressure act on FSR sensor 2 on experiment 1 show that the runner only exerted more force at right side of the foot while left foot remain lower than 50kg through the experiment. This different behavior act on the foot can cause related to running injury on the foot as time pass by. Thus, create this insole monitoring can help the runner in correct their running style by control the force distribution apply on the foot during running with the data obtain through the system. This system can track user force data lively as long as the runner has stable internet connection when running.

A. Jogging experiment

Table 5 : Jogging result

Jogging	**Figure**
FSR sensor 1	
FSR sensor 2	
FSR sensor 3	
FSR sensor 4	
FSR sensor 5	

Although difficulties and problem exist during the test, the system managed to encounter the problem and obtain the data. The system itself had limitation, the FSR sensor can only sense on certain point. It could get an accurate reading as the force applied on the area of the sensor only. Thus, some error could occur during the experiment process. Another limitation is, the data could be export to the Microsoft Excel, but the result is taken only one reading on average in one minute. Thus, for the future work this can be improve by develop the system own application to improve the data storage on the application.

B. Running experiment

Running	Figure
FSR sensor 1	
FSR sensor 2	
FSR sensor 3	
FSR sensor 4	
FSR sensor 5	

V. CONCLUSION & RECOMMENDATION

As a conclusion, this project has successfully fulfilled the main objective which is to design and develop an insole monitoring system using ESP 32 development board and FSR sensors to detect the force distribution on runner's foot. This system is capable to track and sense the force distribution once the runner applies amount of weight to the point of FSR sensor. Then, the monitoring force data has been obtained based on real time analysis through the interaction of Wi-Fi development board (ESP 32) with Blynk Application. Lastly the development of insole monitoring system was success in integrated style and characteristic of running based on foot force distribution of runner.

This research can be further improved and continued in order to build more efficiency system for the future. There were some issues in wiring system that leads to inconsistence data collected by the system. Thus, it is suggested to use marker circuit with conductive ink instead of using jumper cable. So that, it may improve the system efficiency together with the aesthetic appearance of the insole. Besides, the insole can be improved by adding stepper counter and GPS system to track the runner's steps and track routes for their daily routine training.

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