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A Portable Insole Pressure Mapping System

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Abstract

The human locomotion is studied through gait analysis and is best observed instrumentally rather than observing visually. Thus, a portable insole pressure mapping system is built to assist in studying the human gait cycle. The pressure distribution is determined by instrumentally mapping the insole using force sensitive resistive sensors that are connected to Arduino UNO via cables. The values are saved into a secure digital card that could be post processed. Hardware and software design phase are executed for the development of this project. The outcomes match to the knowledge of human gait definitions in static posture and normal walking.

Keywords: *insole pressure mapping, force sensitive resistive, Arduino Uno, secure digital card*

1. Introduction

Human is naturally gifted with two feet and these feet are essential in many aspects of human life. The foot has permanent exposure with an outer surface, giving assistance and equilibrium when walking [1]. Unfortunately, people nowadays pay less attention towards the wellness of their feet. This is due to wrong walking posture or even wrong footwear thus, resulting in uneven distribution of load towards the feet. Due to this, a portable insole pressure mapping is developed to obtain insole pressure. This insole pressure mapping would describe the gait feature and pressure upon foot. It provides an instrumental guide for posture correction. This project is mainly developing a portable monitoring system by measuring the insole pressure mapping during activities. In conjunction, a portable microcontroller system will be used to observe the pressure distribution of the feet.

Biomechanics is the research regarding the law and purpose such as biological systems of human [2]. Thus research on the feet also falls under biomechanics. The capability of being transported is known as portable. Besides that, insoles are placed within the shoe, under the sole of a foot. It provides arch support and shock absorption for the feet. A graphical presentation of procedure, process structure or any system that has a connection with another component is known as a mapping system.

1.1. The Human Walking

Gait analysis is investigating an individual's motion and the structured research on human locomotion [3]. Gait analysis studies human gait using the right measuring equipments. When a human walks, he/she walks with a specific gait features throughout stance and swing phase. These gait features will be repeated every stride. The movement of legs comprises of the foot reaches the ground on the heel, the foot in full contact with the ground, the foot lifting off the ground with only toes and partially front part having contact with the ground and finally swinging in the air. The forces will be applied to all parts of the foot from front to back. These forces are essential to provide support to the body, withstand the foot impact against the ground

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and enable human to carry out the desired movement. Walking is also a cyclic process, whereby important findings can be obtained during a complete gait cycle.

Walking has completely different feet movement from running. One of the legs will be swinging while another staying put on the ground. Walking with a pair of legs enable human to maintain body balance, stand upright and walk appropriately. The human walking is separated into two phases, which is the stance phase and the swing phase [4]. During the stance phase, the foot will be having contact with the ground, while during the swing phase the foot is in the air swinging to make the next contact. By calculation, the stance phase is about 60% while the swing phase is about 40% out of a stride.

The gait phases and features are detected and analyzed in this project [5]. Heel strike is the first gait feature in walking cycle and it is the first contact to the ground, the contralateral leg will be in a toe off position. These both feet have less amount of contact with the ground. The second gait feature is the loading of the foot on the ground with full contact and another foot starting with the initial swing. The third gait feature is mid-stance of the foot whereby most of the body weight is supported by this foot with full contact and the other foot is in mid-swing position. The fourth feaures is the terminal stance which is also known as heel off which comprises of the whole foot's heel and the fifth gait feature is toe off of the foot whereby only the front part of the heel with the great toe is used. By the time of heel off, the contralateral leg had already landed on ground. The gait feature goes on shifting to another foot [6]. A productive development amid walking is created by the human spine. Ultimately, walking depends on placing the right and left foot frontwards to make a beat rhythm in a relentless musicality manner [7].

2. Research Method

2.1. Positioning of Sensor for Right Foot

First and foremost, only the right foot is chosen mainly due to tight budget constraint. Moreover, it is assumed that the left foot is replicating the right foot. A further project expansion could be easily achieved once the project is proven to be working. The sensors used in this project are the Force Sensitive Resistor (FSR) (Part No. 402, http://interlinkelectronics.com). The sensors are actually a component that turns physical measurement to an electrical output. A number of these sensors will be grouped to determine the scattering of pressure. The force acting upon the sensors will be triggered by putting pressure on the FSR sensors by walking or standing. These sensors are placed in the insole. The positioning of sensors in the insole must be able to map the pressure of foot correctly. Thus these sensors are placed in places of foot whereby the majority of pressure being applied.

Thus it has examined as one of the option to design the positions to place the sensors on the foot region. The FSR sensors are the major component to map the pressure distribution of the foot. The FSR sensors will be placed at the heel, medial and lateral heel, great toe, first metatarsal and fifth metatarsal [8]. Altogether six pieces of FSR sensors will be placed evenly at the mentioned position of the foot as shown in Figure 1.

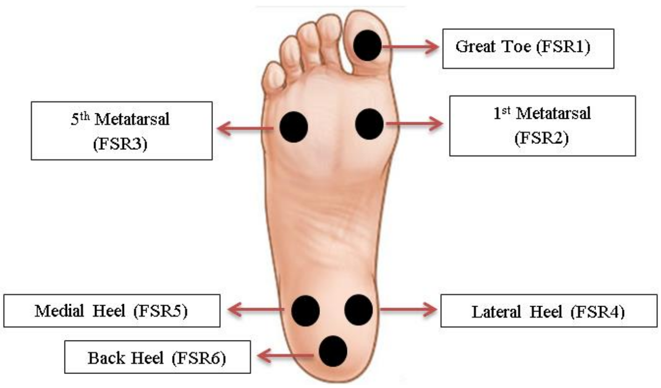


Figure 1. Positioning of The FSR Sensors

Besides that, FSR sensors are a good decision for this project as it is resilient, has a decent amount of thickness for comfort [9] and is easy to be wired. In addition, the sensor is made up of a thin yet robust polymer film. These sensors showcase a reduction in resistance with increment of force when the pressure is applied to the sensor's surface.

The operation whereby the analog signal from the output of the sensor being manipulated is known as signal conditioning. In conjunction, all the sensors should engage in a signal conditioning process first. The outcome from each sensor will be able to be processed and scrutinized. Besides that, there are amplifiers to amplify the signals by reducing or increasing the signal's amplitude. The signal amplification consists of two essential tasks, which are the increment of the input signal's resolution and the signal-to-noise ratio.

2.2. Hardware Design and Assembly

The major hardware items that will be used in building the portable insole pressure mapping system are shown in Figure 2 as followed:

1) Microcontroller (Arduino UNO)
2) Force Sensitive Resistors (FSR)-Part No 402, www.interlinkelectronics.com
3) Operational Amplifiers (LM324)
4) LCD Display (16x2)
5) Secure Digital (SD) Card and Module
6) Switch (Toggle)

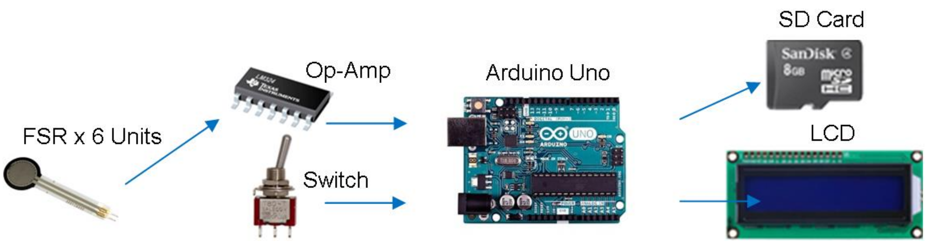


Figure 2. Major Hardware

The circuit diagram is designed using a computer-aided design software, Proteus 8 Professional (www.labcenter.com). The components that are utilized to construct the circuit consist of a switch, SD card, variable resistors, battery, FSR, and LCD display. The LCD display is connected to the digital pins of the Arduino UNO. Moreover, two LM324 operational amplifiers are utilized in this system design to amplify six FSRs and its outputs are connected to analog inputs of the microcontroller. The power source is connected to the step-up converters and the +5V regulators is connected to the step up converter as constant +5V and -5V voltage supplies. The basic connection of FSR to LM324 is shown is Figure 3 which is an inverting op-amp [10]. The final product is shown in Figure 4 which is the Data Acquisition (DAQ) that converts analog waveforms into digital values (ADC) for processing and it consists of sensors, circuitry, and programmed Arduino Uno.

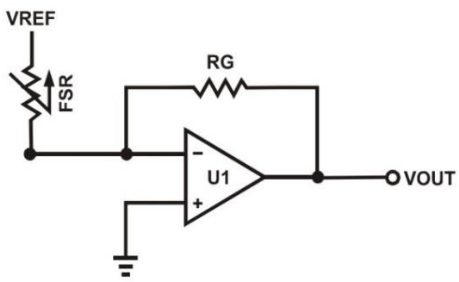


Figure 3. Inverting Op-amp

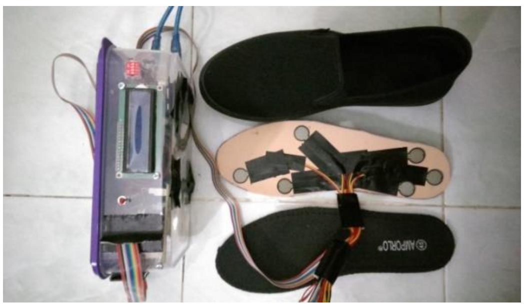


Figure 4. Final Product of DAQ Hardware

The following equations [10] are used to obtain the output gain between 0 – 1 that matches to an output voltage ranging from 0 to +5 Volts. *RG* is set to 100 Ohms. -*VREF is* negative and set at constant -5V.

$$Gain = -\ RG/RFSR \quad (1)$$

The output of the amplifier is explained in the following equation:

$$VOUT = -\ VREF \bullet Gain \quad (2)$$

The sampling rate is 77 samples/sec for this project. The sampling rate is computed by using the equation:

$$Frequency = Number\ of\ samples\ /\ Time \quad (3)$$

Saved ADC data range from 0 to 255. At current stage, it is of high interest to identify the gait phases and features. The ADC data are not converted into any pressure unit.

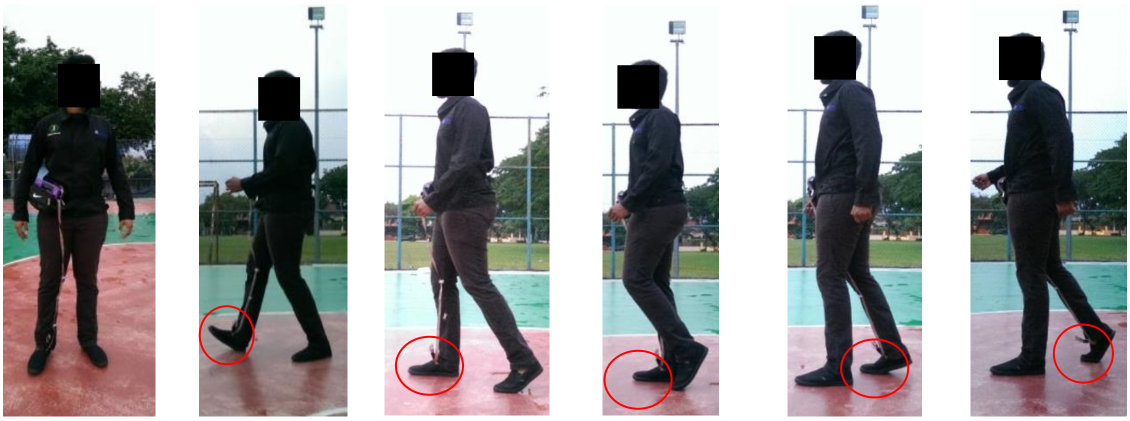
2.3. Software Development

In this project, the programming software (Arduino 1.6.8, www.arduino.cc) is used to create a program, compile, verify and upload the program to the Arduino UNO microcontroller. Proteus 8 is used to design the schematic and board diagram. Besides that, a double layer design circuit is created to connect all the electronic components. Its board diagram is generated and a PCB board is developed accordingly.

3. Results and Analysis

3.1. Static Postures

Static postures comprised of five main gait features that occur in a normal walking of human are trialed for 10 seconds each and are repeated three times. They are Heel strike (HS), loading response (LR), mid-stance (MS), heel off (HO) and toe off (TO). The system is tested on a healthy volunteer. Figure 5 illustrates the mentioned gait features in the right leg.



(a) (b) (c) (d) (e) (f)

Figure 5: (a) System setup, (b) Right-HS, (c) Right-LR, (d) Right-MS, (e) Right-HO, (f) Right-TO

3.2. Heel Strike in Static Posture

Figure 6 shows the feature of heel strike. The medial heel, lateral heel and back heel of the right leg corresponding to FSR 4, FSR 5 and FSR 6, display significant output readings while others are suppressed nearly to zero. Based on the values from the graph, the pressure acting on the FSR 6 (back heel) is the highest followed by FSR 5 (medial heel) and FSR 4 (lateral heel).

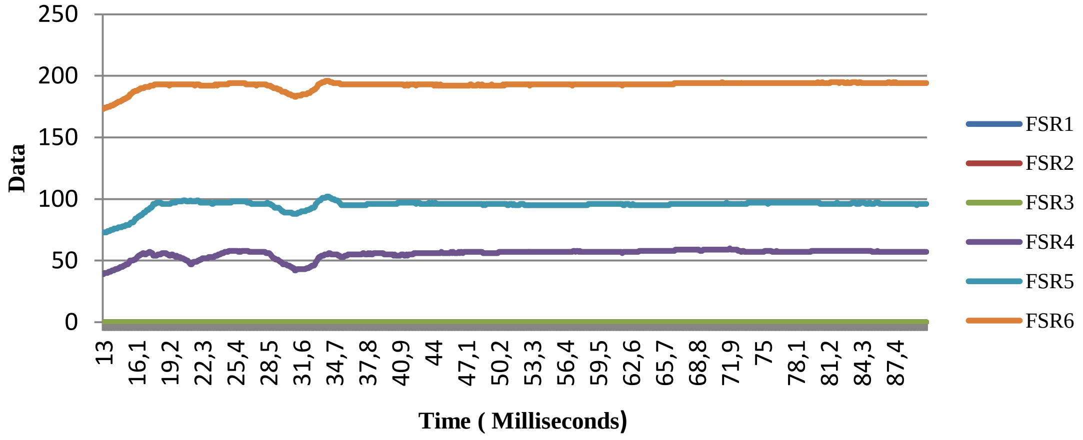


Figure 6. Heel Strike

3.3. Loading Response in Static Posture

Figure 7 portrays the feature of loading response. The great toe, 1st metatarsal. 5th metatarsal, lateral heel, medial heel and the back heel are involved. Based on the obtained graph, pressure acting on FSR 6 (back heel) is the highest followed by FSR 5 (medial heel), FSR 4 (lateral heel), FSR 3 (5th metatarsal) and FSR 1 (great toe). However, reading of FSR 2 (1st metatarsal) is displaying excursion suggesting that the 1st Metatarsal is essential to balance the body.

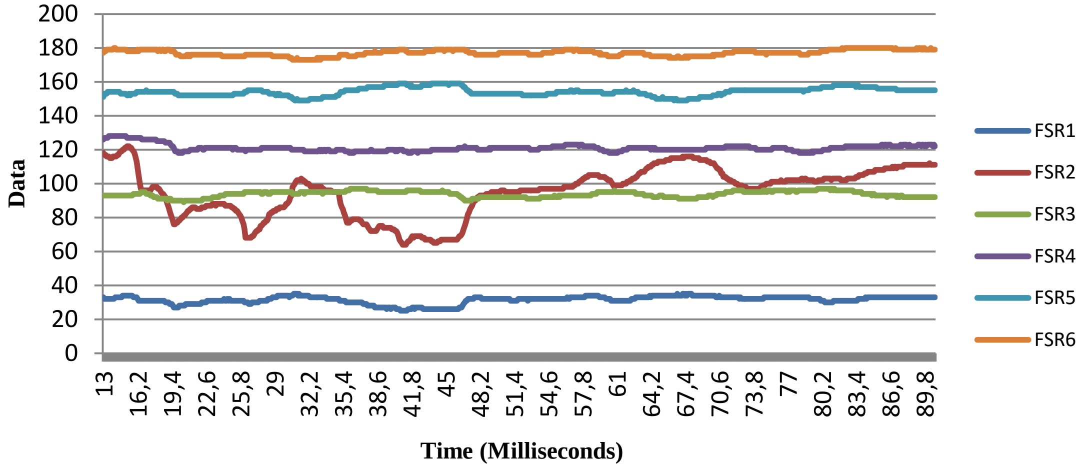


Figure 7. Loading Response

3.4. Mid-Stance in Static Posture

Figure 8 displays the feature of mid-stance. The great toe, 1st metatarsal. 5th metatarsal, lateral heel, medial heel and the back heel are involved. The set of readings obtained are higher than loading response as only the right foot is set on ground while the left in on air swinging forward. It has the same trend as loading response but with a higher amount of pressure exerted on the sensors. The reading of FSR 2 (1st metatarsal) displays significant excursion as the body is balanced on one leg.

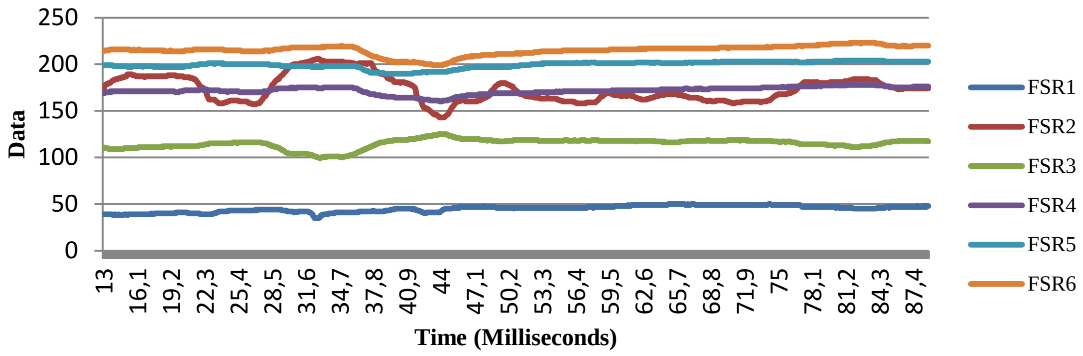


Figure 8. Mid-Stance

3.5. Heel Off in Static Posture

Figure 9 presents the heel off feature. The great toe, 1st metatarsal and 5th metatarsal which consist of FSR 1, 2, and 3, show significant readings while others diminish to near zero. Pressure exerted on FSR 2 (1st metatarsal) has the highest value followed by FSR 3 (5th metatarsal) and FSR 1 (great toe).

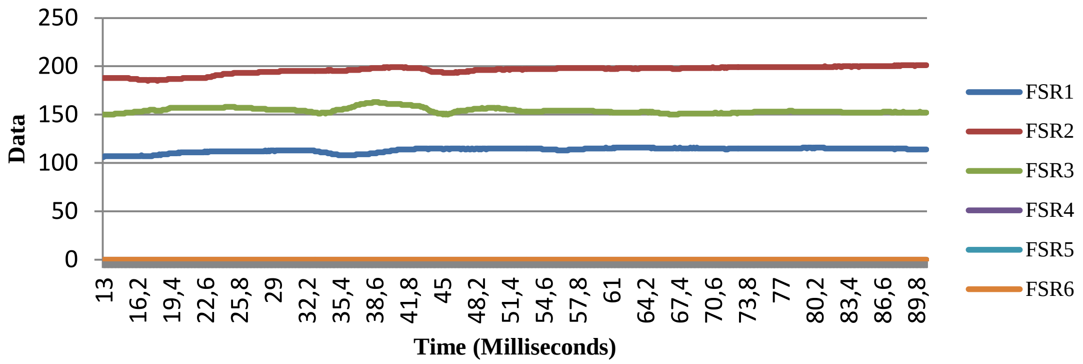


Figure 9. Heel Off

3.6. Toe Off in Static Posture

Figure 10 exhibits the feature of toe off. Only the great toe, 1st metatarsal and 5th metatarsal which is FSR1, 2 and 3 are involved. The pressure acting on FSR 1 (great toe) is highest followed by FSR 2 (1st metatarsal) and FSR 3 (5th metatarsal). As it is toe off phase, higher pressure is exerted on FSR 1 (great toe) compared to heel off.

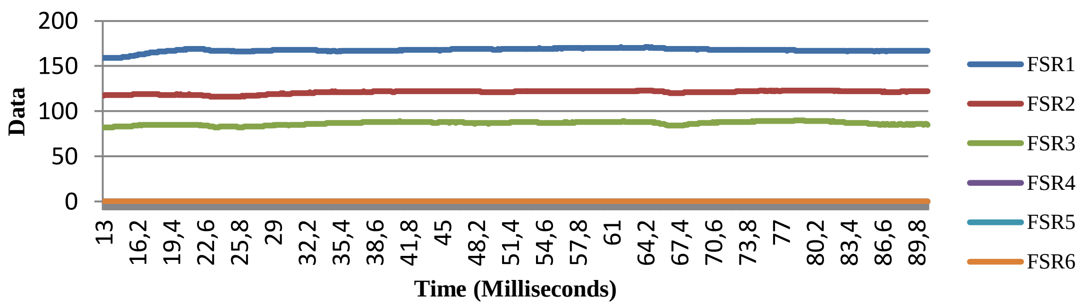


Figure 10. Toe Off

3.7. Normal Gait

Figure 11 shows a part of the graph that consists of all five different gait features of normal walking taken for a period of 30.5 seconds from a healthy volunteer. The graph portrays two main phases of gait cycle which are the stance and the swing phase. Walking cycle starts at stance phase. From Figure 11, Indicator 1 indicates the heel strike gait feature which consists of the lateral heel, medial heel and back heel. This gait feature occurs for a very short period of time and the values of FSR 4, 5 and 6 increases. The walking cycle then enters the loading response phase in Indicator 2 which consists of the great toe, 1st metatarsal, 5th metatarsal, lateral heel, medial heel, and back heel whereby the value of FSR 3 increases. Indicator 3 indicates the mid-stance whereby the whole body balances on one leg thus, all the position as in loading response will be involved but with a higher amount of pressure acting beneath the foot whereby the value of FSR 4, 5 and 6 goes low while the value of FSR 1, 2 and 3 goes high. This is the transition from heel strike to loading response and mid-stance to heel off and toe off.

The cycle enters the heel off phase in Indicator 4 which consists of the great toe, 1st metatarsal and 5th metatarsal only whereby the FSR 4, 5 and 6 are near zero readings while the values of FSR 1, 2 and 3 increases and gradually moves to toe off phase in Indicator 5 whereby the values of FSR 1, 2 and 3 will decrease and end in swing phase. This cycle will repeat in every normal gait. The distributions of pressure acting on the foot is similar to [11], whereby at heel strike phase, the lateral heel, medial heel and back heel are involved; at loading response phase the great toe, 1st metatarsal, 5th metatarsal, lateral heel, medial heel and back heel are involved; at mid-stance phase the involvement is the same as loading response phase; at heel off phase the great toe, 1st metatarsal and 5th metatarsal are involved and lastly the toe off phase that has the same involvement as heel off phase.

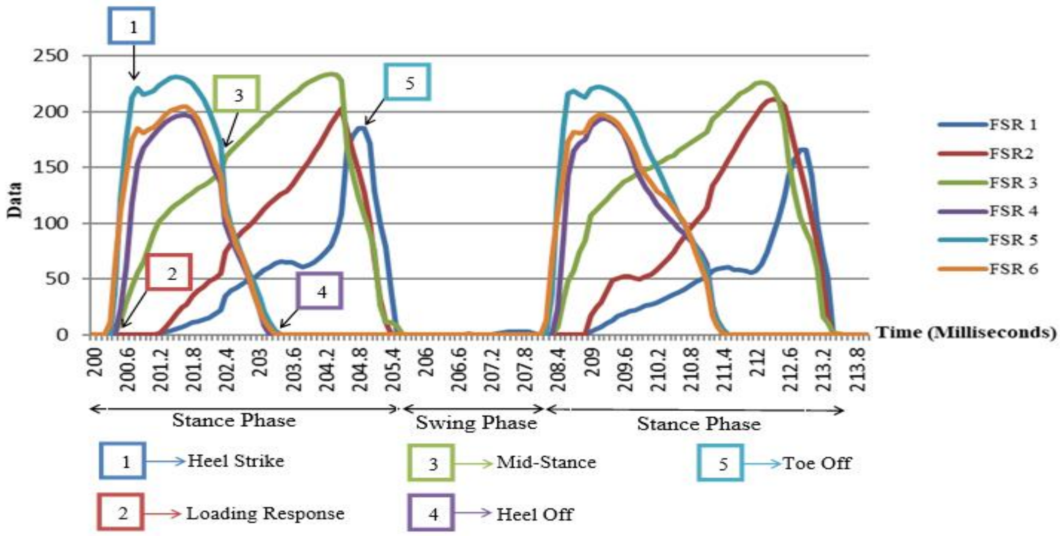


Figure 11. Normal Gait

4. Conclusion

As for a conclusion from the results obtained, the gait features are actually a body movement of swaying or swinging right when using right leg and left when using left leg. In this context, right leg is implemented so the body sways right when moving forward. On the other hand FSR 2 which is located at the 1st metatarsal is suggested to be essential for balancing the body due to its most drastic change of data set among the other sensors. Besides that, FSR 3 (5th metatarsal) and FSR 5 (medial heel) have the highest pressure of all when walking. These two locations can be suggested that it is essential to withstand high pressure. The results suggest that the system could quantitatively reveal insole pressure patterns that match to the knowledge of normal walking. Thus it could be served as an assistive guide during a gait assessment. In future, adding number of FSR could provide more detail on insole pressure.

Acknowledgement

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