A Development of Force Plate for Biomechanics Analysis of Standing and Walking

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Abstract. Force plates are known as an excellent teaching aid to demonstrate the kinematics and dynamics of motion and commonly used in biomechanics laboratories to measure ground forces involved in the motion of human. It is consist of a metal plate with sensors attached to give an electrical output proportional to the force on the plate. Moreover, force plates are useful for examining the kinetic characteristics of an athlete's movement. They provide information about the external forces involved in movement that can aid a coach or sports scientist to quantitatively evaluate the athlete's skill development. In this study, we develop our prototype of force plate with less than $100,- simply by using flexible force transducer attached inside rubber matt, in the form of square blocks (dimension: 250 mm x 150 mm x 10 mm), with maximum load up to 60 kg. The handmade force plate was tested by applying biomechanics analysis for standing and walking. The testing was done on Experimental Soccer Courses' students at the Department of Physical Education, Health and Recreation, University of Cenderawasih. The design of the force plate system together with biomechanics analysis will be discussed.

1. Introduction

The role of science and technology in sports are becoming very important. Over the last 25 years there has been a significant growth in the importance of sports science in assisting, improving, and monitoring athlete preparation, specifically for the Olympic Games [1]. List of Summer Olympic Medals shows countries which has evolved science in sports were those who accomplished highest number of medals [2]. United States, France, Russia, England and Germany were top five, while China, Japan and South Korea were the top three Asia countries in the list. Contrarily, Indonesia is standing in 56th position. Limited development of sports science in Indonesia, both national level and regional level, was the main reason. Therefore, it is important for Indonesia to concern on this issue.

Sport science is concerned with applying the study of movement. The main purpose of sport science is to assist an athlete in maximizing his potential with the least possible risk of injury. The branch of science in sport is biomechanics, which study the forces and their effect on living systems [3]. Force plate, most common tool in biomechanics laboratory, applied the biomechanics principle to demonstrate the kinematics and dynamics of motion by measuring forces involved in the motion of human or animal subjects [4-5]. Force plate also can be used as teaching aid in undergraduate physics classes to demonstrate relationships between force, acceleration, velocity, and displacement [6]. Moreover it is very ideally to be used in physical education or sports science classes in giving illustration and improving the athletes or students performances.

A force plate usually consists of one or more sensors attached in a plat to give an electrical output proportional to the force on the plate. It performs the same function as a bathroom weighing scale, but given different scale. The application of a force plate is to measure the ground reaction force on each foot while standing, walking, running, and jumping [6-8]. For walking process, the force plate recorded that the force rises from zero to a maximum value of about Mg, then drops below Mg, and then rises again to about Mg, then drops to zero, given the force wave form in time function. Using the curve, the reader could analyze magnitude and direction of the horizontal component of the force on each foot, not just walking, but also other process such as standing, jumping, etc.

Unfortunately, commercial force plate systems cost more than \$20.000 which mean very expensive for universities and sports scientist in developing region like Papua. Interestingly, a group from University of Sidney [6] developed their force plate by using five piezoelectric sensor made from PZT ceramic, with total cost approximately \$100. By using 4 piezo-sensors, they developed a homemade force plate which can provide vertical component ground force data that is similar in quality to commercial versions. In this paper, we describe the new construction of force plate, with total cost less than \$50. The detail of the construction together with the application for standing and walking analysis will be given in the next section.

2. Design and Construction

Our developed prototype of force plate is simply a rubber plate with one sensor attached in the bottom to give an electrical output proportional to the force on the plate. The dimension of the plate is 250 mm × 150 mm × 10 mm, about 50% smaller than the commercial ones but still sufficient to locate two feet on the plate. Instead of piezo disks sensor [6], we used flexy-force pressure sensor from TEKSCAN which connected to the interface based on chip microcontroller ATmega 328. This configuration generated an output voltage of 50 mV per Newton. Other advantages of the prototype are flexible, light, and portable for outdoor usage. Hard and solid ceramic used as the home base of the whole systems to reduce external distortion that might interfered the measurement. Figure 1 shows the schematic and the real image of the prototype of force plate.

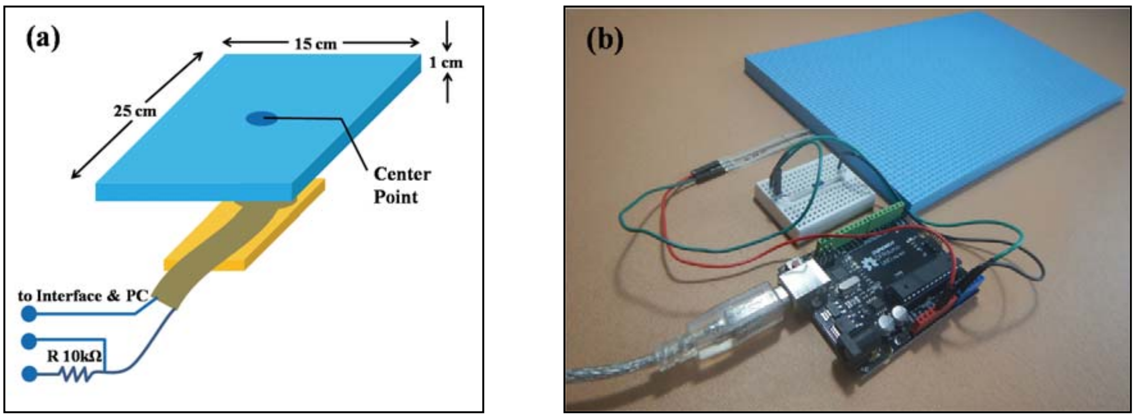

Figure 1. The prototype of force plate: (a) schematic and (b) real images.

The developed prototype was testing on Experimental Soccer Courses' students at the Department of Physical Education, Health and Recreation, University of Cenderawasih. A student with a body weight of 60 kg was performed standing and walking motion on the plate. In the next section the biomechanics analysis for standing and walking will be described.

3. Biomechanics Analysis

A gravitational force on a body is a certain type of pull that is directed toward a second body [9]. Suppose a body of mass m is in free fall with the free-fall acceleration of magnitude g. If we neglect the effects of the air, and place a vertical y axis along the body's path with the positive direction upward, then the Newton's second law can be written in the form F_g (or F_y in $-y$ direction):

$$-F_g = M(-g) \tag{1}$$

or

$$F_y = Mg \tag{2}$$

Walking or running analysis is ideally suited for a class of physical education or sports science students. It illustrates some interesting aspects of elementary biomechanics. When a person is walking or running at constant speed, no horizontal force is required. The main retarding force arises from the front foot pushes forwards on the ground, resulting in an impulse that is equal and opposite the impulse generated when the back foot pushes backwards. If a person stands with both feet on a force plate, the vertical direction will register $F = Mg$. But, when a person bending the knees, therefore the centre of mass is lowered, resulted force decreases and then increases before settling back to Mg. Figure 2 shows the wave form observed when a person steps onto the force plate, then stands up straight, then steps off the force plate. The saturated force in time history from 3 s up to 4 s shows the person stands up straight in balance position.

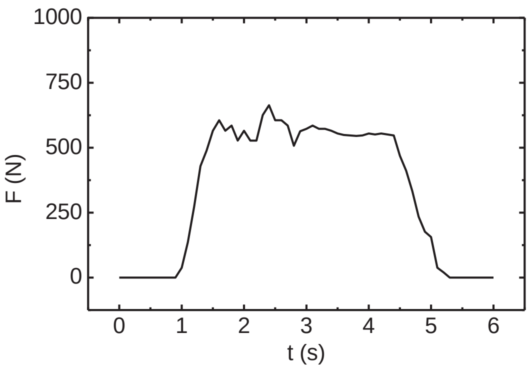

Figure 2. The wave form observed when standing with both feet on a force plate.

The force wave form can be interpreted in terms of the vertical motion of the centre mass [6]. The vertical component of the force acting on one foot when walking on the force plate is shown in Fig. 4. The horizontal component was not measured with our prototype, due to its limitation. The vertical force wave form observed from slow-walking, has two distinct peaks similar like the previous version [6]. Both peaks are similar in amplitude. The force rises from zero as weight is transferred from the back to the front foot, and returns to zero when weight is transferred back to the other foot at the end of the stride. However, it is hardly to distinguish two peaks from fast-walking wave form. Improvement of sensitivity, specifically for short periods, is needed in our machine.

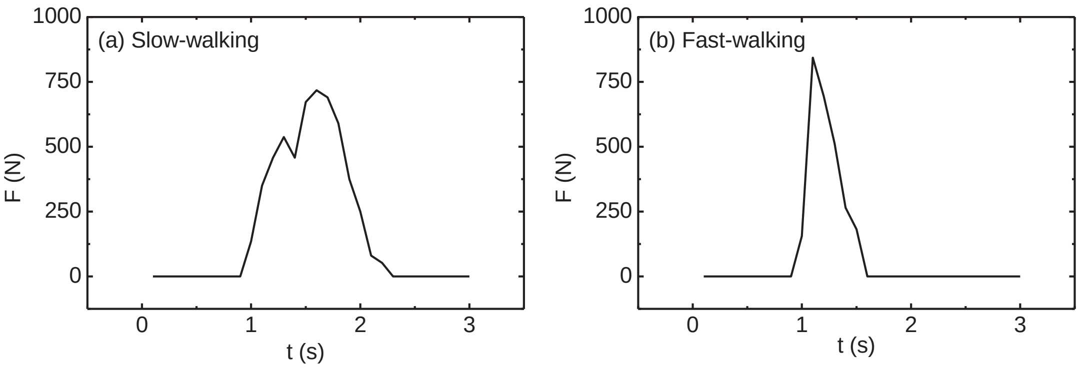

Figure 3. The wave form observed when (a) slow-walking and (b) fast-walking on a force plate.

4. Conclusion

It has been shown that a new and low cost budget of force plate can be constructed to provide vertical component forces data that is similar in quality to commercial version. Such a plate can be used as an aid in teaching experimental courses in physics education or sports science classes. Our first prototype of the force plate was able to give quantitative experiments in standing and running. For future works, improvement in sensitivity and sensors configuration may able to increased the quality of the plate and expand its application in running and jumping analysis.

Acknowledgments

This work is supported by grant Bantuan Operasional Perguruan Tinggi Negeri (BOPTN) in the scheme of Penelitian Dosen Muda Universitas Cenderawasih of year 2015.

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