

Development of force plate for prosthetic applications interfacing with internet of things

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Abstract

Force Plate is a measuring instrument which is used to calibrate the ground reaction force in gait cycle analysis of a subject (human or animal). Force plates are used to examine the lower limb kinematics for the applications of prosthetics, sports etc. In this study, a prototype of force plate is developed indigenously in an economical manner. It comprises of two metallic frames with a load cell (force transducer) mounted between them to produce an electrical signal as output, that is proportional to the amount of force applied on the surface of force plate. This prototype has a maximum load capacity of 3000N. The design of the force plate system along with the ground reaction force analysis and results are discussed below.

Keywords: Force Plate; Gait Cycle; Internet of Things; Load Cell

1. Introduction

Prosthetics are used as a replacement for the body limbs, which may be affected due to disease or accidents. They are intended to restore the functionality of the missing body part. A person who undergoes transfemoral amputation is subjected to consume more than 80% of the energy to walk when compared to a normal person. Prosthetics are designed to make the transfemoral amputee feel more likely as a normal person when he walks, runs or stands. Advancements in the field of prosthetics is so crucial to better enhance features for a transfemoral amputee. Data required to develop a prosthetic limb is obtained using gait analysis technique.

The gait cycle is defined as the pattern of series of footsteps that is being exhibited by the subject (human or animal) at particular speeds. Gait analysis is a systematic analysis of locomotion which is used for pretreatment assessment, surgical decision making, post-operative follow-up and management of patients[1]. Basically, the gait cycle is of two phases, i.e. stance phase and swing phase[2]. Stance phase can be defined as the phase in which the foot is in contact with the ground. Swing phase is defined as the phase in which the foot is not in contact with the ground. Figure 1 shows various phases of Gait Cycle.

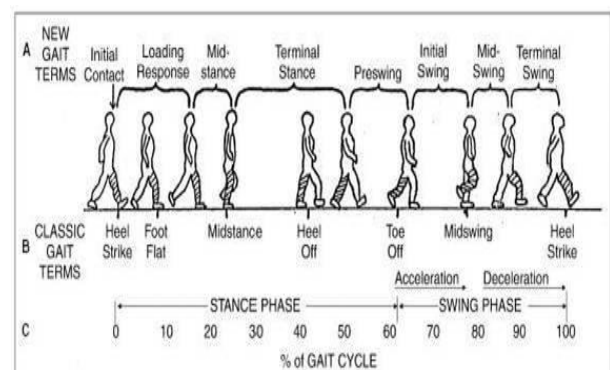


Fig. 1: Phases of Gait Cycle [3].

Force plate is employed in this present study to calibrate the ground reaction force during the Stance phase. Force plate is a commonly used tool in biomechanics laboratory. The biomechanics principles were applied to demonstrate the kinematics and dynamics of motion of a subject (human or animal subjects) by measuring forces involved in its motion[4]. Force plates are also used for teaching aid to demonstrate relationships between displacement, velocity, acceleration, and force[5]. A force plate is made of an electrical sensor that is fixed on a platform, which generates an electrical output proportional to the applied input force. T. Liu[6] has developed a mobile force plate and 3D motion analysis system (M3D) by integrating small tri-axial force sensors and 3D inertial sensors for estimating multi-axial GRF and orientations of feet during successive gait movements, to the clinical applications. S Wardoyo[7] has designed a force plate by using flexible force transducer attached inside rubber mat, in the form of square blocks, for the calibration of vertical ground reaction force while standing and walking Biomechanics laboratory. Rod Cross[5] has developed a force plate using two parallel aluminium plates with four piezoelectric elements embedded

on the plate, one in each corner, for each for the calibration of vertical ground reaction force while standing, walking, running and jumping.

2. Design and modeling

In order to design, model and construction of the frames, it is extremely important to first understand the structural requirements. They were listed as load bearing capacity, deformation or bending, durability, etc. These factors mainly rely on the material selection. Material selection has a greater impact on the structural strength and durability. The other major factors that are to be taken into consideration while selecting a material were its Mechanical properties and its cost. Figures 2 and 3 are the virtual 3D model of the prototype.

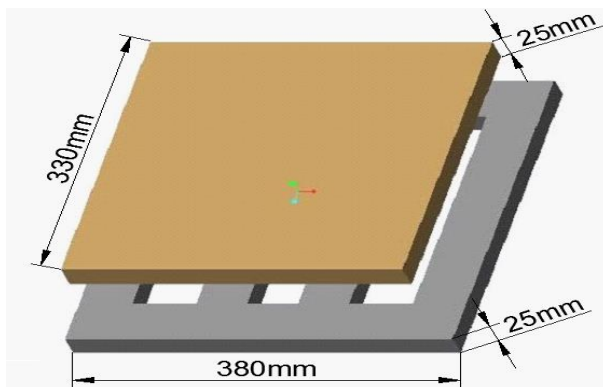


Fig. 2: Virtual 3D Model of the Force Plate.

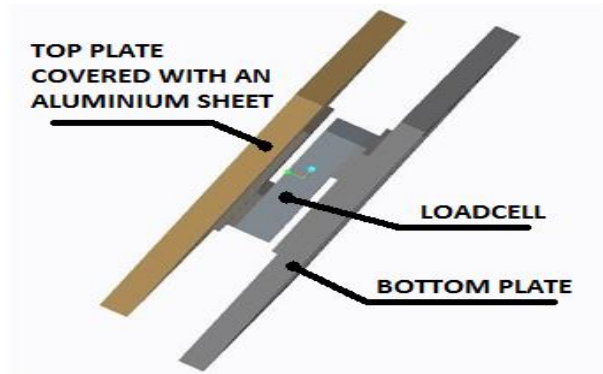


Fig. 3: Virtual 3D Model of Side View of Force Plate.

3. Virtual analysis

The virtual 3D model of the force plate was analysed using Ansys software. A load of 300 kg is applied on the top surface of the force plate and deformation of the plate was observed. Figures 4 and 5 shows the results of a virtual 3D model of force plate analysed in Ansys.

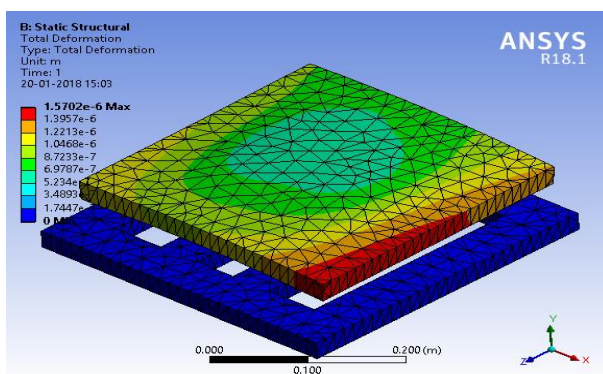


Fig. 4: Deformation Results of Force Plate in Ansys.

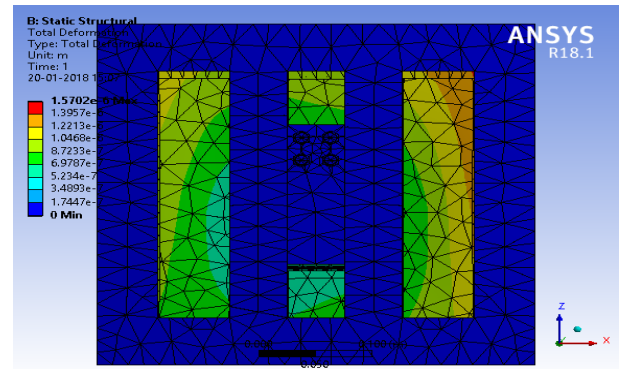


Fig. 5: Deformation results of force plate in ansys.

4. Fabrication

The force plate is composed of two frames, an amplifier, a data acquisition board and an output device, as exhibited in figure 6.

The prototype of force plate is designed with a load sensor attached in between the two frames to derive an electrical output which is proportional to the force applied on the plate. Figure 9 shows a real-time picture of the force plate. The force plate is constructed with two plates and a load cell is mounted in between them. The dimension of the top frame is : 330 mm x 330 mm x 25 mm, the dimension of the bottom frame is: 380 mm x 380 mm x 25 mm. The construction is smaller when compared to the commercially available product in the present market, however it is sufficient to place two feet comfortably on the plate. The top plate in the prototype is covered with an aluminium sheet to create a platform which allows the subject to walk, stand or jump. In this prototype, a strain gauge load cell is used to calibrate the vertical ground reaction force which will be detailed in the discussion section. Figure 7 is a picture of the load cell.

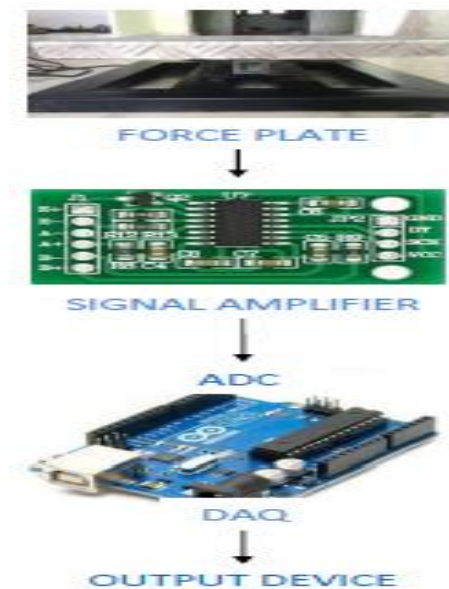


Fig. 6: Schematic Diagram of Force Plate.



Fig. 7: Load Cell.

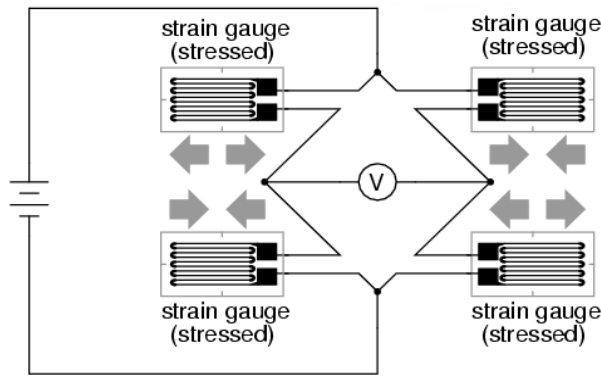


Fig. 8: Wheatstone Bridge Configuration of Strain Gauges in the Load Cell.

The output signal from the strain gauge load cell is in the order of millivolts, so an HX711 amplifier module is used to amplify the output signal. This amplifier module is interfaced with Arduino Uno microcontroller for the calibration of the ground reaction force. Figure 10 shows the real-time picture of the Arduino and HX711 circuit.



Fig. 9: Prototype of the Force Plate.

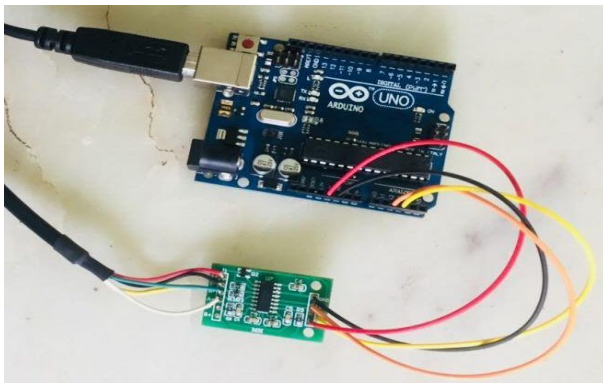


Fig. 10: Arduino and HX711 Circuit.

5. Computational analysis

Body weight of a subject is because of gravitational force applied by the Earth. Consider a subject with a body mass m which is subjected to free fall from certain height in earth's gravity (g), then by neglecting the effect of air friction the force (F) is given as the product of mass and acceleration due to gravity.

When a person stands on a force plate, the ground reaction force will be registered as $F = Mg$. But, when a person bending his knees, therefore the center of his mass will be lowered and resulting force decreases which then increases the force before settling back to Mg [5] [7] [8]. The prototype was tested on a healthy person of body weight 75 kg who performed walking and standing on the plate. The platform of the force plate is set to ground level by placing it into a pit and then the results are analyzed. This force platform can only show the vertical ground reaction force due to its limitations. Figure 11 is the graph observed when a person stepped onto the force plate,

bent his knee, stands straight for a while and then steps off the force plate.

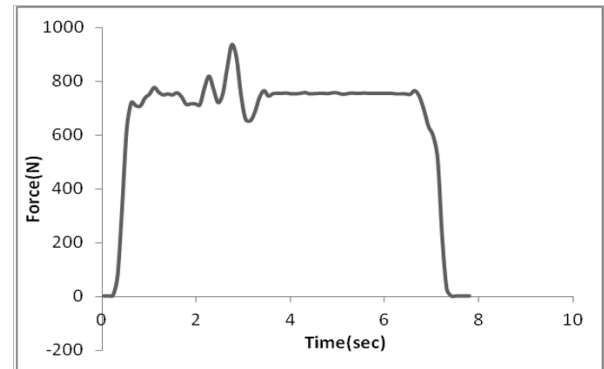


Fig. 11: Waveform Obtained when Subject Is Standing on Force Plate.

The force applied on the ground while walking depends on various factors like body mass, speed, velocity and displacement of the center of gravity of the subject. If the subject travels at low speed, then the resultant ground reaction force will be low and then in vice versa. Figures 12 and 13 are the graphs observed when the person walk on the force plate with low and high speeds respectively. The force acting on the ground while jumping is due to the acceleration due to gravity (g), body mass of the subject, and the height jumped by the subject. Figure 14 shows the graphs observed when the person jumps on the force plate.

6. IOT and cloud computing techniques

The data obtained from the force plate analysis has been recorded and is stored in the cloud using IOT (Internet of Things) technology. We collect the data from the Arduino board and the data is being linked to cloud with the help of the Internet. This data has been stored in a dedicated cloud server. Figure 15 shows the architecture of IOT [9].

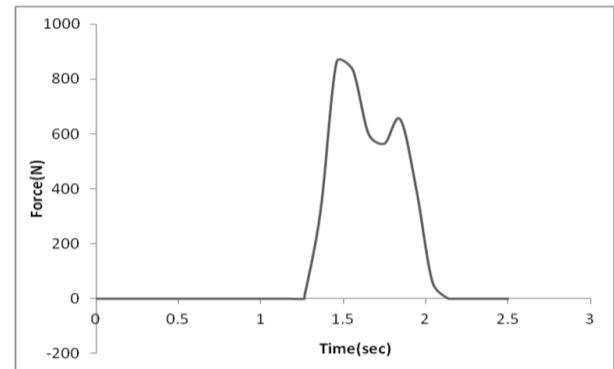


Fig. 12: Waveform Observed when Subject Is Walking at Low Speed on the Force Plate.

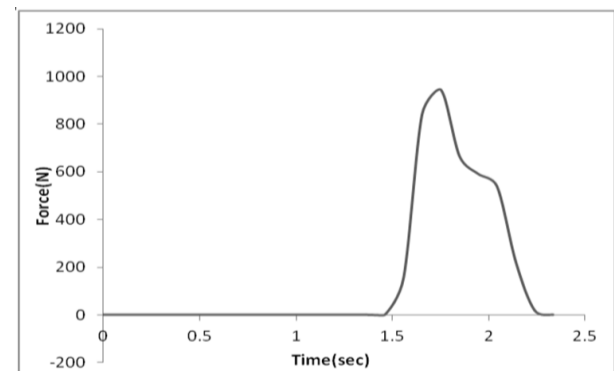


Fig. 13: Waveform Observed when Subject Is Walking at A Greater Speed on the Force Plate.

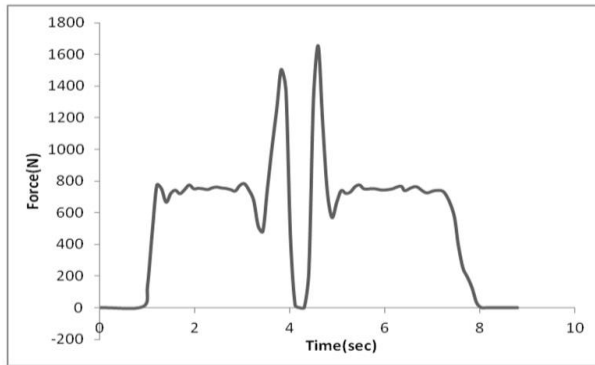


Fig. 14: Waveform Observed when Subject Jumped on the Force Plate.

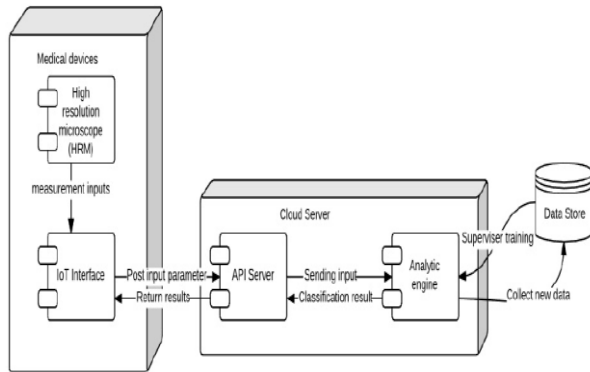


Fig. 15: Iot Architecture.

When the users, across the world needs to select appropriate prosthetics, taking his body mass and sizes into consideration, exact prosthetics will be chosen with the help of the data that has been incorporated in the cloud server using data analytics and Backpropagation algorithm concepts from Neural Networks Technology. This made the computation time much easier and led the user to select the prosthetics according to their needs and requirements.

7. Conclusion

The working principle of the strain gauge load cell is similar to the working principle of the strain gauge [10]. A strain gauge is a sensor which shows a change in electric resistance for an applied force, tension, pressure, and weight. In a strain gauge load cell there are four strain gauges which are arranged in a Wheatstone bridge configuration as shown in figure 8.

Arduino is an inexpensive open-source and comes with free authoring software [2] [7]. Its software/hardware is accessible and very pliant to be customized and extended. It can adapt to digital and analog inputs, SPI and serial interface and digital and PWM outputs. It can communicate using standard serial protocol and can be connected to pc via USB.

Force plate analysis procedure has been designed and constructed to provide vertical ground reaction force data that is similar in quality to commercial version indigenously with both Economical and Ergonomic means. Such a force plate technique can be used for sports, prosthetics and educational purpose for analysis of vertical ground reaction force with respect to time. Low cost of the force plate design results in a decrease of capital for the prosthetics and gives better results.

Acknowledgement

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