Team 12 (RRKKT)
Design for the Human Body
13 November 2019

Foot Load Sensors

Biomechanics:

Our device will interface with the body as a wearable. It is designed as a sock that can be worn inside the shoe and has two sensors: one placed on the ball of the foot and one on the heel. The varying pressures at different stages of the gait cycle will be recorded from two separate places on the foot. The data can then be analyzed to see the loading locally on the foot and therefore extrapolate how weight is distributed throughout the body.

The foot and ankle play a significant role in weight bearing and walking. The foot is the only point in contact with the ground and the ankle supports the weight of the rest of the body.

Ankle:

The joint most impacted by our design is the ankle. The tibia and fibula bones of the leg are connected to the talus bones of the foot. It functions as a hinge joint that allows for plantar flexion and dorsiflexion of the foot joint. Plantar flexion is pointing the foot away from the body and dorsiflexion is pulling the foot up towards the body. The main muscles involved in pulling about the ankle are the posterior muscles (gastrocnemius, soleus, plantaris, and posterior tibialis), which allow for plantar flexion. Anterior muscles (tibialis anterior, extensor hallucis longus and extensor digitorum longus) control dorsiflexion. There are two main ligament groups in the ankle joint: the medial ligaments and the lateral ligaments.

Foot:

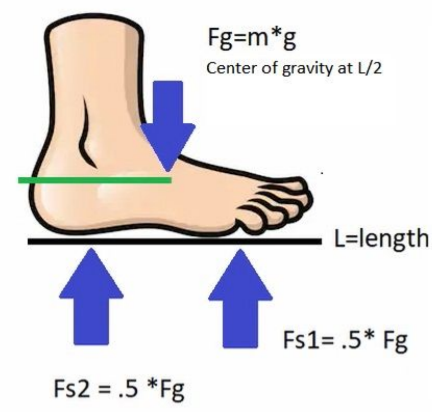
The other joint impacted by the design is the metatarsophalangeal joint of the big toe. This is the ball of the foot. Muscles in the foot such as extensors and flexors work together to stabilize and raise the foot – these will also be impacted by sensor placement as these are used in the gait cycle.

Mechanism:

Our design focuses on readings from two points in the foot, the ball of the foot and heel. These points were chosen because it is where most of the weight of the body is distributed. According to an article, *Pressure Distribution under Symptom-Free Feet during Barefoot Standing*, by Peter R Cavanaugh their study found that “load distribution analysis showed that the heel carried 60%, the midfoot 8%, and the forefoot 28% of the weight bearing load.” In our design, an insert will be placed between the foot and shoe sole. This will affect how the foot naturally rests against the shoe and floor. With an additional height, the foot will not rest naturally at 90 degrees as it would if one were standing on the floor with no support. According to Allen Anderson in his article “Sports Medicine, Anatomy Ankle,” with increasing plantar flexion, the bony constraints are decreased, and the ligaments are more susceptible to strain and injury. So in our design, we need to be sure that when the insert is in use, the ankle does not rest at an angle significantly above 90 degrees. Additionally, we will be placing an Arduino on the user’s ankle, which marginally increases weight.

Joint Forces/Approximations:

Free Body Diagram with Static Loading



In this FBD, we assuming that there are two major stability points of the foot: the heel and ball. We placed our sensors at these two points; assuming the static loading forces will be concentrated at these areas.

Assuming the average mass of the person is 55.0kg, the force of gravity is m*g.

Fg=55.0kg*9.8m/s^2 = 539N

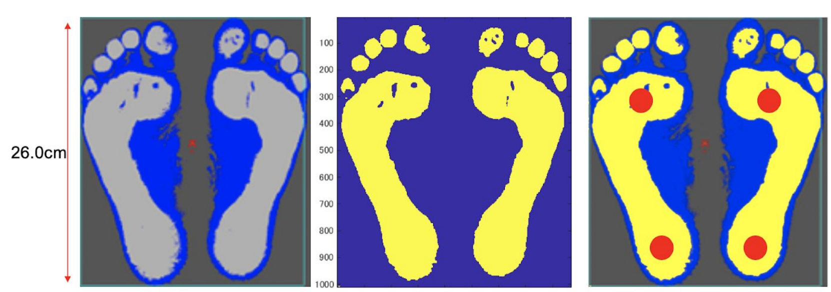
Assuming there is an equal distribution of static loading between the two sensors,

Fs1 = Fs2 = .5*Fg
Fs1 = Fs2 = .5*539N = 269.5N

We know the assumptions of equal and concentrated force distribution is not entirely representative of the real forces acting on the foot. There is an unequal force distribution that acts on all points of the foot in contact with the ground. We needed to place our sensors in areas that these forces are mostly concentrated at and find the load distribution at these points to see if they are in fact equal during static loading and walking. Below we take another approach in the force analysis by looking at the pressure distribution across the foot during static loading.

The normal force acts on the contact area of both feet. We estimated how much force acts on each force sensor under a normal standing condition. For simplification, we hypothesized that the pressure distribution of the contact area is uniform.

Figure1. Foot area estimation

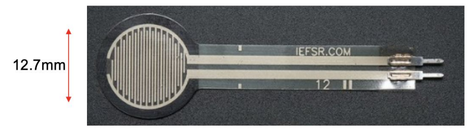


Original | Foot area | Merged (Red balls are sensors)

The contact area can be calculated using the image to the right.

- Body weight: $M = 55.0\ kg$
- Foot contact area: $S = 2.11 \times 10^{-2}\ m^2$
- Sensor's diameter: $D = 12.7\ mm$
- Sensor's active area: $s = 1.27 \times 10^{-4}\ m^2$
- Gravity acceleration: $g = 9.81\ m/s^2$

Figure2. Force sensor



Given that the body load is distributed equally onto the contact area, the pressure P can be calculated as follows.

$$P = Mg/S = 2.55 \times 10^4\ [Pa]$$

Therefore the magnitude of force that acts on each foot sensors is

$$F = P \times s = 3.24\ [N]$$

During the gait cycle, the magnitude of force acting on one sensor varies according to the change of the contact area on the sensor. As the force sensitivity range of this sensor is 0.1N~100N, this base value is suitable for measuring a wide range of values during the gait cycle.

Concerns with Modifying Loads:

Some potential modified loads include standing on one leg, lifting weight, standing on tiptoes (plantar flexion), or rocking back and forth. The major concern is the weight capacity of the sensors. Overloading may give erroneous data. The next concern is that only two sensors may not be enough to account for all of the changing forces.

Low-fidelity Prototype:

Our prototype was made by stitching together pieces of fabric to make a sock and then adding on cardboard sensors and small wires attached to a modeled Arduino and battery. This prototype is a "looks-like" version to demonstrate how our device will interface with the user.

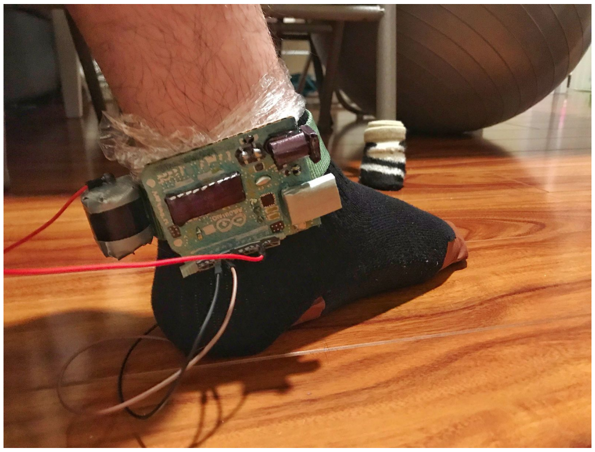


Fig. 3: Back view

Fig. 4: Left side view

Fig. 5: Right side view

Fig. 6: Normal activity while wearing prototype

Fig. 7: Bottom view

Comments by client:

Our client pointed out that the dimensions on our prototype did not necessarily reflect those of the pressure sensors, so we incorporated that feedback into our modified design. Additionally, we will look into more robust sensors that can sustain weights above what we are currently able to find. We have attached the Arduino onto the sock prototype and have tested comfort levels for the user.

Brief Testing:

When testing our prototype, we noticed that the sock itself may not necessarily fit all users. As a result, it was tight around the stitching. However, the wires, sensors and Arduino were almost imperceptible, and the overall design was comfortable (disregarding size of sock). The only concern is the wires may get caught on something, which would hinder device performance. It was commented by a tester as comfortable enough to wear for an extended period of time, while the tester wore the prototype and performed normal household tasks without noted discomfort (Fig. 6). Moving forward, the size and lack of elasticity as well as the placement of wires will be taken into account.

REFERENCES

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5. Cavanagh, Peter & Rodgers, Mary & Iiboshi, Akira. (1987). Pressure Distribution under Symptom-Free Feet during Barefoot Standing. Foot & ankle. 7. 262-76. 10.1177/107110078700700502.