Biomedical devices research paper

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1 The Team

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2 The Problem

Over time, wrong posture and foot placement can lead to adverse health effects. Foot biomechanics play a critical role in overall health and performance. The ability to accurately measure the pressure distribution and gait pattern provides valuable insight into both clinical and athletic contexts. Traditionally, foot assessments rely on static observations, subjective gait analysis, or external pressure plates that can be limited in accuracy and convenience. An insole embedded with pressure and motion sensors can address these limitations by offering real-time, dynamic data collection directly from the user's footwear.

From a medical standpoint, pressure-mapping insoles can aid in diagnosing and managing a variety of conditions. For example, diabetic patients often suffer from peripheral neuropathy which can cause a loss of sensation. This can lead to unnoticed pressure points that can develop into ulcers. By visualizing high-pressure zones, clinicians can intervene early to prevent complications. Similarly, abnormalities in gait and load distribution may indicate neurological disorders, such as Parkinson's Disease or Multiple Sclerosis, where early detection through subtle changes in walking patterns is crucial for timely management.

For athletes, real-time feedback on foot pressure and gait mechanics is a powerful tool for performance optimization and injury prevention. Runners, for instance, can analyze their pronation, arch support, and impact forces to adjust their technique and reduce the risk of stress facture. In sports like soccer or basketball, where rapid changes in direction and load are frequent, monitoring pressure distribution can help tailor training programs and footwear to enhance agility and reduce strain on joints and muscles.

By integrating sensor technology into a user friendly insole, this system bridges the gap between clinical diagnostics and athletic performance enhancement, making biomechanical data accessible outside specialized laboratories.

3 Medical Background

3.1 Gait Cycle

When a person walks, pressure distribution under the foot follows a characteristic pattern referred to as the gait cycle. The gait cycle begins with the heel bone making the initial contact with the ground. During this phase, pressure is predominantly concentration on the heel, absorbing much of the impact force. As the foot flattens, the pressure transitions anteriorly and medially across the mid foot. The arch also bears weight with the plantar fascia, helping to manage load distribution. As the body moves forward, pressure localizes to the metatarsal heads, especially under the first and second metatarsal heads. This phase is critical for propulsion. Finally, pressure shifts to the distal phalanges, particularly the first metatarsal head, as the foot pushes of the ground to initiate walking, or the swing phase.

3.2 Pronation

In individuals with overpronation, the arch collapses excessively during the midstance. This results in a higher concentration of pressure along the medial midfoot. Overtime, this can contribute to pathologies such as plantar fasciitis. Individuals with supination, or underpronation, exhibit a reduced medial shift of pressure, keeping loads predominately on the lateral aspect of the foot, including the fifth metatarsal head. This abnormal loading increases the risk of lateral ankle sprains, stress fractures of the fifth metatarsal, and peroneal tendinopathy. In patients with pes planus, or flat foot, the collapse of the arch leads to increased pressure in the midfoot and reduced effectiveness of the foot's natural shock absorption mechanism. This can cause compensatory pressure increases in the forefoot, particularly under the first and second metatarsal heads. Pes cavus, or high arch, results in poor shock absorption due to a rigid, elevated arch. This leads to excessive plantar pressures localized to the heel and forefoot, making patients susceptible to calluses and stress injuries. In patients with peripheral neuropathy, they experience sensory deficits and impaired proprioception, resulting in abnormal loading patterns and prolonged pressure in the forefoot, especially under the metatarsal heads. This predisposes patient to diabetic foot ulcers, particularly in regions of sustained high plantar pressure.

4 Existing solutions

4.1 Products on the market

Various companies offer foot scanning solutions, but they often have limitations. FleetFeet provides in-store scanning services to recommend footwear, while Aetrex and Tekscan offer advanced analysis tools that are costly and primarily targeted toward research or professional use. Nike and Adidas incorporate similar technologies for elite athletes, but their solutions are not widely accessible.

Tekscan's F-Scan GO and F-Scan64 systems provide advanced gait analysis with high-frequency data capture. However, these products are designed for clinical and research applications rather than everyday users, making them expensive and less accessible.

- tekscan is a company that makes a similar product
- Their flagship product costs from 5000 to 10000
- Their other product is more similar to ours

5 The Solution

Based on the injury, the way they walk as they are getting rehabilitated can change. If they're walking in a wrong way, this can be counterproductive.

We aim to fix this by tracking the exact movements of a foot, and providing potential corrections to the user's gait.

Unlike existing solutions, Happy Feet is designed for everyday individuals who want to monitor their walking habits and improve foot health. By making foot pressure analysis affordable and user-friendly, the product empowers users to take proactive steps in preventing injuries and optimizing comfort.

The insole is designed with strategically placed sensors to track foot pressure, weight distribution, and walking angles. Lightweight and flexible wiring ensures comfort while transmitting data to a small chip embedded in the insole. This chip collects information and sends it to the mobile app, providing users with real-time gait analysis and actionable insights.

6 Fabrication

6.1 Cost

The estimated cost includes force sensors ($48 total), a genaric shoe insole (price), a gyroscope ($6.99), a flex sensor ($10), and an Arduino Uno microcontroller ($30). These components ensure a low-cost, yet high-quality product for users.

6.2 Assembly

The current working prototype is a generic shoe insole slid into a fabric sleeve with 4 pockets on the top and a pocket on the bottom. Each pocket on the top of the insole corresponds to a force sensor, there is a pocket at the heel, the lateral side of the foot, the ball, and the big toe. These four sensor locations were selected based on the average pressure distribution that a person exhibits during their gait cycle. Two IMUs are used, one to measure the angle of the foot and the other to measure the angle between the foot and the ankle. The IMU corresponding to the foot is placed on the bottom side of the insole in a pocket beneath the arch. This location was selected because the average person applies the least amount of pressure in their arch when walking or standing. The IMU corresponding to the ankle, along with the Arduino, is placed underneath a band that wraps around the ankle. This band is made of two pieces of elastic fabric sewed together at the top so that the Arduino and IMU can slide between the fabrics, eliminating the possibility for the Arduino to move during walking and to ensure comfortability for the user.

6.3 Testing

The testing of the product couldn't take place directly with a foot applying the pressure, but we were able to manipulate the sensor separately to test each of the individual force sensors, as well as the responsiveness of the angle measurements.

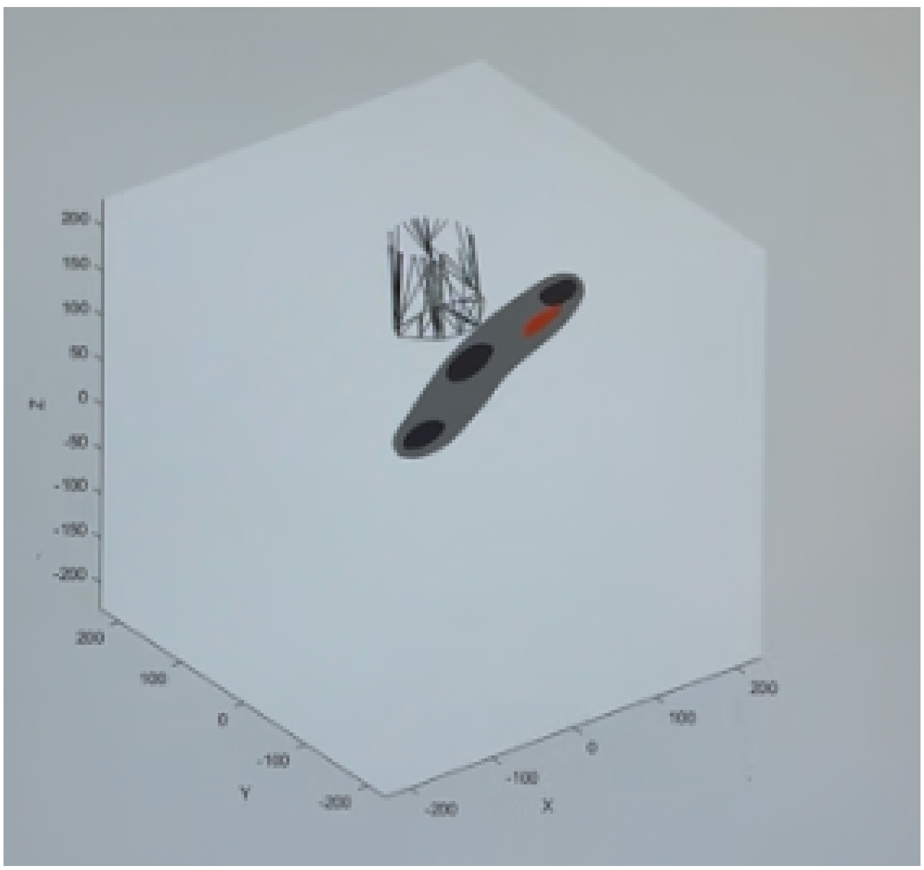

Figure 1: Screenshot of how the sensor relays the data to matlab. The red part is lit up due to pressure being applied specifically at that point

6.4 Future Work

Some of the future work includes using an Arduino nano instead of an Uno, since it has a much slimmer form factor. The nano also has a built-in IMU, which allows us to obtain the data even without an external IMU. This setup requires less wiring and is less bulky. In the current setup, we also have a physical connection to the computer which sends serial data to MATLAB which is then processed and displayed. We plan on using the Bluetooth capabilities of the Arduino nano to remove the need for a physical connection, which will allow the user to actually place the sole in their shoe and move around to gather data. It can be powered using a traditional phone battery bank, a 9V battery, or a lithium polymer battery, which is small and flat enough to fit the sole of the shoe. This will make the sensor fully self-contained, with just a port sticking out used for charging and updating the software. In a future version, a charging pad could wirelessly charge the sensor when the user removes their shoe, eliminating the need to plug it in. This version would be the ideal user experience, where the user could go about their daily tasks/exercise without paying attention and view the data and diagnosis at their leisure.

7 References