Inflashoe: A Shape Changing Shoe to Control Underfoot Pressure

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Abstract
We present Inflashoe, an interactive shoe that uses a pneumatic system to change the inflation level within the sole. This allows the shoe to adapt its shape to different surfaces and users' foot morphology, or to alter users' gait. Inflashoe can not only change the overall inflation, but can also individually control the inflation of the back and front of the insole, creating different levels of elevation across the shoe when needed. In this paper we describe our prototype implementation and present the results of a preliminary evaluation study. We show that 85% of participants found Inflashoe to be equal to or more comfortable than their ordinary shoes, and that nearly 60% of them would prefer comfort to style. In the light of the results, we then discuss the potential applications of Inflashoe, in particular targeting specific kinds of pain or injury.

Author Keywords
Shape-changing shoes; pneumatic; interactive device.

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces.

Introduction
As a result of the foot's relatively small surface area, foot pain is commonplace from the amount of impact that is exerted upon it from contact with the ground. Whilst standard shoes aim to reduce this, because of

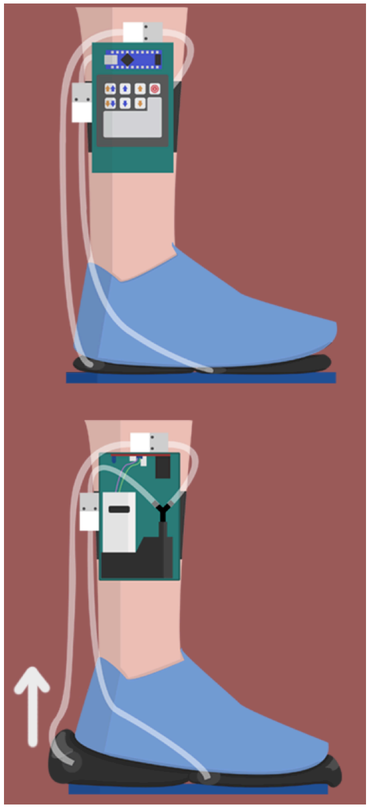

Figure 1: Inflashoe is a shape-changing shoe, which uses localized pneumatic insoles to provide adaptive comfort. (top) Inflashoe in its deflated state. (bottom) Inflation of the heel inner tube, and the internals of the leg mounted controls.

the limits induced by economic rationale and standardization, consumers are often met with ill-fitting shoes, which only exacerbate the problem.

A typical solution for reducing impact and providing comfort involves insoles. However, due to the nature of standardized shoe sizes, insoles can only have a limited thickness before they result in reduced space for the foot and potential discomfort. Additionally, static insoles cannot adapt to different surfaces upon which the users walk and thus do not provide adaptive levels of support.

There have been several works exploring inflatable accessories for the shoes. For instance, the Reebok Pump [8] shoes have inflatable ankle supports, but they need to be mechanically actuated by the user. Inflasole [7] is an orthopedic inflatable insole, which also suffers from the same limitation. In this paper we go a step further by adding an interactive aspect to the shoes.

We present Inflashoe, a shape-changing shoe which uses pneumatic insoles to provide adaptive comfort. For example, the insoles can change its shape depending on the surface walked upon, or adapt to the user's foot morphology. Inflashoe (Figure 1) makes use of the inflation of two carefully arranged inner bladders to allow the user to tailor a level of comfort for both the heel and ball of the foot independently.

Figure 2 illustrates our implementation of Inflashoe. The labeled buttons control which bicycle inner tube air is pumped into or released from via valves. This allows the shoe to provide personalized support and comfort when worn like in figure 2 (bottom), as well as consistency across many surfaces by placing a layer of air between the shoe and the ground.

Inflashoe exhibits various benefits over standard shoes, as well as inflatable insole and ankle approaches:

- The inflatable layer is between the bottom of the shoe and the sole, and therefore does not affect the internal sizing of the standard shoe.
- The thickness and wide range of potential inflation levels allow Inflashoe to provide a consistent comfort experience across many surfaces at a high inflation level.
- The inflation level beneath each foot's heel and ball is independently and fully customizable to the user's personal preference using the leg-mounted controls.
- The user can use Inflashoe to alter gait and relieve pressure by elevating areas under the ball and heel of their foot.

We used our prototype in a preliminary study aiming to assess the comfort of Inflashoe. The results showed that nearly 85% of users found our prototype to be equal or greater in comfort compared to their ordinary shoe. Our results suggest that Inflashoe has potential and could be developed further in future work for relieving foot pain or correcting gait.

Related work

One of the most closely related items for sale on the market is a product by the company Inflasole [7] who sells insoles that can be inserted into a shoe before subsequently being inflated. The idea is similar in that it uses air to reduce the amount of pressure exerted underneath a user's foot. However, by inserting this inflatable padding inside an existing shoe, it limits the amount of space within it. Typically, shoes tend to be tight by design. By reducing the space inside a shoe even further, it most importantly reduces the amount of air that can be pumped into the shoe. Additionally,

Figure 2: (top) The two-part inflatable layer allows independent ball and heel elevation; (middle) the prototype uses leg mounted controls to allows the user to personalise their desired support; (bottom) a user wearing the Inflashoe.

the inflation is only done prior to the placement of the insole in the shoe. Inflashoe differs in that the inner tubes have a lot of room to inflate into, allowing a more significant amount of air to be used for cushioning.

A product relating to our device is the Reebok Pump [8]. This shoe was first introduced in 1989 and found its uniqueness through the pockets of air around the top of the shoe that could be inflated to provide cushioning and ankle support. The air pockets would tighten around the ankle as they inflated, providing stabilization and comfort. To control this, the users must mechanically pump air into the insole. The use of air in this product proved very successful and resulted in the shoe being very popular due to its benefits of providing comfort and sufficient cushioning. This motivated us to consider a more interactive version of this similar system.

There has also been research into creating interactive shoes that can sense the user's gait or track their activities [1]. However, we are not aware of any related work looking at using interactive shape-changing attributes directly on the shoe. Using inflation within shoes to relieve pressure is a concept that we can find through a quick search on Google, but we did not find any products being made. Additionally, no studies into their actual usability appear to have been carried out.

Inflashoe

Design

Figure 1 illustrates an example of the Inflashoe inflation process. The user, on experiencing pain in their foot, decides they require some pressure relief on the heel. To achieve this, the user presses a button on the keypad to start inflating the inner tube placed beneath the heel. Once satisfied with the level of pressure relief, the off button is pressed to close all valves and keep air within the insole. If the user wishes to further adjust the inflation level, they can inflate again, or deflate by pressing another button to open the valve and release some air. When the user walks, the pressure exerted by their heel is absorbed by the pocket of air beneath it, resulting in less strain on the injured area and a more comfortable walk.

We choose to focus on inflating the ball and heel of the sole because these are the two main points of contact with the floor, and thus the areas receiving the most pressure on the foot.

Implementation

Our Inflashoe prototype uses the following components:

- A 12V DC vacuum pump for inflation or deflation
- An Arduino board
- Two 12V DC solenoid valves, normally closed
- Two bike inner tubes as the sole of the shoe
- A keypad
- Tubes to connect the pump to the valves, and the valves to the bike inner tubes
- A 12V DC power supply

The electrical circuit of the prototype is shown in Figure 3. An Arduino board controls Inflashoe. When the microcontroller receives a key press, it gives the corresponding outputs (HIGH or LOW) to the pump and valves for the desired operation. The pump inflates when it receives a HIGH voltage (12V DC) to its inputs. The solenoid valves are normally closed. This means when no voltage is applied to them, no air can pass through. The output voltage of the Arduino is limited to a maximum of 5V, so we used motor shields powered

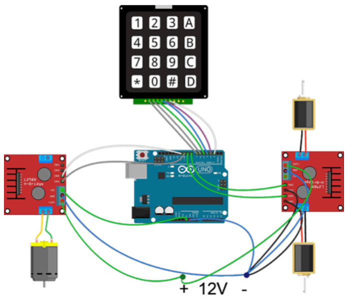

Figure 3: The electrical circuit of the leg mounted controls. On the left is a motor shield with a pump attached. On the right is another motor shield with the two valves attached.

Figure 4: The different materials and techniques tried when designing the shape changing sole. From left to right:

1. Air/Inner Tube/inflation
2. Puffed Cereal/Balloon/Jamming
3. Air/Balloon/Inflation
4. Coffee/Balloon/Jamming
5. Polystyrene Balls/Balloon/Jamming

at 12V DC by an external DC power supply to drive the inductive loads (pump, valves) of the circuit. Finally, the valves are connected to the pump and to the insole of the shoe, allowing them to control the airflow to the inner tubes. All parts of the electrical circuit fit in a box so the device can be portable and wearable.

Alternative designs

Figure 4 shows the different materials and techniques that were examined for the shape changing sole before reaching the final prototype. We initially experimented with jamming techniques [4]. Jamming consists of filling a bladder with small particles. When inflated (unjammed) the bladder is flexible, whereas when deflated (jammed) the bladder is very rigid. We used small polystyrene balls, coffee beans and puffed rice as particles. We wanted to alter the hardness of the insole by creating a vacuum, thus compacting the granular materials. However, we found that stepping on a sole that was subject to jamming resulted in little variation in sole hardness. This was due to the fact the granular materials were always compacted by the pressure of the foot. This lead us to concentrate on simple pneumatic actuation and we found that small bicycle inner tubes were the most durable housing material and that they felt sufficiently comfortable only containing air.

Evaluation

We conducted a usability study to determine the validity of our concept. Twelve users placed an Inflashoe on each foot, and were asked to walk whilst wearing them in both the inflated and deflated state. Participants then answered a series of questions based on their experience using a Likert scale. The questions focused on how much comfort Inflashoe could offer to the users whilst inflated or deflated, and how often the users experienced problems due to the uncomfortable nature of their own shoes. We could therefore measure the utility of our implementation and receive constructive feedback for the further development of our prototype.

Results

<u>User's current shoe satisfaction</u>

Four out of ten questions in the survey were used to measure the level of discomfort the users experience with their current shoes. Even though all users that participated in our survey argued that they are pleased with the comfort they feel from their current shoe, 25% of them claimed that they wear uncomfortable shoes a few times a month. Furthermore, 41.7% of the users expressed that they sometimes experience foot pain. Figure 5 (bottom) shows that a majority of participants valued shoe comfort over style, indicating that the intended comfort benefits of Inflashoe could be something desired by users.

<u>Comfort level of Inflashoe</u>

The remaining questions aimed to measure the potential of Inflashoe based on how comfortable the participant felt whilst wearing them. Most of the users (33.3% in each case) found the prototype to be mediocre and comfortable, even when deflated. This changed dramatically when we started automatically inflating the inner tubes, in which case 41.7% of the users found Inflashoe very comfortable and 16.7% claimed that it was fairly comfortable. In addition, we asked the users to compare their ordinary shoes to the inflated prototype, as shown in figure 5 (top). Almost 85% of users found the inflated shoe to have equal or greater comfort than their existing shoe, with 41.7% of users stating it was significantly more comfortable. However, the deflated prototype was not substantially

Figure 5: The results of two questions asked to the 12 participants in our user study: (top) Shows that nearly 85% of participants found the inflated shoe to be more comfortable than their existing shoe; (bottom) Shows more participants value a comfortable shoe over a stylish one.

more comfortable than the users' current shoe (only 25% of the users stated that it is marginally more comfortable). Ultimately, 41.7% and 25% of the users asserted that they are respectively very likely and fairly likely to recommend Inflashoe to their friends.

Design feedback

At the end of our survey we encouraged the users to comment on our implementation. The feedback was supportive. Users found our prototype to be comfortable and relaxing for their feet. We also received some very supportive comments pushing us towards expanding our implementation for adjusting to different terrain, making it more portable and focusing on medical and occupational use cases. One user commented: "Impressive demo. Very comfortable and has potential to adjust to the terrain! Go to market!".

Applications

With positive results of the initial evaluation, we now refined the potential applications for the use of Inflashoe to support the health and wellbeing of feet.

We focus on health and wellbeing because we use our feet every day to get us from A to B, which leads to various forms of foot pain. The most common areas to experience pain are in the heel, ball and arch of the foot [2]. For example, heel spurs are bone-like calcium deposits that build up on the underside of the heel bone. They result in painful inflammations of the plantar fascia; a tissue that connects the heel and ball of the foot [2]. Heel spurs are caused by strain on the foot muscles and ligaments, and are therefore common amongst athletes running on hard surfaces or people with an abnormal gait [6].

Common remedies include placing orthotics into the shoe to relieve pressure on the heel. These can come in the form of custom orthotics, or cheap off-the-counter gel inserts to support the heel. Custom orthotics require booking an appointment to assess the foot, waiting for the orthotic to be produced, and usually involve a large price tag. Cheaper alternatives come in a fixed size and rigidity, which may not be suitable for every foot pain sufferer. Both solutions have no way of further tweaking the orthotic to allow for the healing or worsening of the foot pain, or to be re-used if the user develops an alternative foot pain in the future. Due to the shape changing nature of the sole within our shoe, Inflashoe would be able to solve the problems described. We therefore present two applications.

Prevention of Various Foot Pains

Inflashoe can be used to prevent foot pain before it becomes severe. The ability to alter the heights of the areas of the sole mean that a single pair of shoes could be used to help fix all types of gait abnormalities, and thus prevent foot pain caused from it. Coupled with additional sensors (e.g. [1]) on the bottom of the shoe, Athletes' shoes could automatically change the level of impact absorption required when running on different surfaces. This protects the foot from damage, and has the economic advantage of the user only requiring one pair of shoes for different surfaces.

Healing and Relief of Various Foot Pains

The ability to inflate the sole in multiple areas means that one pair of shoes can be used to treat different types of foot pain at varying stages of their lifecycle. Within our prototype, we have placed two inflatable areas beneath the parts of the foot that experience the most pressure; the heel and ball of the foot [3]. This allows a sufferer of heel spurs to inflate the heel area of the sole to the level that provides them with comfortable pressure relief. As the foot pain heals, the user can adjust the inflation level to align with the pressure relief required for that stage of the healing process. An orthopedic doctor could also automatically program this feature in the shoe. When the foot pain is gone, the user can fully deflate the sole and still have a comfortable, normal shoe. If the user then develops pain in the ball of their foot, they can use the same shoe to provide pressure relief in that area. This adaptive, shape-changing nature is something not available in current orthotics and would also help to achieve gait/posture correction.

Conclusion and Future Work

The most prominent benefit of Inflashoe is its ability to allow the user to use the leg-mounted unit and controls to customize the inflation level to their preference. However, this feature resulted in added complexity for the solution and although our participants did not find interaction with the device difficult, we would like to explore the adaption of the control mechanism into a mobile application. As this would remove the need for the user to bend down to reach the controls, as well as allow the user to be more precise when inflating the shoe. This added level of precision would mean that the user could easily fine tune and save any preferences they have for any surface, so that later they could switch through them with a few taps of their phone.

At the time of the study we used an external power supply. However, this did not limit portability or maneuverability because we could inflate the shoe and then disconnect the power supply without losing inflation. Thus, on a hardware level we wish to firstly integrate a battery to improve practicality and add more independently inflatable areas for even more control over the dispersion of air beneath the foot.

We would also use pressure sensors to introduce a fully automated mode, which would detect where most of the pressure is being applied to the shoe to adjust the sole to an optimal inflation level. Converting from commodity components to a more bespoke solution would significantly reduce the size of the pneumatic hardware to a scale that can be integrated within the shoe itself. This would allow us to do away with the bulky leg unit for a truly self-contained product.

We want to investigate the extension of the applications of Inflashoe from comfort and common foot ailments, into the realms of foot protection by extruding the inflation layer out from the shoe to act as a buffer between the foot and the environment. This would be helpful to sufferers of diseases which cause a loss of sensory nerves in the foot, due to the fact they often end up unnoticeably damaging their feet. One use case would be protecting people with diabetes who often develop peripheral neuropathy from further foot related ailments or infections [5].

Finally, we want to conduct stronger evaluations to validate participants' perceptions and preferences. A longitudinal study could also be appropriate to get further insights about long-term adoption, perceived ease-of-use, influences from and to social circles or impact on participants' levels of self-reflection.

Overall, we wish to consolidate our concept of a comfortable, customizable shoe into a self-contained product, which is as simple and automated as possible, whilst still remaining fully flexible. Nevertheless, despite some of its limitations, the prototype we have presented and the results of the evaluation show that shape-changing shoes are feasible and have a potential to support the health and wellbeing of feet.

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