Inflashoe: A Shape Changing Shoe to Control Underfoot Pressure

Katerina Baousi
University of Bristol
ab16651@my.bristol.ac.uk

Nate Fear
University of Bristol
nf16713@my.bristol.ac.uk

Christos Mourouzis
University of Bristol
cm16663@my.bristol.ac.uk

Ben Stokes
University of Bristol
bs13831@my.bristol.ac.uk

Henry Wood
University of Bristol
hw13120@my.bristol.ac.uk

Interactive device unit 2016
University of Bristol

Abstract

There has been minor research into creating interactive shoes that can sense the user's gait or track their activities[1], but nothing has been done towards exploring the shoe as a shape-changing device. We present Inflashoe, an interactive shoe that can change its shape to adapt to various conditions using inflation within the sole of the shoe. For example, the entire sole can be inflated to relieve the pressure of walking or running on hard ground. The shoes can also change the internal shape to adapt to the user's foot morphology or to alter the user's gait in different scenarios. For example, in addition to adapting overall inflation for different surfaces, the back and the front of the shoe can be inflated separately, creating different levels of elevation across the shoe when needed. We achieve this by building a prototype using a pneumatic system to change the shapes of different pockets of rubber inside the shoe, and hence adapting the overall shape. We present our prototype and its applications, as well as the results of a preliminary study showing that of the participants who tried our prototype, nearly 85% of them found our shoes to be equal to or more comfortable than their ordinary shoe, and that nearly 60% of them would prefer comfort to style.

Figure 1: (a) (top) The two-part inflatable layer allows independent ball and heel elevation. (b) (middle) The final prototype uses leg mounted controls to allows the user to personalise their desired support. (c) (bottom) A user wearing the Inflashoe prototype.

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 the limits induced by economic rationale and standardisation, consumers are often met with ill-fitting shoes which only exacerbate the problem. A typical solution for reducing impact and providing comfort would involve insoles, but due to the nature of standardised shoe sizes, insoles can only have a limited thickness before they result in reduced space for the foot and potential discomfort. Another approach would be to have bespoke shoes made, however as well as being costly the shoes would still be unable to provide optimal comfort because the surfaces that are walked upon change the levels of support and comfort that is required. More advanced solutions such as Inflasole[2] the inflatable insole and Reebok Pump[3] shoes which have inflatable ankle support have been introduced with some success, however they still succumb to the same limitations as standard insoles or do not improve comfort in relation to the force exerted by contact with the ground.

To overcome the issues of the current solutions, we present Inflashoe, a shoe which uses localised pneumatic support to provide comfort. In this paper, we contribute how to make a comfortable shape changing shoe with and inflatable layer and its corresponding leg mounted controls. Inflashoe (Figure 1a) makes use of the inflation of two carefully arranged bicycle inner tubes to allow the user to tailor a level of comfort for both the heel and ball of the foot independently.

Figure 1b illustrates our implementation of Inflashoe, the labelled buttons control which bicycle inner tube air is pumped to or released from via valves. It is these mechanisms which allow the shoe to provide personalised support and comfort when worn like in figure 1c, 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 insole and ankle based comfort approaches:

- The inflatable layer of Inflashoe 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 of Inflashoe is independently and fully customisable beneath each foot's heel and ball 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 differently.

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

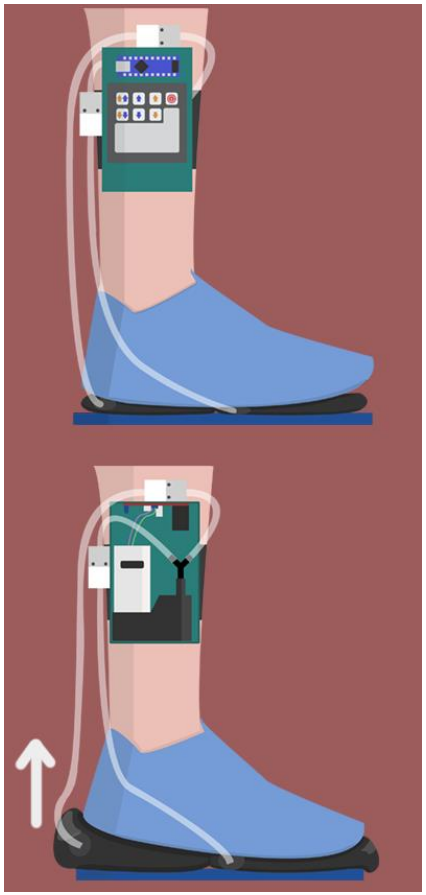

Figure 2: (a) (top) Inflashoe in its deflated state. (b) (bottom) Inflation of the heel inner tube, and the internals of the leg mounted controls.

Walkthrough

Figure 2 illustrates an example of the Inflashoe inflation process. The user, on experiencing pain in their foot, decides they require some pressure relief on their 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 tubes. If the user wishes to further adjust the inflation level, they can inflate again, or deflate by pressing another button to open the back valve and release some air. When the user now 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.

Related work

One of the most closely related items for sale on the current market is a product by the company Inflasole, who sell 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, you limit the amount of space within it. Typically, shoes tend to be tight by design. By reducing the space inside a shoe even further, you most importantly reduce the amount of air that can be pumped into the shoe. Inflashoe differs by the fact 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 more unique product relating to our device is the Reebok Pump. 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 stabilisation and comfort. Inflation also required no additional hardware as the force of a step would fill the pockets with air. The product itself is reasonably different to our prototype in that it doesn't serve the same purpose of relieving underfoot pressure, but is still comparable to a degree. For example, the use of air in the shoe proved very successful and resulted in the shoe being very popular due to its benefits of providing comfort and sufficient cushioning.

In terms of related research, there is effectively no content for us to relate to. Using inflation within shoes to relieve pressure is a concept only found on Google Patents without any products being made, meanwhile no studies into their actual usability appear to have been carried out either. Therefore, our product seems to fit well into the shoe related research market given that we have been able to create a product that has tested the usability of inflation and compared it to ordinary shoes.

Implementation

The final prototype of Inflashoe 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

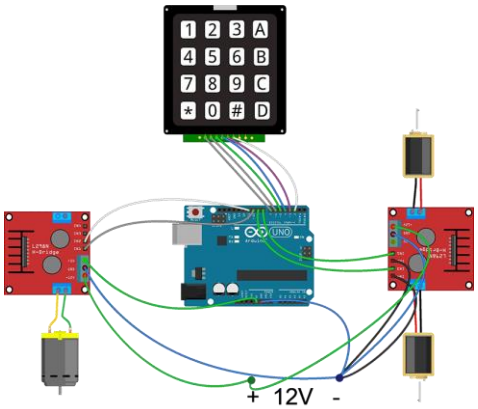

Figure 3: The electrical circuit of the leg mounted controls. On the left is a motor shield with a pump attached. On the right is another motor shield with the two valves attached.

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

The electrical circuit of the prototype is shown in Figure 3. Inflashoe is controlled by an Arduino board. 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. They only open when receiving a 12V DC voltage. The output voltage of the Arduino is limited to a maximum of 5V, so motor shields powered at 12V DC by an external DC power supply are used 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.

Figure 4 shows the different materials and techniques that were examined for the shoe's shape changing sole before reaching the final prototype. We experimented with jamming techniques using small polystyrene balls, coffee beans and puffed rice. The motive was 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. We found that small bicycle inner tubes were the most durable housing material and that they felt sufficiently comfortable only containing air.

Applications

Inflashoe has many potential applications for the health and wellbeing of feet. We use our feet every day to get us from A to B, which results in lots of people experiencing various forms of foot pain. The most common areas to experience pain are in the heel, ball and arch of the foot. 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[4]. 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[5].
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 all problems described for the current solutions. We therefore present two applications.

I 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 different 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. Athletes could use the shoe to change the level of impact absorption they require when running on

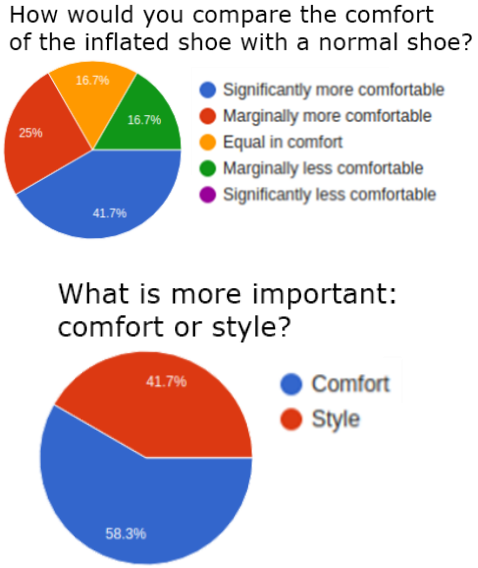

Figure 5: The results of two questions asked to the 12 participants in our user study. (a) (top) Shows that nearly 85% of participants found the inflated shoe to be more comfortable than their existing shoe. (b) (bottom) Shows more participants value a comfortable shoe over a stylish one.

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.

II 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[6]. 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. 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.

Formative study

During a demonstration of the prototype, we conducted a usability study to determine the validity of our concept. Twelve users placed the shoes on their feet, and were given the opportunity to walk around wearing them both in the inflated and deflated state. Participants then answered a series of questions based on their experience. 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.

Evaluating the user's current shoe satisfaction

Four out of ten questions included 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 5b shows that a majority of participants valued shoe comfort over style, indicating that the intended comfort benefits of Inflashoe is something desired by users.

Measuring the comfort level of Inflashoe and comparing it to users' current shoe

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 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 5a. 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 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.

In the final section of our survey we encouraged the users to comment on our implementation. The feedback was supportive as users found our prototype to be comfortable and relaxing for their feet. Furthermore, we 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!".

Conclusion and Future Work

The most prominent benefit of Inflashoe is its ability to allow the user to be able to use the leg mounted unit and controls to customise 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 to be difficult, we would still 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.

Due to a lack of availability, at the time of the study we did not have a battery to integrate so instead opted to use a 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 then add more independently inflatable areas into the shoes 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.

Finally, we would like 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 of Inflashoe out from the shoe to act as a buffer between the foot and the environment. As this would be helpful to the suffers 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 Diabetes sufferers who, as a by-product of Diabetes, often develop peripheral neuropathy from further foot related ailments or infections[7].

Overall, we wish to consolidate our concept of a comfortable, customisable shoe into a self-contained product which is as simple and automated as possible, whilst still remaining fully flexible.

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