“My Heels Are Better Than Yours”

Wearable- Based Data Visualization in the Design of HHS: Minimizing Discomfort and Possible Impacts for the Luxury Fashion Business

By

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"My Heels Are Better Than Yours"

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The role that technology plays in our lives is rapidly growing. We are becoming increasingly dependent on and less willing to separate ourselves from our devices. The rise of wearable technology has been fueled by technology's tendency to get faster and smaller. In the fashion industry, luxury brands have focused on exclusivity that includes bespoke fashion, high levels of craftsmanship, and high-quality materials. However, a subtle shift is starting as luxury brands look to technology, and wearable technology in particular, as a means of providing exclusive, customized products. The high-heeled shoe is an important part of the luxury shoe market, but high heels can cause discomfort and more serious health problems for the wearer. This research project explores the possibility of a wearable-based web data visualization application that offers an approach for female to wear comfortable high-heeled footwear, while it also provides possibility of customized services for luxury brand fashion footwear.

Keywords: Wearable Technology, Data Visualization, Center of Pressure (CoP), Footwear Design, Luxury Brand

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Introduction

"Give a girl the right shoes and she can conquer the world."

-Marilyn Monroe

The high heel has generated much interest for centuries. It is often considered a rather modern invention. Although there is still confusion of when the high heel was introduced, research shows that it can be traced back to ancient Egypt (Stewart, 1972).

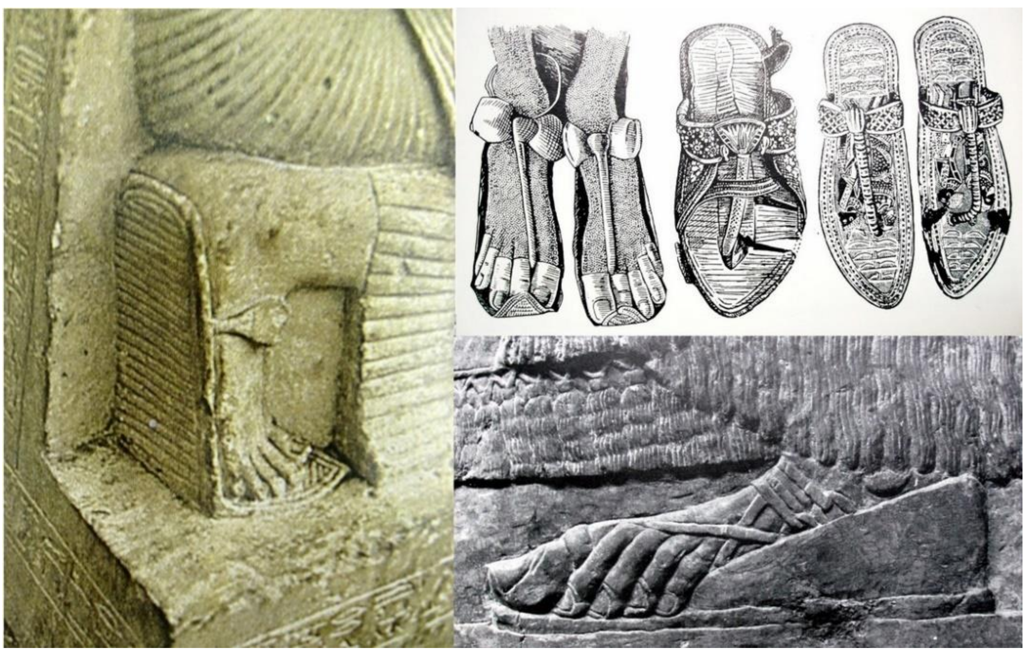

Figure 1. Ancient Egypt Heeled Shoes Source from nimmafashionsource.blogspot.com

It has been assumed by a few extent records that people from higher classes wore high heels during the Egyptian period to set them apart from the lower classes (Stewart, 1972). High heel shoes were worn by both male and females from the higher class as a symbol of social status. "It has been suggested that wearing high heels as a fashion statement was pioneered by Catherine de Medici, a

Franco/Italian noblewoman" (King, 2016; Frieda, 2011). From there, high heels become a symbol of the upper class, denoting the wealth and status of an individual.

Figure 2. Catherine de Medici Source from http://dealsonheels.net/

High heels have significant values for female in culture. Traditionally, wearing high heels is a symbol of being feminine. It is also socially acknowledged that wearing high heels could extend female attractiveness. However, high heels are also considered to be a symbol of being submissive and vulnerable to man in society (Chambers, 2005). High heels are indicative of a widespread, virulent, anti-feminist cultural misogyny. But Queen Elizabeth once said that, "I know I have but the body of a weak and feeble woman, but I have the heart of a king, and of a king of England, too." And in the context of the day, that was her way of asserting that her body didn't stop her from being powerful, which commanded trust and respect from the men who fought and served under her.

Today, high heels are typically worn with heights varying from 1.5 inches (3.8 cm) to that of 5 inches (13 cm) or more. Extremely high heels (over 15 cm) are normally considered impractical to wear (Maarouf, 2015). According to the Guinness World record, the highest heels available are boots produced by James Syiemiong (India) in 2004, boasting a combination of 43 cm (17 in) platforms and 51 cm (20 in) heels (guinnessworldrecords, 2015). Although this height of shoe is not sold in the vast majority of luxury brands, the sartorial influence of figures such as the pop star Lady Gaga, and pop star/fashion designer, Victoria Beckham, led to the sale of 9-inch heels in 2011.

Figure 3 . Lady GaGa with Alexander McQueen extreme platform heels Source from https://www.pinterest.com/pin/452963674995541851/

Luxury footwear designers Jimmy Choo and Christian Louboutin have long favored extremely high stiletto heels, and their designs have gained them a firm following of celebrities as well as everyday people. While high-heels shoes have strong aesthetic values, recent studies indicate that high heels have a deleterious action on the muscle movement of the lower limbs. Wearing high-heeled shoes has been reported to increase load on the toes, to alter foot shape and gait patterns, to cause lordosis and back pain, and to shorten Achilles tendons and stride length (Tedeschi et al., 2012; Kim et al., 2015; Xiong and Hapsari, 2014). The continuous use of high-heeled shoes is prone to cause higher venous pressure in the leg. Venous hypertension is related to harmful consequences such as varicose veins and undesirable symptoms (Tedeschi et al., 2012). It is also suggested that increasing shoe heel height decreases an individual's balance, as shown by poor postural balance, limits of stability regarding excursions and directional control, and functional mobility (Xiong and Hapsari, 2014).

Luxury footwear designs are incompatible with the accessibility that is advocated by researchers. In June 2015, the Victoria & Albert Museum in London featured *Shoes: Pleasure and Pain*, an important exhibition whose 200 pairs of shoes chart humankind's sadomasochistic relationship with footwear. The exhibition presented a whole collection of footwear technology, creating the possibility of even higher heels and dramatic shapes. The exhibition revealed how impractical shoes have been worn to represent privileged and leisurely lifestyles--their design, shape, and material can often make them unsuitable for walking and how shoes also dictate the way in which the wearer moves, how they are seen and even heard (Shoes: Pleasure and pain, 2015).

Figure 4. NightWalker Source from http://www.racked.com/2010/12/13/7779685/noritaka-tatehana

In 1923, Sir Herbert Baker presented his research on the health problem created by high heels in an interview published by the Central News on Saturday:

> "…I have examined many thousands of women's feet, and I do not hesitate to say that in 90 per cent of them I have found some skeletal defect, either slight or severe, brought about entirely by the outrageous boots and shoes that women wear. Enlarged great toe joints and twisted small toes are the commonest results of unhealthy footwear, while Morton disease, most painful affliction of the ball of the foot, caused by the weight being thrown forward by high heels, and more or less deformed ankles, are common results of high heels and V-shaped toes. Let commonsense and the desire for physical fitness decide this controversy and the entire nation will benefit. It seems to me criminal to place a child's perfect little feet into what are nothing more than instruments of torture, and I should like to see the legislators put a stop to it…" （A GREAT SURGEON ON DEFORMED FEET, 1924）.

The health issues surrounding the wearing of high heel shoes have been acknowledged for some time (Simonsen et al., 2012). However, the development of advanced imaging, sensing, and wearable technologies are offering a potential solution to the problem. Smart wearable devices can be traced back to the 1980s and the start of mass-production of microchips. This opened up the possibility to make smaller, more portable and ultimately more wearable devices. Since then, the processing of smart wearable devices has become faster, especially in the healthcare and wellness market. Recent advances in telecommunications, microelectronics, sensor manufacturing and data analysis techniques have opened up new possibilities for using wearable technology in the digital health ecosystem to achieve a wide range of health outcomes. Sensors and wearables can be integrated into various accessories such as garments, hats, wristbands, socks, shoes, eyeglasses, wristwatches, headphones and smartphones. Many wearable tech products use multiple digital health sensors that are typically integrated into sensor networks comprising other body-worn and ambient sensors. Some monitoring systems require the gathered sensor and wearables data to be uploaded to a remote site, such as a hospital server, for further clinical analysis.

This body of research investigates the use of emerging wearable sensing technology and data visualization techniques to provide a solution to the health issues surrounding the wearing of high heel shoes. This research purposes a system that consists of wearable high heeled shoes that can retrieve and send wearers' foot planar pressure load data wirelessly, and two web applications which provide different visualizations that help both designers and wearers to gain insight into the wearers’ walking behaviors.

Background: The use, marketing and branding of wearable technology in luxury fashion

The concept of luxury is multifaceted. "It is simultaneously addressing financial (e.g., exclusivity), functional (e.g., product excellence), individual (e.g., personal enjoyment) and social value components (e.g., prestige and status)" (*The European Financial Review*, 2016). Luxury labels count on the perceived value of their brands as their major selling point. According to the annual report on brand value published by brand strategy firm Millward Brown, top luxury brands, such as Prada, Gucci, and Cartier, lost about US$7 billion in combined brand value from 2014 to 2015 (*2015 BrandZ Top 100 Report*, 2015).

Researcher found that some consumers, particularly millennials, viewed luxury products as expensive indulgences inconsistent with their desire to live in a modest and sustainable way. In addition, luxury brands limited efforts to reach a mass audience and instead reaffirmed exclusivity as a vital characteristic of luxury. Luxury brands relied heavily on content, such as live streaming fashion shows, to introduce new customers to the brand experience.

Another significant shift that affects luxury brands is the economic slowdown in China. In the past few years, with the ongoing global economic crisis, luxury brands have faced an unpleasant prospect. The world's largest luxury goods markets, particularly Europe, Japan, and the United States, have shown decreases in 2009 (Cavender and Rein, 2009). In a report published by People's Daily, readers were assured that “while the financial crisis causes demand for luxury brands to decline in Europe and the United States, the Chinese luxury market is still.” At present, China's luxury consumption accounts for 25% of the global market, surpassing the United States, becoming the world's second-largest luxury goods consumption market after the United Kingdom (People’s Daily, 2016; Crowe, 2015).

The situation has declined in recent years when sales of luxury goods in China suffered a downturn in 2014, due in part to changing consumer preferences and the country's economic slowdown (Welitzkin, 2015). The slowdown of the Chinese economy particularly affected Prada. With one-third of its sales coming from the Asia-Pacific region, Prada’s annual profits and brand value decreased significantly. Both Louis Vuitton and Gucci, which expanded their territory rapidly in China, were impacted by the economic slowdown and by anti-corruption regulations (*2015 BrandZ Top 100 Report*, 2015).

Another shift is the change of perceptions that the fast-growing generations of consumers have towards luxury brands. Young consumers today tend to prefer to purchase unique pieces instead of highly recognizable handbags from luxury brands such as Louis Vuitton, Gucci, and Prada. Post-recession consumers, especially millennials, have a harder time aligning luxury purchases with their views about consuming responsibly and expect brands to serve a higher societal purpose (*2015 BrandZ Top 100 Report*, 2015). With time, a consumer's behavior and attitude toward luxury items keeps evolving. In response, brands must adjust their strategies to cater to the changing requirements of its target consumer group (King, 2015).

Individuality will be reinforced. Though heritage is important as always, the exclusivity in personalization of the experience, as well as the emotional attachment a consumer has towards the brand, should also be taken care of especially in millennials' perspective. The new symbol of status is having something that speaks to the consumer as an individual, not something that exhibits wealth (*2015 BrandZ Top 100 Report*, 2015). Personalization can be an extremely effective approach to further enrich the experience of consumers' emotional attachment. With improvements in customer data and digital reach, the opportunities for a luxury marketer to customize their marketing are vast (Stokes, 2014). Wearable technology might just be the solution.

"Wearables will become the interface between body, apps, data, and services" (Montanus, 2014). Wearables are capable of collecting personal information such as biometric and location data. There are already some examples on the market, such us Apple Watch and Fitbit. During its 2013 London fashion show, Burberry provided smart personalization service in which customers could order bespoke pieces directly, with the option to have their name engraved into the metal coat tag or on the bag plate The products were also embedded with digital chips. This provided an extra function that allowed consumers to scan it with their mobile devices. The scan would unlock content regarding the history of the item purchased, from the initial sketch to the runway fittings. Designer labels are connecting technology companies from Silicon Valley with traditional luxury to create unique product lines such as iPad and iPhone cases. Brands are also already developing bespoke accessories, notably straps, for the new Apple Watch. Technology firms rely on fashion to put the 'wear' into wearables, which, even more than mobile phones, are a form of personal expression. The collaboration between Diane von Fürstenberg (DVF) and Google in the design of Google Glass also emphasizes this trend (Hyland, 2014).

"Luxury consumers are likely to select wearable devices that are autonomous, well-crafted and visually pleasing, as they prefer products that combine fashion and function" (Wearable Technology, 2015). James Green, the CEO of Magnetics also stated that "digital creative is critical to the luxury consumers – it needs to drive innovation without jeopardizing brand integrity and exclusivity" (Green, 2016).

Literature Review

Human Foot Planar Pressure Measurement Review: Sensor Configuration, and Medical Research in Center of Pressure (CoP) Shifting and Ideal Heal Height

1. Sensor Configuration

"Foot plantar pressure is the pressure field that acts between the foot and the support surface during every day movement activities" (Abdul et al., 2012). Data retrieved from such pressure measures is vital in gait and posture research for identifying lower limb problems, enhancing footwear design, sport biomechanics and other applications in clinical services (Abdul et al., 2012). A variety of sensor configurations are used for different purposes.

There are three types of sensor configurations used for planar pressure measurement: pressure distribution platforms, imaging technologies with sophisticated image processing software and in-sole system which enable extra mobility (Abdul et al., 2012). These methods can be categorized into platform/force platform systems and in-shoe systems, filtered based on mobility and flexibility (Abdul et al., 2012; Salpavaara et al., 2009). Spatial resolution, sampling frequency, accuracy, sensitivity and calibration of sensors are also important for researchers to consider when executing a pressure measurement test (Gefen, 2007).

Platform systems are constructed from a flat, rigid array of pressure sensing elements arranged in a matrix and embedded in the floor to allow normal measurement (Adbul et al., 2012). This type of planar pressure measurement method is restricted to laboratories. The pros of this type of system are that they are stationary and flat, reducing the complexity in use. A major disadvantage of these systems is that that participants require familiarization of the measurement process to ensure a natural and accurate measurement. Platform-based systems require participants to make directly a contact with the active area of the sensor mat to ensure an effective reading. These areas are always located in the center of the platform (MacWilliams and Armstrong, 2000). This approach can impede data retrieving as participants may have direct contact outside the effective area.

Figure 5. EMED Platform Foot Planar Pressure Sensor Source from http://www.novel.de/novelcontent/emed

To obtain a natural measurement, increasing numbers of researchers and institutions turn to in-shoe systems, mostly for the greater portability, even though these systems function in an environment, which, may lead to sensor inaccuracy, either due to temperature or moisture variability or creasing of sensor matrix within the shoe. There has been considerable work in both research and commercial spheres focused on the development of more mobile methods of analyzing measurement. In 1990, Wertsch et al. developed a tethered system for measuring the pressure distribution beneath the foot to quantify the differences between shuffling and walking and identified the need to collect data over a long period (Wertsch et al., 1990; Bamberg et al., 2008).

The in-shoe system is usually embedded with various kinds of sensors. Because of this embedded feature, which reflect the interface between the foot and the shoe, it is suitable for various studies ranging from footwear design to terrain gauging (MacWilliams and Armstrong, 2000).

Though in-shoe foot planar pressure systems are highly recommended for studying orthotics and footwear design (Ramizuddin and Washimkar, 2013), there is the possibility for sensor slipping to cause inaccurate readings (Abdul et al., 2012; Gefen, 2007). In-shoe systems are also restricted in their low spatial resolution due to size limitations (Gefen, 2007; MacWilliams and Armstrong, 2000). There can be additional disadvantages such as mechanical durability and stability during long-term use (Salpavaara et at, 2009). However, its low cost has made it very popular among researcher groups as a way to focus on observing pressure distribution.

Commercial systems also employ several types of sensor technology leading to different sensing characteristics and interpretation of the magnitude and temporal parameters of pressure. The data produced from the measurements obtained from these systems are only of value if any potential inaccuracies can be quantified (Barnett and West, 2001).

Within current means, the inaccuracies could be bridged by the advancing technology. The highly embedded capacitive sensor matrix, utilized in the OpenGo Insole can calibrate each sensor in the matrix. OpenGo Insoles are calibrated using a mobile application or a windows application applying pressure ramped up in increments from 0 to 4000 kPa (equals a force load of 102 kg), each sensor producing an individual calibration curve (Appendix D).

Figure 6. OpenGo Sensor Insole Source from http://www.medicalexpo.com

There are several different types of pressure sensor that have been already used for pressure measurement research. They are capacitive sensors, resistive sensors, piezoelectric sensors and piezoresistive sensors. These sensors provide electrical signal output (either voltage or current) that is proportional to the measured pressure (Abdul et al., 2012).

“Capacitive sensors consist of two conductive electrically charged plates separated by a dielectric elastic layer” (Abdul et al, 2012). Once a pressure is applied the dielectric elastic layer bends, which shortens the distance between the two plates, resulting in a voltage change proportional to the applied pressure. This type of sensor is used in in-shoe systems like Pedar and OpenGo Insole, as well as platform based system like EMED (Barnett et al, 2001; Abdul et al, 2012). Modern touchscreens, such as Super AMOLED, also uses such sensors, but are produced with in-cell technology, to detect the change of the voltage in order to located where users have touched on the screen.

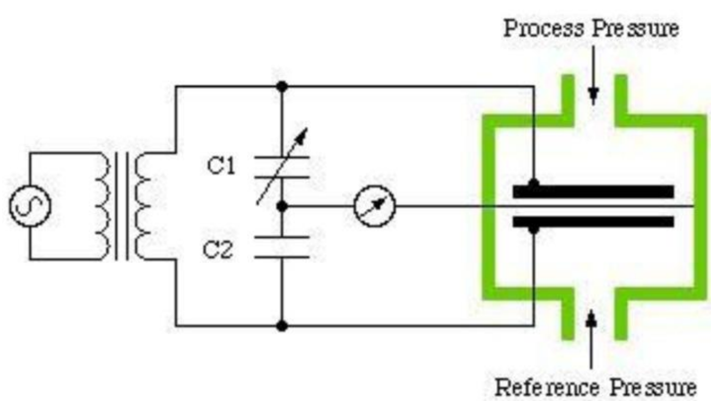

Figure 7. Capacitive Pressure Sensor Construction Source from ResearchGate

Another commonly used resistive sensors in pressure measurement are Force Sensor Resistors (FSRs). “FSRs are made of a conductive polymer that changes resistance with force; applying force causes conductive particles to touch, increasing the current through the sensors” (Abdul et al, 2012).

Piezoelectric sensors measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge dynamically. They are typically not suited for static pressure measurements. Commercial products that are based on this technology include FlexiForce and ParoTec.

Figure 8. FlexiForce A201 Force Sensitive Resistor Source from www.tekscan.com

Figure 9. ParoTec Planar Pressure Measurement System Source from http://www.molinarilife.it/parotec/

In addition to these four types of traditional sensors, the MEMS pressure sensors have many advantages. For example, easy communication with electrical elements in semiconductor chips, small size, lower power consumption, low cost, increased reliability and higher precision (Abdul et al, 2012). Other sensors like infrared sensors and laser range scanners are used in some other applications for high resolution data scanning through complicated imaging technology (Mendez-Zorrilla et al, 2014).

Therefore, the conclusion can be drawn that, in order to effectively measure the foot's planar pressure distribution both dynamically (in movement) and statically (standing), an in-shoe wireless system is preferred. The sensors used for building such a system have to be flexible, thin, and light enough to avoid lessening comfort when activities involving movement are performed. Durability and availability should also be taken into consideration. However, issues about how the data retrieved from the pressure sensor should be used and what features are important to keep wearers in balance should be dealt with in order to answer the research question, which is about the use of wearable technology and data visualization techniques to help designers and researchers design healthier high-heeled bespoke shoes that minimize discomfort in ways that are both effective and thorough.

2. Medical Research in Center of Pressure (CoP) Shifting and Ideal Heal Height

Feet are important segments of the human body, and they are the main form of interaction with the environment. The feet receive some stimulation whenever humans walk, and we wear shoes to protect our feet, to absorb impact, and to make human gait natural and comfortable. However, most women consider design and fashion rather than health and comfort as their top priorities when selecting shoes (Ko and Lee, 2013). According to Ko and Lee, "on the wearing of shoes, 37–69% of women prefer to wear a high heel, but high heeled shoes with an excessive focus on fashion can induce musculoskeletal diseases such as plantar fasciitis, hallux valgus, ankle sprain, and chronic lower back pain" (Ko and Lee, 2013).

"Tracking center of pressure (CoP) locations under the shoe or the foot has broad utility/application in the field of biomechanics and motor control" (Kim and Nussbaum, 2014). CoP refers to the point on a body at which the total sum of the pressure acts, causing a force with no moment about that point. A detailed definition provided by Pinsault et al. (2008) claimed that "under the conditions, when a single foot is in contact with the ground, the field of pressure forces (normal to the sole) is equivalent to a single resultant force, exerted at the point where the resultant moment is zero. This point is termed CoP" (Pinsault et al., 2008). The CoP has been used for several years as an index of standing postural stability (Ruhe, Fejer, and Walker, 2011). The CoP can also predict the dynamic balance ability (Ko and Lee, 2013). CoP is associated with force distribution of a walker in performing activities and exerting force by direct contact (Pinsault et al., 2008).

High heel shoes increase the potential for wearers to slip and fall. This is due to the consequent changes in local sensation around the ankle, which affect women's postural balance (Ko and Lee, 2013). Therefore, some previous studies had been done to decide the appropriate heel height for female to walk and to perform other daily activities. Studies show that the best heel height for maintaining balance ranges from 3cm to 5cm (Ryu, 2010). Heels higher than 5cm would cause difficulty for females in walking or in maintaining balance (Ko and Lee, 2013). However, a research study carried by Bae et al,2015 claimed that revised high heeled shoes could significantly increase rear foot pressure and lower fore foot pressure compared to conventional high heels. Additionally, revised high heeled shoes have a positive effect in static balance when compared to conventional high heel shoes (Bae et al., 2015).

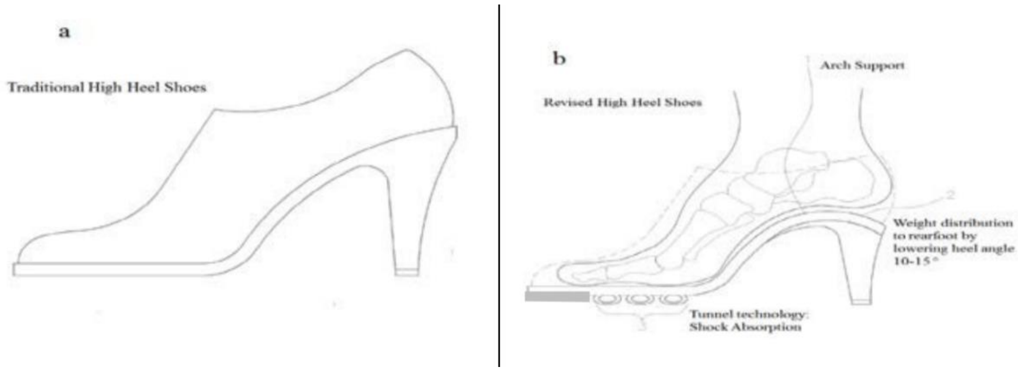

Figure 10. Traditional high heeled shoes (a) and revised high heeled shoes (b), Source from Bae et al, 2015

Previous findings show that wearers' CoP shifted significantly, when performing walking both in flat shoes (heel height = 0.5cm) and in high heel shoes (heel height = 9cm), from rearfoot to hindfoot (Ko and Lee, 2013). It is also suggested that there was no significant change in CoP when walking in 4 cm heels (Ryu, 2010; Ko and Lee, 2013). The shift in flat shoes could be due to walking patterns. Walking in flat shoes involves more contact of the hindfoot than of the rearfoot. The unchanged CoP could ensure the stability of walking and maintain the level of muscle activity around ankle and knees. Increase heel height could lower the walking speed (Esenyel et al., 2003). Walking speed has a significant influence on joint moments in the sagittal plane while not in the frontal plane (Simonsen et al., 2012). Increasing shoe heel height may induce inappropriate neuromuscular control of the trunk muscles during treadmill walking, especially at high speeds (Nam et al., 2014).

Medically, Joint Moments means muscles produce moments of force across joints during the walking cycle. Previous research concludes that knee joint moment in the frontal plane showed abductor dominance and increased significantly by about 10% when wearing high-heeled shoes (Simonsen et al., 2012). The increment of 1% in the knee joint abduction increase the risk of osteoarthritis (joint pain and stiffness) by 6.46 times (Miyazaki et al., 2002). Walking in high heels significantly increase the activity in leg muscles and trunk muscles (muscles that are on the front, including the muscles of the chest, abdomen, and the pelvis) (Barton et al., 2009). This supports the observation that metabolic energy consumption increases when walking in high-heeled shoes, which explains the decreased walking speed in high-heel activities. For both experienced and inexperienced walkers, walking in high heels, compared to barefoot walking, extensor (any of the muscles that increase the angle between members of a limb, as by straightening the elbow or knee or bending the wrist or spine backward) moment increased accordingly in knee joints and hip joints (Ebbeling et al, 1994; Simonsen et al, 2012).

The suggestion is that a heel height ranging from three cm to five cm would maintain a stable CoP (Ryu, 2010); the claim is made in previous research that "even shoes with 3.8 cm heel heights would likely find 7% increased extensor moment in young female subjects and 14% increased knee abduction movement in elderly women." Thus, the conclusion may be drawn that even moderately high-heeled shoes can contribute to the development of osteoarthritis in the knee joint (Kerrigan et al., 2005). However, this conclusion may have been reached partially due to the specific selection of the high-heeled shoes tested in the study. Thus, it is fair to hypothesize that different designs of high-heeled shoes may cause different levels of extensor movement changes. Therefore, continued research about footwear design will provide more information regarding the proposed research question.

Footwear Design: General Process and Trend

1. Footwear Manufacturing Process

"Footwear could be defined as garments that are worn on the feet" (teonline, 2016). The main purpose of footwear is to protect the wearer's feet. Nowadays, footwear has become an important component of fashion accessories. Though their basic purpose remains, adornment or defining style statement have become significant features.

Though there are many different types of shoes and categories, the basic anatomy of shoes and the general process of footwear manufacturing are similar. While shoemaking can be considered a traditional handicraft profession, it has been largely taken over by industrial manufacturers. A variety of materials can be used for making shoes: leather, plastic, rubber, wood, jute fabrics, and metal. Traditionally, it requires more than 200 operations to manufacture a pair of shoes. With modern technologies, a pair of shoes can be made in very little time by separate machines.

A shoe could be deconstructed into an upper, or a vamp, and a sole. The upper is designed to enclose and provide cushioning to the foot. The upper also typically includes an insole to provide initial support and to cushion to the bottom of the foot. The upper is attached to a sole, which provides additional protection and cushioning primarily to the bottom of the foot.

The sole is the exterior bottom part of a shoe; that acts as support. The sole also imparts stability to the shoe (Skaja and Shorten, 1996). The sole could be deconstructed into midsole, outsole, and heel. The insole is the interior bottom of a shoe, which directly contacts with wearers' feet. In some cases, they can be removed and replaced. In some of the shoes, extra insoles are often added for comfort, health or other purposes, for example, to control odours and moisture. Outsoles represent the layer of the shoe that is in direct contact with the ground. They are made with different materials for different purposes. The midsole is the layer that lies between the insole and the outsole for stock absorption. As for the heel, it is usually located at the rear part at the bottom of a shoe. It supports the heels of the feet and is usually made from the same material as the sole.

To manufacture a pair of shoes, there are usually several steps. These are: clicking or cutting for making the vamp; closing or machining for producing the complete upper; lasting and making for adjusting and molding the whole shoes as well as the assembly of attaching molded sole and heel. If the shoes are made from leather or other material they need to be post processed such as waxed and softened, and the shoes need to go through the finishing process where edges and heels are trimmed and buffed. (teonline, 2016).

The making of a vamp starts from a blank material (Dieter, 1997; Okajima, 1993; teonline, 2016). The shoe upper usually has a toe portion, a pair of side portions, a heel portion, and a bottom portion. The blank of material is formed into a configuration having two sections. The first section includes a heel portion adapted to wrap around the heel of a foot; medial and lateral side portions adapted to cover the medial and lateral sides of a foot, and a toe portion adapted to cover the toes of a foot. The second section extends from the first section and includes a bottom portion adapted to underlie the bottom of a foot. Using strip metal knives, the worker cuts out pieces of various shapes from the blank material, according to the portion placement, to make the form of the vamp (Dieter, 1997; teonline, 2016). Parts cut and selected from this step are sewn together to produce the completed upper during the closing or machining section in which a specific last (a plastic shape that simulates the foot shape) is used. (teonline, 2016).

To complete the shoes, soles and heels need to be attached to the insole board. Soles are usually made of plastic or foamed polyurethane as such shoe-soles serve the foot softly and elastically, and result in an agreeable feeling during walking. Other materials such as leather or rubber are also supported (teonline, 2016). The fixing of the uppers to shoe-soles can be accomplished by nailing, screwing or clipping whereby the uppers, in general, are fastened laterally on the shoe-sole (Ehrlich, 1985). The sole must be made specifically for the last (the solid form around which a shoe is molded) used for the making of vamp. The bottom pattern of the last is used for the insole board and the sole. The upper and the sole are stitched together using a double-stitch method in which the shoemaker weaves two needles through the same hole but with the thread going in opposite directions.

There are several steps to manufacture a shoe sole traditionally. The first is to mold a sprayed die casting so that it is dimensioned to extend across said sole from one side edge thereof to the opposite side edge thereof. The second is to arrange the sprayed die casting in a mold corresponding to the sole to be made in spacing from the bottom of the mold. Next is inserting a plastic material to be formed into the mold so that the die-casting is embedded in the plastic material and extends between the opposite side edges, therefore, securing a sole upper to the sole. The last step, after solidifying of the plastic material, is releasing of the sole from the mold (Ehrlich, 1985). Nowadays, shoe sole making machines are used extensively to cover the whole manufacture procedure.

The heel itself may be attached to the shoe using nails, screw nails, tacks, cement, staples, or sets of molded prongs (or some combination), depending on the style of the shoe, the height of the heel, the materials used in construction, and other factors including cost. Frequently the heel body is of wood or other materials, such as plastics and rubber (Quirk, 1958; Maccarone, 1932). Also, some shoes adopted the method of adding steel reinforcement to heels in ladies' shoes, to produce better supportability and durability (Cornwell, 1980). In some method of producing shoe heels, the heels are designed to include a composition of rubber and a steel spring, helping to fasten the heels to the shoes (Carlin, 1956).

2. Luxury High Heel Design Trend in 2016

It could be observed from recent fashion weeks in 2015 (London, New York, Paris, and Milan), that there are several shifts, regarding the overall design of luxury high heel footwear: material selection, color choice and the form factor, that are of vital importance for footwear designs in 2016 and later.

In the trend of material selection, leather is being favored by many designer labels. Luxury brand such as Derek Lam, Gucci, Lanvin, Jason Wu, Valentino and Dior all published their major works designed and developed in leather (Najarian, 2015).

Figure 11. Left: Lanvin; Middle: Jason Wu; Right: Gucci Source from http://www.Najarian.com/trends/spring-summer-2016-shoe-trends/

Another material that can be found frequently during the fashion week is suede (Najarian, 2015). Suede is a soft and versatile fabric used for cooler weather apparel and home décor accents. Compare to leather, suede products received more promotion than leather products (Smith, 2015). It has a variety of colors available for designers to make skirts, jackets, and vests. It also usually is used for making fashion accessories like belts, headbands, and handbags (fabric.com, 2016). It is also thinner, more delicate and easier to clean than leather. Suede is less expensive than leather. During the past fashion week in New York, suede can be observed mostly on saddle shoes and mules' shoes. Luxury footwear brands such as Marissa Webb, Mansur Gavriel, and Oscar de la Renta have published their new product in this manner.

Figure 12. Left: Giambattista Valli; Middle: Balmain; Right: Dries Van Noten Source from http://www.Najarian.com/trends/spring-summer-2016-shoe-trends/

In the trend of color selections for 2016 footwear design, silver appears to be favored by many designer labels alongside the classic black and white. Brands like Givenchy and Emanuel Ungaro use silver as main color to embellish their product. It also appears in this years' clothing and garment design (Najarian, 2015).

Figure 13. Left: Emanuel Ungare; Middle Givenchy; Right: Isabel Marant Source from http://www.Najarian.com/trends/spring-summer-2016-shoe-trends/

There are several trends regarding the overall form choice. Many brands are choosing slingback design as their products' foundation (The Ultimate Shoe Guide, 2015). Other embellishments such as fringes and laces are used as decorations based on this convention. Brands like Jason Wu, Givenchy, Dries Van Noten and Chanel have already presented products in this trend. Mansur Gavriel and Gucci also presented their design on Lela Rose Runaway show (Najarian, 2015).

Figure 14. Chanel 2016 Slingback Source from www.avechannah.com

Another trend that can be found in high heel design is the addition of new elements to traditional designs (Najarian, 2015). This trend is especially obvious for wide heel design, which is also a major style trend in high heel footwear form trend, but other types of shoes, such as sandals, stilettos, and platform heel, also adopt such design innovations. Embellishment elements such as fringes, laces, sculptures, gingham, plaid prints, chains, pearl, and buckles are embedded in the design of their product to transform the old convention. Luxury brands such as Marissa Webb, Salvatore Ferragamo, J. Crew, Chanel, Miu Miu, Louis Vuitton, Alexander Wang, Burberry, Prorsum, Mary Katrantzou and Emilio Pucci all have adopted this formula in their product design (Vogue, 2015; Najarian, 2015).

Besides, traditional wide heels and stilettos are still prevalent in high heel design. Many luxury brands such as Marissa Webb, Prabal Gurung, Marc Jacobs and Miu Miu present their products in these styles. Besides traditional high heel design, a fusion of platform heels and flat shoes (termed as flatform) have been adopted by designer brand such as Giambattista Valli, Burberry, Louis Vuitton and Versace and Dries Van Noten. Other followers in this domain include Rag & Bone, Stella McCartney, Michael Kors, Chanel, Alexander Wang and 10 Crosby Derek Lam (Najarian, 2015; The Ultimate Shoe Guide, 2015).

In summary, the observation can be made from the general footwear manufacturing process and the design of fashionable high-heeled shoes that the form of the design of high-heeled shoes can be attributed mainly to the shoes' uppers. The design of the upper is more multivariate than that of a shoe's soles and heels as more procedures are designed for this process. The making of a shoe's heels and soles proceeds mainly according to the shape of the upper. The choice of material does have an influence on the overall comfort and performance of high-heeled shoes. Thus, the conclusion can be drawn that heel height accounts for the greatest part of the wearer's stability and for the influence on the joint movement. Thus, any discomfort occurs largely because of inappropriate pressure distribution and unstable CoP caused by unsuitable heel height.

Design Process

Chapter Overview

To manifest the solution to use wearable technology and data visualization techniques enhancing the design of high heel shoes in minimizing the discomfort, two web applications and a pair of wearable shoes have been designed and developed.

In this chapter, the research first demonstrates the methodology and explains the rationale. Secondly, it illustrated the whole design and development process in detail. In the following two sub-sections, this body of research provides a narrative description of the design and development process in two different domains; hardware design and experiments and web application design and development, respectively. Finally, in the user testing section, methodology and results are being discussed and demonstrated in detail.

Research Methodology

The research method employed is prototypes as filters (Lim et al., 2008). "Prototyping is an activity with the purpose of creating a manifestation that, in its simplest form, filters the qualities in which designers are interested, without distorting the understanding of the whole" (Lim, Stoltermannd, and Tenenberg, 2008). A scaled down system is recommended to construct a portion of a complex system in a short time, test it, and improve it in several iterations in an engineering-oriented project (Shao and Hanna, 1990).

Five types of filter dimensions are defined to set the boundary of the research: appearance dimension, data dimension, functionality dimension, interactivity dimension and spatial structure dimension (Lim et al., 2008). Appearance dimension refers to the physical properties of a design. It may include but is not limited to forms, colors, textures, sizes, weights, and shapes, as well as proportional relationships among these attributes.

Data dimension is the data architecture and model of a design. It may include the overall data size, the count of letters shown on labels, the ratio of visible data to the invisible data on screen and the types of information.

The functionality dimensions are the functions that can be performed by the design. The interactivity dimensions are the rules defined by designers, in which people interact with the target system. The spatial structure dimension refers to how each component of a system is connected to each other. It includes considerations of interface layout or information elements in an interactive space.

The design aspects in this research include a hardware component for data capturing as well as the web applications. In each aspect, there are several sub-aspects that need to be prototyped: user interface layout, color template, ration of sensor performance to its dimension, graphic content and footwear performance as well as its aesthetic value.

This research will be limited in presenting central demo functionalities (i.e. pressure data capture and analysis, data visualization in different graphs on a web platform) for users to capture the basic information regarding wearers' foot planar pressure load condition and an insight into appropriate heel height. The system is expected to achieve a moderate resolution user interface design. The dimensions defined in this research for prototyping will be discussed in the following section.

Project Research Design

The whole research project includes two prototyping cycles. The composition of each cycle is: field study, prototype design and development, and a user testing session. In each of the user testing sessions, the data gathered will be used for modification of the next cycle of prototyping. In each cycle, each prototype will be completed through several experiments. Each prototype consists of two parts: digital fabrication and hardware development, and web application design and development.

The filter dimensions defined within this research include: the appearance dimension, the data dimension, the functionality dimension, the interactivity dimension, and the spatial structure dimension. The appearance dimension includes the web application user interface layout, the colour template selection for the web application, the font choices, the size of the electronic components, the form designed for the in-shoe system, and the physical material used by the in-shoe system.

The data dimension can be defined as including visible data and invisible data. Visible data includes post-analysis of the data that is based on raw data received from the sensors, data visualization in graphs and charts, and customized data created by designers or researchers. The format of the raw data will be stored in tab-separate values (tsv) file(s) and encoded in binary form.

The interactivity dimension defines how users login and logout of the web system, and how they review analyzed data in different visualizations. The web system allows designers and researchers to manipulate the designed high-heeled shoes' heel height on the basis of the data analysis result, and also to send notifications to their supervised users. The in-shoe system allows its users to perform various movement-related tasks.

In the spatial structure dimension, the whole system is connected to available wi-fi networks. The designed and developed in-shoe system will transfer its received data from sensors to a local server, where the data will be received and stored in a standard tsv file. The designer/researcher-based web application will read the generated tsv file periodically and then analyze and visualize the results on screens. The consumer-based application will present the same information in all text formats, without charts or graphs, through local wi-fi networks.

The research will start in December 2015 and end in April 2016. The first cycle of prototyping will be completed at the beginning of the March 2016, and the second cycle will be completed at the end of March 2016.

In-Shoe System Design and Development: Sensors and Structures

1. Field Research: Sensors and Their Placement

The in-shoe system proposed in this research would gather wearers' pressure data in different locations across their feet and send such data to the web application wirelessly for further analysis. Thus, suitable pressure sensors and an effective sensor configuration are required. Sensors for planar pressure measurement need to adhere to two main standards in order to handle any biomechanical gait matters: target implementation requirements and planar pressure sensor requirements (Abdul et al., 2012).

Target implementation requirements refer to design sensor devices in a flexible and mobile friendly approach. Therefore, the sensor components have to be small and light enough. The number of cables should be limited in the configuration to ensure a safe measurement from the sensor. Wireless is preferred. It is documented that a shoe attachment of less than 300 grams will not affect the gait process (Bamberg et al., 2008). Also, a thin and flexible sensor is a must for in-shoe measurement. The placement of sensors is crucial for making a natural measurement (Abdul et al., 2012). Ideally, 15 sensors should be place in different areas under the bottom of the feet to keep track of the shift of the CoP (Shu et al., 2009).

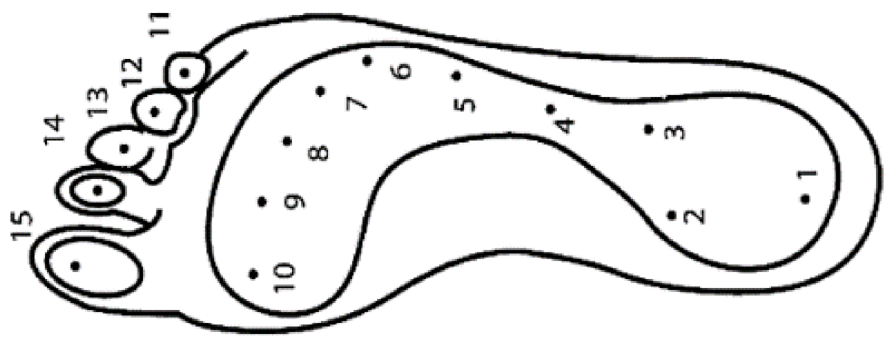

Figure 15. Foot anatomical areas Source from Shu et al., 2009

The sensor requirements for planar pressure measurement are associated with their technical aspects: linearity, hysteresis, temperature sensitivity, sensing size and pressure range (Urry, 1999). Linearity represents the response of the sensor to the applied pressure (Abdul et al., 2012). Linearity indicates how simple or complicated the signal processing circuitry will be, a highly linear response requires very simple signal processing circuitry and vice versa, a linear pressure sensor is, therefore, preferred. Hysteresis can be determined by observing the shift difference output signal when the sensor is loaded and unloaded. Electrical issues could cause hysteresis phenomenon and will cause noise during the measuring process. A lower hysteresis is recommended. In-shoe temperature will interfere the sensor measurement, and it can be altered by the level of activity hat participants have performed. Thus, a sensor with low temperature sensitivity is preferred for natural measurement.

The size and the number of the sensor influences the resolution of a reading. It is suggested that a minimum 5mm x 5mm area should be defined as an effective reading area. Sensors that are smaller than this should be placed in a form of array (Abdul et al., 2012). Pressure range is the key specification for a pressure sensor. Typically, a range around 1900kpa could be considered as appropriate for gaiting general activities, as documented in related literatures. For some extreme condition, a 3mpa record has been documented (Urry, 1999). This pressure value is equal to a healthy person of 75 kg body mass standing on only one forefoot. Besides, to ensure the availability of the sensors and to let researchers focus on developing novel sensor solutions, the chosen sensor has to be low cost in order to fit into general application usage (Abdul et al., 2012; Tanwar et al., 2007).

Sensor placement is important for pressure measurement. The in-shoe system designed and developed by Shu et al. had six force sensors attached in different locations on the insole, to achieve an effective reading, as shown in the graph below (Shu et al., 2009). Another similar sensor configuration can be found from the work done by Edgar et al., in which the sensor was used for a rehabilitation support system (Edgar et al., 2010). Researchers claim that the system had 99% accuracy in the classification. The system applied a microcontroller, a Bluetooth module, accelerometer sensor and an insole pressure sensor, positioned within the insole as shown in the figure below (Edgar et al., 2010; Abdul et al., 2012). The designed sensor can measure a pressure range from 10 kPa to 800 kPa, which makes it suitable for a wide variety of human-apparel interfaces. The sensor is packaged in silicon rubber to avoid moisture and dust (Shu et al., 2009). The textile sensor is soft, light and has high-pressure sensitivity.

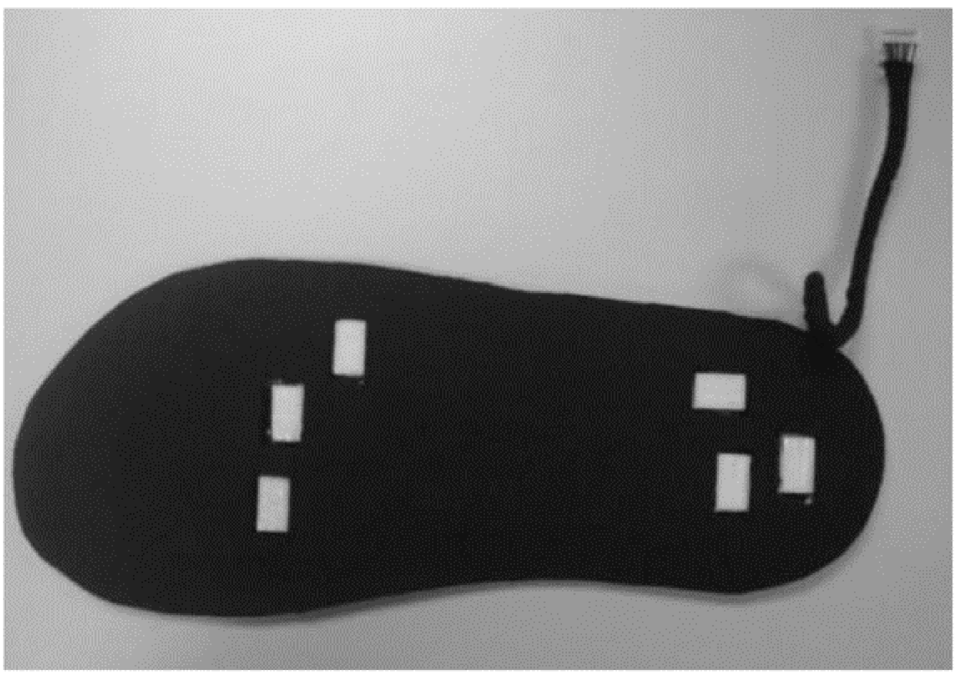

Figure 16. Fabric pressure sensing array indicating sensor placement Source from Shu et al, 2009

Similar placement can also be found in works done by Salpavaara et al. and Holleczek et al. These two projects employed innovative new sensors for their application using custom made laminated capacitive sensor matrix and textile pressure sensors. The in-shoe system designed by Salpavaara et al., 2009 can monitor the timing and movement of the legs of an athlete during throwing, jumping and running in various sporting events. The obtained data can be used to improve coaching and training. It used five-sensor placements to measure the CoP shift (Salpavaara et al., 2009).

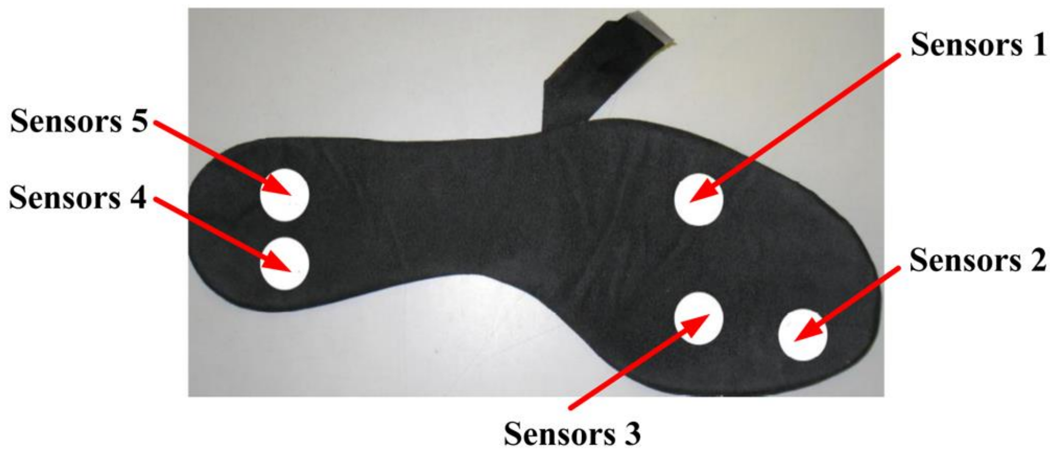

Figure 17. The five sensors placement of Salpavaara et al. designed system.

Holleczek et al. claimed that their system, "SnowPro," is capable of supporting snowboarders in improving their skill. The system can analyze the dynamics of the weight distribution inside the boots (Holleczek et al., 2010). The system placed three sensors on the insole for measuring planar pressure distribution in the form of socks. Thus, the system is inaccurate because of the fewer sensors.

Thus, it could be concluded that it is recommended to have a wireless in-shoe system in which limited number of visible cables are used. Sensors should be flexible, thin and lightweight and placed within the effective areas defined on the bottom of the foot. It is also suggested to use sensors that are highly linear in data responding, low hysteresis, insensitive to ambient temperature changes and have a wider pressure detection range to cover various daily activities.

2. Hardware Design and Development

In the design of the hardware prototype, I've adopted three different types of sensors for prototyping and decided their usage based on their performance throughout field research and experiment: FlexiForce A201, PlugandWear 8x8 Switch Matrix Sensor (PW087) and Adafruit force sensitive film.

The FlexiForce A201 is a thin and flexible piezoresistive force sensor. The sensor contains two layers of polyester/polyimide film. On the surface of each layer, a conductive material, made of silver, is applied, with a layer of conductive ink layered on top of it. The silver circle defines the active area in which sensor will provide pressure data. Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads (Hollinger and Wanderley, 2006).

The active area is 9.53mm diameter, and the thickness of the sensor is 0.203mm (Tekscan Inc, 2005), which ensures its mobility (Abdul et al., 2012). The FlexiForce sensors present great response in linearity, time drift (low hysteresis), and hysteresis accuracy while the lack of durability (Sacchetti et al., 2000;

Hollinger and Wanderley, 2006) makes it fragile and not suitable for heavy and constant activity measurement.

The maximum force that could be measured is around 100lbs (overload) (Tekscan Inc, 2005). The documented maximum overload pressure that A201 able to detect is approximately 2.89 mPa. In normal usage, a constant 111 N (11.32 kg) is documented that could achieve an accurate yet effective reading (Tekscan Inc, 2005). This makes its unsuitable for activities like standing.

The PlugandWear 8x8 Switch Matrix Sensor (PW087) is a textile-based sensor, which is flexible and skin friendly. The matrix sensor consists of five layers of fabric; the two external layers are exploited as external protection, and a knitted striped fabric is glued to each external layer. The fabric is made of alternate conductive and non-conductive stripes, with the width of the stripes determining the resolution of the fabric. The two striped layers of fabric are arranged perpendicular to one other defining a matrix of rows and columns. A piezoresistive material is placed in between the two striped layers, and when the sensor is pressed and one row is connected to a positive voltage source a current can flow in that row and passes to the other conductive layer through the piezoresistive material, in the area where the sensor is pressed. All five layers of fabric are sewn to form one unit. Flat cables connect the conductive stripes of the striped fabrics to the data acquisition unit (Appendix C).

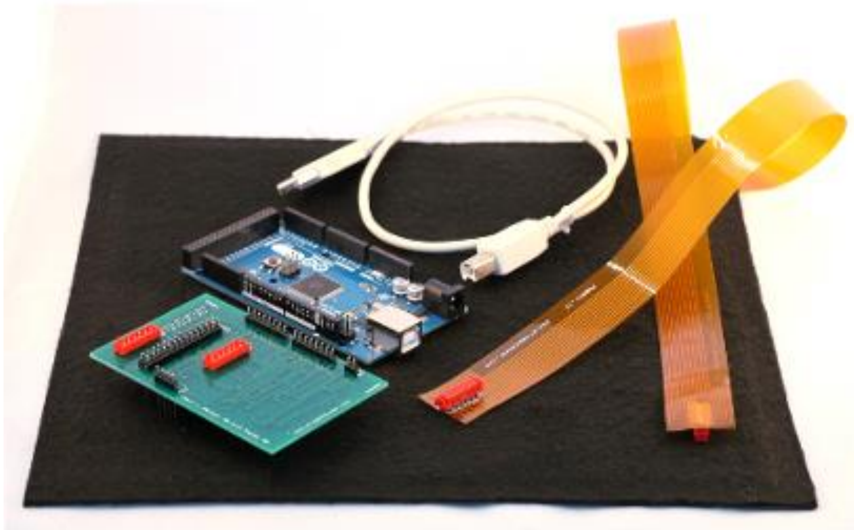

Figure 18. PlugandWear 8 x 8 SWITCH Matrix Sensor Kit

The shape can be changed by cutting and sewing. However, it needs to be re-sewn carefully following specific rules to avoid damaging the conductive area. The wiring output will be damaged and will have to be reconfigured during reshaping. The documented detectable pressure ranged from 1.8 KPa to 0.1 MPa constantly. The matrix sensor is not highly linear in response. During the experiment, the matrix sensor failed in detecting subtle force changes. Through experiment, PW087 though it has the ability to detect high-pressure value, it failed to provide identification in a moderate resolution. As well, constant noise caused by high hysteresis is also a major issue during prototyping.

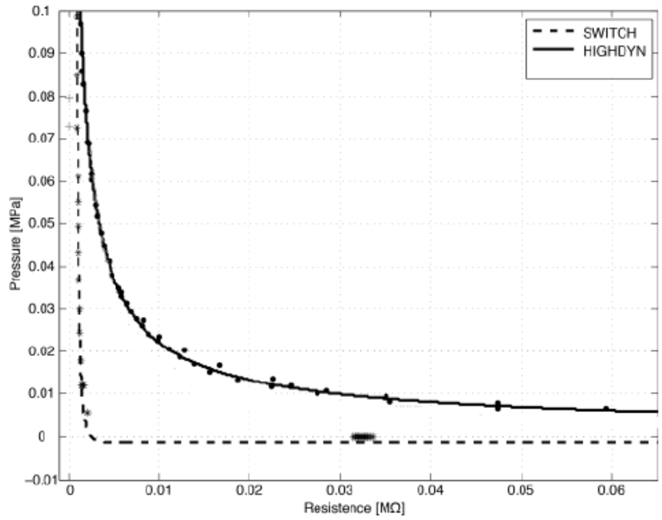

Figure 19. PW087(SWITCH) Pressure Graph

Adafruit FSR film sensor is the last type of sensor that was examined throughout the research. It is made of force sensitive film that could be easily reformed into a variety of shapes simply by cutting. The sensor film consists of a smart plastic film that can be cut to any shape to make force-sensitive switches and sensors. The black plastic sensor film is an ultra-durable material that changes its electrical resistance when force is applied to it.

Figure 20. Adafruit Film FSR Source from https://www.adafruit.com/products/1917

The film in this set of force sensors is a polymer, which is different from all other force sensing film technologies, due to the physics of how it obtains force measurements. Other force sensing film technologies use rubber-like polymers or inks that change their electrical resistance due to compressive deformation of the material, which manifests a relatively poor long-term durability. The sensor polymer contained in the FSR film sensor has the highest impact and wear resistance of any thermoplastic (ultra-high molecular weight polyethylene) such that even when very high forces are applied, there is negligible compressive deformation of the polymer film. Ultra-high molecular weight polyethylene, which has often been called UHMWPE, is a type of polymer which is used in different fields such as medicine, engineering, microelectronics and biology (Valenza et al., 2004).

During the prototyping, the sensor can detect minimal forces of a few ounces to maximum forces (overload) of 2000 pounds without changing the measurement resistor powered by constant voltage. Low hysteresis was observed. There are no current leaking issues even at these extreme overload conditions. The sensor can effectively detect pressure up to 2.48 MPa constantly. This range covers the recommended range suggested by Urry (1900 kPa) for daily gait and also covers the suggested pressure range for walking measurement (1000 kPa) (Urry, 1999).

Throughout the two prototyping stages, it was concluded that the Adafruit FSR film pressure sensor is the most appropriate choice for data resolution (wide pressure range), durability (slow deformation in constant use) and ease of configuration (thin, lightweight, highly customizable in shaping).

The "brain" of the wearable system is the micro-controller. For prototyping, I have chosen three different micro-controllers and tested their performance both in programmability and physical dimensions: Arduino Mega 2560 R3, Arduino Yun, and Particle Photon.

Arduino Mega 2560 R3 is designed for more complex projects. The Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It also has 256 KB flash memory and 8 KB of SRAM. It's accepted voltage range is from 5V to 20V with a voltage regulator. The current value that directly runs from this micro-controller starts from 30 mA (5V) to 50 mA (3.3V). It has a dimension of 101.52 mm in length, 53.3 mm in width and weight 37g.

Figure 21. Arduino Mega 2560 R3 Source from https://www.pololu.com/product/1699

In the first experiment, I adopted Arduino Mega 2560 R3 as the micro-controller and stacked with PlugandWear PW104 Matrix sensor shield specifically for Arduino Mega to support the 8 x 8 matrix sensor (PW087). To make it wireless, another Wi-Fi module was added to make data transfer wirelessly without the support of USB cable. There are very few Wi-Fi shields available on the market that support all I/O pin extended out for stacking shield like PW104. In this prototype, a customized Wi-Fi shield was used. The Wi-Fi module I used is a customized Wi-Fi module, which enables all I/O extension. This Wi-Fi module on the shield is ESP8266MOD. It also supports Bluetooth and I/O pin for OLED display.

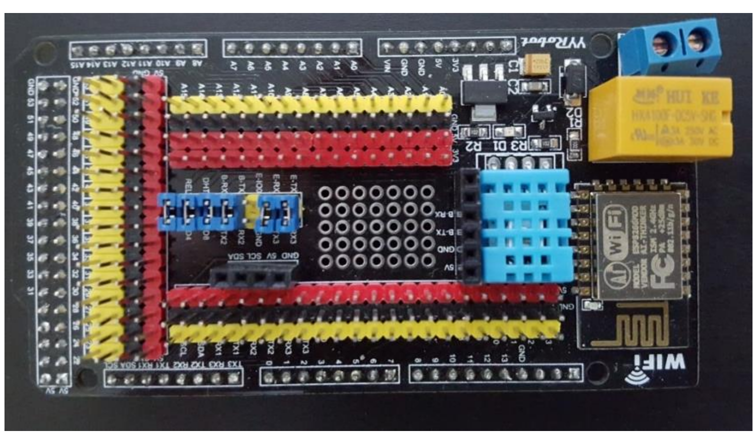

Figure 22. Customized WiFi Shield for Arduino Mega 2560

One of the major problems it is the overall dimension of the stacked electronic components. The available space inside the shoe is 8cm (length) x 3.3cm (width) x 4.25cm (height). The overall dimension of this experiment is: 6cm (width) x 12cm (length) x 22cm (height). Thus, it is not able to be placed inside the in-shoe system though this experiment outperformed others regarding functionality.

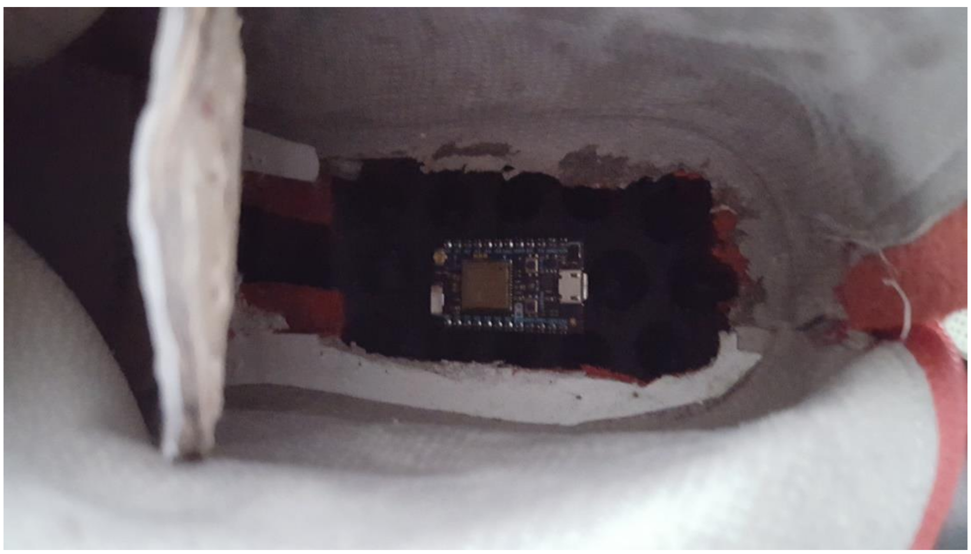

Figure 23. Available Space in the In-Shoe System

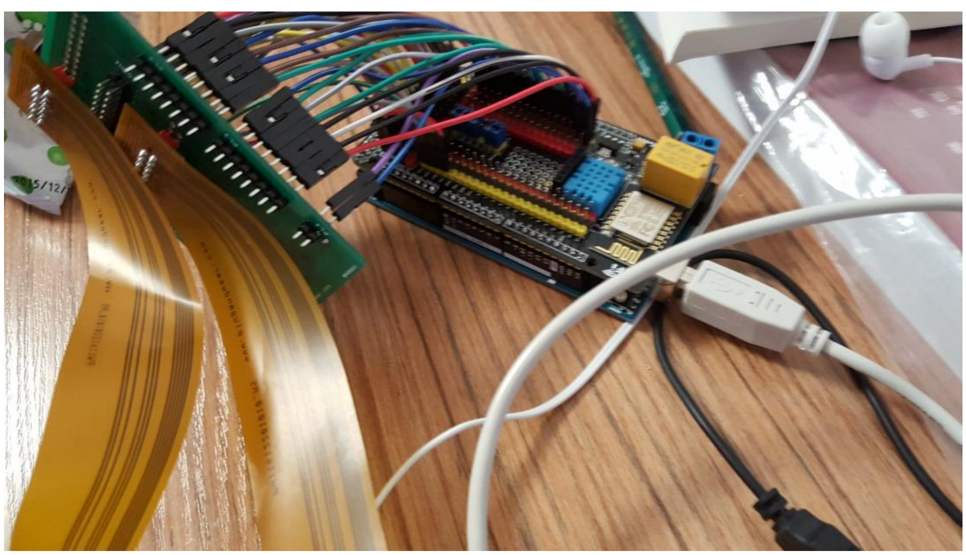

Figure 24. Overall Dimension of the Hardware Component in this Experiment

The second microcontroller is the Arduino Yún. The Arduino Yún uses the same processor as the Arduino Leonardo, the Atmel ATmega32U4. It also has an additional processor, an Atheros AR9331, running Linux and the OpenWrt wireless stack. A full install of Python 2.7 is included. There is an on-board SD slot, Ethernet jack, a USB-A Host connector and onboard Wi-Fi.

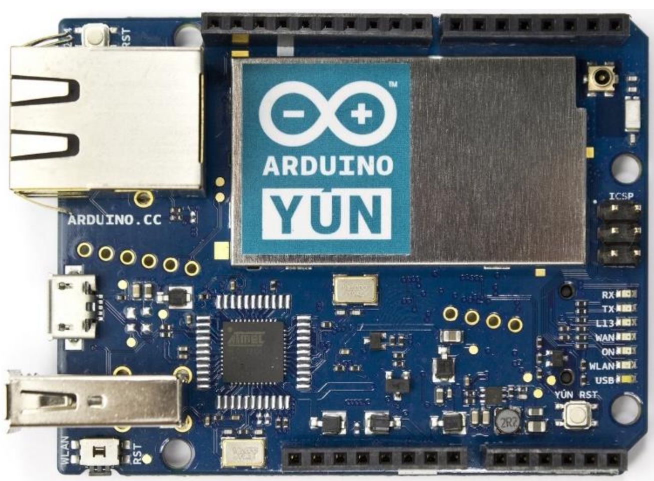

Figure 25. Arduino Yun Source from https://www.pubnub.com/blog/2015-01-07-stream-data-signal-and-trigger-actions-with-arduino-yun/

The Arduino Yun has only 20 digital and 12 analog extension pins and are therefore incompatible with The PW087/PW088 and the required extension shield, PW104. In this prototype, I used five Adafruit Film sensors. As with the first prototype, though considerably smaller in dimension (approximately 8cm in length, 5cm in width and 2.5cm in height), the Arduino Yun could still not fit into the limited space provided in the heel part of the shoes completely.

Particle Photon is a combination of ARM Cortex M3 micro controller and Broadcom Wi-Fi chips. Power to the Photon is supplied via the on-board USB Micro

B connector or directly via the VIN pin. The voltage should be regulated between 3.6V and 5.5V if powered externally. Its dimension (36.58mm x 20.32 mm x 6.86 mm) is ideal for the construction of the in-shoe system. It has the largest RAM (128 KB). Compared to the Arduino Yun and the Arduino Mega 2560 R3, the Photon does not support direct code flash. Programming on the Photon relies heavily on Particle Build - a cloud-programming platform specifically made for Photon. It only supports eight digital pins and six analog inputs, which potentially reduces the resolution of the data captured. Notably, Photon is the only valid choice due to its small size. However, during the prototyping stage, photon revealed several issues: limited storage, unstable connection to the cloud and limited numbers in I/O pins.

Currently, there is neither a micro SD card slot nor available SD card module available for Photon on the market. To resolve the first problems, the Photon is programmed to post an activated reading every 1 minutes to reduce the log size stored temporarily in RAM and the problem of lags. The second issue is unavoidable. As a cloud based micro controller, it relies heavily on Particle Build. Thus, the connection status relies highly on current Wi-Fi network condition and the Particle Server. In theory, the maximum number of sensors that can be activated by Photon is 6 (analog sensors) but, during testing, six sensors consume power quickly, which is not ideal for constant measurement, thus, five sensors are used for maintain the data resolution. The sensor placement is following

Salpavaara et al.'s method with a 3.7 V 80 mAh rechargeable Li-on battery as external power supply.

Figure 26. Finished Prototype

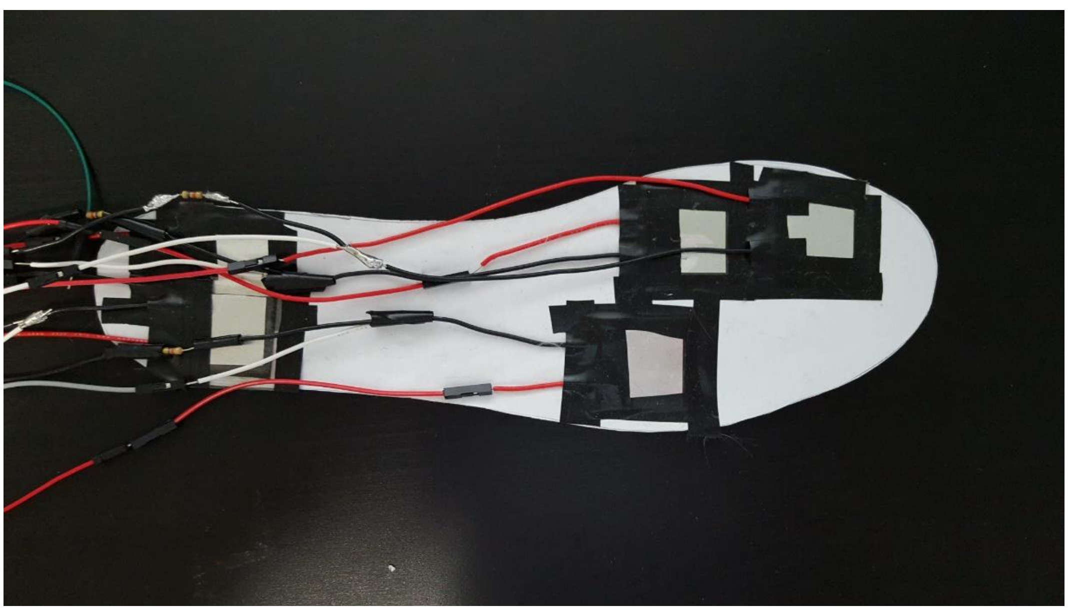

Figure 27. Sensor Placement

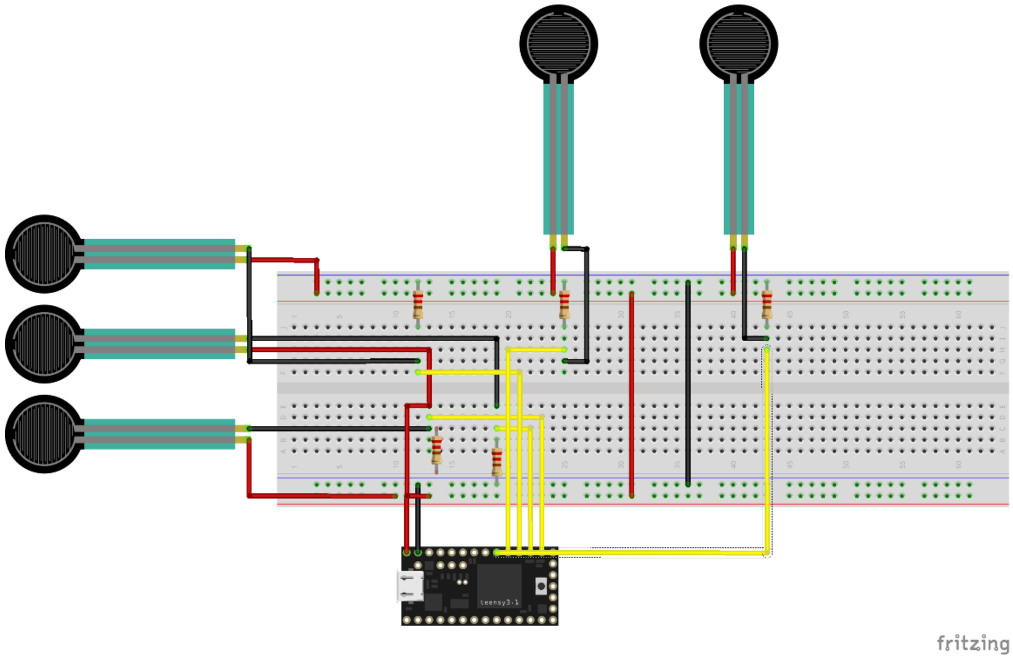

Figure 28. Circuit Structure

Web Application Design and Development

1. Field Research: Infographic

Two web applications for data processing and output were designed for this research. One is developed for footwear designers or researchers, and the other was for users/wearers to receive the analyzed data. The most important parts of the visualization are the user interface design and the appropriate approach to visualization for presentation of information related to planar pressure distribution. All of these elements are related to infographics design.

Infographics or information graphics combine elements of data visualization with design and have become increasingly popular means for dissemination of data. Infographics are usually used to communicate complex data in an engaging manner. Infographics, which are defined as collections of one or more visualizations that have been manually modified to highlight specific points about the data, provide the audience with an overview of a topic through data and other available materials (Borkin et al., 2013). The research suggests that infographics and data visualizations have been observed as exercising a positive influence on users' engagement (Bateman et al., 2010) and capacity to remember (Borkin et al., 2013).

Previous research suggested that the aesthetic aspects are some of the main contributors to this influence (Bateman et al., 2010; Borkin et al., 2013). The first impressions of infographic works may be due to their colour and visual complexity (Harrison et al., 2015). Colour has been shown to affect perceived trustworthiness (Cyr, Head, and Larios, 2010), users' loyalty (Cyr, 2008; Cyr, Head, and Larios, 2010), and the intention to purchase (Hall and Hanna, 2004). Colourfulness or the perceived colourfulness is very dependent on the distribution of colors in an image and on the composition of adjoining colours. A high number and variety of colours in an image and a high level of brightness can increase audiences' perceptions of colourfulness (Reineke et al., 2013). Some researchers argue that visual complexity is one of the main attributes that influence the overall visual appeal of a web application (Tuch et al., 2012; Tuch et al., 2009). Colourfulness and complexity account for 34% of the variation in participants' ratings of appeal (Harrison et al., 2015). The audience's first impression can be modified by changing the overall colourfulness and complexity (Reineke et al., 2013).

A design should be optimized by attaining a low-to-medium level of complexity and a medium-to-high level of colourfulness. The lower the level of visual complexity, the faster the response time will be. It has been shown that consumers prefer interfaces with moderate visual complexity (Geissler et al., 2006). Researchers found that moderate complexity has the greatest user feedback. Researchers also found that, among female users, colourful and yet less complex infographics are preferred. Among male users, less saturated colours are favored. Complexity is relatively unimportant for male audience members. The preference for simple infographics increases slightly with age and education. Thus, infographic works with little text and image areas and a moderate level of perceived colourfulness might appeal to most participants.

Direct charts are preferred for presentation of information in collections of visualizations. Experts such as Edward Tufte have made the criticism that adding decorations and other kinds of imagery that are not essential for description purposes to a chart can make interpretation more difficult and can distract the audience from the data (Tufte, 1983; Reineke et al., 2013). However, other researchers have claimed that embellished graphics can draw the audience's attention to the content (Bateman et al., 2010). At this point, there is no definite answer to this question, but the research does suggest that minor decoration in charts might not cause an incorrect interpretation. Research in the field of psychology has shown that the use of imagery can influence the capacity to remember information in an infographics work. However, there are very few signs that indicate how the imagery in a chart can affect the way people view information in a chart.

There is no difference regarding the accuracy of interpretation that arises from the way data is presented both in embellished and minimal contexts. Yet an embellished interface does increase the capacity to remember, and this greater capacity suggests that “the addition of strong visual images does help people to remember both the topic and details of the chart” (Bateman et al., 2010).

A high data-ink ratio (the ratio of actual data to graphical decorations) is correlated positively with faster response times and better accuracy, but there is also the suggestion that, by altering the overall layout, audience response times and perceived accuracy could possibly be changed (Gillan and Richman, 1994). From the audience’s perspective, a graphically embellished chart could provide a better level of memorability, and its performance in user evaluations is no worse than the performance of a minimalist chart (Bateman et al., 2010).

2. Application Design and Development

The prototyping stage includes two parts: user interface prototyping and functionality prototyping. The user interface prototyping focuses on the layout and the colour template, while the functionality focuses on how users can use the application and what functionality should be provided.

The system has two web applications designed and developed for different clients in different frameworks. The first one, developed in PHP, is targeted for fashion footwear designers or laboratory researchers. Thus, it provides information that is visualized in various graphs and charts (Multiple Stacked Graph, Multiple Linear Graph, Heat Map) that are necessary for designers or researchers to use. The other one is designed and developed for high-end consumers, who wear bespoke high heels with electronic components embedded. The two applications share the same database, and they are both running in local environments at this moment.

The two applications share the same interface layout, with variations in the choice of transition animation and colours. Another difference between these two applications is that the consumer one has been designed and developed to be responsive across platforms. This means that consumers can have access to the application on screens with different resolutions. The designer/researcher application does not have this feature, however.

The layout being adopted in this prototype is based on the rational layout type (Hsu, 2011), but it eliminates the traditional top navigation section and integrates it into the left-hand bar. This layout is relevant in today's application dashboard design. Applications such as Chartbeat, Squarespace, and Youtube are all based on this convention. Rational layout performed well in functional evaluations, but could not get the audience emotionally involved (Hsu, 2011). It is superior as a functional layout for multi-task interfaces and processes with more concentrated overall fixation points. In addition, three of its variation layouts are superior in terms of overall user experimentation (Shao et al., 2015). However, this type of layout does show its weakness in total fixation duration.

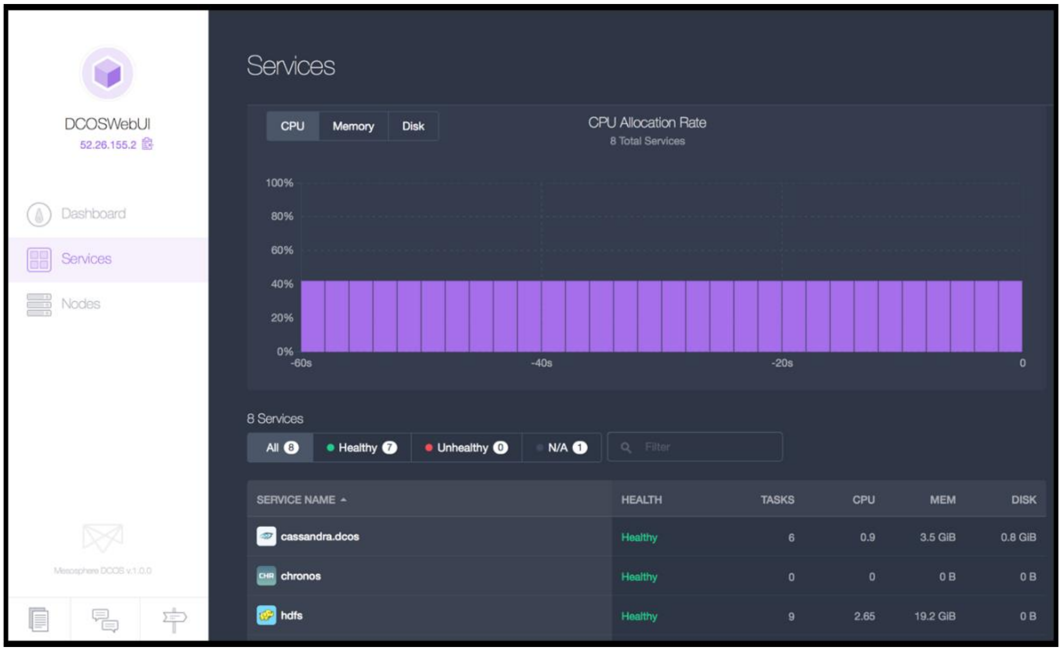

Figure 29. Rational Layout Example Source from
https://docs.mesosphere.com/administration/webinterface/

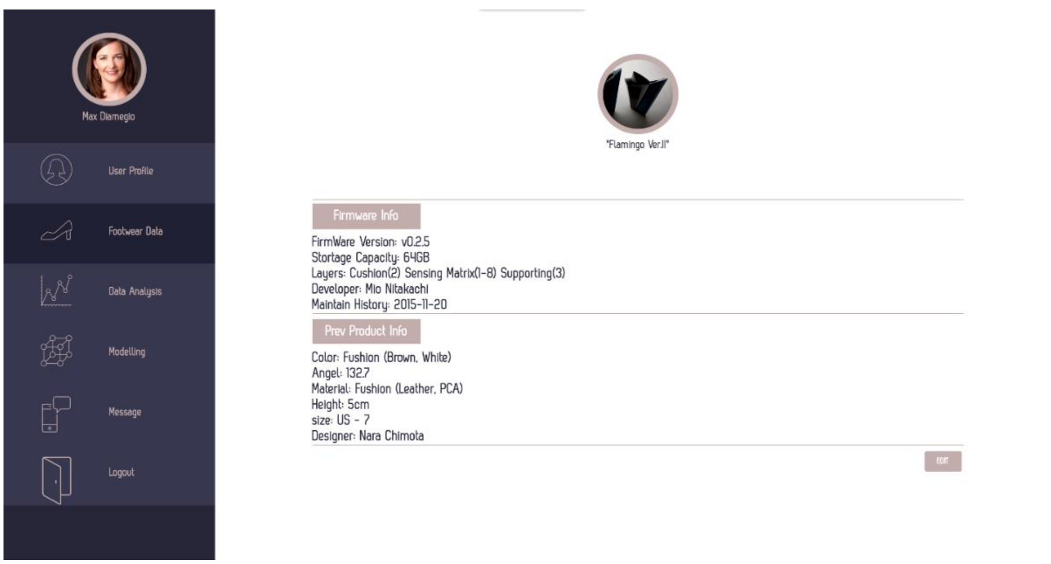

Figure 30. The System Interface Layout

The designer/researcher-based application is developed in PHP on the PHP web framework Laravel (version 5.1). The Laravel PHP Framework is built with a focus on writing code syntax that is simple and expressive. Laravel is based on the

MVC (Model, View, and Controller) structure. Laravel provides a powerful database migration system that alleviates daily tasks such as version control and database query. The designer/researcher-based application provides functions for users to: acquire information regarding planar pressure distribution and CoP shifting of wearers in real-time through three types of visualizations, send analysis results to associate wearers through wi-fi, and interface protocols for users to decide the appropriate heel height of wearers.

There are two types of data analysis defined within the application: CoP Shifting Analysis and Planar Pressure Distribution (PPD) Analysis. In CoP Shifting Analysis, heat map was used as the visualization method. The system categorized the area of the foot bottom into three parts: rear, medial, and hinder. Different colours were used in this visualization to represent where the current CoP is (rear: yellow; medial: green; hinder: orange). The In-Shoe system keeps sending data wirelessly per minute; the data is then received by a node server and analyzed to represent the current CoP location in the backend. Finally, the data is stored in both a local tsv file, which is read by the front end of the web application with the help of D3.js, and a local SQLite3 databse. At the bottom of the CoP Analysis interface is the description section, where a summary of the current wearer's pressure distribution information is displayed. The information includes: the average pressure value of the rear, medial, and hinder part of foot; the expectation of the pressure value of the rear, medial, and hinder part of the foot in the next timestamp; and the average CoP location throughout the entire time.

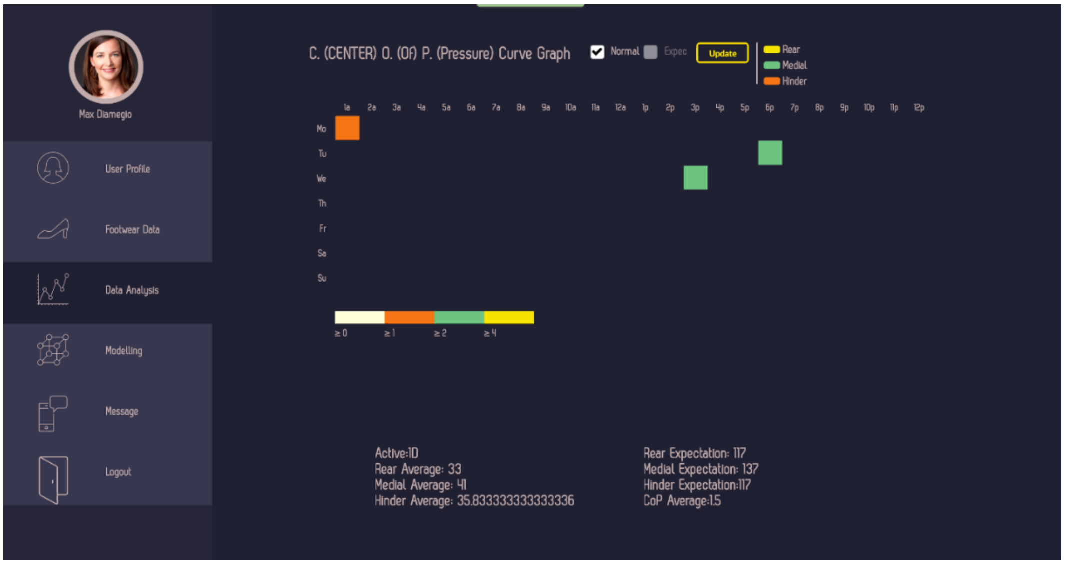

Figure 31. The Interface of the CoP Shifting Analysis Visulization

The PPD Analysis adopted both the multiple stacked graph and the multiple linear graph as visualization methods. The stacked graph is used for showing the overall distribution condition of the whole foot, while the multiple linear graph is used for presenting the value change of each of the five sensors. The five sensors are also categorized in three sections consistent with the foot area definition: two sensors for the hinder and medial, and one for the rear. By selecting the toggle on the top of the interface, users can switch visualizations and which area of the foot they want to inspect. A description section is also presented in this interface. The summary information is the same as that of the CoP Analysis.

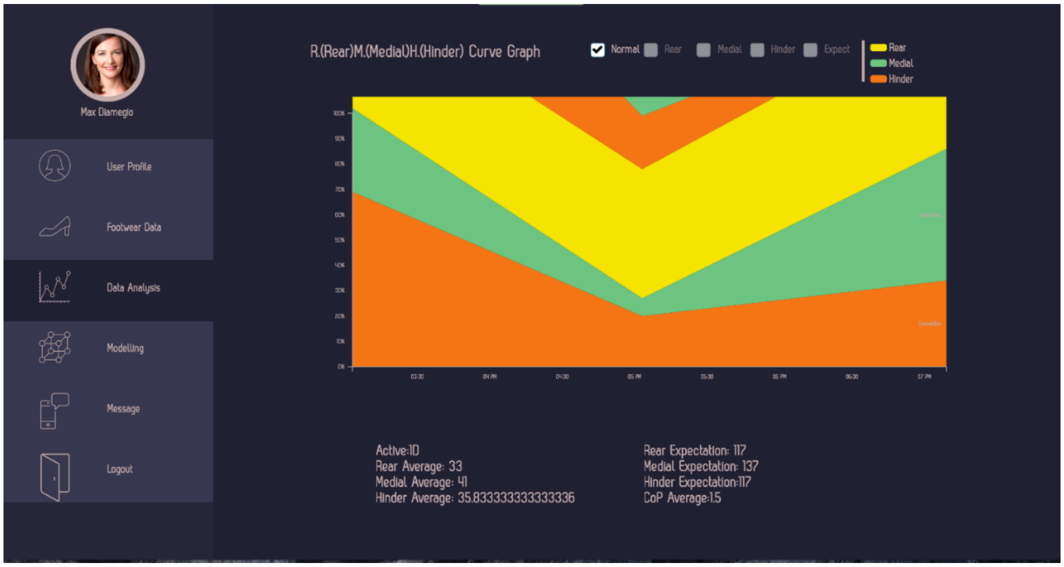

Figure 32. The Interface of the PPD Analysis (Multiple Stacked Graph) Visualization

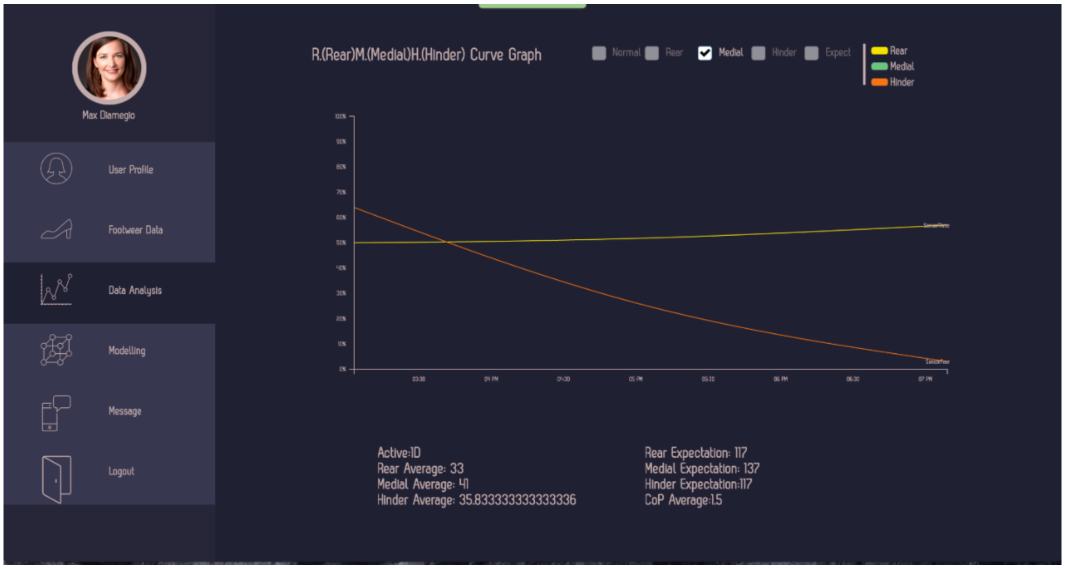

Figure 33. The Interface of the PPD Analysis (Multiple Linear Graph) Visualization

D3.js is a JavaScript library for manipulating documents based on data. D3 helps developers and data scientists bring data to life using HTML, SVG, and CSS. D3's emphasis on web standards provides consumers the full capabilities of modern browsers without tying them to a proprietary framework; D3 combines powerful visualization components and a data-driven approach to DOM manipulation.

Three.js is used to contribute to the “modelling” function, in which the system provides spaces for designers/researchers to manipulate the heel height. In this way, functions are provided that allow designers to explore the potential height, based on the data derived from the bundled in-shoe system.

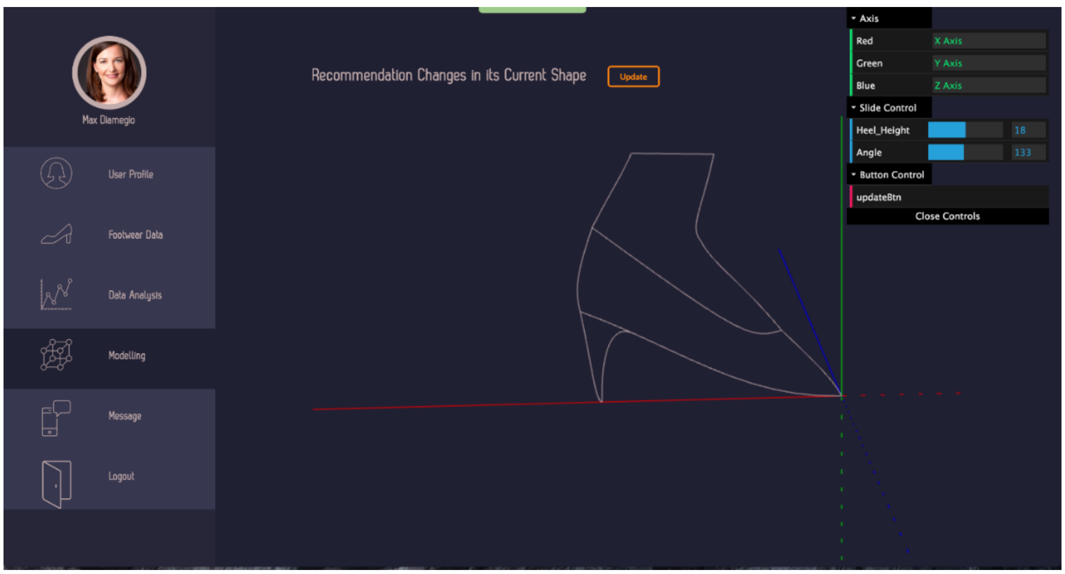

Figure 34. The Interface of the Modelling Function

The designer/ researcher-based application is also designed to provide a channel for users to send customized messages to the related client-based application through a HTTP request. This channel is used to ensure that clients will receive the most recent information about their walking pattern and about whether the current shoes they are wearing are suitable or not, in addition to the basic analyzed information.

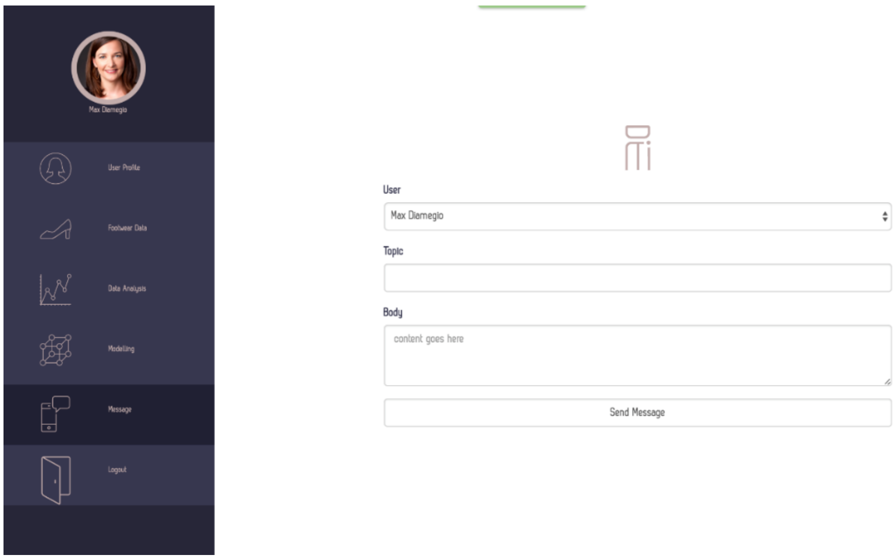

Figure 35. The Interface of the Message Function

The client interface is designed around Python, which is based on a web framework, Django. Like Laravel, Django is based on MVC and, because of its notable longevity, it has a considerable fan base, which results in better support and documentation. Another advantage that leads me to use this as a client-based framework is the better form of support as well as easy ACL (Access Control List) support.

The client-based application receives information from the database of the designer/researcher-based application. Thus, in the first prototype, the application is not equipped with detailed data visualization, nor it is necessary to have such a detailed monitoring function embedded. In the plan, the application will present only post-analysis information, such as appropriate heel height according to users' walking behaviors and their current CoP, and customized messages from their responsible designers.

Figure 36. The Interface of the Client Side Application – Function "Monitor Results"

Figure 37. The Interface of the Client Side Application – Function "Notification"

To conclude this section, the image that shows the overall structure of the designed system is presented below.

Figure 38. System Structure

User Testing

1. Overview

To identify user issues with the performance of the designed and developed wearable-based visualization system, two cycles of user testing were designed to pinpoint user preference and usability issues within this research. In each user testing cycle, in-person interviews and on-site surveys were included. Participants were asked to perform a series of tasks designed by the principle investigator (PI) in order to evaluate the interactivity and functionality of the proposed system during the in-person interview. Participants were asked to evaluate the overall design and quality of the system during the survey session. The Survey on Evaluation of the Wearable-Based Visualization System is presented in Appendix 1. Audio taping was used during the entire user testing process based on participants' consent. Raw data gathered in user testing was preserved in an encrypted hard drive for 24 hours before permanent deletion. No visual data was included in order to ensure the privacy of the participants. This user testing focused on testing the functionality, usability, and user interface appearance of the web application. This user testing did not test the participants' performance differences in various heel heights.

2. Participants

The research population consisted of females from 22 to 55 years of age. In each user testing cycle, four female participants were recruited. Participants had to have on wearable shoes with a heel height of five cm for a minimum of 30 minutes and a maximum of 45 minutes, with isolation-protected layers (plastic bags and woolen socks). Differences in age, height, and mass among participants were not significant. Before the testing, participants were fully informed about the experimental procedures and provided their written consent. Participants took part in the user testing at 205 Richmond Street West, Room 7602. The research was approved by the Institutional Human Research Ethics Committee. It should be noted that there were no background requirements for the recruitment of the participants. Though the system consists of two web applications, and one of them is designed for fashion designers and researchers, the resources for recruiting such candidates were limited. However, most of the participants came from a design background, and some of them had experiences with various data analysis research projects.

3. Protocol

Participants were asked to perform a series of tasks involving movement during the in-person interview. These tasks included walking, jumping, and slow running. Participants performed such activities at a self-selected speed on a flat, straight walkway approximately eight m in length, with the In-Shoe system. Prior to the data collection, the participants performed several practice trials to determine the optimal starting point, to prevent the interference of undefined variables in the testing results, and to make sure that the walkway was in the same safe condition for each participant. After the movement test, participants were asked to operate the web application to retrieve information regarding the activities the participants had just performed and to perform the tasks of analysis: The Current CoP, the Planar Pressure Distribution, the Force Distribution Expectation Analysis, and the Maximum Heel Height Prediction. Participants were asked to provide their opinions regarding the design aspect of the system (user interface layout and color appropriateness). A full list of questions can be found in appendix 2, Interview Questions.

4. Data Collection and Analysis

Planar pressure data generated in the user testing was gathered from five Adafruit Force Sensitive Resistors (2cm x 2 cm) placed in different locations in the participants' insoles in real-time. The data was received by Particle Photon and stored in the JSON format, ready for internet transmission to the web visualization application as output. The raw data was stored in a tsv file on a local server. The post-analysis data was stored in the SQLite3 database on a local server.

The completed questionnaires were documented digitally and also organized in Excel. The similarity and tendency of the feedback were captured and documented for the research. The analyzed data was presented in figures.

5. Results

A total of eight participants took part in the two user testing sessions; each session had four participants. The participants' ages fit into these age groups: 22 to 27 (four participants), 28 to 33 (two participants) and 34 to 39 (two participants). The participants' backgrounds are all design/media related. This user testing session looked of the user feedback for appearance dimension (user interface, perceived colourfulness), data dimension (information sufficiency, data sufficiency, and accuracy), and interactivity dimension (functionality sufficiency, the system's overall performance and usability). The two web applications and the In-Shoe system (designer/researcher-used and user-used) were evaluated respectively.

5.1 Appearance Dimension Evaluation

5.1.1 Designer/Researcher Based Web Application

During the interview, all the participants evaluated the overall appearance of the user interface as decent and clear. Two of them claimed that the layout choice is more suitable for a desktop application than for a web application. One participant claimed that the grid system used in the interface design did not follow the golden ratio, and it appeared to be slightly imbalanced.

Seven of the eight agreed that the overall layout is good for navigation. One participant stated that users will need to go through two layers in order to access the "data analysis" function provided by the system. Three participants agreed that the color choice for the system is professional, but not exciting to see. Half of the participants questioned the choice of the icons used to represent each function provided by the system. They stated that, without the word description on the left, these icons would be difficult for the audience to identify. Two participants required a responsive design in the designer/researcher-based web application.

Two of the eight participants suggested that the fonts used for the applications are not regular fonts that are default pre-installed on PCs or Macs. They appeared to be smaller and narrower, characteristics that could create difficulties in identification and possibly cause sight impairment.

None of participants indicated any issue regarding the colour choice, but they did suggest that the colour is professional, yet less than exciting at the same time.

5.1.2 Client Based Web Application

In a way that was consistent with the evaluation of the designer/researcher-based application, all participants evaluated the overall appearance of the user interface as decent and clear. Five of the eight noticed the responsive design of the application and agreed with the design concept. None of the participants experienced issues in navigation and information queries. There was no question raised regarding the choice of the icon used for this application during the user testing. Two participants were concerned about the color choice in this application and stated that it was a little bit dark.

5.2 Data Dimension Evaluation

5.2.1 Designer/Researcher Based Web Application

Five of the eight relied on the word description section on the interface to accomplish the tasks (see Appendix 1) at the beginning. Half of the participants agreed that the learning curve for the visualization provided by this application is high and that they needed further context to understand the meaning of the Planar Pressure Distribution Stacked Graph. Only two participants understood through observation the "Planar Pressure Distribution (PPD) Stacked Graph" visualization without further description. Seven of the eight encountered no issues in understanding and inquiring about information from the "CoP Shifting Map" visualization and could complete tasks, such as "finding the overall CoP" and "predicting the trend of the CoP change in next timestamp." Six participants understood the type of data measured by this system without further clarification. Two of the eight questioned the information sufficiency of this system and were not sure if designers/researchers could develop healthier high-heeled shoes with the given data. Five of the eight were able to predict the maximum heel height, given the available information, and these predictions were compatible with their personal experience. Five of the eight felt that the data analysis was consistent with their wearing experience.

5.2.2 Client Based Web Application

There was no graphic visualization provided in this application. Six of the participants agreed that the word summary was consistent with their expectation. Half of the participants suggested that they would like to have more information regarding their walking behaviours, such as walking posture feedback. All participants agreed that the customized message sent by the designers was very helpful for them in terms of developing insights about their walking patterns.

5.3 Interactivity Dimension Evaluation

5.3.1 Designer/Researcher Based Web Application

Six participants agreed that the functions provided by the system were sufficient for users to understand the wearers' planar pressure distribution during walking. Half of the participants could use the functions to accomplish all the tasks pre-defined for the user testing without the provision of further information.

All the participants agreed that the modelling function provided by the system is fun to play with and could have much more potential in the future. They also thought that the customized message function would be important for professional designers or researchers in the provision of more noteworthy information to their supervised wearers.

Participants did not experience any difficulties in utilizing functions to accomplish given tasks during the user testing session. Five of the eight participants thought that the system was relatively complete overall, but that more development should occur for further polish. The others suggested a focus on the current functions, especially modification of the visualization to make it simpler.

5.3.2 Client Based Web Application

All the participants could accomplish the tasks designed for the user testing without difficulties. Three of the participants thought that more analyzed information should be provided to the user. All participants thought that the notification function has more potential and should be more developed. Five of the participants stated that that this application is complete overall.

5.3.3 In-Shoe System

None of the participants experienced any imbalance issues during the movement test before the interview, when they performed activities with the wearable insole. The participants agreed that the wearable insole were working correctly during the user test. Half of the participants expressed concerns about the durability of the wearable insole.

6. Discussion

During the two rounds of user testing, all the participants agreed that the overall resolution of the user interface is moderate and decent at this stage. The layout choice performed well overall in navigation. Two participants suggested that the layout is more desktop-like rather than like a traditional web page. The suggestion was also made that the overall appeal of the two applications is professional. Though this layout is not like a conventional web page, it does provide better navigation and a lower level of visual complexity. Participants also noted an overall good level of perceived colourfulness. However, the participants did state that the overall colour choice is less exciting and has a regular professional appeal. The suggestion from the previous research is that a high saturation colour choice could increase the colourfulness, and the result could be a better first impression. The user feedback is consistent with such findings. The dark background colour choice was used to make the visualization more obvious, and to let users focus on it.

Most of the participants suggested that the proposed system (both applications) is complete in its functionality at its current stage. Some participants felt that the monitoring- related functions in the client-based web application are too simple. More information needs to be provided. This impression occurred because of the initial design concept, which oriented the user-based web application to act as a real-time data receiver, a usage that is different from that of the designer/researcher-based application. However, the suggestion is considered, but not adopted at this current stage because of limited resources.

It was noted that some of the participants encountered difficulties in obtaining information from the visualization interface in the designer/researcher-based application. This difficulty occurred because some participants were not familiar with the graph layout. Their real-life profession is not necessarily associated with data analysis. There was no background requirement for participant. In light of the fact that all the participants were able to accomplish tasks successfully, the conclusion might be drawn that the higher learning curve in the designer/researcher-based application is acceptable.

Participants expressed their expectations about further development of the functions of modelling and customized messages. At the current stage, the modelling and message functions could not be fully developed because of resource limitations (human resources and time). This expectation is consistent with the future work of this system.

Overall, the performance and completeness of the system received moderate confirmation. The user interface achieved an acceptable score in every evaluation dimension. Users are able to use the system to predict an appropriate heel height, according to the data, and the prediction's accuracy is confirmed through participants' knowledge and personal experimentation. The proposed system did support the hypothesis that the system is creating a solution for designers and researchers so that they may design appropriate high heels that minimize the discomfort of traditional high heels.

Conclusion

Traditional luxury high-heeled shoes cause health problem for their wearers. The CoP of wearers shifted when they were wearing high heels, and the shift led to imbalance. There are also reports that wearing high-heeled shoes increases the possibility that wearers will fall and slip. This kind of accident may occur because of the changes in local sensations around the ankles (Ko and Lee, 2013). Increasing the heels' height may also slow down wearers' walking speed (Esenyel et al., 2003) because of inappropriate neuromuscular control of the trunk muscles during treadmill walking. Increasing the heels' height can levitate the knee joint's abduction movement (Miyazaki et al., 2002), a shift that increases the risk of the progression of osteoarthritis. These problems are in conflict with the interests of luxury fashion footwear industry, which continues to advertise its products in designs such as wide heels and stilettos with aesthetic embellishments. There are also reports that luxury brands are now facing challenges in improving customers' personal experiences (*2015 BrandZ Top 100 Report*, 2015). Many corporations, like Burberry, have already started, as a further promotion, to work with technology companies to produce wearable products that provide a customized experience.

The insole planar pressure measurement system has already been used for various research purposes, such as sports and rehabilitation pressure monitoring

(Abdul et al., 2012). Such systems effectively provide insights about participants' personal conditions, but they are rarely used in the field of high-heeled shoes design nor could be wore in daily life.

This research focuses on the issue that high-heeled shoes usually lead to instability and can possibly produce lower limb injuries. This research leads to the design of a wearable visualization system, which includes two web applications and a pair wearable shoes. Although the project has limited resources (i.e., time and participants who are professional fashion designers), the feedback from user testing indicates that the effectiveness of this proposed system can be confirmed.

The participants demonstrated that this system is friendly for users, who may interact with it. The system's functionality is documented as an appropriate functionality that enables users to obtain insights about wearers' walking conditions. The proposed system could be used for providing wearers' real-time CoP and planar pressure distribution results for fashion footwear designers and researchers to manufacture high-heeled shoes with appropriate heel height. However, the system does not undercut the high-heeled footwear form design. Analyzed data and reports could lead to customized high-heeled footwear, suitable for the wearers, which could minimize the discomfort usually wearing high-heeled shoes would cause.

Such reports will also be sent to the wearers to inform them about their balance and recommendation of appropriate heel height. It should be noted that the system does not advise wearers to stop wearing high heels at any conditions. With the data, wearers will be could decide if they should change their current footwear or which pair of high heels is suitable for them to buy.

Future Works

The research presented in this thesis meets its limitation in time scope and human resources, thus further investigation and testing will be required to evaluate the performance and usability of the proposed system in fashion footwear industry.

At current stage, the proposed system is developed for footwear designer and researchers as a tool for gathering wearers' live pressure data, which could be used for manufacturing comfort high-heeled shoes. However, other directions may also be take into consideration. These directions may include providing data support for designing high-heeled shoes that specifically fits for dance performance, and orthotics high heels shoes that fits for wearers with special needs.

To obtain a detail description of the wearers' balance condition, other type of data, such as temperature, humidity, posture, and break suggestions will also be measured and reported in future. Such improvement is coherent with the feedback from the user testing, in which participants were expected to see more information in the client side application.

From the user testing, participants are enthusiastic about the modelling function in the system. Thus, a further development will be done in the future. At the current stage, this function could only provide suggestions of the appropriate heel height according to the live data. In future, with the collaboration of various luxury footwear brand, the form data of classic high-heeled shoes, such as Jimmy Choo's stiletto, will be integrated into the system. Eventually, a complete and appropriate designed high-heeled shoes will be suggested in the modelling function, according to the need of each manufacture and the walking condition of the wearers. In this a, a high-end customization footwear service will be formed.

The wearable shoes in the proposed in-shoe system ideally will be designed and manufactured with the help of 3D printing technology, which will create enough space for necessary electronic components. The current finished wearable shoes are 3D printed in nylon, a material that is fragile and as a result confines most fashion shoe applications to high-end special occasion footwear. With the maturing of 3D printing technology there will be greater choice of material that will be more robust and suitable for daily wear not just special occasions. The cost of the manufacturing technology will also decrease, particularly with the predicted advent of Direct Digital Manufacturing where consumers can print products in their own home or office. This is expected within the next decade. The convergence of lower cost and advances in technologies with new manufacturing and consumer engagement will offer new possibilities and markets for my product and the service it provides in the future.

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Appendix A - The Survey on Evaluation of Wearable-Based Visualization System

The aim of this user test is to get user feedback on the overall performance and functionality of the purposed wearable based visualization system. The questionnaire includes 12 questions. It is required that all the following questions need to be addressed. The questions are presented in a combination of single choice, multiple choices, and fill-in questions. You will not be asked to provide any specific information except your name. Please note that all participants have the right to withdraw or alter their feedback in 15 days after their participation. Your name will not be included in the research for any purposes. Thanks for your participation.

1. May I know your name?

____

2. Please select your age group [single choice]

○ 20 - 25
○ 26 - 31
○ 32 - 37
○ 38 - 43
○ 44 - 49
○ 50 - 55

3. How often do you wear high heel shoes? [single choice]

○ Everyday
○ Quite often, few times per week
○ Occasionally, few times monthly
○ Few times per year
○ I don't have high heels

4. If you don't wear high heels that often, what are the reasons behind it? [multiple choice]

□ They limited my activity.
□ They hurt my feet
□ They are not supportive.
□ They don't make me that much taller
□ They are not that beautifully designed compare to flat shoes

5. During the user test, do you feel any discomfort in performing activities when wearing the wearable footwear? [single choice]

○ No
○ Yes

6. If you select yes in the above question, please describe the reason you think that cause the discomfort.

7. During the user test, do you feel any difficulties in using the system to complete tasks that are asked by the principle investigator? [single choice]

○ Yes

○ No

8. If you select yes in the above question, please specific the reason.

9. From 1 to 5, how to you rate the appearance of the interface of the web application?

Terrible ❶❷❸❹❺ **Beautifully Designed**

10. From 1 to 5, how do you rate the accuracy of the result presented by the wearable system?

Absolutely Random ❶❷❸❹❺ **Perfectly Good**

11. From 1 to 5, how much do you think this system will benefit fashion high heel footwear designers to design healthier high heels?

It will not work for them ❶❷❸❹❺ **Perfectly Improved**

12. Please provide any additional suggestion for us to improve on.

Appendix B – In-Person Interview Question List

The aim of this interview is to get direct feedback on the performance and functionality of the testing wearable based visualization system. The meeting will take around 20 to 30 minutes. There are two sections include in the interview, and the first section requires participants to answer a series of questions. Five questions in total need to be addressed. It should be noted that participants have to refuse the right to respond any question based on their personal preferences. In the second section, the principle investigator will ask people to perform series tasks on the testing wearable system. There are five tasks in total. During the user test, participants are encouraged to talk out loud about their feelings and thoughts while performing any tasks during the interview. The principle investigator is not to allow any other personal opinions nor instructions during the interview. The interview will only be audio taped based on participants' confirmation.

Section One: interview Questions

1. Based on the previous observation, can you describe the whole system in terms of functionality, system composition and possible usage in the real world?

2. Based on the previous observation, can you describe the differences between the testing footwear and ordinary high heel footwear regarding functionality and comfort?

3. Based on the previous observation, can you describe what kind of data is being captured and measured by the system?

4. Based on the previous observation, can you tell what kind of analyses are done by the testing system?

5. Based on the previous observation and your personal experience, in what areas do you envision this system will benefit most?

Section Two: Tasks Operation

1. What is the current centre of pressure value and its tendency in the next shift?

2. What are the current value in each of the pressure point and their overall trends? Please describe respectively.

3. Which part of the feet contains the most pressure? Is this coherent with your physical feeling?

4. Can you predict the maximum heel height based on the data? Is this prediction accurate according to your personal experience?

5. Can you give an overall report regarding your walking posture and come to a generalization of the suitable footwear for you?

Appendix C – PlugandWear© PW087/PW088 Datasheet

PW088-8x8/HIGHDYN
PW087-8x8/SWITCH

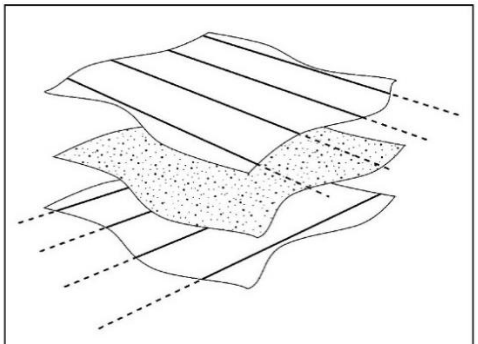
PRESSURE SENSITIVE MATRICIAL FABRIC

FEATURES

- FLEXIBLE MATRICIAL TEXTILE SENSOR
- TYPICAL PRESSURE RANGE: 1.8 kPa to 0.1 MPa
- SPATIAL RESOLUTION: 20 mm
- SIZE (width-height-thickness): 160-160-4 mm
- SENSITIVE AREA:50%

DESCRIPTION

Knitted pressure sensitive fabric. Both outer sides of the fabric are made of conductive layers, while the inner layer is made of a piezo-resistive material. By pressing the fabric the piezoresistive material changes its electrical characteristics.



Matrix Sensor

PRESSURE/RESISTANCE RANGES (T_{amb}= 25°C)

	HIGHDYN	SWITCH	UNIT
Maximum detectable pressure	**>0.1**	~	MPa
Minimum detectable pressure	**1.8 10^{-3}**	**0.2 10^{-3}**	MPa
Maximum Resistance	**>0.4**	~	MΩ
Minimum Resistance	**0.8 10^{-3}**	~	MΩ

Table 1: pressure and resistance ranges of textile pressure sensors

SENSOR STRUCTURE

The matrix sensor is made by 5 layers of fabric, the two external layers are exploited as external protection and a knitted striped fabric is glued to each external layer. The fabric is made of alternate conductive and not conductive stripes and the width of the stripes determines the resolution of the fabric. The two striped layers of fabric are at 90° with respect to each other defining a matrix of rows and columns. A piezo-resistive material is placed in between the two striped layers, and when the sensor is pressed and one row is connected to a positive voltage source, current can flow in that row and passes to the other conductive layer through the piezo-resistive material, in the area where the sensor is pressed. All 5 layers of fabric are sewn to form one unit. Flat cables connect the conductive stripes of the striped fabrics to the data acquisition unit.

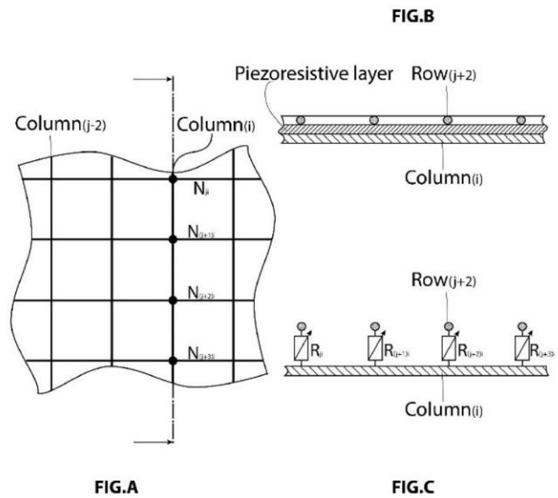


Fig. 1 sensor structure

READ/ POWER SUPPLY IDEAL CIRCUIT (ARDUINO)

The sensor's reading and supply can be performed using an high input impedance data acquisition board (e.g. the Arduino platform), the other components of the circuit follows.

- one demultiplexer (DEMUX) to connect the selected row to the voltage source.
- one multiplexer (MUX) to read the selected column.
- pull down resistance (R_{pd}) of 4.7 kOhm.

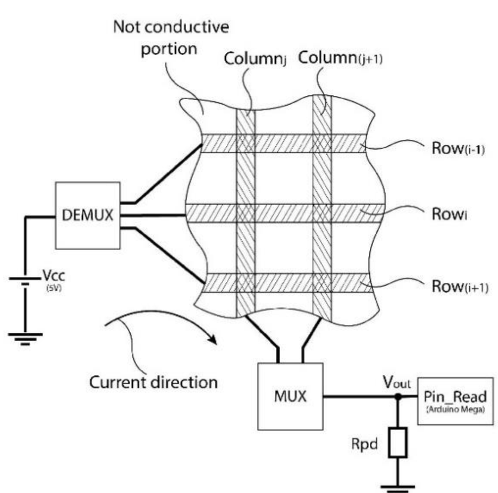


fig. 2 read/power circuit

TABLE OF COEFFICIENTS(pull up resistor of 4.7kOhm)

	HIGHDYN	SWITCH
a	**2.3e7**	**7.154e16**
b	**-0.7582**	**-4.03**
c	**700.6**	**-1381**

Table 2. Coefficients for the different dynamics pressure sensors

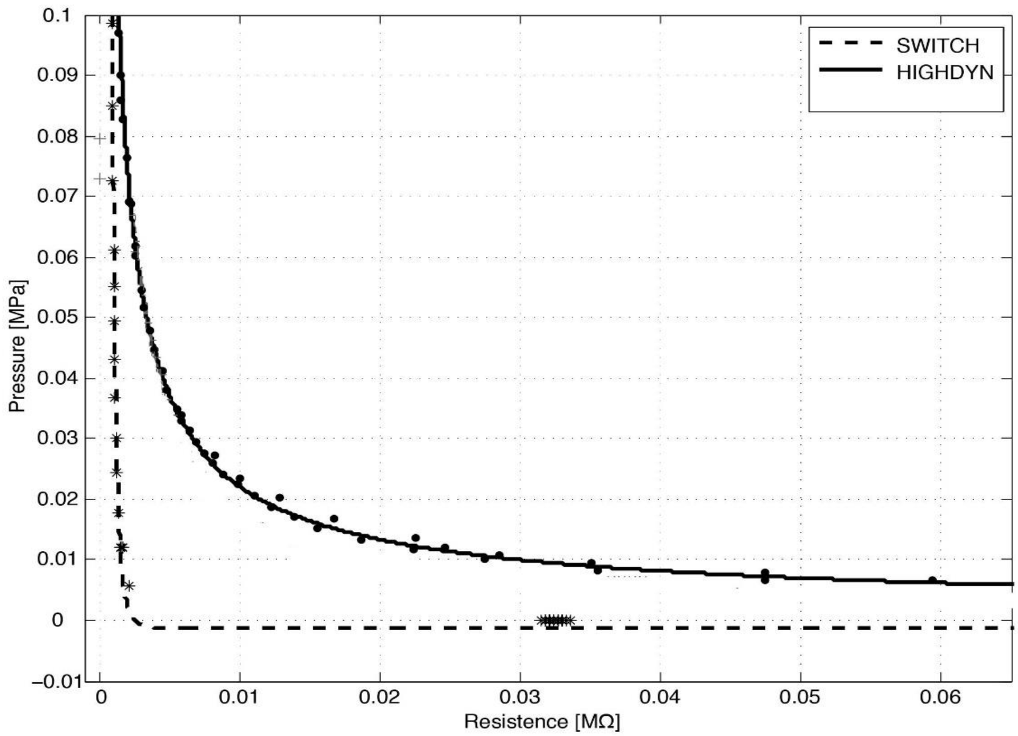
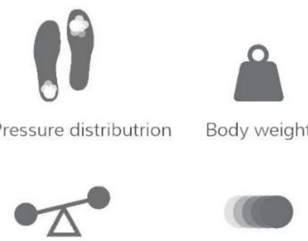


fig. 3 plot of the Pressure/resistance relationship for the different sensors

Appendix D – OpenGo© Insole Technology Datasheet

OpenGo *physio*
TECHNOLOGY

What's measured by the sensor insole?



Pressure distributrion

Body weight

Balance

Moticon

What's inside the sensor insole?

All high-tech components are completely integrated into the sensor insole.

Advanced sensors, microprocessors, memory and a wireless module are fully adapted for best performance.

For further technical information please visit our homepage under www.moticon.com

Layout sensor insole

Technical information

Acceleration sensor		Pressure sensors	
Principle	inertia mass	Principle	capacitive
Quantity	1 per sensor insole	Quantity	13 per sensor
Type	triaxial XYZ (MEMS)	Coverage	~50 %
Range	± 2, 4, 8 g	Range	0.0 – 40.0 N/cm²
Position	midfoot	Sensitivity	0.25 N/cm²
Output resolution	7 bit	Output resolution	7 bit
Sampling frequency	5, 10, 25, 50, 100 Hz	Sampling frequency	5, 10, 25, 50, 100 Hz

Appendix E – Exhibition Documentation

This section documented the exhibition of this research. The exhibition started at April 15th, 2016 and ended at April 20th, 2016. The exhibition location is 49 Mccaul Street. The title of my exhibition is “MHBTY (My Heels Are Better Than Yours)”. Following are pictures taken from the exhibit.

Figure 39. Exhibition Setup

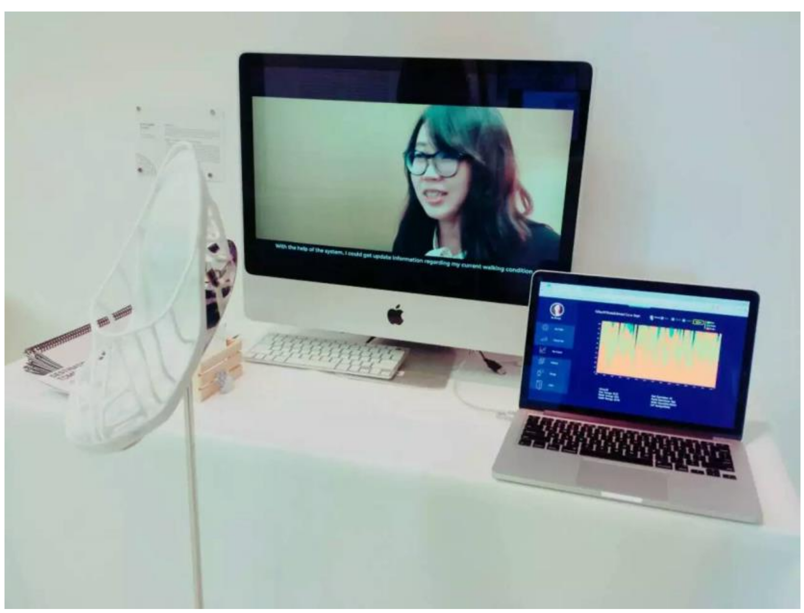


Figure 40. 3D Printed Wearable Shoe