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Design of Smart Shoes for Blind People

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Abstract
Our daily lives depend heavily on our eyes. Eyesight is our most valuable gift, enabling us to see the world around us. However, some people suffer from visual impairments that hinder their ability to visualize such things. As a result, such people will experience difficulties moving comfortably in public places. One crucial aspect of mobile accessibility is detecting elevation changes. These include changes in the height of the ground or a floor, such as stairs, curbing, and potholes. They are common in both indoor and outdoor environments. People who are blind or visually impaired must detect these changes and assess their distance and extent to navigate them safely and effectively. Depth perception is essential to doing so and can be challenging for those with visual impairments. Therefore, this research aims to design a smart shoe that assists in climbing up and down the stairs using an IMU sensor to detect the user's movement. Before constructing a controller, the system is modelled using mathematical and physical modelling. Mathematical modelling is derived based on the mobility of people with visual impairment. The smart shoes are modelled in a 3D virtual world using the SolidWorks software. In addition, the shoe integrates with ultrasonic sensors whenever it detects any obstacles or barriers; they alert the users via vibration. This resulted in the intelligent shoes unlocking the heels whenever the low or high elevation was detected and vibrating if there was an obstacle. With the help of this device, the confidence level of people with visual impairment to walk independently will be improved.

Keywords:
Blind people;
Mathematical modelling;
Smart Shoes;
Visual Impairment;

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INTRODUCTION

According to the World Health Organization (WHO), 285 million people are visually impaired worldwide, 39 million are blind, and 246 have a low vision [1]. Of the estimated 39 million who are blind, 90% live in low-income settings, and 82% of people living with blindness are aged 50 and above. Working with a guide dog or cane helps blind people get around safely, but they still face obstacles walking on roads especially climbing the stairs [2]. The hardships and daily challenges cannot be removed. However, by utilizing advanced technologies, the issues faced by visually impaired people might be reduced [3].

There are other walking aids for people with visual impairments besides Smart Shoes, such as the WeWALK [4], UltraCane [5] and BawaCane [6]. Although a few products are similar to our design, it operates differently than ours. We have thoroughly examined the current products to create more effective and superior ones. Although there is always space for improvement, every product is flawed.

The Smart Shoe is a long-term solution for people who are blind to walk anywhere independently by providing real-time sensory feedback about their surroundings. With Smart Shoes, we lend a hand to visually impaired people. In order to allow the user to utilize both hands while walking, we created a compact, wearable, hands-free device.

Wearable technology gathers data about the user or the environment, processes it (locally or globally), and then relays it back to the user through acoustic or haptic signals in real-time [7]. When designing the product, several patents are considered, giving ideas on tackling the problem statements. In addition, to reach the main aim, which is to assist blind or partial people when using the stairs more effectively and increase the self-confidence of those who are blind so they can live independently every day [8][9].

The Smart Shoe system is designed to work as an extension and is compatible with any design of shoes and as a guide for people with visual impairment to locate their feet when using different stairs. The basic principle of the system is that it can activate two different modes: step up the stair and step down the stair. In addition, the shoe is expected to detect the change in surface elevation and signal the user if an obstacle is in the way. The shoes are also attached to IR sensor, which detects obstacles in front of the user and vibrates to alert them.

METHOD

The suggested system is worn on the user's both legs with leg support and monitors the path in front of them up to 4 m away. The system triggers a vibration whenever it detects an object in front of the user, and the heel will unlock if there are any elevation changes.

Mathematical modelling on the system

Figure 1 shows the heel's initial position, which is our locking system at the bottom of the shoes. During this position, the extension spring is hooked and placed horizontally to its optimum length, c, connecting parts a and b, using the length of c. Part b is rigid. In contrast, part a will stay at the fixed position until the servo unlocks and release the heel. The material used for this part is entirely from 3D printing, Acrylonitrile Butadiene Styrene (ABS filament) [10, 11, 12].

Here is the design specification based on Figure 1 at an initial position. According to cosine rules, it found the angle of A:

$$\cos(A) = \frac{b^2 + c^2 - a^2}{2(b)(c\,)} \quad (1)$$

where the coefficient of a, b and c are 4.50cm,3.25cm and 5.00cm, respectively.

$$\cos(A) = \frac{3.252^2 + 5^2 - 4.5^2}{2(3.25)(5)} \quad (2)$$

$$A = 61.89° \quad (3)$$

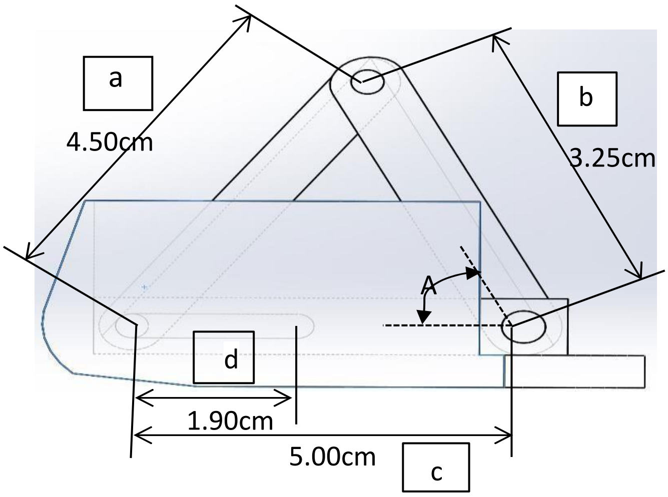

Figure 1. The position of the heel before the IMU sensor detects the stairs

Figure 2 shows the position when the heel is released. When the sensor detects the stairs, the servo will unlock part a. The extension spring will return to its original length, 5 cm to 3.1 cm. From the calculation, we can observe that the angle is now changing, thus allowing the heel, which is "x", to slip out with a length of 2 cm. Figure 3 shows the design of the spring extension of the heel, which is used for unlocking the heel when the IMU sensor detects the elevation changes. In contrast, Figure 4 displays the complete mechanism of the spring extension at the shoe's base [13, 14, 15].

The design specification based on Figure 2 when the heel is released:

$$\cos(B) = \frac{b^2 + c^2 - a^2}{2(b)(c)} \quad (4)$$

where the coefficient of a, b and c are 4.50cm, 3.25cm and 3.10cm, respectively.

$$B = 85.41° \quad (5)$$
$$B - A = 85.41° - 61.89° = 23.53° \quad (6)$$

Using trigonometry:

$$x = 5\sin(23.53°) = 2\ cm \quad (7)$$

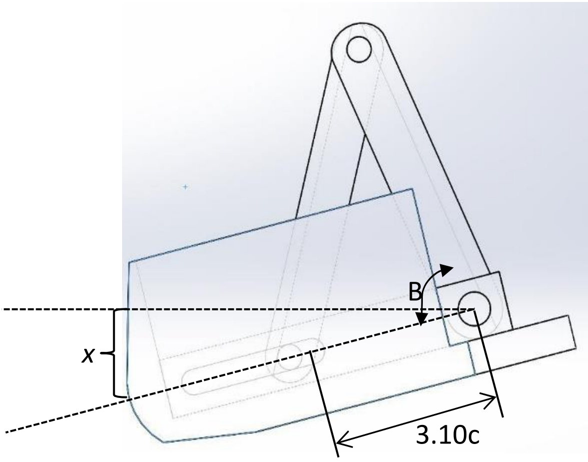

Figure 2. The position of the heel after the IMU sensor detects the stairs

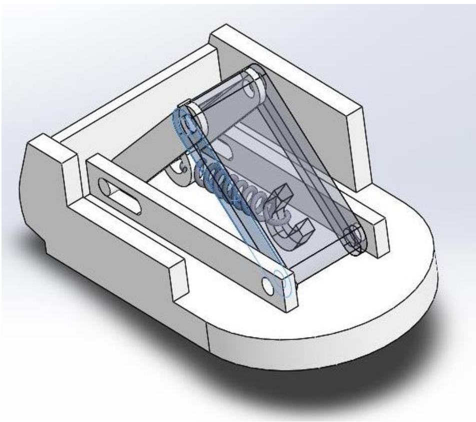

Figure 3. Extension spring design for the heel in Solidworks

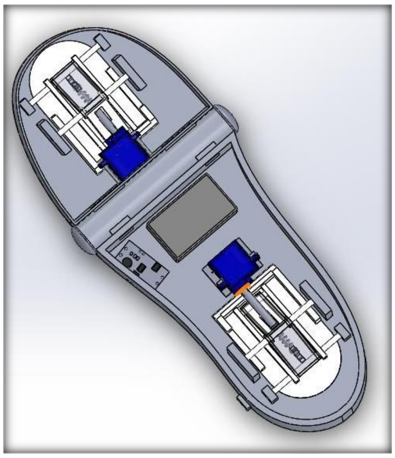

Figure 4. The mechanism for Extension Spring

We choose ABS filament for this part because it is pretty flexible and lightweight. This filament is also durable and easy to extrude. The calculation below shows the pressure our material can withstand from the force exerted by the user. The material is placed between the heels and the shoe's sole. The maximum mass from the user must also be specified to determine the maximum pressure exerted [16][17].

Design Specification

We set the maximum mass(M) for 100 kg from the user for our product:

$$F = Mg \quad (8)$$

$$F = 100\ (10)\ =\ 1000\ N \quad (9)$$

The average surface area covered by a human's foot is between $117.5\ cm^2$ - $225.5\ cm^2$ and the minimum value;

$$P = \frac{F}{A} \quad (10)$$

$$P = 85.1\ kPA \quad (11)$$

We chose Aluminum alloy T6-6061 as the material to be placed between the heels part and the shoe's sole because it has a high strength to low weight ratio, can withstand high pressure, has a high tensile strength value and has a high yield strength value. From the characteristics of the materials, we can assure you that the material used can withstand the pressure exerted by the user based on our design specifications.

From the locking system, we can design the extension spring and calculate the maximum force the heel part can pull to ensure it will not exceed the elastic limit, thus breaking the mechanism part. The material used for the spring is Music Wire ASTM A228, and the diameter ranges from 0.0127 – 0.3175 cm. It has the highest shear modulus value and is most widely used for small springs in tight spaces.

From the Design of Machine Element's formula:

$$k = \frac{GD^4}{8D^3N} \quad (12)$$

where:

d = wire diameter
D= Mean diameter = OD –d
G = Shear Modulus of Material
N = Number of active coils
k = Spring constant

An example of calculating the system is presented in Figure 5.

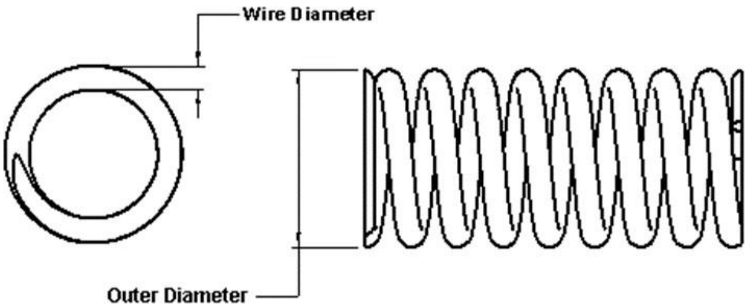

Figure 5. Spring diameter

According to Hooke's Law

$$F = k(x) \quad (13)$$

where:
F = Force applied to the spring
K = The spring constant
X =The extension of the spring

$$F = 9.52\ (50 - 31) = 180.88\ N \quad (14)$$

The value of the F is the maximum force part an of the heel (as seen in Figure 2) can exert on the spring based on the design specification. To prevent the spring from reaching the elastic limit, we can increase the length of the spring by 1 mm.

$$F = 171.36\ N < 180.88\ N \quad (15)$$

From the specification of the servo motor, we use a 9G micro servo motor with a speed of 0.10sec/60°. So, theoretically, we can set the speed to 0.15s /90°, which is 0.025 RPM. This speed will be used to lock and unlock the heels. The article "Study Compares Older and Younger Pedestrian Walking Speeds", retrieved from 2009-08-24, shows that the average human walking speed is about 1.4 m/s. Besides, the article "lower limb angular velocity during walking at various speeds" shows the highest angular speed of the knee when walking is about 384.05 ± 45.74 °/s.

Operational Sequence on the System

The flowchart from the user start point until the end is shown in Figure 6. The smart shoes are attached to an IMU sensor, which can detect the user's body's specific force, angular rate, and orientation. If the user starts climbing either up or down the stairs, the heels will unlock respectively, allowing the user to ascend or descend the stairs more easily. The IR sensor had been integrated in the smart shoes to detect any obstacles in front of the user and alert them via vibration.

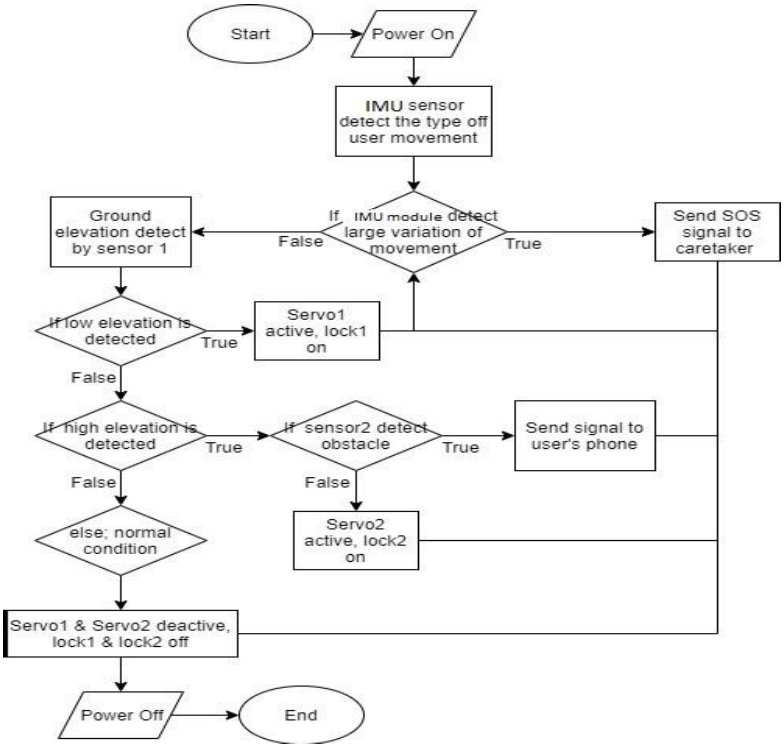

Figure 6. Operation flowchart of the Smart Shoe

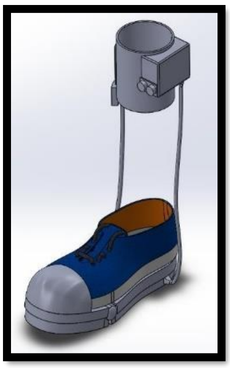

Figure 7. Smart Shoe Design

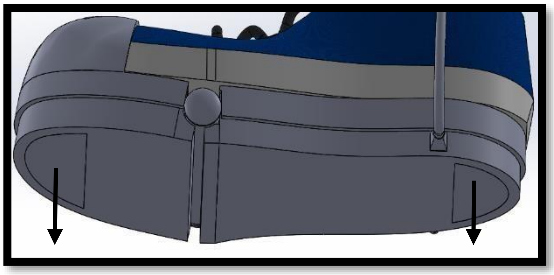

Figure 8. Part of The Extension of the Spring

Figure 7 shows the Smart Shoes' overall design, leg support, and IR sensor. The IR sensor detects any obstacle in front of the user, and a vibrator alerts the user. The part where the heel will extend when the user starts to climb up or down the stairs is presented in Figure 8, respectively.

RESULTS AND DISCUSSION

We heavily prioritize the safety aspects of our product. This is because we will only consider our product successful if it is safe. While designing, we make it as safe as possible without impeding any design functionality, thus, making it reliable and effective. The locking system is not rigid. Thus, if the user still needs to get used to our product, the locking system will save the user from tripping with the flexible build that we made. The soles are not slippery, which is the primary concern of the people regarding this product. The soles will be layered with rubber or any material usually equipped on everyday shoes to ensure the feet stay locked on the ground while walking.

The vibrator signals the user, which is an alternative to an alarm or buzzer that is supposed to signal the user when approaching obstacles. We want them to be highly cautious while walking by, not having to occupy their sense of hearing in the crowd or any situation. They cannot see, so it is inefficient for us if we have to disrupt their sense of hearing to make the product works. Furthermore, the IMU module will detect unusual movements and notify the emergency contact.

CONCLUSION

A design of a smart shoe that assists in climbing up and down stairs has been performed. Some calculations for designing it have been done based on mathematical and physical models. Furthermore, a 3D virtual world is modelled using SolidWorks. In conclusion, these smart shoes have achieved the objectives of helping blind people walk on stairs and help them with unfamiliar places. Hopefully, the help of this device will improve the confidence level of people with visual impairment. In the future, this device can also be used to rehabilitate any physical impairment when dealing with stairs.

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