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SMART SHOE FOR VISUALLY IMAPAIRED

Arish Ali[*1], Abdullah Bin Junaid[2], Abdullah Hanif[3]

[1] *Department of Mechanical Engineering, National University of Sciences and Technology, Karachi, Pakistan*

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Corresponding Author: *
Arish Ali

Abstract

Mobility is one of the biggest challenges that is faced by person that has lost the gift of sight. The lack of visual prowess results in continuous accidents which in turn cause frequent injuries and limited lifestyle. In order to help these strata of people this project proposes development of smart shoe that would make use of ultrasonic sensor and haptic feedback to timely alert the user. We are thinking of fabricating a smart shoe made up of typical rubber that is found in shoe sole this ensures that project is economical and implementable. Ultrasonic distance sensors (AJ-SR04 Waterproof Ultrasonic Distance Sensor) are to be inculcated into the shoe and the time it would take for transducer to receive radiation would be used to measure distance and alert user. This information would be used by Arduino nano, which is our main processing unit and would compare it with a predefined threshold. When the object crosses the threshold signal from nano would cause motor to vibrate, providing user with haptic feedback. The electronics are to be powered by lithium phosphate battery or cell which would in turn be charged by TP 4056 charging module this ensures long term use. This system hence aims to reduce collision and accidents and be practical in terms of long-term wearability

INTRODUCTION

1.1 Problem Statement

Being independent while moving has become a big challenge for people with visual impariness . Day-to-day task such as crossing streets and moving in crowded places tend to produce so much risk for visually impaired which in turn results in cognitive load for the person while he is moving outside. This reduced environmental awareness leads many individuals to depend on others for guidance, reducing autonomy and confidence in routine activities (Ricci et al., 2024). On a global scale, vision impairment has affected many people. The World Health Organization (WHO) reports that over 2.2 billion people live with some form of near- or distance-vision loss, and nearly 1 billion of these cases could have been prevented or are still untreated (WHO, 2023).

VI is strongly associated with falls and fall-related outcomes, a leading cause of injury and loss of independence in older adults. Longitudinal evidence from India reports that about one-third of adults ≥65 experience at least one fall annually; compared with those without VI, people with low vision show 16% higher odds of falls, and those with blindness 40% higher odds (Singh et al., 2022). Beyond acuity alone, contrast- sensitivity impairment is a particularly important predictor and is associated with higher prevalence of recent and recurrent falls (Jin et al., 2024). The dangers associated with mobility challenges also take a toll on mental and social well-being. Among older adults, difficulties with vision are often linked to higher levels of depression, increased dependence on others, and a greater worry about falling. This causes hesitation in activities which in turn results in person restricting himself to the confinement of his/her home resulting in decreased quality of life (Ehrlich et al., 2019; Jin et al., 2024).

Traditional mobility aids have played a big role in minimizing the risk of visually impaired, for instance we have white canes which are very economical and precise in offering timely detection of ground level objects, but constant sweeping motion tends to be tiring and also it offers limited protection from overhanging objects. Guide dogs are more active in terms of offering timely detection but however cost of training and issue of scalability is a problem in low resource setting (Ricci et al., 2024). Considering these problems there is a great need for a system that is low cost, practical and proactive in terms of providing timely detection.

This project responds to that gap by proposing a smart insole integrated within everyday footwear. Using ultrasonic obstacle detection and directional haptic feedback, the insole aims to deliver early warnings (at distances greater than ground-contact range), support safer route choices in crowded or complex environments, and preserve user discretion and comfort. By improving advance detection while remaining low-profile and cost- reasonable, the proposed insole seeks to reduce collision and fall risk, attenuate fear of falling, and restore independence in community mobility for visually impaired users.

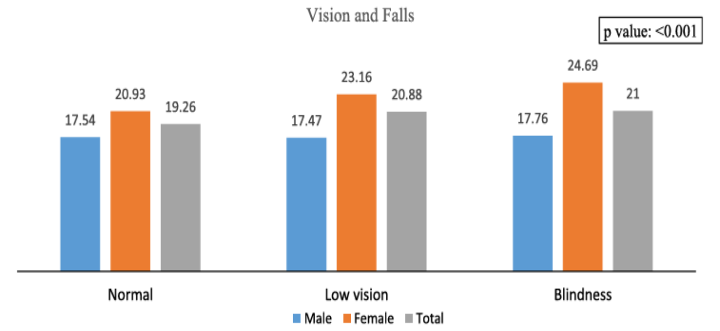

Fig. 1 Association between measured visual impairment and fall among older adults and elderly in India, 2017-18

Figure 1: Singh, R. R., & Maurya, P. (2022). Visual impairment and falls among older adults and elderly: Evidence from longitudinal study of ageing in India. *BMC Public Health, 22*(2324). https://doi.org/10.1186/s12889-022-14697-2

1.2 Proposed Solution

Work done on footwear design tends to comment that sole hardness has great impact on comfort . It is typically noted that harder sole tends to provide greater ankle stability which is important in case you are standing while softer sole tends to provide greater comfort at the cost of stability increasing chances of ankle twist (Kang et al., 2025) so in order to make a sole which is applicable for everyday use we have to reach the goldilocks region between these extremities a typical soft rubber based sole tends to provide that balance hence we have decided to base our system in a rubber based sole . Factors such as availability and cost have also been the guiding light in making this decision

1. Sole-Based Electronics Concept:

The smart sole will serve as the housing platform for all components, including the microcontroller (Arduino Nano), power supply (lithium-ion battery), ultrasonic sensors, and vibration motors. By adding electronics directly into the sole, we aim to create lightweight and compact system, addressing one of the major problems associated with wearable is that they are bulky and aren't able to integrate technology effectively (Almomani et al., 2023).

2. Obstacle Detection Using Ultrasonic Sensors

Obstacle detection will be achieved by placing an ultrasonic sensor near the toe. These sensors would utilize the time taken for the ultrasonic radiation to return to calculate distance. The data is processed by the Arduino Nano microcontroller, which compares the readings with a threshold distance to identify obstacles in the user's path.

Previous research has shown proof of concept for an ultrasonic sensor integrated for obstacle detection. The trials have shown over 99% user satisfaction (Almomani et al., 2023). By implementing an ultrasonic sensor in a compact form, we are planning to make a proven concept feasible in terms of implementation on a large scale

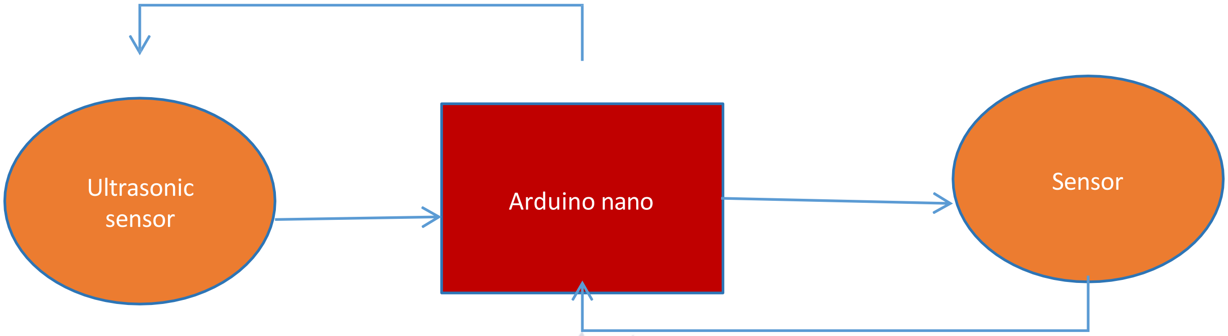

Figure 2: Simplest flow diagram of our system

3. Haptic Vibration Feedback for Navigation Support

This project proposes using single-sole haptic feedback instead of auditory feedback, as auditory feedback tends to distract people from their surroundings. As noted by Khusro et al. (2022), auditory feedback "is not applicable in a noisy environment and may occupy the most important auditory sense," while vibration is language- independent and preserves privacy. We are planning to use one sole as it simplifies the fabrication cost and relying on haptic feedback simplifies things for the user instead of complex directional commands. The design employs a vibration motor around the heel area—not beneath it—to prevent pressure damage while generating distinct vibration patterns that communicate obstacle distance safely and intuitively.

Table 1: Showing feedback pattern

Distances	Vibration pattern
70 cm	Small pulses (alert)
50-25 cm	Medium pulses
0-20 cm	Continuous vibration

1.3 Aim and Objectives

The current goal of the project is to enhance the mobility of visually impaired people without compromising on their safety. Traditionally we had tool like walking canes, guide dogs and human assistance although effective there can be no denying that they have some inherent flaws for instance the walking canes gives you feedback after making a physical contact with the object and hence the user might have to less of a time to respond. Guide dogs or human assistance, though slightly safer, compromises your independence. (Amballa, 2018).

To address this problem, our smart shoes have integrated three ultrasonic sensors near the toe region capable of detecting obstacles within 0–100 cm vicinity. When a potential hazard is detected, vibration signals first with impulses and the continuous vibration would alert the user, allowing him to change his path preventing a potential collision (Smart Shoe for Visually Impaired People, 2023). Using this technology, we aim to provide users with timely alerts about potential obstacles to ensure their safety (Sathvik et al., 2024).

In addition to safety, the design emphasizes independence and accessibility. By implementing all the electronics within the sole, we aim to create a sole that is compact and hence easy to use for everyday affairs.

The sole will be manufactured using natural rubber this is because originally materials such as ethylene-vinyl acetate or polyurethane were foam like materials and didn't have enough durability on the contrary rubber allows you to vary concentration of different elastomer such as carbon black this improves tensile properties which are related to hardness of the sole (Golubeva, 2021).

So, in summary, the objectives can be classified as:

1. Enhance the safety and independence of visually impaired users by reducing reliance on human assistance or guide dogs.
2. Prevent collisions and falls through timely obstacle detection (0–100 cm range) and vibration feedback
3. Design compact shoe-based system using rubber sole so that we can vary concentration of elastomers to reach desired properties

Table 2: Comparing walking cane, guide dogs with proposed solution

Feature	Walking Cane	Guide Dog	Smart sole (Proposed)
Detection Range	Contact-based (≈0 cm) Obstacle detected only upon physical touch	Medium range (visual awareness of dog, ˜1–2 m) but limited by training and environment	Ultrasonic sensor range 100 cm before contact, with potential for expansion
Reaction Time	Late – user alerted only after collision risk	Moderate – depends on dog's response and user interpretation	Early – vibration feedback provides time to react
Cost	Low (≈USD $30–50)	High (≈USD $20,000–50,000 including training and upkeep)	Low to moderate (Affordable via customized rubber sole)
Independence	High reliance on physical skill; limited in new/unfamiliar environments	Dependence on animal care, trainer, and regular upkeep	High independence – self-sufficient navigation via sensor alerts
Portability/Usability	Lightweight, portable, but physically intrusive	Requires extensive care and living conditions	Compact insole – embedded electronics, unobtrusive, everyday wear
Aesthetics	Visible aid (may signal disability)	Visible companion (socially positive but not always practical)	Discrete design – electronics embedded inside footwear

1.4 Key Design Considerations

1.4.1Comfort and prevention of failure

While designing the shoe one of primary objective was to ensure comfort without compromising structural integrity that could damage the electronics for that purpose, we have decided to use vulcanized rubber which is, a process in which rubber is heated with sulfur to improve its properties. Vulcanization results in sulfur forming links between the rubber molecules, which makes the material stronger while still allowing it to remain elastic and flexible (Chan, 2013). Because of this combination of strength and flexibility, vulcanized rubber can absorb ground forces produced during walking without easily deforming or breaking. This allows us to achieve the first objective in terms of design, that is to ensure comfort and prevent failure to ensure protection of electronics.

Other considerations to achieve our first objective include the fact the vibration motors are planned to be placed around the periphery of the heel. Placing motor on the periphery ensures comfort as the user won't have to feel the hard surface and it also ensures structural safety of component . Additionally, most electronic components are positioned along the medial arch, where the natural curvature of the foot prevents them from contacting the circuitry. This ergonomic arrangement not only safeguards comfort but also maintains a stable balance and natural gait pattern.

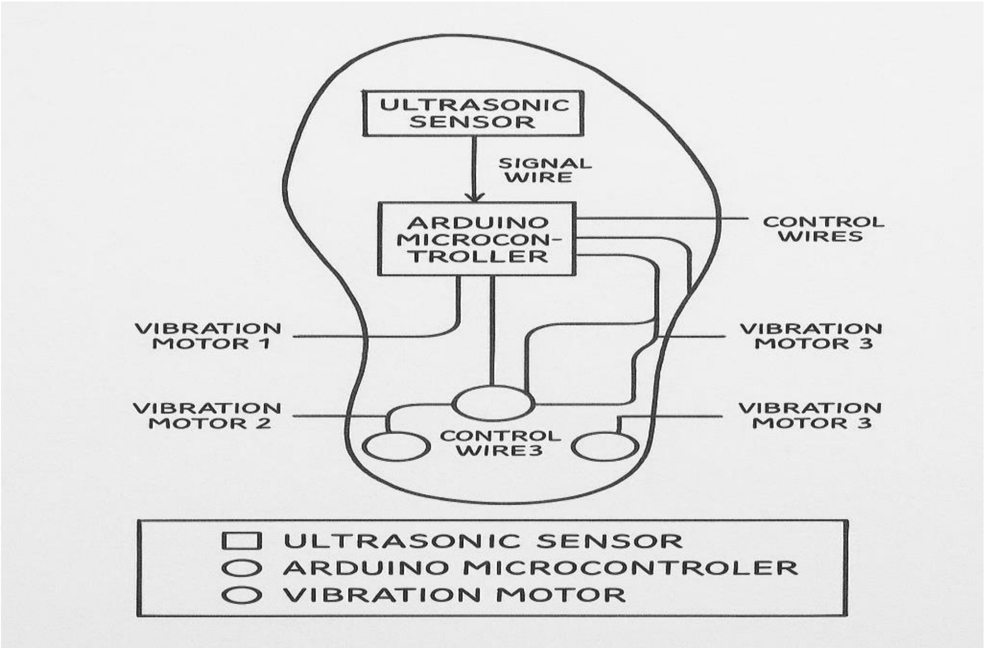

Figure 3: showing basic layout of circuitry involved in the project)

1.4.2Compact Circuit Cavity

One of the main objectives we would like to achieve is compact electronic system that is low profile and doesn't compromise comfort. A lithium phosphate battery/cell would be used, and its slim geometry ensures that comfort isn't compromised along with preventing uneven pressure distribution that can affect structural integrity of the battery. The processing unit would mainly consist of Arduino nano, its low physical presence and power consumption which makes it perfect for use. Combining all these components ensures we create a electronic system that thin making it practical for use. In our project we chose medial arch position as the main place for deployment of electronics as the natural arch ensures no excessive load would be placed on electronics. Ensuring that our sensor is accurate in environment which would contain moisture to an extent we have decided to use aj sor04t which has proven reliability in proximity application (Rashid et al., 2021). By inculcating these electronics in the shoe sole we are planning to reduce external wiring which in turn produces comfort and aesthetic appeal.

1.5 Comparing different sole materials

Table 3: comparison of rubber with conventional sole material

Material	Comfort (Shock Absorption)	Durability	Water Resistance	Flexibility
Natural Rubber	Rubber can absorb ground impact during walking, which improves comfort (Chan, 2013)	Rubber compounds can be designed to improve strength and wear resistance (Golubeva, 2021)	Rubber has low water absorption and resists moisture (Thomas et al., 2013)	Vulcanization makes rubber strong while still flexible (Chan, 2013)
EVA	Very soft cushioning but compresses easily	Lower durability compared to rubber	Moderate water resistance	Very flexible
Polyurethane (PU)	Good cushioning	Good durability	Good water resistance	Moderate flexibility
TPR	Moderate cushioning	Moderate durability	Moderate water resistance	Flexible
PVC	Hard and less comfortable	Durable but rigid	High water resistance	Low flexibility

1.6 Scope of the Project

1.6.1 Application Environment

This project is designed so that it has application in both indoor and outdoor areas ranging from shopping malls to park and sidewalk

Visually impaired individuals face significant challenge when an obstacle appear suddenly in ground level. Through the proposed system we are planning to offer timely detection to the user by making use of ultrasonic sensor and motor embedded in the periphery of heel region

Through this system we are planning to improve mobility of the user and reducing risk while navigating in surrounding

1.6.2 Target Audience

The sole that we are making is designed for people of all age groups but however special priority were to be given then it would the elderly this is because older people are susceptible to impairness and the consequences of accident that is associated with it

According to a survey conducted in united states, 46.7 percent of adults aged 65 and older with severe vision impairment reported at least one fall within a year, compared with 27.7 percent among those without vision problems (Crews et al., 2016). These incidents have consequences of injuries, discouragement for mobility resulting in social isolation.

Hence it is really important that is age strata is prioritized is application of this system can severely reduce these negative implications currently being faced

1.6.3 Expected Outcomes

The outcome that we hope comes out of this effort is a shoe-based system that offers timely detection in form of haptic feedback to the user.

Through this we would in turn instill confidence in visually impaired people so that they are able to move in pedestrian setting as well internal setting confidently However one major problem in the form false detections from harmless objects is expected this is because when the ultrasonic sensor is inculcated inside the sole it might sometimes classify small, low-lying items (such as pebbles or uneven textures) as threats.

To counter this problem we are thinking that the sensor should be angled slightly upward to consider only obstacles of meaningful height. Although this adjustment reduces error, further refining through coding would still be needed.

1.7 Significance of the Project

1.7.1Social Impact: Improved Mobility and Confidence

Upon a closer look at the statistics, you would come to the realization that there is a great barrier to visually impaired social life. Limited outdoor maneuverability often confines them to their homes, reducing their quality of life and independence. As emphasized by *An Effective Insole Shoe for Blind People for Mobility Assistance* (Zain et al., 2023), visually impaired people "undoubtedly have challenges daily... Moving and transporting visually impaired people from one location to another used to be the most common problem in the past... white canes and guide dogs only partially address safe and independent mobility."

Considering the problem faced by the VI, we are planning to design a compact system that can be used by daily life users to enhance their mobility and safety within the constraints of their home. It would boost confidence and social participation, ultimately improving the quality of life for the visually impaired community.

1.7.2Contribution to Assistive Technology Innovation

Inspite of the fact that in recent year we have seen great improvement in wearable technologies, but the fact is active wear tends to still lack in aesthetically comfortable and not being bulky. A comprehensive review by Zhou et al. (2022) found that "most existing smart insole devices maintain bulky designs, with some parts attached to the shoes, ankles, and thighs," this highlight that achieving minimalism is a hurdle that has prevented wide spread adoption of assistive wear.

Through this project we hope to take stride in that direction as well by including all the electronics in the confinement of the sole . With rubber customs to the user's need, we are hopeful that we will achieve user comfort and find a solution that is acceptable. Summarizing, we are hoping to make a system that is functional as well as elegant allowing a stride in right direction in field of assistive wear.

1.7.3Commercialization and Scalability Potential

Interpreting the statistics would result in the realization that fall-related death and injuries are one of the major health concerns around the world, especially among senior citizens. According to Zhou et al. (2022), "falling is one of the most frequent problem faced by elderly," on the other hand deployment of smart soles equipped with pressure sensors and inertial measurement units has demonstrated detection accuracies of up to 99 percent in experimental studies this gives us a valuable insight that sole based technology has proof of concept (Qian et al., 2019, as cited in Zhou et al., 2022).

The finding regarding the accuracy of a sole-based system indicates that it is feasible for us to deliver a sole-based technology system with high accuracy, and given the number of people affected by visual impairments, we have a potential market as well.

By integrating a network of sensors in a compact form, it would provide a leeway to potentially use sensor-based technology for achieving various tasks like fatigue detection and terrain detection. Its cost-effective and easy-to-use features suggest it has potential appeal among the elderly as well as people across the age spectrum, further emphasizing the commercial aspect of our project.

Literature Review

2.1 Introduction

Throughout the years, scholars have examined numerous methods to assist individuals with visual impairments in moving through their environment safely and on their own. This section examines how such initiatives have progressed, starting with basic aids like white canes and guide dogs, then shifting to contemporary sensor-driven devices that identify obstructions and deliver instant feedback. The goal here is to grasp what advancements have been made, what shortcomings persist, as well as how these observations can steer the creation of improved assistive tools.

Among the approaches tackling this issue, intelligent footwear has received notable interest, as it effortlessly bridges the gap between the wearer and their surroundings. Several experiments have sought to integrate sensors into smart shoes or soles to build a system for gait analysis or step tracking. However, consideration of ergonomics, aesthetics, and compactness has always seemed peripheral to these efforts, leaving a significant gap to be addressed. Having established the gap that needs addressing, we have come to the realization that we would be creating a single, sole-based smart shoe system that prioritizes cost, comfort, and aesthetics. Further findings from the literature review in this chapter provide the intricate detail required to establish the technical foundation for our proposed system.

2.2.1 Traditional Aids: White Cane and Guide Dogs

For the longest time, the white cane has been the go-to method for the visually impaired to navigate their surroundings. It first came to the scene around the 20th century, during World War 1, to assist French war veterans who had gone blind during the war. It soon spread to the United States of America, where American instructor Richard Hoover further refined the sweeping technique (Bäckman, 2024). Usually, the cane is 100 or 150 cm long, and it mainly comes in two sizes. The cane is primarily designed to signal to others the user's visual limitation, while a longer one is primarily used for obstacle detection through sweeping to orient the user in the correct direction (Bäckman, 2024). Because it is lightweight, foldable, and inexpensive, the white cane remains the most common mobility aid. The fact that the method is very minimal, easy to use, and requires very little training to be used is something that other assistive technologies have tried to implement from it (Mashiata et al., 2022).

Guide dogs are another way to navigate the environment, acting as responsive partners rather than mechanical machines. Due to their enhanced sensitivity, they help the user navigate unfamiliar surroundings more quickly as they pick up cues and avoid obstacles with greater precision. Glenk et al. (2019) concluded that owning a dog led to far greater confidence and physical exertion, as the owner feels safe navigating an unfamiliar environment. Beyond functionality of helping the user navigate the environment, it is

also felt that dogs help in the emotional well-being of the user, as well as the owners tend to find them as a loyal connection who gives them reassurance and a leeway for social connection. In this way, guide dogs extend mobility beyond navigation—they foster trust, belonging, and a renewed sense of confidence in everyday life (Glenk et al., 2019).

Figure 4: pictorial representation of walking cane and guide dog

2.2.2 Limitations of Conventional Aids

It has been pretty much established that, over the past few years, traditional aids such as walking canes and guide dogs have assisted people in navigating and making the system easier to use. However, over time, people have increasingly come to realize that these methods are inadequate for use in unfamiliar environments. Each conventional method listed has safety or range constraints that limit its use in a practical environment.

Limitations of the White Cane

The white cane delivers tactile feedback solely upon direct contact with an object, offering minimal forewarning of nearby impediments. Given its effective span measures approximately one to one-and-a-half meters, individuals frequently identify hazards—such as vertical surfaces, pavement edges, or sudden depressions—only when these are already within immediate proximity, a circumstance that heightens the risk of mishaps (Mashiata et al., 2022). Moreover, the device proves inadequate for sensing overhead obstructions, exposing users to potential impacts with signage or architectural protrusions. In environments characterized by auditory distractions or irregular terrain, the resultant tapping feedback may become unreliable, necessitating excessive dependence on sound-based signals and recalling spatial information.

Beyond its technical limitations, the white cane encompasses a social aspect. As Bäckman (2024) observes, empirical evidence suggests that while the walking aid fosters a perception of autonomy, it simultaneously draws undue scrutiny by making the user's disability conspicuous. This paradox frequently undermines self-assured utilization in densely populated or unfamiliar surroundings, rendering the instrument both liberating and socially restrictive.

Limitations of Guide Dogs

Guide dogs provide a collaborative relationship that enables people with visual impairments to navigate varied environments more fluidly. Still, multiple practical limitations hinder their widespread adoption. Research by Glenk et al. (2019) highlights that exclusive dependence on these animals remains unviable due to their limited global availability; moreover, the expense linked to their instruction can climb as high as €34,000 to €40,000, narrowing accessibility to a select few. Even after acquisition, caretaking involves ongoing responsibilities, including nourishment, maintenance, and medical attention, which may be unmanageable for some.

Psychological and societal elements further influence suitability. Not all individuals feel at ease relying on an animal companion due to allergies, cultural apprehensions, or unsuitable living arrangements. While handlers often assert their enhanced mobility and emotional well-being, investigations such as those conducted by Glenk et al. (2019) reveal no robust statistical enhancements in life quality metrics relative to those without guide dogs.

Summary

So, summarizing, there can be no denying that walking canes and guide dogs improve independence and mobility, but the limitation in terms of range, safety, availability, and social stigmas associated limits their ability to fully address the problem. These constraints have motivated researchers to explore technological innovations—such as smart footwear and sensor-integrated insoles—that could provide safer, wider-range navigation while maintaining affordability and discretion.

2.2.3Emergence of Technological Solutions

In consideration of the limitations of traditional aids, assistive technology has undergone significant development in the past few years, and now, rather than purely mechanical devices to assist navigation, we have developed an electromechanical system that can assist the user in a far better manner. This change can mainly be associated with major advances in the electronics industry, which have made the system more compact and easier to integrate for everyday use. As noted by Lavric et al. (2024), the decline in sensor cost has significantly allowed researchers and developers to integrate sensors into a variety of systems. Microcontrollers, ultrasonic sensors, cameras and communication modules that were once excessively expensive are now available extremely cheap, this has allowed even small research groups to prototype of wearable assistive devices. Similarly, Mashiata et al. (2022) also stresses that microcontrollers and embedded sensors have dramatically reduced their cost, making electronic mobility aids more economical since a few years ago, which fosters even further research interest.

Another important development has been the miniaturization of electronics. Through the advancement of semiconductor manufacturing, lightweight energy-efficient processors have been developed and integrated into handheld and body mounted devices.

Lavric et al. (2024) has pointed out the miniaturization of lidar and cameras in compact setting of wearable system without compromising user comfort. This has consequently resulted in technology which was big into compact setting of wearable in-form belt, shoes and glasses making it practical for everyday use.

Another factor for this change is the forthcoming of cloud computing. The effective role of Internet-of-Things architecture along with 5g network allows processing of dating externally rather than on device itself, (Lavric et al., 2024). Having heavy communication be done on remote servers means that there is no need of processing units along with storage keeping device lightweight and comfortable. At the same time, it enables real-time data analysis and updates, further improving the adaptability of assistive systems.

Together, these factors, the affordability of sensors and microcontrollers, the compactness of electronics, and the accessibility of cloud computing—have made technological solutions increasingly mainstream in the field of visual assistance. They mark a decisive turning point from traditional tools toward intelligent, connected, and user-friendly systems capable of addressing the limitations of earlier aids.

2.3 Existing smart assistive technology

2.3.1 Introduction to Smart Assistive Technologies

Smart assistive wear is a step forward from conventional aids that would give a user more real-time awareness of their surroundings using sensors and electronics . These systems mainly make use of AI (Artificial Intelligence),ML(Machine learning), and sensors to determine the surroundings and provide feedback to the user in the form of audio or vibrations. In contrast to traditional aids, these smarter technologies rely mainly on computational function as well as sensors to better gauge the environment in comparison to traditional aids.

Lavric et al. (2024) describe modern assistive technologies as “systems that combine multiple sensing modalities, advanced signal processing, and AI-driven decision- making to enhance perception and situational awareness for visually impaired users” (p. 3). The writer is thus emphasizing that use of microcontroller and miniaturized sensor, are new technologies that can perceive the environment thoroughly and provide a safe passage for the user. Through this integration of hardware and intelligent electronics, these technologically innovative systems can provide the system with much better spatial awareness of its surroundings, like what people with visual prowess normally have.

Hence, if we were to summarize the smart assistive technology, it could be classified as seamless integration of sensors along with an algorithm to provide user feedback of the surroundings. This combination of perception, computation, and feedback marks a decisive step toward truly adaptive and user-centered mobility support.

2.3.2 Navigation-Based Wearables

The evolution in microelectronics and sensor-based systems has allowed the development of wearable assistive technology. These navigation-based wearables have allowed users to become aware of their environment by using sensors and processing the signals. According to Han et al. (2024), it is the form factor of these devices that determines their practicality as well as defines their broad categories: hand-mounted, head-mounted, and body-mounted systems. Each approach combines environmental sensing with user-friendly feedback yet differs in how information is captured and conveyed as well as in implementation.

Hand-Mounted Devices

Hand-mounted systems are the most readily available since they refer to smart phones which we already own. Modern phones tend to inculcate cameras , GPS module along with accelerometers in one system allowing image capture and motion tracking when these devices study the data collected locally or through the use of latest cloud based technology allowing it to help in nearby obstacle detection and offer directional cues both through haptic and auditory feedback. This category represents an important entry point for assistive innovation, as it merges everyday consumer hardware with real-time navigation intelligence (Han et al., 2024).

Head-Mounted Devices

Head-mounted technologies like smart glasses or headset tend to introduce sensor directly in line of sight of the user usually these devices make use of forward facing camera and processing unit to get awareness of surrounding from user perspective. Since the cameras are oriented towards user gaze the system can better provide real time awareness of user’s space. As Han et al. (2024) note, this design closely mimics natural perception, allowing users to maintain head-up posture and intuitive orientation while navigating unfamiliar surroundings.

Body-Mounted Devices

Body-mounted are recent development in field of assistive wear. These include mainly refers to backpack and west which are closely placed with respect to user center of gravity which allows ensures a stable sensing field aligned in direction of walking and detection which is more consistent. Since these devices tend to have area which is far greater it means these devices can house batteries which are far bigger resulting in better battery life in these devices feedback is mainly haptic which is delivered through a vibrating pad that is placed near user torso to direct vibrating feedback. The importance that has been given to ensuring that there is balance and comfort in the system has made body-mounted systems increasingly practical for daily use (Han et al., 2024).

Table 4: Comparison between various assitive technologies

Device Category	Examples	Primary Sensors Used	Feedback Method	Placement / Focus Area
Face- Mounted	Smart glasses, goggles, AR headsets	Camera, IMU, AI-based vision sensors	Audio cues, haptic vibration, voice output	Aligned with user's gaze
Hand-Mounted	Smartphone apps, smart canes, haptic wristbands	Ultrasonic, camera, GPS, accelerometer	Audio, vibration, tactile feedback	In user's hand or wrist
Body-Mounted	Belts, vests, backpacks, smart shoes/insoles	Ultrasonic, LiDAR, radar, pressure sensors	Haptic pads, vibration motors	Centered on torso or lower body

2.3.3Limitations in Current Wearable Assistance Methods

There is no denying the stride that have been made in technological aspect of assistive footwear, however sustained practical wearability is still a question mark . This is noted by Han et al. (2024), that existing assistive wearables tend to have ergonomic limiting aspects which compromise their ability to be widely implemented. Another limiting factor in the previous effort is lack of ability to give consistent reading as they tend to mainly rely on cameras or light sensor whose performance is greatly affected by changes in light intensity giving inconsistent reading also having to achieve right balance in power supply remained a considerable challenge that effort made prior found difficult to address as using larger batteries gave better duration would but at the cost of a system that is often bulky while efforts trying to reduce weight resulted in use of compact batteries at the cost of duration of operation.

Based on our reading of the current situation current system tends to rely on auditory feedback which ends up drawing unwanted attention and also is interpretation results in a cognitive load . Efforts to have made cloud server act as processing unit also didn't seem to bear the expected fruit because the constant uploading and downloading would end up introducing latency which in turn effect's ability to provide timely feedback. Recognizing the fact that that current methodology also isn't very consistent in its ability to prevent overheating and excessive perspiration upon wearing is another limitation that we would like to address. Summarizing it all it can be said that current system though faring much better in technical aspect, often fails in practical wearability which ensures long term wear.

Recognizing these persistent gaps provides the rationale for the present project's **sole- based assistive system**, we feel like our sole based system tends to bring a idea which is compact and ergonomic which achieves both functionality and practicality.

2.4 Role of gait analysis in assistive wear

2.4.1Addressing Limitations of Assistive Wearables through Smart Footwear

By taking a look over the current assistive wearables like body mounted devices which bring with itself physical strain upon or the hand held device which requires constant handling we believe there is a need for a system which is more comfortable and user friendly for use hence we feel like that smart shoe is a great way to address current limitation of practicality as they are going to have presence and embedding electronics on the shoe would mean that constant handling would be required a problem that is found in hand held devices.

As described by Rukmini et al. (2024), a smart shoe can refer to assistive footwear that makes use of integrated sensors, mainly pressure, temperature, and ultrasonic sensors that collect data about the user's movement and surrounding this data is then transmitted either through wired channel or wirelessly through the use of

Bluetooth. Such integration enables the device to function without interfering with the user's normal activities and with significantly lower energy demand compared to other wearable categories.

In this section, we will review the current standing of smart shoe technology in terms of its applications, components, and working principles. This examination will help clarify how various researchers have combined sensors and feedback mechanisms, providing valuable insight for integrating similar systems within our project. It will also illustrate how advances in smart footwear design have addressed two of the main limitations seen in previous assistive wearables—ergonomics and battery efficiency—thereby reinforcing its suitability as a foundation for the proposed sole-based assistive system.

2.4.2Gait-Analysis Applications

Gait analysis is defined as the science of studying person walking pattern by making use of data collected as he walks this effort is done to recognize changes in walking patterns from what is normal in order to identify any injuries that person have developed due to variety of factors such as aging. In order to achieve the said objective components like accelerometer and gyroscope are installed on the person limbs this component in turn gather data gather like person stride length and step count after comparison with what is normal any abnormality is determined and flagged (Tao et al., 2012; Lin et al., 2016).

Gait analysis have also undergone significant changes in the way it is implemented initially it was done in controlled setting of laboratory by making user walk on pressure mats or treadmill being continuously monitored by cameras though accurate, these methodology were expensive and were a far cry from representing person natural walking pattern (Lin et al., 2016).

This is where development of compact sensors come into play as they allow analysis to be conducted in actual environment this can be seen from study of Lin et al. (2016) who developed Smart Insole, which integrated array of pressure-sensor array and an Inertial Measurement Unit (IMU) consisting of a 3-axis accelerometer, gyroscope, and magnetometer. This combination allowed accurate gait monitoring in real-life situations like hallway walking or stair climbing.

This development has allowed us to move from lab-based setup to the application of gait analysis in everyday environments, which consequently contributed to the development of the concept of smartphone. By embedding sensors within the sole, gait parameters can now be measured continuously and comfortably, overcoming the earlier problems of restricted movement. For research such as the present project, studying existing smart sole systems provides useful insight into

sensor placement, data acquisition, and feedback design, which are essential for developing a compact, ergonomic, and energy-efficient assistive shoe.

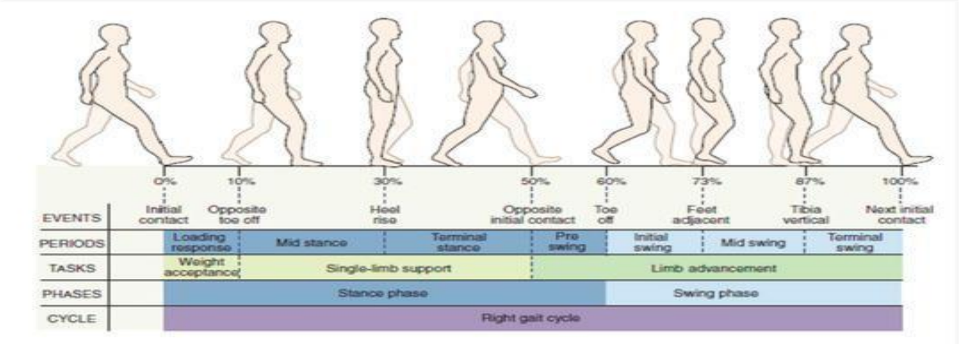

Figure 4:The human gait cycle illustrating the key phases of walking, from initial contact to the next heel strike, used in smart footwear systems to identify and analyze movement patterns

2.4.3 Sensor Integration in Footwear

Advances in gait analysis have shown a proof of concept that we are effectively able to integrate relevant electronics into a compact sole . Most prototypes employ three to five sensors strategically placed under the heel, midfoot, and toe areas, enabling detection of step phases such as heel strike and toe-off (Santos et al., 2025). The sensors most frequently used in such systems include pressure sensors for ground-contact measurement, accelerometers for motion tracking, and, in assistive applications, ultrasonic sensors for obstacle detection (Tao et al., 2012; Lin et al., 2016).

These studies confirm that sensor integration within footwear is technically achievable and can be combined with compact microcontrollers—for example, Arduino or ESP- based boards—that process and transmit data wirelessly to a computer or mobile device for analysis. Such arrangements allow continuous monitoring of user movement while maintaining a lightweight and ergonomic design.

Extensive literature continues to point out that the placement and the quality of the sensor have a significant impact on the accuracy of data collected. Sensors with high hysteresis or poor linearity can drift or provide inconsistent readings, which leads to incorrect detection of gait events. Therefore, high-sensitivity, durable sensors positioned at the main pressure points of the foot are essential for reliable results (Santos et al., 2025).

Collectively, these findings provide a clear technical foundation for the present project, confirming that integrating motion and pressure sensors with a microcontroller inside a flexible sole is both practical and reliable. The literature review done helps to provide guidance on the quality of sensors and their placement to ensure accurate data is being collected, also provides an insight to use soft rubber as a material for the sole because of its high strength and water resistance without compromising on users' comfort.

2.4.4Data Acquisition and Feedback Mechanisms

By understanding the recent work on smart shoe technology it can be concluded the working principle when implementing tech on shoe is similar which consists of sensing , processing and delivering a response we usually have ultrasonic sensor or pressure sensor to fulfill the first aspect of this flow after sensing the input information is sent microcontroller which upon processing provides feedback to the user. Amballa (2018) has given tangible evidence that this working principle is logical by having data of her inertial measurement unit processed by teensys microcontroller. Further support to this working logic is evident by Joseph et al. (2023) work who stated that most wearable uses sensor data to provide real time feedback which is either haptic or auditory in nature. Based on this recent research we were able to determine the foundation of workflow logic of our assistive system.

Table 5 : Comparison of feedback modalities used in smart-footwear systems (based on Amballa 2018 and Joseph 2023).

Feedback Type	Modality	Typical Use	Advantages	Limitations
Haptic	Vibration motors	Navigation, obstacle alerts	Silent, intuitive	Limited detail
Audio	Buzzer / Voice	Direction cues	Informative	Distracting, not ideal for visually impaired users
Visual	LEDs / Screen	Sports, rehab	Easy to interpret	Not suitable for blind users

2.4.5Comparative Analysis of Existing Research and Products

Based on our reading and understanding of current landscape we have concluded that current effort was more interested in delivering proof of concept which was of gathering data accurately it is because of such alignment that current system is lacking in ergonomics and aesthetical aspect which limits their continuous use. This is evidenced from the fact that current system tends to mount electronics on the externalities of the shoe this methodology however increases weight which in turn effect user balance. As noted by Joseph et al. (2023), several models have effectively been able to integrate sensors and electronics like batteries to produce a working system, but have failed to make it ergonomic and aesthetic, preventing them from being viable for everyday use. A similar concern was also pointed out by Santos et al. (2024), who emphasized that many sole-based systems have not transitioned to real-world use due to their lack of lightweight construction, high energy consumption, and limited ergonomic refinement. This challenge of achieving comfort and compactness comes from the need to integrate electronics into a compact system. Rigid sensor casings and surface-mounted wiring can alter pressure distribution across the sole, potentially affecting gait and causing discomfort during extended wear.

The findings above suggest that although the current body of work has effectively been able to ensure proof of concept, that is, the collection and processing of data, it has failed to account for user comfort and aesthetics, which are essential for everyday use. It is because of the reasons mentioned above that we are proposing to use customized rubber with most of the electronics restricted in the confinement of the sole ensuring both comfort and certain level of aesthetics

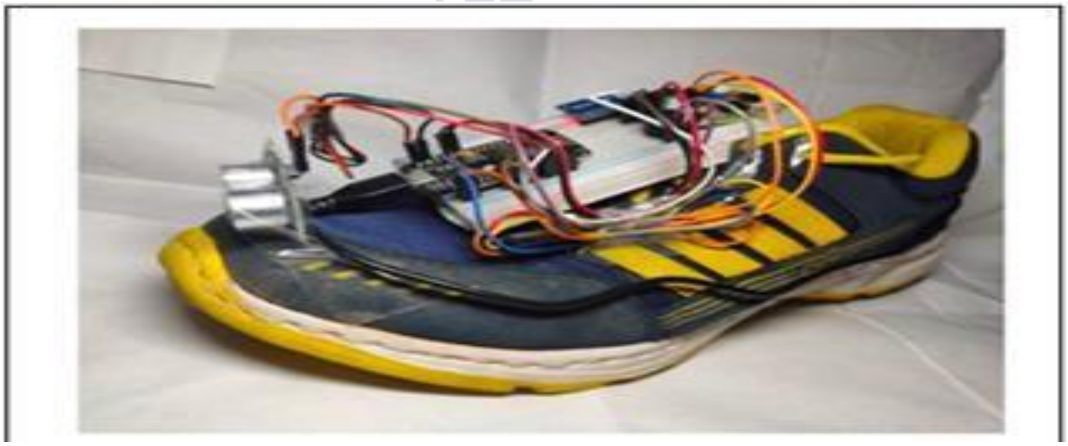

Figure 5:Example of an early assistive-shoe prototype with surface-mounted wiring and external components, illustrating the bulk and discomfort associated with current designs (adapted from Joseph et al., 2023).

2.5 Emphasizing new product by analyzing shortcoming in existing work

In order to attach due significance on the importance of project it is important that we take a view on earlier work so that we are able to distinguish our effort from other smart shoe effort already undertaken . Reviewing earlier designs helps highlight the fundamental weaknesses that continue to limit their real-world use. While these systems demonstrate considerable innovation, they often suffer from restricted connectivity, poor ergonomics, high power consumption, or limited user safety. A comparison of selected representative studies is therefore presented below to identify where current technologies fall short and how these limitations guide the direction of this work.

Table 6: Comparison matrix of various work on smart assistive footwear

Study / Device	Technology Used	Accuracy / Performance	Approx. Cost	Major Limitations
Amballa (2018) – Haptic Feedback Smart Shoes	Combined accelerometer , gyroscope, and magnetometer to sense motion and orientation. Communicated with a smartphone via Bluetooth Low Energy (BLE) to deliver directional vibration cues for navigation.	Reliable indoor navigation with accuracy within roughly one metre when the Bluetooth signal was stable.	Moderate (standard IMU + BLE modules).	Depended heavily on BLE connectivity and beacons; signal weakened through shoe casing; unsuitable for wide- area or outdoor navigation.

Drăgulinesc u et al. (2020) – Smart Insole for Gait Monitoring	Embedded pressure and motion sensors within an insole to record balance and step data for medical and rehabilitation purposes.	Highly precise data capture under controlled laboratory settings.	Moderate to high (clinical- grade sensors).	Designed solely for data recording and clinical gait analysis; lacked any obstacle-detection or navigation feature, making it irrelevant for visually impaired mobility.
Reddy et al. (2019) – RFID and Infrared- Based Navigation Aid	Used infrared sensors for obstacle detection and RFID tags placed along walking paths to provide location information with auditory feedback.	Worked effectively only along pre-tagged routes.	High (due to RFID infrastructure requirement) .	Required installation of RFID tags along every route—impractical for public use. Audio feedback distracted users from ambient traffic sounds, posing safety concerns.
Siddiqui et al. (2019) – Raspberry Pi Image-Recognition Footwear	Integrated Raspberry Pi, camera, and Wi-Fi for image-based obstacle recognition and real-time alerts.	Achieved object detection under test conditions.	High (multiple modules and battery pack).	Bulky, power-intensive, and dependent on continuous Wi-Fi connectivity ; complex design unsuitable for everyday wear.

The studies discussed have shown that most of the work done on smart shoes has been concentrated around gait analysis and determining walking patterns, which, although important in identifying injuries, offer very little for safe navigation for visually impaired people. Furthermore, any proposed system that relies on Bluetooth and wifi signals will fail to work in the context of Pakistan because of limited and unstable signals. In response to these limitations, the proposed project adopts a sole-based design that prioritizes both ergonomics and practicality. As mentioned, due to the limited network around Pakistan, the system will mainly be offline based, relying on ultrasonic sensors, microcontrollers and vibration motors. By following the said approach we will achieve two targets that long battery time and comfort this ensures its use in everyday life

2.5.2 Discussion of why most existing designs prioritize gait analysis rather than navigation or obstacle detection for the visually impaired.

If you look at different work done in field of assistive wear you would find that focus has been concentrated on gait analysis as mentioned by Borysiak et al. (2024), that this trend is because gait analysis has vast commercial and clinical appeal .These include use in rehabilitation and sports monitoring where important parameter such as stride length and cadence help unearth important revelation of the individual health . This wide array of application attracts greater funding and support coupled by the fact that there lesser ethical and safety concerns involved when applying assistive wearable technology for gait analysis where individuals can safely be monitored in the confinement of laboratory. There is no denying that there is lesser resistance to entry when applying assistive technology for gait analysis due to former mentioned reasons however this has prevented problems of visually impaired people from being addressed. To achieve genuine inclusivity, research must now extend beyond financially secure domains and confront the social responsibility of enabling independent mobility. Overcoming safety-related hesitation through staged field testing and user-centered design can ensure that future smart footwear moves beyond mere medical observation and becomes a practical, empowering tool for those who rely on it most.

2.6 Identified Research Gaps

2.6.1 Lack of Ergonomic Focus

Literature review has continuously shown that smart shoes for visually impaired people have always focused on accurate collection of data and showing proof of concept, resulting in ergonomic and aesthetic considerations being secondary. This has been highlighted by Rukmini et al. (2024) that continuous effort has been made to ensure refinement of the sensor and digital system, while ergonomic and comfort have largely remained unexplored. This observation indicates that although technology has become more advanced, the design has not yet evolved to account for individual wearability or long-term use.

The same tendency can be seen in the work of Sathvik et al. (2024), which heavily prioritized power generation, GPS connectivity and vibration feedback. While these features are functionally innovative, the paper devotes minimal discussion to the shape, fit, or ergonomic considerations of the shoe itself hence we can confidently conclude that their focus prioritized functionality and get things running and minimal effort was done to ensure aesthetics and comfort is also achieved.

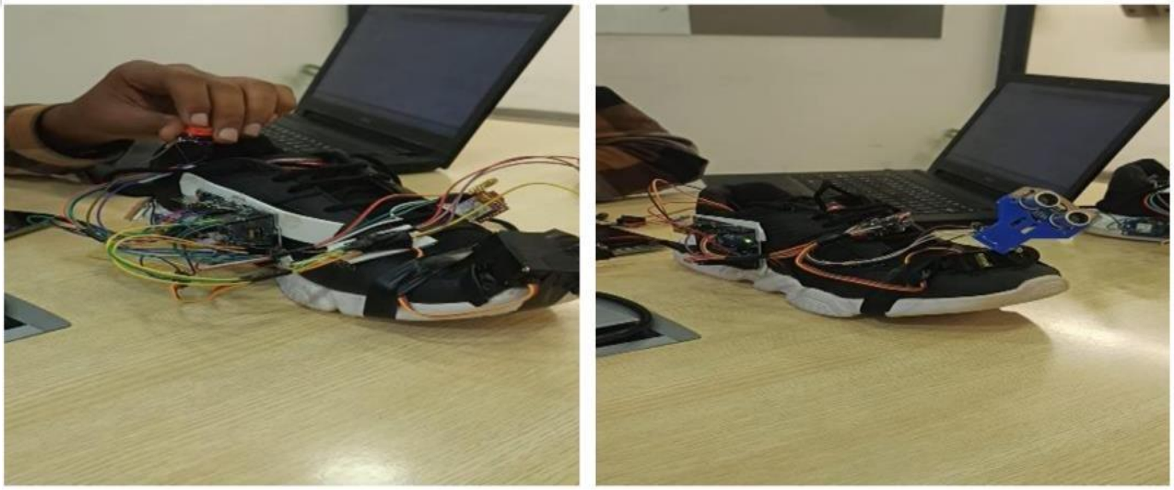

Figure 6:This figure provides a visual representation of the current design approach, where electronic components are attached onto the externalities of shoe's structure, illustrating the lack of ergonomic and aesthetic attention in existing prototypes.

A more general conclusion based on earlier revelation in the section we can safely say that there has been lack of effort in terms of achieving practicality of product by not giving importance to comfort and aesthetical appeal this is a compromise that should not be made in technology designed specifically for visually impaired people for whom comfort should not be an option but priority. Hence our effort is trying to bridge the gap between functionality and comfort aspect of smart shoe. Techniques such as computer-aided design (CAD) and customized footwear hold promise for addressing this gap by enabling adaptive, custom-fit design that merges technology with genuine ergonomic value.

2.6.2Limited Integration of Compact Sensor Systems

Furthermore, efforts in gait analysis were not aligned to ensure the development of an ergonomic approach, but on accurate data acquisition, so little to no effort has been made in any field that can have an association with smart shoe technology. As highlighted by Joseph et al. (2024), most of these studies have been carried out in controlled environments where accuracy of measurement was prioritized over system practicality. Because of this laboratory-focused approach, less effort has been directed toward integrating multiple sensors into a single, compact, and self-contained platform capable of functioning reliably in real time.

Similarly, the review conducted by Almuteb et al. (2022) found that various efforts have been made to ensure the accuracy of individual sensors, but little to no exploration is done on integrating multiple sensors into a compact system, ensuring they work in conundrum with one another . This lack of synchronization often results in signal instability and inconsistent readings.

The reason why no significant strides have been made towards producing a compact system is that there are barriers associated with producing small electronics. Power management is one of the major hurdles since you cannot house big batteries; ensuring a considerable duration of the system in terms of battery life is a significant challenge. Furthermore, tight spacing usually means problems such as overheating and signal interference would come up as a challenge. These issues reduce both the accuracy and reliability of such systems, making them unsuitable for consistent use outside experimental settings.

So in summary, considerable effort has been made to ensure improvement in the accuracy of individual sensors and electrical components, while ensuring functionality while housing them in a compact space is still area that has remained underexplored. Future research needs to shift focus toward improving overall system coordination, minimizing power losses, and ensuring that compact designs can perform effectively in real-world conditions.

2.6.3Poor Real-Time Feedback Optimization

Another problem associated with the current body of work is that it concentrates on data acquisition rather than exploring the area of real-time data gathering and providing feedback to the user. As discussed by Joseph et al. (2024), most of the experiments using shoe-based structure were also for accuracy purposes, carried out in a controlled setting where the objective was to ensure accurate data collection rather than developing a system that would interact with the user in any capacity. It is because of this approach that current shoe based system don't have the capacity to provide real time feedback that is aligned with environment and to the user.

Further review by Almuteb et al. (2022) reinforces this observation based on their effort of analyzing over eighty insole-based system they concluded that system performance is solely judged based on their accuracy and precision and not on its ability to provide responsive feedback. This trend is mainly because current studies are done in controlled environment of laboratory where safety isn't a real concern and hence providing feedback takes back seat. All this results in underdeveloped feedback mechanism

Furthermore the reason for this slow progress, as noted in the work of Van Hooren et al. (2024), is because of the fact that maintaining proper coordination between the sensor data stream and the software remained a considerable challenge. This problem existed in the past because systems had to process reading from multiple sensors within short duration to prevent any sort of dysconnectivity . Older version of microcontroller struggled to keep up with processing such data and at the same time being able to minimize heat generation and power consumption because such contradiction existed between quick response ability and being stable in performance many researcher became hesitant on implementing feedback mechanism on compact systems.

Based on the prior stated information it can be concluded that there is lack of feedback mechanism in assistive wear this is a big blow for visually impaired people for whom having immediate feedback mechanism is a top priority in order to safely navigate through a environment . Future research must therefore focus on developing a architecture which provides real time feedback the success in developing such mechanism is solely dependent on the advancement made in processing feats made in recent time

Table 7: Comparison showing how current systems emphasize offline data analysis, while real-time feedback—vital for visually impaired users—remains limited by technical and energy constraints.

Aspect	Offline Data Processing	Real-Time Feedback
Focus	Data collection for later study	Instant user response
Environment	Controlled lab tests	Real-world use
Processing	Post-session analysis on PC	On-device computation
User Role	Passive; no live input	Active; guided by alerts
Hardware Demand	Moderate	High-speed, power-efficient
Main Limitation	Delayed usefulness	Power & synchronization issues

2.6.4Lack of Cost-Feasibility Studies

Based on previous work another gap that

currently exist in the literature is the fact that no effort has been in terms of determining the economic viability of the product or making this product economically feasible . The reason for such trend is because projects(smart shoe+ assistive wear) are often developed and tested in controlled environment with no intention of making it commercial or available to larger society hence there is lack of feasibility studies .
This claim is supported by several studies done across the world for example, Rukmini et al. (2024) made an effort on developing innovative smart shoe but based on his efforts concluding that system is still expensive and hence not applicable for
every day use this conclusion can further be backed by Almuteb et al. (2022) who pointed that even smart shoe made for commercial scale largely remained restricted to laboratory because of high cost and significant hurdle in relation to battery life . The work of Sathvik et al. (2024) also seems to exemplify this limitation: their prototype effectively integrates obstacle detection, vibration motors, and GPS tracking; effectively, it remains a one-off experimental model, with no accompanying analysis of production cost, long-term maintenance, or affordability for visually impaired users in developing contexts.
Moreover, the challenge of achieving compact, energy-efficient integration— discussed in Section 2.6.2—adds to the financial complexity. As electronic components are miniaturized and combined into tighter spaces, manufacturing precision, heat management, and component shielding become more expensive. Furthermore considering ergonomic fit for every individual also adds to the cost , as noted by Rukmini et al. (2024), doing so inherently increases fabrication and testing costs. So despite the fact there is advancement in the technology the lack of effort in terms of making the system feasible prevents its deployment in larger market
For us to solve this problem we have to consider feasibility as part of design rather then commenting or considering it after the completion of project we would consider the financial aspect in our project by making thoughtful decision when choosing electrical components and material for our sole structure. By taking in to such effort we will not only be considering the technical aspect of system but also ensuring its deployment in the wider market

2.7 Summary of Literature Review

After we reviewed current body of work on smart shoe we came to the conclusion that the focus has been consistently on ensuring proof of concept rather making the product widely available to the market by considering the economical aspects of it . The research work consistently showed that sensor and microcontroller can communicate in the confinement of a shoe but however no tangible effort or result are available that comment on weather the user is comfortable while adopting the technology for themselves. Considering the comfort aspect along with other three there are in total 4 gaps we have identified in our literature review which would be discussed below.
The first gap concerns ergonomics. Based on our go through of research papers we concluded that focus has mainly been on ensuring effective communication between sensor and microcontroller rather then on comfort . When the focus is only to confine the rubber sole use in labs or for testing comfort and ergonomics are bound to take backseat. To address this limitation our project is considering using soft yet durable rubber sole which combines both element of comfort and functionality
The second gap is the lack of aesthetic or more profoundly not trying to make the system compact currently the effort tend to mount different electronics on to the surface of the shoe this makes the shoe unappealing and bulky . To solve this problem current project is considering restricting the electronics to the inside of the sole but not at the cost of functionality . This methodology would help to achieve a cleaner design which can be used in everyday life by the visually impaired
The third gap identified is the lack of real-time feedback optimization. As previously mentioned

since most of the effort has been aligned towards gait analysis in which processing of data can take place separately there has been little effort on having a system that provides real time feedback through this project we are hoping to create a

system that interacts with environment and provides real time feedback to user Finally, the fourth gap concerns the lack of cost-feasibility assessment. This is because most of effort for smart shoe wear has been restricted to the lab work with no intention in mind of making the work be commercial .Throughout the course of this project we are hence hoping to reach a feasible solution to this problem and at the same time recording the expenses beared so cost feasibility assessment can be done through our effort as well.

So summarizing our literature review we have reached the conclusion that there is no denying the fact that there has been effort in terms of making a technology which can employed onto shoe and in turn can help visually impaired but the shortcoming are clearly seen in terms of lack of mentioned factors Hence our project would like to address these short coming by considering comfort, compactness and affordability to reach a result that is practical.

Table 8: Gaps identifed through literautre review

Identified Gap	Underlying Cause in Literature	Effect on Existing Designs	Proposed Project Response
Lack of Ergonomic Focus	Most studies emphasized proof- of-concept and data validation over user comfort or fit.	Designs are bulky, rigid, and unsuitable for long-term wear, especially for visually impaired users.	Introduce a soft yet durable rubber sole to enhance comfort, flexibility, and long-duration usability.
Limited Integration of Compact Systems	Components (sensors, power units, controllers) often mounted externally; little attention to space optimization.	Overheating, signal interference, and reduced reliability during prolonged use.	Embed electronics within the sole, ensuring spacing for ventilation and sensor shielding to maintain accuracy.
Poor Real- Time Feedback Optimization	Research focused on offline gait analysis; systems tested in controlled lab settings.	No instant feedback to users, limiting real-world applicability for navigation and safety.	Integrate sensors, microcontroller, and vibration motor to deliver immediate tactile feedback to the wearer.
Absence of Cost-Feasibility Studies	Prototypes built for academic validation without economic evaluation or large-scale outlook.	Systems remain expensive, complex, and impractical for mass production.	Include cost analysis during design to ensure material and assembly choices remain commercially viable and accessible.

Methodology / System Design

3.1 Introduction

3.1.1 Overview of Project Methodology

We set out to build a working prototype of smart shoes that help visually impaired people move around more safely. We mixed design work with hands-on testing – fitting electronics into a small, comfortable shoe. Computer Programming the Arduino was key – it processes sensor data and triggers vibrations. After multiple discussions and a detailed review of existing research, the team finalized the core concept of the system. The shoe uses an ultrasonic sensor to spot obstacles, a microcontroller to decide when to react, and vibration motors to warn the user. We wanted a shoe that works – with a custom rubber sole that detects obstacles well but still feels comfortable and lasts

3.2 System Overview

3.2.1 Block Diagram

The diagram shows a high-level view of how the smart shoe's parts connect – ignoring wire details to keep it clear. It shows how power and data move between the sensors, Arduino, motors, and battery to detect obstacles and vibrate.

Figure 3.2 shows the flow: toe-mounted sensors measure distance, Arduino checks if it's under 100 cm, then vibrates to provide haptic feedback, alerting the user to the potential hazard. The entire system is powered by a Lipo cell supported by a voltage regulation unit, which ensures stable and reliable operation of all components. This arrangement allows the smart shoe to function effectively while maintaining a compact and practical design suitable for daily use.

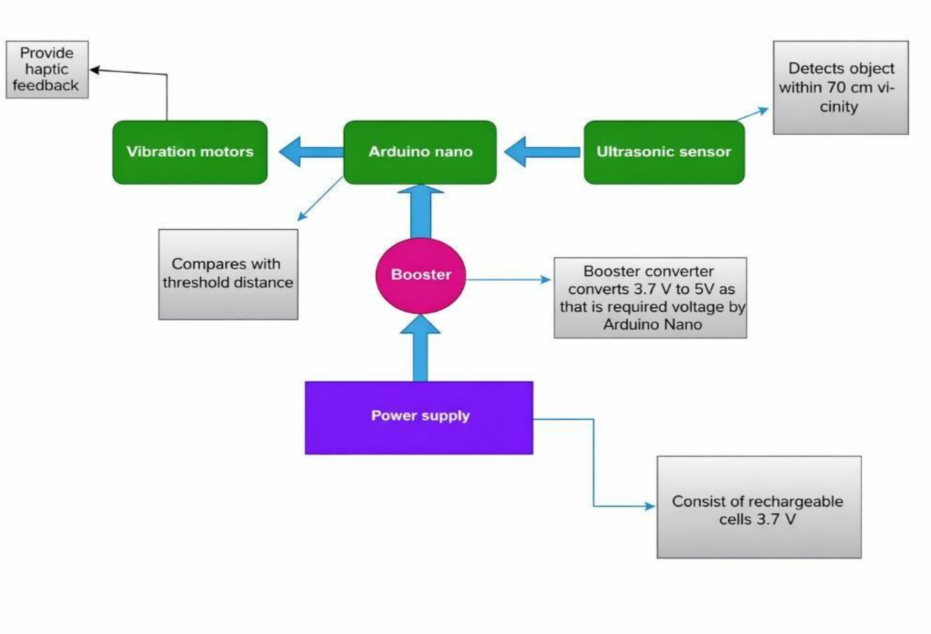

Figure 7: (Block diagram of our proposed system)

3.2.2 Description of Each Block

a) Power Supply

The system is powered by a flat 3.7 V lithium-ion cell. This type of battery was chosen because of its slim and lightweight design, making it suitable for placement inside the shoe without causing discomfort to the user. The small size would allow us to embed it deep inside the sole , so the user barely notices the electronics while walking.

b) Booster Circuit

The booster steps up 3.7V to 5V because the Arduino and sensors need 5V.

c) Ultrasonic Sensors

Three AJ-SR04 sensors (waterproof) sit near the toe. They send out sound pulses and measure how long the echo takes to bounce back – that tells us the distance between the shoe and the object ahead. As each sensor can detect objects within a range of approximately 20 cm to 600 cm, however we are concerned with the objects with the range of 0–150 cm. It is felt that obstacles within this distance are more likely to affect the user's walking and require timely alerts so we only warn the user about things within 1.5 meters.

d) Microcontroller (Arduino Nano)

At the center of the system is the Arduino Nano which continuously receives distance data from the ultrasonic sensors and processes this information to determine how close an obstacle is to the user.

The Arduino checks distances constantly but only triggers vibration under 100 cm.. This threshold was selected because it represents a practical distance at

which the user may need to slow down or stop in order to avoid a possible collision.

e) Vibration Motors

Three small motors vibrate to warn the user. We put them where they're easy to feel – one near the heel, two along the sides. The vibration gets stronger as you get closer – so you can feel how near the obstacle is without looking. As a result, the Smart Sole offers an intuitive and practical way for visually impaired individuals to detect obstacles and move more confidently.

3.2.2 Working Principle

How it works: power flows battery → booster → Arduino/sensors; data flows sensors → Arduino → motors (as shown in Figure 7)

Summary

In summary, the Smart Sole combines these five functional blocks to form a compact, low-power, and reliable obstacle detection system. While the microcontroller responds when the object is 100 cm or below .

3.3 Hardware Design – Introduction

Below we explain why we picked each component, how we wired them, and how we fit everything into the sole.

3.31Hardware Components

1- Ultrasonic sensor () – rationale behind choosing Aj sr04

We picked the AJ-SR04 over other sensors for three reasons. First, it's cheap. Cameras or IR systems would cost much more, but this sensor works well for obstacle detection. Even in its waterproof configuration, the AJ-SR04 remains reasonably priced at approximately Rs. 1,421, whereas premium options such as the MaxBotix series can cost more than Rs. 13,000.

Second, it's waterproof. Normal sensors like HC-SR04 have open transducers – they'd die if you step in a puddle. The AJ-SR04 is sealed. This allows it to operate reliably even when exposed to moisture, dirt, or splashes—conditions that are difficult to avoid for a sensor integrated into a shoe sole.

Third, it's compact, single-probe design. Conventional sensors such as the HC-SR04 use two separate transducers for transmitting and receiving ultrasonic waves, which increases their size and makes them harder to accommodate within the limited space of a shoe sole. In contrast, the AJ-SR04 uses a single cylindrical probe along with a

low-profile control module, making it easier to integrate without affecting the user's comfort or natural walking pattern.

2- Arduino nano microcontroller – rationale for selection & role

The Arduino Nano was selected as the central controller for the Smart Sole because of its compact size and low power requirements, both of which are important for a shoe- mounted system. Since the entire device operates on a limited battery supply, the Nano's low energy consumption becomes a key advantage, allowing the system to run for longer periods without frequent recharging.

Another reason for choosing the Arduino Nano is its sufficient number of input and output pins. This makes it possible to connect multiple components—such as ultrasonic sensors and vibration motors—without the need for additional interface boards. As a result, the wiring remains simpler and the internal layout is easier to manage within the limited space of the shoe sole.

In terms of performance, the ATmega328P microcontroller used in the Arduino Nano provides adequate processing capability and memory for handling real-time distance data from the ultrasonic sensors. It can also efficiently control the vibration motors to generate timely haptic feedback.

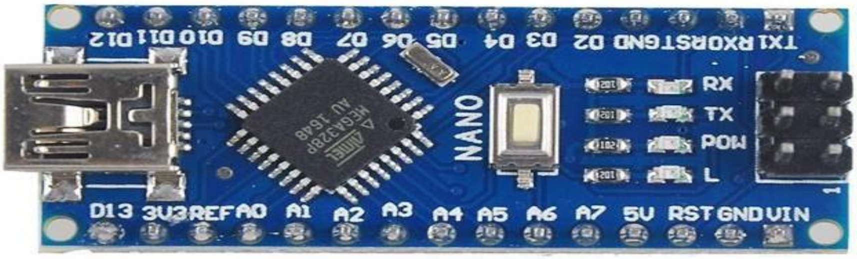

Figure 8: showing pictorial layout of Arduino nano

3- Rationale Behind Using Lithium-Cell

The reason why we have decided to use lithium cell lies in various aspects ranging from safety , life cycle and performance . In regards to safety lithium cell have shown that it doesn't undergo considerable swelling and overheating when under pressure furthermore it has shown that it has considerable longer life cycle as it can survive greater number of charging cycles especially considering the amount of current our system would be operating at finally in regards to performance which was the most valuable aspect that made us consider lithium phosphate cell was the fact that the performance of the cell doesn't vary much considering the temperature range that the system would be operating at stable input to booster converter ensures it smooth operation which in turn prevents the Arduino to shut down or ultrasonic sensor and motor to become ineffective

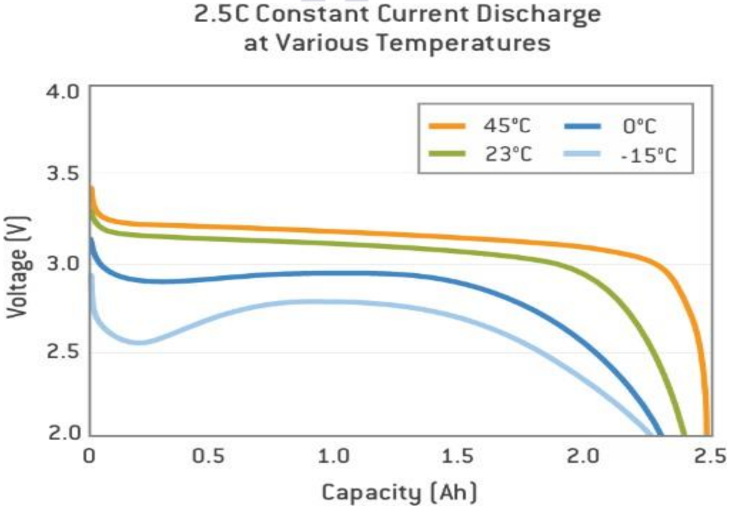

Figure 9: Graph showing that cell output voltage doesn't vary much

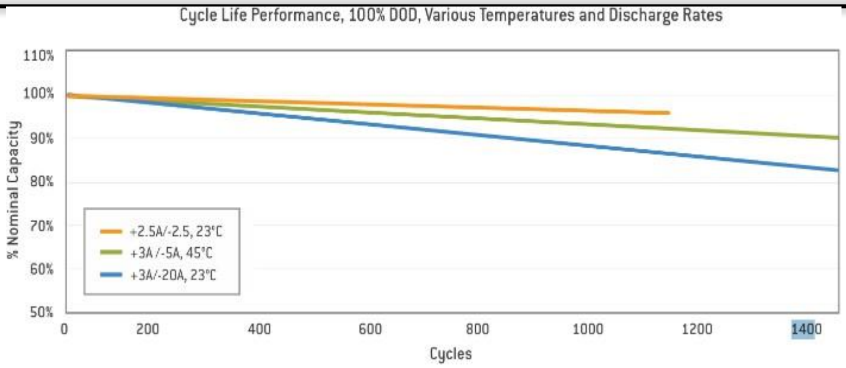

Figure 10: Graph showing high number of life cycle of cell

Figure 11: pictorial representation of lipo cell

4- Rationale behind using eccentric vibration motor (3-6 V)

A eccentric vibration motor was chosen to provide haptic feedback since it contains eccentric mass that upon rotating provides noticeable tactile feedback to the user fulfilling its major objective of alerting the user . Along with this other specification such as its low electrical consumption roughly 70 mA at 5V is also perfect when working with limited power supply moreover the fact that it can work in voltage ranging from 3 to 6 V make it suitable for our system which is going to operate at 5V . Finally its lower profile dimensions such as roughly 12 mm diameter and 20 mm motor height allows it to fit inside sole based system easily.

Figure 12: eccentric vibration motor

3.3.2Circuit Design

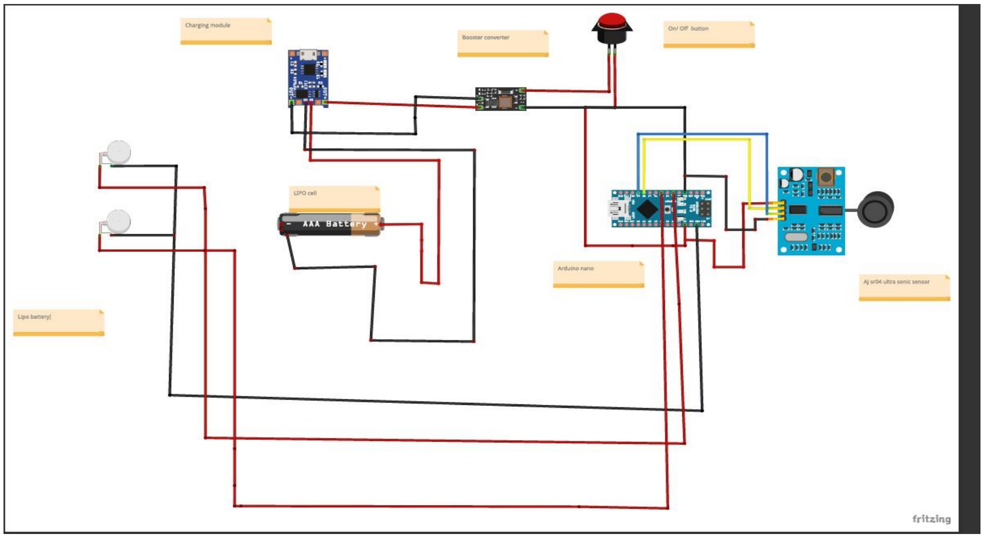

Figure 13:(Fig showing circuit diagram to be used in our project)

The circuit design for the smart shoe system integrates the power supply, charging module, voltage regulation stage, ultrasonic sensing units, Arduino Nano microcontroller, and vibration motors in a compact and wearable configuration.

The system is powered by a 3.7V Lithium-phosphate cell , chosen for its safety m longevity and performance. To ensure safe and efficient recharging, the battery is connected to a TP4056 charging module, which provides over-charge, over-discharge, and short-circuit protection. An On/Off push button is placed after the booster converter module and functions as a master switch. This allows the entire system to be turned off when the shoe is not in use, helping conserve battery power and extend operating time between charges.

Since the Arduino Nano and ultrasonic sensors require a 5 V supply, the battery output is first routed through a boost converter. This converter increases the battery voltage from 3.7 V to a stable 5 V level. The regulated output is then supplied to the 5 V (or Vin, depending on configuration) pin of the Arduino Nano, as well as to the ultrasonic sensors.

To ensure reliable operation, a common ground is maintained between the battery, boost converter, sensors, and Arduino Nano. This shared ground provides proper signal referencing and helps maintain stable communication between all components of the system.

The AJ-SR04 waterproof ultrasonic sensors are positioned in the toe region of the shoe, allowing them to detect obstacles directly in the user's walking path. Each sensor is connected to the Arduino Nano using four pins: VCC, GND, TRIG, and ECHO.

The Arduino Nano sends a short trigger pulse to the TRIG pin, which prompts the sensor to emit an ultrasonic wave. This wave travels forward and reflects back when it encounters an obstacle. The sensor then sends a signal through the ECHO pin, indicating the time taken for the wave to return. Using this information, the Arduino calculates the distance to the obstacle and determines whether feedback needs to be provided to the user. The time taken for this wave to reflect back and be detected by the ECHO pin is measured. Distance is computed using the time-of-flight principle: Distance=speed of sound x time/2

The distance determined is continuously compared by Arduino with the 100cm threshold this . If an obstacle is detected within this range, Arduino activates the appropriate vibration motor. Two eccentric cylinder type vibration motor (3-6 V). We kept the circuit small by sharing grounds and using the TP4056's built-in protection. One issue we ran into was noise from the boost converter – adding a 100µF capacitor fixed it (not shown in the diagram).

3.3.3Veroboard

A veroboard was also designed to be integrated in our smart shoe system since it houses all of the major electronics in a compact and organized structure as it has minimal dimension of 2.7 x 1.4 in . It houses major electronics such Arduino nano , TP 4056 charging module along with booster converter . The components in PCB interacts with each other and other components in smart shoe system to ensure effective operation . First the TP4056 charging module would charge the Lipo battery which in turn provides power to the booster converter whose main job is to convert the 3.7 volt power supply to 5v one since that is required by the Arduino nano to operate which in turn interact with the vibration motor and ultrasonic sensor whose pins are integrated into the board

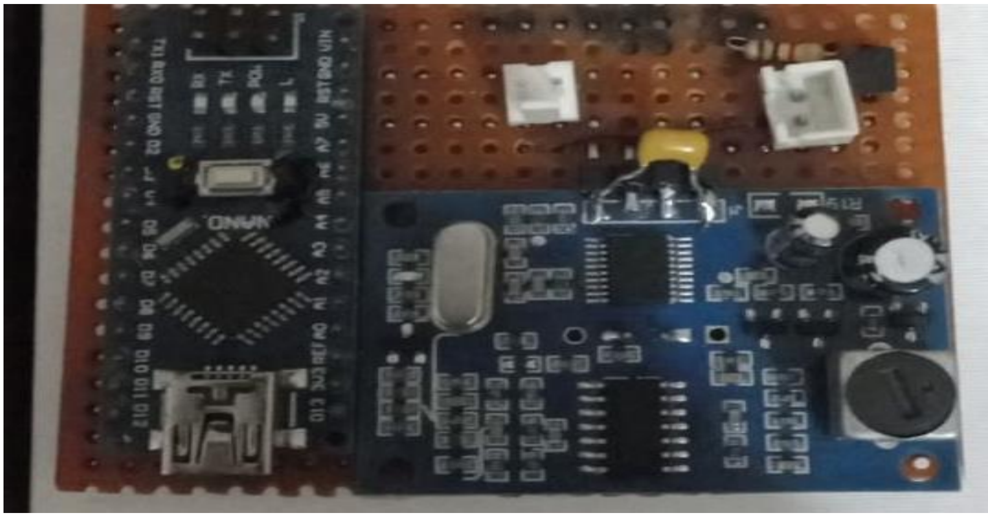

Figure 14 Veroboard to be used in system

Section 3.4 – Mechanical Design (Introductory Paragraph)

In this section, we outline the mechanical design choices that shaped the overall structure of our prototype. The focus is on explaining what thought went behind in our logic of placing the components. Our design revolves around ensuring compactness, prioritizing user comfort while at the same time not compromising on the functionality. The following subsections discuss the rationale behind the arrangement of the internal components, and the factors we weighed in shaping the device's physical layout.

Section 3.4.1 – CAD Modelling

CAD helped us see problems early. We could move components around virtually before cutting any foam. We tried three different layouts in CAD before finding one that fit everything without bulging the sole.

During the modelling phase, it became evident that the electronic components could not be easily accommodated within the existing shoe structure. Simply attaching the modules to the original sole would have affected comfort, durability, and overall usability. As a result, the decision was made to design a dedicated outer sole that would replace the original one, allowing proper integration of the electronics while maintaining comfort and structural integrity.

This allowed us to define controlled internal spaces and establish a safe clearance to ensure electronics safety and maintain user comfort . Maintaining this gap was important because it prevents the user’s foot pressure from directly acting on sensitive components such as the battery, PCB, and sensors. Without this spacing, repeated pressure during walking could damage the electronics or affect their performance over time. CAD helped us choose the right sole thickness and keep electronics safe from foot pressure.

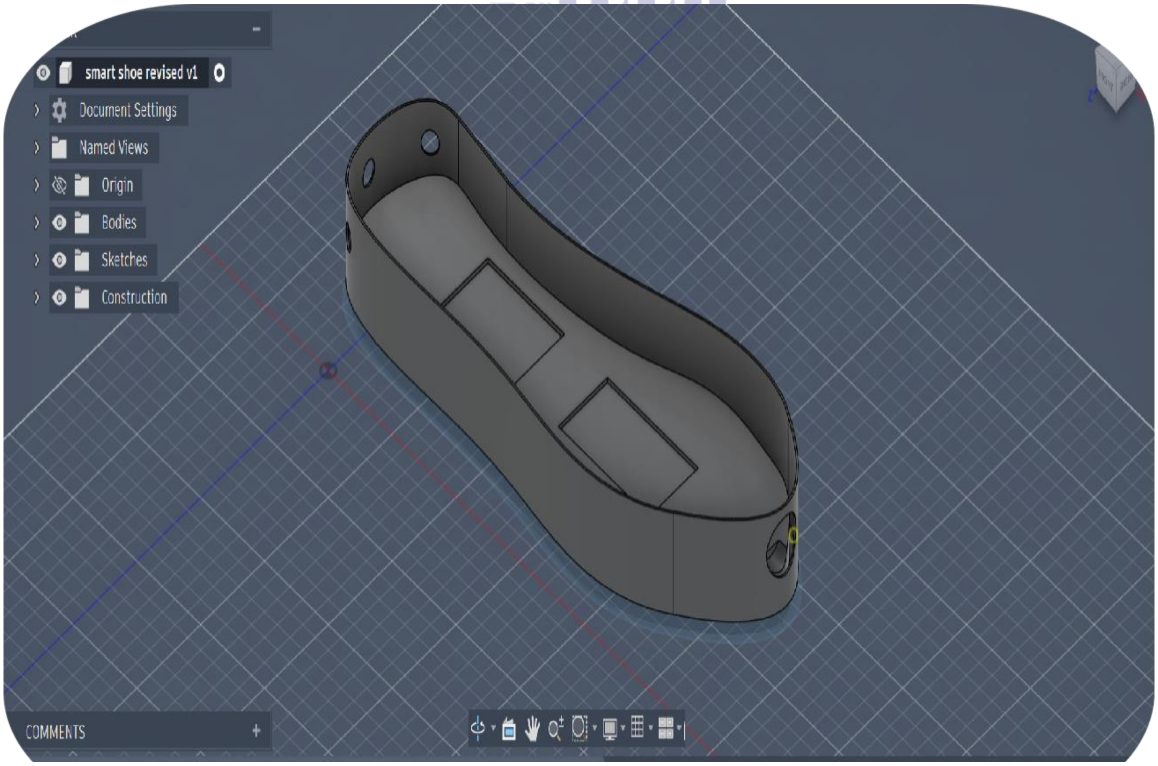

Figure 15: CAD model of our shoe-based design

3.4.2 Sensor Positioning and Ergonomic Considerations

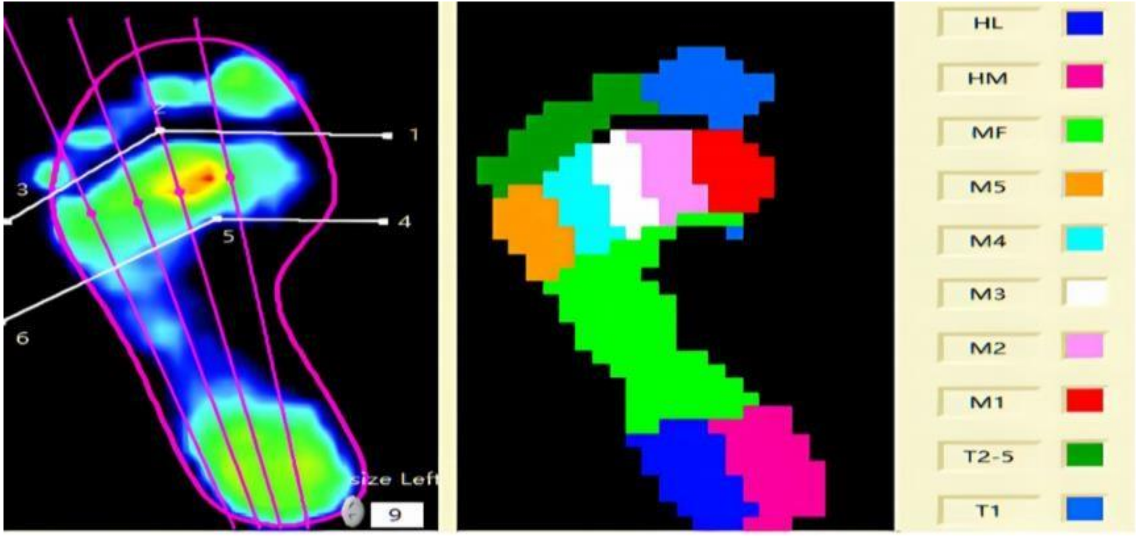

Figure 16: :(Fig showing plantar foot distributionSource:Bai, X., Hou, X., Song, Y., Tang, Z., Huo, H., & Liu, J. (2025). Plantar pressure classification and feature extraction based on multiple fusion algorithms. Scientific Reports, 15, Article 13274. https://doi.org/10.1038/s41598-025-96440-6
)

1- Placement logic (toe, heel)

Research on plantar pressure during walking played an important role in deciding the placement of sensors and internal components within the sole. According to the pressure maps presented by Bai and colleagues (2025), the midfoot and medial arch experience consistently lower pressure across different walking patterns. These regions appear relatively cooler on pressure maps, indicating fewer contact forces during movement. As a result, the medial arch was identified as the most suitable location for housing sensitive components such as the battery, PCB, and other electronics, since this area is naturally protected from high compression. In contrast, the forefoot— particularly the regions beneath the first and fifth metatarsal heads—shows significantly higher pressure levels during walking. These areas experience repeated pressure peaks during the push-off phase, making them unsuitable for placing delicate components. Therefore, no electronics were positioned directly under the ball of the foot to avoid potential damage and discomfort. The heel region also experiences a strong initial impact during heel strike. To account for this, the vibration motor was placed toward the outer perimeter of the heel. This positioning helps protect the motor from direct impact while still allowing the vibration signals to be clearly felt by the user. Overall, the final layout follows the plantar-pressure characteristics identified by Bai et al. (2025). This approach ensures that all embedded components remain protected during normal walking, while maintaining comfort, durability, and effective system performance.

2- Justification based on user comfort and detection angle

User comfort and effective obstacle detection were also key considerations in determining the placement of electronic components. Positioning the electronics along the medial arch was a deliberate choice, as the natural curvature of this region reduces direct pressure from the foot. This allows the user to walk comfortably without feeling rigid components beneath the sole. In addition, the internal clearance provided by the cavities creates space for natural foot movement and flexing, further minimizing discomfort and preventing accidental contact with the electronic housing. For obstacle detection, the ultrasonic sensors were placed near the toe region, where they have a clear forward-facing view. The sensors were also slightly angled upward to prevent the system from reacting to small ground-level objects such as pebbles or minor surface irregularities. This approach helps focus detection on obstacles that are more likely to pose a real hazard to the user. A similar strategy is discussed by Sathvik et al. (2024), who note that tilting the ultrasonic sensors upward allows the system to detect objects of meaningful height rather than responding to unnecessary ground clutter.

With sensors offering an approximate 60-degree detection field, this configuration provides a broad sensing area. When combined with the upward tilt, it enables reliable obstacle detection while maintaining a comfortable and unobtrusive user experience.

3.4.2Carbon fiber casing:

Electronic components inside the smart shoe are subjected to repeated forces during walking and everyday use. Over time, these forces can potentially damage sensitive parts such as the PCB if adequate protection is not provided. To address this, a protective casing was considered as part of the design to shield the electronics from mechanical stress and impact. Carbon fiber–reinforced materials are commonly used in applications where both strength and lightweight properties are required. Research indicates that carbon fibers exhibit high compressive strength due to their internal graphitic structure and strong carbon–carbon bonding (Kumar, Anderson, & Crasto, 1993). These characteristics allow the material to withstand mechanical loads without significant deformation. By enclosing the PCB within a carbon fiber casing, the electronic components are better protected from external pressure and impact during walking. At the same time, the lightweight nature of carbon fiber ensures that the overall system remains suitable for wearable use, maintaining comfort while improving durability.

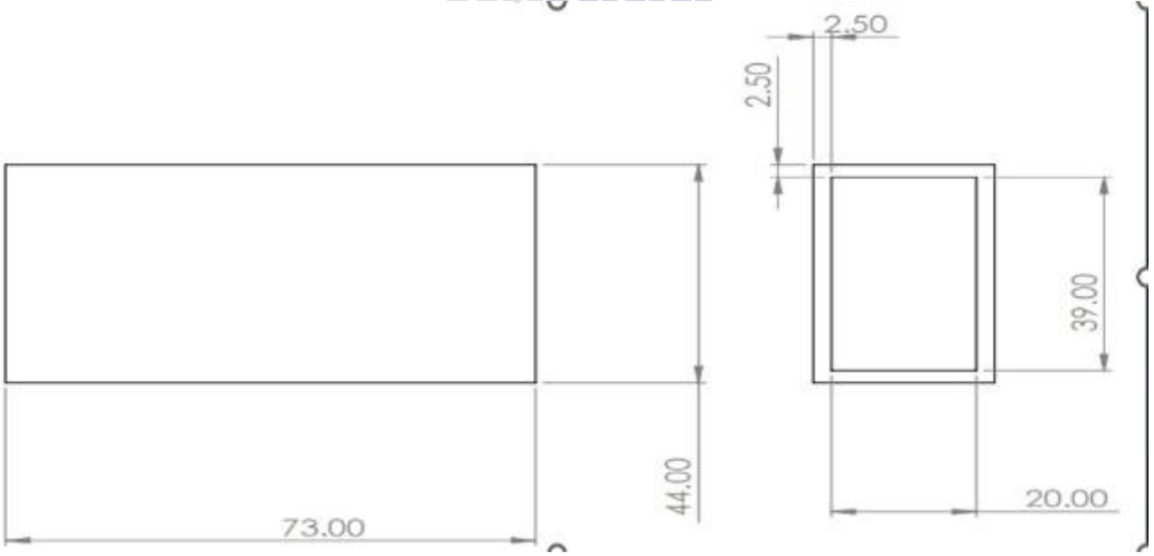

Figure 17: Visual layout of PCB casing

3.5 Summary

We ended up with a shoe that detects obstacles under 100 cm and vibrates harder as you get closer. The electronics sit in the medial arch (low pressure) with a carbon fiber casing for protection.

Simulation & Analysis

4.1 Preamble/Introduction:

The making of the smart shoe system included the integration of electronic components within the sole , which introduced certain risk in terms of safety and operation . This included structural failure as load would be applied during walking as well as overheating because of electronics included in the sole . If not catered for it would compromise both the comfort as well as the safety of the components in our system. Hence it became necessary to carry out basic FEA structural analysis along with simple heat analysis to prevent former mentioned problems. Consequently chapter presents the structural and thermal evaluation performed to verify that the proposed design is reliable for practical use.

4.2 Objectives of Simulation

The main goal of the simulation and analysis were to ensure that our proposed idea is safe both in terms of use as well protecting the electronics inculcated in it . For us to meet this end goal we conducted FEA analysis on the PCB casing to ensure protection of components such as Arduino , charging module and booster converter , then the casing was made part of the whole system and it was observed how the system as a complete system would respond to load during standing or walking we also observed stress and strain is normally distributed in the shoe to figure any area of weakness finally we conducted simple heat analysis using educated assumption and simple calculation involving Fourier law of heat conduction to estimate temperature rise inside the shoe all this was done with with objective mentioned at the start of the section .

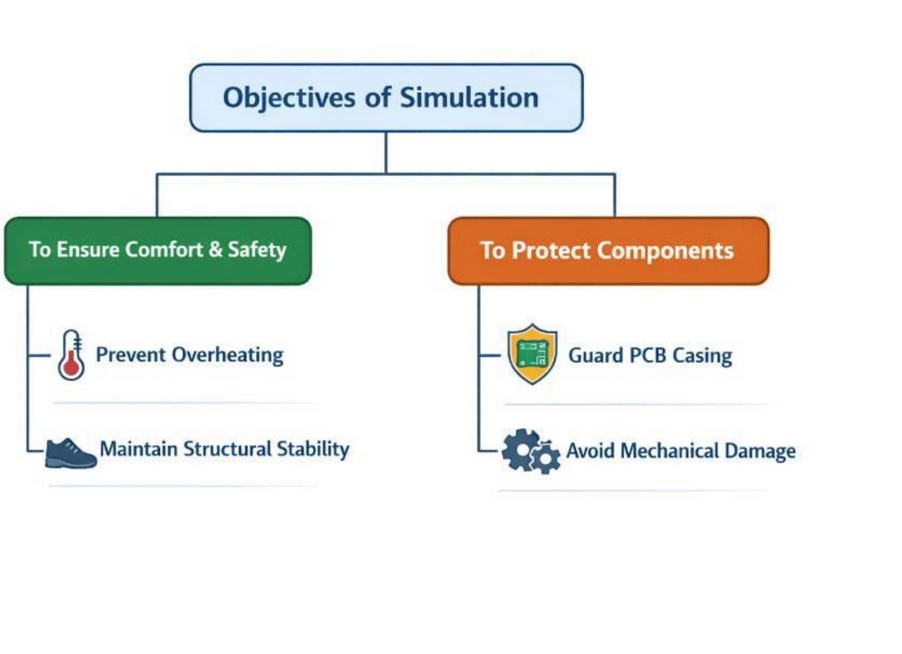

Figure 18: Basic summary of the objective of simulation

4.3 Methodology

4.3.1Structural Analysis

To determine the structural integrity of the shoe a FEA methodology was developed and applied both on the PCB casing as well the shoe to conduct FEA first of all a basic CAD model of the PCB and the shoe were developed on solid works and then imported onto the ANSYS software. After importing relevant materials were applied to casing and shoe these were carbon fibre and rubber respectively then static structural option was chosen for conducting a comprehensive analysis of the shoe We have assumed that shoe would be wore by average male adult with mass 75 kg this would correspond to him exerting force of 735 N , to account for additional stresses during walking, a safety factor of 1.5 was included, resulting in a total load of approximately 1100 N. This load was applied in both the casing and full shoe simulations to evaluate stress distribution and deformation under realistic conditions.

4.3.2 Thermal Analysis

To determine temperature rise of the shoe a simplified heat analysis was conducted using electrical power consumed by components . The total current used by the system was determined using typical value of current consumed by them when operating at 5V . Using the operating voltage of 5V, the electrical power consumption was calculated.

Using booster converter conversion efficiency of 90 % the total power produced by the battery was also determined this was estimated to be equal to the heat produced as all of the electrical power eventually turns into heat . To estimate the temperature rise, typical values of shoe sole area, thickness, and thermal conductivity of rubber- based material were used. Based on these assumptions, a simple heat transfer calculation was performed based on Fourier law of heat conduction to determine whether the resulting temperature remains within a safe and comfortable range for the user.

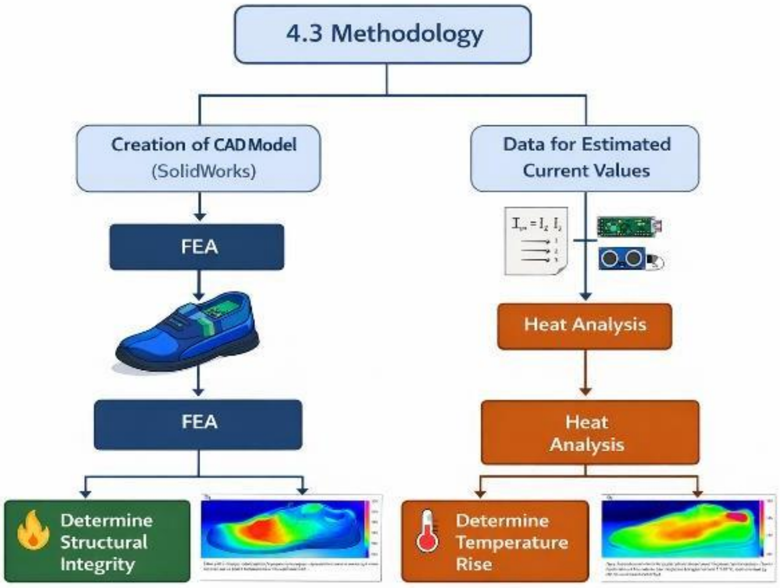

Figure 19: Summarizing project methodology

4.4 Structural Analysis

4.4.1FEA of PCB Casing

The PCB casing plays a critical role of housing essential electronics associated with our project since the casing houses sensitive components such as the microcontroller and sensor connections, ensuring its structural integrity is essential for reliable operation. In this design, carbon fibre was selected as the casing material due to its high strength and good resistance to compressive loads, making it suitable for protecting internal electronics it has been previously been stated that carbon fibre has high load bearing capacity (Kumar et al., 1993).

To evaluate its performance, a finite element analysis was carried out by assuming that person who is most likely to wear it is going to 75 kg this because researches have shown the average human weight across region to vary from 62 kg to 80.7 kg (Walpole et al., 2012) hence we feel like value of 75 kg is safe assumption this corresponds to load of approximately 1100 N, which includes a generally acceptable safety factor of 1.5 (Budynas & Nisbett, 2015). over the average user weight. The load was applied so that we can simulate real life as much as possible. The results of the simulation showed that the PCB casing experienced minimal deformation, with a maximum deformation of approximately 0.148 mm. This indicates that the casing is sufficiently strong to withstand expected loads without compromising the safety of the electronic components.

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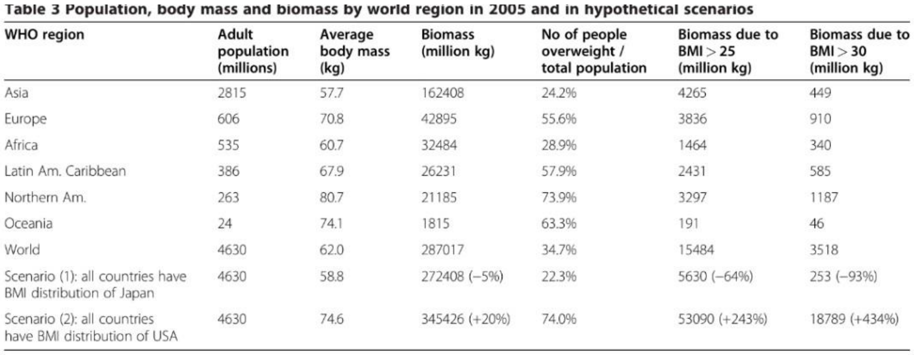


Table 3 Population, body mass and biomass by world region in 2005 and in hypothetical scenarios

WHO region	Adult population (millions)	Average body mass (kg)	Biomass (million kg)	No of people overweight / total population	Biomass due to BMI > 25 (million kg)	Biomass due to BMI > 30 (million kg)
Asia	2815	57.7	162408	24.2%	4265	449
Europe	606	70.8	42895	55.6%	3836	910
Africa	535	60.7	32484	28.9%	1464	340
Latin Am. Caribbean	386	67.9	26231	57.9%	2431	585
Northern Am.	263	80.7	21185	73.9%	3297	1187
Oceania	24	74.1	1815	63.3%	191	46
World	4630	62.0	287017	34.7%	15484	3518
Scenario (1): all countries have BMI distribution of Japan	4630	58.8	272408 (−5%)	22.3%	5630 (−64%)	253 (−93%)
Scenario (2): all countries have BMI distribution of USA	4630	74.6	345426 (+20%)	74.0%	53090 (+243%)	18789 (+434%)

Figure 20: table showing average mass distribution across the world

Walpole, S. C., Prieto-Merino, D., Edwards, P., Cleland, J., Stevens, G., & Roberts, I. (2012). *The weight of nations: An estimation of adult human biomass*. **BMC Public Health, 12**, 439. https://doi.org/10.1186/1471-2458-12-439

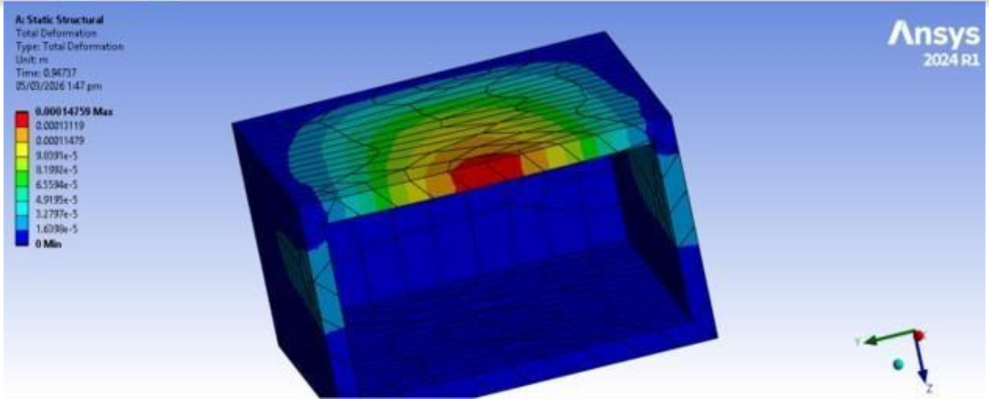


Figure 21: Results fea on PCB case showing minimum deformation

4.4.2FEA considering PCB casing inside shoe

The analysis of the complete shoe structure was carried out to ensure that whole shoe setup was able to withstand load and also when inculcating the casing inside shoe doesn't cause any excessive deformation furthermore this step was important to verify that the selected material, primarily rubber, is suitable for the overall design and that the integration of the PCB casing within the shoe does not introduce any structural weaknesses or risk of failure.

To simulate real-world conditions, a load of approximately 1100 N was applied, incorporating a factor of safety of 1.5 to account for dynamic effects during walking. The results of the finite element analysis indicate that the maximum deformation observed in the complete shoe structure is approximately 0.016 mm, which is significantly low considering that rubber has ability to bear considerable load with permanently deforming (Mars, W. V., & Fatemi, A. (2002)). This minimal deformation of the material shows that material has sufficient strength and

flexibility to handle applied loads without undergoing failure. Furthermore, it confirms that the inclusion of the PCB casing does not adversely affect the integrity of the overall system The deformation distribution is shown in the simulation results attached below upon evaluating the results it can be seen that the deformation of the shoe is within safe limits

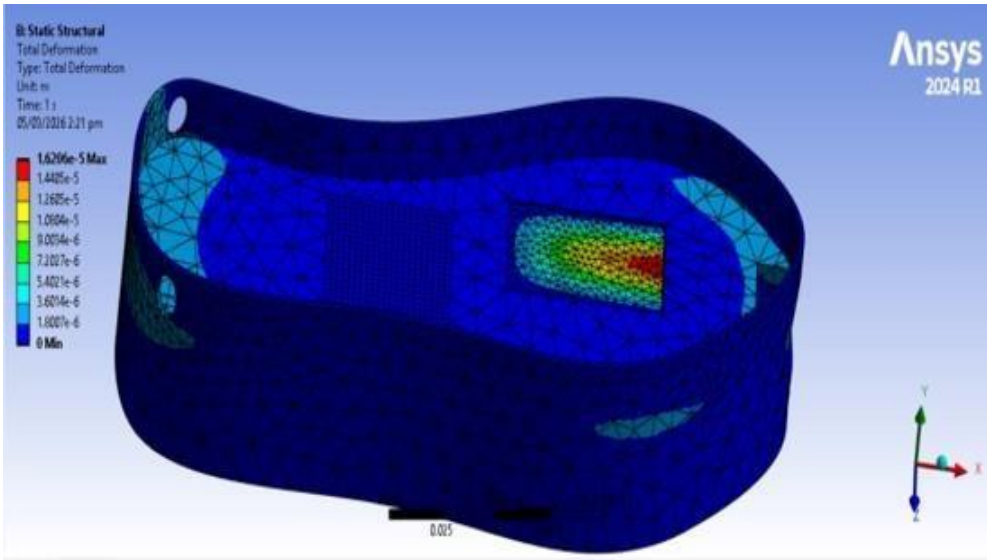
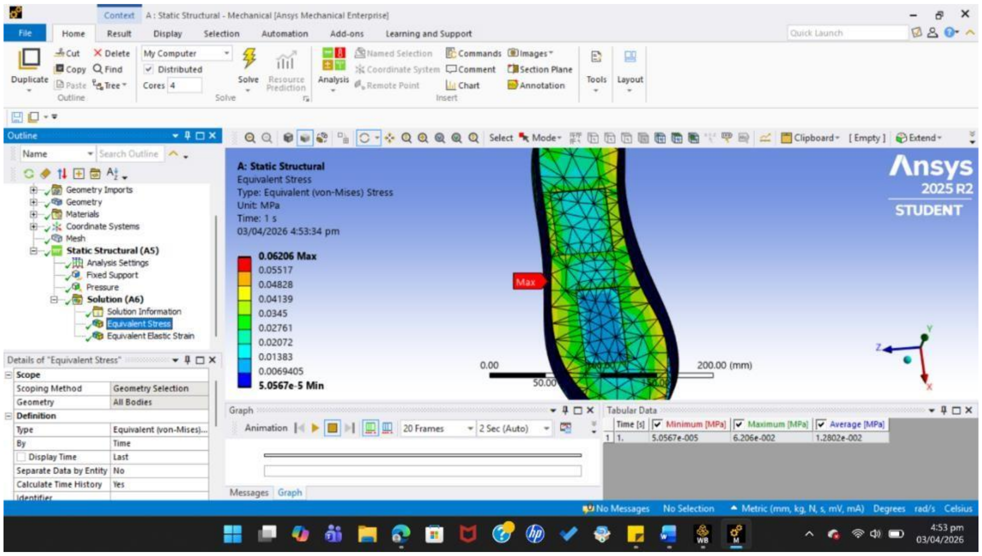


Figure 22: Showing the strain analysis of complete shoe

4.4.3 FEA of standing case (complete shoe)

In order to determine weather shoe would be able to sustain human weight while he is standing it was first assumed that the person wearing it would have weight around 75 kg as research paper have shown that average human weight varies 62 kg to 80.7 kg across region around the world (Walpole et al., 2012) hence we feel like value of 75 kg is a safe assumption . A 75 kg person would exert a pressure of 0.04 MPA on the shoe considering this a FEA was conducted and the results show there to be no excessive deformation that would cause failure this is consistent with the claim made by our scientific peer who state that rubber has ability to bear excessive load without permanently deforming (Mars, W. V., & Fatemi, A. (2002)).

Furthermore it is also seen that there is no excessive load on the medial arch region which would end up keeping our electronics safe



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s
03/04/2026 4:53:34 pm

0.06206 Max
0.05517
0.04828
0.04139
0.0345
0.02761
0.02072
0.01383
0.0069405
5.0567e-5 Min

Details of "Equivalent Stress"

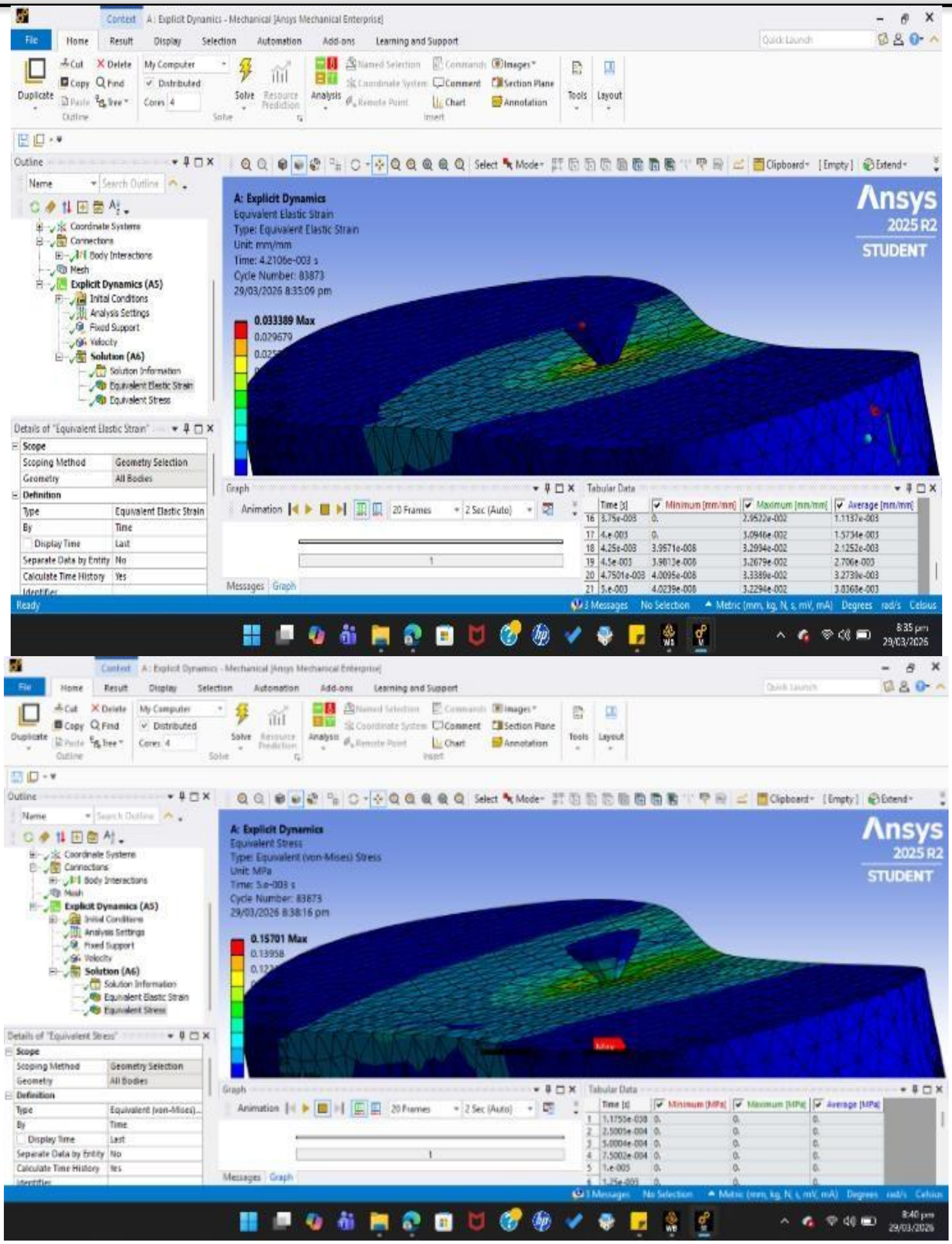
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises)...
By	Time
☐ Display Time	Last
Separate Data by Entity	No
Calculate Time History	Yes
Identifier	

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]	☑ Average [MPa]
1	1.	5.0567e-005	6.206e-002	1.2802e-002

Figure 23: Results FEA showing stress to be below 5mpa(typical tensile strength of rubber)

4.4.5 FEA needle puncture case

In order to ensure that shoe was safe for everyday we needed to ensure that it survives the puncture test putting it in more layman terms it is important we analysed weather the shoe can prevent needle from penetrating and harming the individual for that we conducted FEA analysis using explicit dynamics as needle penetration is fairly quick event . After assigning rubber and steel to shoe and needle respectively we caused the needle to approach the shoe at around 1 m/s and result in terms of stress and strain developed were recorded these result are shown in the images below:



A: Explicit Dynamics
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: mm/mm
Time: 4.2106e-003 s
Cycle Number: 83873
29/03/2026 8:35:09 pm

Details of "Equivalent Elastic Strain"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent Elastic Strain
By	Time
Display Time	Last
Separate Data by Entity	No
Calculate Time History	Yes

	Time [s]	☑ Minimum [mm/mm]	☑ Maximum [mm/mm]	☑ Average [mm/mm]
16	3.75e-003	0.	2.9522e-002	1.1137e-003
17	4.e-003	0.	3.0946e-002	1.5734e-003
18	4.25e-003	3.9571e-008	3.2994e-002	2.1252e-003
19	4.5e-003	3.9813e-008	3.2679e-002	2.706e-003
20	4.7501e-003	4.0095e-008	3.3389e-002	3.2739e-003
21	5.e-003	4.0239e-008	3.2294e-002	3.0368e-003

3 Messages No Selection Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius

A: Explicit Dynamics
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 5.e-003 s
Cycle Number: 83873
29/03/2026 8:38:16 pm

Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises)...
By	Time
Display Time	Last
Separate Data by Entity	No
Calculate Time History	Yes

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]	☑ Average [MPa]
1	1.1755e-038	0.	0.	0.
2	2.5005e-004	0.	0.	0.
3	5.0004e-004	0.	0.	0.
4	7.5002e-004	0.	0.	0.
5	1.e-003	0.	0.	0.
6	1.25e-003	0.	0.	0.

3 Messages No Selection Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius

Figure 24: stress strain puncture case

From the result it can be seen that max stress is 0.157 MPA making it 32 times less then 5MPa value at which typically rubber starts to fail this is further supported by the fact that strain is 3.3 % which is considerably low as rubber allows 100 % strain making our result well within safety margins and hence the shoe can survive in case of needle puncture.

4.5 Thermal Analysis

A basic thermal analysis was done to determine temperature rise within the shoe and consequently the final temperature all this was done to ensure that the heat generated by the electronic components does not lead to overheating or discomfort for the user. An ambient temperature of 30 C was used since that is generally the temperature around different region around the world.

The total heat generated was estimated to be equal to the amount of power consumed by the components in order to do so current value at the operating voltage of 5V were taken based on the user manual references to them would be made at the end of paper . with this approach the total power consumption by the components was determined. Additionally, the effect of the booster converter efficiency was considered to estimate the actual power drawn from the battery.

Using these values, a simplified heat transfer calculation was performed to estimate the temperature rise through the shoe material. While conducting the heat analysis we made calculated estimate by using standard values for sole and thermal conductivity. The results provide an approximate understanding of how heat is distributed and confirm that the temperature rise remains within acceptable limits during operation.

The simplified calculation are shown as follows:

Current from components (using estimated values from user manual):

- ➢ Arduino Nano ≈ 19 mA
- ➢ AJ-SR04T sensor ≈ 8 mA
- ➢ Vibration motor ≈ 70 mA

Total current = 19 + 8 + 70 =97 mA =0.097 A

- Electrical power used (Electronics run at 5V): P= I *V= 0.097*5=0.485 W
- Considering that booster converter typically operates at 90% efficiency P(battery)=0.485/0.9 equals 0.54 W
- Considering typical jogger sole of US size 12 :

❑ Area =0.03 m ^2

❑ thickness L=0.04 m

❑ thermal conductivity of typical jogger (EVA or rubber based) =0.13W / m k reference to paper (Shimazaki & Aisaka, 2018)

- Rearranging Fourier law of conduction (Q= kA delta(T)/L) we calculate the temperature difference as:

❑ delta T=0.54 *0.04 / 0.13*0.03= 5.5 C change in temperature (Temp rises to the point heat production = heat dissipation)

- T shoe= T ambient + delta T = 30 C+ 5.5 C= 35.5 C
- The temperature of the shoe is similar to the temperature reached in every day use as mentioned by research paper (Puszkarz & Usupov, 2019) who conducted experiment to determine temperature distribution and found the max temp to be 35 C

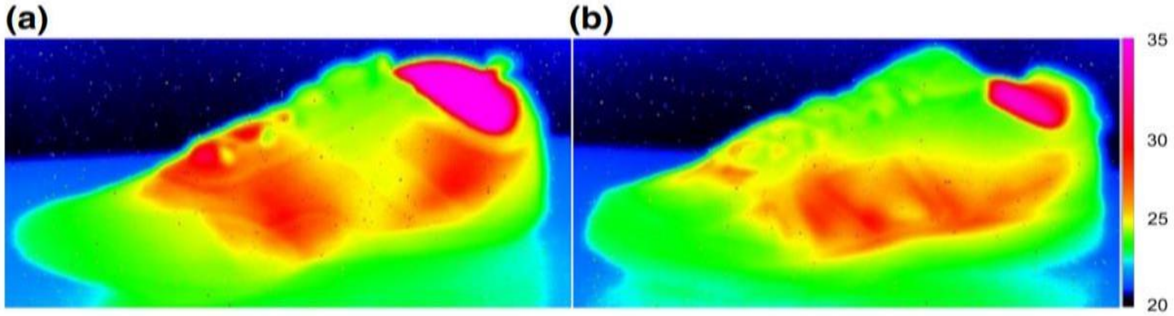


Fig. 7 Temperature distributions on outer surfaces of real shoes for ambient temperature: 20 °C obtained by thermal imaging camera (a) *Shoe A*, (b) *Shoe B*

Figure 25: Puszkarz, A. K., & Usupov, A. (2019). The study of footwear thermal insulation using thermography and the finite volume method. International Journal of Thermophysics, 40, 45. https://doi.org/10.1007/s10765-019-2509-1

4.6 Risk Assessment

Table 9: Showing risk assessment matrix

Risk	Cause	Impact	Mitigation
Casing break	Load/Impact	Damage to PCB	Strong material (carbon fiber)
Shoe deformation	Body weight	User discomfort	Rubber sole design
Heat build up	Electronics	Discomfort	Low power design
Puncture case	Needle	Penetration rubber sole	Using thick rubber sole

4.7 Validation of Results

To ensure that the design is reliable, simulation and calculation results were evaluated in comparison with practical conditions. The applied loads, material selection, and operating environment were selected to closely replicate real-world usage. The deformation results, as well as the findings from thermal analysis, showed that the results were within acceptable limits. These findings confirm that the design is appropriate for its intended application and ensures sufficient safety for the user.

FABRICATION & PROTOTYPE DEVELOPMENT

5.1 Materials Acquired

5.1.1 Electrical Components

When procuring material for our project we decided to first procure the electrical components that are to be used in our system . The components were sourced from local markets to ensure feasibility both in terms of cost and accessibility . The main processing unit we choose was Arduino nano for it compact size making it suitable for integration into the shoe . For obstacle detection, the AJ-SR04T ultrasonic sensor was used as the sensing element because of its good enough range (20 to 600 cm) and ability to be water proof . To provide haptic feedback to the user, eccentric vibration motors were acquired furthermore a 2000 Mah V Li-Po cell was selected to serve as the primary power source for the system. In addition to this, supporting components such as the TP4056 charging module and a boost converter were also procured. All these secondary components were integrated onto a Vero board fabricated from local vendor this would save space and reduce loose wiring

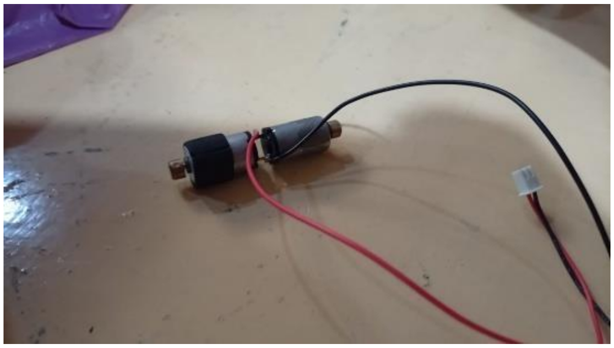


Figure 26: eccentric vibration motor

Figure 27: lipocell

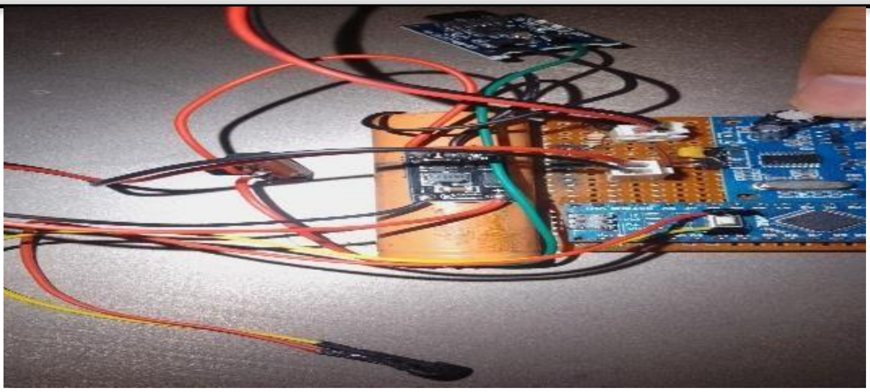


Figure 28: veroboard with electronics mounted

5.1.2Mechanical Components

In addition to the electrical components, the mechanical components were also considered . A thick rubber sheet of roughly 4cm was attained from local market . This sheet was then cut into the required shoe shape and attached to the base of the shoe to create a thick sole structure. The purpose of this increased thickness was to provide sufficient space for accommodating the electrical components but also reduce impact from ground as well user weight

5.2 Manufacturing & Assembly Process

5.2.1 Sole Fabrication

To begin the fabrication of the sole, CAD model was first created in order to effectively visualize the shoe sole . After finalizing the design, we discussed about different material such EVA, TPU and rubber to be our material for sole . Among these options, rubber was selected due to its ability to handle higher loads and provide better durability without going any considerable permanent deformation (Mars, W. V., & Fatemi, A. (2002)). Since ready-made soles of the required thickness were not available in the market, a thick rubber sheet was procured instead. This sheet was then cut according to the shape of the shoe sole. After cutting out the required sole cavities were then made with depth in such a way that the electrical components become flushed with the surface. This helped in maintaining both comfort and stability during use.

Figure 29: shoe with cavities

5.2.2Sensor Integration

The ultrasonic sensor was placed in the toe region of the shoe, pointing in the direction of walking . This was done because most of the obstacle are going to come from that direction making it the most effective . Proper alignment of the sensor was ensured so that it points straight ahead for accurate distance measurement.

The sensor was then connected to the Arduino Nano. The VCC pin of the sensor was connected to the 5V pin of the Arduino to supply power, while the GND pin was connected to the ground to complete the circuit. The TRIG pin was connected to digital pin D7, this connection ensured signal being sent from Arduino nano to the sensor for emitting radiation . The ECHO pin was connected to D6 which ensured that signals from the sensor are received by the controller to determine the distance of obstacle .This setup ensured reliable detection of obstacles in front of the user and proper communication between the sensor and the control unit.

Figure 30:sensor placement in toe region

5.2.3Electronics Assembly (PCB & Wiring) (needs reworking)

When doing component placing several important steps were undertaken this included placing PCB in such a way that it was placed near motor side as this would keep motor wire short and battery towards the sensor side this arrangement and battery closer to sensor side the larger surface area of foot would allow us to place battery easily

Another important decision was to keep the PCB and sensor apart since sensor already had long wire length we could easily route it between PCB and the sensor board

Through out this wiring process we tried level best to minimize visible wire but however if this effort compromised the functionality of the system then aesthetics took a back seat but overall our effort was quite impressive in terms of achieving a neat design

Figure 31: pcb placing

5.2.4 Vibration Motor Placement(needs reworking)

The vibration motors were placed at the medial arch region . This placement was selected to avoid exposing the motors to high loads during walking. Studies on foot pressure distribution show that pressure around the arch is significantly lower then heel or toe region (Pataky et al., 2008). Referencing the prior stated information it can be inferred , the outer regions of the heel experience relatively lower pressure compared to the central contact area. Placing the motors in these regions helps protect them from excessive mechanical stress while still allowing effective vibration feedback to the user.

Figure 32:vibration motor placement

5.2.5Protective Casing (Carbon Fiber)

To ensure that the PCB remained protected we decide to make use of carbon fiber sheet by first of all printing a 3d printed box of PLA according to dimension that would fit inside the shoe . The carbon fiber sheet were cut to size and wrapped around the box and was mid stick using epoxy and allowed to harden over the course of one day so that we attain a casing that was strong to bear the load of human weight without failing and damaging the electronics inside .

Figure 33: carbon fiber casing

5.3 cost analysis

A cost analysis was conducted carried out to determine the estimate the total expense required for the project. This was done to ensure that the necessary funds could be arranged in advance and that the project could proceed without any interruptions. The detailed breakdown of all costs involved is presented in the table below.

Table 10: Table showing cost breakdown

S.No	Component	Price/Unit (PKR)	Quantity	Total Price (PKR)
1	Arduino Nano	750	1	750
2	Vibration Motor	80	3	240
3	AJ-SR04M Waterproof Ultrasonic Sensor	1450	3	4350
4	Li-Po Battery 3.7V 1800 mAh	1500	1	1500
5	TP4056 Type-C Charging Module	70	1	70
6	On/Off Button	160	1	160
7	AL253 Boost Converter	110	1	110
8	Veroboard	350	1	350
9	40-Pin Female Header	40	2	80
10	Solder Wire	210	1	210
11	Softcore Wire	10	10	100
12	PCB development			5000

13	Customized rubber	–	–	2500
14	**subtotal**			15204

5.4 Design Trade-offs Due to Constraints

5.4.1 Cost vs Performance

When starting of this project we were going with maxbotix waterproof ultrasonic sensor since it had the ability to internally process the reading and provide the distance this saved up processing power . However the very high cost of ultrasonic sensor made us move away from it with a much cheaper option that allowed us to maintain affordability, the design was later shifted to the AJ-SR04T sensor, which, although does not process readings internally and requires the microcontroller to perform calculations, is significantly more economical at around PKR 4,350. This trade-off allowed the system to remain cost-effective while still achieving acceptable performance.

Another important design change involved the choice of sole material. Initially, a 3D- printed TPU-based sole was considered due to its superior water resistance and durability (Xu et al., 2020). However, the high cost that was associated with 3d printing around 20K made us think otherwise further feedback from CDRB, the design was modified to use conventional rubber material. Although rubber offers slightly lower performance in terms of water resistance and wear, it provides a much more economical and feasible solution for implementation.

5.5 Fabrication Challenges & Solutions

5.5.1 Space Constraints in Shoe

When developing the smart shoe one of the problems that we faced was finding a thick enough sole so that cavities of desired depth can be created. While surveying available shoes in the market, it was difficult to find a pre-made shoe with a thick enough sole to accommodate the required components. This limitation made it impossible to create cavities of the desired depth for placing the electronics safely. To solve this problem we decided to use a rubber sheet of approximately 4cm and cut a shoe sole out of it . By creating a custom sole from rubber sheet we were able to have sufficient depth that would allow us to place electronic with enough clearance between electronics and foot preventing excessive pressure build up

Figure 34: rubber sheet for sole preparation

5.5.2 Wire management

Another challenge faced during the project was managing the wiring inside the shoe without causing clutter and breaking wires. Limited space made the routing of wires more complicated and increased the chances of loose or improper connections. To solve this issue, careful planning was done for the placement of each component. In order to minimise this problem, components were placed closer to one another so that the length of wire can be reduced and the connection simpler. This approach helped in keeping the internal layout organised and improved the overall durability of the system.

5.5.3Motor performance challenge

At the time of writing the system has been designed in such a way that motor provides pulses when the system is at a 100 cm mark . However, this pulsing requires a sudden supply of current, which is not very smooth. Consequently, there is a slight delay in the haptic feedback, affecting the responsiveness of the system. A temporary solution which would act as our safety net is that we end up relying on continuous vibration and varying intensity in order to communicate however further improvements are still in progress to achieve a better between responsiveness and power delivery.

5.5.4Comfort & Wearability:

In terms of comfort, one concern was that the electrical components could come into contact with the user's foot and cause irritation or discomfort during use. To address this, cavities were designed within the sole with sufficient depth to house all electronic components securely. This ensured that there was no direct contact between the user's foot and the electronics, thereby maintaining comfort while using the shoe.

5.5.6 issue of detachable sole:

One of the genuine concern raised by CDRB and dab board was ease of maintenance in case the system malfunctioned . After much brainstorming we figured out that the only way to solve the mentioned concern was to create a detachable sole.

After figuring this out came the question of how we are going to meet the stated objective we looked at various alternatives starting from Velcro however upon deeper introspection we found it to be to weak to hold shoe sole then came the option of using neodymium 52 magnets though much stronger we found it to still leave a small gap in different sole layers which raised a slight safety concern as water could enter the sole damaging electronics .

Looking at the former mentioned alternatives we concluded that any mechanism we were going to use had to be strong and at the same time ensure there is minimal gap between different shoe layer making shoe perfect for daily use in varying environment
this where using screws as our detaching mechanism came to play their strong ease of availability meant that we can easily implement them in our system

Figure 35: shoe with slots for screw

5.6 Final prototype

Figure 36: showing final prototype

Testing and Validation

Several tests were performed in order to get a gist of the performance of the proposed smart shoe system. These included sensor accuracy testing, span angle and determining the battery life based on recording the reading of different components in our PCB. The purpose of these tests was to validate the reliability, responsiveness, and practicality of the system for real-world use

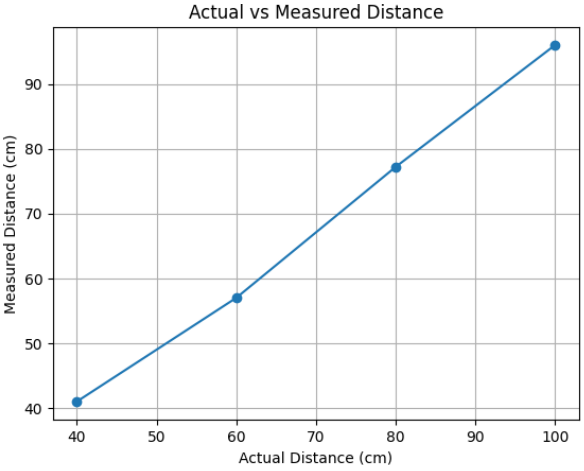
6.1 Sensor Accuracy

To ensure that system is operating in a reliable manner sensor accuracy test was conducted . The objective of this test was to verify that the sensor accurately measures the distance from an obstacle and does not provide false readings to the user. Accurate distance measurement is important to ensure timely and appropriate haptic feedback. For this purpose, the sensor was placed at a fixed distance of **100cm , 60cm , 40 cm** from an obstacle. The system was then allowed to take multiple readings under the same conditions. These readings were recorded to evaluate the consistency and accuracy of the sensor.

After collecting the data, the following results were obtained:

Actual distance (cm)	Reading 1(cm)	Reading 2 (cm)	Reading 3 (cm)	Average (cm)	Accuracy(%)
100	96	96	96	96	96
60	57	57	57	57	95
40	41	41	41	41	97.5

From the results it could be seen that sensor reading doesn't vary much causing the sensor accuracy to remain in high 90's the high sensor accuracy is also signified by the fact that graph that shows a straight line which means the measured and actual distance closely follows one another



6.2 Sensor Span

Effort was also made to determine the span of sensor this was crucial to determine the number of sensor we were going to use in our setup . For this we simply fixed the ultrasonic sensor in one position and allowed the object to move away from the centreline first in one direction and then in other c till the point where the Arduino ide stopped giving reading this was recognized as the extreme point of the sensor span lines were drawn in those respective point and trigonometry was applied more specifically cosine rule was applied in order to get a measure of sensor span the reading measured out to be 60 degree . The 60 degree helped us realize that one sensor is enough for system as it would in accurate detection which isn't irritating.

The pictures attached below will give the reader better idea of the context of this paragraph.

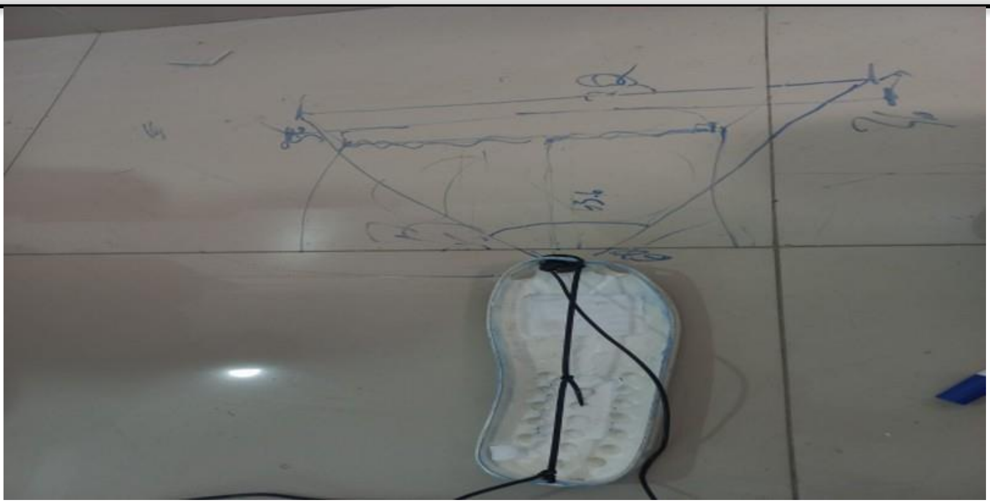


Figure 37: experiment to determine sensor span

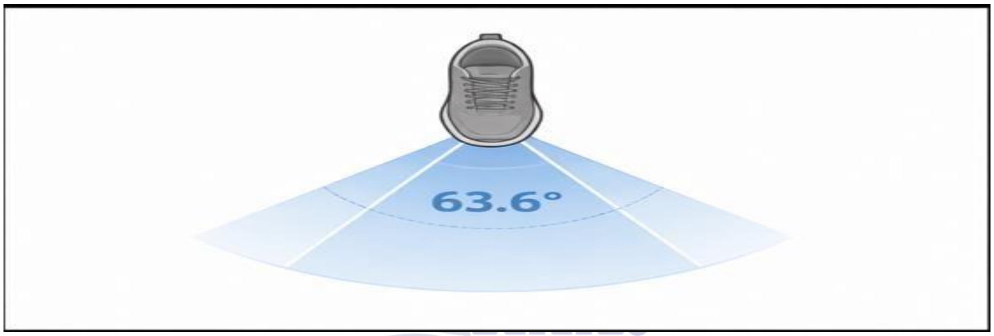


Figure 38: simplified schematic

6.3 Battery life:

An effort was made from our side to determine the expected operating hours of our system . For that we recorded the current consumed by different components in our system the results are summarized below

Table 11: Showing consumption by electrical components

Component	Estimated Current (mA)
Arduino Nano	10 mA
Ultrasonic Sensor	15 mA
Vibration Motor 1	100 mA(high frequency use)
Vibration Motor 2	100 mA(high frequency use)
Total	225 mA

The lithium ion that we were using had capacity of 4000 Mah considering this data the battery hours can be calculated simply with the formula :

Operating Time (hours) = Battery Capacity (Mah) / Current Draw (mA) Operating Time (hours)= 2000/225= 8.8889 hours

This simple calculation shows that our system is low power consuming system and hence can operate for a long duration with single charge

6.4 System response time

In order to ensure that system had good enough response time so that it can be safely implemented in the environment we an experiment where the shoe was placed at fixed threshold of 20 cm , 40 cm and 60 cm and the time it took for system to detect , process and provide feedback was then recorded the results are shown in the table below :

Table 12: System response time

Distance (cm)	Response time(microsecond)
20	135000
40	136528
60	143628

Based on the results it can be concluded that system response time was very fast in comparison to the human reaction time which is reported to be around 200000 microseconds (Kosinski, 2008) upon closer introspection of the results it can be safely concluded that the user would have sufficient time to react and take corrective course of action

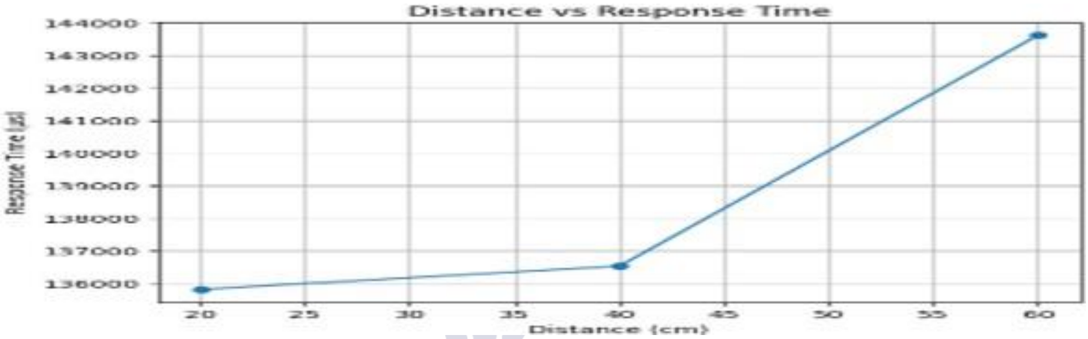


Figure 39: graphical representation of system response time

Design Modifications and Improvements

7.1 Introduction:

During this project we made several changes these changes were made with intent of improving project in terms of applicability and reducing cost of the project these changing would be discussed in detail in the following sections

7.2 Transition from TPU sole to rubber sole:

At the start of this project we were going to use 3d printing using TPU as our printing material several reason made us incline towards the use of TPU for instance Xu et al. (2020) describe TPU as a highly ductile polymer with strong resistance to abrasion, a property that has contributed to its widespread use in demanding applications such as sports equipment and wearable structures however the fact that the nature of our project was very iterative meant that using TPU wasn't feasible and also if we aren't able to implement our system in rubber sole that takes away from the practicality of our idea hence we decided that we need to achieve same level customization in rubber sole .

7.3 Removal of Carbon Fiber Protective Casing:

In order to better protect our PCB casing we decided to make use carbon fiber casing which would house our PCB the reason why we decided to use carbon fiber casing in our project is because Studies have shown that carbon fiber possess high compressive strength because of their internal graphitic structure and strong carbon– carbon bonding (Kumar, Anderson, & Crasto, 1993)

Future Work and Improvements (With References)

The developed smart shoe system successfully demonstrates obstacle detection using ultrasonic sensing and haptic feedback. Inspite of these achievement there are areas where we can improve upon to improve performance and add dimensions to the system . The following improvements are proposed for future development.

8.1 Reduction in Sole Thickness

One of the primary limitations observed in the current design is the thickness of the shoe sole. The increased thickness is primarily because of inclusion of electronics be it the Lipo battery and the sensor . This results in a relatively thicker sole which might seem slightly odd .

In future iterations could be made to use more compact electronics to ensure a thinner sole . A thinner sole will improve wearability, make the design more practical for daily use, and reduce the visual difference from conventional footwear.

8.2 Integration of Navigation Functionality

The current system is limited to detecting obstacles and providing immediate feedback to the user. However we can make this system multi dimensional by including GPS based technology in the system this would in turn lead to integration of navigation functionality, allowing the system to guide the user along a defined path. This can be achieved by having the system communicate with smart phone or GPS-based device to provide user instructions at which direction they should move.

Research in assistive technology shows that modern systems have potential
towards providing navigation-based assistance, where users receive guided directions instead of only obstacle warnings. Systems such as NavCog demonstrate how visually impaired users can be assisted through turn-by-turn navigation to reach their destination independently (Ahmetovic et al., 2016).

By combining obstacle detection with navigation, the system can become more self-sufficient, helping users not only avoid obstacles but also move confidently in unfamiliar environments.

8.3 Integration of Artificial Intelligence

The current system solely operates on distance measurement based on predefined logic with little room for flexibility. However, it doesn't provide information on the type of obstacle and nature of its danger, resulting sometimes in warnings that aren't required . The inclusion of Artificial Intelligence (AI) can significantly enhance the system's capability by enabling it to better understand its surroundings.

AI-based systems use image data from cameras or advanced sensors to recognize objects, text, and other environmental features. Reading of these research have shown that AI system will have the ability to provide more descriptive feedback to the visually impaired person (Kumar et al., 2023).

With the integration of AI, the proposed system can:

- With it use the shoe based system will be able distinguish between obstacle that are dangerous or not
- Provide a more thro and descriptive information of the type of obstacle ahead so the person would be able to distinguish much better (such as a person, wall, or moving object)
- Also help the individual navigate much better by giving him description of a safe path by analysing the surrounding of user

By inculcating AI system we would able to shift the focus from simple detection to system that is intelligent and acts based on the data that it analyses in real time .

However, implementing AI would require more advanced hardware and processing capability compared to the current prototype, and therefore remains a direction for future development.

8.4 Conclusion of Chapter

The proposed improvements highlight the potential evolution of the smart shoe system from a basic obstacle detection device to a multi-dimensional system with the ability to help users both navigate and offer smarter detection regarding the nature of the obstacle. By addressing current limitations, including navigation features and integrating artificial intelligence decision making , will allow the system to operate in a more optimal manner

Key Achievements and Learnings

9.1 Key Achievements

One of the significant achievements of this project was to create a smart shoe that had potential not only for experimental setup but for everyday use. This was because, unlike many systems that are limited to laboratory-based gait analysis, this design was developed with the intent that it can be used in everyday life. It was this focus that made the system more meaningful from a social impact perspective.

Another important accomplishment was our ability to make the system more low- profile by reducing external wiring and components. This not only enhanced the visual appearance of the product but also contributed to reducing unnecessary weight and improving user comfort.

Cost-effectiveness was also a major achievement. The fact that the system didn't employ. This opens the possibility for future commercialisation, as affordability is a key factor for assistive devices intended for wider public use.

Additionally, the team successfully designed a sole-based system that is detachable. This feature significantly improved the practicality of the product as it allowed for far easier maintenance. It also adds flexibility in terms of replacement and upgrades.

9.2 Key Learnings

Throughout the project, we learnt several important lesson both in the design and execution part . One of the earliest realizations was related to material availability. The team initially assumed that thick shoe soles (around 4cm) were readily available in market however this was not the case and we had to rely 4cm thick rubber, which highlighted the importance of quick decision making skills.

Another key learning came from the design approach. Since we initially decided to fabricate the sole using 3d printed. However, based on feedback from the CDRB who advised that it would significantly increase product price and advised to keep the product economical . This led to a strategic shift towards using customized rubber, which proved to be a more economical and practical alternative while still meeting design requirements.

Lastly, the inclusion of making this sole detachable was a significant change based on the advice of CDRB . This change improved the system by making maintenance, troubleshooting, and charging much more convenient, ultimately enhancing the usability of the product.

Comparison with other products

10.1 : Introduction

In this section we would have a look at other smart shoe this is to highlight that our smart shoe project hasn't been a repetition but a improvement over previous works this improvement can be seen mainly in the aspect that our smart shoe system has introduced a feedback mechanism which wasn't required in gait analysis effort and has to an extent streamlined design by reducing messy external wiring and tried to confine electronics inside the sole of the shoe .

10.2 : Existing smart shoe effort:

There have been some effort that have been made in implementing smart shoe technology we are going to discuss them in this section we don't deny that some of the efforts were really good but however there were short comings which we feel like our project addresses the best .

For instance if you have a look at Joseph et al. (2013) effort since it was way earlier in the timeline it was more concentrated on getting the system running it is precisely because of this reason that he mounted electronic on to the externalities though the system was functional it added onto the weight and bulkiness this would take away from the comfort that is required during walking

Alotaibi et al. (2022) also made a smart shoe that used ultrasonic sensor and water sensor for water detection and Arduino UNO for processing though the system was low cost since the components used were inexpensive but there was no mention of accounting for comfort and minimizing wiring only to the confinement of the shoe this would mean that their shoe is also not practical for everyday use.

Finally another effort that we felt like was the most impressive was done by Sandeep et al. (2022) whose system had the ability for both obstacle detection and navigation along with tracking coupled by the fact that it had ability to generate power using piezoelectric . Without any shame we will admit that this project surpasses our own in terms of features included but however again including both navigation instruction and feedback due to obstacle detection means complex instruction and also more wiring this means making the system compact becomes difficult

So based on the current body of work we can safely say that our system performs best in terms of being functional and also being aesthetically pleasing .

Figure 40: showing our proposed system with minimal wiring and compactness

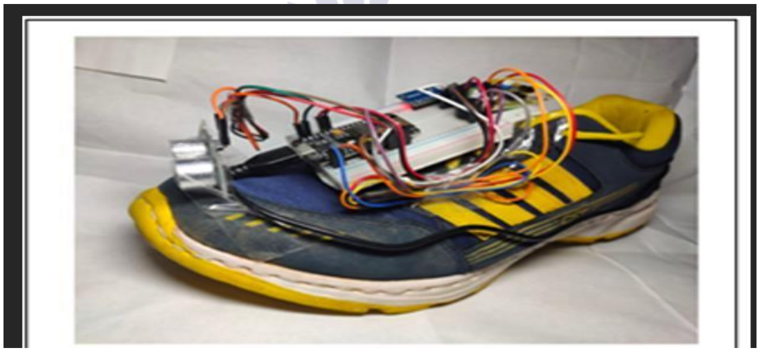


Figure 41: Previous effort electronics mounted externally

10.3 : Comparison with existing smart shoe model

Figure 42: comparison with existing model

Feature	Joseph et al. (2013)	Alotaibi et al. (2022)	Sandeep et al. (2022)	Proposed Smart Shoe
Main Idea	External mounted smart shoe	Obstacle + water detection	IoT-based GPS smart shoe	Compact embedded smart shoe
Sensors Used	Ultrasonic	Ultrasonic + Water sensor	Ultrasonic + GPS + GSM	Ultrasonic

Electronics Placement	External (bulky)	Partially external	Multiple external modules	Embedded inside shoe
System Complexity	Moderate	Simple	High	Simple and compact
Comfort	Low	Moderate	Low	High
Practicality	Low	Moderate	Low	High

10.4 Summary of comparison:

Based on our effort in comparing different smart shoe model we came across similar theme that though previous models were able to make a functional system or performed really well in terms introducing variety of functionality they lacked in terms of making the system compact and minimize external wiring as much as possible this reduced practicality of the system while on the contrary our effort in housing the system and components inside the shoe would make the system lightweight aesthetic and consequently more practical .

REFERENCES

Amballa, D. P. (2018). Haptic feedback-enabled smart shoes for visually impaired navigation assistance. *Journal of Scientific and Engineering Research, 5*(1), 266–270.

Almuteb, I., et al. (2022). Smart insoles review (2008–2021): Applications, potentials, and challenges. *Smart Health, 25*, 100309. https://doi.org/10.1016/j.smhl.2022.100309

Bäckman, M. (2024). The white cane: An ethnographic account on the widespread ambivalence amongst visually impaired people towards an iconic aid. *Scandinavian Journal of Disability Research, 26*(1), 82–94. https://doi.org/10.16993/sjdr.1024

Borysiak, A., Zieliński, J., & Wójcik, K. (2024). Enhancing intelligent shoes with gait analysis: A review on the spatiotemporal estimation techniques. *Sensors, 24*(24), 7880. https://doi.org/10.3390/s24247880

Drăgulinescu, A. M., Andrei, G., & Ionescu, C. (2020). Smart insole system for gait monitoring and analysis. *Sensors, 20*(17), 4925. https://doi.org/10.3390/s20174925

Glenk, L. M., Přibylová, L., Stetina, B. U., Demirel, S., & Weissenbacher, K. (2019). Perceptions on health benefits of guide dog ownership in an Austrian population of blind people with and without a guide dog. *Animals, 9*(7), 428. https://doi.org/10.3390/ani9070428

Han, J., Kim, S., & Kim, J. (2024). Wearables for persons with blindness and low vision: Form factor matters. *Frontiers in Rehabilitation Sciences, 5*, 1415014. https://doi.org/10.3389/fresc.2024.1415014

Joseph, A. M., Kian, A., & Begg, R. (2024). Enhancing intelligent shoes with gait analysis: A review on the spatiotemporal estimation techniques. *Sensors, 24*(24), 7880. https://doi.org/10.3390/s24247880

Lavric, A., Popa, V., & Nica, A. S. (2024). Emerging assistive technologies for the visually impaired: A survey of AI and visible light communication (VLC)-based solutions. *Sensors, 24*(7), 3219. https://doi.org/10.3390/s24073219

Lin, F., Wang, A., Zhuang, Y., Tomita, M. R., & Xu, W. (2016). Smart insole: A wearable sensor device for unobtrusive gait monitoring in daily life. *IEEE Transactions on Industrial Informatics, 12*(6), 2281–2291.

Mashiata, M., Ali, T., Das, P., Tasneem, Z., Rahman Badal, M. F., Sarker, S. K., Hasan,

M. M., Abhi, S. H., Islam, M. R., Ali, M. F., Ahamed, M. H., & Islam, M. M. (2022).

Towards assisting visually impaired individuals: A review on current status and future prospects. *Biosensors and Bioelectronics: X, 12*, 100265. https://doi.org/10.1016/j.biosx.2022.100265

Reddy, P. B., Kumar, R. P., & Sharma, R. (2019). RFID and infrared-based navigation aid for visually impaired individuals. *International Journal of Innovative Research in Computer and Communication Engineering, 7*(4), 2451–2456.

Ricci, F. S., Deshpande, V., & Bojinov, H. (2024). Navigation training for persons with visual disability: Conventional aids and emerging electronic solutions. https://pmc.ncbi.nlm.nih.gov/articles/PMC11612587/

Rukmini, P., Reddy, S., & Suresh, B. (2024). Recent innovations in footwear and the role of smart footwear in healthcare—A survey. *Sensors, 24*(13), 4301. https://doi.org/10.3390/s24134301

Santos, P., Silva, C., Sousa, N., & Rocha, L. A. (2024). A systematic review of insole sensor technology: Recent studies and future directions. *Applied Sciences, 14*(14), 6085. https://doi.org/10.3390/app14146085

Santos, V. M., et al. (2025). A systematic review on smart insole prototypes and wearable gait-monitoring systems. *Actuators, 14*(8), 408.

Sathvik, J. P., Param, A., Bharath, G., Guruprasad, U., & Vijapur, N. A. (2024). Embedded smart shoes for the visually impaired. *Indiana Journal of Multidisciplinary Research, 4*(3), 1–5. https://doi.org/10.5281/zenodo.12666743

Siddiqui, M. A., Alam, M. A., & Rahman, K. (2019). Design and implementation of Raspberry Pi-based smart shoes for visually impaired people. *International Journal of Advanced Computer Science and Applications, 10*(8), 305–312. https://doi.org/10.14569/IJACSA.2019.0100841

Tao, W., Liu, T., Zheng, R., & Feng, H. (2012). Gait analysis using wearable sensors.

Sensors, 12(2), 2255–2283. https://doi.org/10.3390/s120202255

Van Hooren, B., et al. (2024). The effect of wearable-based real-time feedback on running-related variables: A systematic review. *Sensors, 24*(10), 3381. https://doi.org/10.3390/s24103381

World Health Organization. (2023, August 10). *Blindness and vision impairment – Key facts.* https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment

Bai, X., Hou, X., Song, Y., Tang, Z., Huo, H., & Liu, J. (2025). Plantar pressure classification and feature extraction based on multiple fusion algorithms. *Scientific Reports, 15*, Article 13274. https://doi.org/10.1038/s41598-025-96440-6

Sathvik, J. P., Param, A., Bharath, G., Guruprasad, U., & Vijapur, N. A. (2024). Embedded smart shoes for the visually impaired. *Indiana Journal of Multidisciplinary Research, 4*(3), 1–5. https://doi.org/10.5281/zenodo.12666743

Kumar, S., Anderson, D. P., & Crasto, A. S. (1993). Carbon fibre compressive strength and its dependence on structure and morphology. *Journal of Materials Science, 28*, 423–439.

Budynas, R. G., & Nisbett, J. K. (2015). *Shigley's mechanical engineering design* (10th ed.). McGraw-Hill Education.

Walpole, S. C., Prieto-Merino, D., Edwards, P., Cleland, J., Stevens, G., & Roberts, I. (2012). *The weight of nations: An estimation of adult human biomass*. **BMC Public Health, 12**, 439. https://doi.org/10.1186/1471-2458-12-439

Mars, W. V., & Fatemi, A. (2002). *A literature survey on fatigue analysis approaches for rubber*. International Journal of Fatigue, 24(9), 949–961. https://doi.org/10.1016/S0142-1123(02)00008-4

Shimazaki, Y., & Aisaka, K. (2018). *Novel thermal analysis model of the foot–shoe sole interface during gait motion*. Proceedings of the 12th Conference of Association. https://doi.org/10.3390/proceedings2060212

Puszkarz, A. K., & Usupov, A. (2019). The study of footwear thermal insulation using thermography and the finite volume method. International Journal of Thermophysics, 40, 45. https://doi.org/10.1007/s10765-019-2509-1

Xu, Z., Chen, Q., Liu, Y., & Yang, S. (2020). Mechanical properties of additively manufactured thermoplastic polyurethane (TPU) material affected by various processing parameters. *Polymers*, 12(12), 3010. https://doi.org/10.3390/polym12123010

Ahmetovic, D., Gleason, C., Kitani, K. M., Takagi, H., & Asakawa, C. (2016). *NavCog: Turn-by-turn smartphone navigation assistant for people with visual impairments*. Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility.

Kumar, S., Mishra, D. N., Ganie, S. M., Bharathikannan, R., & Vijayakanthan, K. (2023). *Artificial intelligence solutions for the visually impaired: A review*. IGI Global.

Panazan, C.-E., & Dulf, E.-H. (2024). Intelligent cane for assisting the visually impaired. *Technologies*, *12*(6), 75. https://doi.org/10.3390/technologies12060075