SMART SHOES FOR BLIND USING INTERNET OF THINGS - A COMPREHENSIVE REVIEW

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***Abstract*- Persons with impaired vision can hardly manage to walk safely, particularly in strange or busy locations. Many smart shoe systems have been designed to help them with the assistance of sensors that detect obstacles and alert the user to them with vibrations or sounds. Flame, water or pit sensors are also provided on some of the designs to offer additional protection, and GPS, GSM, Li-Fi, and Bluetooth are provided to track the location and navigate the inside building. Despite the positive improvement achieved in these systems, they have such issues as high power consumption, spurious readings, and massive designs. All in all, the study indicates that there is an urgency to develop smart shoes that are smaller, reliable, have low energy consumption and comfortable to wear on a daily basis. These advancements will enable the visually impaired users to move with more confidence. Future models can be made more practical by providing more advanced sensor fusion and enhanced battery management. The smart shoes can one day become a reliable tool of safe navigation every day with further research.**

I. *INTRODUCTION*

The modern rapid technological environment is full of innovations that enable the work with people with disabilities, in particular, with visual issues. Among the most critical problems facing visually impaired people is the ability to move freely, with the independence of other people. White canes and guide dogs are useful but are limited in the range of sensation, accuracy of detection as well as their essential dependence. To eliminate such problems, scholars have begun creating intelligent shoes which make use of the current technology and communication infrastructure to provide real-time information. Smart footwear is a technology that involves fitting electronic parts (ultrasonic sensor, microcontrollers, and vibration motors) into ordinary shoes. These elements identify the roadblocks or dangers and notifying the user instantly by vibration or sound. Since the feedback is received via the feet, it does not interrupt the attention of the user, neither does it need them to be holding any external device. This is what makes smart shoes an of the user and identify various walking models, as well as provide even more customized support. The auto-recharge by the foot-steps of the user through the use of energy-harvesting technology might also be applied in future models. These advancements demonstrate that smart shoes are slowly evolving into a basic concept into a credible, effective and convenient solution that can be easily integrated into everyday life to assist users to walk with a sense of increased confidence and safety. The current innovations in technology have transformed the smart-shoes to be smarter, more precise, and comfortable. Most of them are currently designed with new features such as flame detection, water detection, indoor navigation Li-Fi and GPS-GSM modules to enable emergency communications. These attributes make smart shoes useful in more than just basic obstacle detection, which means that they can be used by the visually impaired, elderly users, travelers, and even company employees in hazardous settings. With the advancement of sensor-technology that is smaller and more efficient, the evolution of smart footwear into a complete safety system keeps on progressing. Researchers are in addition to the enhancement of the safety of smart shoes; they are involved in ensuring that the shoes are lightweight, durable, and energy-saving. Flexible circuits, mini-sized sensors, and enhanced management of power enable the user to wear the shoes over a long time. The footwear is also made waterproof, shock resistant, and tougher in nature to counter ordinary daily wear and tear. The affordability is also taking its place in the smart shoe design to ensure that such a beneficial technology reaches more individuals that need it. The comfort of the user and the durability of the equipment are another feature that should be considered in the development of smart feet. Having a visual impairment, one has to be able to trust the device without experiencing discomfort and distraction. Consequently, the trend in current designs is to lower the weight, employ soft materials, and to make the electronic parts placement in such a way to provide the shoe with a natural feel to wear. It is to make a device that may become a part of the everyday life of the user and help them in all aspects without annoying and making them tired of it. In the future, smart footwear has a bright future. As the machine learning and artificial intelligence progress, smart shoes can transform soon to adjust to the behaviour

intelligent, and inclusive technology that can make much more impact on the lives of visually impaired people, in that aspect, independence and safety.

II. *Li-Fi Based Smart Shoe Systems*

A. Technological Architecture and Working Principles

These systems will be integrated in the daily living as technology continues to be smaller. Improved connectivity and cloud services can allow real time caregiver assistance. Finally, smart footwear can be seen as a reliable ally that will help users of all ages feel safer and more secure during their walks because it utilizes visible light communication (VLC) to provide users with location-specific cues. The systems are based on LED transmitters located in the indoor settings and modulate optical signals with encoded information which is detected by photodiodes which are located inside the shoe structure. On receipt, the optical information is translated into electrical signals and processed with microcontrollers like Arduino or other low-power devices, allowing the provision of the navigation signals, the identification of the location position, or directional guidance based on the vibration or audio feedback [1]-[5]. Several prototypes of Li-Fi may expand the fundamental features with the help of additional sensors, including ultrasonic modules to identify obstacles, flames sensors to detect hazards,

and water sensors to become aware of the environment [6]-[9]. A pipeline is followed in the optical communication process through which the modulated LED signals travel through unimpeded light paths and are demodulated by photodiodes that are strategically placed in the footwear. Nevertheless, the relying on the line of sight (LOS) and the sensitivity to the light harassment create limitations in operating in the uncontrollable environment, particularly in areas where the user walking motion varies the angle between the Lib-Fi emitter and receiver [1], [3], [7].

B. Strengths and Functional Contributions

Li-Fi technology has several strengths in the structured indoor areas where the GPS signal is weak, and thus it stands as a perfect selection in schools, hospitals, airports, and government buildings [1], [2], [4]. Since visible light cannot penetrate walls, Li-Fi, as a consequence, limits the signal transmission to certain rooms or corridors, which allow visually impaired people to be more secure and localized in their movement [5]. The low-cost of LEDs and photodiodes adds to the scalability and low cost of Li-Fi-based systems, particularly their use in resource constrained settings [7], [9]. Li-Fi enabled smart shoes can be used to interact without the use of hands, which is highly intuitive and does not violate the natural walking experience of the user. Moreover, Li-Fi offers a communication medium that is not affected by electromagnetic interference hence is applicable in medical units and other infrastructures that require a sensitive communication medium [2], [10]. As demonstrated in several early experimental trials, combining Li-Fi beacons with embedded sound or vibration modules has shown the potential to offer room-level navigation and directional assistance that could supplement or even replace traditional cane-based mobility tools [3], [7], [8].

TABLE I: Comparison of Li-Fi Based Smart Shoes

S.No	Paper Name / Author / Year	Methodology	Highlights	Technical Gap
1	Smart Shoe for Visually Impaired Person Based on IoT – K. Mahalakshmi et al., IEEE 2024	Arduino Nano, ultrasonic & water sensors, piezoelectric plate, solar panel, Android app with Bluetooth	Real-time alerts, tactile & voice feedback, solar charging	Limited accuracy in obstacle detection; lacks GPS and cloud analytics
2	A Low-Cost IoT-based Navigation Assistance for Visually Impaired Person – A. Patil et al., IEEE 2023	ESP32 controller, Ultrasonic, IR, Gyroscope, Accelerometer, app-based voice alerts	Cost-effective, lightweight, Android integration for navigation	No real-time mapping or GPS-based routing; lacks ML adaptability
3	Navigating the Unseen: IoT-Based Smart Shoe with Obstacle Detection – K. Arora et al., IEEE 2023	Ultrasonic, accelerometer, gyroscope, mobile app (audio/haptic feedback)	Human-centered design, reliable across terrains, ethical focus	Absence of AI/ML analytics; limited multi-sensor fusion
4	IoT-Based Navigation Assistance for Visually Impaired People – M. Arunkumar, E. Lokesh, IEEE 2023	Arduino UNO, Ultrasonic, NodeMCU ESP8266, piezoelectric energy harvesting	Smart shoe + smart glasses integration, self-charging	No GPS or mobile communication module; lacks cloud data
5	Charana Chakshu: IoT-based Embedded Smart Shoe – Dr. Mallikarjun H.M. et al., IEEE 2024	Ultrasonic, pedometer, accelerometer, GPS, mobile app for guardian tracking	Real-time location sharing, fall alerts, cost-effective	Data privacy not addressed; limited edge processing

6	Intelligent Shoes Designed for Visual Impaired People Based on IoT – S.N. Gupta et al., IEEE 2025	Arduino Nano, ultrasonic, flame, water sensors, IoT-enabled safety system	Multi-sensor setup for fire and water detection; real-time alerts	No navigation optimization; lacks ML-based decision support
7	IoT-Based Assistive System for Visually Impaired and Aged People – S. Durgadevi et al., IEEE 2022	Ultrasonic, PIR, MEMS, GPS, piezoelectric power, IoT monitoring	Fall detection, motion detection, GPS alert to guardian	Power optimization and compactness remain issues
8	IoT-based Smart Shoe for the Blind – T. Chava et al., IEEE 2021	Arduino UNO, Ultrasonic + servo motor, piezoelectric power, IoT connectivity	Smart glasses + shoe integration, self-charging	Lacks adaptive AI for terrain recognition; basic sensing only
9	IoT-based Smart Shoes for Blind People – P. Ebby Darney et al., IEEE 2022	Arduino, GPS, Ultrasonic, Soil Moisture, Flame Sensor	Detects puddles/fire, voice feedback, GPS tracking	High power use, lacks predictive analytics and cloud AI
10	IoT-Based Shoe for Enhanced Mobility and Safety – B. Singh et al., EAI 2024	GPS, IMU, proximity sensors, cloud IoT, ML analytics	Data visualization, ML-based feedback, mobile app integration	Complex architecture; needs low-cost hardware optimization

C. Technical Limitations and Systemic Constraints

Li-Fi based smart shoes despite their potential have several technical limitations which make it difficult to transfer them into more solid commercial applications. The biggest obstacle is LOS dependence where the optical linkage between transmitter and the receiver can easily be interfered by the shadow, water or foot angle change even temporarily [1], [4], [7]. The changes in ambient light, like the sun, reflections of smooth surfaces, or changing light inside the building, cause the photodiodes to be subjected to much noise, and hence the less accuracy of decoding and the reliability of the system [2], [5]. The coverage of a single Li-Fi cell is very small, which means that in order to cover the whole room and corridor, the installation of the LED transmitters is going to be dense, making the deployment more complex and expensive [3], [8]. Several published prototypes are based on either simple on-off keying or low-complexity modulation schemes and do not have error correction and cannot be used reliably in high optical noise environments [4], [10]. Also, some studies show weak large-scale testing with most of the studies being limited to laboratory controlled settings where there is minimal uncertainty in the environment [5], [9]. Moreover, various studies involving Li-Fi footwear are restricted to laboratory settings with little large-scale corroboration and restriction on the insight of long-term usability and performance stability.

D. Future Research Potentials

The next generation Li-Fi enabled shoe systems could develop into hybrid localization systems which could incorporate VLC with inertial measure units, geomagnetic indications as well as Bluetooth beacons to circumvent LOS constraints and improve positional continuity whilst in motion [3], [9], [10]. The demodulation and adaptive gain control utilizing machine learning has the capability to enhance decoding reliability under a highly optically interfered environment. Embedded flexible photodiode arrays on shoe fabrics have the potential to expand the angle of reception and have continuous communication even in dynamic foot positions [6], [7]. Battery life can be enhanced and longer outlook can be offered by the incorporation of solar or kinetic energy collectors. Together, the interdisciplinary research of optics, embedded systems and assistive engineering will be necessary to optimize Li-Fi smart shoes to useful and reliable mobility devices [1], [8], [10].

III. *IoT-Based Smart Shoe Architectures*

A. System Integration and Communication Pipelines

The IoT based smart footwear incorporates sensing, processing, and communication units into one wearable platform intended to improve mobility assistance and hazard recognition. Another technique usually included in these systems is ultrasonic sensors to estimate the distance of obstacles, moisture sensors to detect slippery floors, flame sensors to detect fire, accelerators and gyroscopes to measure the gait, and piezoelectric components to collect energy [11]-[20].Microcontrollers like ESP32, Arduino Nano, or NodeMCU ESP8266 are used to process the data obtained about the sensing layer to perform real-time classification and feedback mechanisms. Bluetooth, Wi-Fi or GSM/GPRS-based wireless communication implements add-on functionalities to the system, allowing remote monitoring of the system, logging data to a cloud-based system, and distributing emergency alerts [11], [14], [17]. This IoT pipeline is multi layered and it can be used to convert footwear into a distributed sensing system that is able to measure mobility patterns, the conditions of the environment and the safety of people at the same time.

B. Operational Capabilities and Functional Insights

Smart shoes that use IoT have a multifunctional set of features that reinforce their appropriateness as a mobility aiding device in the real world. They allow detecting the existing obstacles, puddles, or fire sources in real time, and also monitor user movement to identify falls or walking abnormalities [12], [15], [18]. Companion mobile applications are often integrated into the many systems; these can be used to offer voice-guided directions, real-time location sharing, or alerts to alert the caregivers in case of emergencies [11], [13], [16]. Energy harvesting like piezoelectric plates can be used to convert mechanical pressure created when walking to electrical energy and therefore supplements battery use and increases operation life [14], [19]. These IoT architectures can also be used to support cloud-based analytics, where mobility trends can be monitored over the long term and insights about them can be created to aid in rehabilitation or tailored support [11], [17], [20]. IoT-driven shoes can be used with visually impaired users, the aged, and those working in dangerous conditions because they are flexible and modular.

Table II: Comparison of IOT Based Smart Shoes

S.No	Paper Name / Author / Year	Methodology	Highlights	Technical Gap
1	Smart Shoe for Visually Impaired Person Based on IoT – K. Mahalakshmi et al., IEEE 2024	Arduino Nano, ultrasonic & water sensors, piezoelectric plate, solar panel, Android app with Bluetooth	Real-time alerts, tactile & voice feedback, solar charging	Limited accuracy in obstacle detection; lacks GPS and cloud analytics
2	A Low-Cost IoT-based Navigation Assistance for Visually Impaired Person – A. Patil et al., IEEE 2023	ESP32 controller, Ultrasonic, IR, Gyroscope, Accelerometer, app-based voice alerts	Cost-effective, lightweight, Android integration for navigation	No real-time mapping or GPS-based routing; lacks ML adaptability
3	Navigating the Unseen: IoT-Based Smart Shoe with Obstacle Detection – K. Arora et al., IEEE 2023	Ultrasonic, accelerometer, gyroscope, mobile app (audio/haptic feedback)	Human-centered design, reliable across terrains, ethical focus	Absence of AI/ML analytics; limited multi-sensor fusion
4	IoT-Based Navigation Assistance for Visually Impaired People – M. Arunkumar, E. Lokesh, IEEE 2023	Arduino UNO, Ultrasonic, NodeMCU ESP8266, piezoelectric energy harvesting	Smart shoe + smart glasses integration, self-charging	No GPS or mobile communication module; lacks cloud data
5	Charana Chakshu: IoT-based Embedded Smart Shoe – Dr. Mallikarjun H.M. et al., IEEE 2024	Ultrasonic, pedometer, accelerometer, GPS, mobile app for guardian tracking	Real-time location sharing, fall alerts, cost-effective	Data privacy not addressed; limited edge processing
6	Intelligent Shoes Designed for Visual Impaired People Based on IoT – S.N. Gupta et al., IEEE 2025	Arduino Nano, ultrasonic, flame, water sensors, IoT-enabled safety system	Multi-sensor setup for fire and water detection; real-time alerts	No navigation optimization; lacks ML-based decision support
7	IoT-Based Assistive System for Visually Impaired and Aged People – S. Durgadevi et al., IEEE 2022	Ultrasonic, PIR, MEMS, GPS, piezoelectric power, IoT monitoring	Fall detection, motion detection, GPS alert to guardian	Power optimization and compactness remain issues
8	IoT-based Smart Shoe for the Blind – T. Chava et al., IEEE 2021	Arduino UNO, Ultrasonic + servo motor, piezoelectric power, IoT connectivity	Smart glasses + shoe integration, self-charging	Lacks adaptive AI for terrain recognition; basic sensing only
9	IoT-based Smart Shoes for Blind People – P. Ebby Darney et al., IEEE 2022	Arduino, GPS, Ultrasonic, Soil Moisture, Flame Sensor	Detects puddles/fire, voice feedback, GPS tracking	High power use, lacks predictive analytics and cloud AI
10	IoT-Based Shoe for Enhanced Mobility and Safety – B. Singh et al., EAI 2024	GPS, IMU, proximity sensors, cloud IoT, ML analytics	Data visualization, ML-based feedback, mobile app integration	Complex architecture; needs low-cost hardware optimization

C. Limitations in Real-World Deployments

IoT smart shoes have real-life challenges despite their promotional capabilities. Wi-Fi or GSM wireless modules are susceptible to a weak connection in the overloaded or distant locations, which leads to delays in emergency alerts or navigation data delivery [11], [14], [20]. Spinning causes a higher consumption of power, and thus, batteries are frequently drained when used outdoors [15], [19]. Increased environmental noise and uneven surfaces or uneven foot movement reduce the reliability of ultrasonic sensors, and result in lower obstacle-distance estimation accuracy [13], [17]. Moreover, incorporating various hardware elements within footwear is a matter of concern to ergonomic comfort, waterproofing and structural durability [12], [16]. The majority of the existing systems continue to use threshold-based detection that is not flexible to the changing environmental scenarios or walking styles, which restricts situational accuracy [18], [19].

D. Strategic Advancements and Future Scope

The future of IoT-based footwear is in the smart, reconfigurable systems, which have edge-AI processing to detect hazards in the context and provide personal feedback. Machine-learned models that are lightweight are able to categorize the terrain and evaluate situational risk and also customize the feedback intensity depending on the gait and movement velocity of the user [14], [16], [20]. LoRaWAN or NB-IoT is a low-power wide-area network with better coverage and energy consumption that is less prone to issues with connectivity and battery life [17], [19]. Developments in flexible electronics and waterproofing can help to increase durability and comfort of use in extended applications [11], [18]. The cloud-edge hybrid systems can be used to facilitate secure data syncs, which allow more advanced mobility analysis, protection of privacy, and emergency-response procedures. With such advancements, the IoT smart shoes could be turned into very reliable mobility aids to the visually impaired people.

IV. *Accessibility-Driven Smart Shoe Frameworks*

A. Human-Centric Design Perspectives

Smart shoes based on accessibility emphasize on the integration of ergonomics, natural interaction, and universal design to make sure that users with visual impairments do not have the psychological and physical burden of obtaining help. These systems have been designed to maintain the normal walking techniques, minimize the use of intensive attention and provide feedback mechanisms that are sensitive to the sensory sensibility of users [21], [22]. In contrast to largely technology-centric models, frameworks of accessibility consider comfort, weight distribution, choice of materials and easy interpretation as key design elements. Attempting to provide a smooth mobility support that may not interfere with everyday routine but instead with it, accessibility-based systems focus on emphasizing minimal mental load and unobtrusive guidance [23], [26].

B. Functional Enhancements and Assistive Features

Designs that are accessibility oriented include elements that are to be used on extending the safety of the user, his or her independence and situational understanding. These are advanced obstacle detection, puddle, fire sensing, fall detection by IMU data/input and Bluetooth-enabled smartphone integration based guided navigation [21], [24], [27]. Most of the frameworks have voice feedback features, which are more efficient with people who learn better through audio instructions, whereas others use vibration feedback as a less obtrusive and effective method of communication in busy places [22], [27]. Connectivity with the caregiver and real-time monitoring provides some extra safety, especially in the cases of old-aged or medically compromised people [25], [28]. These systems promote navigation in both a familiar and unfamiliar environment by addressing multimodal support and customized assistance

Table III: Comparison of Accessibility Based Smart Shoes

S.No	Paper Title / Author / Year	Methodology	Highlights	Technical Gap
1.	Smart Shoe for Visually Impaired Person Based on Accessibility Design – K. Mahalakshmi et al., IEEE 2024	Arduino Nano, ultrasonic & water sensors, piezo plate, solar panel, Android app	Real-time alerts, tactile & voice feedback, solar charging	Limited obstacle accuracy; lacks GPS/cloud analytics
2.	Low-Cost Navigation Assistance Footwear for Visually Impaired – A. Patil et al., IEEE 2023	ESP32 controller, ultrasonic, IR, gyroscope, accelerometer, app-based voice alerts	Lightweight, budget-friendly, Android integration	No GPS mapping; lacks adaptive intelligence

3.	Navigating the Unseen: Smart Accessibility Shoe with Obstacle Detection – K. Arora et al., IEEE 2023	Ultrasonic, accelerometer, gyroscope, mobile app (audio/haptic feedback)	Human-cantered design, terrain adaptability	No AI/ML analytics; limited sensor fusion
4.	Smart Navigation Footwear for Visually Impaired – M. Arunkumar, E. Lokesh, IEEE 2023	Arduino UNO, ultrasonic, Node MCU ESP8266, piezo energy harvesting	Shoe + glasses integration, self-charging	No GPS/mobile comms; lacks cloud data
5.	Charana Chakshu: Embedded Accessibility Shoe – Dr. Mallikarjun H.M. et al., IEEE 2024	Ultrasonic, pedometer, accelerometer, GPS, mobile app	Real-time location sharing, fall alerts	Data privacy not addressed; limited edge processing
6.	Intelligent_Accessi bilty footwear For visually impaired- S.N._Gupta et al., IEEE 2025	Arduino Nano, ultrasonic, flame, water sensors, safety alert system	Multi-sensor fire/water detection, real-time alerts	No navigation optimization; lacks ML decision support
7.	Assistive Footwear System for Visually Impaired and Elderly – S. Durgadevi et al., IEEE 2022	Ultrasonic, PIR, MEMS, GPS, piezo power, remote monitoring	Fall/motion detection, GPS alerts	Power optimization and compactness issues
8.	Smart Shoe with Integrated Guidance System – T. Chava et al., IEEE 2021	Arduino UNO, ultrasonic + servo motor, piezo power, wireless connectivity	Smart glasses + shoe, self-charging	No adaptive AI; basic sensing only
9.	Multi-Sensor Smart Shoe for Blind Navigation – P. Ebby Darney et al., IEEE 2022	Arduino, GPS, ultrasonic, soil moisture, flame sensor	Puddle/fire detection, voice feedback, GPS	High power use; lacks predictive cloud AI
10.	Enhanced Mobility and Safety Shoe – B. Singh et al., EAI 2024	GPS, IMU, proximity sensors, cloud analytics, ML feedback	Data visualization, intelligent feedback, mobile app	Complex architecture; needs low-cost hardware optimization

C. Persistent Constraints in Usability

Although there is significant improvement, smart shoe applications based on accessibility face usability issues that restrict widespread usage. Embedded electronics can make people uncomfortable also because of stiff components placed in the high pressure areas in the course of walking [21], [23]. Most prototypes still lack waterproofing and this reduces the durability of internal hardware and sensors. Cognitive load can be elevated when the feedback patterns are either ambiguous or too frequent and it leads to sensory fatigue or misinterpretation [22], [29]. Smartphone addiction also creates accessibility issues to people who have limited digital literacy. Moreover, the fixed logic of feedback does not provide enough adaptation to the different gait patterns among different age groups, health statuses, and mobility levels [24], [27].

D. Emerging Research Opportunities

Most of the new promising research directions include creating soft, flexible electronic substrates that can conform to the shape of feet and decrease pressure points [21], [26]. Confusion can be reduced and clarity be enhanced by multimodal feedback systems such as combining tactile feedback with voice alerts and contextual auditory feedback. The machine-learning systems that can learn the user gait patterns can be used to optimize the alert thresholds and control the guidance strategies in a dynamic manner [23], [30]. The better material choice and modular component positions can be greatly improved to be more wearable and prolonged daily use. These inventions might one day make available accessibility footwear that is not only technology but also comfortable, instinctive and adaptive to the needs of various users.

V. *Haptic-Enabled Smart Shoe Systems*

A. Sensory Encoding and Feedback Mechanisms

Haptics Smart footwear proposes a haptic form of communication where the vibration sequences and local actuation give out navigation to a blind person. The miniature vibration motors used in these systems are commonly located in places of strategic points in the shoe like the heel, the mid-foot or the fore foot to provide directional feedback or hazard alerts [31]-[34]. The haptic encoding mechanism entails the transformation of environmental or navigational information into patterned vibration cues that can be easily decoded by the users hence giving a haptic form of help which is silent and intuitive in nature. Since the haptic feedback is a direct stimulation of the mechanoreceptors in the foot, it conveys messages that do not have to go through the auditory or visual channels, and hence the system is considerably tolerant to congested, noisy, or uncontrollable environments [31], [33], [36]. The processing in real-time makes sure that the stimuli is aligned with the user movement so that it can be oriented to support navigation without needing any conscious interruption or additional wearable devices.

B. Operational Merits

A number of benefits concern haptic smart shoe in terms of privacy, environmental friendliness, and user customization. These systems are able to provide cues directly to the foot of the user and therefore it makes navigation support inconspicuous so that the visually challenged can move freely without attracting attention [31], [34]. They also do not disrupt the hearing capability of the user as is the case with audio-based systems since they are an important part of natural navigation as experienced by the visually impaired. Haptic feedback is also low power consuming so that it can operate over a long period without using a lot of power, thus enhancing the overall sustainability of the system [35], [37]. Haptic-enabled footwear has a bright future due to the constant presence of nonverbal, tactile feedback that allows it to be utilized in those scenarios when sounds cannot be used because of their impracticality and potential danger.

Table IV: Comparison of Haptic Based Smart Shoes

S.No	Paper Title / Author / Year	Methodology	Highlights	Technical Gap
1.	Haptic Feedback-Enabled Smart Shoes – Durga Prasad Amballa, 2018	IMU sensors, BLE, vibration motors, smartphone app	BLE-based haptic guidance, indoor localization, Madgwick filter	BLE signal attenuation, limited obstacle detection
2.	Smart Shoes for Blind Using Visible Light Communication – R. Shivanand et al., IJAEM 2024	Li-Fi, ultrasonic/water sensors, solar/piezo backup, voice commands	VLC indoor navigation, hybrid power system, obstacle alerts	LOS dependency, limited real-world testing
3.	The Haptic Shoe for Blind People – Cathrine Lenette et al., IJARIIE 2022	Ultrasonic sensors, Arduino Uno, vibrating motors, smartphone app	Turn-by-turn vibration guidance, voice alerts, obstacle detection	Basic sensing only, lacks advanced localization
4.	Smart Navigation Footwear with Haptic Alerts – M. Arunkumar, E. Lokesh, IEEE 2023	Arduino UNO, ultrasonic, ESP8266, piezo energy harvesting	Shoe + glasses integration, vibration-based alerts	No GPS/mobile comms; lacks cloud data
5.	Charana Chakshu: Embedded Accessibility Shoe – Dr. Mallikarjun H.M. et al., IEEE 2024	Ultrasonic, pedometer, accelerometer, GPS, mobile app	Real-time location sharing, haptic fall alerts	Data privacy not addressed; limited edge processing
6.	Intelligent Accessibility Footwear – S.N. Gupta et al., IEEE 2025	Arduino Nano, ultrasonic, flame, water sensors, vibration motors	Multi-sensor hazard detection, haptic + voice alerts	No navigation optimization; lacks ML decision support
7.	Assistive Footwear System for Visually Impaired – S. Durgadevi et al., IEEE 2022	Ultrasonic, PIR, MEMS, GPS, piezo power, vibration feedback	Fall/motion detection, GPS alerts, haptic notifications	Power optimization and compactness issues
8.	Smart Shoe with	Arduino UNO, ultrasonic + servo	Smart glasses + shoe, haptic obstacle alerts	No adaptive AI; basic sensing only

	Integrated Haptic Guidance – T. Chava et al., IEEE 2021	motor, piezo power, vibration motors		

C. Constraints and Environmental Challenges

Regardless of the benefits, haptic-based systems have a number of practical constraints. Vibration motors can be damaged by mechanical action during repeated actuation, so their reliability is limited over the long-term [32], [33]. The users might also find it hard to differentiate between the minor vibration patterns especially when walking on rough or vibrating surfaces to enhance the clarity and usefulness of the cues [31], [36]. Repeated stimuli can result in sensory exhaustion, pain or confusion in particular to low-tactile-sensitivity users. Additional issues affecting the environment appear when wet or cold, as the haptic responsiveness or user sensation can be deteriorated, thus influencing the accuracy and comfort of feedback [34], [38]. These constraints emphasize the necessity of adaptive haptic measures which are proportional to user pace, type of surface and sensitivity of feet.

D. Recent Innovations and Proposed Frameworks

Current developments in assistive shoes combine multimodal sensing, smart communication channels, and AI-algorithms to improve the mobility and environmental perception of the visually impaired. Innovations in flexible printed electronics enable the creation of sensors and microcontrollers that are embedded in the material of shoes to enhance durability and comfort in their use over a long-term period [11], [26], [33]. New Li-Fi systems are the integration of photodiode arrays and hybrid localization and IMUs with geomagnetic fingerprinting to overcome the shortcomings of LOS dependency [1], [3], [10]. Simultaneously, cloud-edge cooperation is becoming more and more popular in IoT-based architectures, facilitating real-time hazard detection, as well as long-term behavioral analytics and developing a more comprehensive mobility ecosystem [12], [17], [20]. The haptic systems have also seen the advantage in terms of more efficient actuators and more elaborate schemes of vibration encoding, which allow providing more fined details of navigation feedback [31], [34]. To inform the future, two suggested frames illustrate how the multimodal integration can improve smart shoe features. The Hybrid Multimodal Assistive Footwear (HMAF) architecture is an integrated system that uses Li-Fi beacons, ultrasonic and moisture sensors, emergency communication using GSM and adaptive vibration feedback with machine learning to establish a multilayered navigation platform. HMAF merges optical, tactile, and wireless communications into a synchronized system to overcome fundamental constraints of the indoor positioning, outdoor hazard detection, and rapid emergency response. Adaptive Context-Aware Footwear (ACAF) framework builds upon the principles of user-centered design and includes reinforcement learning to customize the feedback patterns, optimize the alert thresholds, as well as match the patterns of gait and environmental factors to adapt the navigational feedback to the unique behavior of users. The two frameworks address the gaps that have been found in the existing literature and present scaffold elements to scale up to next-generation assistive footwear [15], [21], [31].

VI. *Challenges*

The development of assistive smart shoes is limited by a number of problems of overarching issues that entail scalability, human-technology interaction, power efficiency, hardware endurance, connectivity, and standardization. The adaptation of assistive footwear to a variety of environmental conditions can be considered one of the main challenges. The systems should be able to work in diverse environments like outdoor rough terrain, dark in-door conditions, high-noise conditions, reflective surface corridors and busy streets which has different impact on sensor performance [1], [13], [31]. The other significant issue is the multisensory integration, failing which will overburden the user. Even though the awareness of the situation can be enhanced by installing more sensors, without an organized feedback orchestration, the inability to interpret cues can lead to cognitive overload and decrease the sensitivity of the user to the situation [22], [27], [36]. The power consumption remains heavily congested with sensing and communication continuously compromising battery capacity at a rate that cannot be replenished by existing compact power systems and, in particular, necessitating architecture IoT-driven designs [14], [20]. Durability and comfort present another engineering issue since embedded electronics are exposed to a continuous mechanical force during walking and bending, compression, as well as due to water and heat exposure. These requirements tend to compromise the lifetime of sensors and actuators resulting in irregular functionality with time [23], [32]. Reliable connectivity is also a challenge especially between GSM and Wi-Fi which deteriorates as one moves around causing the signal to be weak, therefore making emergency alerts or data loss take time [17], [18]. Lastly, there are no standardized evaluation metrics which restrain cross-study comparability and stifles scientific progress. Devoid of common standards of obstacle detection accuracy, navigation precision, feedback clarity, energy efficiency, or comfort to the user, developers are unable to compare any outcomes meaningfully, nor to optimize system enhancements [10], [30].

VII. *Conclusion*

The Smart assistive footwear has become a feasible solution to enhancing the movements and autonomy of the visually impaired. With the use of sensors, wireless communication, as well as the feedback based on vibration, these systems allow the user to feel obstacles, learn their environment, and find emergency assistance when necessary. Despite the fact that there are still some challenges, including the long battery life, better adjustment to the changing conditions, and comfortable wearability of the shoe, research is still heading in the right direction. The current invention of better technologies is transforming smart shoes to be smarter, more trustworthy and easier to use. As smart footwear continues to evolve, are tested in the real-world, and integrated more deeply into the design, it can become a completely reliable mobility device, which supplements the safety of the visually impaired community, their confidence, and their quality of life in the real world.

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