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Eyes in Every Step: Navigating the Future using Smart Shoe

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ABSTRACT: Blind and visually impaired people encounter many challenges in their mobility and navigation. Their daily activities are obstructed due to their inability to adapt or identify accurately their surroundings which becomes the main reason of accidents, falling off, and getting lost in unknown areas. In this paper, the design, the implementation and the validation of smart shoes that would serve as an effective solution for more secured movements for blind and visually impaired people will be proposed. This system is developed to detect obstacles, wet floor and patients' falls. In case of presence of one of the above incidents, the user will be notified acoustically using some voice alarms. Moreover, a compatible phone application is designed to notify the patient's parents in case of any issue and share his location. As the system is dealing with human health, some safety measurements were taken into consideration in the design phase, mainly electrical safety, in order to reduce error and false alarms as well as to increase accuracy. The system was tested over five subjects and the results have shown low faulty errors and good accuracy and detection percentages along with an accuracy that reached about 96%.

KEYWORDS: Smart shoes; Obstacle detection; Fall detection; Blind and visually impaired people; Phone application; Location detection; Electrical safe systems .

I. INTRODUCTION

Blindness is the most severe form of visual impairment. In 2010, it was estimated that 285 million people were visually impaired of whom 39 million were blind. 90% of visually impaired people live in low- and middle-income countries, meaning that their access to preventive care education, curative services and quality rehabilitation is not available at a moderate cost. Studies have also shown that 82% of all people with blindness are over 50 years old whereas 28 % of them are in their working years, which has an impact on their productive life [1]

[2]. Actually, most of the engineering tools aimed to help impaired patients rely on the use of canes. Although these canes are technologically developed, lots of problems are still questionable, whether their dimensions, the need to be handled all the time (thus, one of the hands is no more free) the high possibility of getting broken if hitting something hard, the difficulty to detect road humps and bumps and so on

Thus, the aim of this work is to develop low cost, high accuracy smart shoes for blind and visually impaired people. This system will have the ability to detect obstacles and to provide safe and secure indoor and outdoor movements. The novelty of the work consists in embedding more than one functionality in one system: detection of obstacles, wet floors and falls as well as the notification of health care providers or parents of the actual position of the deaf patient and in case of falls. Added to that, another important feature of the proposed system is the electrical safety of the design following the 60601 IEC norms [3].

Thus, the false alarms and the electrical hazards will be limited to the maximum and the safe state will be initiated when the response of one of the subsystems becomes questionable. Before starting by the presentation of the technical part, let's show briefly some of the previous works already achieved in this domain. In 2011, Abd Wahab et al. proposed a cane for people with visual impairment to prevent unwanted collisions with obstacles. This prototype is supplied by different sensors to detect the obstacles and the presence of humid floor. The smart cane alerts the user about the distance to reach the obstacle using an audible message. According to the tests performed on the system, the voice alerts used are too repetitive so the user will feel confused each time a voice is heard. Added to that, the results of the analysis of the water detector sensor showed that after being wet, the beeper cannot be stopped unless the sensor is dry [4].

In 2016, another study, conducted by Hussain et al., proposed a design that let blind people overcome their difficulties by using a smart cane. The developed prototype is implemented by a combination of sensors responsible for the detection of irregular surfaces or any obstacle in the way of the person. Pre-recorded messages are sent over the earphones so that the user could be alerted before hitting the obstacle. A GPS is used to locate the user. Moreover, the performance test applied on blind and blindfolded people to compare the efficacy of this prototype with the ordinary white cane showed a high offset value in the detection of obstacles below waist and in the detection of mud and wet surfaces. Added to that, the proposed cane is heavy in weight after being compared with similar market products [5].

In 2017, Mutiara et al. proposed an assistive smart cane that helps visually impaired people with their mobility activity. This prototype detects obstacles and holes; in addition to that, it locates their destination. If the user falls while getting to the specified location, no one would be warned about it and this is a major disadvantage that could menace the user’s safety. In addition, according to a questionnaire filled by eight users, six declared that this system is heavy to be used, resulting in some walking difficulties [6].

In the same year, Chandekar et al. proposed a system to help people with vision problems to navigate without the use of any external tool other than their smart phones and shoes. The prototype works as an audio guidance system. It comprises a real time navigation system based on an android application that communicates with Google maps. Input is taken from the sensors attached to the shoes of the user. Concerning the disadvantages, this system is not a stand-alone system as it requires the use of a smart phone and the accuracy of the GPS may cause some damage for the user because of the location offset and when dealing with movable obstacles

II. BLOCK DIAGRAM

As already discussed, the system will be based on four major functionalities: detection of obstacles, wet floor and patients fall as well as the development of a phone application. Concerning the alarm systems, it consists of two modules: the embedded alarms in the shoes (vibration motors and audible notifications) and the phone application notifications. All these modules are based on hardware and software parts and the communication protocols and tools needed for the communication between each one of them. Figure 1 shows the block diagram of the complete system. the system consists of the central processing unit, which is the microcontroller for this system. It is the master processor that collects data from all sensors, processes them and generates the required alarms, if needed. Concerning the communication between the microcontroller and the phone, it is based on Bluetooth technology. Note that the mobile must be always connected to the internet in order to allow the update of the user status on the phone app.

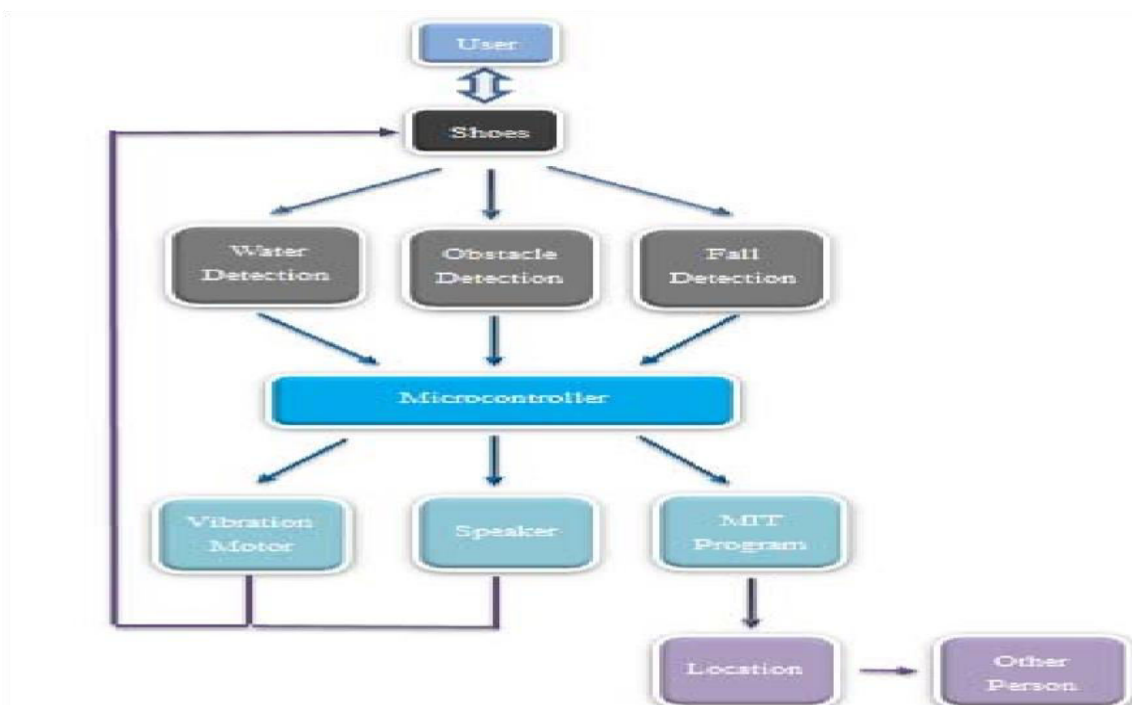


Figure 1. Block diagram of the complete system

III. SYSTEM COMPONENTS

This section will present first the processing unit, sensors, alarms, actuators and communication modules used for this system. Note that these components were chosen in a way to ensure the low cost, reliability, accuracy and electrical safety

Concerning the processing unit, the Arduino Mega was chosen due to the need for a high number of I/O lines. The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [16] [17]. The connectivity with processing unit will be shown in details in the next section after introduction the safety features to the design. Although the use of a safer processing unit, as the Hercules microprocessor

As for the sensors, the ultrasonic sensors (HC-SR04) were used do detected obstacles as they are able to locate fixed and movable obstacle between 2cm and 300cm. Added to that, due to its small size (21.3 mm x 45.7 mm), low cost and high reliability, more than one sensor can be placed on the shoes [18] [19]. Concerning wet floors, the water detection sensor is used. As the sensor will deliver nonzero values until it gets dry, welding six metal pins in the sensor fixing hole was the solution to limit false alarms. This way, each pair of pin is far from the other and automatically after their contact with the water, the sensor will give specific values; thus, a threshold is specified for the input values to the controllers and the reading will be analog to identify if the patient get out of the wet floor. Figure 2 shows the installation of the sensor wires on the shoes. As for the fall detection sensor, the MPU6050 sensor was used. It consists of a 3 axis accelerometer and a 3 axis gyroscope [20]. Here also, a threshold value is specified based on the three gyroscope readings to detect falls. The sensor is placed at the center of the patient's waist. Added to that, a voltage divider was applied to detect the battery level. At the end, the Neo-6mv2 GPS sensor was used to identify the location of the patient [21]. The circuitry and connections of all these modules with the microcontroller will be presented in section5 after introducing the electrical safety measurements.



Figure 2. Placement of the wet floor sensor wires on the shoes

Concerning the alarm system, speakers were used to generate sound. They were connected to the Arduino and a special library was used to generate the required voice commands (“obstacle to the left”, “obstacle to the left”, “obstacle to the left”, “wet floor” as well as the distance with the obstacle). The use of the speakers requires additional circuitry such as an audio amplifier that will serve to adjust the amplitude with respect to the distance with the obstacle. Note that the user can also use an earpiece.

As for the actuators, a coin vibration motor was used to let the blind and visually impaired people feel the presence of an obstacle. The vibration amplitude will be proportional to the distance with the obstacle: once the patient approaches the obstacle, the vibrations increase and vice-versa. An electric circuit, shown in figure 3, shows the connectivity between the motor and Arduino.

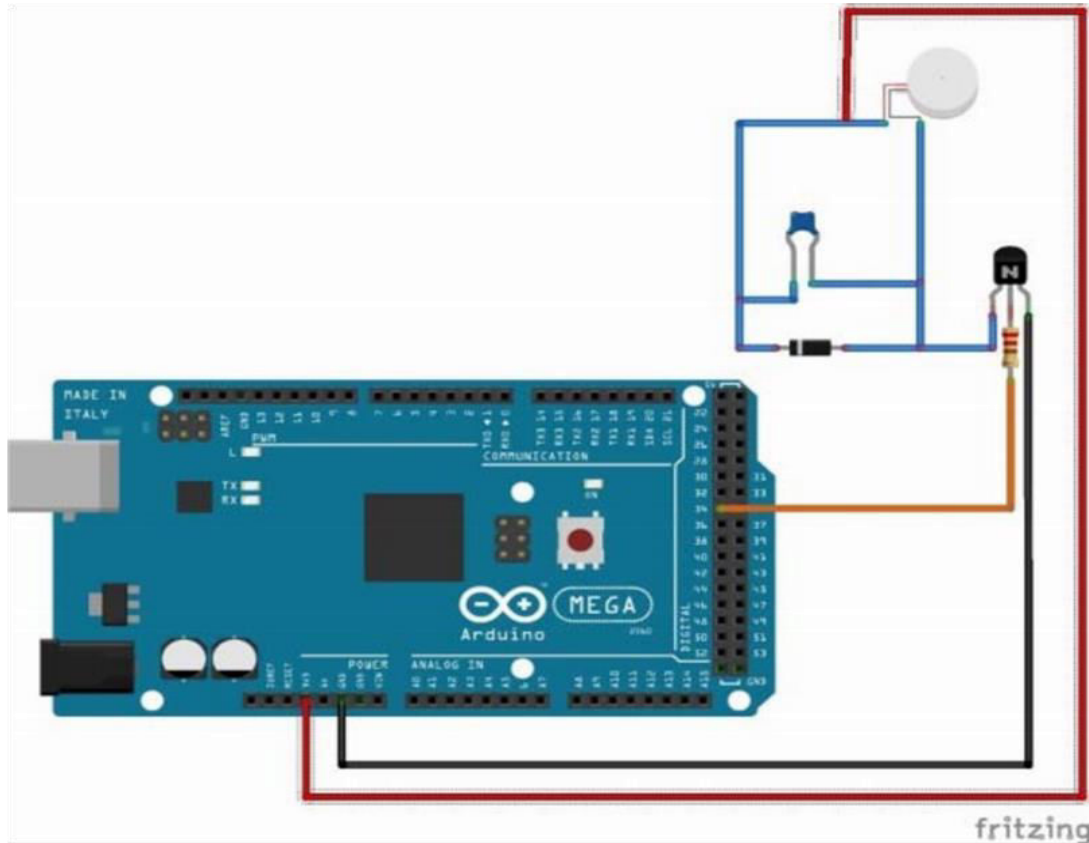


Figure 3. Connectivity between the coin vibration motor and the Arduino

At the end, the communication unit used is the Bluetooth communication. This module is embedded in almost all phones. It is easily connected to Arduino and it is cheap. Thus, this module has been chosen to transfer data between the modules of the system.

Figure 4 shows the flowchart of the program of the microcontroller. Note that, because of space limitations, the electrical safety was integrated in the program at this level. This part will be explained in details in the next section. The processing unit will check simultaneously for the fall detection (through the orientation values), the battery level, the obstacles and the status of the floor.

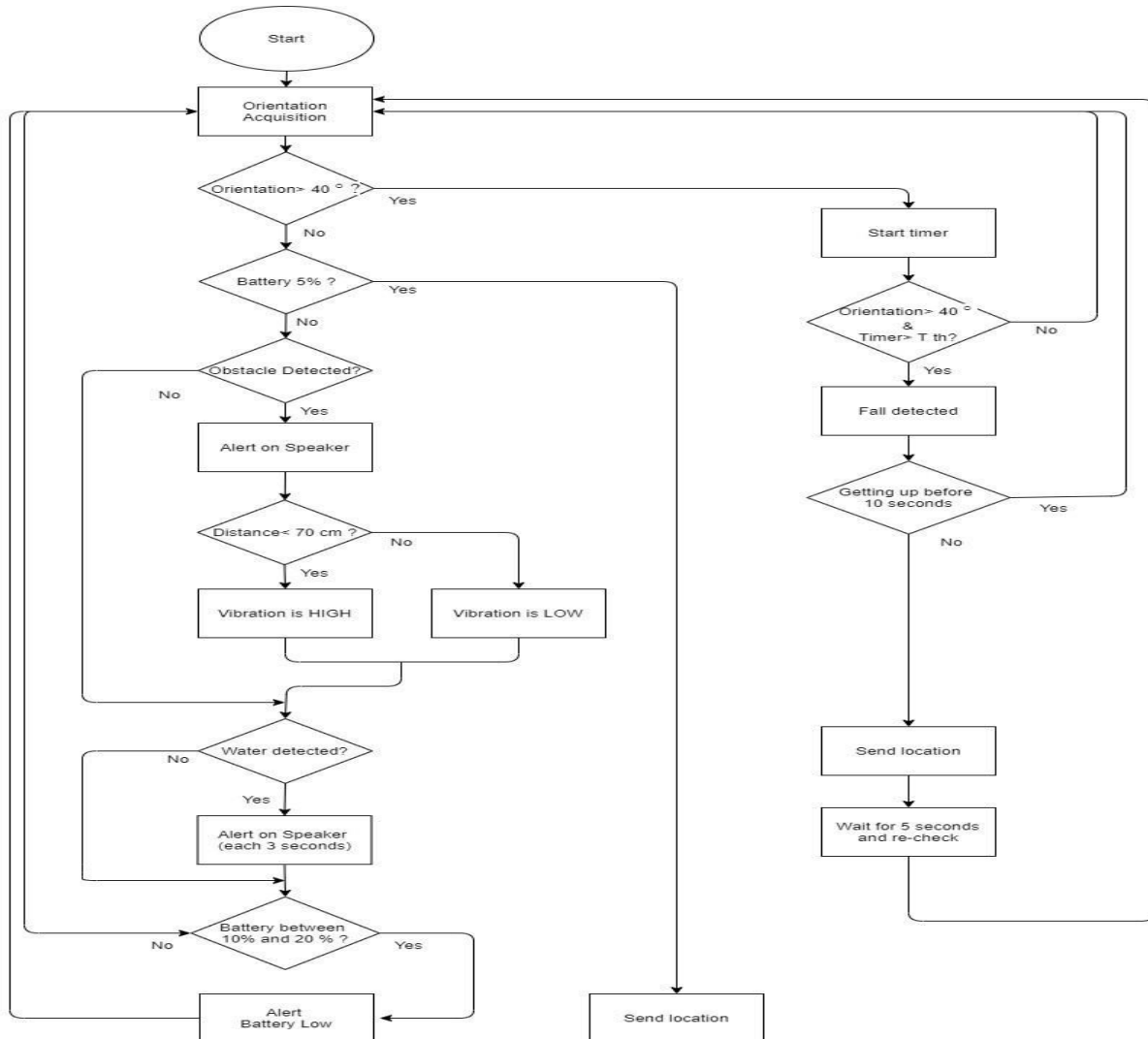


Figure 4. Flowchart of the complete process

The first signal that the system will search for comes from the orientation sensors. A standard orientation equal to 40 degrees was used a threshold based on previous studies [16] [17]; thus, if the value of the gyroscope sensor is above this value, a fall is detected. The system will wait for 10 seconds (considered to be the threshold value) while continuously checking the value of the gyroscope sensor. In case the value remains above this value, an alarm is sent to the patient’s parents or health care professionals via the phone application containing the actual status of the patient (the patient location as well as a heart rate sensor that can be also added in this system). Otherwise, no alarms are generated and the system will continue executing the remaining tasks.

The second test is performed on the battery level. If it is below 5%, an alarm signal is also sent to the phone application along with the patient position. If the second battery is still charged, a switching between the batteries will take place, otherwise the safe state will be generated (we will present this part in more details in the next section).

Then comes the obstacle detection subsystem. In case of presence of a signal of one of the ultrasound sensors, the speakers and the vibration motors will turn ON. As long as the distance between the user and the obstacle is higher than 70 cm, the vibration motor works slowly (low duty cycle) and the speaker’s volume remains low. However, if the obstacle is at a distance less than 70 cm, the vibration will be at its highest ratio. The duty cycle ratio and the speaker volume can be calibrated easily with respect to the patient using the system.

The last test concerns the detection of wet floor. The speakers will be turned ON to warn the user about the presence of the water. Note that, during navigation, if the battery percentage is between 10 and 20 %, the user will be alerted about it.

IV. SAFETY SYSTEM FEATURES

As safety is a major concern when dealing with systems related to human health, electrical safety systems have been implemented in this design in order, not only to limit the false alarms generated, but also to make sure that no internal electrical or communication problems occur within the system itself. One of the methods to increase the safety of the system is by applying redundancies, i.e. going from 1-out-of-1 (1oo1) architecture to 1-out-of-2 (1oo2), 1 out-of 3 (1oo3) or 2 out-of 3 (2OO3) architectures (other architectures could be also applied) [24]. Other existent methods are to do a diagnostic for the processing unit before and during the simulation to make sure that the system is functioning well. This method is known as 1-out-of-2 architecture with Diagnostic (1oo2D).

In this system, several safety measures have been taken. We will list them below:

1. Concerning the obstacle detection subsystem, four sensors have been used. It was configured to be 2-out-of-4 system meaning that at least two must detect the obstacle in order to turn on the alarm system;
2. Concerning the processing unit, a test was made while turning it on to check its internal memory and ports. Added to that, every few seconds, some inputs and memory slots are chosen arbitrary to make sure that the Arduino is functioning well;
3. Concerning the communication, a parity bit is added to make sure that the data sent between the Arduino and the phone application to make sure of the data validity;
4. Two batteries have been used to power up the system. When the main battery level reaches 10%, a switch towards the second one is made.

Concerning the safe state, it consists of turning manual the whole system; in case of one of the last three previously discussed issues are encountered, a voice command is generated and the phone application will display that the system is no more functioning.

Of course, several other safety options could be implemented within this system. However, due to the constraints that were already set, e.g. the low cost, the portability and the low power consumption, we were limited to add these modules to the system to increase the electrical safety and to limit hazards.

V. METHODOLOGY

EXISTING SYSTEM

Sticks are provided to blind as an aid to navigation. Blind people can find the obstacles on the path using sticks but always need a support for finding the path. They always rely on someone for navigation, thus Sticks are not effective. Another option is to provide blind with the guide dogs. Guide dogs are specially trained dogs for assisting the blind. These dogs are trained as per the owner requirement. These incorporate sensors and technology to detect obstacles and provide feedback to the user. Various wearable devices, such as vests or belts, equipped with sensors and GPS technology, offer navigation assistance. These devices can provide feedback through vibrations, guiding the user to their destination. There are numerous smartphone apps designed to assist visually impaired individuals with navigation. These apps often utilize GPS, voice commands, and audio feedback to guide users along routes and provide information about nearby points of interest.

VI. PROPOSED SYSTEM

- The proposed system is an IoT-based smart shoe designed to enhance the well-being and safety of users.
- Equipped with various sensors, including accelerometers and pressure sensors, the smart shoe collects real-time data on the user's gait, step count, and foot pressure distribution.
- This information is then transmitted wirelessly to a centralized hub or a mobile application, allowing users to track their activity levels .
- Additionally, the smart shoe integrates GPS technology for location tracking, ensuring the safety of individuals, especially in unfamiliar environments.
- Output section Sensor- It includes ultrasonic sensors, pedometer sensor module, water sensor. The ultrasonic sensors will detect the obstacle within 3m.

- The water sensor will detect the presence of water, step counter will count the number of steps to detect object Power Supply-A DC power supply of 12V is used in Smart shoes.
- Controlling unit-Arduino Uno is used in this system as Arduino boards are inexpensive, assembly of the boards are easy and can run on various operating systems

VII. APPLICATIONS

A "smart shoe" designed for blind people could offer various applications aimed at enhancing their mobility, safety, and independence. Here are some potential applications:

Obstacle Detection: Sensors embedded in the shoe could detect obstacles in the user's path, such as curbs, steps, or objects on the ground. The shoe could then provide feedback to the user, such as vibrations or audible alerts, to warn them of potential hazards.

Navigation Assistance: By integrating GPS and mapping technology, the smart shoe could provide turn-by-turn navigation instructions to help users reach their desired destinations. This could include guiding the user along a predefined route and providing updates on their progress.

Indoor Navigation: In addition to outdoor navigation, the smart shoe could also assist users in navigating indoor environments, such as buildings, malls, or public transportation terminals. This could involve using indoor positioning systems (IPS) or Bluetooth beacons to provide real-time navigation guidance.

Fall Detection and Prevention: Accelerometers and gyroscopes in the shoe could help detect sudden changes in movement or orientation that may indicate a fall. The shoe could then alert the user or caregivers and provide assistance, such as calling for help or stabilizing the user's position.

Environmental Feedback: The smart shoe could provide information about the user's surroundings, such as the presence of stairs, ramps, or doorways. This could help users better understand their environment and navigate with greater confidence.

Health Monitoring: Beyond navigation assistance, the smart shoe could also incorporate health monitoring features, such as tracking the user's steps, distance traveled, and activity levels. This information could be useful for monitoring overall health and fitness.

Customizable Feedback: Users could customize the feedback provided by the smart shoe to suit their preferences and needs. This could include adjusting the intensity of vibrations, choosing different types of alerts, or selecting specific navigation preferences.

VIII. ADVANTAGES

Smart shoes designed for blind people offer several advantages that can significantly enhance their mobility, safety, and overall quality of life. Some of these advantages include:

Increased Independence: Smart shoes enable blind individuals to navigate their surroundings more independently, reducing the need for constant assistance from others.

Real-Time Navigation Assistance: Smart shoes provide real-time navigation guidance, helping users to navigate unfamiliar environments and reach their destinations more efficiently.

Obstacle Detection: Embedded sensors in smart shoes detect obstacles in the user's path, alerting them to potential hazards such as curbs, steps, or objects on the ground.

Improved Safety: By alerting users to obstacles and potential hazards, smart shoes help prevent accidents and reduce the risk of falls or injuries.

Enhanced Confidence: With the assistance of smart shoes, blind individuals can move around with greater confidence and autonomy, knowing that they have support in navigating their surroundings.

Customizable Feedback: Smart shoes allow users to customize the feedback they receive based on their preferences and needs, ensuring a personalized and comfortable user experience.

Integration with Other Devices: Smart shoes can integrate with other assistive devices, such as smartphones or smartwatches, to provide a seamless user experience and access additional functionalities.

Health Monitoring: Some smart shoes incorporate health monitoring features, such as step counting and activity tracking, allowing users to monitor their physical activity levels and overall health.

Accessibility: Smart shoes are designed specifically for blind individuals, ensuring that the technology is accessible and easy to use for people with visual impairments.

IX. CONCLUSION

The proposed system is based on an embedded system where the hardware and the software are integrated together thus creating a developed navigational assistance system. This system is mainly used for blind and visually impaired people to detect obstacles, wet floor and to determine their position when a fall occurs by developing a phone application installed on their parents or health professional phone. In conclusion, the IEC 60601 safety electronic standard was applied to find electrical safe solutions for each problem exposed. This way, following a series of technical standards that ensure the safety of electrical equipment and systems, we were able to develop a standalone, low cost and electrically safe smart shoes for blind and visually impaired people that ensure a safe and secured navigation that provides assistance in case of falls and presents of unwanted collisions. The system was tested on 5 subjects and the results were promising. Lots of ideas can be added to this work in order to increase its functionality and to limit the false alarms. For example, other sensors adding more accuracy to the measurements will be highly recommended as well as sensors measuring the patient vital signs following a fall as the case of heart rate sensors. Added to that, testing this prototype on a larger population to identify all system issues in order to get a better performance in upcoming versions is of high interest.

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