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A VISION-FREE OBSTACLE DETECTION AND ALERT SYSTEM USING SMART KNEE GLOVES

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Abstract
This paper introduces a novel obstacle detection and warning system specifically designed for visually impaired individuals, utilizing an innovative wearable device known as "Knee Gloves." These Knee Gloves are equipped with ultrasonic sensors that detect obstacles in the wearer's path, from ground level up to knee height, which are commonly missed by traditional cane methods. The system uses vibration feedback to alert the user to the presence and proximity of obstacles, allowing for real-time navigation adjustments. We detail the design and implementation of the Knee Gloves, including the integration of sensors, feedback mechanisms, and power management. Through a series of controlled trials and real-world testing with visually impaired volunteers, we evaluate our system's effectiveness, accuracy, and user acceptance. The results indicate a significant improvement in obstacle detection and navigation safety, with users reporting increased confidence and mobility in everyday environments. The paper discusses the potential for integrating advanced technologies such as AI and IoT to further enhance the system's capabilities. It concludes with future research directions, focusing on miniaturization, improved ergonomic design, and enhanced sensory feedback. Obstacle detection and warning can improve the mobility as well as the safety of visually impaired people, especially in unfamiliar environments. For this, obstacles are detected and localized, and then information about the obstacles is sent to visually impaired people using different modalities such as voice, tactile, and vibration. In this proposed model, we presented an assistive system for visually impaired people based on the Internet of Things and computer vision-based models. This system consists of two main components: environmental information acquisition and analysis, and information representation. The first component aims at capturing the environment by using sensors and analyzing it to detect predefined obstacles for visually impaired people, while the second component tries to represent the obstacle's information in the form of an electrode matrix.

INTRODUCTION

Travel consists of a long list of travel subtasks. There are two main categories of the subtasks in travel activity, i.e., mobility and environmental access [1, 2]. Mobility itself can be divided into obstacle avoidance and orientation/navigation [3, 4], while environmental access consists of hazard minimization and information/sign. Most of the subtasks in the travel activity are based on visual information [5]. For this, sighted people mainly rely on their sense of sight. The visually impaired are only able to use their sense of sight to a limited extent or possibly not at all [6]. Therefore, visually impaired people require support from assistive technology to carry out different travel activity subtasks [7, 8]. In this research work, we focus on developing assistive technology for obstacle avoidance for visually impaired people, because it has always been considered a primary requirement for aided mobility. Obstacle avoidance technology needs to address two issues: obstacle detection and obstacle warning [9, 10]. The obstacle detection means the perception of potentially hazardous objects in the environment ahead of time [11, 12], while the latter one concerns the manner to convey obstacle information to the visually impaired people [13, 14]. The white cane can be considered the first obstacle avoidance assistive tool [15, 16]. However, this tool is generally not used to detect obstacles above knee height [17, 18]. Recently, the advancement in sensor technology has made several obstacle avoidance technologies available for visually impaired people [19]. However, most researches focus on obstacle detection, obstacle warning is not well studied [20, 21].

The Internet of Things [22], known as IOT, plays an important role in our daily life. It gives a real-time glimpse into the inner workings, reducing costs, increasing safety, and improving quality [23, 24]. As wearable devices are now capable of monitoring the health of a person [25, 26], they are now termed as wearable health devices [27, 28]. In this research activity, we proposed a model of smart shoes that can monitor a blind person to track by avoiding obstacles using IOT technology. IOT is used in many applications like monitoring health using sensors [29], some band devices for the wrist, and sensors in smart caps, smart glasses to facilitate visually impaired people [30, 31].

Many researchers have proposed different solutions to tackle this problem using sensors. Work has been done on a system that can divide customers' gait into normal, out-toeing, and in-toeing [32, 33].

According to the WHO reports, the total number of visually impaired people of all ages is estimated to be 285 million, of whom 39 million are blind [34]. People 50 years and older make up 82% of the blind population [35]. These people require constant support from someone; in fact, no one has time in his or her daily routine to look after them [36, 37]. Most often, these people are considered a burden by others, while some just ignore their presence and leave them to care for themselves all alone [38, 39]. The feeling of loneliness when all ignores them is a big demotivation and loss of confidence [37]. Some of the major challenges include difficulty in moving from one place to another without the assistance of someone Most of the time [40], blind people wait for others to help them cross the road and to move from one place to another [41, 42]. There is a need for a device or a system to make them independent. Researchers have developed many types of obstacle detection to help them. Primary devices are a white cane and a guide dog [43]. Some people are not comfortable with white canes in malls or other public places, and the same with the for-guide dogs [44], so to their needs to they feel comfortable and independent, we use an obstacle detection algorithm, sensors, and cameras [45]. Moreover, over white can have some range issues in detecting the object [46].

In this research, an obstacle detection model has been proposed to decrease the detection miss by using plane segmentation on an organized point cloud and eliminating the assumption that obstacles are on the ground. Secondly, instead of using a stimulation signal for obstacle warning based on visual substitution as described in [47]. We input the obstacle warning by the output of obstacle detection. Finally, we introduced new patterns on the electrode array for mapping information about obstacles and performed different experiments to evaluate the proposed mapping solution.

1. Literature Review

In the domain of obstacles, detection and alarming accordingly, several researchers proposed their models, with the calculation of the area of distance measurement as shown in Table 1. The Android app will receive the signal from the transmitter and alert the healthcare provider

Table 1: Stat-of-the-art studies

Year	Sensors	Future work	Conclusion
[48]2017	FSR sensor, In-sole shoe, IoT, Plantar pressure distribution	The Android app will receive the signal from the transmitter and alert the healthcare provider	Measuring a person who has foot abnormalities, preventing disease
[49]2017	WAX sensor	Nill	Feature learning and activity recognition
[50]2017	Embedded system, Arduino, Android, visually impaired, sensors	Nill	Can work without internet
[51]2017	camera, 3D depth sensor, accelerometer, ambient light sensor, barometer, compass, GPS, gyroscope	Assistive navigation solutions for individuals utilizing game engines	Can enhance Functionality and usability
[46]2018	Smart stick, ultrasonic sensor, moisture sensor, Arduino microcontroller, buzzers, vibration motor, RF remote.	Classify the Objects.	Switch can be pressed from about 300 meters if the stick is lost

A research work has been proposed by [48], in which FSR sensors have been used with planter pressure distribution. Their proposed system also uses an Android app to receive and send signals to visually impaired people. In another study conducted by [49], smart shoes have been introduced that use WAX sensors to detect unobtrusive human activities [52]. In another study conducted by [50], the researchers have proposed a model for obstacle detection and a navigation system to assist the visually impaired using smart shoes. Their model also uses the embedded system, [53] [54] Arduino, and an Android application [55]. Visual and infrared sensor data-based obstacle detection for the visually impaired persons, using the Google Project Tango tablet development kit and the Unity engine, has been proposed by [51]. Their proposed model uses a motion tracking camera, 3D depth sensor, accelerometer, ambient light sensor, barometer, compass, GPS, gyroscope, etc.

Similarly, an embedded assistive stick for visually impaired persons using a smart stick, an ultrasonic sensor, a moisture sensor, an Arduino microcontroller, buzzers, a vibration motor, RF remote has been proposed by [46]. Their model is also able to classify the objects as small, medium, and large according to their height [56]. A similar study for unifying obstacle detection, recognition, and fusion based on millimeter wave radar and RGB-depth sensors for the visually impaired using an RGB-Depth (RGB-D) sensor, a low-power millimeter wave (MMW) radar sensor has been conducted. The reported model uses a data fusion algorithm on the Field Programmable Gate Array (FPGA) chip [57]. This greatly reduces the size and weight of the system, which is more portable during navigation. Another study with the development of a vertical obstacle detection system for visually impaired individuals using a Bluetooth module (RBT-001; MicroTechnica Corp.), AVR (Atmega328PPU; Microchip Technology) [58, 59], and an ultrasonic distance sensor has been reported recently by researchers. Their reported model uses a dynamic obstacle detection system developed using a Doppler sensor. From the reviewed literature, it has been revealed that much work has been performed for obstacle detection, while some of the work has been performed to guide visually impaired people according to their route path [60]. They either use sensors or use cameras, but none of them have used both sensors and cameras [61, 62]. Therefore, the reported model will be able to use both sensors and digital cameras to process visual inputs. Not only this, but the reported model will also be able to guide them about their route, etc.

2. Materials and Methods

2.1. The Proposed System

The proposed model consists of several steps, i.e., input through sensors and cameras, preprocessing of this received information with the aims of segmentation and extra information removal, evaluation of the received input regarding detection of obstacles (even their types) and their distance etc., transmission of the perceived information to the visually impaired persons, and path planning in total automated manners shown in Figure 1.

Step 1: Input through sensors and cameras

Step 2: Preprocessing of this received information with the aim of segmentation and extra information removal

Step 3: Enhancement of the information (restoration of original information, which was lost during segmentation or in the previous step, noise removal, edges highlighting, etc.)

Step 4: Evaluation of the received input regarding detection of obstacles (even their types) and their distance, etc.

Step 5: Transmission of the perceived information to visually impaired people

Step 6: Path planning in a totally automated manner

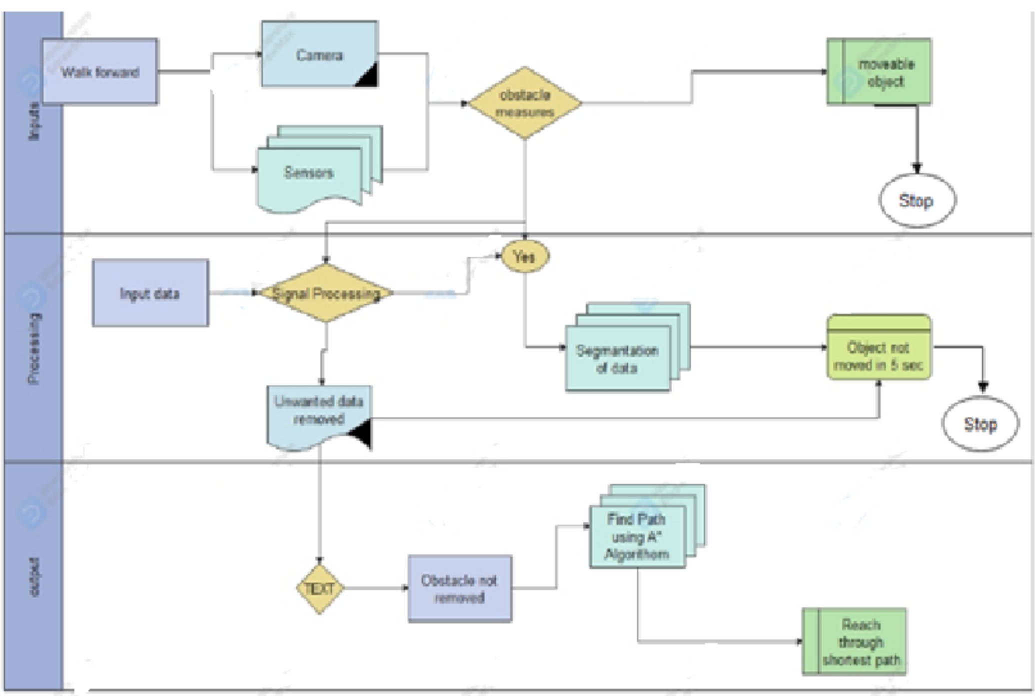

Figure 1: Dataflow diagram of the proposed model

The details of each of the following are as under;

2.2. Input through sensors and cameras

Input received through Passive Infrared thermopile array (PIR) sensors and the microcontroller (Raspberry Pi) will receive cameras (High Definition), where all information will be combined to make it able for further processing by placing it into indexed arrays [63]. PIR is a group of sensors that is used to detect human presence shown in Figure 2. in this model, we connect these PIR sensors with Arduino, a microcontroller. Sensors are fitted in a knee glove, also holding a High-definition camera, which is used to detect the panorama effect. Obstacles can be of any type, like birds, traffic, humans, storms on the road, so the camera will help us detect multiple interactions.

Figure 2: Infrared thermopile array (PIR) sensors

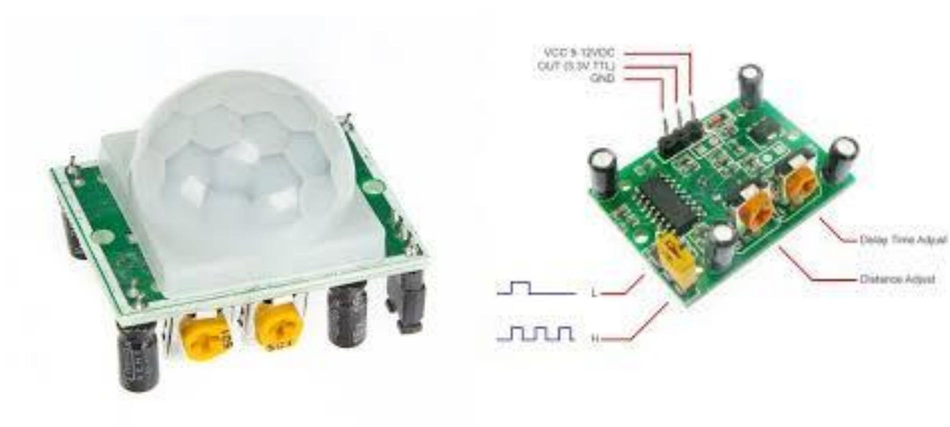

Figure 3: HC-SR501 Passive Infrared (PIR) Motion Sensor Module

2.3. Preprocessing of this received information with the aim of segmentation and extra information removal

The information received from sensors and digital cameras will be preprocessed to be placed into indexed arrays, so that it may be able to further processed by the proposed model steps. The information received through different sensors and digital cameras may contain irrelevant information such as noise, so this unwanted information will be removed using signal processing and noise removing techniques, including optimal linear filtering method, Wiener filtering, Kalman filtering, and/or spectral subtraction technique, etc [64]. In signal processing, filtering is a device or process of removing unwanted information from a signal. Especially in the field of image processing, there are many options for filtering [65, 66].

When unwanted information is removed, it will save time to complete the obstacle detection process. This information includes movable objects like birds [67], traffic, and any person who walks through, which will be removed within 5 seconds [68]. This type of information should not be processed because it has just passed by [69].

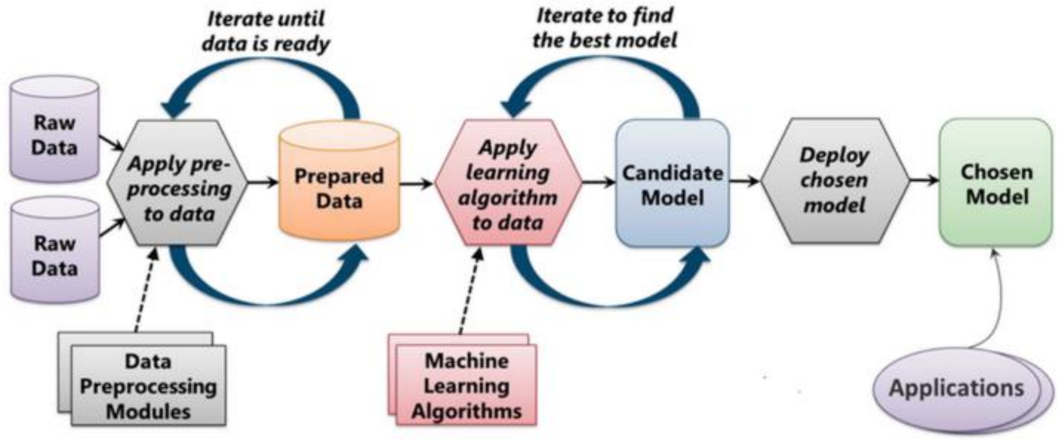

Figure 4: This figure shows how raw data is submitted for processing by applying a learning algorithm to the data. After receiving the information from the sensor data sent for processing to be segmented into different categories.
This diagram shows how the model fits practically in any visually impaired person's sensor.

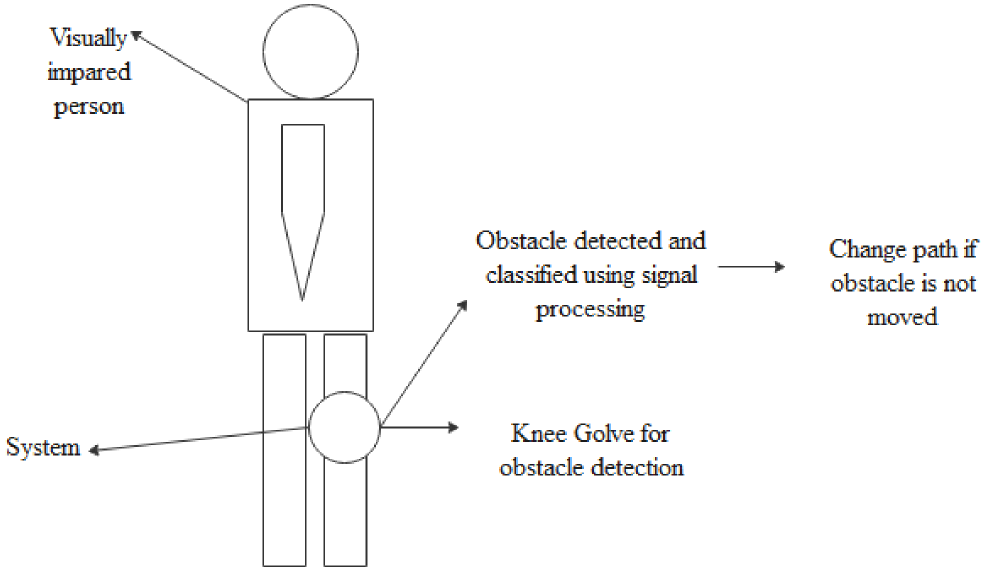

Figure 6: Obstacle Detection

This figure shows how the visually impaired person will carry the system in his knee glove and how it will work [70]. in this model, access of camera range has been increased by using a high-definition camera, which can access vertically aligned obstacles coming from the upper level of the person's head.

2.4. Enhancement of the information (restoration of original information, which was lost during segmentation or in a previous step, noise removing, edges highlighting, etc.)

The information received through different sensors, and digital cameras for imagery data, where necessary, edge information will also be highlighted using edge detection algorithms from computer vision techniques [71]. The popular edge detection algorithms include Canny, first-order methods, thresholding and linking [72], Edge thinning, second-order approaches, differential, phase congruency-based, physics-inspired, subpixel, etc.

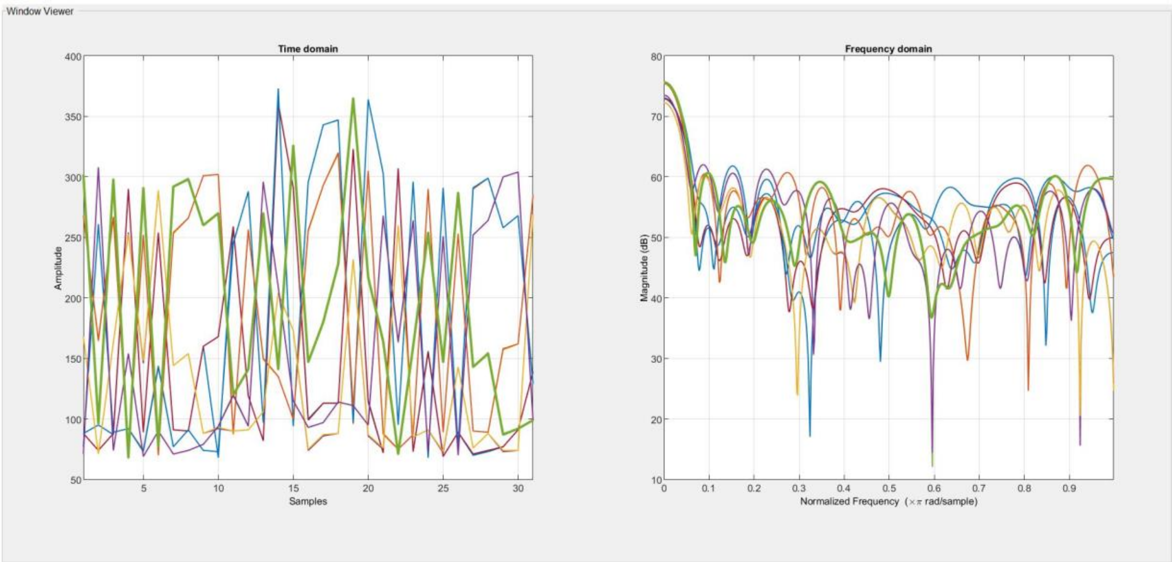

Figure 7: Time and Frequency Domain Representation of Multichannel Sensor Signals

The technique used for signal processing is:
It is designed to recover a signal d[n] from the noise

X(n) = d(n) + v(n)..(1)

d(n) and v(n) can be wide – sense stationary process. Technique Weiner considered the problem of designing a filter that will produce a minimum mean square estimate of d(n) by using x(n).

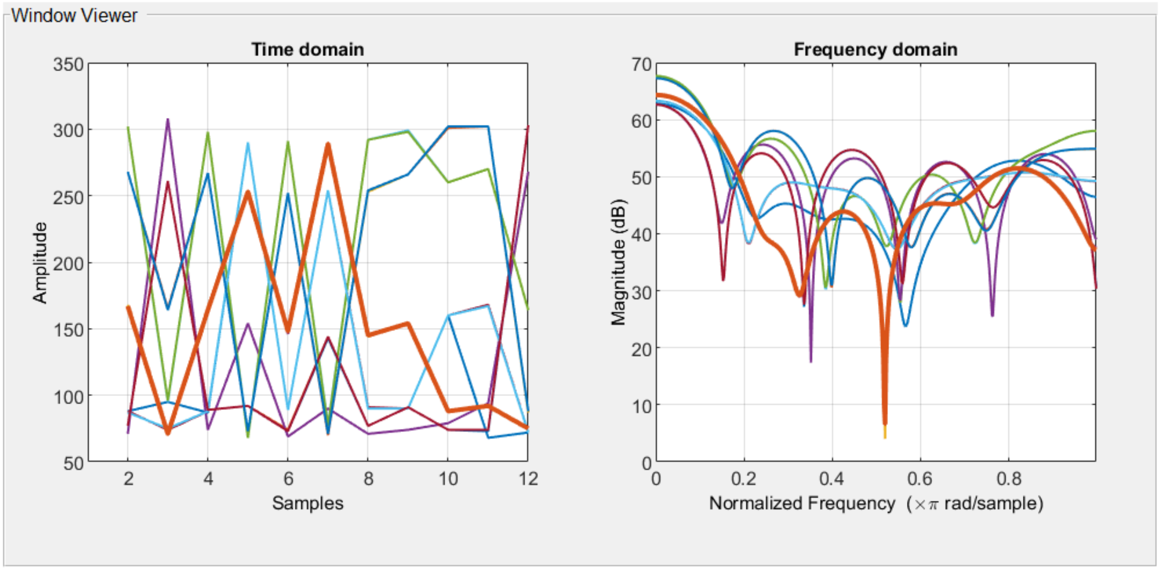

Figure 8: Time and Frequency Domain Representation of Multichannel Sensor Signals

2.5. Evaluation of the received input regarding detection of obstacles (even them

Ready to further process with the aim of obstacle detection. The beauty of this proposed model is that it can detect even vertically aligned objects, which are above the mid-level height of the impaired subjects [73]. All the information will be placed into indexed arrays, analyzed, and objects will be detected using direction, distance, and height on a vibrotactile waistband method. Not only this, the distance and type of obstacle using a pretrained model, i.e., AlexNet, will also be determined in this step of the proposed model [74]. AlexNet is the name of a convolutional neural network (CNN), it is the most popular model used for the image classification problem. CNN is used for image classification and recognition for its high accuracy.

2.6. Transmission of the perceived information to visually impaired people

Upon successful decision of the proposed model about obstacle detection, its distance, type, and alignment, the whole of the information will be communicated, transmitted, and alerted to visually impaired people [75]. This information will be transmitted using all the available means. If, for instance [4], a visually impaired person is also deaf, other means will help him/her for further route planning.
There are different phases of the model that take input through sensors. Processing of this received information with the aim of segmentation and extra information removal. Restoration of original information that was lost during segmentation, now evaluate the received input regarding the detection of obstacles and detect even their types and distances. Transmit the perceived information to the visually impaired person.

2.7. Path planning in a totally automated manner

This is also the beauty of the proposed model that the GPS data will be saved in offline mode, which will help in automated route planning. Upon reception of the decision, the path will be planned to use the A* (A Star) algorithm. As a path, planning is one of the fundamental problems in autonomous bodies' movement. It is typically defined as finding a sequence of state transitions from its initial state to some desired goal state.

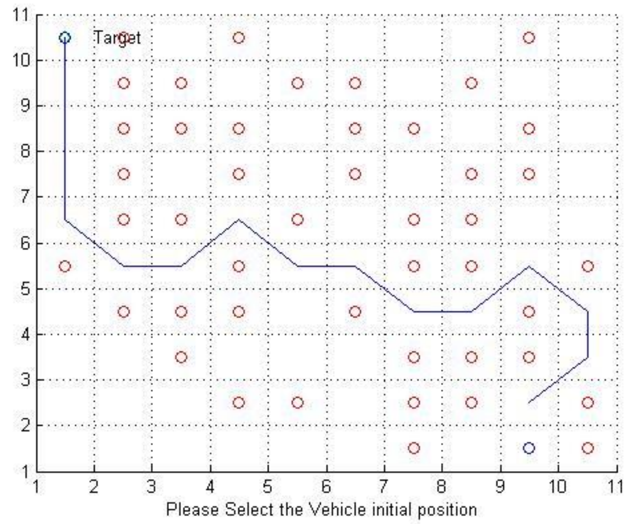

Figure 9: Path Planning for Autonomous Vehicle Navigation in a Grid Environment

According to the information on obstacles, the working environment can be categorized as a completely known environment, a partially known environment, a completely unknown environment, and a dynamic environment. The planned path can be evaluated according to path length, movement time, energy consumption, or risk level. There have been numerous algorithms proposed for path planning for navigational objects, such as the probabilistic roadmap method (PRM), the rapidly exploring random trees algorithm (RRT), the expansive space trees algorithm (EST), the rapidly exploring random trees star (RRT*) algorithm, the artificial potential field method (APF), the model predictive control method (MPC), fuzzy logic approach, the artificial neural networks algorithm (ANN), the genetic algorithm (GA), ant colony optimization (ACO), particle swarm optimization (PSO), and other new nature-inspired meta-heuristic algorithms etc. Compared to these algorithms, the

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A* algorithm has been widely investigated and applied because of its advantages, such as its simple principle, easy realization, high efficiency, and ability to find the optimal solution. To further increase the applicability of the A* algorithm, many scholars have improved the conventional A* algorithm. First, the evaluation function of the A* algorithm has been improved so that the planned path can meet specific requirements. A* algorithm is shown in Figure 2, while the logical structure is shown in Figure 10, and the top-down approach of the proposed model is shown in Figure 3.

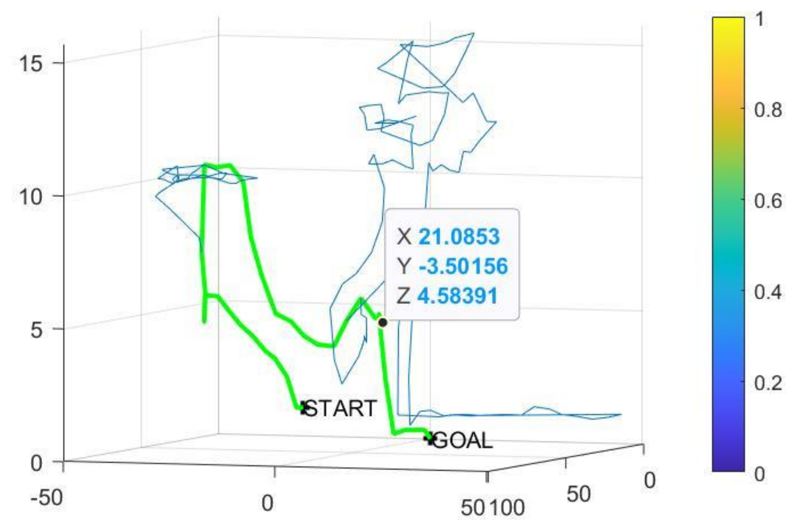

Figure 11: Results

A* is an informed search algorithm, or a best-first search, meaning that it is formulated in terms of weighted graphs: starting from a specific starting node of a graph, it aims to find a path to the given goal node having the smallest cost (least distance travelled, shortest time, etc.). This is an output that shows best shortest and clearest path to the person. The red line is the recommended path after applying A* algorithm to the input, whereas the blue line is the actual, long, and full of hurdles way to the destination.

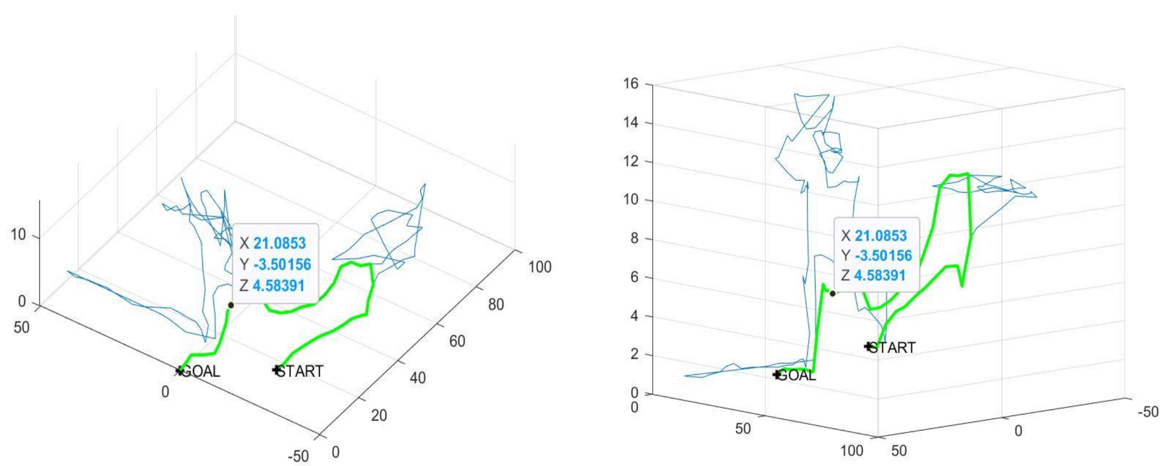

Figure 12: Results

We take data from sensors and add values of x, y, z, and plot them in MATLAB in terms of directions a person wants to move from which plan and what is its destination. These 3 diagrams show 3D results from different angles.

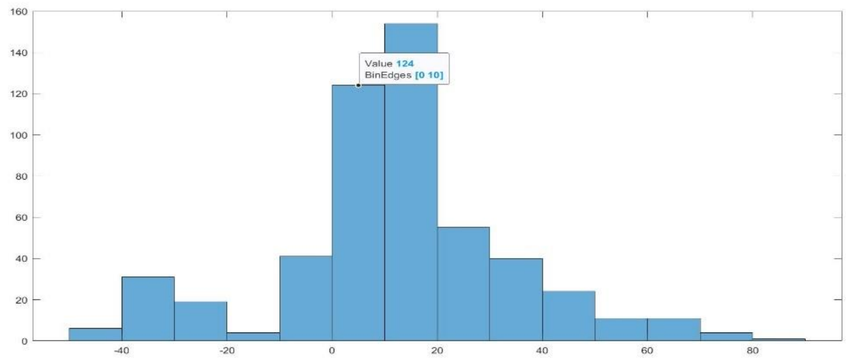

Figure 13: x, y, z, and plot MATLAB.

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