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Research Article

SMART CANE THAT FOLLOWS THE DISABLED PATH (YELLOW LINE) CONTROLLED BY A MICROCONTROLLER AND PROTECTS AGAINST COLLISIONS FOR VISUALLY IMPAIRED INDIVIDUALS

GÖRME ENGELLI BIREYLER IÇIN MIKRODENETLEYICI KONTROLLÜ ENGELLI YOLU (SARI ŞERIT) TAKIP EDEN VE ÇARPMALARDAN KORUYAN AKILLI BASTON

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Article Info	ABSTRACT
Keywords: Microcontroller, Robotic Coding, Smart Cane, Color Sensor	Visually impaired people are a part of society. It is important to make life easier for them, integrate them into society, and ensure they can navigate safely on their own. In this study, a microcontroller-controlled smart cane application was implemented to enable these individuals to navigate streets, sidewalks, and pavements without colliding with obstacles, pedestrians, vehicles, etc. In this study, unlike other classical smart cane applications, in addition to the features of the cane that alert against collisions with obstacles, an automatic warning system has been added that allows walking without stepping outside the disabled path (yellow strip) designed for disabled individuals. In this way, it is aimed to ensure the safe navigation of visually impaired individuals by enabling them to follow the disabled path on sidewalks and streets. To prevent collisions with the cane, an ultrasonic distance sensor (HC-SR04) has been added, and to follow the disabled path (yellow strip), a color sensor (TCS series) has been included. The data from these sensors are processed by the microcontroller, and the necessary alerts are provided audibly and vibrationally, ensuring the safe navigation of the disabled individual.

Makale Bilgileri	ÖZET
Anahtar Kelimeler: Mikrodenetleyici, Robotik kodlama, Akıllı Baston, Renk Sönsürü	Görme engelli insanlar toplumun bir parçasıdır. Hayatı onlar için kolaylaştırmak, onları topluma kazandırmak ve kendi başlarına güvenli şekilde gezintilerini temin etmek önemlidir. Yapılan bu çalışmada, bu bireylerin caddelerde, sokaklarda ve kaldırımlarda engellere, yayalara, araçlara v.b. çarpmadan gezinebilmesi için mikrodenetleyici kontrollü akıllı baston uygulaması gerçekleştirilmiştir. Yapılan çalışmada diğer klasik akıllı baston uygulamalarından farklı olarak, engellere çarpmalara karşı uyaran bastonların özelliklerine ek olarak, engelli bireyler için tasarlanmış olan engelli yolu (sarı renkli şerit) dışına çıkılmadan yürümeyi sağlayan otomatik uyarıcı sistem eklenmiştir. Bu sayede görme engelli bireylerin kaldırımlardaki ve caddelerdeki engelli yolunu takip etmeleri sağlanarak güvenli gezintilerinin sağlanması hedeflenmiştir. Baston üzerine çarpmaları önlemek için ultrasonik mesafe sensörü (HC-SR04) ve engelli yolunu (sarı şerit) takip etmek için ise renk sensörü (TCS serisi) eklenmiştir. Bu sensörlerden gelen veriler mikrodenetleyicide işlenerek

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gereken uyarılar sesli ve titreşimsel olarak yapılıp engelli bireyin güvenli gezintisi sağlanmaktadır.

1. INTRODUCTION

With the development and advancement of technology, autonomous systems have become a part of our lives, and their facilitative effects are increasing day by day. These effects have become even more significant recently with the rapid advancement and intertwining of the fields of robotics and artificial intelligence.

Artificial intelligence and robotics have been widely used recently, especially in the healthcare field for diagnosis and treatment purposes. Additionally, daily life is becoming easier thanks to smart and autonomous systems. These can be multiplied in the form of automatic systems in industrial fields, smart home systems, irrigation systems, autonomous vehicles, service robots, and smart vacuums.

Individuals with disabilities are a part of society. It is possible to remove barriers using science and technology to integrate them into society. For people who are blind or have low vision, walking and finding their way around on their own is either very hard or impossible. At this point, we need studies and designs that will help people who can't see or hear.

Nowadays, classic white canes are insufficient in ensuring the safe navigation of visually impaired individuals, which is an important activity for them. For this reason, many studies and innovations have been made to help visually impaired individuals, facilitate their lives, and meet their needs by providing them with the ability to navigate without human assistance. These studies are generally focused on protecting individuals with disabilities from accidents, collisions, and getting lost, enabling them to navigate safely without assistance, and meeting their needs.

This study was conducted to ensure that visually impaired individuals can navigate safely on streets, avenues, and even within their homes.

Generally, many smart canes are designed solely to avoid obstacles for individuals. In this study, in addition to this, the individual's navigation is made safer by tracking the disabled paths (yellow strips) made for the disabled on streets and sidewalks.

Nowadays, there are many smart cane designs available. The costs of these canes vary depending on the technology used. In these canes, basic obstacle detection sensors can be used with Arduino, while higher-cost single-board computers like Jetson Nano B01, STM32, and Raspberry Pi can be integrated with devices such as 2D LiDAR, RGB-D camera, IMU, GPS, GSM, and Wi-Fi. Additionally, using machine learning algorithms such as YOLO and SLAM technology in software will not only add extra features to the cane but also incur additional costs. As a result, while such enhancements increase the features of the canes, the associated cost increases make access to smart canes more difficult.

In this study, materials with low design costs have been selected specifically for an effective solution at a low cost. Thanks to the lower cost, access to and usage of these smart canes will be greater. In this regard, the study was conducted using an Arduino microcontroller instead of a Raspberry Pi single-board computer.

2. LITERATURE REVIEW

Numerous studies have been conducted to help visually impaired individuals recognize obstacles and reach their destinations smoothly. In these efforts, various sensors and schemes, including ultrasonic sensors, infrared sensors, cameras, LIDARs, laser distance scanners, color sensors, RFID (Radio Frequency Identification), and GPS, along with artificial intelligence algorithms, have been extensively integrated into the research and development of smart canes. Some of these studies aim not only to help users avoid obstacles but also to guide them to their desired destinations. However, some of these projects are high-cost and not feasible for mass production.
The existing body of work can be categorized as follows:

- Classic Smart Cane Applications and Obstacle Detection
- Lane Following and Navigation-Focused Smart Canes
- Advanced Features, IoT Integration, and Machine Learning

Initial and most common studies on smart canes for the visually impaired have primarily focused on detecting environmental obstacles and alerting the user. These systems typically utilize distance-sensing technologies like ultrasonic or infrared sensors, providing auditory or vibrational feedback based on the detected obstacle's proximity.

A significant emerging approach in smart cane technology, also highlighted in this study, is the lane following feature (specifically, the yellow tactile paving). Such systems often aim to track a specific path or pattern using technologies such as color sensors, image processing techniques, or RFID (Radio Frequency Identification).

Beyond conventional designs, a distinct category of smart canes has emerged, focusing on integrating diverse sensors and advanced technologies to develop more sophisticated and user-friendly solutions. The evolution of technologies like the Internet of Things (IoT) and machine learning has significantly enhanced the capabilities of these assistive devices.

(Kocamaz et al.,2006) aimed to provide a superior solution compared to traditional white canes by developing a smart cane that measures the distance to an obstacle using ultrasonic sound waves and transmits this information to the visually impaired user through audible or vibrational alerts.
(Wahab et al.,2011) presented research on a smart cane prototype, termed "Smart Cane," designed to help visually impaired individuals walk more safely. Their objective was to create a cane capable of detecting objects or obstacles in the user's path and relaying warnings via voice messages and vibrations. A series of tests on this prototype demonstrated its effective functionality in alerting users to front-facing obstacles.

(Çakır et al.,2015) addressed the limitations of classic white canes in obstacle detection with a low-cost smart cane and smart hat application. Their primary goal was to overcome these disadvantages and enable the detection of head-level obstacles. They utilized an Arduino Nano board as the control mechanism to process data from sensors. Based on data from the ultrasonic distance sensor, the user is guided with audible and vibrational cues, thereby facilitating obstacle avoidance.

(Halim et al.,2018) developed an electronic white cane augmented with GPS to extend the navigation range for visually impaired individuals without distance limitations. Their design incorporated ultrasonic distance sensors for measurement and servo motors as actuators to form a radar system. If an obstacle is nearby, notifications are provided through vibrations, with the intensity increasing as the obstacle approaches. They also aimed to enable easy location of visually impaired individuals by tracking their position via the cane's GPS and transmitting it to their families when assistance is needed.

(In their study, Chinchai et al.,2022) replaced the insufficient obstacle-detection sensor at the tip of classic white canes with two ultrasonic distance sensors mounted on the cane, facing upwards and downwards. This innovation protects the user by alerting them to obstacles near the ground within their walking area, as well as those at chest and head levels. Experimental findings indicated that users were more satisfied with their modified cane compared to traditional white canes.

(Khan et al.,2018) conducted a survey-based review to understand the potential role of white canes in developing user-friendly navigation tools. Their objective was to identify current trends from articles published between 2010 and 2017 and contribute to future research directions.

(Mai et al.,2023) introduces and classifies smart canes, then investigates vision sensing-based, laser sensing-based, and laser vision sensing-based smart canes, detailing the current research status of laser vision sensing smart canes. The advantages and disadvantages of various laser vision sensing smart canes are summarized, with particular emphasis on research and development focusing on laser vision fusion as the core of next-generation smart canes. This paper also provides an overview of future development prospects for laser vision sensing smart canes, aiming to accelerate their advancement and ensure safe and efficient travel for the visually impaired.

(Șipoș et al.,2022) proposed a smart assistant comprising a smart cane and a central unit, where communication between the user and the assistant occurs through voice messages. The assistant is equipped with GPS, an electronic compass, Wi-Fi, ultrasonic sensors, an optical sensor, and an RFID reader to aid safe navigation. The system supports daily activities by providing features such as physical condition monitoring, medication reminders, shopping assistance, and weather information. Preliminary tests demonstrated promising results, suggesting the prototype's potential to significantly enhance the independence of visually impaired individuals in their daily lives.

(Ramisetti et al.,2022) designed a smart cane capable of detecting obstacles and alerting visually impaired individuals with buzzer sounds, enabling them to move forward. The cane also incorporates fire and water sensors that emit warning sounds of varying intensities to draw the user's attention. If the user forgets the cane somewhere, an alert is sent to their mobile phone. Additionally, a vibration sensor on the cane sends messages to the user's relatives via an Arduino board with GPS and GSM connectivity in case of an accident.

(Abu-Abdoun et al.,2022), in their developed cane, utilized a Global Positioning System (GPS) and a water detector. Their smart cane features various charging methods, including a lithium battery and a piezo element that generates power from pressure. This developed smart cane is expected to enable visually impaired individuals to move more easily, interact more with the community, reduce their fear of walking alone, and move safely.

(Mai et al.,2024) developed an intelligent guide system for visually impaired people utilizing 2D LiDAR and RGB-D camera sensing onboard of a smart cane. The intelligent guide is completely reliant on hardware, specifically a 2D LiDAR, RGB-D camera, IMU, GPS, Jetson Nano B01, and STM32. The smart cane measures the distance to obstacles with the 2D LiDAR enabling SLAM. The intelligent guide uses the YOLOv5 algorithm, allowing the intelligent guide to fastly and accurately detect pedestrians, vehicles, crosswalks, traffic lights, warning posts, stone piers, tactile paving, and other objects in front of a visually impaired person. The intelligent guide system is able to effectively lead the visually impaired anywhere and avoid obstacles and arrive safely to their destination and help identify obstacles along the way with speed and precision.

WeWalk (Smart Cane) (WeWalk, 2025) is a smart cane designed with systems by Turkish engineers for people with visual impairments. The smart cane has the following features to be of significant assistance.

Obstacle Detection: Detects obstacles (vehicles, people, trees, signs) in walking paths of people with visual impairments and alerts the individual.

Phone Integration: By connecting to a mobile phone via Bluetooth wireless technology, it allows control of both the phone and the cane.

Open Platform: It has the ability to integrate with many mobile applications. This way, new features can be added.

Artificial Intelligence: It offers the possibility of a smart voice assistant with GPT integration.

3. MATERIALS AND METHODS

Microcontroller (Arduino / Raspberry Pi)

In this study, an Arduino Uno microcontroller was used to receive data from sensors and process this data to avoid obstacles and automatically follow the disabled path on the streets.

Arduino has digital and analog input/output (I/O) pins that can interact with other circuits. Thanks to these pins, sensors, drivers, etc., can be controlled, and data can be received from environmental components. Arduino can be programmed in a computer environment using the IDE (Integrated Development Environment). Power can be supplied to Arduino via USB, and it can also be powered by an external battery. In the studies to be conducted, considering the space it occupies, cost, and features, a suitable microcontroller/single-board computer like Arduino/Raspberry Pi should be selected and used.

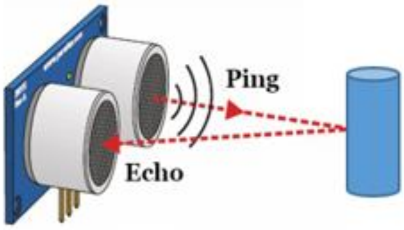
Sensors

Sensors are used to detect data or changes in the environment and transfer this information to other electronic devices. In this study, in addition to software, values such as environmental objects and color information are also needed to establish a smart cane system. The way to obtain information about these values is to collect or measure environmental data with appropriate sensors. The Arduino microcontroller used in this study can easily process the data received from the sensors as input.

Sensor Types

Sensors are like sensory organs for autonomous systems, just as in humans. Autonomous systems generate responses based on the data they receive from sensors. In this context, an ultrasonic distance sensor (HC-SR04) and a color sensor (TCS3200 or TCS34724) have been used in the study. If distinguishing between black and white is sufficient for the project, the CYN70 color sensor should be used for faster measurements.

A) Ultrasonic Distance Sensor and Working Principle: Ultrasonic distance sensors (Figure 1.a) measure distance using high-frequency sound waves (Figure 1.b).



a) **b)**

a) Ultrasonic distance sensor **b)** Working principle

The ultrasonic distance sensor works by following these steps:

- The sensor produces ultrasonic waves at a specific frequency.
- These waves are sent towards an object or surface.
- Waves reflect off the object and return.
- The sensor detects the returning waves.
- The distance is calculated by finding the echo time from these perceived sound waves.

In the HC-SR04 ultrasonic distance sensor (Figure 1.a), there are 4 pins: Trig, Echo, VCC, and GND. Ultrasonic sensors are used in various fields such as distance measurement, presence detection, obstacle detection, and robotic applications.

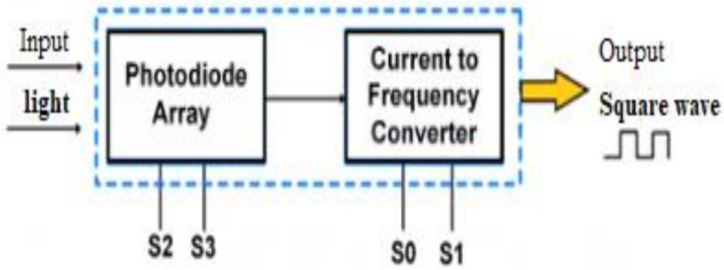
B) TCS Series Color Sensors (TCS3200): TCS3200 is a color sensor used for color detection applications (Figure 2). This sensor can detect the RGB (red, green, blue) components of colors and can be used in various electronic projects for color recognition, color classification, or detection of colored objects.

TCS3200 can be used in many application areas such as robotics, industrial automation, color object classification systems, and control of colored light effects.

To select the color read by the sensor, the S2 and S3 control pins should be used. Since the photodiodes are connected in parallel, different combinations of S2 and S3 (LOW and HIGH) are used to select different photodiodes (Table 1). Thus, color selection is made.

Table 1. Filter Selection

Photodiode Type	S2	S3
Red	LOW	LOW
Blue	LOW	HIGH
Green	HIGH	HIGH
No Filter	HIGH	LOW



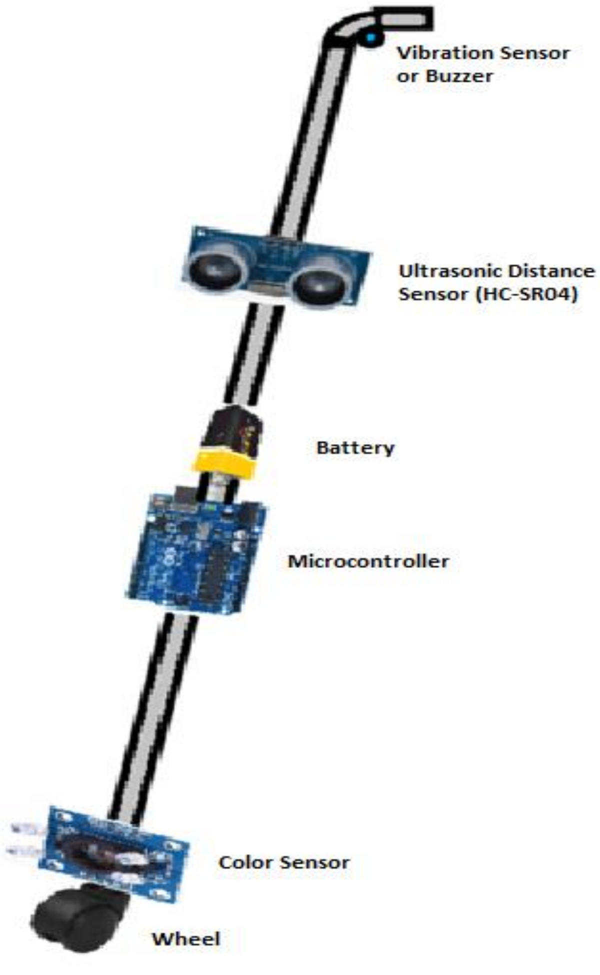
TCS3200 Color Sensor and Working Principle

Smart Cane Design and Implementation

The design of the smart cane begins primarily with the connections of the necessary hardware (circuit components) in the simulation environment and the coding. From this perspective, simulations are very important. After all test phases are tried and any problems are resolved, the actual circuit (physical circuit) is designed and operated.
The following equipment is required for physical design:

• An approximately 1-meter-long hollow tube, which can be made of plastic, will serve as the main body of the cane. The hollow interior of the pipe is preferred to ensure that the microcontroller and inter-device cables are not exposed.
• The microcontroller should be selected from the Arduino/Raspberry Pi family based on the specific needs of the project. At this point, the microcontroller to be selected should be chosen based on the project to be implemented and the additional circuit connection elements (for sufficient pin count).
• Sensors: In this study, an ultrasonic distance sensor (HC-SR04) and a color sensor (TCS3200 or TCS34724) were used as sensors. If the strip consists of black and white colors, the CYN70 color sensor can be used for faster measurements.
• Vibration motor and buzzer: They will be used for guidance to ensure that visually impaired individuals can navigate their desired environment without any problems. If the individual also has a hearing impairment, guidance can be provided through vibrations.
• Power Source: A 9-volt battery will be used to power the circuit.
• Wheel: It will be placed on the end of the cane.
• Protective plastic boxes.

The physical design of the cane is shown in Figure 3.

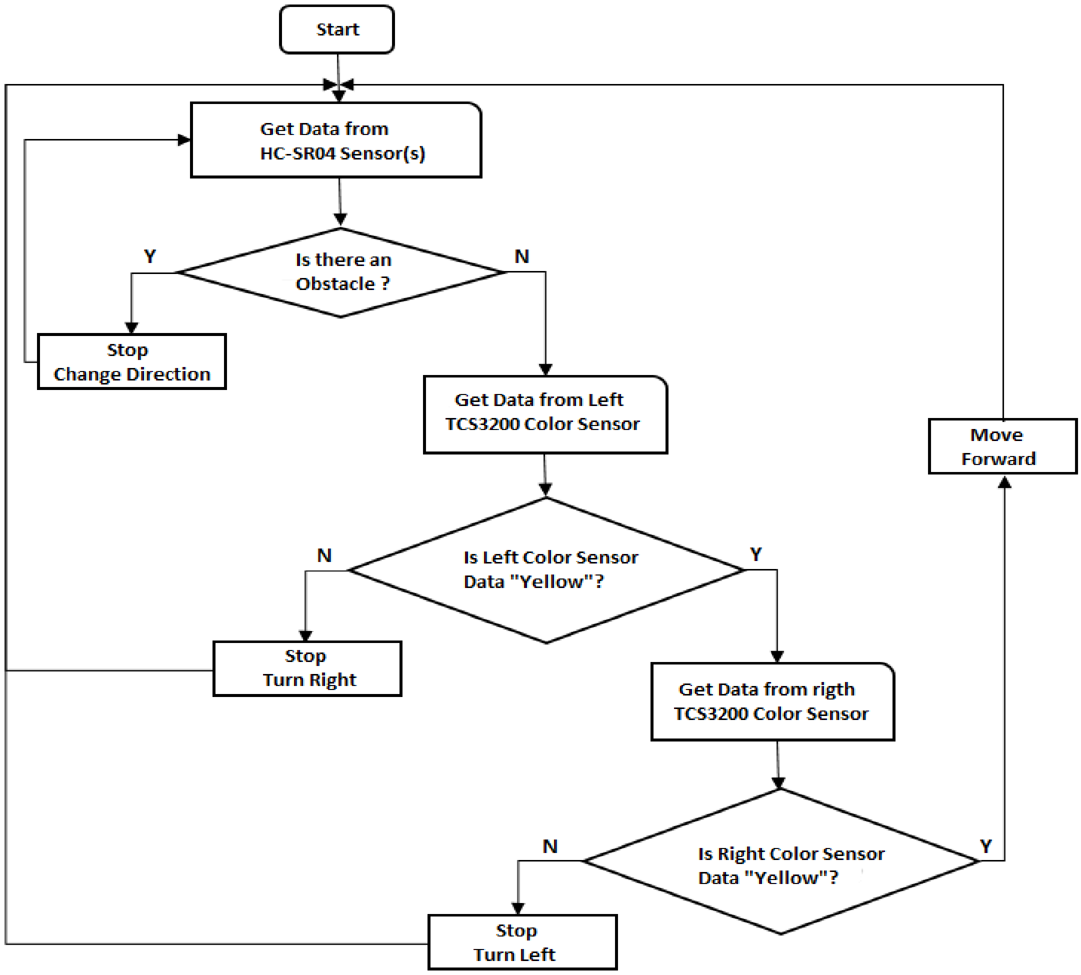


Smart Cane Design for Obstacle Path Tracking and Collision Prevention

The coding and implementation steps of the cane are shown in the flowchart in Figure 4. First, data is received from the ultrasonic distance sensor and checked. If there is an obstacle, the cane stops and changes direction; otherwise, data is received from the left color sensor, which is placed near the tip of the cane, and the color information is checked. If it is not yellow, guidance is given to turn right, and data is received again from the distance sensor to continue to the next steps. If the color is yellow, the same steps are performed for the right distance sensor. If the data received from the right color sensor is yellow, guidance is given to move forward. After each movement, these steps are repeated. Thus, both the obstacle condition and the yellow line tracking condition are checked to ensure the visually impaired individual can proceed safely.

In the design of the cane, both a buzzer for audible alerts and a vibration sensor for tactile notifications have been added to the handheld grip. The purpose here is that the visually impaired individual may also have a hearing problem. For this reason, instead of holding the smart cane with the hand, a vibration sensor has been added in addition to the buzzer. In this way, when encountering an obstacle or deviating from the disabled path, both auditory and tactile notifications have been provided as a solution.

Arduino microcontroller coding has been carried out in the Arduino IDE environment. Previously, the system was set up as a prototype in a virtual environment, and the written codes were tested. Later, it was uploaded onto the microcontroller.



Flowchart of the Smart Cane Operation Steps

a) b)

a) Obstacle testing b) Obstacle path (yellow strip on sidewalks and streets)

4. CONCLUSIONS AND RECOMMENDATIONS

One of the most important things in the travel of a visually impaired individual is to ensure they avoid obstacles. At this point, infrared sensors, ultrasonic distance sensors, and laser sensors (LiDAR) are important for obstacle detection. From a cost perspective, using ultrasonic distance sensors results in lower costs. Using Raspberry PI for line tracking, color tracking, object classification, and distance measurement is more effective but increases the cost.

In addition to obstacle-detecting sensors for a visually impaired individual's travel, sensors measuring moisture/water conditions for wet surfaces or puddles can be added to help the individual avoid such terrains. Additionally, if the visually impaired individual also has a hearing problem, auditory feedback for guidance will not be useful. In this case, vibrational feedback should be added to the cane, and design and coding should be done accordingly. Again, if location information feedback is needed (such as in the case of getting lost), a smart cane design that includes GPS should be prioritized. The use of GPS in the design will incur an additional cost, which needs to be considered.

In this study, the obstacle avoidance steps were first implemented and tested as shown in Figure 5.a. Then, a color sensor was added to follow the yellow color and alert the disabled individual. Line following and object tracking are used in vehicles and robots. In this study, in addition to avoiding obstacles, a color sensor was used to follow the yellow lines (Figure 5.b) that already exist (have been made) on sidewalks, streets, and avenues. Color sensors detect many colors. According to the data obtained from the color sensor, the visually impaired individual is kept on the yellow line. Thus, the individual is able to navigate safely along the disabled lane.

In this study, coding and calibration processes were carried out to follow the disabled lane (yellow line) on the streets and sidewalks. If the smart cane is to be used to guide a disabled individual indoors, it can be easily used with a small adjustment in the code. In this case, a strip of the desired color (for example, a black strip) is created on the floor of the building/apartment (concrete, tiles, laminate flooring, etc.). Then, the coding and calibration can be adjusted according to this color, allowing it to be used in indoor spaces as well.

In the case of line following, unfavorable conditions such as uneven surfaces, faded colors, strips with excessively different color tones, lighting conditions, and dark environments can cause problems in color perception. In cases of lighting-related issues, a solution can be to add an illuminating LED next to the color sensor. In areas without a strip or where the sensor does not detect, the yellow line tracking can be disabled with a button placed on the smart cane.

This study involves creating a colored strip for the indoor navigation of individuals with disabilities, and data related to that color (for example, black) can be obtained from a color sensor, allowing the coding to be adapted accordingly.

This study is particularly suited to fill the gap in the existing literature with its automatic warning system feature that enables walking without stepping outside the disabled path (yellow strip). In addition to the obstacle detection capabilities of classic smart canes, the ability to follow a designated path can enable visually impaired individuals to move more safely and independently, especially in organized areas (such as disabled paths on sidewalks). The device aims to enhance the user's orientation and safety by going beyond the tactile feedback provided by the traditional white cane, digitally detecting and converting visual cues.

The smart cane designed in this study has the most significant advantage of being very low-cost compared to other cane designs. In the literature, there are many cane designs with high-cost additional features, but access to these is difficult due to their cost. In the cane design of this study, cost-performance has been prioritized. Another advantageous aspect is that energy consumption will be low because no additional equipment has been added. Additionally, the maintenance and repair costs will be lower.

The implementation of such studies is important for the integration of individuals with disabilities into society and for their ability to live independently without support. It is important to diversify designs according to individuals' different disability conditions and to address their needs.

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Authors' Contributions

In this study, all tasks such as conceptual design, data collection, analysis, writing, and interpretation were carried out by Mustafa AKSU.

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Conflict of Interest

There is no conflict of interest among the authors.

Data Availability

The data obtained in this study can be provided by the corresponding author upon request.