PathGuide SpatialScan Cane.

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Abstract:

The PathGuide SpatialScan cane is an innovative solution specifically designed to address the navigation and mobility challenges individuals with visual impairments face in indoor environments. By leveraging spatial scanning technologies, artificial intelligence, and motion sensing, this project transforms the traditional cane from a simple tool into a highly sophisticated navigational device. It acts as a bridge, closing the gap between traditional obstacle detection and an intelligent, efficient indoor guidance system, providing precise, real-time directions to help navigate indoor home spaces safely and confidently.

Historically, spatial scanning technology was primarily used in interior design to map spaces and plan furniture layouts. Now, it serves as a "digital eye" for the visually impaired, helping them create a clear, vivid mental map of their surroundings. The project's methodology relies on 3D Spatial Mapping technology, in which a camera creates a digital map of the environment, which AI analyzes to provide accurate navigational instructions.

The system depends on a smart cane equipped with ultrasonic sensors and an Inertial Measurement Unit (IMU) to accurately track directions, angles, and movements. This cane is linked to a mobile application that scans the environment and creates a digital map, which the system analyzes to provide direct guidance through haptic vibrations in the cane's handle.

Technically, this system consists of two main components: the smart cane equipped with obstacle detection sensors and a vibration motor, and the mobile application that performs environmental scanning and data storage. When a user issues a

command, the app compares the immediate environment with the stored map to determine the exact location. This is followed by a three-stage operational workflow: beginning with scanning the environment, then recognizing the space and confirming directions, and finally, the guidance phase via vibrations to help the user stay on the correct path or correct any deviation.

The true innovation of this project lies in the radical shift from passive obstacle alert systems that merely effective guidance systems. The cane does not just detect obstacles; it understands the environment and provides immediate directions, similar to indoor navigation systems. This aims to empower personal independence, enhance physical activity, and reduce health risks resulting from accessibility difficulties. In line with Saudi Vision 2030, the project contributes to expanding into other inclusive smart indoor spaces that enhance accessibility for all. Ultimately, the PathGuide SpatialScan cane represents a qualitative leap in technological innovation and human-centered design, granting individuals greater independence, confidence, and a better quality of life.

1. Introduction

In the modern era, technology has become a vital tool for improving the lives of individuals with disabilities, significantly contributing to the provision of effective solutions to the challenges they face. Among these challenges, visual impairment stands out as one of the major issues affecting millions of people worldwide. Vision is one of the essential senses we rely on to interact with our surroundingsWhen . this ability is affected, individuals are forced to rely on other means and tools for navigation and interaction with the environment.

Visual impairment greatly impacts daily life, leading to challenges such as difficulty in navigation, social isolation, and psychological distress.

Over the years, significant developments have been witnessed in the design of assistive devices, with continuous innovation focusing primarily on outdoor environments or isolated obstacle detection. Many current innovations and existing devices have successfully employed ultrasonic sensors and smart cameras to identify objects and barriers in front of the user, providing auditory or vibrating alerts to prevent collisions. However, these innovations often stop at the boundary of" detection "without offering any form of active guidance or navigational orientation. Even the most advanced systems are often designed for open spaces, leaving a critical gap for the specific needs of indoor mobility.

The fundamental gap in current innovations is that most solutions provide only a" safety net "rather than a functional" roadmap ". While a user might be alerted to a wall or a chair, these alerts are insufficient because they don't provide the directional context needed to navigate. To solve this, we can look at current Spatial Scanning technologies, which are highly advanced and widely used for professional furniture scanning and detailed interior mapping to create" digital twins

Although these tools have mastered the art of documenting every inch of a room's dimensions, they have been strictly limited to design purposes and haven't been utilized to guide blind people. This lack of spatial guidance means that even with a smart device, a visually impaired person remains trapped in a cycle of detecting obstacles without knowing their actual path, leaving them dependent on others for directional instructions inside their own homes or specific buildings.

To address this, the PathGuide SpatialScan Cane aims to develop an innovative, integrated system that repurposes this scanning technology to shift the focus from simple obstacle avoidance to intelligent indoor orientation. By combining advanced Artificial Intelligence, motion sensing, and computer vision, this project introduces a system that doesn't just" see "obstacles, but" understands " the environment. It matches live surroundings with a pre-mapped visual database to provide precise instructions. Furthermore, the system empowers the user through a sophisticated feedback mechanism that distinguishes between immediate physical dangers and directional path corrections. By bridging the gap between sensing and guidance, the PathGuide SpatialScan Cane transforms the navigation process into a confident, goal-oriented experience, granting users the autonomy to move freely and purposefully within any indoor space

2. Literature Review

Mobility and independent navigation represent significant challenges for individuals with visual impairments. As a result, orientation and mobility (O&M) training and assistive mobility devices have become central elements in rehabilitation programs for blind and visually impaired individuals. The white cane, in particular, has been widely recognized as the most common and practical mobility aid. Researchers have examined its effectiveness, social implications, training methodologies, and the potential for integrating modern technologies to enhance its functionality.

The white cane is among the oldest and most widely used assistive devices for individuals with visual impairment. Its main purpose is to enable users to detect obstacles, changes in ground surfaces, and environmental features through tactile feedback. By extending the sense of touch beyond the body, the cane allows individuals to safely explore their environment before proceeding. The white cane plays a critical role in enhancing independent mobility and enabling visually impaired individuals to interact more confidently with their surroundings. The cane functions not only as a mobility aid but also as a social indicator, signaling to others that the user has a visual impairment and potentially encouraging assistance and community awareness.

Effective use of the white cane is closely associated with orientation and mobility training. O&M training programs instruct visually impaired individuals in interpreting environmental cues, navigating unfamiliar areas, and utilizing mobility aids efficiently. Such training significantly enhances independence by improving spatial awareness and navigation skills. Structured mobility training programs promote greater participation in social and community activities by increasing individuals' confidence in moving through their environments.

Several techniques have been developed to maximize the effectiveness of the white cane in practical use. The “two-point touch technique,” in which the user moves the cane from side to side to detect obstacles and changes in surface conditions, is among the most widely adopted methods. This approach enables individuals to identify potential hazards before advancing. Such techniques are fundamental to safe travel for individuals with visual impairment, as they provide essential information about terrain, obstacles, and spatial layout through tactile feedback. In addition to its practical mobility benefits, the white cane contributes

significantly to the psychological and social well-being of individuals with visual impairment. Consistent use of the white cane is associated with improved social adjustment and increased independence. Regular cane users often demonstrate greater confidence when navigating public spaces and interacting with others. This enhanced independence frequently leads to better societal integration and an improved overall quality of life.

Despite its numerous advantages, the traditional white cane has notable limitations. Conventional canes primarily detect obstacles at ground level or within a short range of the user. They may not identify hazards above waist level, such as hanging objects, branches, or signboards. This limitation can create safety risks, especially in crowded or unfamiliar environments. Furthermore, traditional canes do not convey information about distant obstacles or navigation directions, making travel in complex environments more challenging.

To overcome these limitations, researchers and engineers have focused on developing smart or electronic white canes that incorporate modern technologies. These advanced devices extend the capabilities of traditional canes by integrating sensors and feedback systems. For example, some devices utilize LiDAR technology to detect obstacles at various heights and distances. Upon detecting obstacles, the cane delivers haptic feedback through vibration, enabling users to respond promptly and adjust their movement.

Experimental results indicate that this technology significantly improves obstacle detection and enhances mobility performance relative to conventional canes.

Many smart cane systems also use ultrasonic sensors to detect objects and provide alerts via vibration or sound.

Integrating electronic sensors into the cane can significantly enhance users' environmental awareness and safety during travel. Recent research has also explored integrating navigation systems, such as GPS and smartphone connectivity, into smart cane designs. These systems provide users with route guidance and location information, facilitating independent travel in unfamiliar environments. Such technological advancements represent significant progress in assistive mobility devices for individuals with visual impairment.

User acceptance of mobility aids is another important aspect addressed in the literature. Although many visually impaired individuals recognize the benefits of the white cane, some initially resist its use due to social stigma or concerns about being perceived as disabled. Social attitudes and cultural perceptions influence individuals' willingness to adopt the white cane. Consequently, education and awareness programs are essential to promote acceptance and encourage the use of mobility aids that enhance safety and independence.

Many studies demonstrate that the white cane remains an essential mobility tool for individuals with visual impairments, offering a simple, reliable, and cost-effective means of navigation. However, integrating modern technologies presents significant opportunities to address the limitations of traditional canes and further enhance their functionality. Technological advancements, including ultrasonic sensors, depth sensing units, artificial intelligence, and GPS navigation,

have the potential to transform the traditional white cane into a sophisticated assistive device that provides real-time environmental information. These innovations can improve obstacle detection, enhance navigation accuracy, and increase the safety and independence of individuals with visual impairment

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The continued development of smart cane technologies represents a critical direction for future research and innovation in assistive mobility systems.

By combining the reliability of the traditional white cane with modern technological capabilities, researchers can develop more effective mobility solutions that significantly improve the quality of life for individuals with visual impairment.

3. Methodology

The core of this project relies on Spatial Mapping. The system uses the camera to create a comprehensive 3D digital twin of the environment (as shown in the spatial scanning of rooms). This digital map serves as the foundation for the AI to determine precise paths, allowing the system to locate the user within this spatial context and send accurate navigation commands to the smart cane. This methodology aims to develop a technical framework that integrates hardware sensing with mobile-based Artificial Intelligence to facilitate safe indoor navigation.

3.1 System Design

The proposed system will consist of two main units: the Physical Sensing Unit (The Smart Cane) and the Intelligent Processing Unit (The Mobile Application). To ensure a seamless wireless connection, the two units will communicate via a Bluetooth module. Furthermore, the entire hardware system will be powered by an integrated battery embedded within the cane's handle to ensure portability.

3.1.1 The Smart Cane Components

The cane will be integrated with an Arduino microcontroller to serve as the central processing unit. To ensure safe and directed navigation, the following sensing technologies will be explored:

- Obstacle Detection: An Ultrasonic sensor will be utilized to measure distances and detect physical barriers in real-time.
- Orientation Tracking: An Inertial Measurement Unit (IMU) will be incorporated to monitor the user's movement and detect changes in direction.

- Feedback Mechanism: A vibration motor will be embedded in the handle to provide tactile alerts, ensuring a non-intrusive way to communicate with the user.

3.1.2 Mobile Application & AI Processing

The smartphone application acts as the central controller by linking the Camera to the Artificial Intelligence (AI). The system allows the user to perform a 3D/Panoramic scan of the rooms, capturing the entire environment as a single spatial map. The AI then recognizes the image and its location on this map and stores these visual features in memory for future use. The mechanism is as follows:

1. Scanning and Processing: The camera performs a wide-angle scan of the room and sends a comprehensive data feed to the Image Classification Model in the app.
2. Recognition and Spatial Storage: The AI instantly analyzes the features of the entire scanned area to identify locations, then saves this spatial map in the Local Memory as a reference.
3. Linking and Control: Once the live view matches any part of the stored spatial map, the application issues a command via Bluetooth to the Arduino in the cane.
4. Initiating Movement & Voice Guidance: When the user issues a voice command for a destination, the AI matches the live feed with the stored 3D map to determine the user's high-precision location. Upon confirmation, the app sends real-time signals to the cane to trigger the vibration motor if a deviation occurs, guiding the user accurately until a voice notification confirms arrival.

3.2 The Navigation Procedure

The core of this project will follow a three-phase operational workflow:

- Phase One: Environment Mapping: A sighted assistant uses the application to perform a comprehensive scan of various rooms, creating a visual reference database stored locally.
- Phase Two: Intelligent Room Recognition: When the user issues a voice command, the system activates the camera and compares the live surroundings with the stored spatial map.
- Phase Three: Guidance and Feedback Strategy:
  - In the Correct Path: The system remains silent as long as the user is moving correctly toward the target.
  - is triggered immediately.
  - Upon Arrival: The application provides a voice notification to confirm arrival.

3.3 The System Testing and Validation

The project will test the accuracy of the sensors in detecting various objects and audit the firmware code for efficient real-time data processing. It will also measure the success rate of the AI model in recognizing rooms under different lighting conditions and verify the Bluetooth communication protocols between the app and the Arduino to ensure minimal latency in command delivery. Finally, it will evaluate the efficiency of the vibration alerts in guiding the user safely".

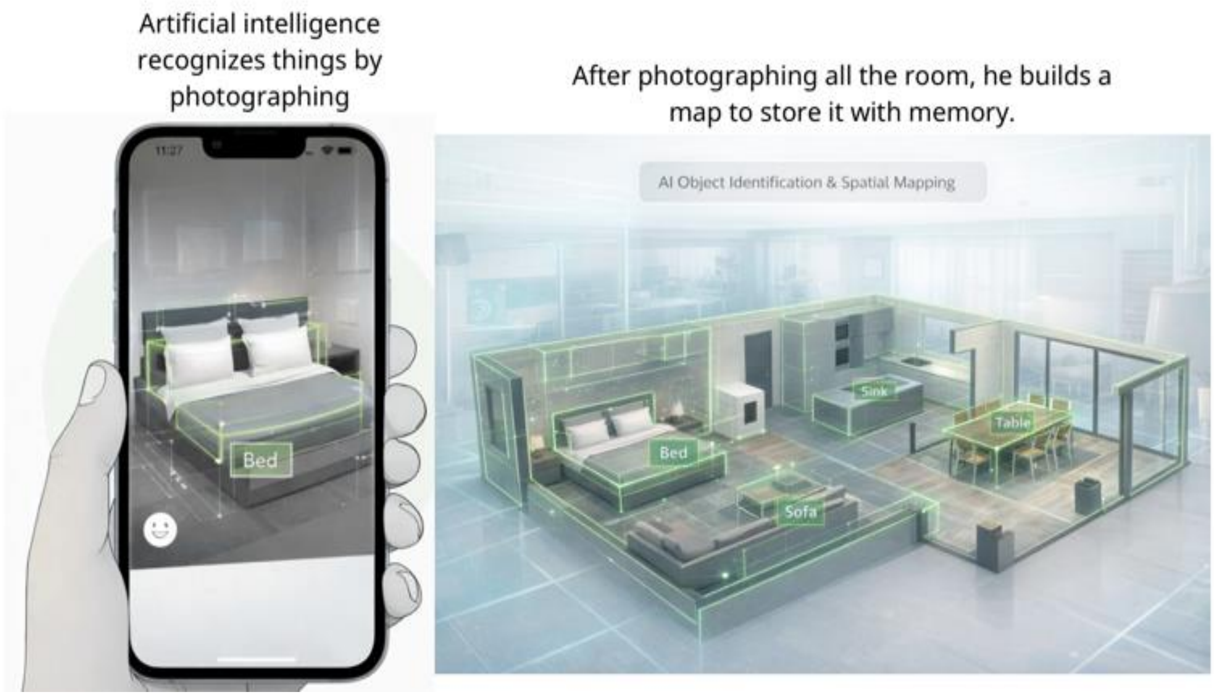

Figure 1 image for Initial concept of innovation and how the application works

4. Expected Impact

- Achieving Personal Autonomy & Quality of Life: Empowering users to rely entirely on themselves for daily tasks, turning routine movements—like reaching the kitchen or restroom—into spontaneous actions, making the home environment digitally accessible and stress-free.
- Prevention of Physical Health Issues: The system contributes directly to the user's health by facilitating independent access to restrooms, helping prevent urinary tract infections and bladder issues caused by delayed movement.
- Encourages physical activity, which improves cardiovascular health and blood circulation.
- Improving Physical Activity: Breaking the" stationary lifestyle "often forced upon blind people due to the fear of collisions. This innovation motivates users to walk and stay active indoors, improving their overall physical fitness.
- Psychological Empowerment: Replacing the feeling of helplessness with a sense of control and confidence. This reduces psychological distress and frustration caused by getting lost, leading to higher morale and mental well-being.
- Bridging the Technical Gap: Repurposing Spatial Scanning technology—originally used for furniture and interior design—into a vital navigation tool that serves human independence and accessibility.
- Creating a Roadmap for the Future: Setting the foundation for smart indoor navigation in hospitals, airports, and malls, making the world more inclusive and accessible for everyone.

5. Conclusion

The PathGuide SpatialScan Cane represents a pioneering model in harnessing technology to serve humanity. It does not merely offer a traditional tool for obstacle avoidance but rather grants the visually impaired a" Digital Insight "that perceives spatial dimensions and creates a safe, independent roadmap. By repurposing Spatial Scanning technology—which was long confined to the design and furniture sectors—this research proves that true innovation lies in bridging technical gaps and transforming them into solutions that touch the quality of human life. This innovation represents a qualitative leap that transcends being merely a technical project; it clearly aligns with the goals of Saudi Vision 2030 to empower individuals with disabilities, foster inclusive smart cities, and raise quality-of-life indicators, based on the belief that individual empowerment is the cornerstone of nation-building. Ultimately, this innovation is not just a smart cane; it is a promise of a future in which technology grants the visually impaired the حright to move freely and independently.