CCNY Smart Cane

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Abstract— **This paper presents SmartCane - the CCNY Smart Cane system, a robotic white cane and mobile device navigation software for visually impaired people. The system includes software for Google Tango devices that utilizes simultaneous localization and mapping (SLAM) to plan a path and guide a visually impaired user to waypoints within indoor environments. A control panel is mounted on the standard white cane that enables visually impaired users to communicate with the navigation software and is additionally used to provide navigation instructions via haptic feedback. Based on the motion-tracking and localization capabilities of the Google Tango, the SmartCane is able to generate a safe path to the destination waypoint indicated by the user.**

Keywords— Indoor assistive navigation, SLAM, Tango device, blind and visual impairment

I. INTRODUCTION

According to the World Health Organization (WHO), there are 285 million blind and visually impaired (BVI) individuals worldwide, of which 39 million are blind [1]. In the USA alone there are 10 million visually impaired. Due to their visual impairments, these people face severe challenges in wayfinding and navigation, and particularly in unfamiliar indoor environments. Although most visually impaired people are hardworking individuals, they are limited to specific positions, or are unable to maintain employment. Because of the challenges they face in navigation, BVI individuals are limited to working in jobs that are mostly stationary. For example, navigating independently in complex office buildings, such as multi-floor offices and university campuses, is a daunting task for the visually impaired. As a result, this prevents BVI individuals from seeking employment in larger, complex offices/buildings. According to statistics published by the National Federation of the Blind, only 40.2% of the visually impaired population in the United States are employed, and 90% of the world's visually impaired, live in low-income settings. The ability of visually impaired people to comfortably navigate in indoor environments will enhance employment opportunities, and foster self-sufficiency [2].

In this paper, we propose CCNY SmartCane - a Smart Cane system developed at the City College of New York (CCNY), a robotic white cane and mobile device software that allows for visually impaired people to navigate within an indoor environment. As a summary, we have the following contributions:

1) We implement indoor navigation software for Google Tango devices.

2) We design the SmartCane, an enhanced white cane, capable of communicating with the Tango software and guiding a BVI user to a destination.

3) We demonstrate the effectiveness of the SmartCane system in aiding visually impaired users in navigating indoors.

This paper is organized as follows. In Section II, recent systems for indoor navigation for the visually impaired are reviewed. Section III provides an overview of the proposed SmartCane system. Section IV describes the SmartCane designs (including the navigation framework and the control/feedback interfaces), and Section V explains the navigation software (including path planning and human-machine interface). Finally, Sections VI and VII present conclusions and discuss directions of future work.

II. RELATED WORK

A. SLAM Based Navigation

Due to advancements in computer vision, a lot of interesting work has been done in utilizing SLAM – Simultaneous Localization and Mapping - to create indoor navigation systems to aid the visually impaired. SLAM is the process of building a map of an unknown environment while localizing the device/robot within the map [3]. In [4] Li, et al propose ISANA - context aware indoor assistive navigation mobile device software implemented on the Google Tango for visually impaired people. The proposed prototype is demonstrated in effectively performing indoor assistive navigation.

B. *Robotic Canes*

There exists a lot of interesting work related to the design of a smart cane. Central Michigan University has created a smart cane, whose goal was to help a BVI user safely navigate through a pre-designed location with cues and obstacle detection [5]. Specifically, the system consisted of radio-frequency identification (RFID) sensors for navigation cues, and ultrasonic sensors for obstacle detection. The RFID sensor consists of four parts: reader, antenna, computer system, and transponder or tag. The tags hold the location information, and were installed in predefined locations throughout the campus. The tags start to communicate the location information to the reader when it gets within 3 meters of range. The weakness with this smart cane design was the limited range of the RFID sensors. The tags are to be installed in pre-designed locations, which can be costly as the size of the system is too big.

In Borenstein's design [6], the GuideCane was an enhanced white cane equipped with 10 ultrasonic sensors and a servomotor, which steered the wheel left or right to avoid the obstacles detected. The GuideCane is far heavier than an ordinary white cane and is non portable as it cannot be folded.

The University of Arkansas at Little Rock, USA proposed a Co-Robotic Cane for assisting the blind in navigation [7]. The Co-Robotic Cane was a white cane equipped with a 3D camera for pose estimation and obstacle detection, and was able to recognize indoor structures. The cane was a 'co-robot'-able to detect human intent and collaborate to perform the navigation task to avoid obstacles, instead of leading the user.

The problem with this and many other smart canes is that there is no centralized platform for both, detecting obstacles and navigation. Portability was another issue with their designs of a smart cane. We plan on addressing these issues and designing a product that is affordable and lightweight that will assist a BVI user in navigating through an indoor environment.

III. SYSTEM OVERVIEW

Fig. 1 illustrates the system architecture of the proposed SmartCane system on a user. The system consists of two major components: a Google Tango enabled mobile device (phone or tablet) mounting on the user's chest, and a robotic white cane in his/her hand. The mobile device is used to recognize an indoor location and provide navigation guidance via audio to the user to a specific destination. The mobile device will also communicate with the robotic white cane via Bluetooth to steer a visually impaired user accordingly.

Figure 1. SmartCane placed on user

A. *Google Tango*

The Lenovo Phab2, a phone/tablet hybrid that is a Google Tango enabled device, is utilized to implement the SmartCane software. The device integrates a motion tracking camera and an infrared (IR) 3D depth sensor, which allows the device to perform scanning and to track its motion in 3D [8]. Due to all these sensors embedded in the device, a Google Tango enabled mobile device is able to perceive information about its surrounding environment and use computer vision to understand its relative position in that environment, without the use of GPS or other external signals. Google Tango achieves this using 3 of its major features: motion tracking, area learning and depth perception. All these features are included in a 175 x 89.5 x 9.6 mm device weighing only 225 grams.

The *motion tracking* feature allows the device to understand its motion and orientation as it moves through a 3D environment in real-time. A Google Tango device uses a wide-angle lens camera, gyroscope, and accelerometers to achieve this feat. Additionally, Tango uses visual-inertia odometry (VIO), to determine a change in position through various images, while supplemented with inertial motion sensors for greater accuracy in measuring acceleration and rotation. The Tango APIs provide data on the device's position and orientation in the form of a device's pose in real time. The pose consists of two main parts, a vector for the translation of the device in meters, and a quaternion for rotation.

However, motion tracking alone does not allow for the device to fully understand where it is in the area around it. In other words, the device is able to see where it goes, but does not remember the visual features that define its location. The *area learning* feature gives the Tango device the ability to remember key visual features of a physical space - such as doors, and rooms, so that it can recognize that area again later. Area learning is based on the well known SLAM approach. Area learning is accomplished by initially recording and saving an Area Description File (ADF), which stores a mathematical description of the visual features in an indoor environment. Just as if a person would remember and know where he/she has been to before, the Tango device will do the same using the ADF.

With the addition of area learning, the device's pose can be referenced to a base frame. This feature will be utilized to plan a route to predetermined locations within that environment for the user by using the origin of the recorded ADF as the base.

Finally, *depth perception* gives the ability to find objects from a distance by utilizing the IR sensors on the device to produce point clouds. The application that is created, utilizes these 3 core features of the Google Tango to plan a route for a BVI user to predetermined destinations within an indoor environment, while avoiding any objects that happen to be in the way.

B. The SmartCane

The SmartCane unit can be easily mounted on a standard white cane, and is comprised of a microcontroller, Bluetooth Low Energy (BLE) chip, an IMU (inertial measurement unit), two vibration motors indicating the turning direction, and a joystick with two buttons mounted on a custom PCB board as the user input device (Fig.2). The proposed hardware will allow the SmartCane to last approximately 17 hours without the need to charge the batteries at full load. In a real-world scenario, the SmartCane will not be in use continuously for 24 hours, therefore, the SmartCane system will be able to last for an entire day on a single charge.

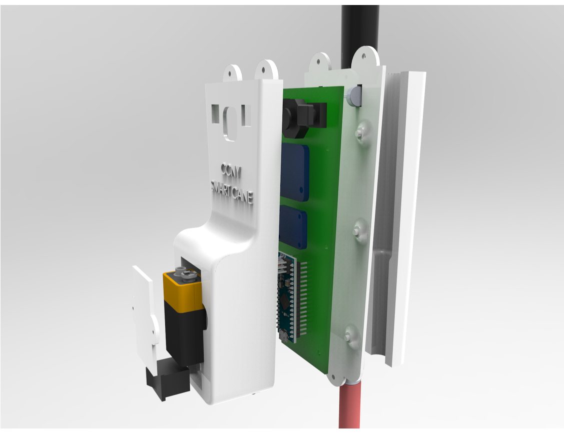

Figure 2. SmartCane control panel

C. Functionality

The SmartCane is a system designed to aid visually impaired people in navigating in unfamiliar or complex indoor environments, such as multi-floor office buildings or university campuses. The core functionalities of the SmartCane system include:

1) *Indoor mapping.* The ability to build a map of an unknown environment while at the same time localizing the mobile device mounted on the user within that map. By utilizing the built-in SLAM capability of the Google Tango device, the navigation software designed can create a map of an indoor environment overlaid with information about waypoints (such as rooms, elevators, etc.) and track the user's location and orientation within that map in real-time.

2) *Path planning.* The ability for the navigation software to plan a path from the location of the user to any waypoint within an indoor environment.

3) *Control panel.* The physical interface on the control panel mounted on the SmartCane can be utilized by the user to scroll through available waypoints and select destination to be navigated to.

4) *Multimodal feedback.* The SmartCane system has the ability to guide the user to the selected waypoint by communicating the directions via audio and also by utilizing the vibration motors mounted on the control panel on the cane to indicate directions.

IV. SMARTCANE

A. Navigation Framework

In order to achieve real-time indoor navigation for visually impaired people, we implemented a navigation framework consisting of the following elements (Fig. 3):

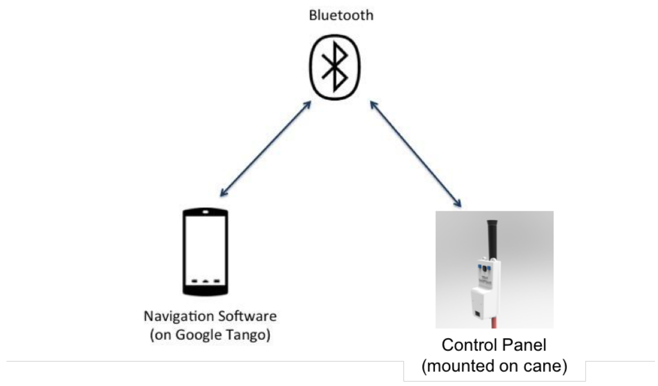

Figure 3. Diagram of Navigation Framework

(1) *Navigation software* is implemented on a Google Tango mobile device that utilizes SLAM to plan a path and guide a blind and visually impaired user to waypoints within

indoor environment.

(2) A physical *control panel* mounted on the white cane is used to track the orientation of cane relative to user and to convey navigation directions via vibration to user.

(3) Bluetooth handles all communication and data transfer between the navigation software on the mobile device and hardware components within the control panel mounted on the white cane.

The Google Tango Navigation software will communicate the turn angles via Bluetooth to the built-in microcontroller, and the microcontroller will process information and gather data from the IMU on the SmartCane to determine the orientation it needs to turn. The user can steer himself in the correct direction based on the vibration motor intensity until the destination is reached.

B. Control/Feedback Interface

Destination selection. The SmartCane will support two methods for allowing the user to select a destination. The user will be presented through audio the available destinations within an indoor environment:

1) The user may use speech to specify the desired destination.

2) The user may use the scrolling button on the cane handle to select the destination.

Guidance modes. The SmartCane will support multiple modes for providing navigation instructions to the user:

1) Audio - the user will be given detailed navigation directions through audio.

2) Haptic - The two vibration motors on the SmartCane handle will be used to indicate to rotate right or left, and their intensity will decrease as the user steering to the correct orientation. Vibrations will stop when the correct rotation is reached.

V. NAVIGATION SOFTWARE

A. Path Planning

Path planning is an essential feature of a navigation application. In order to begin plotting a path of coordinates from a starting location to a goal location, a graph is necessary. However, the ADF provided by the Google Tango, is only useful for localizing, but not mapping. Since ADFs contain descriptions of recorded images in a compressed format, the file internals were not easily accessible and do not contain associated pose data regarding translation information.

To overcome this obstacle, translation data needs to be recorded as walkable nodes containing coordinate information. The process of collecting the coordinates begin along with ADF recording. As the motion tracking records translation data, each data point is recorded with respect to the rounding granularity. These nodes are saved in a set data structure during the recording. Once ADF recording is finished, the coordinates are stored in a JSON file, along with saved destinations, for later use by the BVI user.

A granularity scale of 0.5 meters was chosen in consideration of the measurement unit of meters used by the pose translation. This number was a trade-off between precision, and ease of use for recording purposes. The nodes for pathfinding need to contain coordinates that wouldn't be too large or too small from the actual real world data. Plus, the recording of the coordinates should be reasonable, such that it would contain efficient information about a hallway without the need of rasterizing in a rigorous manner when recording. In Fig. 4, the node is a point within a 0.5m x 0.5m tile.

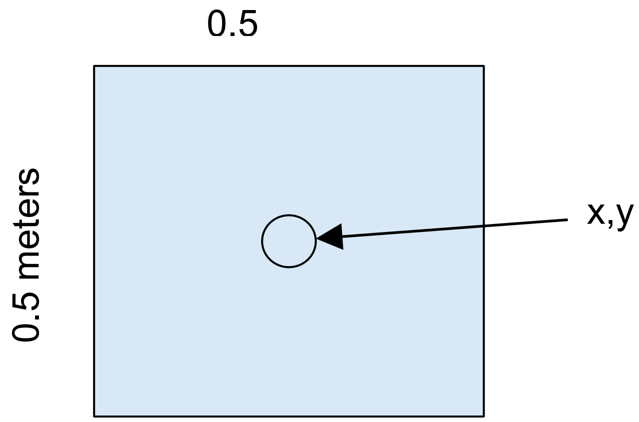

Figure 4. Depiction of coordinate measurement

When the user is ready to navigate, a start and a goal is defined for the path finding algorithm by getting the current location of the user relative to the ADF, and the chosen destination. These two components, along with the coordinate set retrieved from JSON will be the main building blocks for our chosen path finding algorithm, the *A* search algorithm*.

In our implementation of A* [9], we are using an admissible heuristic supported by Manhattan distance. A closed list and open priority queue are used to keep track of nodes visited. Initially the open list containing the start node is removed and placed into the closed list. Each neighbor of the current node that is not in the closed list is placed in the open list with its travel cost, distance to the goal, and previous node updated. However, if the neighbor node is already in the open list, then cost and previous node is updated only if the new travel cost is less than what it was previously. This process continues until the open list is either empty, indicating no paths, or the current node is the goal, indicating a path has been found.

After retrieving the list of coordinates, the path is then passed into an iterative *end-point fit algorithm* also known as Douglas-Peucker algorithm [10]. The algorithm begins by drawing a line between the start and end points. Searching through the list of points between the start and end, a point with the maximum perpendicular distance from the line is chosen. If the furthest point is greater than a defined threshold, □, then the furthest point is kept, and the algorithm recursively divides the line with calls to the start and furthest point, and the furthest point and end point. Otherwise, the start and end points are kept. Fig. 5 shows the automatic waypoint selections on a recorded map through the end-point fit algorithm.

Finally, the squashed path is used to calculate the rotation necessary prior to walking to the next waypoint using arctan. Given the new path and list of rotations, the user then receives vibration indicating the direction and magnitude of the angle in rotation before being told to walk straight by audio. Once the user has reached a waypoint, the process repeats, until the user has finally reached his/her destination.

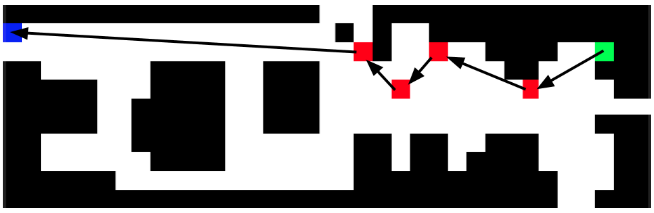

Figure 5. Map recorded containing waypoints of the path from green to blue using a 0.75-meter threshold for end-point fitting

B. *Human-Machine Interface*

The SmartCane system is designed with a blind and visually impaired user in mind. The following interface is designed to make it comfortable and simple for a visually impaired user to use when choosing a waypoint to be navigated to. The joystick and buttons on the control panel of the cane allow a user to seamlessly communicate with the SmartCane Navigation App. Using the joystick, a user can scroll through the available waypoints and *text-to-speech (TTS)* is utilized by the SmartCane Navigation App to inform user of each waypoint. By clicking down on the joystick the user is able to select the desired waypoint to be navigated. The user can use a separate button on the control panel to cancel that choice.

In order to guide a user to the selected waypoint, two modalities are utilized by the SmartCane system:

1) Text-to-speech is used to provide directions via audio.

2) The vibration motors on the control panel mounted on the cane are utilized to provide directions via vibrations corresponding to the magnitude and direction of rotation.

The SmartCane system is designed so that the enhancements added to the cane do not interfere with the original functionality of the standard white cane. The user is still able to use the cane as a tool for detecting obstacles via contact.

VI. System Evaluation & evaluation

In order to gauge the effectiveness of the SmartCane system, pilot tests were conducted with sighted users with their eye closed in various indoor environments (university campus, hotel, office building). The SmartCane system was able to successfully guide a sighted user to the selected destination.

Future evaluations will be performed intending to measure the accuracy of the mapping coordinates, and the efficiency of the paths that the user takes to get to a destination. Future experiments are also to be conducted with blind and visually impaired users in order to evaluate their overall experience of the system, and ease of use of the control panel. Improvements and changes, which include modifying the chosen threshold □ from the Douglas-Peucker algorithm, or choosing a different line fitting algorithm entirely, should be made in response to the evaluations of the paths created. Further research is required when weighing one path finding technique and line fitting algorithm over another.

VII. Conclusion

In this paper we present the SmartCane system, a robotic white cane and mobile device software for aiding blind and visually impaired people in navigating indoors. The software on the mobile device is capable of communicating with the robotic white cane to plan a route and navigate a BVI user to a destination within an indoor environment. Further improvements can be made on the accuracy of the position and rotation of the cane. Currently the cane's position is not being referenced within the coordinate system from the Google Tango camera. As of now, the IMU's rotation is an uncalibrated solution, which we are solving by telling the user to put the cane in front of them before beginning the rotation. Instead, we can consider using Google Tango's image processing to track the smart cane in real time. By doing so, we can better assist the user by providing more accurate turning indication. A rotational wheel can be added to the tip of the SmartCane to further assist steer user in the right direction. We also plan to include a functionality that allows the maps created by the SmartCane software to be continuously updated and improved every time the software is used for navigating. This allows for more detailed maps and better path finding, as the first-time recording may not always cover all of the coordinates that are walkable.

Acknowledgment

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