Autonomous Navigation using Robot Operating System on Raspberry Pi-based Intelligent Walking Stick

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***Abstract-* The mobility of visually impaired individuals has always been a concern of society as it is a challenge for them to go from one place to another especially if they are not yet familiar with the area they move around. The LiDAR-based Technology for Mapping and Object Detection, integrated into a Raspberry Pi-based Intelligent Walking Stick, significantly enhances the mobility and independence of visually impaired individuals. By utilizing the Simultaneous Localization and Mapping (SLAM) algorithm, the device is capable of mapping its surroundings and accurately localizing itself within these maps. This is particularly beneficial for users at the Philippine National School for the Blind (PNSB). The walking stick's system allows visually impaired users to interact with it through voice input, enabling them to provide their destination and receive navigation information for effective guidance. Additionally, the integration of obstacle detection and avoidance feature ensures the user's safety while navigating. This innovative device is lightweight, portable, and highly accurate, making it an accessible and practical solution for enhancing the independence of visually impaired individuals.**

Keywords----- LiDAR-based technology, simultaneous localization and mapping (SLAM), visually impaired, object detection, mobility aid (keywords)

I. INTRODUCTION

An intelligent walking stick is a device designed to aid individuals with impairments or mobility challenges in navigating their surroundings safely and independently. By integrating advanced technologies like robotics along with the concept of assistive devices such as the intelligent walking stick, these modern walking sticks are capable of autonomously sensing and responding to the environment, which offers users enhanced mobility and confidence.

The Robot Operating System (ROS) is free and open-source software that defines the components, interfaces, and tools for building advanced robots [1]. It is a middleware that allows different components of a robot system to communicate and exchange data [1]. This middleware is very suitable for autonomous navigation using the Robot Operating System's navigation stack.

The ROS navigation stack is a collection of packages that provide the functionality for navigating mobile robots autonomously [2]. This includes mainly four components, such as the odometry, which estimates the robot's position and orientation based on the sensor data such as wheel encoders and IMU sensors; the localization, which uses the map and the sensor data to correct the robot's pose; the map server, which provides a static map of the environment; and lastly, the path planning, which gives and executes the trajectory path for the device to reach a goal [2].

Considering the compatibility of ROS, Raspberry Pi can run ROS on either Linux or Raspbian OS, either as a standalone system or as part of a network of ROS nodes for a headless setup. Two critical aspects of handheld intelligent blind sticks are the accuracy and reliable navigation. Traditional navigation methods often rely solely on tactile feedback and auditory cues, which may not provide sufficient information about the surrounding environment. Considering this, integrating sensor fusion techniques, such as combining data from wheel encoders and Inertial Measurement Unit (IMU) sensors through Extended Kalman Filtering (EKF) offers a viable solution for this [3]. Sensor fusion is a useful technique to combine both types of positioning sensors to provide high accuracy estimates at high update rates [3].

BACKGROUND OF THE STUDY

Traditional walking aids provide basic support but lack the ability to navigate complex environments autonomously, limiting users' independence. By using ROS and Raspberry Pi, this study aims to develop a solution that integrates robotics and assistive technology. The primary objective is to design and implement a robust autonomous navigation system, encompassing real-time perception, mapping, localization, path planning, and obstacle avoidance. The project involves a combination of hardware development, software implementation, testing, and user evaluation phases. The device mainly utilized the 2D navigation stack of the Robot Operating System (ROS), which takes in information from odometry, sensor streams, and a goal pose, and outputs safe velocity commands that are sent to a mobile base, which is the device.

A ROS system is mainly comprised of several independent nodes, where each communicates with the other nodes using a publish/subscribe messaging model. ROS Master allows all other ROS software processes to find and talk to each other [4]. ROS node is a process that performs computation, which is an executable program running inside your application. All nodes must register with the master during startup and throughout the operation.

Wheel encoders installed on the mobile robot's wheels can evaluate the mobile robot's position and heading angle while it is traveling. The terminology for this technique is odometry [5]. However, they may suffer from drifts and errors over time, especially in dynamic environments. An IMU works by sensing motion including the type, rate, and direction of that motion using a combination of accelerometers and gyroscopes. [6]. This may suffer from integration drift, particularly in long-term navigation scenarios. By fusing data from encoders and IMU sensor using EKF, it is possible to synergistically leverage the strengths of both sensor types while compensating for their individual limitations. EKF algorithm enables complementary compensation for each sensor’s limitations, and the resulting performance of the sensor system is better than individual sensors.

The dynamics of the handheld smart blind stick system are nonlinear, as they involve complex interactions between the user's movement, environmental factors, and sensor measurements. The EKF simultaneously estimates a model of the environment (map) and the position of the robot based on odometric and exteroceptive sensor information [7]. By applying EKF for sensor data fusion in the handheld smart blind stick project, the navigation capabilities of the device are significantly enhanced. The accurate estimation of the user's state allows for precise obstacle detection, path planning, and navigation assistance, ultimately improving the mobility and independence of visually impaired individuals.

Odometry is a fundamental algorithm for computing robotic motion. It approximates the location of a robot, which can be obtained by repeatedly computing the distance moved and the change direction from the velocity of the wheels [7] and the output from an IMU sensor. It is also a form of localization where the robot must determine its position in the environment [8]. In odometry, we determine position by measuring the change from the robot’s known initial position, while localization refers to the determination of the position of a robot relative to the known positions of other elements, such as landmarks [8].

OBJECTIVES

This journal aims to develop an intelligent walking stick with auto navigation feature using a ROS (Robot Operating System) to:

- Develop a path planning algorithm using ROS that is specifically adapted to the mobility needs of the intelligent walking stick.
- Implement ROS odometry algorithms for precise localization and motion tracking.
- Develop enhanced navigation and obstacle detection using EKF.
- Minimize the effects of sensor noise and drift to the navigation from wheel encoders and IMU sensor using EKF.

The research aims to develop a path planning algorithm within the Robot Operating System (ROS) framework tailored to the specific mobility requirements of an intelligent walking stick. This involves designing and implementing an algorithm that can autonomously navigate through diverse environments while considering mobility constraints and environmental factors.

Additionally, the research aims to implement ROS odometry algorithms to achieve precise localization and motion tracking for the walking stick. By accurately estimating the walking stick's position and orientation in real- time, these algorithms aim to enhance its navigational capabilities, enabling it to maintain its position, track movement, and execute planned paths with improved accuracy and reliability.

EKF enhances obstacle detection and avoidance by integrating data from wheel encoders and IMU sensor with the user's state estimate. By fusing information about the user's position and orientation with obstacle location data, EKF enables the system to accurately estimate the user's proximity to obstacles and provide timely alerts or navigation guidance to avoid collisions. It improves navigation accuracy by integrating data from multiple sensors, such as encoders and IMU sensors, to refine the estimation of the user's state. By continuously updating the state estimate based on new sensor measurements and incorporating a dynamic model of the system, EKF ensures that the navigation system accurately reflects changes in the user's environment and movement.

EKF addresses sensor noise and drift by continuously updating the state estimate based on new sensor measurements. By incorporating a dynamic model of the system and probabilistic estimation techniques, EKF can account for uncertainties in sensor measurements and adaptively adjust the state estimate to minimize the impact of noise and drift.

II. RELATED LITERATURE

The study Software Architectures for Mobile Robots [9] delves into the ROS Navigation Stack, offering a comprehensive framework for planning and executing navigation tasks in mobile robots. This framework encompasses modules for localization, mapping, path planning, and obstacle avoidance, providing invaluable insights into the implementation of ROS-based navigation systems. In the project, which involves the development of an intelligent walking stick for visually impaired individuals, the principles outlined in the ROS Navigation Stack serve as foundational elements. By leveraging ROS for navigation, the project aims to incorporate robust localization, efficient path planning, and obstacle avoidance capabilities, ultimately enhancing the mobility and autonomy of user.

Post et. al (2017) presented that the uniformity of terrain and lack of distinct features pose significant challenges for navigation [10]. While the Hokuyo UTM30LX-EW laser scanner performs well indoors, its performance is inconsistent in sparse outdoor environments. RTAB-Map, initially evaluated for visual odometry and mapping, proved inadequate due to small errors in odometry estimation and the sparse, unchanging outdoor environment. The study emphasizes the need for a reliable 2-D obstacle map overlaid on a topographic elevation map for effective outdoor navigation in agricultural contexts. This study explains the challenges presented in mapping and navigation.

In study Localization and Navigation for Indoor Mobile Robot Based on ROS [11] modular mobile robot platform is designed, with the robot control system divided into two parts: the upper control system and the real-time control system. This division enhances system stability and reduces coupling between modules. The main sensors used for environmental perception are Lidar and RGB-D camera Kinect. The robot software system is developed using the distributed software framework of the Robot Operating System (ROS). The SLAM algorithm based on particle filter is employed to achieve Simultaneous Localization and Mapping (SLAM) in unknown environments. Experimental results demonstrate the system's capability to construct accurate maps of indoor environments and autonomously navigate based on these maps. The proposed approach offers advantages such as low cost, high performance, short development cycle, and easy expansion, making it a promising solution for indoor robotic navigation applications.
In study Simulating Human-Aware Autonomous Navigation Using ROS and Gazebo [12] service robots are increasingly being deployed in pedestrian-intensive environments like as healthcare and hospitality. To solve navigation issues in these environments, researchers created a human-aware autonomous navigation system. They used ROS for control and Python for algorithms to simulate scenarios such as passing, crossing, and overtaking people in Gazebo. Tests revealed that the robot safely avoided people walking at speeds ranging from 0.9 to 1.4 m/s, paused for crossing pedestrians, and successfully overtook individuals walking at speeds ranging from 0.5 to 0.7 m/s, accomplishing targets with less than 2% error.

III. METHODOLOGY

As the device has an auto navigation feature, the device uses algorithms that can build a map of a certain environment while simultaneously navigating within it and localizing the robot's position relative to the map. Also, the device utilizes different software tools that contribute to attaining the full functionality of the device such as in localization, path planning, and navigation.

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A. Software Design of the device

Most of the device's functionality is based on software, such as the Robot Operating System (ROS) and the various tools that the device used, some of which are represented in the figures below.

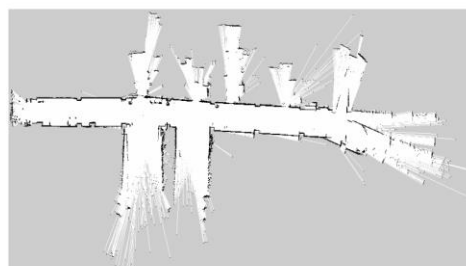

Fig. 1. Mapping of the Device using Hector SLAM

This tool primarily uses laser scan data with the use of LiDAR that can generate a 2D map of the specific environment while estimating the device's trajectory.

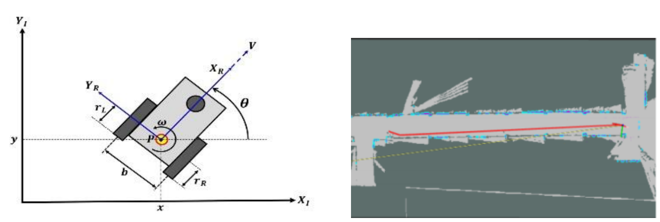

Fig. 2&3. Odometry & Localization in ROS

The odometry tool estimates the device's position using sensor data from the wheel encoders. The device used this tool when integrated with rviz (a ROS visualization tool) to display odometry data in real time. This enables the researchers to track how the device's estimated position changes as it moves with its environment. While the odometry estimates the device's position, in localization, it corrects this estimation by using external references or maps just like in the figure above. With these two, the device managed to navigate effectively in dynamic environments, avoiding obstacles and reaching destinations accurately.

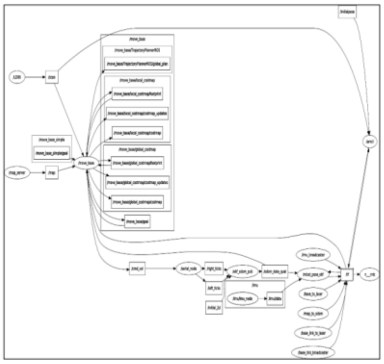

Fig. 4. RQt graph of the system

This tool visualizes the ROS system's computation graph. This tool consists of nodes and topics that exchange messages within the system. These nodes and topics are incorporated within the device itself. Multiple nodes in this ROS setup work together to enable autonomous robot navigation and localization. These nodes include the following:

- The LIDAR sensor node (/LD06) gathers environmental scan data published on /scan
- The IMU node (/imu/imu_node) provides orientation and motion data on /imu/data.
- Wheel encoder nodes (/left_ticks and /right_ticks) contribute odometry data crucial for tracking movement.
- AMCL subscribes to /initialpose for initial pose estimates and integrates sensor data to refine the robot's position.
- the Robot Pose EKF (/robot_pose_ekf) employs an Extended Kalman Filter to fuse odometry and IMU data, publishing the robot's pose on /tf for coordinate transformations.
- The Map Server (/map_server) serves the static environment map on /map, vital for path planning executed by /move_base, which subscribes to /map and /scan for navigation planning and publishes commands on /cmd_vel to control the robot's movement.
- Nodes like /serial_node handle hardware communication.
- n_rviz, depicting the robot's state, sensor data, and navigation goals visually for monitoring and debugging purposes.

Based on the previous research related with intelligent walking sticks for visually impaired people, there were a lot of lapses regarding the efficiency of the user's mobility. Many of these lapses come from the software part of the device. Some are focused only on mobility and feedback, and some are more on hardware iterations. But the proponents developed an intelligent walking stick that fulfilled these lapses using these tools shown above to develop an innovative solution to help visually impaired people to increase their mobility using the device such as obstacle detection, accurate localization, and auto navigation.

B. Functionality

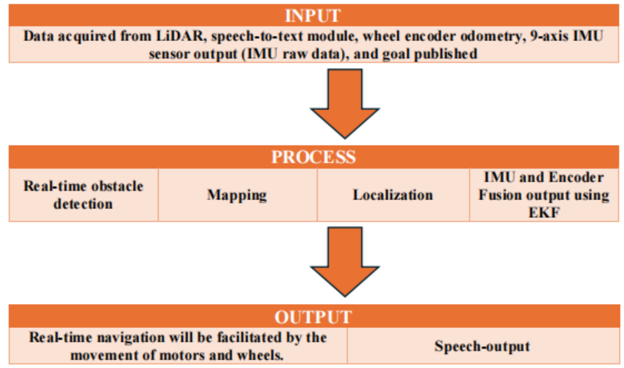

Fig. 5. IPO Model of the MATA System

The diagram above illustrates the sequential process of real-time navigation. Initially, data is collected from various sensors including LiDAR, a speech recognition module, wheel encoders for odometry, and a 9-axis IMU (Inertial Measurement Unit). The IMU's raw data undergoes processing and potentially integrates with odometry data using techniques such as an Extended Kalman Filter. This combined data serves two primary functions: constructing a map of the surroundings and determining the system's precise location within that map. Subsequently, the system utilizes this up-to-date location information to direct navigation by issuing commands to the motors and wheels. Additionally, the speech-to-text module enables voice commands or feedback to be incorporated into the system's operations.

Since the device is designed for real-time navigation, primarily aiming to guide users to their destinations. This is achieved by utilizing ROS's capabilities in mapping and localization. Mapping involves creating an environment map to facilitate navigation, while localization integrates sensor data, such as from the IMU processed with the EKF (Extended Kalman Filter), to estimate the device's position and orientation relative to a global or local reference frame. Throughout navigation, the device uses these sensors to detect and recognize obstacles in its surroundings. With the user's current location identified, the device's motors and wheels adjust automatically to facilitate navigation towards the desired destination.

IV. TESTING AND RESULTS

Fig. 6. Actual Testing of Device of a visually impaired individual

The actual testing of the device by a visually impaired individual. Starting from the rightmost part of the vicinity, the user was prompted to navigate through the clinic room of the PNSB Administration Building.

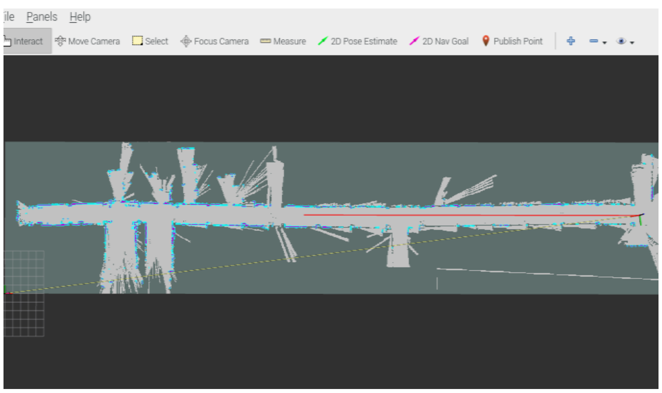

Fig. 7. Localization and Path Planning of Device for Actual Testing

The localization and path planned by the device were based on the current situation of the environment and the pre-determined map. The colored dots and lines represent the point cloud data, which is obtained from LiDAR LD06. This shows the environment around the robot and the user. The long red line represents the path planned by the device which is from the rightmost part of the vicinity going to the clinic room.

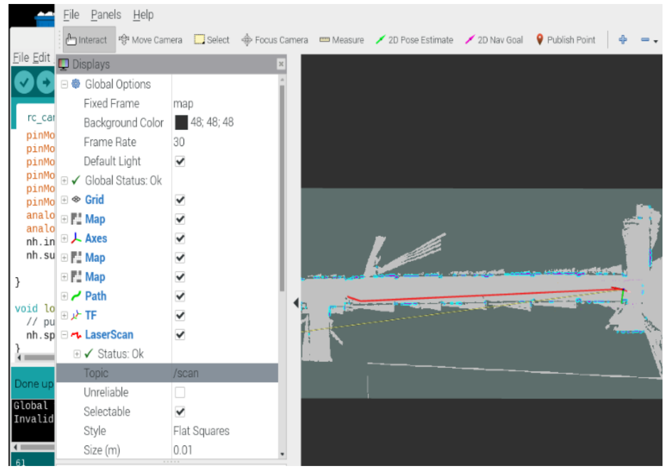

Fig. 8. Actual Testing of Device of a visually impaired individual

The localization and path planned by the device were based on the current situation of the environment and the pre-determined map. The colored dots and lines represent the point cloud data, which is obtained from LiDAR LD06. Same as presented in Figure 18, this shows the environment around the device and the user. The long red line represents the path planned by the device which is from the rightmost part of the vicinity going to the comfort room.

V. CONCLUSION

The integration of the Okdo LiDAR LD06 sensor into the Raspberry Pi-based walking stick successfully enabled accurate real-time detection of obstacles. The system effectively used point cloud data to prevent potential collisions, significantly enhancing user safety. The driving motor system was designed and implemented to respond accurately to navigation commands derived from speech-to-text input. This system demonstrated smooth and responsive movement according to user directions during testing, ensuring reliable performance. Extensive testing of the device in both controlled and real-world environments confirmed its reliability and effectiveness. The evaluations indicated that the device met its objectives, providing a safe and autonomous navigation aid for visually impaired individuals. The device's performance in varied conditions demonstrated its potential as a practical mobility aid.

The research successfully developed an intelligent walking stick using the Robot Operating System (ROS) framework integrated with various sensors to aid visually impaired individuals in navigation. The device utilizes a LiDAR sensor, IMU, wheel encoders, and an Extended Kalman Filter (EKF) for accurate localization and obstacle detection. The system demonstrates reliable real-time path planning and navigation, enabling users to navigate through different environments autonomously. The incorporation of speech recognition and feedback further enhances the user experience, making the walking stick an effective assistive device for visually impaired individuals.

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