Comparative Study of ORB-SLAM2 and IR-Based Revolution Counting with Ultrasonic Obstacle Avoidance for Autonomous Wheelchair Navigation

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Abstract: Wheelchairs are crucial to the mobility of people with disabilities. Conventional manual wheelchairs have come a long way to the powered and smart designs that allow for different types of controls. Nevertheless, indoor navigation and evasion of obstacles is a challenge to most users, especially to those with disabilities on powered wheelchairs. With technological advancement, the use of autonomous systems has gotten wider scope incorporating both external and internal spaces. Moreover, nowadays use of expensive lidars is used for indoor navigation but that makes the entire wheelchair costly. To reduce the cost use of stereo cameras or monocular cameras started for indoor mapping. ORB-SLAM2 is an algorithm where VSLAM works using a monocular camera because of which the cost of the wheelchair manufacture reduces.

1 INTRODUCTION

Wheelchairs have been used by the physically challenged for movement for many years. The simple manually operated wheelchairs have in recent years given way to powered wheelchairs, with various modes of control. Nowadays, wheelchairs have features like stair climbing and autonomous navigation built in the wheelchairs. But the cost of these wheelchairs is high and not only that these wheelchairs cannot be transported easily

SLAM has been a field of study for many decades. From radars and range finders to cameras and lasers, many modalities of SLAM-finding sensors pose a global representation. Development of Lidar sensors made major developments in SLAM-based localization since these Lidars can give an accurate measure of the z-axis distance of its surroundings. There have been many developments in the algorithms used in SLAM like ORB-SLAM2 and ORB-SLAM3, Vins-Fusion, DSO (Direct Sparse Odometry), RTAB-Map and LSD-SLAM, and Kimera. Nowadays VSLAM (Visual-Inertial SLAM) has become a major topic of study due to its applications in robotics, avionics, AR/VR, etc.

In most cases, custom-made wheelchair motors are used which are quite costly. In many scenarios, motors that are used in the electric bicycles are employed but they have a much higher rated rpm than what is efficient and smooth operation of the wheelchair requires. As Parik (Parikh et al., 2005) implemented in the Usability study of a control framework for an intelligent wheelchair, robotics to a wheelchair. The study's objective is to combine three approaches to motion control to evaluate the usefulness and efficacy of three paradigms, namely, deliberative plans, local reactive behaviors, and

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human inputs. The wheelchair is self-operating, that is it goes to any given destination on its own. The navigation system utilizes lasers to determine the direction by locating certain landmarks. To detect obstacles, IR proximity sensors are used and the wheelchair will then bypass the obstacles using reactive controllers. The wheelchair also has an override control which allows the user to operate it via a joystick and manually directs it to any other point. Research by U. Masud. (Masud et al., 2017) presents a vision-based control of a wheelchair, allowing the users to have complete control of the movement of the wheelchair using their eyes. This allows users even with multiple disabilities to control the wheelchair independently with no assistance from anyone. As per research by Shahnaz et al (Mur-Artal and Tardós, 2017). (2017) a low-cost smart electric wheelchair that incorporates destination mapping and intelligent control features. This study emphasizes the importance of cost-effectiveness in design while maintaining functionality. The wheelchair is equipped with microcontrollers for autonomous navigation, obstacle detection, and slope management. The study demonstrates how smart technology can be leveraged to improve wheelchair accessibility and usability, particularly for users in low-resource settings. there are plenty of ways to make this wheelchair autonomous. In this paper, we have used Orb_Slam2 (Oriented Fast and Rotated Brief SLAM 2) which is a widely used open-source simultaneous localization and mapping (SLAM) system.

It enables real-time tracking, mapping, and relocalization using monocular, stereo, or RGB-D cameras. ORB-SLAM2 uses ORB features for keypoint detection and description, making it computationally efficient while maintaining accuracy. In the paper (Mur-Artal et al., 2015) "ORB-SLAM2," the authors presented an improved SLAM system capable of operating with monocular, stereo, and RGB-D cameras. The system provides real-time tracking, mapping, and relocalization functionalities, leveraging ORB features for efficiency and robustness. It introduces stereo and RGB-D support while improving the loop-closing and relocalization capabilities of its predecessor, ORB-SLAM. The framework is versatile and suitable for robotics and augmented reality applications, offering open-source access for broader adoption and further research. In the paper (Wolf, 2003) "ORB-SLAM," the authors introduced a versatile and accurate SLAM system designed for monocular cameras.

It provides real-time tracking, mapping, and relocalization capabilities using ORB features for efficiency. The system includes a robust loop-closing mechanism to detect previously visited locations and an effective map-recovery method for relocalization after tracking loss. Its computational efficiency and accuracy make it suitable for robotics and augmented reality applications, and the open-source availability facilitates broader adoption and innovation.

There are plenty of ways of controlling wheelchairs other than joystick. Erik Jason Wolf (Chieein et al., 2009) investigates the effects of whole-body vibration on users of electric-powered wheelchairs. The study evaluates wheelchair designs and user exposure to vibrations, aiming to improve comfort, safety, and health outcomes. The research highlights the importance of biomechanical and ergonomic considerations in wheelchair development

2 PROPOSED METHOD

Wheelchairs, when used for indoor navigation, have to be very precise in identifying the objects around them as an indoor setup might have multiple obstacles at closer distances. So, we used orb-slam2 which creates an indoor map of the surroundings with a monocular camera in real time as navigation occurs, and visual odometry for accurate motion within intricate outdoor settings. This will improve mobility, and assist users in overcoming difficult environments.

2.1 ORB SLAM 2

The autonomous navigation feature of the retrofittable electric smart wheels utilizes ORB-SLAM2 (Oriented FAST and Rotated BRIEF SLAM 2) for real-time mapping and localization. ORB-SLAM2 uses ORB features to track key points in the environment, creating a map while maintaining accurate localization even in dynamic settings. It is capable of loop closure detection, which allows the wheelchair to recognize previously visited locations and correct drift in its map, making navigation more reliable. This system enables autonomous movement without relying on GPS, ideal for complex, outdoor environments.

2.2 Object Detection

Employing the use of InfraRed (IR) and ultrasonic sensors: IR sensors detect objects by sending out an IR wave from their transmitter and waiting for the reflection back. These sensors are inexpensive and assure good close-range object detection. Four IR sensors were mounted on the wheelchair; two on the handles and the other set near the wheels, to ensure that all the possible directions in which the wheelchair is moving are scanned for any obstacles. The signals from these sensors were however picked up by the control unit to detect any obstruction in the path of the wheelchair.

A drawback however of IR sensors is that they cannot provide any information concerning the distance of the detected object.

3 METHOD

3.1 SLAM Navigation with ORB-SLAM 2

The system design for the customizable electric smart wheelchair is detailed in Figure 3. The wheelchair is mounted with a battery and a controller while the computational activities are executed by a Jetson Nano which runs the ORB-SLAM2 algorithm for mapping and localizing the environment. There is a wireless communication link between the Jetson and the controller where the Jetson is used to control the wheels' motion. A camera fixed on the Jetson device provides the depth information that is transformed into a point cloud. This form of data is paired with Visual SLAM (VSLAM) techniques that allow the wheels to navigate on their own without any usage of GPS regardless of the mating surfaces.

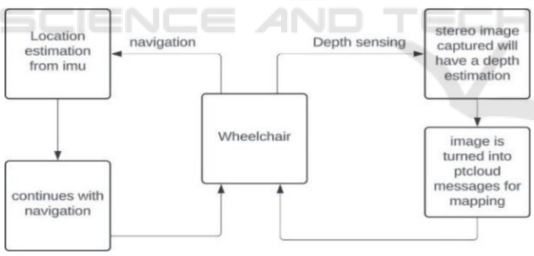

Figure 1: Block diagram of SLAM-based navigation.

Figure 3. illustrates the block diagram of the wheelchair system. The wheelchair is integrated with a battery, BLDC motor, and motor controller that drives the movement. The Jetson Nano serves as the main control unit, responsible for processing data from the camera and running the ORB-SLAM2 algorithm for autonomous navigation. A joystick is connected to the Jetson for manual control, allowing the user to override the autonomous system if needed. Communication between the ESP32 motor controllers is established via the ESP-NOW protocol, providing efficient and low-latency wireless data transfer for smooth coordination of the system components

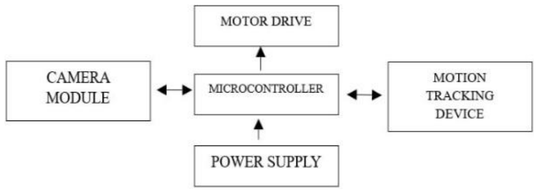

Figure 2: Block diagram of wheelchair.

3.2 Obstacle Avoidance Using IR Sensor

The wheelchair comes with an ultrasonic sensor to help identify obstacles and provide a safe way to navigate. The sensor is always active, sweeping in front of the wheelchair and perceptive to any objects and barriers within the path. In case an obstacle is sensed, the wheelchair automatically freezes and no further motion of the machine is allowed, thus averting all manner of accidents. The wheelchair stays in that position until such a time the obstruction has been removed or that a clear sunlit path is established and then it continues moving without any delays.

The navigation system follows a set path that has already been programmed. The wheelchair is controlled, and the ultrasonic sensor scans for obstacles as the wheelchair travels along the pre-programmed path. This way, the wheelchair enables safe and effective mobility indoors or within any structured space making it comfortable for the users. Ultrasonic sensors act as a safety measure for the

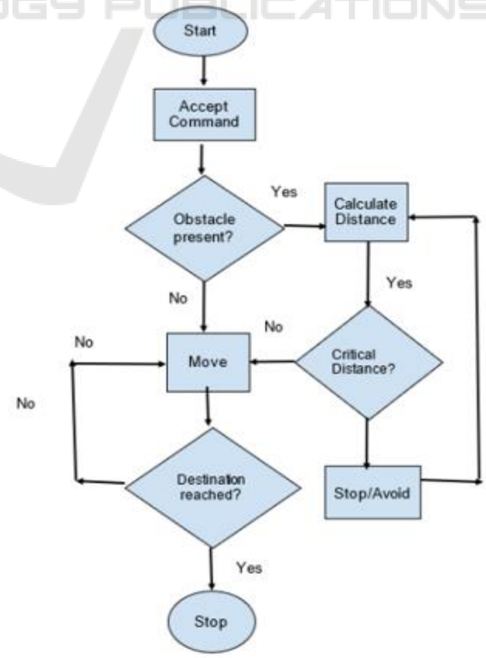

Figure 3: Working of the wheelchair with IR sensor.

system since they facilitate the detection and avoidance of obstacles in real-time. This makes the system applicable in environments where obstacles may not be static and could come at any moment

4 RESULTS

In the paper, the authors use the KITTI dataset to compare an IR- and ultrasonic-based system with a stereo camera system in terms of timing and navigation. Tracking-related tasks like ORB extraction were slower using the stereo system than compared to the IR and ultrasonic-based system, ~10.0 ± 5.0 ms compared to 24.83 ± 8.28 ms, pose prediction ~3.0 ± 2.0 ms compared to 2.36 ± 1.84 ms ascribed to the lesser number of features used, thus lesser computational complexity. However, in the case of mapping processes, that required slightly more time: Local BA (~80.0 ± 40.0 ms vs. 69.29 ± 61.88 ms), and also Map Point Creation (~50.0 ± 20.0 ms vs. 47.69 ± 29.52 ms), since the involved working with IR and ultrasonic data.

Table 1: Performance on the distance of navigation.

Performance on distance of navigation		
Distance to be navigated (m)	Navigation accuracy with ir (%)	Navigation accuracy with camera (%)
> 10	85	90
5 to 10	92	94
2.5 to 5	95	95
2.5 to 1.5	98	97

Accuracy of navigation IR system The IR system was less accurate at higher ranges (>10 m: 85% vs. 90%) but comparable for nearer ranges (2.5 to 5 m: 95%; 2.5 to 1.5 m: 98%). These results indicate that though IR and ultrasonic systems can be excellent for reasonable performance, the mapping capabilities and long-range navigation accuracy are lagging behind the stereo camera systems; it is very much important to select the correct sensor system according to the requirement of the application.

Table 2: Timing results comparison of each thread in ORB SLAM 2 System to IR and Ultrasonic based System.

Settings	Dataset	KITTI	KITTI
	Sensor	Stereo Camera	IR and Ultra-Sonic
	Resolution	1226 × 370	X
	Camera FPS	10 Hz	X
	ORB Features	2000	X
Tracking	**ORB Extraction**	24.83 ± 8.28	~10.0 ± 5.0
	Stereo Matching	15.51 ± 4.12	X
	Pose Prediction	2.36 ± 1.84	~3.0 ± 2.0
	Local Map Tracking	5.38 ± 3.52	~6.0 ± 4.0
	New Keyframe Decision	1.91 ± 1.06	~2.5 ± 1.0
	Total Time	49.47 ± 12.10	~21.5 ± 9.0
Mapping	**Keyframe Insertion**	X	~1.0 ± 0.5
	Map Point Culling	0.45 ± 0.38	~0.6 ± 0.4
	Map Point Creation	47.69 ± 29.52	~50.0 ± 20.0
	Local BA	69.29 ± 61.88	~80.0 ± 40.0
	Keyframe Culling	0.99 ± 0.92	~1.5 ± 0.8
	Total	129.52 ± 88.52	~133.0 ± 70.0

5 CONCLUSIONS

In conclusion, this research presents a promising solution for enhancing wheelchair mobility. By integrating autonomous navigation via ORB-SLAM, the system offers both manual and autonomous control to users, improving accessibility and independence, particularly in outdoor environments. The use of ESP32 communication for motor control and depth-sensing cameras for navigation ensures both reliability and precision. This adaptable system not only addresses the limitations of existing wheelchairs but also offers an affordable, scalable solution for users in resource-constrained areas. Future work will focus on refining the system's robustness and expanding its capabilities for broader applications.

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