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Review: Issues and Challenges of Simultaneous Localization and Mapping (SLAM) Technology in Autonomous Robot

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***Abstract*—To aid in robot navigation and environment analysis, visual SLAM systems process visual data. Things like AMRs (autonomous mobile robots) and AGVs (autonomous guided vehicles) have been gaining popularity in recent years. These robots depend significantly on simultaneous localization and mapping (SLAM) technology to keep the factory floor free of accidents. vSLAM employs a technique for estimating the precise positioning and orientation of a sensor relative to its environment as well as the navigation of the region around it. SLAM algorithms can be used in various applications, including self-driving vehicles, mobile robots, drones, etc. Visual SLAM does not refer to a particular set of methods or software. This paper proposes to review some of the issues and challenges facing SLAM technology in autonomous robot applications and draw a conclusion.**

***Keywords*—Autonomous mobile robots, Autonomous guided vehicles, Navigation, vSLAM**

I. INTRODUCTION

In the past decade, simultaneous localization, and mapping (SLAM) have expanded swiftly. It can be used for a variety of purposes, including self-exploration in a variety of geographical contexts, by autonomous mobile robots. Recent advancements in SLAM have spurred a resurgence of interest in autonomous self-exploring mobile robots. Using the SLAM method, a robot/sensor system gathers information about its environs and predicts its position in the environment using this data. Since SLAM's inception, numerous SLAM algorithms have been devised to implement it in the real world. Numerous SLAM modalities, including radars, rangefinders, cameras, and lasers, have been developed to solve the fundamental problem of sensor localization in a global representation [1].

Autonomous robots employ the Simultaneous Localization and Mapping (SLAM) approach to simultaneously map their surroundings and locate themselves inside the surroundings [2]. Some of the current issues and challenges in SLAM include:

A. Accuracy and precision

One of the main challenges in SLAM is achieving high accuracy and precision in the map and the robot's location estimate. This is particularly important in applications where the robot needs to navigate through tight spaces or perform precise tasks.

B. Dynamic Environments

SLAM algorithms can struggle to cope with dynamic environments, where objects or features in the environment are constantly changing. This can lead to drift in the map and the robot's location estimate.

C. Limited Sensors

Many SLAM algorithms rely on sensors such as laser scanners or stereo cameras to gather data about the environment. These sensors can be expensive, bulky, and power-hungry, which can limit the use of SLAM in small or low-power autonomous robots.

D. Computational Complexity

SLAM algorithms can be computationally intensive, which can be a challenge for robots with limited processing power. This can be particularly problematic for real-time applications, where the robot needs to constantly update its map and location estimate.

E. Sparse environments

Some environments, such as those with few distinctive features, can be difficult for SLAM algorithms to work with. This can lead to poor map quality and imprecise location estimates [2].

F. Sensor Noise and Data Association

One of the difficulties that SLAM must contend with is the Data Association Problem, which is also known as the Correspondence Problem. The process of establishing communication within different measurements taken by sensors received at various points in time and various positions between the sensing devices' statistics and map attributes, or between map features, to identify the possibility that they arise from the same bodily entity in the surroundings is known as data association. This may have been done among measurement results from sensors and mapping features, or between features of the map and sensors readings. The accuracy of the data association is necessary to accurately estimate the state of the SLAM problem [3].

The management of sensor noise and the association of data is one of the most significant issues in SLAM technology. The robot's localization and mapping processes are susceptible to inaccuracy when there is sensor noise [1], [3]. The challenge of determining which measurements match which landmarks is referred to as the "data association" problem. This is an especially difficult task in surroundings that are highly dynamic, in which landmarks may shift or come into being for the first time.

Within the realm of autonomous mobile robotics, the technique known as simultaneous localization and mapping (SLAM) has seen substantial development over the course of recent years. However, for effective implementation of SLAM in autonomous mobile robots, there are still significant obstacles that need to be addressed.

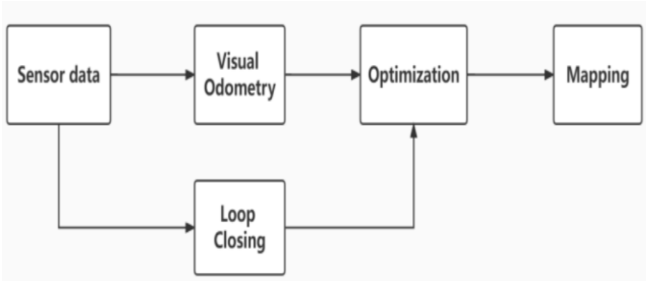

Fig. 1. A Classic SLAM System [4]

Fig. 1 showcases the basic block of the SLAM system operational stages, the data/information are generated from the sensor, whereby visual odometry processes the sensor data and passes to the optimization stage. The data will be optimized to match the mapping surroundings.

Technologies like Visual Simultaneous Localization and Mapping (vSLAM) have overtaken 2D-lidar systems as the main method of navigation for next-generation robots [5]. Different kinds of sensors and cameras are used, such as 3D lens cameras which employ duration of flight, depth and stereo-vision technologies, wide-angle, spherical cameras, and so forth. SLAM systems require a series of instructional algorithms that can assist in guidance and decision-making based on the visuals gathered by the camera [6],[7]. This review consists of sections, Section III consists of reviews of previous papers related to SLAM issues and challenges, Section IV describes a discussion based on reviewed issues and challenges and finally, Section V describes the general conclusion of the reviewed papers.

II. Literature Review

According to [8], one of the key problems of the Visual Simultaneous localization and mapping algorithm for navigation system major problem in the automation and control of the robotic system, in which the vSLAM use techniques to calculate the actual estimate for its unknown surroundings for navigation purpose. Autonomous navigation was designed to control portable robots' navigation system with the use of a dispersed filter, the designed method is to minimize sounds from both inside and outside, in which the designed developed system can guide the robot in unknown surroundings so that the robot will determine its location and be able to reconstruct it surroundings and path. Moreover, the vSLAM technique was employed to enhance the navigation efficiency by calculating the robot's location using encoders, also the comparison of image methodology was implemented on mapping techniques to estimate and filtering of pose distribution utilizing Kalman filtering to minimize noise in remote or input visuals that is called Distributed Filter Technique. The proposed mobile navigation system employs distributed filtering and vSLAM was able to move 100 meters at a frequency of 433Mhz with a maximum matching found at location 2, at a match percentage: of 28.74%.

vSLAM can be used in today's self-driving cars for them to be able to navigate within their surroundings. Of this, it's important to explore more about SLAM technology related to autonomous cars, even though most of the autonomous vehicles employ stereo vision and lidar imaging to detect their surroundings and understand the environment in which they are moving. Both approaches can be used to address localization concerns on a stereo or monocular camera and Lidars [5], [9]. As expected, the autonomous vehicle provides a safe road, helps in reducing congestion, and can solve parking problems. in doing so, security is a very important aspect to consider related to autonomous vehicle navigation, as it still faces security issues over the medium of transmission of data (Network).

[9] Discussed issues relating to autonomous vehicles, that since autonomous vehicles rely on digital systems or computers, there must be a protocol or framework employed in the said field. At these levels of networking between autonomous vehicles, there are two frameworks employed which include V-2-V: it composed of communication between vehicles near each other in a small region; and Vehicle-to-Infrastructure communication V-2-I; which deals with networking between vehicles and infrastructure systems. At this point of networking level, sharing crucial data between vehicles is necessary to improve navigation on the roadways, such data include speed, location, and other activity. However, this complex communication can be attacked by two categories of attack techniques [9][10]: Passive and Active Attacks.

Passive attacks can be carried out on network traffic that's not encrypted by spying on the communication channel. Example Eavesdropping (tapping) in which the attacker can listen to messages or traffic that is being communicated and is not meant to change how the system operates., but to acquire some confidential information about the system [9], [11]. Active attacks involve the injection of traffic by the attacker, even though it takes a wider range of forms with many possibilities which include Denial of Services attack (DoS) and Replay attack [10], [11].

In 2022, [12] describe the issues and potential directions in the SLAM field, one issue concerned about SLAM is robustness, Usually, SLAM and odometry techniques still face major issues in algorithm robustness. These issues usually decrease the SLAM algorithm robustness in a static scenario and real-world present in a dynamic environment, which causes tracking failure and reconstruction. The algorithm can find it very challenging to detect the dynamic object, object avoidance, and remove it from the map. Besides the robustness issues, it faces challenges in computational resources, which deal with memory usage and map storage. Saving or storing the Map for a long time can cause memory-limited operations, and there are a lot of works proposing a solution to this issue [13].

In 2016 [14] suggested a novel solution to the SLAM challenge of mobile robots, usually for platform estimation, the Particle filter (PF) and Kalman Filter algorithm are the two most prevalent techniques. Even though KF is ineffective in non-gaussian nonlinear situations, the EKF, or extended Kalman Filter has difficulty building and developing large-scale maps. However, particle filter has an advantage when estimating and filtering nonlinear non-Gaussian time-varying systems. [14] suggest a new approach based on adaptive resampling PF. With a closed-loop and weighted-average method, the estimation of landmarks will be more accurate, and convergence will occur more quickly compared to algorithms without closed-loop feedback. The robot's posture is estimated using a particle filter and the data is collected by the robot's sensors, Additionally, approximated landmark positions are made. Consequently, the position of the robot is rectified at each time step using the landmark data collected by sensing devices. This process is repeated repeatedly to create a closed-loop system, and the algorithm is simulated in MATLAB.

Table I presents the Summary of Issues in Autonomous Robots in Relation to Simultaneous Localization and Mapping (SLAM) Technology that researchers and practitioners can utilize to address the challenges and complexities associated with SLAM. The challenges include pose estimation, communication issues, image correlation, and localization approaches. Various review and analysis approaches were suggested to come up with solutions, such as using Kalman filtering techniques to reduce noise in input images or remote visual data.

TABLE I. SUMMARY OF RELATED ISSUES (SLAM) IN AUTONOMOUS ROBOT

No	Review Title	Ref	Year	Content
1	Design of mobile robot navigation system using vSLAM and distributed filter techniques	[8]	2013	Pose Estimation Issues
2	A Review of SLAM Techniques and Security in Autonomous Driving	[9]	2019	Communication Issues
3	A Comprehensive Survey of Visual SLAM Algorithms	[12]	2022	Odometry and robustness of the Algorithm
4	Simultaneous Localization and Mapping Embedded with Particle Filter Algorithm	[14]	2016	Localization Problem

Fig. 2 describes the basic input/output block diagram of a simple autonomous system. In an Autonomous robot, the input/output block diagram of an autonomous robot typically includes the:

A. Sensors: These are devices that measure various aspects of the robot's environment, such as distance, temperature, humidity, and so on. These sensors provide the robot with information about its surroundings, which it can use to navigate and make decisions.

B. Actuators: These are devices that allow the robot to perform actions in the world, such as moving its wheels or manipulators. They are typically controlled by the robot's control logic, which receives input from the sensors and uses it to determine how the actuators should be activated.

C. Control logic: This is the central processing unit of the robot, which receives input from the sensors and uses it to make decisions about how the actuators should be activated. This can be implemented in a variety of ways, such as with a microcontroller, a computer, or a dedicated hardware device [15].

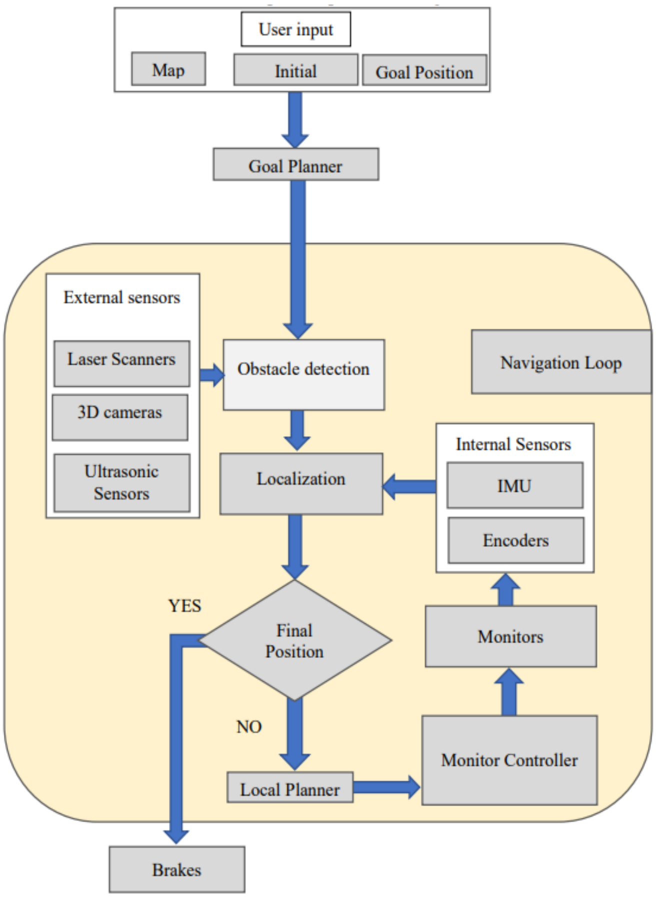

Fig 2. Input/Output Block Diagram [15]

TABLE II. SUMMARY OF LITERATURE REVIEW

S/No	Paper Title	Authors/Year	Methodology	Technique	Result
1	Design of Mobile Robot Navigation System using vSLAM and Distributed Filter Techniques.	Kapil K. Jajulwar, 2013	To minimize noise in autonomous robot navigation in unexplored areas: • Distributed filtering • Visual SLAM is utilized	• In vision-based SLAM, use encoders to calculate the robot's location. • Show correlation coefficients in a visual format for pose estimation. • Use Kalman filters to lessen image smearing.	The proposed mobile navigation system achieved a 28.74% match percentage at position 2, capable of traversing 100 meters at 433 MHz
2	A Review of SLAM Techniques and Security in Autonomous Driving	Ashutosh Singandhupe, Hung Manh La, 2019	The estimate was derived from comparing various methodologies and can be adjusted to suit the complex environmental knowledge needed for effective localization.	• Deliberate about stereo-based SLAM, monocular cameras that use Lidar, and Lidar imaging techniques. • Address safety concerns with autonomous vehicle systems.	The study evaluated various SLAM algorithms for autonomous driving, particularly in the KITTI dataset, and discussed stereo- and Lidar-based odometry methods, as well as various attacks on autonomous driving systems.
3	A Comprehensive Survey of Visual SLAM Algorithms	A Macario, M Michel, 2022	Focused on visual-based techniques that deal with: • Visual-only • Visual-inertial • RGB-D SLAM.	• Uses diagrams and flowcharts to illustrate the primary algorithms of each technique, resulting in the selection of six criteria for evaluating SLAM algorithms.	This work provides a comprehensive overview of visual-based SLAM methods, including visual-only, visual-inertial, and RGB-D SLAM, along with a summary of benchmark datasets for academics and industry professionals.
4	Simultaneous Localization and Mapping Embedded with Particle Filter Algorithm	Wei Wang. Dongying Li. Wenxian Yu, 2016	Particle Filter (PF) algorithms offer a creative solution for SLAM problems in mobile robots, enhancing precision in estimating landmarks using a closed-loop and weighted-average method.	Particle Filtering estimates the robot's posture using sensor data by: • Estimating its surrounding location • Adjusting its position at each time step using landmark data collected by sensing devices.	The simulation results show that the robot's trajectory is estimated with precision and convergence significantly better than comparable methods.

Table II offers a comprehensive overview of the significance of methodologies and techniques employed in addressing complex challenges inherent to simultaneous localization and mapping (SLAM) technology, particularly as applied to autonomous robotic systems. These daily challenges encompass a range of issues, including noise reduction, odometry accuracy, algorithm robustness, and precision inaccuracies, which are particularly pronounced in closed-loop operational environments. The table serves as a valuable resource by presenting a detailed and insightful examination of the solutions that have been implemented to ameliorate these issues, providing a succinct yet thorough summary of their contributions to the field of SLAM.

III. DISCUSSION

A challenge in robotics known as Simultaneous Localization and Mapping (SLAM) involves mapping an uncharted environment while keeping track of the whereabouts of an autonomous unit. It is useful for tasks such as autonomous exploration, rescue operations, and home cleaning. SLAM is challenging because it requires the simultaneous localization and mapping of the environment, which can be affected by uncertainty and noise in the sensor data and the motion of the agent. There are various approaches and algorithms for solving the SLAM problem, including graph-based algorithms and feature-based algorithms. Despite the challenges, significant progress has been made in the field of SLAM in recent years, and it has many practical applications. The review provides a thorough and informative overview of the strategies used to lessen these problems. It provides a concise yet thorough summary of different contributions to the field of simultaneous localization and mapping (SLAM).

IV. CONCLUSION

In this Review, we describe and elaborate on many issues related to Simultaneous and Localization Mapping (SLAM) in autonomous robot applications. In conclusion, the SLAM problem is difficult and significant in robotics with numerous applications. While there are still numerous areas for improvement, significant progress has been made in recent years, and a variety of approaches and algorithms can now solve the SLAM problem in a wide range of environments.

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