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Multi-Agent Robot System for Autonomous Fire Extinguisher Detection and Navigation using Robotic Operating System and Two Turtlebots

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Abstract: Fire is a significant risk that can have devastating consequences, including loss of life, property damage, and environmental destruction. One way to reduce the risk of fires is through the use of fire extinguishers, which can help to cool down the heat or remove the oxygen from a fire to prevent it from continuing to burn. In this project, a multi-agent robot system consisting of two Turtlebot2 robots with the ROS was developed to autonomously locate and navigate to fire extinguishers in an unknown environment. The first robot, called Turtlebot A, moved through the environment and detected the location of the fire extinguisher, which was then defined as a goal for the second robot, called Turtlebot B. Turtlebot A also created a map of the environment using an RGB-D camera and sent it to Turtlebot B, which used it to plan a path and navigate to the fire extinguisher location while avoiding obstacles. The project demonstrated the potential of multi-agent robots to communicate with each other and work together to achieve a shared goal, as well as the capabilities of ROS for autonomous navigation and path planning

Keywords: Robot Operating System (ROS); Turtlebot, Multi-Agent Robot, Path Planning, Avioding Obstacles.

1. Introduction

Fires are a major threat to both open and enclosed spaces, such as forests and factories. They can occur suddenly and without warning, making it difficult to detect and extinguish them quickly. Traditional methods of fire monitoring, such as satellite-based approaches, have limitations in providing comprehensive data for the development of systematic methodologies to reduce the risk of fires.[1,2]

In light of these challenges, the implementation of multi-agent robot systems presents a promising solution. By leveraging the capabilities of such systems, we can enhance fire detection and navigation, enabling faster response times, precise localization, and optimal path planning in dynamic environments.

This research focuses on the design and implementation of a multi-agent robot system for autonomous fire extinguisher detection and navigation using ROS and two Turtlebot robots.

Fire incidents have been the subject of numerous studies and statistics globally[3-7]. In Sweden, for example, a study analyzing fire prevention statistics found that the available data may not be comprehensive enough to develop a systematic methodology for reducing fire risks. [8] Likewise, in the United States, an estimated 1.4 million fires were responded to by local fire departments in 2020 alone. These statistics underscore the need for proactive measures and innovative approaches to fire prevention and mitigation.[9]

Fire prevention is of paramount importance due to the potentially catastrophic consequences fires can have on individuals, families, and communities. Beyond property damage, fires can result in loss of life, severe injuries, and psychological trauma. Moreover, the economic impact of fires, as evidenced by the billions of dollars in property damage, highlights the need for effective fire safety measures. Therefore, it is crucial to develop advanced systems that can detect and extinguish fires rapidly and autonomously to minimize the potential harm they can cause [10-13].

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Fire extinguishers play a crucial role in fire safety plans, not only in homes but also in various other settings such as hospitals, cars, and factories. Their ability to cool down fires or remove oxygen from the environment is instrumental in halting the spread of flames[14-17] Recognizing the significance of fire extinguishers in mitigating fire incidents, the idea to design a multi-agent robot system for autonomous fire extinguisher detection and navigation emerged. By utilizing the advantages of robotic systems, such as mobility and real-time data processing capabilities, we aim to enhance the effectiveness and efficiency of fire extinguishing operations in complex environments.

To implement the proposed project, we will employ two Turtlebot robots. Turtlebot robots are a popular robots widely used in research and educational settings. These robots provide a versatile hardware platform equipped with sensors, actuators, and computing capabilities necessary for autonomous navigation tasks. With the ability to perceive their surroundings using Light Detection and Ranging (LiDAR) sensors and the support of Robot Operating System (ROS), Turtlebots offer a suitable foundation for developing intelligent multi-agent robot systems. The collaboration between two Turtlebot robots enables communication, mapping of the environment, and autonomous navigation to fire extinguisher locations without collisions.[18-21]

Central to the success of the project is the concept of Autonomous Navigation, an advanced robotics project that encompasses state-of-the-art algorithms for path planning, localization, and obstacle avoidance. By leveraging the capabilities of Autonomous Navigation, the multi-agent robot system will navigate through complex environments, map the unknown areas, detect fire extinguishers, and avoid obstacles effectively. The integration of ROS, an open-source framework widely used in robotics, further enhances the system's flexibility, interoperability, and scalability.

The aim of this research project is to design, develop, and evaluate a multi-agent robot system for autonomous fire extinguisher detection and navigation. The specific objectives include real-time fire detection, accurate localization of fire extinguishers, optimal path planning, and collision-free navigation. By achieving these objectives, the project intends to enhance the efficiency of fire extinguishing operations and contribute to improved emergency response capabilities. Additionally, the research seeks to advance the field of robotics and its application in fire safety, with potential implications for various domains where fire prevention and mitigation are critical.

2. METHODOLODY

In this system, a multi-agent robot system is employed, consisting of two synchronized Turtlebot robots. Within this framework, Turtlebot A is designated as the master robot, while Turtlebot B serves as the slave robot. This approach ensures synchronization and coordinated operation between the two robots. Turtlebot B, acting as the slave robot, receives instructions and commands from Turtlebot A, enabling seamless collaboration.

The project aims to showcase the synchronization, coordination, and communication capabilities of a multi-agent robot system using two Turtlebot robots. It demonstrates tasks like mapping, obstacle avoidance, and fire extinguisher detection in a collaborative manner. Although the current methodology may not explicitly justify the use of a second robot to reach the goal when the first robot has already detected it, the focus is on highlighting the potential of a multi-robot system. The methodology can be further developed to detect multiple fire extinguishers and incorporate more slave robots for coordinated operations. The primary purpose is to emphasize the capabilities of the distributed approach, laying the foundation for future advancements and applications in complex environments, offering increased efficiency and adaptability. various ROS packages were utilized as illustrated in Table 1, each incorporating different algorithms to achieve specific tasks.

TABLE I. ROS PACKAGES AND THEIR ALGORITHMS

Algorithm	Purpose
SLAM (Simultaneous Localization and Mapping)	Mapping the environment and estimating robot's pose
Adaptive Monte Carlo Localization (Particle Filter)	Localizing the robot within a known map
Gmapping (Particle Filter)	Generating a 2D occupancy grid map of the environment
A* (A-star)	Path planning algorithm for finding the shortest path

The communication between the two Turtlebot robots is established through a Wi-Fi connection, serving as the primary means of data exchange and coordination. Each robot possesses a unique Internet Protocol (IP) address, defined in the bashrc file, enabling them to communicate and share information effectively.

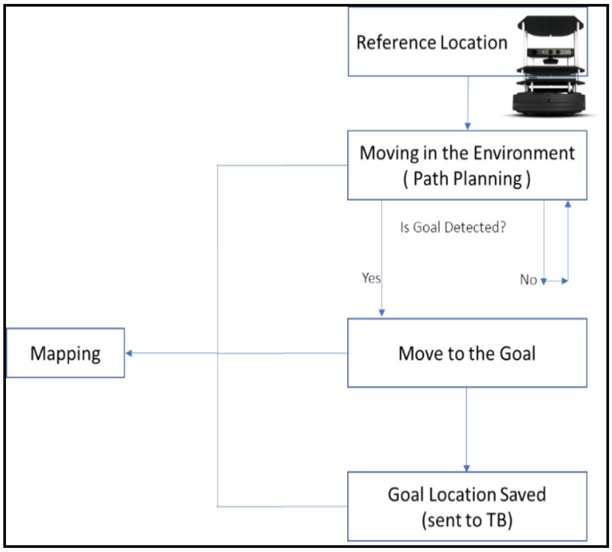

Figure 1. Turtlebot A diagram

Turtlebot A's primary task, as illustrated in Figure 1, is to navigate through an unknown environment and identify the location of the fire extinguisher. The robot continuously scans its surroundings, employing obstacle avoidance techniques to ensure uninterrupted movement. Simultaneously, Turtlebot A utilizes its Red Green Blue-Depth (RGB-D) camera to create a comprehensive map of the environment. This mapping process is crucial as it provides a valuable resource for subsequent navigation and facilitates efficient coordination between the robots. Additionally, Turtlebot A subscribes to multiple ROS topics and publishes relevant topics to assist Turtlebot B during the operation.

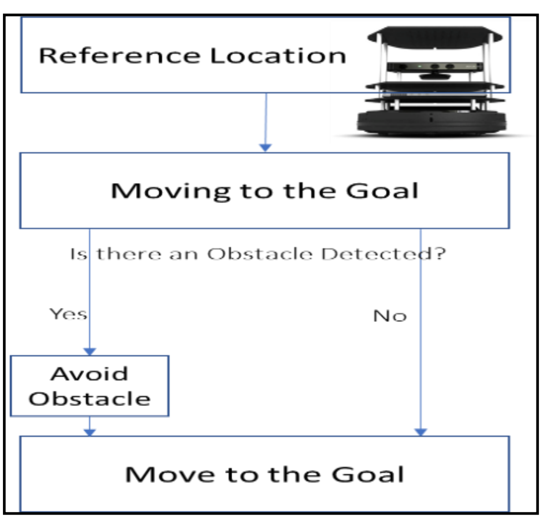

Figure 2. Turtlebot B Diagram

Once the fire extinguisher is detected in the environment, Turtlebot A saves its location and transmits the generated map to Turtlebot B. Furthermore, Turtlebot A publishes odometry information, which Turtlebot B utilizes to navigate autonomously toward the designated fire extinguisher location. The use of the map and odometry data ensures accurate movement and effective obstacle avoidance by Turtlebot B. The diagram depicting Turtlebot B's configuration and operation is presented in Figure 2.

3. RESULTS

The mapping process is performed by Turtlebot A using the gmapping package. It utilizes LiDAR data generated from the depth image captured by the robot's camera. Figure 3 illustrates the mapping of the surroundings. Manual path utilized for planning approach for moving around the area. Instead of relying on an automated algorithm, a pre-defined path was followed by the robot to cover the entire area. The path was manually designed to ensure complete coverage and exploration of the environment. In the conducted experiments, the area under consideration was a rectangular space measuring 3x1.5 square meters. Within this area, the fire extinguisher was randomly placed to simulate realistic scenarios

The Gmapping algorithm, provided by the gmapping package, is a well-known laser-based Simultaneous Localization and Mapping (SLAM) algorithm. It allows us to create a 2D occupancy grid map of the environment using laser and pose data collected by the Turtlebot. The algorithm uses sensor measurements and robot poses to estimate the robot's location while simultaneously building a map of the surrounding area.

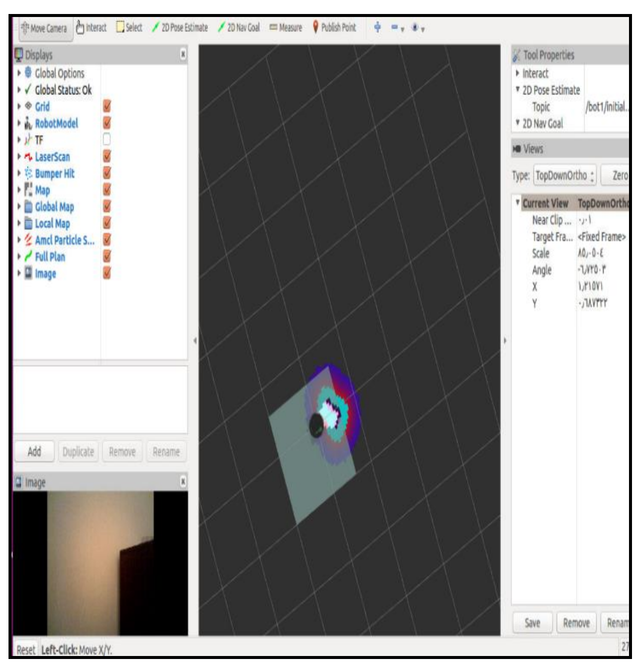

Figure 3. Turtlebot A mapping the surroundings

Fire extinguisher detection is achieved by utilizing the OpenCV Python API. The captured image from the camera is converted to the OpenCV image type using the cv_bridge ROS package. The OpenCV inRange function is then applied to the image, which is first converted to the HSV format. By defining a specific range, a mask of the red color image is created for fire extinguisher detection in Figure 4. Turtlebot B successfully reaches the goal position, as shown in Figure 5.

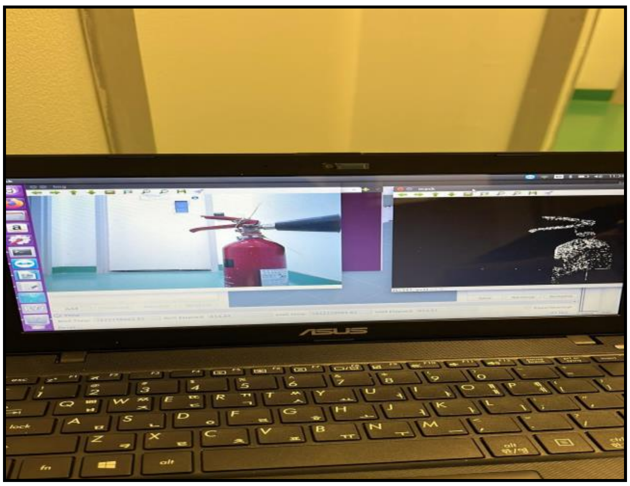

Figure 4. Detected Object

Figure 5. Turtlebot B in the goal position

The navigation of multiple Turtlebots is implemented using the namespace bot1 and bot4 for each individual robot. The amcl and move_base ROS packages are employed for navigation control in both robots. The visualization of both robots is achieved through the use of rviz, as depicted in Figure 6.

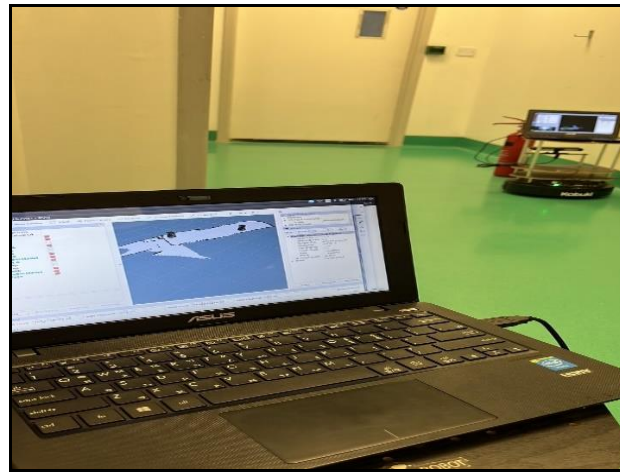

Figure 6. Visualization of multiple Turtlebots in rviz

TABLE II. TRAILS DATA

Trial	Agent 1 accuracy (Detecting Object)	Agent 2 accuracy (Reaching Goal)
1	100%	100%
2	100%	100%
3	0%	0%
4	100%	100%
5	0%	0%
6	100%	0%
7	100%	0%
8	0%	0%
9	100%	100%
10	100%	100%
11	100%	100%
12	100%	100%
13	100%	0%
14	100%	100%
15	100%	100%
16	100%	100%
17	0%	0%
18	100%	100%
Accuracy	**78%**	**61%**

Table 2 represents the data collected during the accuracy test for the multi-agent system. These results suggest that the accuracy of the multi-agent system for detecting the object (Agent 1 accuracy) was 78%, while the accuracy for reaching the goal (Agent 2 accuracy) was 61%. The lower accuracy for reaching the goal compared to detecting the object may be due to a variety of factors, such as the complexity of the environment, the presence of obstacles and the performance of the path planning algorithm. When the agent 1 fault to detect the object the agent 2 will not move to the location, this indicate why accuracy of agent 2 is less than agent 1. In figure 7 the accuracy and loss curve is shown.

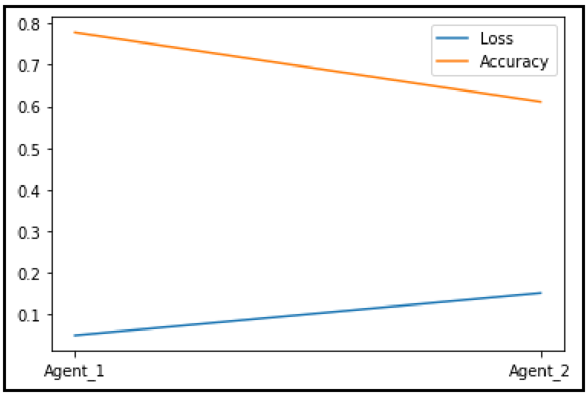

Figure 7. Loss & Accuracy Curve

TABLE III AVERAGE TIME

Task	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10	Trial 11	Trial 12	Trial 13	Trial 14	Trial 15	Trial 16	Trial 17	Trial 18	Average Time (in seconds)
Mapping	132	112	109																117.7
Fire Extinguisher Detection	20	16	15	17	18	16	22	20	15	17	17	18	17	20	21	14	16	18	17.6
Navigation	**35**	**38**	**38**	**38**	**37**	**38**	**37**	**37**	**37**	**37**	**37**	**37**	**38**	**38**	**37**	**37**	**38**	**37**	37.2

The table 3 provided the results for three different tasks: mapping, fire extinguisher detection, and navigation the table also includes an average time, which represents the average time across all trials for each respective task. For the mapping task, the times recorded for each trial range from 109 seconds to 132 seconds. The average time for mapping is calculated to be 117.7 seconds. In the case of fire extinguisher detection, the recorded times range from 14 seconds to 22 seconds across the 18 trials. The average time for fire extinguisher detection is calculated to be 17.6 seconds. For the navigation task, the recorded times range from 35 seconds to 38 seconds across the 18 trials. The average time for navigation is calculated to be 37.2 seconds.

These results provide insights into the performance of the system in terms of time taken to complete each task. The average times give a representative measure of the overall efficiency and effectiveness of the system in accomplishing the mapping, fire extinguisher detection, and navigation tasks.

4. DISCUSSION

The results obtained from the project provide valuable insights into the performance and capabilities of the multi-agent robot system for autonomous fire extinguisher detection and navigation. The mapping process conducted by Turtlebot A using the gmapping package demonstrated its ability to create accurate maps of the environment using LiDAR data. This mapping capability serves as a crucial foundation for subsequent navigation and localization tasks.

The fire extinguisher detection module, employing the OpenCV Python API, showed promising results in identifying fire extinguishers. By converting the captured camera image and applying image processing techniques, the system successfully created a mask of the red color image, enabling reliable detection of fire extinguishers. This capability is crucial for rapid and efficient response to fire incidents.

Navigation of multiple Turtlebots was achieved using namespaces and the amcl and move_base ROS packages. The successful navigation of Turtlebot B to the goal position demonstrates the effectiveness of the system in autonomously guiding the robots to specific locations. The integration of visualization through rviz facilitated real-time monitoring and coordination of the multiple robots.

It is important to note that the accuracy of the multi-agent system for detecting the object (Agent 1 accuracy) was found to be 78%, while the accuracy for reaching the goal (Agent 2 accuracy) was 61%, as indicated in Table 1. The lower accuracy in reaching the goal can be attributed to various factors, such as the complexity of the environment, the presence of obstacles, and the performance of the path planning algorithm. Additionally, when Agent 1 failed to detect the object, Agent 2 did not move to the location, further explaining the discrepancy in accuracies.

In this whole process, a lot of challenges are faced. These challenges are described below:

- Reusing the map

The map created by turtlebot A should be used by turtlebot B. For this, in the launch file of the turtlebot B, remapped the topics performed so that it can use the same topic for map which is used by the turtlebot A.

- Setting up the prefix before transform frames for both the robots

The next problem was that both turtlebots cannot run simultaneously because of the issues with the transforms. For this, in the case of multiple robots, they should have a different prefix in front of the transform frames which can be used to distinguish between both the robots and also can be used by amcl, gmapping, move_base ROS package for localization, mapping and navigation.

- Setting up Turtlebot A as master and Turtlebot B as a slave for ROS communication.

The turtlebot A is used as a master which can be used for communication with the other turtlebots as the other turtlebots should connect to the same network and also configure the ROS_MASTER_URI as http://<TURTLEBOT_A_IP>:11311. With this, they can easily communicate using the tcp/udp protocols. Calibrating the camera: In order to accurately detect objects, the camera on the Turtlebot must be calibrated correctly. This is a complex process, especially when the camera has a wide field of view. Coping with occlusion if objects are partially or fully occluded by other objects, it can be difficult for the system to accurately detect them.

Overall, these results demonstrate the potential and effectiveness of the multi-agent robot system for autonomous fire extinguisher detection and navigation. The successful mapping, fire extinguisher detection, and navigation capabilities highlight the system's ability to enhance fire safety measures by providing efficient and prompt response in complex environments. Future research can focus on further improving the system's accuracy and addressing challenges associated with complex environments and obstacle avoidance to ensure its practical applicability and reliability in real-world scenarios.

5. CONCLUSION

The goal of this project is to design a system that uses two Turtlebot2 robots to autonomously navigate an unknown environment and locate fire extinguishers. These robots will communicate with each other and use advanced robotics algorithms to perform tasks such as localization, mapping, path planning, and obstacle avoidance. The project will utilize the ROS and its open source packages to achieve these capabilities. The final system will be able to map the environment, identify the location of fire extinguishers, plan a path to reach the goal, and avoid obstacles while navigating. The purpose of this project is to aid in fire prevention by efficiently locating and reaching fire extinguishers in the event of a fire.

6. FUTURE WORK

One potential direction for future work on the described multi-agent robot system for fire extinguisher detection and navigation would be to focus on improving the accuracy and reliability of the system. This could involve fine-tuning the algorithms and sensors used by the robots to more accurately detect and locate fire extinguishers, as well as testing the system in a wider range of environments to ensure that it is robust and adaptable to different types of buildings and outdoor spaces. Additionally, integrating the robot system with other emergency response technologies, such as fire alarm systems or sprinkler systems, could help to create a more comprehensive fire prevention and response system, further increasing the effectiveness of the technology.

References

The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use “Ref. [3]” or “reference [3]” except at the beginning of a sentence: “Reference [3] was the first . . .”

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the reference list. Use letters for table footnotes.

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