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Multi-Agent Testbed Integrated With Indoor Vision-Based Positioning System

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Abstract-
This paper presents a multi-agent testbed equipped with an indoor vision-based positioning system designed for the control and localization of a fleet of ground robots. This positioning system relies on overhead cameras that detect AprilTags affixed to the top of each ground robot. These cameras are connected to Raspberry Pi microcontrollers, which communicate the position information to the ground agents through a Wi-Fi network. This system provides each ground agent with accurate position information, akin to an indoor GPS system, facilitating indoor formation control and multi-agent communication. The implementation of this system is demonstrated using NVIDIA's JetBot as the ground vehicle, equipped with a Jetson Nano microcontroller. I employ PID control techniques to implement formation control, and all agents and cameras communicate through the Robotic Operating System (ROS). The AprilTag library in Python is utilized for the detection and extraction of information from AprilTags.

Index Terms- *Multi-agent systems, Robotics, Nvidia Jetbot, Vision-based positioning system, Apriltags*

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I. INTRODUCTION

In recent years, multi-agent systems (MAS) [1-5] have emerged as a prominent and highly dynamic field of study with widespread applications in diverse domains. These systems, featuring multiple autonomous entities that collaborate, compete, or coordinate to achieve objectives, have drawn significant attention in fields such as robotics, autonomous systems, and swarm intelligence. The rationale behind the growing fascination with MAS lies in its ability to solve complex problems that often surpass the capabilities of individual agents. These systems can emulate real-world scenarios and tasks by facilitating interactions among agents, which can be physical robots, virtual entities, or software agents. To harness the full potential of a multi-agent system, however, accurate localization of the individual agents within the environment becomes a fundamental prerequisite. Without precise localization, agents may struggle to comprehend their surroundings, navigate effectively, or work cohesively, significantly impeding the overall system's performance.

This paper addresses the imperative need for agent localization within multi-agent systems by introducing an innovative multi-agent testbed. This testbed incorporates an indoor vision-based positioning system, which stands as a pioneering solution to the localization challenge. At its core, this positioning system relies on a network of strategically positioned overhead cameras, which operate in real-time to monitor and track the movements and positions of ground agents operating within an indoor environment. By affording each agent a precise and continually updated understanding of their location, this system enables them to make informed decisions, coordinate their activities, and accomplish collective goals with remarkable precision. In essence, the integration of the indoor vision-based positioning system into the multi-agent testbed heralds a promising advancement in the realm of multi-agent systems, unlocking new possibilities for improved coordination, communication, and execution of tasks in fields ranging from robotics to autonomous systems and beyond.

II. ARCHITECTURE

A. Vision-Based Positioning System: The vision-based positioning system [6-10] is the cornerstone of this multi-agent testbed, offering a robust solution for precise agent localization. This system is composed of strategically positioned overhead cameras, meticulously placed to ensure comprehensive coverage of the entire operational area. These cameras are used to detect AprilTags affixed to the top of ground robots. AprilTags are a distinctive type of visual marker known for their high-contrast patterns, which are easily discernible by the system's cameras. These markers serve as reference points, allowing the system to accurately track and identify each ground robot within the environment. The combination of overhead camera placement and the use of AprilTags forms a reliable and versatile system for real-time agent tracking and localization.

B. Hardware Setup:The hardware setup is a critical component of the system's architecture. It involves the integration of the cameras with Raspberry Pi microcontrollers. These microcontrollers play a pivotal role in processing the visual data captured by the cameras. Specifically, they extract precise position information from the detected AprilTags. This position data is crucial for determining the exact coordinates of each ground robot within the operational area. Once processed, the position information is transmitted to the ground agents via a Wi-Fi network. This intricate hardware setup ensures that the system operates in a seamless and synchronized manner, providing agents with accurate and up-to-date localization information.

C. Ground Agents: The ground agents, which are exemplified by NVIDIA's JetBot, are equipped with powerful Jetson Nano microcontrollers. Figure 1 shows the assembled jetbot employing a jetson nano microcontroller. These microcontrollers are the brains behind the ground agents, responsible for interpreting and utilizing the position information received from the vision-based positioning system. With this precise localization data in hand, the ground agents can navigate and operate within the environment with a high degree of accuracy. They can adjust their movements, paths, and actions based on the real-time position updates, allowing them to effectively respond to changing circumstances and execute tasks with precision. The mobility of these ground agents is driven by their motors, which respond to control signals generated by the system. The JetBot's capability to move within the environment in accordance with these control signals makes it a versatile and dynamic component of the multi-agent system.

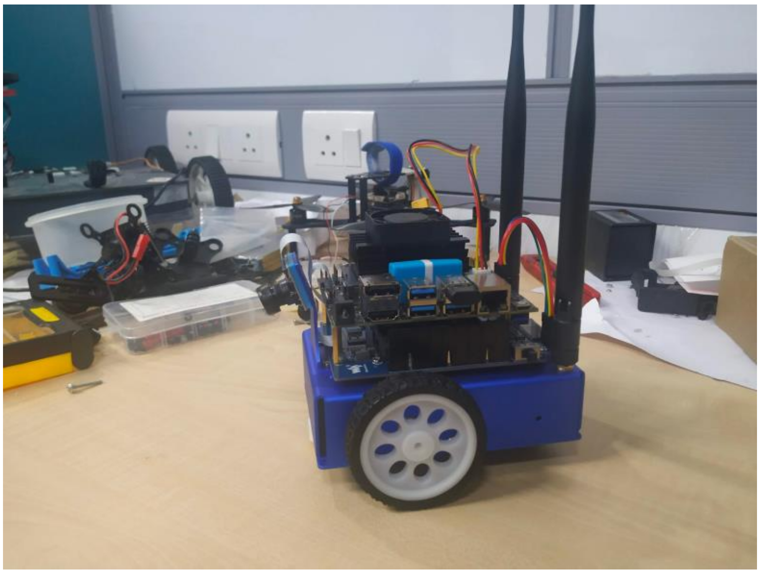

Figure 1: Ground vehicle with apriltag on the top

D. Communication: The communication framework within the system is established using the Robotic Operating System (ROS). ROS acts as the middleware that facilitates real-time message exchange and coordination between the various system components, including the cameras, Raspberry Pi microcontrollers, and ground agents. This communication framework is vital for the seamless operation of the multi-agent system. It enables the sharing of position information, control commands, and other relevant data between the different entities, ensuring that all agents are continuously aware of their positions and the positions of their peers. ROS provides a robust and extensible platform for inter-agent communication and coordination, allowing for complex multi-agent behaviors and applications to be executed effectively and in real-time.

III. INDOOR GPS-LIKE LOCALIZATION

The indoor vision-based positioning system plays a pivotal role in this multi-agent system by furnishing ground agents with highly accurate and real-time position information. This capability transforms the agents into self-aware entities within the operational environment, akin to having an indoor GPS system at their disposal. Each agent can independently and continuously determine its precise location, down to the finest details, with the aid of the overhead cameras and the AprilTags. This real-time location data allows agents to have an up-to-the-minute understanding of their own spatial coordinates, eliminating any ambiguity about their positions within the indoor setting.

Moreover, this position information goes beyond self-localization. The system's ability to provide ground agents with the positions of their neighboring agents is equally crucial. It paves the way for enhanced coordination, collaboration, and communication among the agents. In multi-agent scenarios, such as formation control, this data empowers agents to align themselves with a predetermined formation pattern, adjusting their positions as necessary to maintain the desired spatial relationships. Additionally, this information facilitates inter-agent communication, as agents can exchange location data and coordinate actions effectively. Whether it's a search and rescue mission, an autonomous warehouse operation, or swarm robotics tasks, the accurate and real-time position information delivered by the indoor vision-based positioning system is foundational for achieving a wide range of multi-agent objectives.

IV. FORMATION CONTROL

In the realm of multi-agent systems, achieving coordinated movement and precise formation control is a fundamental challenge. To tackle this challenge effectively, a Proportional-Integral-Derivative (PID) control technique is employed. The PID controller [11-13] is a well-established control mechanism widely used in various control systems, including robotics, to regulate the behavior of agents or systems in response to changes in their environment. In the context of this multi-agent system, the PID controller plays a critical role in orchestrating the coordinated movement and formation control of the ground agents.

The PID controller operates by taking two essential inputs: the desired formation pattern and the current positions of the agents within the system. The desired formation pattern represents the intended spatial configuration that the agents should assume. This pattern can take various shapes, such as a line, a circle, a grid, or any other geometric arrangement based on the specific task or objective. The current positions of the agents are continuously provided by the indoor vision-based positioning system, ensuring that the PID controller always has real-time knowledge of the agents' locations.

The PID controller then processes these inputs to generate control signals that guide the agents towards their desired locations while simultaneously maintaining the formation pattern. The "Proportional" component of the PID controller responds to the error between the current positions and the desired positions, adjusting the agents' movements proportionally to minimize this error. The "Integral" component takes into account the accumulated historical errors, effectively addressing any steady-state inaccuracies. The "Derivative" component anticipates future changes in the error and helps prevent overshooting or oscillations.

In essence, the PID controller acts as the orchestration mechanism that ensures the agents move in a coordinated fashion, adjusting their positions based on real-time data while adhering to the specified formation. This level of control is indispensable in scenarios such as swarm robotics, where precise formation control is critical for effective task execution, and it extends to various applications, including search and rescue missions, surveillance, and precision manufacturing. The utilization of the PID control technique in the context of the multi-agent system underscores the system's capability to achieve dynamic, coordinated, and goal-oriented movement while maintaining formation integrity.

V. APRILTAG DETECTION

The detection and extraction of information from AprilTags are performed using the AprilTag library [13-15] in Python. This library provides robust methods for recognizing and decoding the tags, allowing for precise positioning of the ground agents. Figure 2 shows a custom-built rover having apriltag attached on the top.

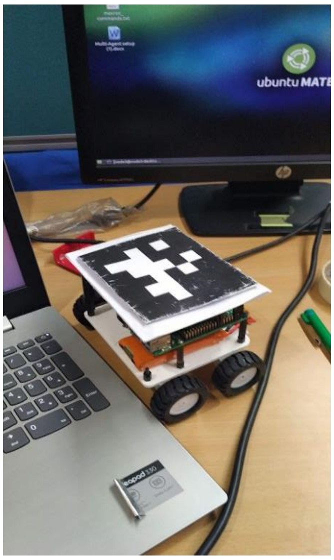

Figure 2: Custom-build ground agent with apriltag

VI. EXPERIMENTAL RESULTS

The multi-agent testbed with the indoor vision-based positioning system was tested in a controlled environment. The system demonstrated its capability to accurately localize and control multiple ground agents simultaneously. Experimental results showed that the system could successfully maintain formation patterns and enable effective communication between agents.

The provided hyperlink directs to a video demonstrating a ground vehicle's successful tracking of a square trajectory by implementing PID control. This achievement was made possible through the utilization of cameras, as detailed in the preceding sections, to determine the vehicle's precise location and orientation. Consequently, the ground vehicle effectively adhered to the intended trajectory, ensuring accurate tracking.

VII. CONCLUSION

This paper introduces a multi-agent testbed integrated with an indoor vision-based positioning system, enabling precise localization of ground agents using overhead cameras and AprilTags. The system's ability to function as an indoor GPS system allows for applications in indoor formation control and multi-agent communication. The implementation of this system using NVIDIA's JetBot and the utilization of PID control techniques were presented. Through communication in the ROS framework and AprilTag detection, the system demonstrates its effectiveness in various multi-agent scenarios.

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