

# **Multiple-Agent Surveillance Mission with Non-Stationary Obstacles**

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## **ABSTRACT**

This paper presents the overall control architecture and the work-in-progress towards demonstrating the feasibility of using a team of autonomous robots to conduct a surveillance mission with non-stationary obstacles using an innovative multi-tiered control architecture. The presented control concept involves a central control computer serving as the hierarchical monitor of the overall mission which relays the pertinent information of the new obstacle positions detected by each robot to other robots involved in the mission. The robot's on-board controllers are being designed to have the intelligence and adaptability to adjust their trajectories.

## **I. INTRODUCTION**

In recent years, there has been a strong push in the world of robotics in two areas: autonomy and multi-agent control. The ability to have several robots working together towards a common goal with little to no human supervision is a valuable tool in today's industry, domestic and government arenas. However, there are several key issues that make autonomy and multi-agent control difficult. First, the robot itself must be robust and durable enough to survive within many different environments. In addition, not only must the robot have the necessary features to allow it to accomplish the necessary tasks, its control architecture must be structured such that it has sufficient power and speed to process information in real-time scenarios. Furthermore, the control architecture must be generic and expandable since proposed missions of multi-agents may consist of not only a mixed team of ground robots but also

other agents including micro aerial vehicles (MAVs) and humans. These multi-agent teams may also be dynamically reconfiguring as mission commands change and/or agents are lost, added or replaced.

## **II. BACKGROUND**

To date, there are a variety of robots available that can be applied to several different applications. One of the most popular robots in recent years has been the PackBot from IRobot, Inc. [1]. Its design allows it to not only navigate through rough terrain but also up stairs. Other existing robots exhibit various modes of mobility and degrees of autonomy.

Due to the dynamic and mixed nature of multi-agents team(s), the right multi-agent algorithm must be used to maximize its efficiency. The Institute for Simulation and Training (IST) at the University of Central Florida (UCF) has modified an Army combat simulation program JANUS into an emergency management simulation program [[2]-[6]]. The experience obtained from that project can be utilized to develop a constructive, "war game"-like aggregative-level for the command and control. During the past two decades, significant progress has been made in the area of motion planning and control of mobile robots. Numerous issues, including motion planning for nonholonomic robots [8] and obstacle avoidance [[9]-[12]] have been investigated. Emerging from these investigations are methodologies and algorithms that utilize differential geometry and optimization theory to solve the motion-planning problem. While these methodologies and algorithms are widely used, they are typically limited to

local domains and tend to be problem specific. Alternate motion planning methodologies that employ input parameterizations, such as sinusoidal input [13], piecewise constant input and polynomial input [14] have been proposed and utilized, but these approaches offer little insight into the transient control design. Additionally, motion planning methodologies that utilize optimal control techniques have been proposed. For example, motion planning can be done numerically based on Ritz approximation theory [15] without analytical results or on approximate time-optimal trajectory to Hamilton-Jacobi-Bellman equation without considering dynamics. Again these approaches suffer from the same deficiencies. Recognizing the deficiencies and limitations of the existing methodologies, researchers have recently developed a real-time collision-free path planning algorithm for mobile robots moving in a 2-D dynamically changing environment [16]. Another popular idea in multi-agent controls is swarming robots where several of the same robots, ranging in numbers from 10s to 1000s, all have limited functionality and work together [17]. Alone, these robots cannot achieve great results, however, when in large numbers, the swarm as a whole is capable of completing many tasks. The advantage to using swarming robots is that each of the robots can be relatively inexpensive. Another advantage is that if one robot is destroyed, the others can still function normally as if nothing has happened. A key disadvantage to swarming robots is that the functionality of the swarm is limited. Also, the efficiency of the swarm begins to decrease as the number of robots increases past an optimal number. For this paper, a multi-tiered control architecture is presented, enabling several mobile robots to work together while leaving difficult computational tasks to be done by the tier above it.

### **III. MULTI-TIERED CONTROL**

The concept behind multi-tiered control allows several robots to operate in a given area while providing a centralized control for immediate command changes. The idea for multi-tiered control can be best visualized by imagining a military hierarchy where the commands come from the higher levels and most of the work and difficult tasks are achieved by the lower levels. For example, a General may issue a command to a few of his/her Lieutenants who would then pass the commands through many levels until eventually several Privates carry out the command. The advantage to this system is that each level must only worry about supervising the level below it and reporting to the level above it. This advantage is a key reason why this system is being further explored in multi-agent robotics. In multi-agent robotics, this style of controls allows the more tedious calculations to be done on the lower levels while freeing the higher levels to perform more complicated task allocations. In turn, a higher level is

able to control several more tiers of robots since there will be more computational power at its level. Figure 1 illustrates a basic example of how a hierarchical system might work in practice.

The figure shows three groups of robots that are being used to diffuse a hostile situation. There are three different groups of robots shown: a group of MAVs, a group of mobile robots, and another group of mobile robots with specialized skills. The MAVs are used to generate an initial map of the area and send the results to the mobile central command station that is far from the hostile situation. The map is then sent to the first group of mobile robots. These robots use the map provided by the central command station and provide details of the site. For example, the robot team can provide information as to the location of obstacles and potential targets (shown in this scenario as bombs). The detailed information is sent up to the command station where it is processed and sent back down to the second group of mobile robots. This group is outfitted with specialized equipment to perform a specific task. In this scenario, the robots can diffuse the bombs. Therefore, the group of robots can use the information provided to it to perform its task. This system allows for the completion of a task with a much greater efficiency than if one group of similar robots were to try and accomplish it alone. In addition, it allows for each different group of robots to work on a specific task without interfering with any of the other group while still allowing the groups to work together with the central command station. Finally, another advantage to the system is its ability to function in real-time situations so that the entire hierarchy can adapt to new sensory information.

The presented work-in-progress intends to first demonstrate multi-tiered control on a much smaller scale where a team of autonomous robots' collective mission is to survey an area. The mission involves continuous registration of a number of fixed checkpoints within a time limit. The terrain database and checkpoint locations are known a priori with each robot equipped with on board pre-planned trajectories. However, during the mission, new obstacles may appear unexpectedly. When a robot encounters a new obstacle, it maneuvers around it and reports to the central control computer. The central control computer in-turn then relays the information to all other robots so that when other robots enter the area with the new obstacle, they expect the existence of it. However, the location of the obstacle may change or it may disappear altogether. Thus, the robots' on-board controller is designed to have the intelligence and adaptability to adjust their trajectories accordingly. Figure 2 shows a diagram of how the different elements of the multi-tiered control architecture will communicate.

#### IV. TEST BED DEVELOPMENT

Being a work-in-progress, only some of the most basic testing has been accomplished thus far. Most of these tests include everything from hardware and software testing to basic implementation of robot control. The current test bed for the multi-tiered controller includes a position measurement system that provides feedback to the main controller that provides command information to the robot. The position measurement system created by PhaseSpace, Inc. consists of cameras that track the position of LEDs attached to the robots. Figure 3 shows an example of the LEDs on one of the mobile robots. The X, Y, and Z positions of the LEDs are fed back into the controller,

which then analyzes the information to update the commands given to the robots [18]. These robots have been given limited autonomy. They receive trajectories definitions from the higher level control center and are able to detect obstacles. Using infrared sensors that are currently placed on the robots, the robots will continue along their path until an obstacle is located. Once the obstacle is found, the robot will note the relative position of the obstacle and report that information to the higher level. The higher level will update its map of the area accordingly while the robot uses its path-planning algorithm to generate another path to the target position. To date, the testing on this system includes tracking a mobile robot to generate a map of its position over the course of its movements.

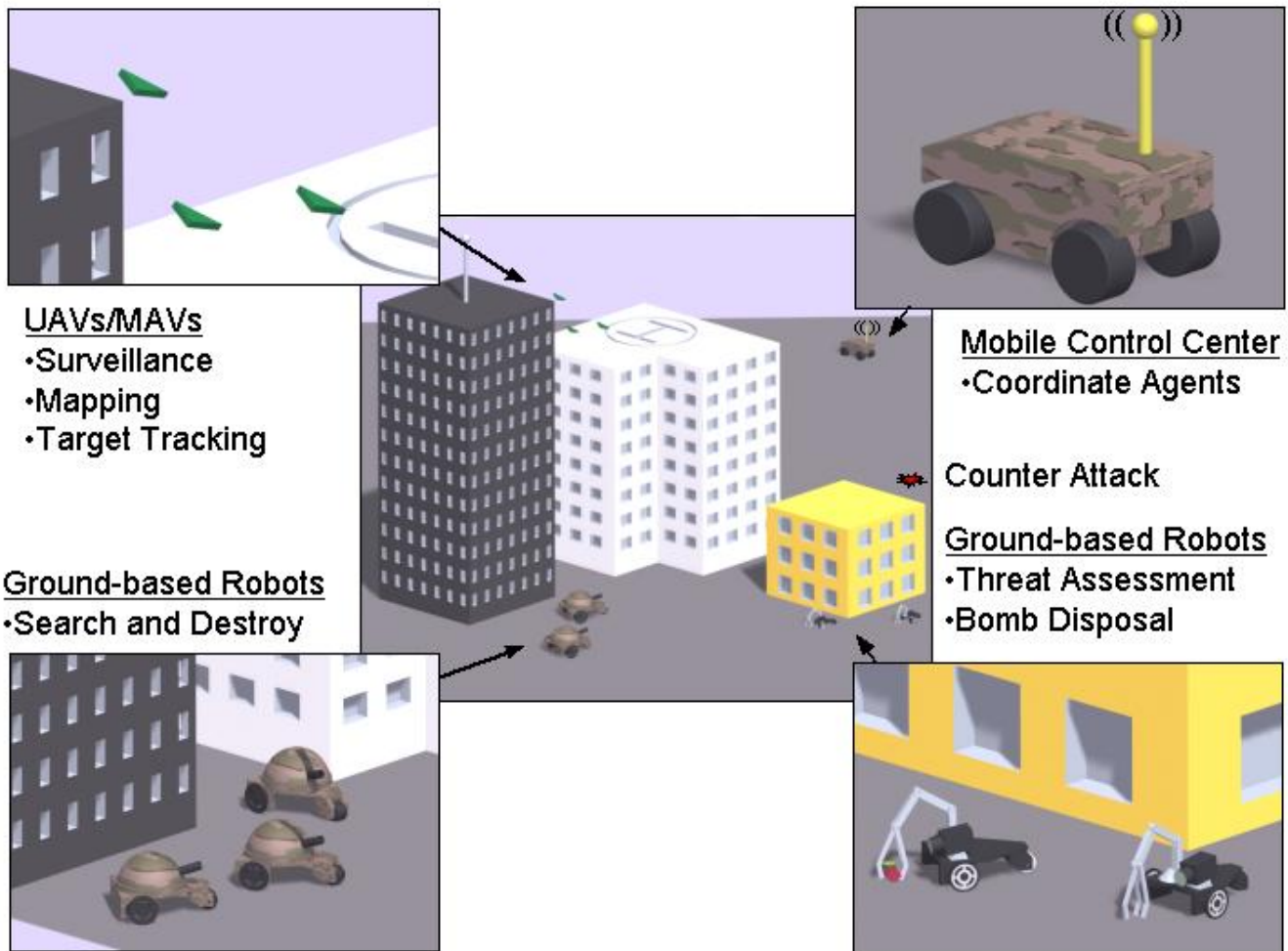


Figure 1: Scenario for multi-agents using a multi-tiered controller

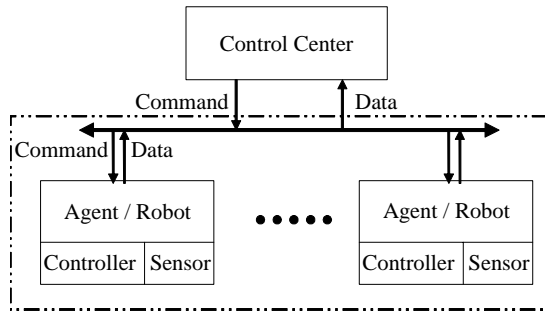


Figure 2: Diagram of multi-tiered control architecture

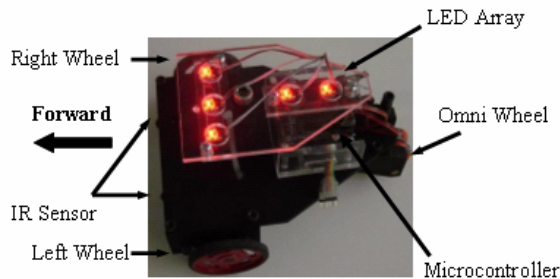


Figure 3: Test robot with LEDs attached

There are several upgrades to the current setup that will greatly improve the testing ability of the multi-tiered system. First, additional cameras will be added. The cameras will increase the viewable area that the robots can function in. Also, additional cameras allow for greater accuracies in the position estimates of the robot. While the inconsistency of accuracy replicates a real situation, the increased position accuracy of the robot creates better efficiency in the early stages of controller development and demonstration. Another key upgrade to the hardware is the addition of wireless LEDs that mount onto the robot and wireless communication with the command station. Without the constraints of wires, more robots can be added to the testing area and the hierarchical system can be tested with several more levels.

The future research plans consist of several steps that will culminate into a complex testing of the multi-tiered system. Some of these are the development of integrated path-planning algorithms and the introduction of static and non-stationary obstacles into the robot arena. For this stage of testing, several algorithms will be investigated to find one that appropriately fits the needs of the system.

The next step in testing involves the cooperation of two different robots. Each robot will represent a group of robots that may exist in the application of the hierarchical system. The first robot will enter the area and attempt to find the target from an a priori position provided to it. The robot will continue along its path, sending obstacle

information to the higher level, until it has reached the target. Soon after, the second robot enters and uses the map that the higher level has generated to find the target. Using this system, the second robot will have knowledge of existing obstacles and, therefore, will be able to generate a more efficient path to the target. Essentially, the higher level prevents the second robot from making the same mistakes as the first.

Improving on the previous test, mobile obstacles and targets show the robots' abilities to act and react in real time to changes in their environment. The robots will be required to continually check for obstacles en route to their assigned targets. In addition, the higher level will be continually updating its map of the area to attempt to provide up-to-date information about possible obstacle and target locations to the robots. The final step of the testing of the system will be the implementation of a vision system on the robots. With cameras directly mounted to the robots, they will be able to identify targets and obstacles with much more accuracy and will be able to provide more information to the higher level with greater detail.

## V. CONCLUSIONS

Although still a work-in-progress, it is expected that full implementation of the described demonstration scenario will show that through accurate position feedback and communication between the central computer and the robot, the multi-tiered controller approach to controlling several robots will be effective.

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