 PRICAI 2000 Workshop on Teams with Adjustable Autonomy

Position Paper
Designing an architecture for adjustably autonomous robot teams

David Kortenkamp
NASA Johnson Space Center – ER2
Houston, TX 77058
kortenkamp@jsc.nasa.gov

1 Introduction

We are beginning a project to develop fundamental capabilities that enable multiple, distributed, heterogeneous robots to coordinate in achieving tasks that cannot be accomplished by the robots individually. The basic concept is to enable the individual robots to act fairly independently of one another, while still allowing for tight, precise coordination when necessary. The individual robots will be highly autonomous, yet will be able to synchronize their behaviors, negotiate with one another to perform tasks, and "advertise" their capabilities. This architectural approach differs from most other work in multi-robot systems, in which the robots are either loosely coupled agents, with little or no explicit coordination [1, 4, 5], or else are tightly coordinated by a highly centralized planning/execution system [3]. Our proposed architecture will support the ability of robots to react to changing and/or previously unknown conditions by replanning and negotiating with one another if the new plans conflict with previously planned-upon cooperative behaviors. The resulting capability will make it possible for teams of robots to undertake complex coordinated tasks, such as assembling large structures, that are beyond the capabilities of any one of the robots individually. Emphasis will be placed on the reliability of the worksystem to monitor and deal with unexpected situations, and flexibility to dynamically reconfigure as situations change and/or new robots join the team.

A main technical challenge of the project is to develop an architectural framework that permits a high degree of autonomy for each individual robot, while providing a coordination structure that enables the group to act as a unified team. Our approach is to extend current state-of-the-art hierarchical, layered robot architectures being developed at NASA JSC (3T) [2] and CMU (TCA) [6] to support distributed, coordinated operations. Our proposed architecture is highly compatible with these single-agent robot architectures, and will extend them to enable multiple robots to handle complex tasks that require a fair degree of coordination and autonomy.

As second technical challenge is to use distributed techniques to provide coordinated control of complex, coupled dynamic systems. For example, a mobile manipulator may have many degrees of freedom and controlling them all from a single controller would be complicated and computationally expensive. However, by breaking the complicated control problem into several simpler control problems and then having the simpler control problems coordinate and cooperate with each other to achieve a task we can reduce complexity and computational requirements. This approach will require the architectural support described in the previous paragraph.

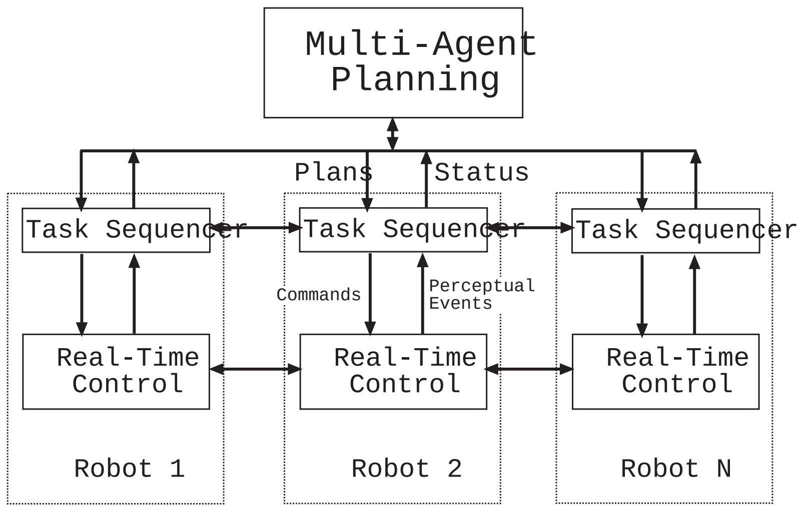

Fig. 1. A distributed, multi-layered robot architecture.

2 Approach

Our basic approach to multi-robot architectures is to distribute the behavior and sequencing layers of the three-tiered architectural approach, while maintaining a centralized planner (Figure 1). The centralized planner sends high-level, abstract plans to individual robots, where the plans include goals to be achieved and temporal constraints between goals. The task sequencer then decomposes the goals into subtasks, and issues commands to the behavior layer. The behavior layer executes the commands, sending data back to the sequencer so that it can monitor task execution. Occasionally, status information is sent back to the planner, especially when the robots encounter problems they cannot solve.

3 Preliminary work

Our project testbed will be a multi-robot construction scenario (see Figure 2). Our most significant achievement to date is the development of distributed visual

Fig. 2. Mobile manipulator and roving camera performing construction task.

Fig. 3. Fixed manipulator and roving camera perform servoing. Colored fiducials are used for vision.

servoing, using a roving eye and fixed manipulator (see Figure 3). The servoing system uses a pair of color stereo cameras to provide a 6DOF pose that is the difference between two colored fiducials. This difference is used to drive the arm. The servoing continues until the target fiducial reaches the desired pose. The roving eye drives around the workspace to keep the targets in sight and centered in the image, and it moves back and forth to ensure that the targets fill most of the camera field of view. The roving eye and arm are completely distributed and autonomous. They use a distributed version of 3T's Skill Manager to coordinate activities. This work was performed jointly by NASA JSC and CMU graduate student David Hershberger, who worked in the NASA JSC labs over the summer. This use of a roving eye, completely separated from the arm it is guiding, is a novel approach to visual servoing and has many applications in construction and manufacturing. We are currently performing experiments to measure quantitatively the precision obtained by this approach.

4 Adjustable autonomy issues

The work we discuss in this paper has not yet directly addressed adjustable autonomy. This section introduces some adjustable autonomy issues and possible solutions.

- **Teaming**: Our approach will allow robots to create dynamic and ad hoc teams to accomplish tasks. Sometimes this will require several robots to become "subservient" to other robots while members of a team. For example, if two robots are moving a long beam, one of the robots may be designated the lead robot and it will pass commands directly to the other robot, which will execute them with limited autonomy. During the course of performing many different tasks, robots may sometimes be in the leader role and sometimes in the follower role. So, they will need to adjust their autonomy level to reflect their role in the team.

- **Operator interaction**: The goal of our research is to develop remote colonies of robots on planetary surfaces. Because of limited bandwidth communication, operator interaction with the robots will be limited. However, there may be times when direct operator control of an individual robot or a team of robots is required. Traded control options will need to be built into our architecture.
- **Human/robot teams**: We also want to allow for the possibility that human crew members could be working along side robotic crew members in construction tasks. While this will require significant human/robot interaction advances (for example in natural language and vision), the adjustable autonomy aspects should not be much different than in the first bullet of this section.

5 Acknowledgements

The development of this proposed architecture has been a collaborative process with Reid Simmons of Carnegie Mellon University and Robert R. Burridge of NASA Johnson Space Center. CMU graduate student David Hershberger implemented the system described in Section 3 while working at NASA Johnson Space Center.

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