Sensor Planning and Coordination in Multiagent Systems *

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Abstract

This paper describes the application of Artificial Intelligence planning techniques to sensor pointing and control. In particular, the SAUSAGES plan execution system has been adapted to execute and control plans generated for the guidance of autonomous vehicles and control of camera movement associated with the vehicle. Additional capabilities have been added to allow for multiple vehicle and sensor coordination.

1. Introduction

Traditionally, research in planning and research in image understanding have been pursued independently. The ARPA Unmanned Ground Vehicle program is pulling together these two technologies in order to autonomously execute multi-vehicle missions.

In this problem domain, planning for vehicle movement and planning for sensor movement must be performed in harmony. One reason for this synchronization is the need to maintain 360 degree security around the platoon formation. This security requires planning for sensor pointing such that the entire area is covered and is divided among the active vehicles.

Another motivation for controlling vehicle and sensor movement together is active RSTA, or coordinated recognition of enemy targets. Executing such a coordinated effort requires planning of both vehicle position and camera angle for maximum coverage of the target while maintaining formation security. A third reason that plan generation is needed for both vehicle and sensor movement is stealth navigation through unknown terrain.

2. Plan Generation and Execution

The plans for coordinated sensor movements are stored and executed by the SAUSAGES system. The SAUSAGES system, developed at Carnegie-Mellon University, represents plans as a set of semantic steps called "links". The links are sequenced together to form a graph, and SAUSAGES' Link Manager is used to execute this "plan" graph. When the Link Manager invokes a link, it executes the action associated with that link, such as "go into road following mode". The link has associated with it production rules such as "if you detect an intersection, end this link", "every second, report the vehicle position to an inspector module", or "if the road ends, report failure of this link". When a link ends, its rules are taken out of the Link Manager's active production system.

SAUSAGES has been successfully used by the Unmanned Ground Vehicle program as a tool for executing missions in the uncertain world of an autonomous vehicle. However, to date SAUSAGES has been designed only as a tool to control vehicle movements. No capabilities have been introduced that allow for sensor planning or for coordination between multiple vehicles, each executing a copy of the SAUSAGES program. The following sections describe our contribution in this area.

3. Adding sensor planning capability to SAUSAGES

SAUSAGES has traditionally been used to control vehicle movement. We have added capabilities to this plan execution system that control sensor movement as well as vehicle movement. For example, the single camera aboard an unmanned ground vehicle is now controlled by our planning system. The range and the current camera angle are determined by the system as is dictated by the mission and the current en-

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vironment.

Figure 1 shows an example vehicle/sensor RSTA plan. The white rectangles indicate a vehicle position, and the pie slices directed out from the vehicle represent the current camera angle, or "field of regard".

A sensor plan is generated according to the specifications derived by the Scenario-Based Engineering Process (SEP) analysis of the RSTA task. The SEP analysis specifies weighted areas of focus for each vehicle that correspond to a particular task within a RSTA mission. Additional factors that can influence the sensor plan are coordination with other vehicles, enemy sightings, and terrain features.

4. Coordinating sensor plans for multiple agents

Another capability that we have added to the SAUSAGES plan execution system is multi-vehicle planning and coordination. To date, SAUSAGES has been used as a system to control a single vehicle. The planning system can be copied on board every available vehicle, but without communication and coordination between the vehicles, the mission will not be executed smoothly. Communication and coordination are necessary to plan collision-free trajectories, to execute active target recognition, and to dynamically change strategies during the mission execution itself.

To enable multi-vehicle coordination, we have implemented the capability to instantiate multiple instances of SAUSAGES as separate processes. The processes communication with each other using the communication protocol TCX. Messages contain information such as current GPS position, current camera angle, current goal and detection of enemy targets. This information is used to complete the mission while maintaining the desired formation. Figure 1 shows sensor and vehicle coordination inside a diamond formation.

5. Conclusions

In this project, we have applied AI planning techniques to the problems of vehicle and sensor control for multiple autonomous vehicles. The SAUSAGES plan execution system has been modified to plan for sensor control as well as vehicle control, and multi-agent coordination capabilities have been added to the system.

The Unmanned Ground Vehicle project provides one domain in which planning for sensor movement is essential. Future work will be performed to carry over this research to other planning problems in active vision and image understanding.

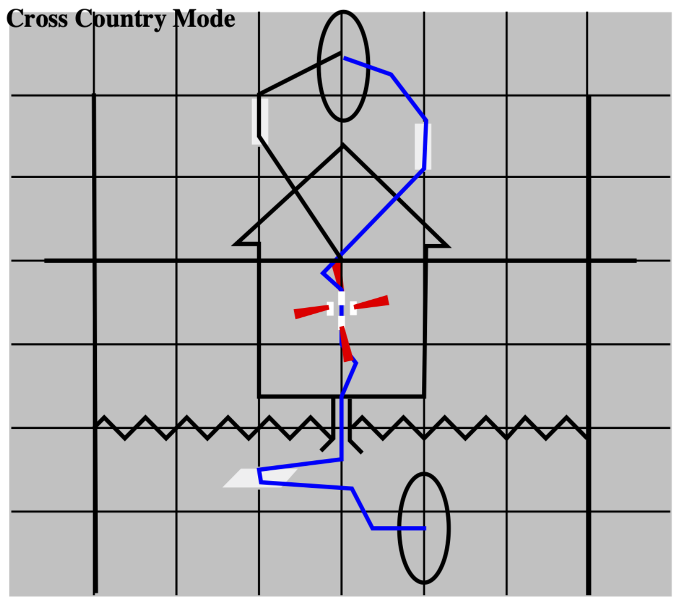

Figure 1: Coordinated sensor and vehicle plan for RSTA