Tactical Operations of Multi-Robot Teams in Urban Warfare

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ABSTRACT

With scaling of multi-robot teams deployed in military operations, there is a need to boost autonomy of individual, as well team behaviors. We developed a feature-rich simulation testbed for experimental evaluation of multi-agent coordination mechanisms applicable in tactical military operations in urban warfare. In particular, we investigated four approaches including multi-agent mission planning and plan repair, reactive planning for teamwork, patrolling of mobile targets, and tracking of smart targets. Besides the live-system demonstrator, we aim to showcase a scenario engaging a human in a pursuit-evasion game against the algorithms we implemented.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Intelligent agents, Multi-agent systems*

Keywords

tactical operations, fame theory, multi-agent coordination and teamwork, planing and plan repair, simulation toolkits

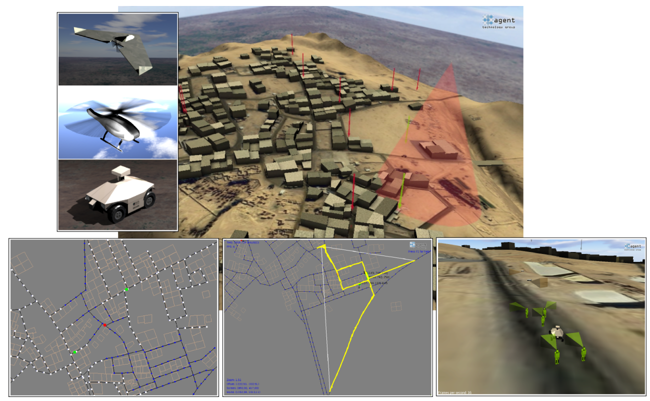

Figure 1: Tactical AgentScout simulator facilitates rich models of physical reality and supports physical mobility dynamics of robots, such as ground and aerial vehicles, be it fixed-wing aircraft, helicopters or various rotorcraft.

1. ROBOTS IN TACTICAL OPERATIONS

Maturing of hardware robotic technologies enabled a widespread utilization of robots as a supportive technology in military operations. Their use in urban warfare has proven its merits, be it in bomb disarmament, or information-collection tasks, such as area surveillance or tracking of mobile targets. While the state-of-the-art techniques for robot control based on teleoperation suffice for handling individual robots, they do not scale with a growing number of assets required for larger-scale operations. Missions like performing several information-collection tasks concurrently in a geographically large urban area are, however, well in reach of the modern hardware technology. In turn, there is a growing need for development of mechanisms for autonomous operation of multi-robot teams in such scenarios.

Here we report on results of the project Tactical AgentScout[1] carried out by our group in the course of the years 2009–2011, in which we studied *coordination mechanisms for multi-agent systems applicable in the context of tactical military operations in urban warfare*. A typical scenario in such operations involves a mixed human-robot team acting in an urban area so as to find and arrive to a safe-house location where a person of interest is held, secure the person and finally escort it to a destination location where the mission ends. In the following, we briefly report on four particular multi-agent coordination mechanisms we studied. To support an experimental evaluation of the proposed techniques, we implemented an agent-based simulation testbed. It allows us to test the resulting agent behaviors in more realistic settings and provides a visually attractive and interactive live-system demonstrator.

[1] `http://agents.cz/projects/agentscout2/`

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2. MULTI-AGENT COORDINATION

We studied four coordination techniques in the context of a rescue scenario in a hostile urban environment described above.

Multi-agent planning and plan repair

To carry out the rescue scenario, the team of cooperative robots with heterogeneous skill-sets needs to plan the mission including the coordination among the team members, none of which is able to complete without help of the others. The hostile urban area represents a highly dynamic environment in which action and in turn also high-level task execution often fails. We investigated techniques of fully decentralized mission planning and subsequent plan repair in the case of a plan failure [2].

At the heart of our approach lies a multi-agent extension of classical planning based on distributed constraint satisfaction. For the case of a plan failure, we proposed several decentralized plan repair algorithms preserving as much of the original plan as possible. The planning, execution, monitoring and plan repair components are all fully distributed and based on a state-of-the-art multi-agent planning approach MA-STRIPS. Our experiments demonstrate that in a case of an unexpected plan failure, decentralized plan repair leads to a lower communication overhead than a naive replanning.

Reactive planning for teamwork

Predictability of peer behavior is of paramount importance in mixed human-robot teams in military scenarios, such as traversal of cluttered urban environment by an alert squad. Execution of pre-scripted behaviors is more suitable in such contexts in contrast to fully automated mechanisms for activity planning. We studied extensions of agent-oriented programming techniques to multi-agent teamwork programming and coordination.

We employed and adapted the framework of *Distributed Commitment Machines* (DCM) and formulated mission specifications as interconnected networks of individually executable agent commitments. A DCM takes care of both activation of new commitments succeeding the completed ones, as well as correct handling of plan interruptions. Our initial experiments indicate that the DCM framework is a promising tool for concise specification of team-level missions and that reactive agent programs implementing a DCM-based mission specification are capable of generating correct and elaboration tolerant behavior patterns.

Patrolling of mobile targets

Convoys traversing a hostile urban area need to be protected. Firstly, an aerial patrol needs to re-visit each target sufficiently often to minimize the window of opportunity for the adversary to attack. Secondly, the route of the patrol must be randomized in order to minimize its own predictability assuming the patrol is observed by the adversaries. To model the scenario, we studied extensions of a computational game-theoretic model termed *patrolling games* [1].

We extended the existing models of patrolling games with the concept of mobile targets, represented by convoys traversing the urban area. We use *Strong Stackelberg Equilibrium* (SSE) as the solution concept in the patrolling games. In turn, we formalized computing SSE as finding a solution to a set of non-linear mathematical programs. We performed an experimental evaluation of the model on a scenario with a large number of adversaries aiming to attack the convoys and compared the game-theoretic approach with the deterministic patrolling strategy. Our technique achieved better results even though a number of simplifying assumptions of the mathematical model were not met in the experimental environment.

Tracking of smart targets

Smart targets are those aware of the fact that they are being pursued and try to actively avoid the tracker. Tracking of such targets is a particularly challenging task due to a need to be able to predict the adversary's moves and execute a rational behavior against its best strategies. Our solution was based on a game-theoretic model of *pursuit-evasion game with imperfect-information* [3].

We model the visibility-based pursuit-evasion game as an imperfect-information extensive form game. The game is too large to compute its exact Nash equilibrium, therefore we use the information-set search approach with paranoid opponent model that computes a guaranteed strategy of the players. In order to meet the real-time computational constraints, we used Monte Carlo tree search to explore the information-set trees. Our experimental results indicate that this combination of techniques allows creating a successful autonomous team of pursuers in practically large domains with real-time computational constraints.

3. DEMONSTRATOR

Our aim is to demonstrate the results of the project embodied in a multi-agent simulator testbed, as well as the underlying technological platform. To this end, we will demonstrate the live Tactical AgentScout system running a series of example scenarios showcasing the multi-agent coordination mechanisms discussed above in an example of a tactical rescue mission in a simulated complex urban environment. The example multi-robot systems are embodied in a simulated physical environment developed in an in-house agent toolkit Alite[2]. Besides facilitating *en masse* experimental data collection, the platform enables rapid modeling of various types of robotic assets (see Figure 1), including features such as physical dynamics of vehicles, physical occlusions, 3D landscape, both discrete, as well as event-based simulations, etc.

Furthermore, the live-system demonstration will be accompanied by an interactive interface allowing a human subject to engage the implemented game-theoretic algorithms for pursuit-evasion game. The human will be able to control the evading unit in at least two basic settings: the full information scenario presenting all the information about the state of the simulation and an incomplete-information scenario providing only limited sensory data about the world to the evader (e.g., unknown positions of the pursuers). The former mode supports debugging and analysis of the presented methods, while the later facilitates evaluation of the methods against a human adversary.

4. DISCUSSION AND FINAL REMARKS

Development and evaluation of multi-agent coordination algorithms targeting their deployment on robotic assets is a challenging task. On one hand, evaluation on target physical platforms is extremely expensive and possibly even risky, or legally problematic (e.g., flight permissions). On the other, testing in a simulation is prone to neglect vital, but often not easily identifiable constraints of the physical reality. Our approach is innovative in that we perform experimental evaluation of the techniques in high-fidelity simulations allowing us to model relevant physical features in detail, be it visibility occlusions by buildings, interactions of terrain features with physical dynamics of ground vehicles, etc. The natural next step, a subject of a currently on-going intensive effort in our group, is to adapt and deploy the discussed coordination techniques to real world robotic hardware, in our case unmanned aircrafts. The underlying multi-agent toolkit Alite provides a very open and flexible platform for rapid implementation of the supporting infrastructure in terms of series of experimental simulations and mixed-reality simulations.

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5. REFERENCES

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[3] Viliam Lisý, Michal Pěchouček, and Branislav Bošanský. Anytime algorithms for multi-agent visibility-based pursuit-evasion games. In *Proceedings of AAMAS 2012*.

[2] `http://agents.cz/projects#alite`