Convoy Protection by Self-Organized Teams of UAVs

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1. INTRODUCTION

A major characteristic of combat is the need to quickly adapt to new situations. Providing support and protection for a convoy is challenging since it requires coordination between the different participants to efficiently allocate the protecting resources. In a combat situation, such as when the convoy is under attack, forces have no spare time to spend. Every second is extremely valuable, and context switching between different tasks is not desirable. Moreover, decision making in a stressful situation, such as combat, tends to be far from efficient. Another aspect that is central to distributed combat is the requirement to keep communication usage as low as possible so that the adversary cannot apply electronic warfare technologies to intercept messages and introduce interference that would disallow distributed collaboration. Another reason is that by reducing the amount of unmanned air vehicle (UAV) communication we provide more reliable communication bandwidth for urgent needs.

We propose innovative use of teams of small and inexpensive UAVs to autonomously allocate convoy protection tasks and robustly adapt their behavior to the changing environment. We envision a dynamically self-organized protective shield based on large-scale multiagent concepts. Each UAV will be controlled by an onboard agent that will sense, reason, and act autonomously according to the changing environment. Communication will be done by observation of the behavior of other UAVs and convoy vehicles rather than by message exchange. To support scalability, many large-scale multiagent paradigms suggest interacting with only a limited number of agents ([2]). Those agents should be carefully selected to provide an efficient and valuable solution. In this work we use concepts inspired by the Reynolds algorithm ([1]) and physics-based theories. Each agent in our scalable solution is capable of reasoning about the behavior of some UAV agents and some vehicles that are part of the protective convoy. A range of interaction is introduced to construct a closed area in which any other UAV or convoy vehicle is notable by the agent. To provide further flexibility and more general applicability, we allow separate interaction ranges for agent-UAV and agent-convoy vehicles.

[1]Using live demo software

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2. THE PROBLEM SCENARIO

A convoy of twenty-five vehicles is moving in Iraq. Fifty UAVs are assigned to provide aerial protection over the convoy. While moving, part of the convoy leaves the rest of the convoy and takes another route. Autonomously, without explicitly communicating with their peers, some of the UAVs take responsibility over the diverting part while the others continue to protect the main convoy. As a result of malfunction, maintenance requirements and low battery power, twenty UAVs leave the convoys, which then have less coverage but are still protected. After a period of time, thirty new UAVs join the protective forces. After another period, twenty more vehicles join the main convoy and receive the protection they need.

3. THE ALGORITHM

By sensing other participants, each agent can find the location and derive the velocity of each nearby participant. Based on that understanding, the agent uses our version of the Reynolds algorithm to control its UAV maneuvers. In our algorithm, each agent is assigned to a fixed set of convoy vehicles. When these vehicles are located within the agent convoy range of interaction, the agent reasons about their location and velocity, to decide on new headings.

We propose an innovative algorithm to be applied by each agent that weights the contribution of the other UAVs and the contribution of convoy vehicles to the control decision. According to the algorithm, each agent follows one of Reynolds' three basic steering rules: cohesion, separation, and alignment. The agent decides to follow a single rule based on a given probability for each rule and follows it for a random amount of time. Inspired by physics concepts we enhanced that algorithm to take into consideration the square range between the UAV and the followed convoy vehicles. By that we established a strong connection to a specific vehicle that can flip if another vehicle comes closer. That characteristic behavior removes the balanced behavior that results in hanging between convoy vehicles and looking for the average location rather than our desired behavior of choosing one vehicle to follow.

Cohesion mode. The agent steers toward the average position of the nearby UAVs and convoy vehicles.

$$\vec{r} = \frac{1-W}{|U|} \cdot \sum_U \Delta\vec{r_i} + W \cdot \sum_V \frac{r_i^2}{R^2} \cdot \Delta\vec{r_i}$$

The agent calculates $\vec{r}$ and steers toward it, taking into account the maximum radial velocity allowed.

Separation mode. The agent steers to avoid crowding UAVs and convoy vehicles.

$$\vec{r} = -\frac{1-W}{|U|} \cdot \sum_U \Delta\vec{r_i} - W \cdot \sum_V \frac{r_i^2}{R^2} \cdot \Delta\vec{r_i}$$

As in the cohesion mode, the agent calculates $\vec{r}$ and steers toward it, taking into account the maximum radial velocity allowed.

Alignment mode. The agent steers toward the weighted average heading of nearby UAVs and convoy vehicles and accelerates or decelerates based on the weighted average speed.

$$\vec{Ir} = \frac{1-W}{|U|} \cdot \sum_U \vec{Ir}_i + W \cdot \sum_V \frac{r_i^2}{R^2} \cdot \vec{Ir}_i$$

$$\vec{r} = \frac{1-W}{|U|} \cdot \sum_U \Delta\vec{r_i} + W \cdot \sum_V \frac{r_i^2}{R^2} \cdot \Delta\vec{r_i}$$

The agent calculates the weighted identity vector and steers accordingly, while taking into account the maximum radial velocity allowed, and adapts the velocity.

4. DEMONSTRATION

A station provides live visualization and control over the scenario, the system, and collaboration parameters. The visualization screen displays a map, a real-time update of the convoy, and each UAV's location and state. A convoy consists of a leading vehicle and an array of following vehicles. The leading vehicle is marked with dark gray, while the following vehicles are marked with light gray. UAVs are colored differently according to their mode of operation. UAVs in cohesion mode are blue, UAVs in separation mode are red, and UAVs in alignment mode are green.

While the simulation is running we demonstrate interactive control. The control panel consists of three categories: UAVs, Convoy, and Preferences.

The UAVs category allows changes to the following:

Collision Range. Minimum distance allowed between two nearby UAVs.

Number of UAVs. Number of participating UAVs.

Speed. Speed of the UAVs.

Max Radial Speed. Maximum allowed radial speed for a UAV.

ROI With UAVS. Range of interaction with other UAVs.

ROI With Convoy. Range of interaction with vehicles in a convoy.

Separation Weight. Probability to switch to separation.

Cohesion Weight. Probability to switch to cohesion.

Alignment Weight. Probability to switch to alignment.

Separation Max Time. Maximum time in seconds that can be randomly picked up for separation mode.

Cohesion Max Time. Maximum time in seconds that can be randomly picked up for cohesion mode.

Alignment Max Time. Maximum time in seconds that can be randomly picked up for alignment mode.

The Convoy category allows changes to the following:

Number of Joints. Number of vehicles participating in a convoy.

Gap Between Joints. Distance between two adjacent vehicles in a convoy.

Speed. Speed of the convoy.

The Preferences category allows changes to the following:

Draw Convoy. Presenting or not presenting convoys.

Draw UAVs. Presenting or not presenting UAVs.

A click anywhere on the map splits all convoys into two separate convoys.

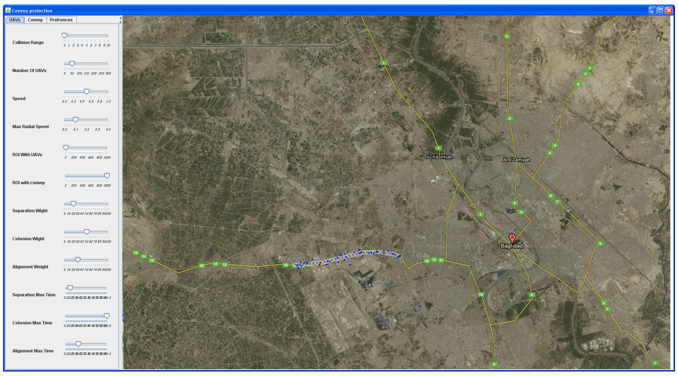

Figure 1: Self-organized teams of UAVs protecting a convoy

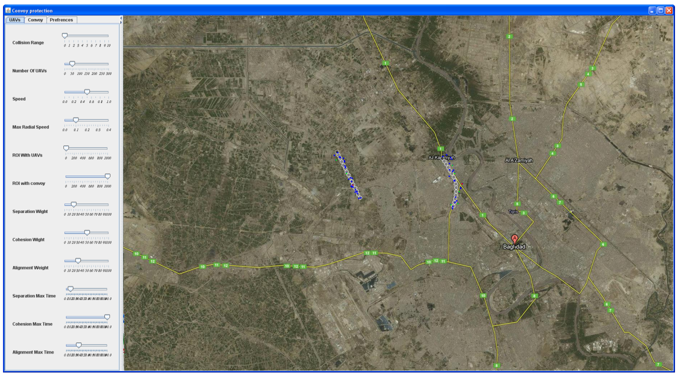

Figure 2: The UAVs reorganize to protect a split convoy

5. REFERENCES

[1] C. W. Reynolds. Flocks, herds, and schools: A distributed behavioral model. *Computer Graphics*, 21(4):25–34, 1987.

[2] O. Yadgar. From local search to global behavior: Ad hoc network example. In *Cooperative Information Agents XI*, pages 196–208, October 2007.