Robust Mobile Robotic Formation Control Using Internet-Like Protocols

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Abstract

This work presents an Internet-Like Protocol (ILP) to coordinate the formation of n second-order agents in a two dimensional (2D) space. The trajectories are specified trough via points and a desired formation at each point. A basis for the proof of convergence is given using Lyapunov second method. Simulink is used to verify the response of the agents in the desired trajectories. The proposed algorithms are robust in the sense that they can accommodate changes in the formation of the agents and more importantly, changes in the umber of agents as some of them drop of or join the formation.

The coordination and formation of multiple agents is a problem of particular interest to numerous research groups [1], [3], [4], [5]. Applications of such research abound in space (satellite formation), military (remotely-operated clusters of vehicles) and civilian applications The problem of distributed coordination and control of such agents has been theoretically studied using various approaches. In [1], a graph-theoretic approach was presented to explain the behavior of n particles in the plane in an attempt to justify the model presented in [2], which had proposed a discrete-time model illustrating the heading alignments of the n particles. Graph theory was also utilized in [3] to define cost functions that govern the movement of the n systems/agents. In [4], virtual potentials were discussed as an analysis tool, while in [5], local sensing and minimal communication was the main focus of the research.

In this paper we present a different approach to the distributed control and coordination problem, inspired by the Internet congestion control protocols [6]. We formulate the coordination and control of various agents as a problem of competing for a common resource. Despite such selfish behavior, it has recently been shown [7] that all users proportionally share in the resource and indirectly cooperate to maximize the global utility of all users. The supervisor of such behavior is a main controller which sets a price to be incurred by a user as a function of the resource usage and resource capacity, then transmits this price to the users. By doing so, all users receive the same feedback price, and the communication overhead is significantly reduced. The purpose of this paper is to show exactly how such algorithms may be adopted to the coordination and control of physical agents, and in particular to the case of two-dimensional mobile agents. Moreover, we illustrate via simulation that such algorithms are robust to changes in the numbers of agents: if a particular robot (or a group of them) drops out of the formation or if others join the formation, the group continues on a stable trajectory. This is similar to the behavior of a network of computers which remains connected despite the

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fact that computers are dropping in an out of the network all the time. The following simulations illustrate the claims made so far.

Figure 1 shows the results when the agent in the right vertex of a triangle removes itself from the formation, when the agents were commanded to reach a triangle formation in 20 seconds. Ten seconds after the start of the trajectory, the agent in the right vertex can not continue in the formation anymore and must return to its initial position. Despite the loss of one agent, the remaining agents keep the formation and complete the trajectory in the commanded time. The cyan circles in figure 1 represent the dropped agent.

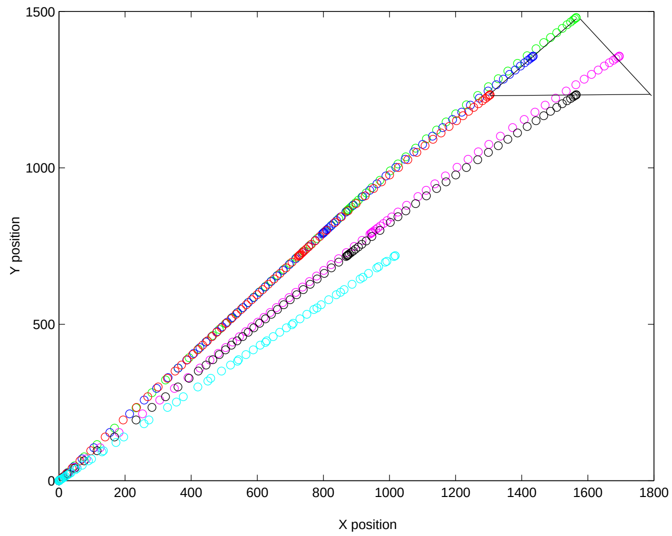

Fig. 1. *Six agents completing a triangle formation, with the removal of one agent in the middle of the trajectory.*

Figure 2 shows the positions, in the x axis, of the six agents as a function of time. Two of the agents have the same position on the x axis, one overlapping the other in the plot. Ten seconds after starting the trajectory, one of the agents returns to its initial position, while the others keeps moving to complete the trajectory.

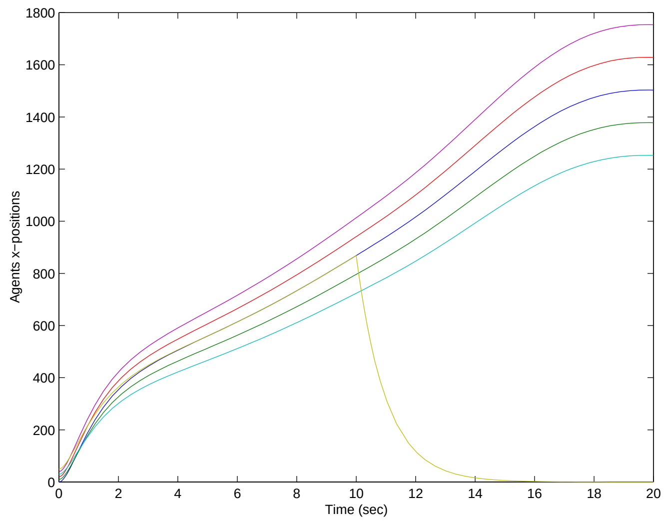

Fig. 2. *Positions of the six agents on the x axis, with the dropping of one agent in the middle of the trajectory.*

Figure 3 shows the positions, in the y axis, of the six agents as a function of time. We have only three different positions on the y axis resulting in overlapping plots. Ten seconds after starting the trajectory, one of the agents returns to its initial position, while the others keeps moving to complete the trajectory.

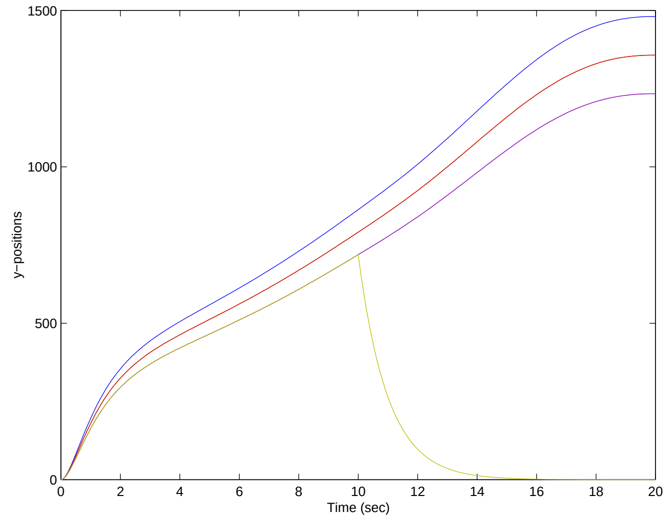

Fig. 3. *Positions of the six agents on the y axis, with the dropping of one agent in the middle of the trajectory.*

Figure 4 shows the simulation when a new agent joins an original wedge formation with five agents. The new agent takes the center position in the wedge, changing the formation to a triangle formation, and the agents are commanded to reach the formation in 20 seconds. The joining takes place ten seconds after the start of the trajectory. Despite the addition of a new agent, the other agents keep the formation and complete the trajectory in the commanded time. The cyan circles in Figure 4 represent the joining agent. Figure

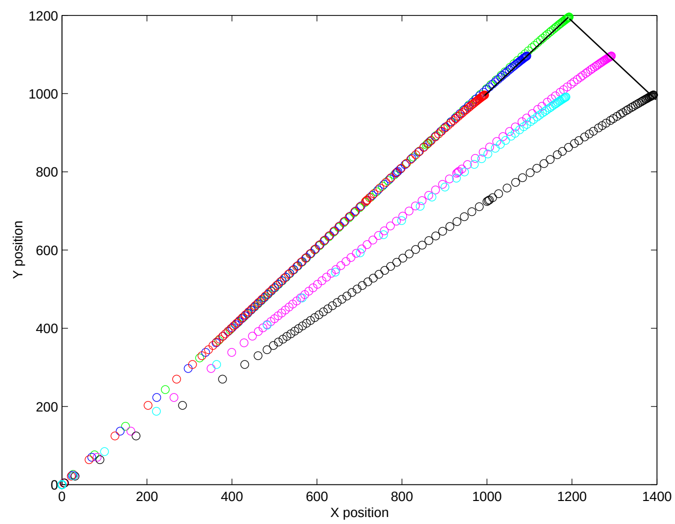

Fig. 4. *Five agents completing a wedge formation, with the addition of a new agent the middle of the trajectory.*

5 shows the positions, on the x axis, of the five agents as a function of time. Ten seconds after starting the trajectory, the new agent joins the formation. Two of the agents have the same position on the x axis, one overlapping the other in the plot. Figure 6 shows the positions, on the y axis, of the five agents as a function of time. We have only three different positions on the y axis resulting in overlapping plots. The final conference paper will present details of the algorithm along with proofs of convergence.

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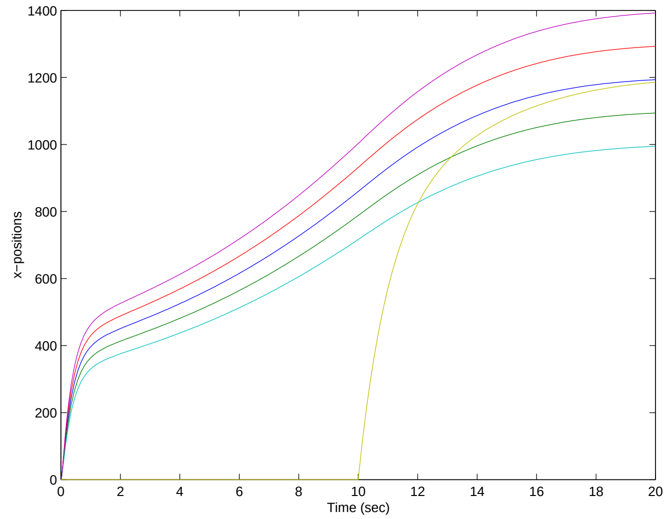

Fig. 5. *Positions of the five agents on the x axis, with the addition of one agent in the middle of the trajectory.*

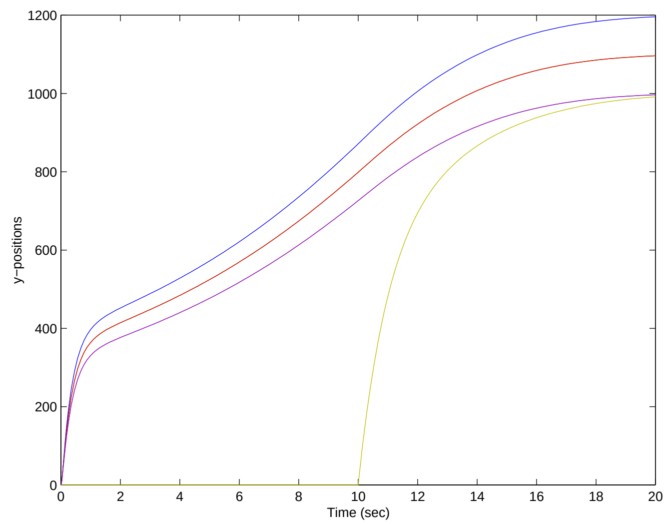

Fig. 6. *Positions of the six agents on the y axis, with the addition of one agent in the middle of the trajectory.*

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