Coordinated USV Control

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Abstract

Many universities have lab exercises in the controls classes which consist of modeling and simulations for vehicles and robotics due to the costs associated with real vehicles, robotics or the test environments. Unmanned surface vehicles such as a Sea Fox can be modeled and simulated in Matlab or a similar software. Multiple vehicle paths can be coordinated to facilitate search patterns or to setup adhoc wireless sensor networks (WSNs) with the vehicles each possessing a node. At Texas A&M University-Kingsville an assignment for coordinated unmanned surface vehicle (USV) control and path planning has been developed. The work builds upon previous labs detailing the USV model and path planning using potential fields. The USVs are simulated in coordinated movements and in a coordinated search pattern. The system of USV systems is simulated in Matlab. This exercise introduces students to biomimetics and artificial intelligence methods such as models for flocking behavior or swarm intelligence. The group of vehicles’ coordinated paths and control can be augmented utilizing data from a WSN to ensure a more efficient path. The efficacy of the assignment is demonstrated through student engagement in the exercise.

1. Introduction

Student involvement in design or simulation increases student attention and interest.[1]-[5] In this project, students were given the theory for simple flock formations. When combined with the potential fields obstacle avoidance methods discussed in [4] the simulated multiple vehicle formations will be able to move collectively while avoiding any obstacles including other vehicles. Multiple unmanned surface vehicles [3]-[7] can be modeled for this coordinated movement. The coordinated movement or collective motion can be simulated utilizing various methods such as models for flocking behavior, swarm intelligence or ant colony optimization. In particular, flocking behavior has been utilized in this student assignment [8]-[9].

1.1 Biomimetics

Biomimetics has been utilized in many disciplines to mimic how natural systems and organisms behave or move. In this case, biomimetics are used to collectively control a small group of robotic vehicles. Collective motion of groups can in general be described by Reynolds’ Rules which include three main concerns: a) collision avoidance, b) velocity matching and c) flock centering [8]-[9].

2. Problem Description

Unmanned surface vehicles can be modeled as in Figure 1 [3]-[7]. The course angle $\chi$, heading angle $\psi$ and sideslip angle $\beta$ are defined as shown. The input $r$ is applied at the rudder. The model as used in this assignment is described in more detail in [3]-[5].
To simplify the USV model for the assignment, one can assume no sideslip. This results in the following relationships.

\[
\begin{align*}
\dot{x} &= U \cos(\psi) \\
\dot{y} &= U \sin(\psi) \\
\dot{\psi} &= r
\end{align*}
\] (1)

The position is \(x, y\), \(U\) is the velocity and \(r\) is the input. This can then be extended to \(i\) vehicles which will move in a flocking behavior, a coordinated formation, with the same direction and velocity. This can be accomplished using a local voting protocol [8]

\[
\begin{align*}
\dot{x}_i &= U_i \cos(\psi_i) \\
\dot{y}_i &= U_i \sin(\psi_i) \\
\dot{U}_i &= u_i
\end{align*}
\] (2)

where in a given neighborhood \(N_i\) around vehicle \(i\) given \(i \neq j\) [8]

\[
\dot{\psi}_i = \sum_{j \in N_i} a_{ij} (\psi_j - \psi_i)
\] (3)

\[
u_i = c_1 \sum_{j \in N_i} a_{ij} \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} + c_2 \sum_{j \in N_i} a_{ij} (U_j - U_i)
\] (4)

where \(a_{ij}\) is the strength of the flocking while \(c_1\) and \(c_2\) are collision avoidance constants [8]. These equations result in a heading angle match and a velocity match between vehicles while reducing the distances between vehicles. However, a vehicle could collide with another vehicle so that when a vehicle \(j\) is within a threshold distance \(d\) which defines a collision neighborhood \(N_i^c\) around vehicle \(i\) seen in Figure 2, the vehicles should repel each other causing a minimum distance to be maintained in order to avoid collisions. This minimum distance should ensure no collisions occur.
This can be accomplished by modifying the equation for the input $u_i$ as follows when the vehicles are too close: [8]

$$u_i = -\sum_{j \in N_i} c_{ij} \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}$$  (5)

Vehicle 1 is designated as the leader. The heading and velocity are assumed to be known for this vehicle. For instance, the leader’s heading and velocity can be determined by required movements for a search pattern for an unknown environment. The other vehicles will then follow the general path given by vehicle 1. All other vehicles other than vehicle 1 will then update their heading and velocities based upon equations (1)-(5). For a practical implementation, vehicles will also need obstacle avoidance algorithms to avoid collisions. One method for obstacle avoidance would be to utilize potential fields as demonstrated in [3]-[5], [10]-[12]. “In this method, waypoints or goals are considered to be objects of attraction and obstacles are considered as objects of repulsion.” [4] “Attraction is a function of the Euclidean distance (between the goal and the vehicle, USV). Thus obstacles will repel the USV and goals will attract the USV.” [4] This obstacle avoidance would then be combined with the collective motion to update the USV positions and headings.

3. Results

Figures 3 and 4 illustrate examples of the expected results for the collective motion given a leader vehicle depicted by the red paths in each figure. The green and blue paths denote following vehicles. As can be seen in the Figures 3 and 4, the two following vehicles successfully match the motion of the leader. Figures 3 and 4 also represent a simple simulation of a three agent (robotic vehicle system). This was used as an example of a simple system of systems in an elective course when discussing systems engineering models.

The students learned the theory behind the collective motion which was based on biomimetics before attempting the simulation. The first part had the students simulate two different cooperative motion models. The students utilized the model described earlier in the paper, but without a leader that then will result in a consensus trajectory. Many students had trouble setting up the initial simulation before simulating the second collective motion model in which the students would implement a more advanced model such as the leader based collective motion. Many groups had to ask for help with the simulation that was based on the differential equations.
The theory for the coordinated movement was discussed as a series of two class lectures on coordinated movement of multi-agent systems. Many students had issues with the initial simulation of cooperative motion which did not have a leader before attempting the second part in which the students would implement a second collective based motion such as the leader based collective motion illustrated here in Figures 3 and 4. This simulation assignment in which students were allotted two weeks to work on the simulation allowed students to simulate simple multi-agent systems. This was part one of a class project. The other half was for a system engineering model for a complex system.

![Figure 3. Two Examples of Collective Motion of Three Vehicles](image1)

![Figure 4. Two Examples of Collective Motion of Three Vehicles in a Set Pattern](image2)

4. Conclusions

The initial group that was assigned this collective motion assignment was a masters level graduate controls course that introduces systems engineering concepts and systems of systems models. The students were looking at multi-agent systems as one model that could be utilized to model a system of systems. The multi-vehicle coordinated movement assignment is currently being modified to be utilized in an undergraduate linear control systems course at Texas A&M University-Kingsville to build upon obstacle avoidance and path planning assignments. The undergraduate linear control systems course is structured as a two hour lecture with a three hour lab for a total of three credit
hours. In this case students will be given a base simulation file that can be modified to incorporate different coordinated movements. The theory for the assignment will be discussed over one to one and a half hours during a lab. Students will have one to two weeks to work on the simulations. Assignment questions for the undergraduate linear control systems assignment will be added including: 1) what happens when the simulation is extended to four or five vehicles; 2) what happens when obstacles are added and 3) what issues will one face when implementing this collective motion on a real system.

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