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Formation Control of Autonomous Boats

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The purpose of this report is to describe a real-world implementation of formation control strategy using autonomous surface vehicles (ASV). A graph-based formation algorithm has been used to control multiple boats tested in several scenarios. Different extensions of the Laplacian graph-based control algorithm have been implemented and analyzed to highlight their characteristics and benefits on the overall formation performance. In addition, a comparison between the results obtained in a simulation framework and on the real boats has been analyzed.

The implementation of the formation control strategies was integrated into the navigation code of the autonomous boat, which runs on an embedded 32-bit autopilot board. The currently existing code, capable of velocity control and waypoints navigation, has been extended to acquire relative range and bearing measurements, which are then used to apply the formation control strategy to handle different formation shapes. An integral and a derivative component were added to the standard Laplacian expression to analyze eventual performance improvements. After a successful evaluation both in PC-based emulation and hardware-in-the-loop simulation, real word experiments with up to three boats were carried out on the lake. In order to do that, two additional boats have been built. In the final stage, simulation and real-word implementations have been analyzed and compared in different scenarios.

The formation algorithm was implemented with multiple number of boats, performing different shapes of formation. The main and most important ones, which have bee extensively tested both in simulation and reality, are the row formation with two boats, the triangle with three boats and the square with four boats. A GPS receiver and a XBee radio communication module were used by each vehicle of the swarm to compute the relative range and bearing of the other boats. With the acquired position information, a graph-based formation algorithm was used to compute the velocity needed by each individual in the formation to obtain the overall desired shape. Initially, the standard Laplacian expression was used. In a later stage both an integral and derivative component have been added to improve the overall performance of the formation. The integral component principally led to a substantial decrease of the steady state error, while the derivative component was used to implement a vehicle response based on the difference in velocity between the members of the swarms. As a consequence of the analysis, we can conclude that the addition of the derivative and integral components to the standard Laplacian expression produced consistent performance improvements both in simulation and reality among all tested scenarios.

Moreover, the analysis of the results highlighted a marked performance difference between simulation and reality. Several non-idealities and sources of errors, such the usage of GPS, both for relative position measurements and fitness calculation, communication losses and real-world external disturbances led the attaining of the formation be much more complicated on the lake rather than on the PC-based simulation. Nevertheless, it must be noted that, even though the desired side's characteristics were not achieved in reality, the overall formation shape was obtained.

Looking forward to a future implementation, one of the possible improvements could be to use a dedicated sensory system to acquire the relative position information, while using the GPS signal with a state estimator only to run the stabilization controller used to set the speed to the vehicle's motors. In addition, each boat could be set to send position messages to the ground station through different radio communication channels; in this way the amount of communication loss would be substantially decreased and the fitness of the formation could be computed offline. Already with these two improvements the overall fitness in the real-world experiments would drastically improve.