Software Architecture for Validation and Verification of Cooperative Autonomy of Multiple Thermaling Gliders*

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Abstract— **This paper describes the evolutionary steps in the design of cooperative control capability of multiple autonomous soaring gliders. The paper reviews the principal components necessary to enable "eternal" flight of a fleet of gliders, and presents initial flight test results that demonstrate high-potential of collaborative autonomous soaring. The paper primarily focuses on the design of the software architecture that allows to verify the designed control algorithms in a high-fidelity simulation prior to the actual flight. The software architecture is based on the tight integration of Condor soaring flight simulator with the advanced capabilities of MatLab/Simulink design environment. The key benefits of the software for the flight control system design include the ability to realistically represent the atmospheric convective airflow and its interaction with 3D terrain, the high-fidelity flight dynamics of a variety of soaring gliders, and the advance tools of the control development and flight data analysis. The cooperative capability is implemented by communicating the states of multiple gliders over the network. Ultimately, the developed system allows verification and validation of advanced cooperative control strategies and their comparison against best practices of human piloted soaring flight.**

I. INTRODUCTION

Imagine a large team of gracefully soaring autonomous gliders, instrumented with sensors capable of detecting convective air currents in the environment. The gliders are launched from a remote location and assigned to provide, for example, wide area network coverage or to serve as pseudo Low-Earth-Orbit satellites to aid in fighting forest fires or to support border protection. The gliders reach the area of operation and remain there unattended for an extended period of time, perhaps up to a year. When a need for maintenance arises the distributed intelligent algorithm reconfigures the team of gliders and calls back the aircraft in need of service. In turn, when a substitute or serviced aircraft returns, the same algorithm reconfigures the team to accept the new player. Members of the flock can either operate in a distributed fashion or fly together in a suitable formation to provide a more focused capability. The latter may include cooperative distributed sensing to achieve a desired sensor resolution, tracking of weather formations, border patrol, and many other tasks that are currently provided by much larger, heavier, and more expensive systems.

There have been several projects that have sought to capitalize on convective lift in the environment to offset or remove the need for propulsion. First demonstrated by human pilots in 1900s (see [1]) the idea of soaring in convective air became feasible for onboard autonomous implementation only in the 1990s, see [2]. A challenge for these vehicles revolves around locating the regions of advantageous lift. While enabling the desired functionality by primarily mimicking the birds flight and indeed achieving significant extended flight capabilities (see [3], [4], and [5]), most of the algorithms used heuristics in the identification of the updraft strength, its potential utility in energy gain, and the decision of when and how to enter the updraft. The reason for employing heuristic approaches is obvious, since both the strength of the updraft and its efficiency are both subject to significant uncertainties and are hard to formalize. The most recent development by [6], [7] demonstrated that teams of aircraft working cooperatively could improve the probability of success by splitting up the search task and sharing location data for regions of lift. Combining the ability to exploit natural lift in the environment with photo-voltaic or wind-driven energy production, the vehicles should be able to stay aloft 24/7, while still having enough additional energy to support the weight and power of meaningful payloads.

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II. INTEGRATED CONTROL DEVELOPMENT ENVIRONMENT

Objective - harness the power of two tools. Describe the benefits of each tool. Overview the architecture that integrates all the functionalities into a feedback loop. Describe what is developed at the end in terms of potential capabilities. Suggested subsections:

A. *Architecture and Software Implementation*

Describe the high-level information flow; what is taken from Condor and submitted to Simulink and what is produced by Simulink.

To facilitate convenient design and verification of the designed algorithms the project developed a realistic simulation environment that is based on tight integration of MatLab/Simulink ([8]) capabilities with the high-fidelity flight dynamics and atmospheric effects of the Condor soaring simulator, see [9]. Besides providing a wide nomenclature of gliders, the software integrates the cooperative behaviors

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of multiple agents that is essential to the project; the collaboration is enabled by sharing the states of gliders over the network. The architecture of the software in the loop setup is presented in Figure.1.

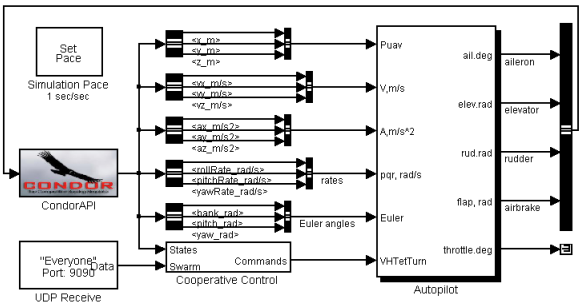

Fig. 1. Integration of Simulink and Condor capabilities.

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B. Potential Capabilities

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III. Principles of Convective Lift Detection and Cooperative Exploitation

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A. Thermals Detection and Exploitation by Single Glider

Sink polar
Total Energy approach
Guidance of a single glider

B. Cooperative Strategies

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IV. Experimental Results

Present results of 3 gliders searching for a single thermal in a bounded box. One of them finds the thermal, estimates its position and shares knowledge with the rest of the team. The other 2 gliders come to the same spot and start climbing.

As an illustration of the achieved capabilities, Figure.2 represents the cooperative flight of three gliders in a simplified scenario introduced above. The gliders start their flight simultaneously at the same altitude, and initially spend some time in search for thermals. When glider #1 detects an updraft utilizing either of the thermal detection approaches, and shares the information about the thermal, the other two gliders arrive to the same thermal and successfully gain height all together. Time history of the altitude of three cooperative gliders is presented next in Figure.3. The result clearly demonstrates the benefits and significant potential of collaborative strategies in harvesting the convective updraft energy from the environment.

Appendix

Appendixes can be used to show snippets of configuration files

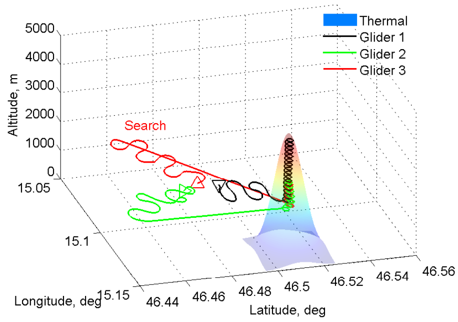

Fig. 2. Cooperative flight of three gliders; starting at different locations they all converge to the same updraft when glider #1 finds it and shares its estimated location.

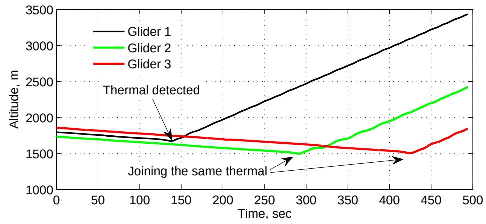

Fig. 3. An example of cooperative flight of three gliders.

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