Glider Control: A Close Look into the Current Glider Controller Structure and Future Developments

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Abstract

Simplicity of operation, extreme endurance and stealth are some of the principal advantages of autonomous underwater gliders. These advantages come at the expense of a minimalist approach in the sense of actuation and permissible power consumption. Also by nature the gliders are highly dependent on their operational environment, notably currents and density gradients. A control system that is able to cope with this challenging dynamic environment and the actuation and sensing constraints has to be robust with respect to environmental uncertainties and at the same time it has to be optimal in the sense of power consumption and accuracy. In this paper we look at the existing controller structure and show possibilities for improvements within the framework of the available sensor information. We summarize the existing controller structure and show results from recent field-tests of Slocum gliders in the Gulf of Mexico that demonstrate the potential for improvements in the sense of reduced power consumption associated with actuation and decreased response time enabling shallow water operations.

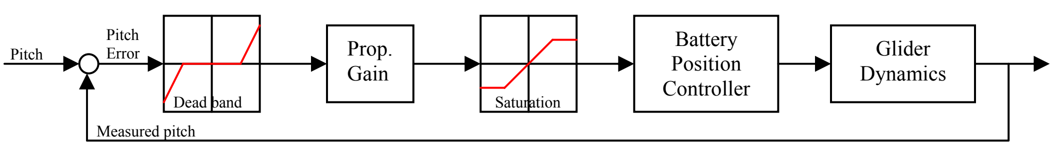

Figure 1: Schematic for typical controller. Pitch controller shown as an example.

1. Current Controller Design

Currently most of the operational gliders [1,2,3] have implemented a simple proportional controller for heading and pitch control. A combination of controller dead-band, variable controller update time and actuator rate limitations in conjunction with the proportional controller is implemented to achieve the goals of energy efficiency and controller accuracy. The choice of the various modules of this controller as well as the associated parameters is based on experience and field-tests by the designers and operators of the gliders. Figure 1 shows the general control structure as it is implemented in most of today's gliders; the schematic does not show the variable update time of the controller design. The controller update-time can be a function of the history of the pitch or heading error.

In order to show the potential for improvements of the overall glider behavior and, correspondingly, the potential for an increase in the operational envelope, we show some results of recent experiments that have been performed with the Slocum gliders.

The Slocum gliders are actively controlled in pitch, depth and heading using some combination of ballast control, battery position control and rudder control. Roll is not controlled on the electric version of the glider. The objective of the experiments was to improve the glider's response in its pitching behavior using the existing controller structure, Fig.1. In addition to the controller structure described above, the glider software uses a look-up

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function of the linearized, steady-state relationship between pitch angle and battery position in order to determine the expected battery position for a given pitch angle.

The data shown in Figures 2-5 was collected in Spring 2003 during a cruise on the Canadian Forces Auxiliary Vessel Quest (CFAV Quest) in collaboration with SPAWAR System Center, San Diego and DRDC Atlantic, Halifax, Canada. Each of the experiments was composed of a set of double yo maneuvers with each yo consisting of one up and one down leg at a desired pitch angle of ±25°. The gliders were flying in a straight line collecting data at a 2 second sampling interval. All data presented was collected using the same glider. Figure 2 shows a comparison of measured and commanded state trajectories for some of the glider's internal and external states, such as battery position, total ballast pumped, pitch angle and depth as a function of time in seconds.

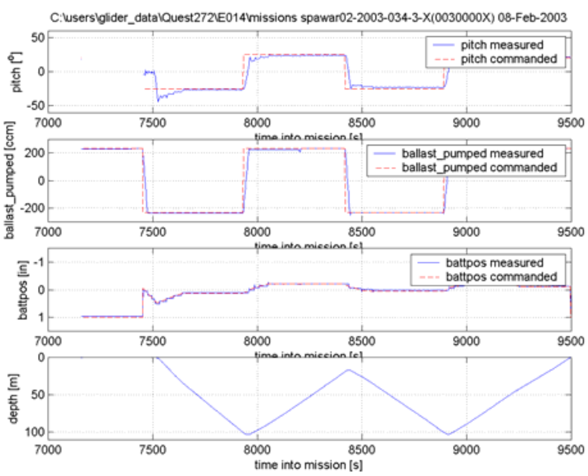

Figure 2: Double yo mission with a 25° pitch angle and the initial controller setting.

The glider's pitch response is over-damped and the glider takes a significant amount of time and therefore depth to reach the desired pitch angle. By the time the glider reaches its desired pitch, it already has descended from the surface to a depth of up to approximately 40m. This creates significant limitations for shallow water operations. The slow rate of convergence is caused by the incremental changes of the battery position servo.

Based on the slow response of the actuator, the step size limit of the actuator was increased from 0.02in to 0.5in. Figure 3 shows the results of this change of parameters for the same type of glides.

The dramatic increase in actuator authority resulted in a much faster response of the vehicle. It also showed the controller gain to be too high, a fact that was previously hidden by the rate limit of the actuator. The considerable oscillations around the desired pitch angle are a direct result of the high gain.

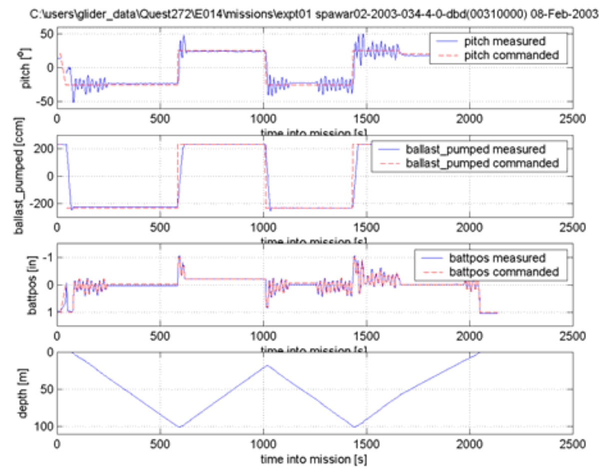

Figure 3: Double yo mission with a 25° pitch angle and the step size limit increased from 0.02" to 0.5".

In a next step the controller gain was changed to -0.5 from -2.86. Figure 4 shows the final results from the change in the controller parameters. The change in gain showed no significant overshoot with an improved response time. Figure 5 shows a close up of the pitch error, i.e. the error between desired and measured pitch, and depth plots for an upward and a downward pitch change for the initial parameter setting and the final parameter setting. The plots show the significant decrease in response time using the new controller parameters. As a result of these improvements the glider can reach its desired pitch angle within a much smaller depth change.

This example shows how even a modestly better understanding of the dynamics and controls of the glider can significantly enlarge the operational envelope of the gliders, including the possibility of shallow water operations.

2. Conclusions, Work in Progress and Future Developments

The above example clearly demonstrates the potential for improvements in the current controller design even within the current control structure. However a more systematic approach is needed in order to design controllers that fulfill the requirements of robustness and energy-efficiency, which are essential to the glider. We are currently working on a further analysis of the controller structure and the glider dynamics using describing functions and nonlinear control theory. In parallel, we are working on new model-based controller designs that could potentially further enhance glider behavior. These developments in glider control will be able to benefit from current developments in nonlinear model-based control [4], robust and optimal control. For glider missions involving a change in mass or buoyancy distribution, recent developments in adaptive control might prove to be a good starting point for future research.

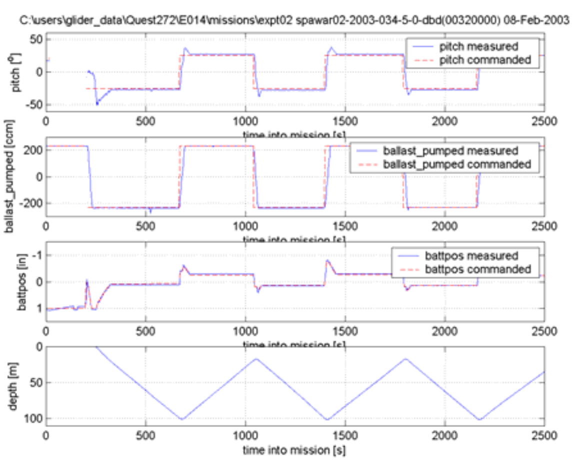

Figure 4: Triple yo mission with a 25° pitch angle, increased step size limit and a controller gain of kp= -0.5 instead of -2.87.

While the above mentioned improvements in controller design can benefit a broad range of glider operations, some more specific glider operations, such as glider operations in the littoral regions pose special challenges to the control system. These more dynamic environments warrant a closer, integrated look at glider design, dynamics and control as well as fouling-resistant, embedded sensing and actuation.

3. Acknowledgements

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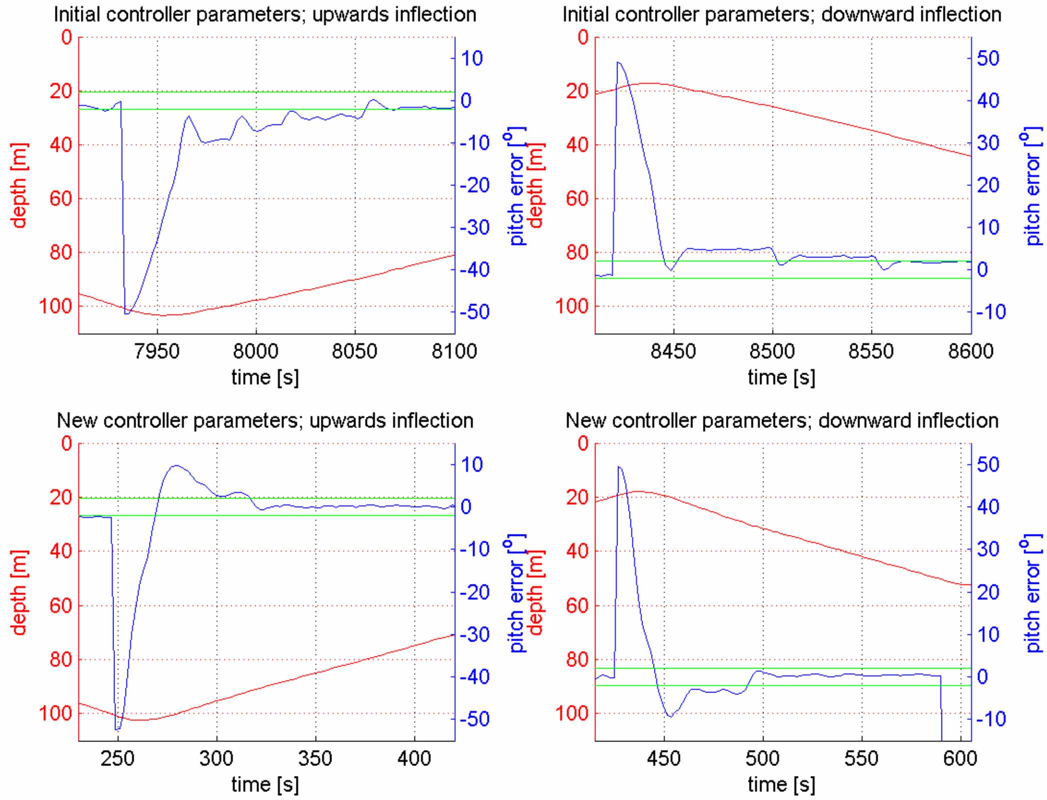

Figure 5: Direct comparison of pitch behavior before (upper plots) and after (lower plots) parameter changes. The left plots show an upward turn and the right plots a downward turn. The solid line (red) represents the depth measurements. The dashed line (blue) is the pitch angle error between commanded and measured pitch. The solid (green) horizontal lines represent the +/-2degrees deadband of the pitch controller.