Cyber Sailer

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Abstract: In this study, in collaboration with the Center for Autonomy at University of Illinois at Urbana-Champaign, I developed a feedback control system to enhance the autonomous navigation performance of Sailbot by utilizing real-time position and orientation data obtained from GPS and rotary encoders. An autonomous sailing robot is a technology that can automatically maintain a route and navigate to a target location in a marine environment without human intervention, and its importance is growing across various applications such as ocean exploration and environmental monitoring. In particular, a control system that tracks precise position and heading using sensors and automatically adjusts the sail and rudder in response to environmental changes offers the advantage of enabling highly efficient navigation.

Despite these benefits, autonomous sailing robots still face challenges in maintaining stability and reliability due to rapidly changing sea conditions and sensor errors. Frequent performance degradation in real-world settings remains a key issue, stemming from insufficient real-time accuracy in sensor data processing and control algorithms, as well as limited adaptability to external disturbances. To address these challenges, I designed an algorithm that integrates GPS-based position tracking with rotary encoder–based heading control, and I implemented a feedback control strategy that automatically adjusts the sail and rudder according to environmental variations. Experimental results demonstrated that the system successfully executed accurate autonomous navigation to the target waypoint under real-world conditions. I expect that Cyber Sailer will serve as a foundation for reliable autonomous navigation technology in extreme marine environments going forward.

My Role: In this project, I personally assembled and connected the key hardware components of the Cyber Sailer system to establish a reliable platform on which sensors and actuators could operate stably. By doing so, I built the infrastructure needed to read and process real-time data from the GPS sensor and rotary encoder, enabling the system to accurately determine the boat's current position and heading.

Based on the collected sensor data, I developed a path-planning algorithm that computes the optimal course for the boat to reach its target waypoint. To ensure the boat actually follows the planned path, I designed a precision control algorithm for sail and rudder actuation. Specifically, I structured the system around a feedback-loop architecture so that the boat can respond quickly and effectively to changing external conditions and continuously adjust its trajectory.

However, relying solely on the rotary encoder made it difficult to detect slippage or minor heading deviations under strong wind conditions, which introduced significant error between the boat's actual heading and the intended control goal. To address this, I implemented a Kalman filter that fuses multiple sensor inputs in order to estimate the boat's attitude and velocity more accurately and robustly.

Furthermore, in real-world sailing conditions—where unpredictable external factors like headwinds or floating debris can prevent the boat from simply following a precomputed trajectory—the nominal path-following approach often failed. To overcome this, I augmented the algorithm so that the boat can still make forward progress efficiently even when facing a headwind.

For real-time obstacle avoidance, I integrated a LiDAR sensor to detect obstacles and am currently developing an A*-based obstacle-avoidance system that re-plans the route on the fly using the incoming point-cloud data.

Finally, to resolve servo motor jitter caused by the Raspberry Pi 5's PWM limitations, I added a PCA9685 servo-driver board to stabilize the control signals. By testing various software libraries and configurations, I successfully eliminated servo jitter, further improving the Cyber Sailer system's overall performance and reliability.