Autonomous Sailboat Navigation In Uncertain Environments

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Abstract

Students from the Olin College Robotic Sailing Team built an autonomous sailboat to compete in the International Robotic Sailbot Competition in Vancouver. This paper describes how autonomous navigation was achieved for the boat. The boat is required to complete a series of tasks autonomously including a long-distance race, a precision event, and a station keeping event. A high level structure was developed in LabView to determine a series of waypoints required to complete each mission. The task of navigating to a waypoint was achieved using a fuzzy logic framework, which evaluates different headings with regard to the mission objectives. The algorithm focuses on efficient path-finding based on environmental conditions, while also avoiding user-defined obstacles. Field-testing and competition performance yielded success, suggesting the feasibility of these algorithms for efficient autonomous sailboat navigation.

Keywords: autonomous, sailing, robotics, navigation, uncertainty

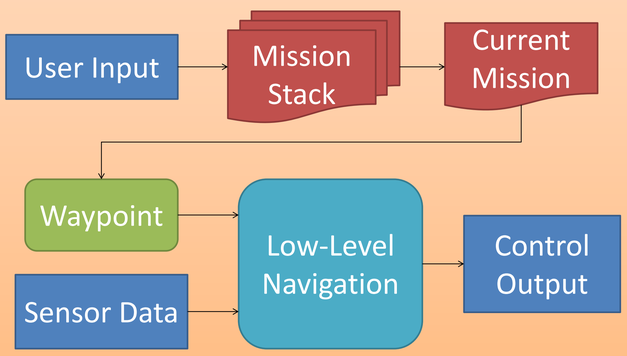
Figure 1. The Olin Sailbot, Blackbody Radiation, sailing in the English Bay in Vancouver, BC, during the 2012 International Sailbot Competition.

Introduction

The International Robotic Sailing Competition consists of 5 events, 3 of which require a robust algorithm for autonomous completion of missions.

Our autonomous system is composed of 2 sub-systems:

- Waypoint Navigation (low-level)
- Mission Definition and Construction (high-level)



Fuzzy Logic Navigation

$$\log(g) = \log\left(\begin{bmatrix} G_1(\theta_1) & \cdots & G_n(\theta_r) \\ \vdots & \ddots & \vdots \\ G_1(\theta_r) & \cdots & G_n(\theta_r) \end{bmatrix}\right) * \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix}$$

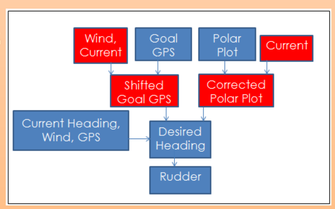
g is the goodess over the sampling of r headings, G_i is the ith goodness function and has weight w_i

At the heart of the system is a fuzzy control algorithm which computes the relative "goodness" of uniform sampling of the possible headings

A heading's goodness in calculated as the weighted combination of:

- Waypoint efficiency (how quickly will it get the boat to the waypoint?)
- Heading change (how drastic of a turn would it require?)
- No-sail zone avoidance (how well does it avoid no sail zones?)

Sensor data is used to account for uncertainties and imperfections at sea. This diagram is an expansion of the Low-Level Navigation block in the introduction section, showing in red the effect of non-ideal elements in our algorithm.



Defining Missions

- 3 Level Hierarchy: Events > Missions > Waypoints
- Events are:
  - Multiple laps through/around buoys
  - Station-keeping (stay within a box)
- Missions are:
  - Round Buoy
  - Pass Between Buoys
  - Stationkeeping
- Waypoints are adjusted based on
  - Wind conditions
  - Relative displacement from boat
  - Next mission location
- Stationkeeping is timed, and has multiple phases to ensure quick exit from the box.
- Missions were input/edited from Operator Control Unit (Figure 3).

Results and Conclusion

The boat performed well in every event, and placed second overall (Figure 2)

What worked:

- Fuzzy logic navigation
- Visual representation of boat brain
- Abstracting missions into waypoints

Future Improvements:

- Optimal navigation with an imperfect sensor
- Perfecting the numerous constants
- Defining "success" for reaching a waypoint
- Computational/power efficiency
- Middle-level subsystem for path-planning

6th Annual Robotic Sailing Championship

June 11 - 14 2012 - RVYC / UBC

Overall Results

Sailbot Division

	Team / Boat	Fleet Racing	Station Keeping	Navigation Contest	Presentation Challenge	Long Distance Race	Total Pts	FINAL Place
1	Memorial University	6	4.4	0	8	5	23.4	5
2	Olin College	9	9.0	10	9	6	43.0	2
3	U S Naval Academy GTB	10	9.0	10	8	2	39.0	3
4	U S Naval Academy WTH	8	8.6	7	7	0	30.6	4
6	University of B.C.	7	10.0	10	10	10	47.0	1

Figure 2. Results from the 2012 International Sailbot Competition. The Olin College placed 2nd overall.

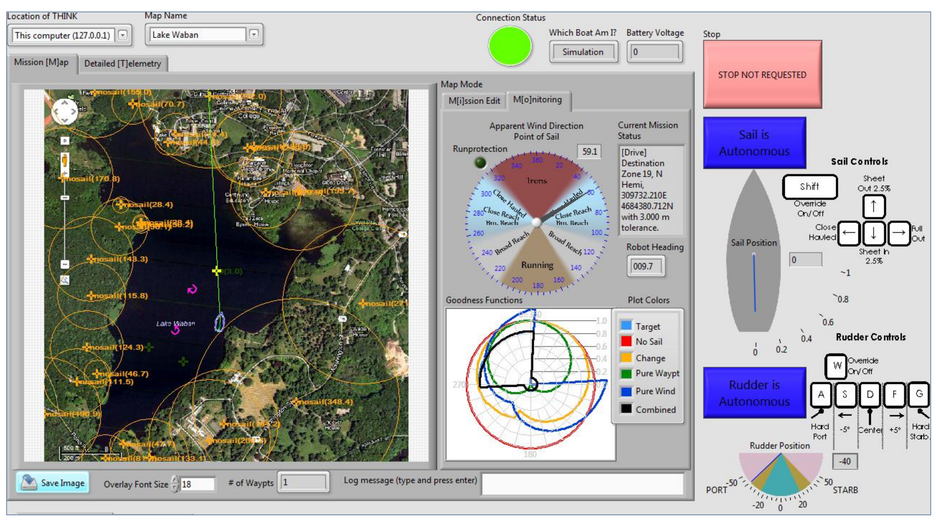


Figure 3. Operator Control Unit,showing (left to right): Preloaded map with missions and avoidance zones, point of sail and logical evaluation of headings, and manual control interface. The ease of communicating with the boat was critical in the testing process.