CBI -RoboSail

Course Reference Book

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www.robosail.org

Community Boating, Inc.

US Sailing REACH Grant

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RoboSail Course, Community Boating, Inc, Boston, Summer 2015

Goals of the course – you will be able to:

1. Program a robotic sailboat to do sailing tasks ranging from simple maneuvers to sailing a course autonomously
2. Code in C in the Arduino development environment,
3. Use a variety of electronic sensors and interface them with the computer
4. Create algorithms that translate sailing knowledge into code for a robot

Course outline

Class 1	Sail the boats RC and think how you can do it in code. Characterize boats. Think what information you need to be able to teach a robot boat to sail. Do robot sailing exercises. Get personal computers ready to program Arduinos.
Class 2	Learn to code Arduinos by experimenting with servo motors. Investigate data from RC Receiver and sensors. Test Rudder and Sail servos using Arduino test code. Put Arduino and electronics in the RC system to test and investigate complete system. Generate algorithms for simple sailing maneuvers.
Class 3	Define frame of reference for sensor data. Create Auto-Sail code where sailwinch is controlled automatically based on data front the Windvane. Develop algorithms for other sailing maneuvers.
Class 4	Develop algorithms/code for a variety of sailing maneuvers with cues from the RC transmitter.
Class 5	Implement Autonomous sailing with manual cues. Add code to read GPS and/or compass and use this data in new code (optional). Review the Regatta challenges and plan your strategy for getting your rating.
Class 6	Do the RoboSail Regatta and get your ratings.

Robosail Workshop 1

Objectives Students will:

- Know each other and the plan for the course.
- Characterize the boats by sailing them radio-control.
- Do “robot sailing” exercises.
- Get personal computers ready to program Arduinos.
- Get started on coding Arduinos by experimenting with servo motors

Materials:

- 1 workbook per boat
- Sailing review sheet for each student
- 4 RC boats, set up for radio control, with good batteries
- Laptops – at least 1 per team, up to 1 per student
- 1 set of (Arduino/USB Cable/Servo/3 bare wires) per laptop computer
- Arduino tutorials – 1 copy for each student

Part I Introduction (40 min)

1. Welcome-sign-in on attendance sheet
    a. Fill in Google form found on RoboSail Community Boating student page
2. Take handout packet / student workbook
3. Boats will available to try out RC - investigate
4. Teacher/Mentor introduction
    a. Training, Engineering Work, Teaching/mentoring exp, Sailing exp,
5. Ground rules
    a. Honor yourself, your classmates, and the learning process:
    b. Phones away!
    c. Be safe, Stay on task, look out for others, ask questions, bring problems/concerns to someone who can do something about them, Have Fun!
6. Materials
    a. Laptop with USB port
    b. Pencils
    c. Good attitude
7. Student Intros
    a. Your Name
    b. Where you are from
    c. Engineering experience, Sailing experience
8. Discuss Overall Goals and Outline of course, resources
    a. Show website
9. Show Regatta plans for 2 last days

Robosail Workshop 1

Part II Sailing Radio-Control boats (60 min)

1. Review Basic Principles of Sailing (have a student do review)
    a. How sailboats works, correct sail trim
    b. Points of sail (POS)
    c. Maneuvers: head up, bear off, tack, gybe, get out of irons, beat, run
2. Characterize boats. Go to dock and try these maneuvers. Take notes on sail position and rudder positions for effective maneuvers.
    a. head up, bear off,
    b. tack, gybe,
    c. get out of irons,
    d. Beat upwind,
    e. run downwind
3. Robot sailing exercise "sense, think, act"
    a. 1 student watches boat and reports back (sensors)
    b. 1 person comes up with commands (computer)
    c. 1 operates controller (servo motors)

Part III Arduino/programming introduction (60 min, add 30+min if students need to download software)

1. Download Arduino IDE and Hardware test code
    a. Links on CBI Student page
    b. Can finish at home
2. Arduino Tutorial 1 with a servo motor
    a. Connect servo motor to Arduino board as instructed.
    b. Connect Arduino to PC with USB cable
    c. Follow tutorial to learn basics
        i. We are intentionally not reviewing the Arduino or servo much. Students experience them first and figure out as much as they can on their own.
    d. Discuss – highlight points from tutorial
        i. Can start with things you didn't like about environment, or did like
        ii. How different words light up in color
        iii. Verify/compile and upload buttons
        iv. Semicolons
        v. Curly brackets and parentheses
        vi. How to name and save sketches (programs)
        vii. camelCase naming convention

3. Wrap-Up
    a. Tutorials and references on www.robosail.org
    b. Show website with fun Arduino projects
    c. Try out Arduino at home – can sign out a board with me

Robosail Workshop 2

Objectives Students will:

- Identify parts and functions of an Arduino computer board.
- Investigate data from RC Receiver and WindVane using Arduinos and test code.
- Learn range of Rudder and Sail servos using Arduinos and test code
- Test the entire RoboSail system using Arduinos and test code.
- Put Arduino and electronics in the RC system to test and investigate complete system.
- Write first Arduino program that takes in data and controls a servo

Materials:

- Wiring diagrams
- Student Worksheet to record ranges of transmitter, sensors, and servos
- Set of wires for each boat: 2 servo “big end” to bare wire, 2 servo “small end” to bare wire, 1 wind connector to bare wire.
- 3 or 4 RC boats
- Up to 4 laptop/Arduino Unos/USB cable for each boat

Part I Arduino Tour (30 min)

1. Arduino parts and functions
    a. Show Arduino tutorial powerpoint (adapted from Sparkfun)
    b. Check out fun Arduino-based projects at http://www.instructables.com/id/20-Unbelievable-Arduino-Projects/

2. Continue Arduino tutorial from last workshop
    a. Rename it ServoXX1 (XX is your intitals) and save
        i. Brief discussion of naming conventions (camelCase, versions)
    b. Show features
        i. How different words light up in color
        ii. Verify/compile and upload buttons
        iii. Semicolons
        iv. Curly brackets and parentheses
        v. Font size (preferences)
        vi. Line numbers (preferences)

Robosail Workshop 2

Part II Use Arduino to investigate sensors and actuators (120 min)

Summary: Students either work individually or in pairs to investigate system components and their associated code. Each student/pair has an Arduino of their own, several can be used on 1 boat. Go through them in any order. Use Worksheet in student booklet to record progress and notes.

1. Investigate the Wind Sensor
    a. Connect Wind Sensor to Arduino board as shown on diagram
    b. Use program WindSensor.ino to verify wind sensor wiring and calibration.
    c. Adjust windvane as needed so that 0 means wind is coming from the bow.
        a. Loosen the nut, rotate the encoder body, tighten nut
        b. Its hard to get closer than 2 or 3 degrees
    d. Check that the values increase in the CCW direction
    e. Check for the maximum raw data coming in from the Wind sensor
        a. should not be greater than 1023 (10 bit digital)
        b. Write on the worksheet
    f. Check that there is not a significant dead spot where the encoder goes back to 0

2. Investigate the RC receiver
    a. Connect the Receiver to Arduino board as shown on diagram
    b. Use program RCReader.ino and verify the connection to receiver.
    c. Record the range of values for Rudder and Sail controls and write on the Worksheet

3. Investigate the Rudder Servo
    a. Connect the Rudder Servo to the Arduino as shown on diagram
    b. Use program RudderServotest.ino
    c. Check that the rudder is centered on 0, if not adjust it mechanically
    d. Find out how many degrees it moves to each side. Write on worksheet

4. Investigate the Sail Servo
    a. Connect the Sail Servo to the Arduino as shown on diagram
    b. Use program SailServotest.ino
    c. Check that the sail is full-in (as for close haul) at 0, adjust lines as necessary
    d. Find out how many degrees it moves for full-out. Write on worksheet

5. Use program RCPassThrough.ino to check full system wiring
    a. Connect all system electronics to the Arduino as shown on diagram
        i. Try out the system – control the boat as before, but with the RC controls going through computer to the servos.
        ii. Unplug the computer and pug in the 9V battery. Check that it works like the original RC boat (but with computer in between the controls and the servos)
    b. Congratulations - You are ready to write code!

Robosail Workshop 2

Part III Create Arduino program: RudderFollowsWindvane (30 min)

Summary: Exercise program where students read in data from windvane and use it to create an output command for the rudder. Note: This is not something that would be done in real sailing, but it is a good exercise to build from.

1. Plan and Code a simple task: Rudder follows Windvane
    a. Draw/write an algorithm for having the rudder follow the WindVane. Remember that the Windvane can go all the way from -180 to +180 and the Rudder can only go -60 to +60.
    b. Your algorithm can have the relationship be 1:1 or scaled. Consider using the Arduino "map" command
        i. Option 1: map range of windvane to range of rudder
        ii. Option2: 1:1 mapping with constraints at range of rudder
    c. Download BoatCodeStarter and save it as RudderFollowsWind
    d. Code your algorithm and test it in the classroom with someone moving the windvane.

Robosail Workshop 3

Objectives Students will:

- Practice frame of reference for sensor data.
- Continue learning how to program on Arduinos.
- Write code to control Sail servo from Windvane and test it out on water.
- Develop algorithms/code for basic sailing maneuvers.

Materials:

- Sensor and Actuator definitions
- Arduino Tutorial 2
- Plastic Boats
- On-the-Water Challenges (may not use today)

Part I Practice specifying positions of rudder, sail, windvane (20 min)

1. Use plastic sailboats to get clear on the frame of reference for sensors and actuators
    a. Define frame of reference
        i. Wind vane reads 0° to +180° for wind on Port side (positive = port)
        ii. Wind vane reads 0° to -180° for wind on Starboard side
        iii. Rudder rotating CCW is positive (looking from above) and range is +60° to -60°
        iv. Sail is 0° to 90° where 0° is full in and 90° is full out. Side doesn't matter
    b. Practice degree definitions
        i. Call out various positions for Windvane, Rudder, Sail
        ii. Kids move parts of boat to appropriate places
    c. Practice Sailing definitions
        i. Do exercises in workbook or at http://www.robosail.org/model-boat-exercises.html
        ii. Kids switch for each exercise, can repeat exercises

Part II Arduino Exercise 2: Serial I/O (40 min)

Summary: Practice getting input from user and displaying on screen

1. Follow Arduino tutorial 2 to learn how to read in numbers from the computer monitor and how to display program values to the screen
    a. Review how to open Serial Monitor
    b. Show examples of integers and floats and chars.
        i. Explain how each is used.
        ii. Note that we will only use ints and floats.
    c. Discuss how reading in and displaying are useful in debugging
        i. Can pause a program while waiting for input from screen
        ii. Can print out calculated program values to check

Robosail Workshop 3

Part III Generate and Program algorithm for Automatic sail control (120 min)

1. Plan and code Autonomous Sail with Manual Rudder (like having a friend control the mainsheet while you steer the boat – they keep an eye on the tell-tales and adjust accordingly)
    a. Figure out the algorithm using the Plastic Boats
    b. Draw/write an algorithm making sure to consider these cases:
        i. windAngle < 45
        ii. windAngle > 45 and windAngle <135
        iii. windAngle > 135
    c. Use BoatCodeStarter program as a starting point for new code. Save it in a new program called AutoSail.
        i. Enter the calibration values for Transmitter and WindSensor
        ii. Look for the place that your code goes and the variables you will set
        iii. Print values to Serial monitor to confirm or debug.
    d. Test indoors with someone moving windvane
    e. Test outdoors on the water.
2. Discuss and compare algorithms as a group
    a. Draw each on a graph on whiteboard. Member of each group explains how it works
    b. Students look for similarities/difference
    c. Discuss/show code used for each.
    d. Can share on google docs and leader display to screen

Robosail Workshop 4

Objectives Students will:

- Create code that allows you to switch between autonomous and manual sail control
- Write/test/debug code for autonomous sailing of simple maneuvers.

Part I Practice specifying positions of rudder, sail, windvane (20 min)

1. Review Autonomous sail algorithms
    a. All worked, but were programmed differently
    b. Review frame of reference for sensors and actuators and practice on plastic sailboats

2. Create code to switch between Autonomous and Manual Sail, test/revise
    a. During regular sailing the sail is least often full-out. We can use this lever position to indicate Autonomous sailing.
    b. Define lever position of > 1850 or so to mean use Autonomous Sail. Anything less than that is Manual Sail
    c. The benefit of this strategy is that you can always take control back from the Arduino and bring the boat home without having to go chase down someone with a skiff to go rescue your boat.
    d. Program this and test it out on the water

3. Discuss how to use the RC Transmitter to initiate a maneuver
    a. Next step in programming is autonomous rudder. That leaves the Rudder lever available to send signals to the boat.
    b. We can continue to use the Sail Lever as Manual or Autonomous as in the first exercise today. Later you can change it to anything you want.
    c. Think of "Rudder Left" (< 1200) as signal L that can tell the boat to turn left by some amount. Similarly "Rudder Right" (> 1800) as signal R that can tell the boat to turn right by some amount.
    d. Discuss how this might be done in code – then put it on hold
        i. Need to get "return to center" from lever before initiating command

Part II Create code for autonomous rudder to hold a given Point of Sail

1. Do exercise on sailing to a Point of Sail using a fan and a student
    a. Blow fan from one direction.
    b. Student turns to various points (beam reach, close haul, run, etc.)
    c. Move fan a bit to simulate shifting wind. Student should follow desired point.
    d. Demonstrate how small steps are used for small adjustments and big steps for big ones.
    e. Define the "error" between the actual wind angle and the desired wind angle.

2. Review ways to use Transmitter while in Autonomous mode.
    a. Use sail lever to make a manual/automatic switch for rudder control
    b. Use rudder lever to send cues to boat when in automatic rudder mode. Cues can be used to change direction.
3. Develop algorithm and code for automatic rudder
    a. Use plastic boats to visualize and test
    b. Create pseudocode for this on whiteboard.
    c. Program using BoatCodeStarter program
    d. Debug/Test/Revise in classroom
4. Add code for automatic/manual rudder control switch (using Sail lever)
    a. Use a boolean variable
    b. Add to existing program
    c. Debug/Test/Revise in classroom

Part III Develop code for changing Point of Sail by using cues from RC Transmitter

1. Develop algorithm and add code for sending cues to change direction
    a. Use a boolean variable
    b. Add to existing program
    c. Debug/Test/Revise in classroom

2. Share results and debrief with other groups

Robosail Workshop 5

Objectives Students will:

- Fully implement Autonomous sailing with manual cues.
- Review the Regatta challenges and plan your strategy for getting your rating.

Part I Complete code for simple Sailing maneuvers with autonomous rudder and a manual cue from Rudder lever.

1. Discuss general plan for code (full Autonomous with Manual Cues)
    a. A good starting place is to Sail to a given point of sail as defined by WindAngle
        i. Use change = (DesiredAngle – WindAngle) to create a command for the rudder such as rudderCommand = change * scalefactor
        ii. Make sure to constrain the rudder command to +- 60°
    b. Consider logic that sends boat to the desired position by turning the easiest way (less than 180 °)
        i. If (change > 180°) then change = change - 360°
        ii. If (change < 180°) then change = change + 360°
    c. Discuss how you are using the RC Transmitter to initiate a maneuver
        i. Use "Rudder Left" (< 1200) and "Rudder Right" (> 1800) as signals that can tell the boat to change direction by some amount
        ii. Check that the Rudder command has gone back to "0" center before starting another maneuver. (check that 1400 < Rudder < 1600)
2. Try this code and observe/record the timing
    a. Tacking, jibing
    b. sailing around a buoy
    c. getting out of irons
    d. Can you program in timing such that it will do a maneuver after a certain amount of time has passed?

Part II Plan for Regatta

1. Present Regatta – a series of tasks that your boat will demonstrate to earn ratings
2. Discuss with your group and plan your work
    a. Create different programs for different tasks.
    b. Get more points for autonomous sailing, but can use manual rudder if necessary
3. Start Coding for regatta tasks

Robosail Workshop 6

Objectives Students will:

- Complete programming and get ratings in the Regatta challenges

Part I Review Regatta challenges

1. Get Score cards and review Regatta options
2. Work with Mentors to plan day's work and write/test code

Part II Regatta / robotic sailing demonstration

1. Demonstrate Regatta challenges on water
    a. Leader checks off and fills out score sheets
2. Review Goals of Course – Did we meet them?
    a. Debrief
3. Closeout

Team Worksheet

Boat:_____ Mentor_____

Team members_____

1. Wind sensor (10 bit magnetic encoder) raw data range: low_____ high _____
2. Transmitter (Sail and Rudder) controls.
    a. Sail full-in (down):_____ Sail full-out (up): _____
    b. Rudder left: _____ Rudder Center: _____ Rudder Right: _____
3. Mechanical adjustment of Rudder (when transmitter lever is centered):

    Completed _____
4. Rudder range (degrees it can move on each side): _____
5. Mechanical adjustment of Sail for close haul:

    Completed _____
6. Position of Sail when transmitter lever is up (degrees): _____
7. Full system wiring check: Control boat with all transmitter commands going through computer on the way to servos.

    Completed _____

