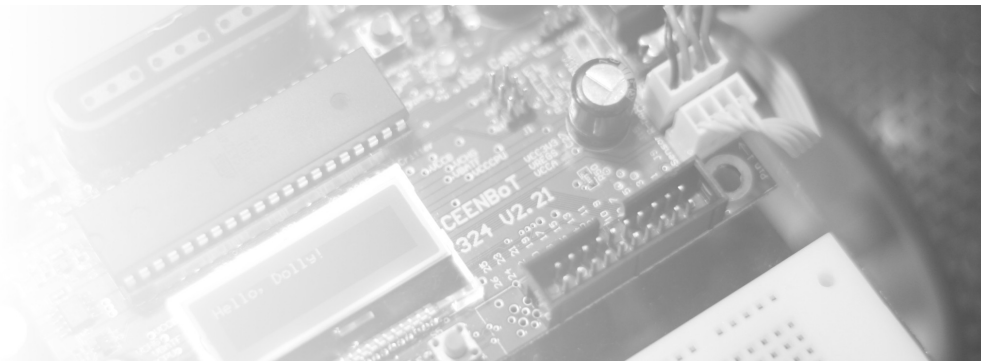


Mobile Robotics I: Lab 7

Line Following with Feedback Control

**CEENBoT™ Mobile Robotics Platform Laboratory Series
CEENBoT v2.21 – '324 Platform**



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Rev 1.01

Purpose

The purpose of this lab is to create a behavior that will enable your robot to follow a black line on a white surface using a pair of IR reflectance sensors in a PID feedback control loop.

Lab Objectives

By following the directions in this lab, you are expected to achieve the following:

- Implement a practical feedback controlled servo behavior for line-following in a behavior-based control structured program.
- Experiment with implementing *Proportional* (P), *Integral* (I) and *Derivative* (D) control and tune the gains to achieve the best performance.
- Fine tune the control so that the robot can successfully follow a black line as described in the lab.

Requirements

Preliminary Readings

- Read about Feedback Control in course texts: Mataric, Chapter 10 and Jones, Chapter 2.
- Read about a practical implementation of PID controllers in: “A PID Controller for LEGO Mindstorm Robots” located here:
http://www.inpharmix.com/jps/PID_Controller_For_Lego_Mindstorms_Robots.html
- Read about the ADC facilities available in the CEENBoT-API in the *Programmer's Reference* if you are not yet familiar with this aspect of the API.

Required Equipment

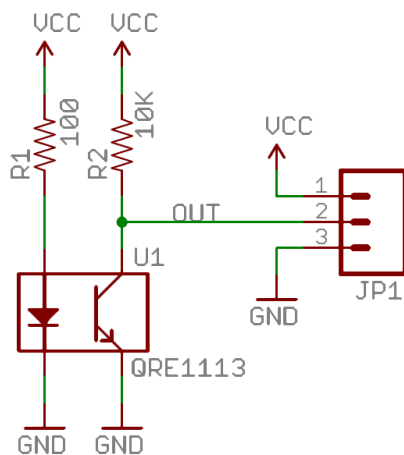
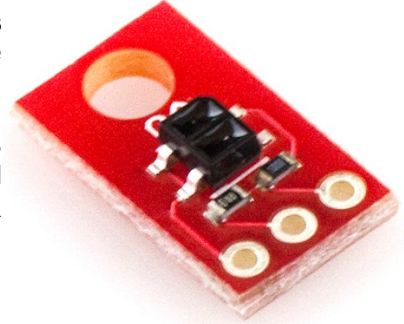
- CEENBoT, platform '324 v2.21.
- Means to program your CEENBoT. (i.e., USB or Serial ISP programmer).

Background

The Line-Following Sensors

You will be using analog IR sensors to accomplish the task of 'tracking' the line. These are the QRE1113 break-out boards as shown right, with a mounting hole that you will use to attach the sensor using L-brackets which will be provided.

These sensors are simple three-terminal devices, with the terminals consisting of **VCC**, **GND**, and **OUT**, with 'OUT' being the analog signal which is *inversely proportional* to the amount of reflectivity from IR light. This can be seen by observing the schematic:



The LED will be constantly emitting an IR light when powered. If this IR light is reflected off a surface (such as the floor in *our* case), then this light will bias the *photo-transistor* and cause it to conduct, resulting in a relatively LOW output voltage via the **OUT** terminal.

However, if this light reflectance is interrupted (such as when the sensor 'hovers over black electrical tape'), then the photo-transistor will not be properly biased, and it will not conduct current, resulting in most of the **VCC** voltage to appear at the **OUT** terminal.

Therefore, voltage values near **VCC** at the **OUT** terminal are indicative of LOW IR reflectance (possible tape detection), while low voltage values at the **OUT** terminal are indicative of HIGH IR reflectance (plain floor).

If you use *two* of these sensors, and feed each **OUT** terminal to a freely available ADC channel, it is possible for you to write a program that allows the CEENBoT to follow a line, using the ADC facilities offered by the CEENBoT-API, which at this point you should be comfortable using.

Wiring

- Connect the **VCC** and **GND** of the analog IR sensors to the **+5V** and **GND** pins on the RC servo ports via header **J7** on the CEENBoT's controller board using the 'plug-in' wires you have been using for all previous labs (these will be supplied). Use Servo ports 3 and 4 for this.
- Connect the **OUT** terminals of the analog IR sensors to a freely available ADC channel of your choosing via header **J3** on the CEENBoT's controller board using the 'plug-in' wires you have been using for all previous labs (these will be supplied).

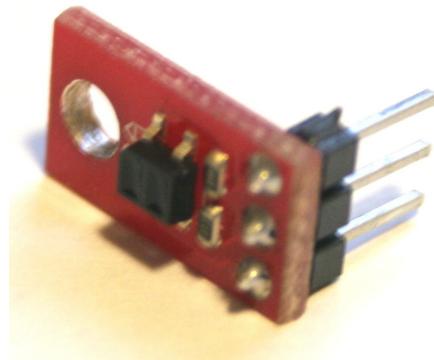
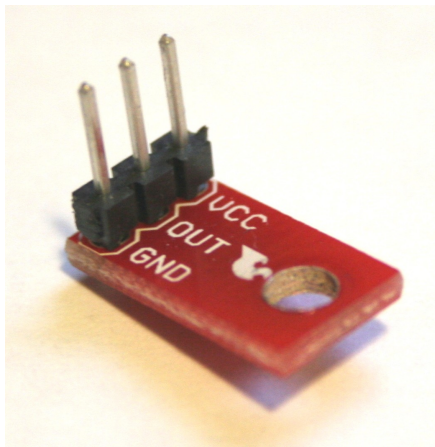
Note: Observe power is taken from pins on **J7**, while signals are fed to pins on **J3**.

The free ADC pins are:

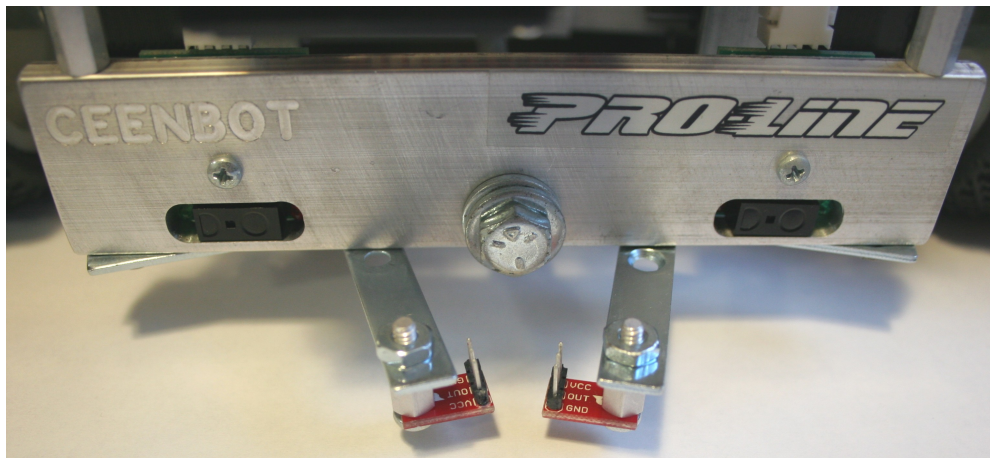
| ADC Channel | Corresponding access pin on Header J3 |
|---------------|---------------------------------------|
| ADC Channel 3 | 1 |
| ADC Channel 4 | 2 |
| ADC Channel 5 | 3 |
| ADC Channel 6 | 4 |
| ADC Channel 7 | 5 |

Assembly & Mounting

The first step is to cut up a strip of 3 consecutive male pins and solder them onto the analog IR sensor board as shown in the images below. They must be soldered such that the side where the wires will be connected are OPPOSITE to the IR sensor itself. Remember that the sensors themselves must point towards the floor surface (see images below):



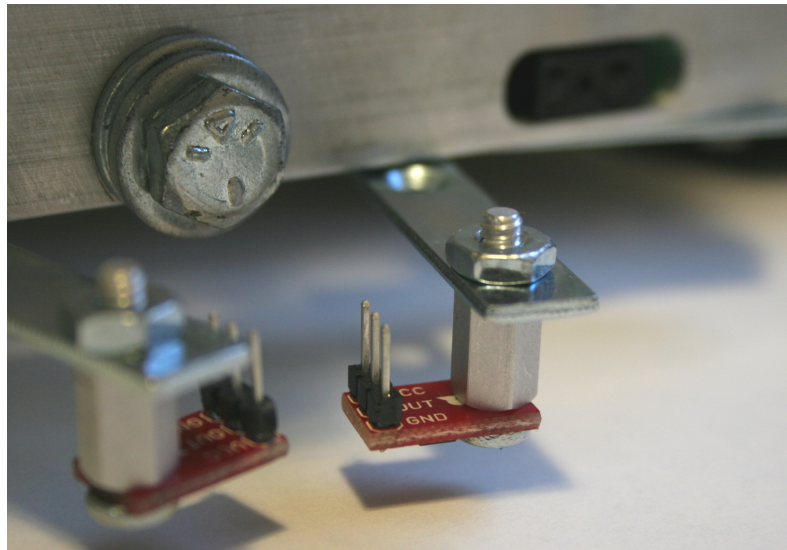
Then, using the L-brackets and stand-offs, you will mount the sensors onto the CEENBoT as shown:



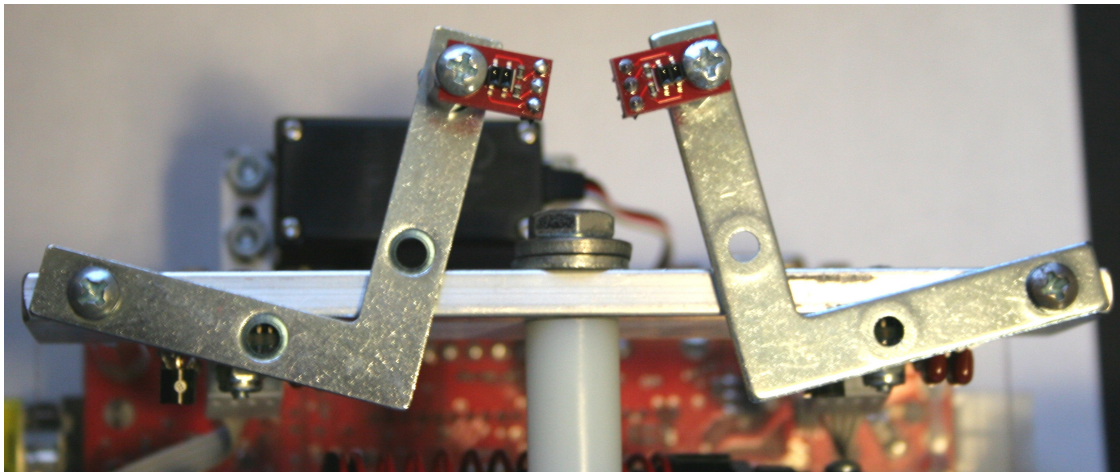
(More images on the *next* page)

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In this image, notice that the *nut* goes on the top side, while the *screw* is used to attached the analog IR board to the stand-off itself on the underside.



The image below shows how the L-brackets should be mounted to the underside of the CEENBoT according to desired proximity.



MAKE SURE YOU MOUNT ONE L-BRACKET AT A TIME! Loosen the screw that is already underneath the faceplate (or 'bumper') of the CEENBoT and mount the first L-bracket, fasten it into position, *then* unscrew the opposite one to mount the *second* L-bracket after you have secured the first one. AGAIN... DO NOT LOOSEN BOTH SCREWS AT ONCE to mount the L-brackets.

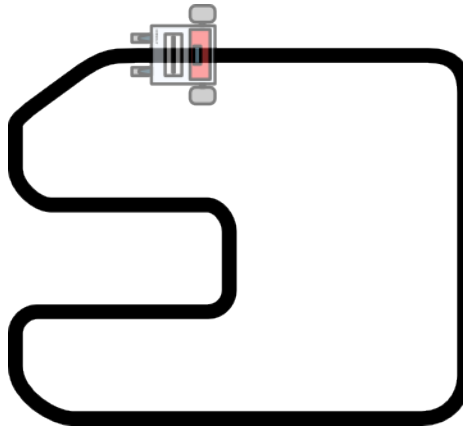
Once you have mounted your line-following sensors, connect your wires, and start coding.

ROBOT PROGRAMMING

You are to use your modified BBC program used in previous labs and add a **Line_Follow** behavior. For the purpose of the demonstration, you will only be required to demonstrate the line follow behavior. Although the other behaviors may still be in the program, this behavior needs to have a higher priority or you can temporarily disable (comment out) the other behaviors.

Directions & Details

1. Install the two IR reflectance sensors on the front of your CEENBoT as discussed in this document using the supplied L-brackets and stand-offs. Also connect the sensor's power and ground lines on the RC Servo ports 3 and 4 (this is J7), while the OUT pins of the sensors will be connected to 2 freely available ADC channel inputs of your choosing (recall these are available via J3), as instructed in the background section of this document.
2. Create a **Line_Follow** behavior based on the outputs from the two IR reflectance sensors such that when the sensors are placed centered on a black line (such as a strip of electrical tape) over a white background (such as the lab tile floor), it will move the motors to keep the sensors centered about the black line, and continue to follow the line.
3. The **Line_Follow** behavior should include elements of feedback control, including (at a minimum) proportional control (P), and to improve the performance, derivative (D) and also integral (I) control might likely need to be added.
4. For the demonstration, **the robot will be started on top of a line**. In the demonstration, the robot should be capable of following:
 - a) a straight line (7/10 points)
 - b) a gentle, rounded 90-degree turn (8/10 points)
 - c) multiple curves and straight lines along a path such as that pictured below (10/10 points)



Note: The above outline is meant to convey the general idea of the line-following task you're expected to achieve – the final configuration may or may not be the same.

5. **Bonus:** The *fastest* performance time through the maze with a level of accuracy that maintains contact with the line (by the instructor's judgment) will be awarded bonus points!

Questions to answer in the RESULTS section of your Report

Answer questions about how you implemented your line-following behavior, the iterations of development that were necessary. Explain in detail the feedback control mechanisms you used (PID), and the performance improvements achieved by adding each. Finally, discuss the overall performance of your `Line_Follow` behavior, and hurdles you found necessary to overcome.

Deliverables

Demonstrations

You will demonstrate your robot's execution of these new capabilities during the designated class meeting or lab time.

C-code

Include a printout of your CEENBoT program. You may include *snippets* of your code and embed them in your lab report as you discuss how your program works, but a separate attachment of your entire source code must be included as part of your report.

Lab Report

The lab report should include all of the following:

- **Title Page** – Include *Course Number, Course Title, Instructor Name, Your Name, Lab Name, & Due Date*.
- **Overview** Section (a brief paragraph of what the lab was about, and the purpose behind it). Please also make sure you touch upon the following as well:
 1. Resources used: (human, text, online or otherwise).
 2. Time invested in this project.
 3. A high-level description of your robot and program.
 4. If this was a *team assignment*, state how tasks were delegated and split up among you.
 5. Known problems with your solution (e.g., the robot will not work on the *carpet*, or... it breaks if you make it go further than 5 ft (for whatever reason), etc.)
- **Background** Section (discuss some of the theory addressed in this particular lab).
- **Procedure** – Briefly describe the lab procedures for each lab – what were you asked to do? What did the process consist of? How *did you* approach it?
- **Discuss your Source Code** – Discuss and explain any relevant details behind the motivation and manner in which you have written your source code. You can *embed* [small] portions on of your code that are relevant to the discussion for clarity, but please ensure to keep a complete copy of your source code as a separate attachment (see *Source Code* section below). You may also have the reader *refer* to particular pages of your source code attachment instead.
- **Results** – Use this section to answer *questions* posted throughout your lab exercise. In particular those given out in the '*Directions*' section. In the '*Procedure*' section, feel free to refer the reader to *this* section for additional info – that is, there is no need to repeat information.
- **Conclusion** – Reiterate the objective of the lab, discuss what you have learned and any further comments you might have.
- **Source Code** – Attach your C-program also.

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Grading

| Laboratory Grading Rubric | | Labs will be graded out of 30 points, unless otherwise | |
|---------------------------|--|---|--|
| Points | Lab Report | Code | Demonstration |
| 10 | Follows lab format, all sections are complete, thorough, concise. Answers all questions posed. | Properly commented, easy to follow with modular components. | Excellent work, the robot performs exactly as required. |
| 7.5 | Does not answer some of the questions or has spelling, grammatical, content errors. | Partial comments and/or not modular. | Performs most of the functionality with minor failures. |
| 5 | Multiple grammatical, format, content, spelling errors, and/or questions not answered. | No comments, not modular, not easy to follow. | Performs some of the functionality but with major failures or parts missing. |
| 0 | Not submitted or submitted late. | Not submitted or submitted late. | Meets none of the design specifications or not submitted. |