LAB 6

IR DISTANCE MEASUREMENT

INTRODUCTION

This week in lab you will be working with the Infrared (IR) sensor, programming the Analog-to-Digital Converter (ADC) module, and demonstrating data acquisition and distance measurement using the ADC and IR sensor.

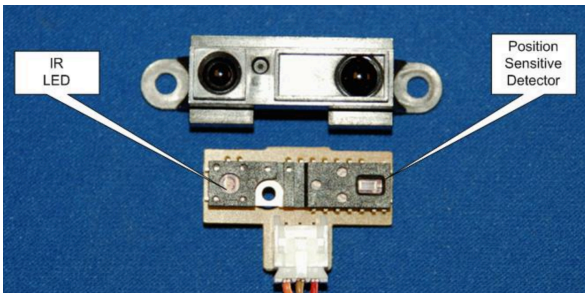


FIGURE 1: INTERNALS OF AN IR ELECTRO-OPTICAL DISTANCE SENSOR

The IR sensor is an electro-optical device that emits an infrared beam from an LED and has a position sensitive detector (PSD) that receives a reflected IR beam; see Figure 1. A lens is positioned in front of the PSD in order to focus the reflection before it reaches the sensor. The PSD sensor is an array of IR detectors, and the distance of an object can be determined through optical triangulation (see Figures 2-4 below). The location of the focused reflection on the PSD is translated to a voltage that corresponds with the measured distance. An IR distance sensor is designed to measure distances in a specific range. The IR sensor used in the lab is designed for 9 - 80+ cm. However, the IR sensor can only fairly accurately display a distance value for an object 9 – 50 cm away. As the distance increases, the voltage decreases. See the IR Sensor Datasheet to learn more about the operation of the IR sensor.

ADC (Analog to Digital Conversion) and DAC (Digital to Analog Conversion) allows our embedded programs to interact with real-world physical systems. Physical quantities such as temperature, pressure, distance, or light are analog and represented using continuously valued signals with infinite possible values in between. In contrast, a digital signal is a discretely valued signal having a fixed precision. Since analog is a continuous value, we need a way to convert a physical analog signal into an n-bit digital signal.

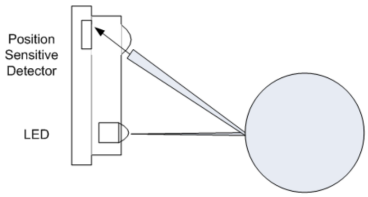


FIGURE 2: OPTICAL TRIANGULATION FOR DISTANCE OF A NEAR OBJECT.

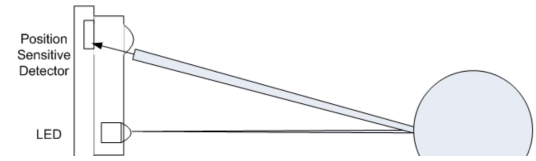


FIGURE 3: OPTICAL TRIANGULATION FOR A DISTANT OBJECT.

Our platform's microcontroller has two 12-bit ADCs. The IR sensor measures a distance and sets the voltage on the wire leading to the GPIO pin. The ADC then converts this voltage into a 12-bit digital value between 0 and 4095 (2^{12} values) and stores it in an ADC register. This digital value is called a conversion result or quantized value. The program then reads the digital (quantized) value and converts it into a distance. After an ADC conversion has been triggered and is complete, the conversion results can be obtained from the ADC Sample Sequence Result FIFO (**ADCSSFIFOn**) register. You may need to think about the correlation between the physical input signal and the digital results. Once you have set up the ADC to generate a digital result (quantized value), you will need to calculate the distances corresponding to the digital results and improve the accuracy of the distance calculations.

Note: The following figure illustrates the use of triangulation to determine the distance to an object based on similar triangles. The IR sensor does this triangulation for you, such that its output voltage represents the distance as shown in the datasheet.

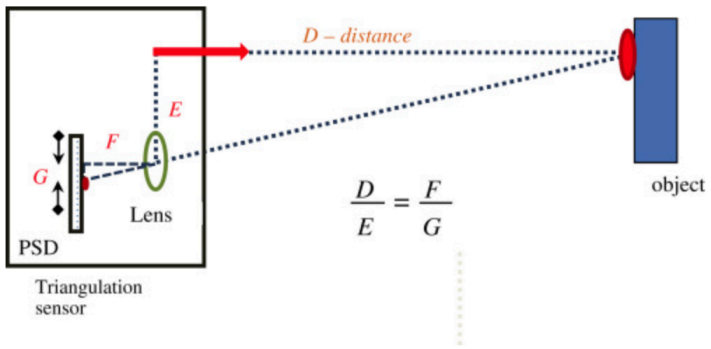


Figure 8 Principle of optical triangulation sensor. The unknown distance, *D*, is determined from the known distances *E*, *F* and the measured value of *G*—the distance to the pixel in the position sensitive detector (PSD) recording the image of the laser spot on the measured object.

FIGURE 4: PRINCIPLE OF OPTICAL TRIANGULATION.

Citation: Garry Berkovic, Ehud Shafir, "Optical methods for distance and displacement measurements," Adv. Opt. Photon. 4, 441-471 (2012); https://www.osapublishing.org/aop/abstract.cfm?uri=aop-4-4-441

REFERENCE FILES

The following reference files will be used in successful completion of this lab:

1. Lab6_Evaluation_Form
2. lcd.c, a program file containing various LCD functions
3. lcd.h, the header file for lcd.c
4. timer.c, A program file containing various wait commands
5. timer.h, the header file for timer.c
6. TM4C123GH6PM Datasheet
7. IR Sensor Datasheet

In addition to the files that have already been included for you, you will need to write your own **adc.c** file and **adc.h** file and the associated functions for setting up and using ADC. Separate functionalities should be in separate functions for good coding quality and reusability purposes. This means that in your adc.c file you should write separate functions for initializing/configuring ADC and taking an ADC sample. Remember to use good naming conventions for function names and variables. For example, you may want to name your ADC initialization function **adc_init** and name your function to take samples **adc_read** as there will be other initialization functions you will write in later labs that will eventually have to be used together. Minimally, we recommend defining the following functions:

```
void adc_init(void);
void adc_read(double distance);
```

PRELAB: ADC REGISTERS

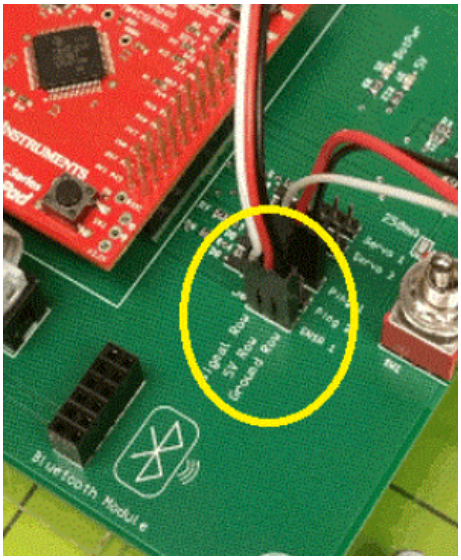
Locate the Prelab 6 Template on Canvas and answer the questions. You must upload your answers as a PDF to Canvas prior to the start of lab under the assignment titled “Lab 6”.

PART 1: INITIALIZING ADC AND DISPLAYING QUANTIZED VALUE

Write a program for the ADC that will initialize and configure the registers needed to sample the analog voltage from the IR distance sensor. Print the digital result (quantized value) to the LCD screen.

The ADC uses Ports B, D, and E. While there are 12 input channels, in lab we will use AIN10 on PB4. See Table 13-1 in the Tiva datasheet for all channels. You may choose which ADC module to use (ADC0 or ADC1) and which Sample Sequencer unit to use (SS0, SS1, SS2, SS3).

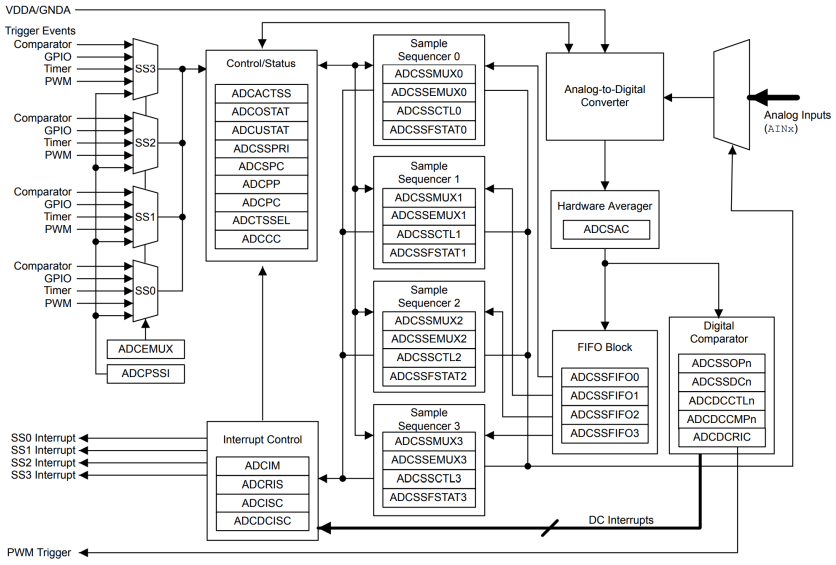
Make sure the IR sensor is connected to the correct pins on the CyBot board, as shown on the right. There are three pins labeled **SNSR1** on the baseboard, which are marked as 3 rows: (1) Signal Row, (2) 5V Row (power), and (3) Ground Row. The Signal Row makes a connection to microcontroller pin PB4 (AIN10). The sensor connector should be oriented such that the white wire connects to Signal and the black wire connects to Ground. The red voltage supply wire is in the center.



Your program should be set up to repeatedly take samples. The displayed quantization values will be dynamic based on conversion results produced by the ADC. You will notice quite a bit of variability in the quantized value even when the CyBot and object are stationary. This is because of noise inherent with ADC operation. You may want to slow down how fast samples are taken as well as how frequently the display is updated.

As you are setting up the registers for ADC, you may find the ADC Module Block Diagram useful for understanding how samples are taken. You can also refer to Chapter 13 in the Tiva Datasheet, which contains sections on signal descriptions, functional descriptions, initialization and configuration steps, as well as the register descriptions. You may not need to read everything in these sections. Look for basic concepts and overviews first, ignore things that seem outside the scope of the lab (whether or not it may be needed later, ignore it for now, such as digital comparators or differential mode). Browse the steps given for initialization, sample sequencer configuration, etc.

Figure 13-2. ADC Module Block Diagram



Another resource that gives a nice overview and selected details of the ADC is Valvano and Yerraballi, Chapter 14: Analog to Digital Conversion, Embedded Systems: Introduction to ARM Cortex-M Microcontrollers, 2014.

CHECKPOINT:

Demonstrate ADC conversion of IR sensor signals to your mentor. Your program should display quantized values read from the ADC (raw digital conversion results). Do not calculate distance for this part. You should be able to explain whether the quantized values appear to be valid. You will calculate and calibrate the distance measured in the next part.

PART 2: CALIBRATING DISTANCE MEASUREMENT

In Part 1, you configured the ADC to generate a quantization value based on the distance of an object. Due to the nonlinear sensor operation, there is not a simple linear transfer function between the distance being measured and the analog voltage output of the sensor. Thus, you will need to implement a technique to map quantization values to distance values. To do this, you will need to take some measurements. Your task is to accurately display a distance value for an object 9 – 50 cm away. In order to calibrate the sensor, you will need to collect several data points consisting of the known distance and quantized value at that distance. Based on these data points, you can create a lookup table or find an equation for a best fit line/curve. Your method will return an estimated distance value for a given quantization value. For full credit, the estimated distance calculated by your program must be within 1 cm of the actual distance. Print to the LCD both the quantization value and the estimated distance in cm.

You should also reduce the variability in values seen in Part 1 by averaging multiple samples. You can use either hardware averaging (Tiva Datasheet section 13.3.3) or software averaging to collect and average 16 samples to get a more stable sensor value. The variability observed in Part 1 can be reduced by averaging multiple samples and treating the average value as the estimated distance value. Use an averaging mechanism in your program.

CHECKPOINT:

Demonstrate the distance measurement. Print to the LCD both the quantization value and the estimated distance in cm. Your distance readings should be within 1 cm of actual values. Additionally, you must implement an averaging mechanism in your program.

PART 3: VISUALIZING DATA

Now that you have calibrated the distance measurements, send the quantized values and distance values to the PC using Putty. You should output this data to a file, similar to Lab 5, and graph it. The output data should be formatted in Putty.

As a bonus (optional), you may want to think of a way to more efficiently perform a recalibration of the IR sensor measurement. IR sensors are bot dependent, and may also be affected by the operating environment, meaning that sensor operation may vary. Thus measurements may need to be recalibrated. Even if you are using the same bot that you previously worked with, sensor data can vary. Additionally, sometimes the sensors need to be replaced, thus it is important to verify that distance measurements you are receiving are accurate.

One recommended way to more efficiently recalibrate is to build off of the knowledge you have from data analysis and the Open Interface API, and write a short function to move the CyBot back from the wall (a known distance) and send back information about the known distance and quantized value as the CyBot moves. You can graph this data, and more quickly update a distance calculation without having to manually move the CyBot and measure each point. This is not the only way you can perform an efficient calibration. You are encouraged to come up with additional ideas. Bonus points (up to 3 points) may be awarded on a case by case basis for students who have a novel implementation.

CHECKPOINT:

Demonstrate your IR/ADC data output in Putty and graph to your mentor. Full credit will be received if the following requirements are met: (1) you must output data using Putty and display a graph, (2) you must be able to explain and justify your calibration methods with a detailed description of how your choices were made or implemented.