Bachelor Thesis
Electrical Engineering

Distance Estimation of Two Distance Sensors

Aditya Pavan Kumar Yenuga
Vamsi Bhargav Kamuju

Dept. of Mathematics and Natural Sciences
Blekinge Institute of Technology
SE–371 79 Karlskrona, Sweden

This thesis is submitted to the Department of Mathematics and Natural Sciences at Blekinge Institute of Technology in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical Engineering. The thesis is equivalent to 10 weeks of full-time studies.

Contact Information:
Author(s):
Vamsi Bhargav Kamuju
E-mail: Vaka20@student.bth.se

Aditya Pavan Kumar Yenuga
E-mail: Adye20@student.bth.se

University advisor:
Irina Gertsovich
Dept. Mathematics and Natural Sciences

Dept. Mathematics and Natural Sciences
Blekinge Institute of Technology
SE–371 79 Karlskrona, Sweden

Internet : www.bth.se/didd
Phone : +46 455 38 50 00
Fax : +46 455 38 50 57

We are very much indebted to Irina Gertsovich. For providing this unique project opportunity and providing facilities that were required. We need to thank her for support and kind cooperation, supervision in completing the project.

Sincerely,
Aditya Pavan Kumar
Vamsi Bhargav Kamuju

Abstract

In modern world sensors play important role where they help to acquire information about the procecess, such as temperature, velocity, distance, etc. Based on this information acquired from the sensors decisions can be made, for example to increase heating in the building or accelerate the car.

In many cases, a single sensor type cannot provide enough information for complex decision making, for example, when the physical properties of the process are outside of the measurement range of the sensor. As a result, in order to achieve desired performance levels, a combination of sensors should be used in an integrated manner.

Sensor generated data need to be processed into information through the use of appropriate decision making models in order to improve overall performance. Here we compare two sensors which are short-range and long-range sensor. We use a short-range and long-range sensor, and calculates the distance from both sensors to the same object by using Arduino UNO microcontroller. The sensors that we use in our work have overlapping or common interval in their measurement ranges. Therefore we investigated how we can make a decision about the distance to an object when the acquired data from both sensors is in that common range.

Keywords: Short-range sensor, long-range sensor, Arduino UNO microcontroller

Contents

Abstract **ii**

1 Introduction **1**

2 Related Work **3**
2.1 Distance Sensors - ToF vs. LiDAR 3

3 Problem Statement, Objectives and Main Contribution **6**
3.1 Problem Statement 6
3.2 Objectives 6
3.3 Main Contribution 7

4 Modelling **8**
4.1 Flowchart 8
4.2 Block Diagram 10

5 Solution **11**
5.1 The Prototype and its Connection Diagram 11
5.2 Hardware Implementation 12
5.2.1 Circuit Diagram 12
5.2.2 Theoretical Background of Components 14
5.3 Software Implementation 19

6 Testing and Validation **20**

7 Conclusions And Future Work **26**

References **27**

List of Figures

2.1 Time-of-Flight Principle [1] 3
2.2 Object Detection and Distance Estimation[2] 5

4.1 Flowchart of Distance Estimation of Two Distance Sensors 8
4.2 Block Diagram of Distance Estimation of Two Distance Sensors . 10

5.1 Hardware Prototype for Estimation of the Distance to the Moving Target 11
5.2 Circuit Diagram of Distance Estimation of Two Distance Sensors . 12
5.3 Arduino Uno Rev3 [3] 14
5.4 DFRobot Gravity IO Expansion Shield [4] 16
5.5 VL6180X ToF Distance Ranging Sensor [5] 17
5.6 TFmini-S LiDAR ToF Laser Range Sensor [6] 18

6.1 Experimental Setup of Distance Estimation of Two Distance Sensors 20
6.2 Serial Monitor Readings of an Obstacle 85 mm Away from the Two Distance Sensors 21
6.3 Serial Monitor Readings of an Obstacle 90 mm Away from the Two Distance Sensors 21
6.4 Serial Monitor Readings of an Obstacle 115 mm Away from the Two Distance Sensors 22

List of Tables

5.1 Specifications ofArduino Uno Rev3 [3] 15
5.2 Specifications of DFRobot Gravity IO Expansion Shield [4] 16
5.3 Specifications of VL6180X ToF Distance Ranging Sensor [5] . . . 17
5.4 Specifications of TFmini-s LiDAR ToF Laser Range Sensor [6] . . 19

6.1 Mean, Variance and Standard Deviation for VL6180X Sensor in the Range from 50 to 150 mm 24

Chapter 1

Introduction

The determination of an object's distance from a sensor is a common area of study in computer vision. A growing number of modern applications such as position determination, object recognition and collision prevention depend on accurate analysis of the distance to the object.

More specifically, we are interested to accurately measure the distance to a moving object from certain fixed position. The applications where such task might arise are for example landing of the airplane or a drone or parking of a car. In the landing procedure for example the object a drone first can be detected at the distance 50 m during its landing the distance can be measured with millimeter precision.

There exist different techniques to measure the distance to a moving object with different complexity, cost and the measurement accuracy and precision. In this thesis we investigate a possibility to measure the distance to a moving object in the range from zero to 12 m using two sensors.

Here we compare two sensors which are short-range and long-range sensor. We use a Fermion: VL6180X ToF Distance Ranging Sensor, which is a short-range sensor [5]. The technology used in this sensor allows distance to be accurately measured independent of target reflectance.

The sensor is rated to perform ranging measurements of 5-100 mm, but it can provide readings up to 200 mm in a good environment. Besides, VL6180X is also equipped with an ambient light sensor, so basically, this sensor combines proximity ranging and ambient light level measurement capacities into a single package.

In the place of a long-range sensor, we use TFmini-S LiDAR(ToF) [6]. The TFMini LiDAR is a time-of-flight (ToF) laser range finder. It comprises optical

and electronic components that incorporate an integrated algorithm for both indoor and outdoor applications. It has a petite body but a high distance measuring efficiency.

To control both short-range and long-range sensors, we use an Arduino UNO and caluclate the distance to an object placed at various fixed distances a stationary point, where both sensors are placed. We validate the sensor accuracy and precision at long and short ranges using the data from several observations. Data from two sensors are acquired and tabulated at different fixed distances from the object and statistical parameters such as mean, standard deviation and variance are calculated for each fixed distance. We compare the performance of the two sensors at comparable distances before recommending which sensor to use at which distance.

Chapter 2

Related Work

2.1 Distance Sensors - ToF vs. LiDAR

ToF: Duration of the flight In a more technical sense, time-of-flight refers to the practice of calculating distance based on the speed of light. Time-of-Flight (ToF) sensors are an alternative to laser scanners and image-based stereo-vision. ToF sensors have a significant impact on current research areas like online object recognition, collision prevention, and scene and object reconstruction [7].

More than three decades ago, radar and Lidar applications were some of the earliest adopters of TOF systems.The fundamental idea is to send a signal in the direction of a target and then analyze some aspect of the signal that comes back from the target [8]. Light is used as the carrier in ToF sensors because it is the only medium that can simultaneously provide greater speed, greater range, lower weight, and eye-safety.

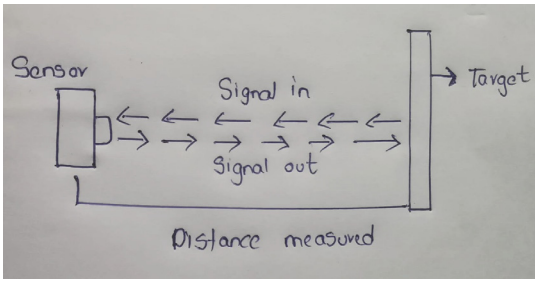

Figure 2.1: Time-of-Flight Principle [1]

Calculating distances from time: Photons travel at light speed, abbreviated c. 300000km/s is lightspeed. Faster travel is impossible. Photons travel great distances quickly. From the sun to the earth, a photon takes eight minutes; from the moon, 1.28 seconds. Photons travel 10 m in 33 ns and 1 m in 3.3 ns. Photons travel 30 cm/ns.

Time-of-Flight is the measurement of the distance in light seconds. To calculate a distance using ToF, we multiply the speed of light by the time it takes for photons to travel from the source to the object and back again, and then we divide by two (since the photons travel the distance twice, once on their way to the object and once on their way back):

distance = speed * time /2

In theory, it all makes perfect sense. The target or object that the light hits, or the environment the sensor and the object are in, can both introduce complications in practice.

LiDAR: The technology of using light to measure distance. This technology, known as LiDAR, is used for gathering information from afar. LiDAR is a measurement technology that uses a laser pulse. These are required when making 3D models and maps of real-world locations. Since automotive LiDAR (Light Detection and Ranging) sensors may be able to provide useful information under conditions that other surrounding observing sensors are not able to detect, they will become an integral part of self-driving cars [9].

Different distance-measuring techniques:

Using millimeter wave radar for distance measuring: In many industrial settings, it's important to measure distances to within a few tens of micrometers [10][11]. For use in hydraulic, dental, and orthodontic applications, as well as industrial liquid level measurement systems. Up to a few meters separate the sensor and the object being measured. The inaccessibility of the object whose distance is to be measured precludes the use of contact-based distance measurement in many contexts. That kind of measuring is also not very accurate [12][13].

Thus, millimeter-wave radar can be used to make relatively precise distance estimates (to within a few micrometers). This demonstrates how the radar's use of frequency-modulated continuous waves (FMCW) enables the distance between the radar sensor and the object reflecting the radar signal to be calculated with great accuracy by measuring both the frequency and the phase of the radar beat signal. Single-chip FMCW radar at 77 GHz with a 4-GHz chirp bandwidth was used to evaluate the method. The estimated relative distance was then compared to the true relative distance at a number of different locations on the object. We show that the Cramer-Rao lower bound can be approached with a variance of less than 10 m in the estimated distance, and we provide a novel solution to minimize estimate bias due to reflections from nearby objects and the undesirable phase ambiguity problem associated with phase recovery during distance estimation [14].

The authors were able to enhance the reliability, accuracy, and precision of these methods by utilizing this method, which requires very little additional complexity [14].

The use of millimeter waves has a number of benefits, such as the ability to transmit at higher rates, use spread spectrum, and be less susceptible to interference, and the fact that multiple short-range uses can occur on the same frequency without interfering with one another. The use of millimeter waves has a few drawbacks, such as a high production cost [15].

Image-based object detection and range calculation: Autonomous obstacle detection, identification, and distance estimation is becoming increasingly important in ADAS (Advanced Driver Assistance Systems) applications, which are increasingly being installed in vehicles [2].

To do this, the camera's surroundings are first identified, and then a 3D point cloud is generated and used to determine distances. so not only can we use it to detect objects, but also to use its distance estimation capabilities [2].

Figure 2.2: Object Detection and Distance Estimation[2]

In tests, the system achieved an impressive 84% detection accuracy with an average distance estimation error of less than 4.7% up to a distance of 5 meters. This means the proposed system can be used successfully in ADAS settings, as well as in settings requiring autonomous robot navigation [2].

Chapter 3

Problem Statement, Objectives and Main Contribution

3.1 Problem Statement

Simple decisions require more data than a single sort of sensor can supply. Combining many sensors in a coordinated fashion is essential for achieving the appropriate degree of performance. In order to boost overall performance, sensor-generated data must be converted into information via the use of suitable decision making models [16].

3.2 Objectives

Main goal of this work is to develop a method to accurately measure the distance in the range from 0 to 12 m with least possible error

Some of the research questions which define the objectives of our project are:

1)How do we combine the information from both sensors(sensor fusion) to estimate the distance of the object?

2)Can we combine the data from two sensors to get the accuracy of the distance to the object?

The main objective of this project is to compare and analyze the distance of the object from the sensors. Here we are using the sensors to caluclate the distance precisely from the object.The object is placed at an equal distance from both sensors and the distance from the both the sensors is recorded. By comparing and analyzing readings from both sensors, we decide what distance to the object is reported as a final distance.

3.3 Main Contribution

The main contribution of the thesis is presenting of an autonomous model for estimation of actual distance of the object in order to improve overall performance. It is highly advisable to check the distance sensors before initializing and starting the actual measurement and object. In this project, we will work on two sensors for long range and short-range and also we will use both sensors at the same time to measure the distance to the incoming object. By the use of the Arduino IDE software we can get the readings from the sensor.

Chapter 4

Modelling

4.1 Flowchart

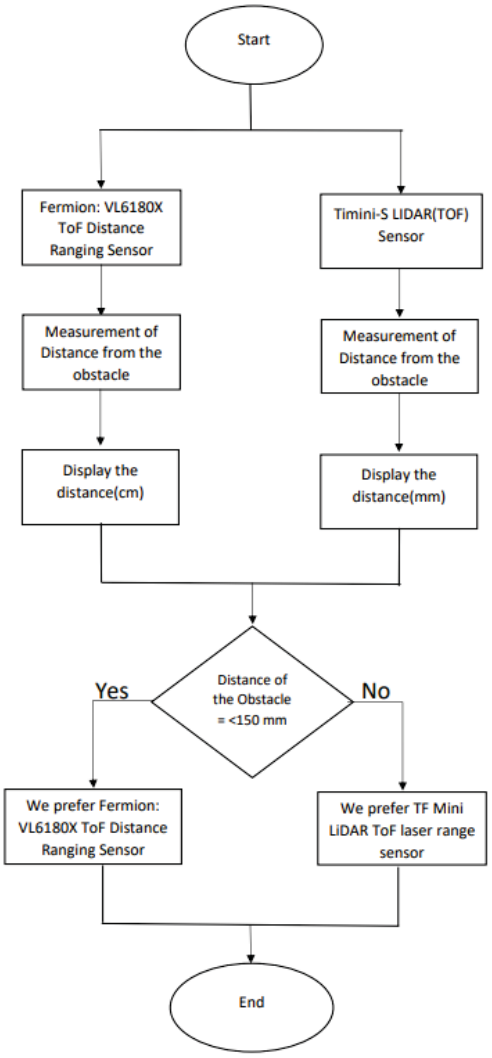

Figure 4.1: Flowchart of Distance Estimation of Two Distance Sensors

Figure 4.1 illustrates the decision-making process based on sensor data in a flowchart. It includes data from the time the Arduino receives the input to the time the intended output is obtained. It consists of the data briefly in sequential steps.

When the program is uploaded. ToF distance ranging sensor will start to measure distance from the obstacle. We will record the readings. Similarly, TFmini-S LiDAR sensor will begin recording the values and it's maximum detection distance is 12 meters. Data will be received by the Arduino.

If the distance of the obstacle is less than 150mm, we prefer Fermion VL6180X TOF Distance Ranging. Whereas, If the distance of the obstacle is greater than 150mm, We prefer the choice of the threshold at 150 mm it explained in the chapter 6 in testing and validation procedure.

4.2 Block Diagram

Figure 4.2 shows the block diagram of the project. The block diagram here depicts the Fermion: VL6180X ToF distance ranging sensor, TFmini-S senor. The inputs are represented on the left side of the Arduino UNO and the outputs are represented on the right side of the Arduino UNO. In this system, the verification of the distance estimation is done initially, by taking the readings from both the sensors. Once the power supply is connected and code is uploaded the sensors send data to Arduino. Both sensors play a vital role in caluclating the distance of the object.

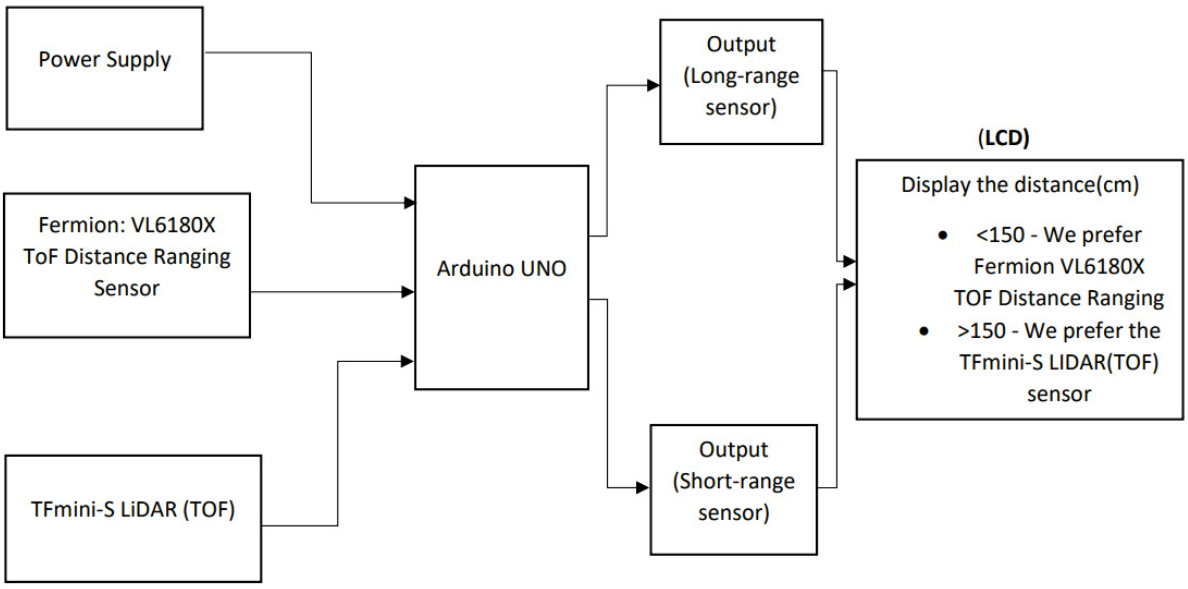

Figure 4.2: Block Diagram of Distance Estimation of Two Distance Sensors

Chapter 5

Solution

5.1 The Prototype and its Connection Diagram

The hardware prototype of the project is shown in Figure 5.1. The VL6180X Sensor, TFmini-S sensor are shown in this prototype. These two sensors are then connected to the Arduino UNO. After uploading the code, we calculate the actual the distances of the several objects.

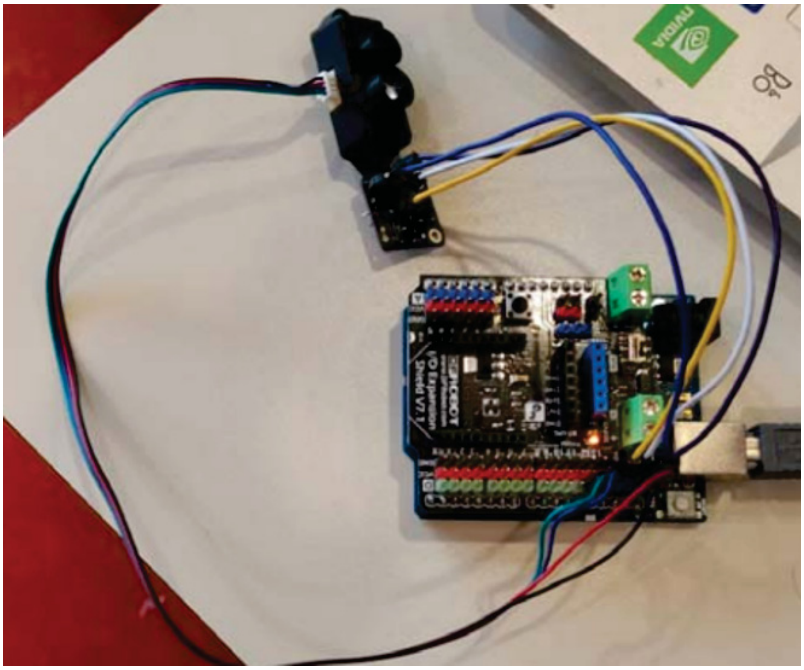

Figure 5.1: Hardware Prototype for Estimation of the Distance to the Moving Target

5.2 Hardware Implementation

5.2.1 Circuit Diagram

Now, as illustrated in the circuit schematic in Figure 5.2, we connect all of the components. The following are the circuit connections:

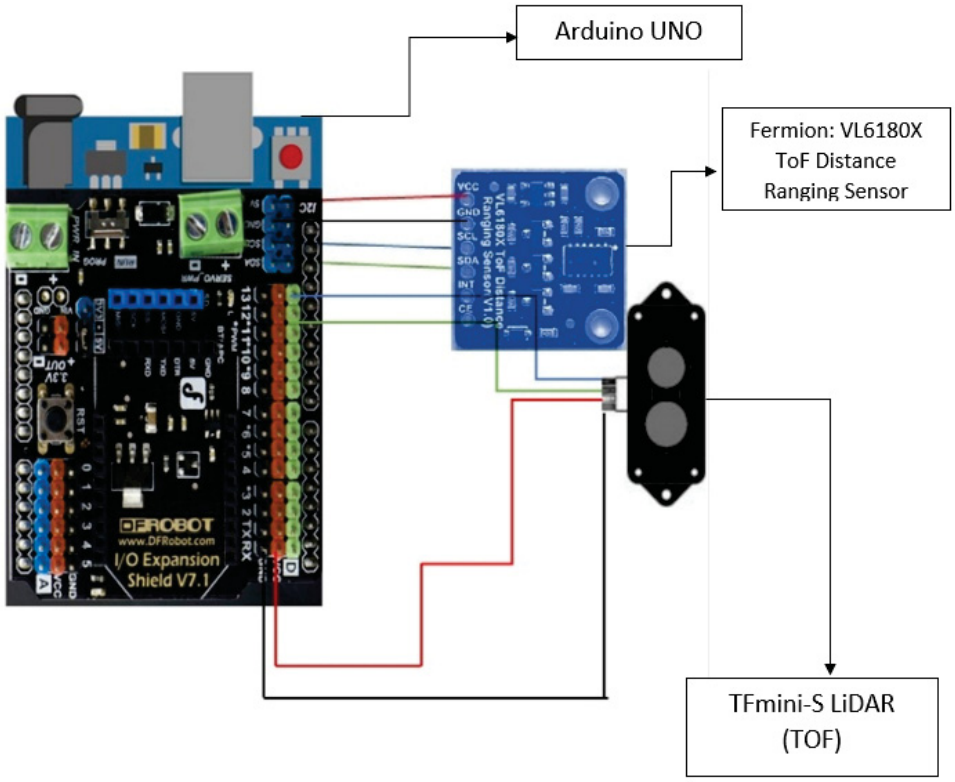

Figure 5.2: Circuit Diagram of Distance Estimation of Two Distance Sensors

List of components used:

- Arduino Uno Rev3
- DFRobot Gravity IO Expansion Shield
- VL6180X ToF Distance Ranging Sensor
- TFmini-S LiDAR ToF laser range sensor

Wiring:

Connect the pins for both sensors as shown in Figure 5.2 in the manner described below.

VL6180X ToF sensor connections:

- Connect Vin to the power source; 3-5 V is acceptable. Utilize the identical voltage that the microcontroller's logic is based on. That's 5V for the majority of Arduinos (red wire on STEMMA).
- Connect the GND to the shared power/data ground (black wire on STEMMA).
- Connect your Arduino's SCL pin to the I2C clock SCL pin. This is also known as A5 on an Arduino UNO '328-based board, digital 21 on a Mega, and digital 3 on a LeonardoMicro (yellow wire on STEMMA).
- Connect your Arduino's SDA pin to the I2C data SDA pin. This is also known as A4 on Arduino UNO '328-based boards, digital 20 on Mega, and digital 2 on LeonardoMicro boards (blue wire on STEMMA).

TFmini-s sensor connections:

- Vin pin of the sensor should be connected to the power source at 5 V.
- Connect the Arduino's GND to GND of the sensor.
- TXD pin of the sensor should be connected to Arduino pin 12.
- RXD pin of the sensor should be connected to Arduino pin 13.

5.2.2 Theoretical Background of Components

Arduino Uno Rev3: An ATmega328P-based microcontroller board, Arduino Uno is the brains behind many electronic projects (datasheet). It comes with a USB port, a power jack, an ICSP header, a reset button, and 14 digital I/O pins (6 of which can be used as PWM outputs). It also has a 16 MHz ceramic resonator (CSTCE16M0V53-R0), 6 analog inputs, and a reset button. It has everything you need to get started with the microcontroller; all you need to do is plug it into a computer via USB or supply power with an AC-to-DC adapter or battery [3].

Arduino Software (IDE) 1.0 was given the Italian name "Uno," which means "one." There have been many revisions of the Arduino platform since its inception with the Uno board and the 1.0 release of the Arduino Software (IDE). In terms of the Arduino platform as a whole, the Uno board serves as both the starting point for a family of USB Arduino boards and the platform's gold standard.

Figure 5.3: Arduino Uno Rev3 [3]

MICROCONTROLLER	ATmega328P
OPERATING VOLTAGE	5V
I/P VOLTAGE (RECOMMENDED)	7-12V
I/P VOLTAGE (LIMIT)	6-20V
DIGITAL I/O PINS	14 (of which 6 provide PWM output)
PWM DIGITAL I/O PINS	6
ANALOG INPUT PINS	6
DC CURRENT PER I/O PIN	20 mA
DC CURRENT FOR 3.3V PIN	50 mA
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
CLOCK SPEED	16 MHz
LED_BUILTIN	13
LENGTH	68.6 mm
WIDTH	53.4 mm
WEIGHT	25 g

Table 5.1: Specifications ofArduino Uno Rev3 [3]

DFRobot Gravity IO Expansion Shield: The IO Expansion shield is a top-tier product available today. With this method, rapid prototyping in robotics is not only possible, but also cheap and easy. Soldering and wiring often become difficult when components fail due to a bridging connection. In addition to increasing in price, project durations are growing steadily longer. Without this solution, such as wire cutters, a soldering station, or a soldering station, prototyping electronics or robots on your own can be a very time-consuming process [4].

The DFRobot Expansion shield was the first product to introduce the now-standard color code for input and output from sensors and actuators. With our ever-expanding inventory of modules, sensors, and devices that are a perfect fit, the three-pin layout of Signal, Voltage, and Ground is extremely convenient. The power input on the board allows it to be powered by a standard wall outlet or a laboratory power supply. widely used Xbee socket that can connect to Bluetooth, radio frequency, and other wireless devices. The new version has a voltage hardware option that can be toggled with a jumper, allowing it to work with a wider variety of 3.3v components like Raspberry Pi and Due, among others. There is also a safety diode and an additional power supply for the servo. In this way, your Arduino can power a wide range of servos.

The most recent release adds a switch that lets you program ATmega328 boards like UNO with another Serial device, such as an Xbee, connected. It's possible

to reprogram it, switch it, and then bring it back online. There is no need to disassemble any parts or disconnect any cables. Including a reset button and an LED on the top board of Arduino boards seems like a logical next step in the product's evolution. The LED is connected to Pin 13 [4].

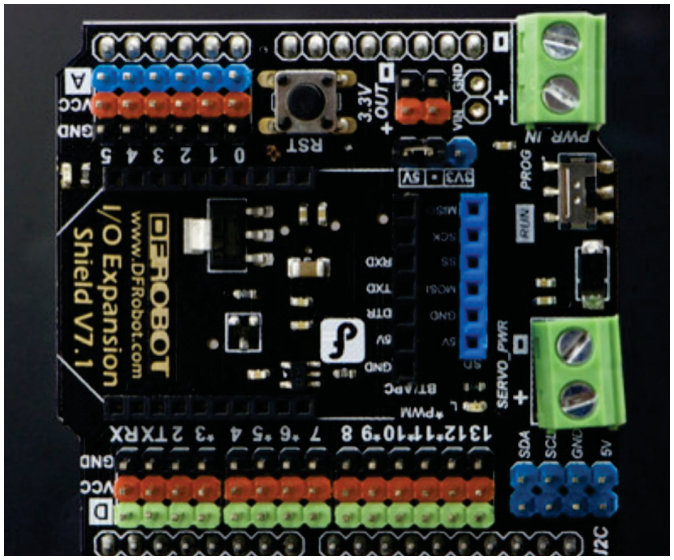

Figure 5.4: DFRobot Gravity IO Expansion Shield [4]

Input Voltage	7-12V, PWR_IN
Compatible module voltage	5V/3.3V
Support interface	I2C, SPI, Xbee (Xbee pro), Bluetooth, APC220

Table 5.2: Specifications of DFRobot Gravity IO Expansion Shield [4]

VL6180X ToF Distance Ranging Sensor: A Time of Flight distance sensor is provided by the VL6180X, which is also referred to as the VL6180. The sensor has both a sensor that corresponds to the very small laser source and a sensor that is part of the sensor itself. The VL6180X has the ability to calculate the "time of flight," which is the amount of time it took for the laser light to come back around to the sensor. Due to the fact that it employs such a focused beam of light, it can accurately determine the distance to the surface that is immediately in front of it [5].

In contrast to sonars that rely on the bouncing of ultrasonic waves, the "cone" of sensing is relatively small. The VL6180X is considerably more accurate than IR distance sensors that attempt to determine the amount of light that is reflected back, and it does not suffer from linearity problems or "double imaging," a phenomenon in which it is impossible to determine whether an object is located very far away or very close to the sensor.

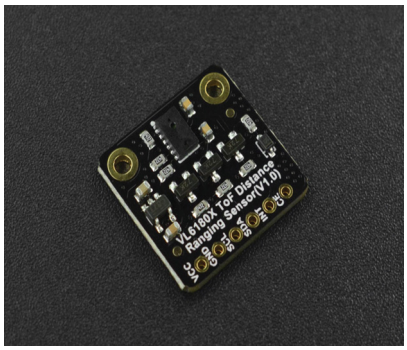

Figure 5.5: VL6180X ToF Distance Ranging Sensor [5]

Power Supply Voltage	3.3V 5V
Operating Current	<5mA
Measuring Distance	5-100mm
Emitter	940 nm invisible laser (VCSEL)
I2C Address	0x29
Operating Temperature Range	-20℃ 85℃
Product Size	19x18mm / 0.75x0.71 inch

Table 5.3: Specifications of VL6180X ToF Distance Ranging Sensor [5]

TFmini-S LiDAR ToF laser range sensor: The TFmini-S LiDAR is a time-of-flight (ToF) laser range finder that only functions in one particular direction. It is comprised of specialized optical and electronic equipment, which incorporates

an adaptable algorithm, and is designed for use in a variety of environments, including indoors as well as outdoors. It has a compact body and is able to measure distances very accurately despite its diminutive size. Because of its diminutive size, light weight, and low power consumption, it is also well suited for the tasks of maintaining altitude and following the terrain [6].

The TFmini-S has a maximum detection range of 12 meters in any environment. In addition, the TF Mini has a sampling resolution of 100Hz and an accuracy of 4cm within 6 meters and 6 cm within 12 meters. Both of these distances are measured in meters. The field of view is 2.3 degrees. It has a high anti-interference capability and is able to function even when exposed to direct sunlight; the total weight of the device is 4.7 g.

Figure 5.6: TFmini-S LiDAR ToF Laser Range Sensor [6]

Voltage Range	4.5V-6V
Communication Interface	: UART (TTL)
Working Range	0.3m-12m (indoor)
Average Power	0.6W
Receive Angle	2.3°
Minimum Resolution	5mm
Refresh Frequency	100Hz
Ranging Accuracy	: 1% (<6m), 2% (6 12m)
Ranging Unit	mm
Band	850nm
size	1.65in x0.59in x0.63in / 42mm x15mm x16mm
Operating Temperature	0°C 60°C
Storage Temperature	-20°C 75°C
Anti-light Environment	70Klux
Weight	4.7g

Table 5.4: Specifications of TFmini-s LiDAR ToF Laser Range Sensor [6]

5.3 Software Implementation

- In our project we use both the sensors to estimate the distance of the object and inform the user the actual distance.
- After connecting to the Arduino UNO, we will then upload code.
- We used DFRobot_TFmini [6] and Adafruit_VL6180X [17] as libraries.
- Based on the signal strength, we were able to calculate the distance from the obstacle in cms using the TFmini-s LiDAR ToF laser range sensor.
- We acquired the distance in mm from the VL6180X sensor.
- The examples of the Arduino IDE serial monitor outputs with measurements acquired from the sensors are shown in the next chapter in Figures 6.2-6.4.

Chapter 6

Testing and Validation

Testing and validation is an important part of the system validation process since it indicates whether a given/considered project, meets the required restrictions or not. In order to complete any job, we require specific instruments and systems. Our project is no exception; in it, we use the Fermion: VL6180X ToF distance ranging sensor, TFmini-S LIDAR(ToF) sensor to detect the distance. Because we knew that distance estimation is one of the attributes that varies depending on the accuracy of the sensor, so we estimated variations of the distances to the objects.

We calculated the distances from the obstacle as shown in Figure 6.1.

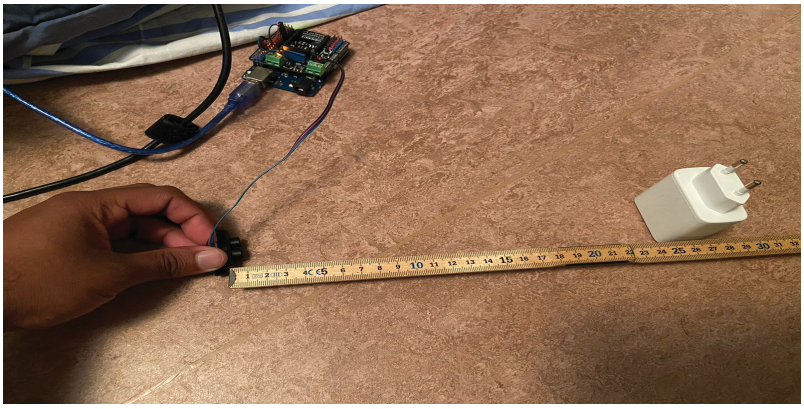

Figure 6.1: Experimental Setup of Distance Estimation of Two Distance Sensors

In the experimental setup mentioned above, a plastic material is employed in place of the item as we calculate the distance using the TFmini-S sensor. We also estimated the distances from 50 mm to 150 mm with both sensors using the identical experimental setup.

We have moved the object from 50 mm to 150 mm with step of 5 mm. At each step we acquired 50 measurements for each sensor. The 5 mm step is chosen because TFmini-S sensor has measurement resolution of 5 mm.

The data received from the long range sensor TFmini-S are not effective below 100 mm, as can be seen from Figures 6.2-6.4.

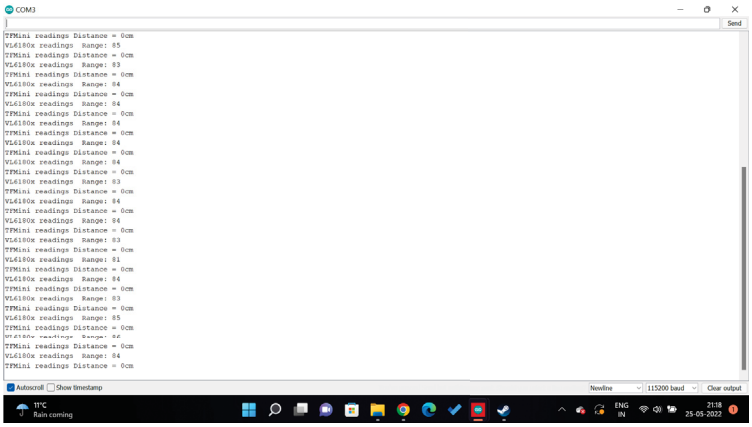

Figure 6.2: Serial Monitor Readings of an Obstacle 85 mm Away from the Two Distance Sensors

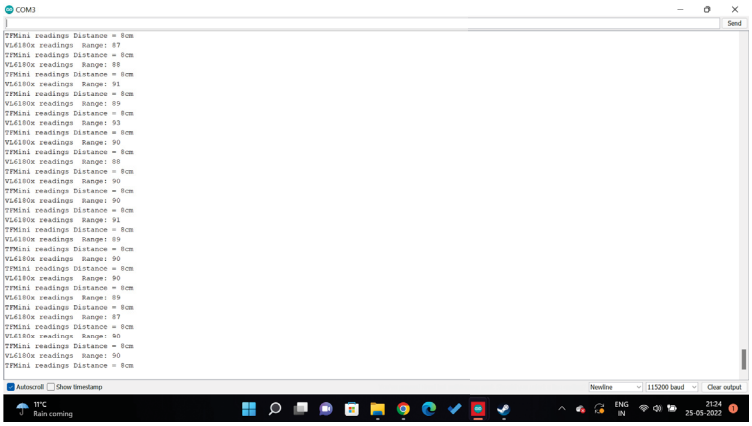

Figure 6.3: Serial Monitor Readings of an Obstacle 90 mm Away from the Two Distance Sensors

From the Figures 6.2-6.4, we have calculated distance from the obstacle with both sensors at 85 mm, 90 mm, 115 mm(which is above 100 mm).

- At 85 mm: TFmini-S sensor is displaying a reading of 0cm.
- At 90 mm: TFmini-S sensor is displaying an inaccurate reading of 8 cms with a 1 cm inaccuracy.
- At 115 mm: TFmini-S sensor is displaying accurate results, but there is a 2.7 mm inaccuracy, as stated in this chapter.

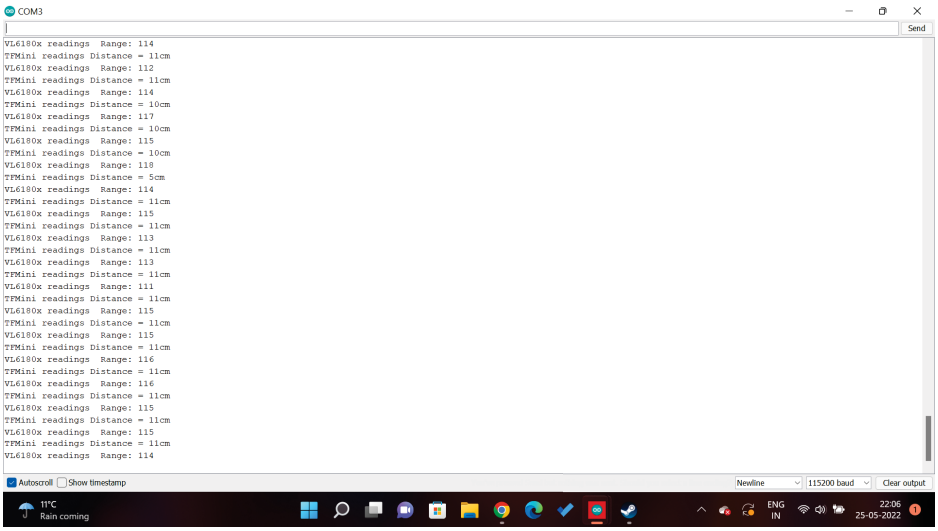

Figure 6.4: Serial Monitor Readings of an Obstacle 115 mm Away from the Two Distance Sensors

We use the results obtained in this observation to validate the sensor accuracy and precision at long and short ranges. Data from the two sensors at various set distances of two different objects is measured and tabulated to see the error value. We test both the sensors at equal and then suggest which sensor to use at what distance.

- Initially, we placed an obstacle 115 mm away from both sensors, and calculated the mean and variance, based on the obtained 50 distance measurements at each fixed distance step for each of the two sensors.
- Equations below is used to calculate mean, variance and the standard deviation:

$$\textbf{Mean} = \mu = \frac{\sum(X)}{N}$$

$$\textbf{Variance} = sigma^2 = \frac{\sum(X-\mu)^2}{N}$$

$$\textbf{Standard Deviation} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

μ = mean
σ^2 = Variance
$\sum$ = Sum of multiple terms
X = Each value
N = Number of values

Distance in (mm)	Mean	Variance	Standard Deviation
50 mm	50.4	2.3	1.51657
55 mm	55.8	1.2	1.09544
60 mm	61.4	0.3	0.54772
65 mm	65	2	1.41421
70 mm	69.6	0.3	0.54772
75 mm	74	1	1
80 mm	80.8	2.2	1.48323
85 mm	83.8	0.2	0.44721
90 mm	90.2	3.2	1.7888
95 mm	95.6	0.8	0.89442
100 mm	99.4	0.8	0.89442
105 mm	103.8	3.2	1.7888
110 mm	109.2	3.2	1.7888
115 mm	114.6	4.3	2.07364
120mm	116.6	1.8	1.34164
125 mm	125	1.5	1.22474
130mm	125.4	4.3	2.07364
135 mm	135.2	8.7	2.94957
140mm	138.4	1.3	1.14017
145mm	145	0.5	0.70710
150mm	149.2	3.2	1.78885

Table 6.1: Mean, Variance and Standard Deviation for VL6180X Sensor in the Range from 50 to 150 mm

Two sensors have the overlapping range, approximately between the 100 and 200 mm. The exact range of the overlap needs to be estimated for the individual pair of long-range and short-range sensors. The reason is that the upper limit of the short-range and the lowest limit for the long-range sensor distance measurements vary significantly between individual sensors.

In this work we have studied the accuracy for the VL6180X short-range sensor in the range from 50 to 150 mm. According to the specification of the sensor the measuring distance range for the sensor is 5-100 mm. However, in "Introduction" it states that "it can provide readings up to 200 mm in a good environment" [18].

The results of the study are shown in the Table 6.1. According to the results the largest standard deviation for this particular VL6180X sensor is 3 mm at 135 mm distance to the object.

According to the specification for TFmini-S LIDAR long-range sensor used in this project the resolution of the sensor is 5 mm [5]. The standard deviation 3 mm of VL6180X sensor is smaller than the measurement resolution 5 mm of the TFmini-S LIDAR sensor. Based on that comparison, when the data in the range up to 150 mm are available from both sensors, the decision is to show the information from the VL6180X sensor, as it shows more precise information. For the range greater than 150 mm the data from the TFmini-S LIDAR sensor is shown as the distance to the object.

Chapter 7

Conclusions And Future Work

We conclude that it is not possible to infer the true distance from the result of a single sensor measurement [19]. We estimated and compared the precise overlapping range for each pair of long-range and short-range sensors present in the system. The comparison shows that the TFmini-S sensor is more accurate at longer distances, while the VL6180X sensor is more accurate at shorter distances.

Finding the object's velocity and acceleration is an approach that can help us improve the project. In the future, we will be able to combine the data from two sensors using more sophisticated algorithms. As a result, the fusion of data provides the data that is the most accurate and reliable in the best possible way. Furthermore, we are able to study the effect that the illumination and the velocity of the moving object have on the estimation of the distance that object travels.

References

[1] Admin_Terabee, "Time of flight principle (tof): Brief overview, Technologies and Advantages." https://www.terabee.com/time-of-flight-principle/, feb 2022.

[2] B. B. Nair *et al.*, "Camera-based object detection, identification and distance estimation," in *2018 2nd International Conference on Micro-Electronics and Telecommunication Engineering (ICMETE)*, pp. 203–205, IEEE, 2018.

[3] "Arduino uno rev3." https://store.arduino.cc/products/arduino-uno-rev3, 2022.

[4] "Gravity: Io expansion shield for arduino v7.1 - dfrobot." https://www.dfrobot.com/product-1009.html.

[5] "Fermion: Vl6180x tof distance ranging sensor breakout wiki dfrobot." https://wiki.dfrobot.com/DFRobot_VL6180X_TOF_Distance_Ranging_Sensor_Breakout_Board_SKU_SEN0427.

[6] "Tf mini lidar tof laser range sensor sku sen0259 dfrobot." https://wiki.dfrobot.com/TF_Mini_LiDAR_ToF__Laser_Range_Sensor_SKU__SEN0259.

[7] M. Lindner, I. Schiller, A. Kolb, and R. Koch, "Time-of-flight sensor calibration for accurate range sensing," *Computer Vision and Image Understanding*, vol. 114, no. 12, pp. 1318–1328, 2010.

[8] S. B. Gokturk, H. Yalcin, and C. Bamji, "A time-of-flight depth sensor-system description, issues and solutions," in *2004 conference on computer vision and pattern recognition workshop*, pp. 35–35, IEEE, 2004.

[9] I. Maksymova, C. Steger, and N. Druml, "Review of lidar sensor data acquisition and compression for automotive applications," *Multidisciplinary Digital Publishing Institute Proceedings*, vol. 2, no. 13, p. 852, 2018.

[10] S. Ayhan, S. Scherr, P. Pahl, T. Kayser, M. Pauli, and T. Zwick, "High-accuracy range detection radar sensor for hydraulic cylinders," *IEEE Sensors Journal*, vol. 14, no. 3, pp. 734–746, 2013.

[11] M. Pauli, B. Göttel, S. Scherr, A. Bhutani, S. Ayhan, W. Winkler, and T. Zwick, "Miniaturized millimeter-wave radar sensor for high-accuracy applications," *IEEE Transactions on Microwave Theory and Techniques*, vol. 65, no. 5, pp. 1707–1715, 2017.

[12] A. G. Stove, "Linear fmcw radar techniques," in *IEE Proceedings F (Radar and Signal Processing)*, vol. 139, pp. 343–350, IET, 1992.

[13] S. Scherr, S. Ayhan, M. Pauli, and T. Zwick, "Accuracy limits of a k-band fmcw radar with phase evaluation," in *2012 9th European Radar Conference*, pp. 246–249, IEEE, 2012.

[14] M. Z. Ikram, A. Ahmad, and D. Wang, "High-accuracy distance measurement using millimeter-wave radar," in *2018 IEEE Radar Conference (RadarConf18)*, pp. 1296–1300, IEEE, 2018.

[15] "Millimeter wave." `https://www3.ntu.edu.sg/home/eccboon/DIP%20website/Milimeter.html`.

[16] A. Soylemezoglu, *Sensor data-based decision making*. Missouri University of Science and Technology, 2010.

[17] "Dfrobot vl6180x arduino reference." `https://www.arduino.cc/reference/en/libraries/dfrobot_vl6180x/`.

[18] "12m cost-effective distance sensor." `http://en.benewake.com/product/detail/5c345e26e5b3a844c472329c.html`.

[19] J. Majchrzak, M. Michalski, and G. Wiczynski, "Distance estimation with a long-range ultrasonic sensor system," *IEEE Sensors Journal*, vol. 9, no. 7, pp. 767–773, 2009.