1. Introduction:

For one of my projects, I required an affordable range finder sensor. After some research, I opted for the **SparkFun Distance Sensor VL53L4CD**, which is a reasonably priced and relatively accurate sensor. In this document, I am sharing all the tests I conducted to assess the performance of this sensor.

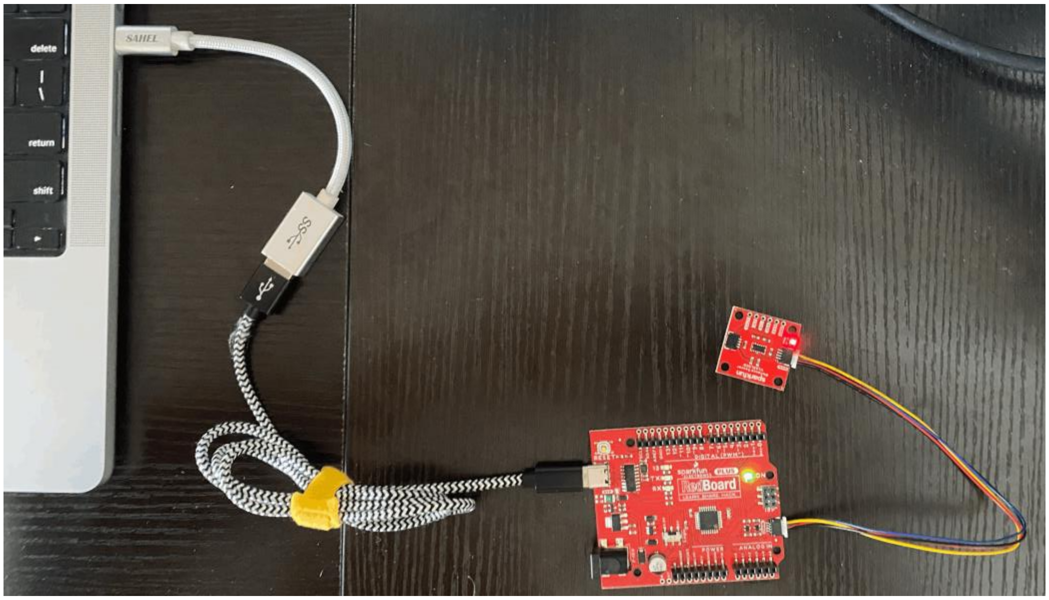
The products I used are:

- SparkFun Distance Sensor VL53L4CD
- SparkFun RedBoard Plus (similar to the Arduino Uno)
- Wall Adapter Power Supply - 9VDC, 650mA (if you want to use an adaptor; otherwise, USB-C is provided on board)

If you need more information and guidance, please refer to the following link: https://learn.sparkfun.com/tutorials/redboard-plus-hookup-guide

2. Installation and setup:

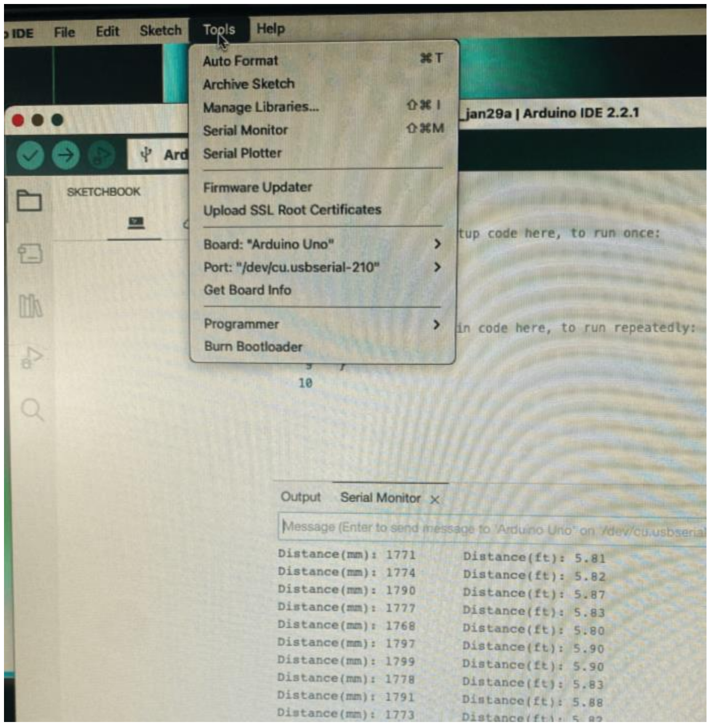
The circuit should be installed like the below figure:



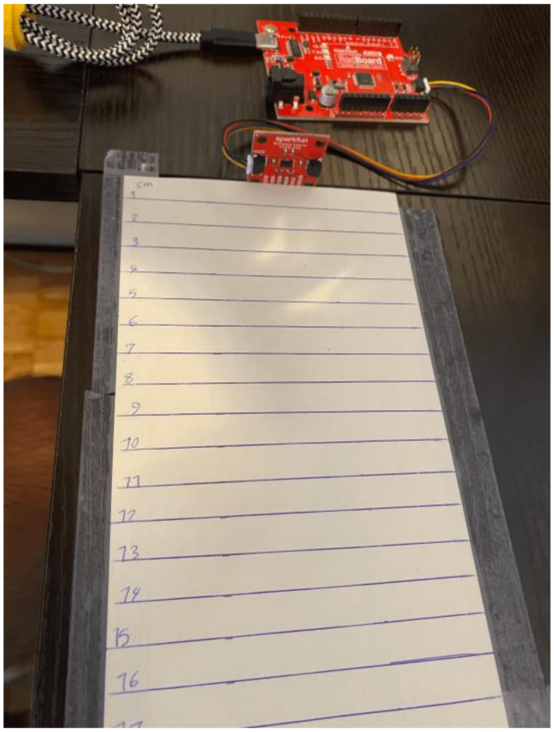
The following links will assist you in easily setting up a serial terminal or installing an Arduino library. I will skip the installation part, and with some simple googling, you can find out how to do that.

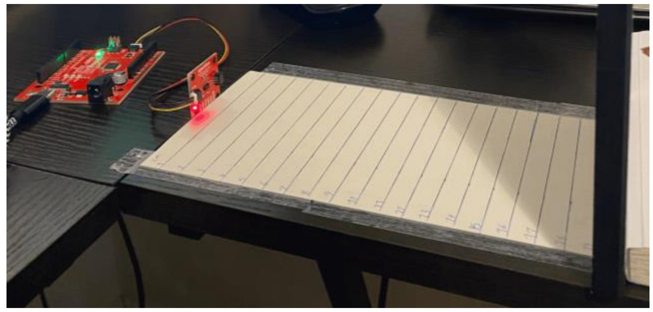
- https://learn.sparkfun.com/tutorials/terminal-basics/arduino-serial-monitor-windows-mac-linux
- https://learn.sparkfun.com/tutorials/installing-an-arduino-library

For example, in my case, the Arduino IDE had the following settings (board = Arduino Uno, proper serial port, 115200 baud) that may differ in your case.



My personal testing setup was as follows:





[Simple video of Setup]

3. Tests:

3.1. Sensor offset calibration

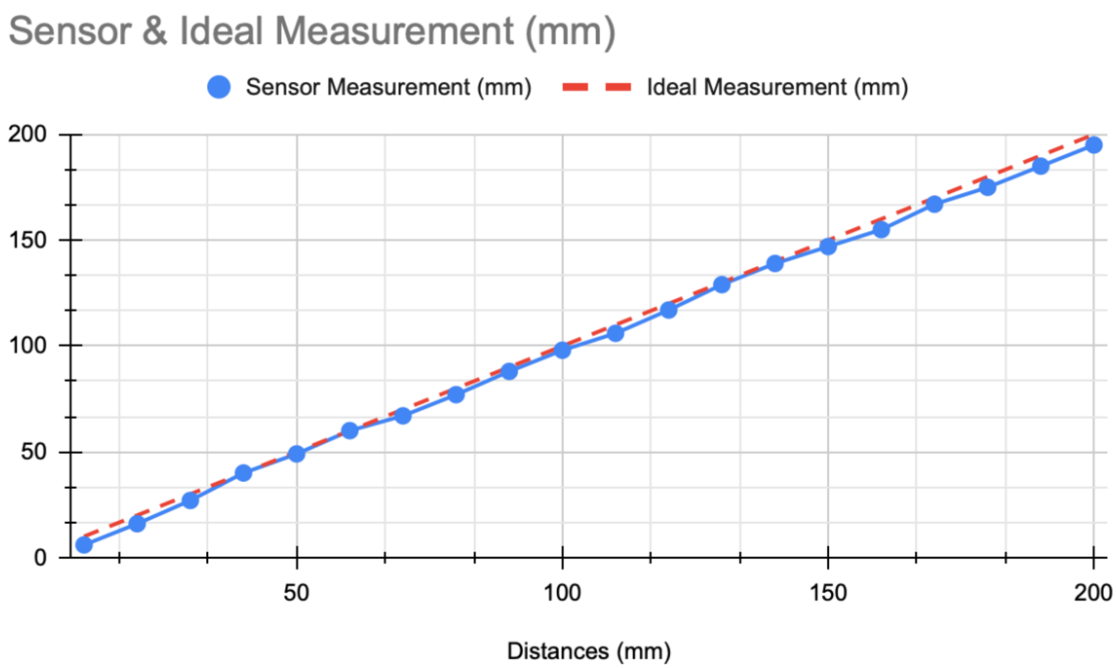
In order to calibrate your sensor, run the Example7_Calibration code. The Sparkfun calibration code does not work, and I added `distanceSensor.startRanging();` at line 86, and everything is good now. While for accurate calibration, users need to place a light gray (17 % gray) target, I personally did calibration with white paper.

When you upload the code to your board, place the target in front of the sensor at a distance below 10 cm. When the sensor detects the target, the calibration will start 5 seconds after a distance below 10 cm has been detected for 1 second. During this 5-second buffer, you should place the target at a distance of 140mm in front of the sensor. The offset is the value that the sensor is reading, and it will automatically save it in memory. However, I added the setOffset() function after begin() in my codes to make sure that the sensor is using a calibrated offset. In my case, the result was something like RealDistance - MeasuredDistance=2037 mm.

3.2. Accuracy measurement

For the first test, I considered a range of between 1 cm and 20 cm in front of the sensor. The results for this test are shown in the below table for sampling every 4 seconds for each centimeter (in order to be more accurate, I sampled at least two times at each distance).

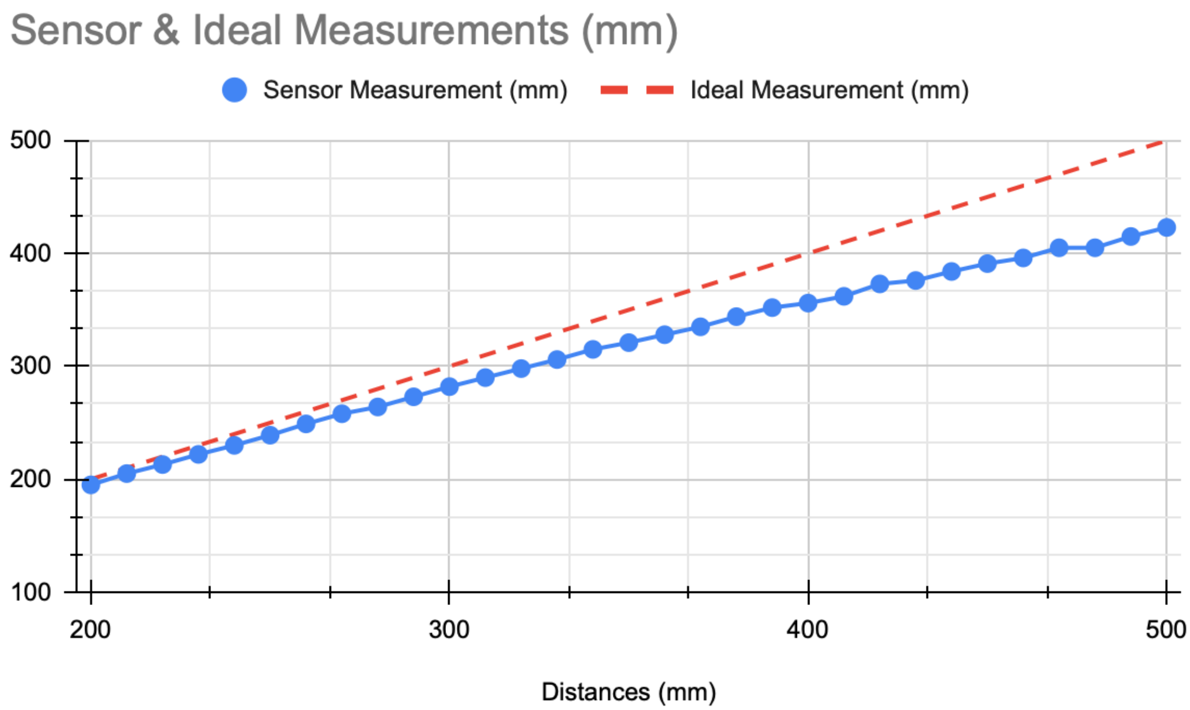
Actual distance (mm)	Measured distance (mm)	Actual distance (mm)	Measured distance (mm)
10	6	110	106
20	16	120	117
30	27	130	129
40	40	140	139
50	49	150	147
60	60	160	155
70	67	170	167
80	77	180	175
90	88	190	185
100	98	200	195



A second test is done for a range of 20 cm to 50 cm in front of the sensor with a similar measurement method.

Actual distance (mm)	Measured distance (mm)	Actual distance (mm)	Measured distance (mm)	Actual distance (mm)	Measured distance (mm)
200	195	300	282	400	356
210	205	310	290	410	362
220	213	320	298	420	373
230	222	330	306	430	376
240	230	340	315	440	384
250	239	350	321	450	391
260	249	360	328	460	396
270	258	370	335	470	405
280	264	380	344	480	405
290	273	390	352	490	415
				500	423

Note: the variation in measurements was a bit high, +/- 7 mm (max) and +/- 1 mm (min). The value that I wrote comes from three to four times of measurement and considering the best option.

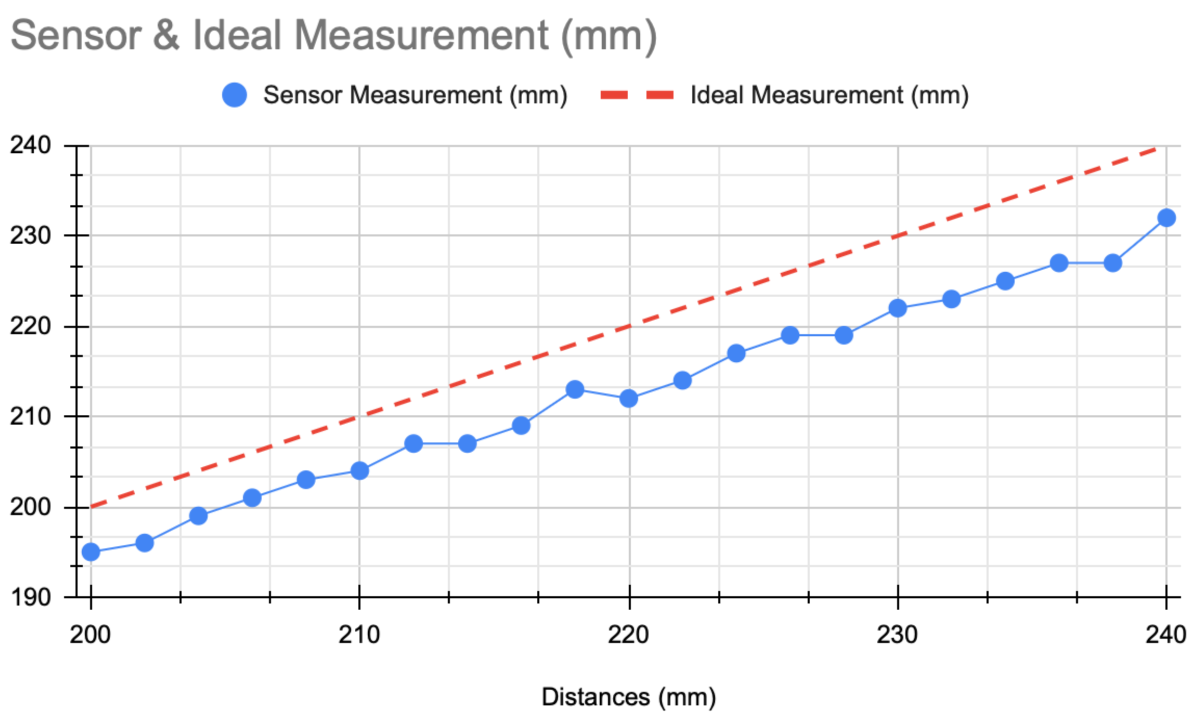


Finally, the third test considered more details. In this evaluation, a range of 20 cm to 25 cm with sampling at every 2 mm is considered. The results are as follows:

Actual distance (mm)	Measured distance (mm)	Actual distance (mm)	Measured distance (mm)
200	195	220	212
202	196	222	214
204	199	224	217
206	201	226	219
208	203	228	219
210	204	230	222
212	207	232	223

214	207	234	225
216	209	236	227
218	213	238	227

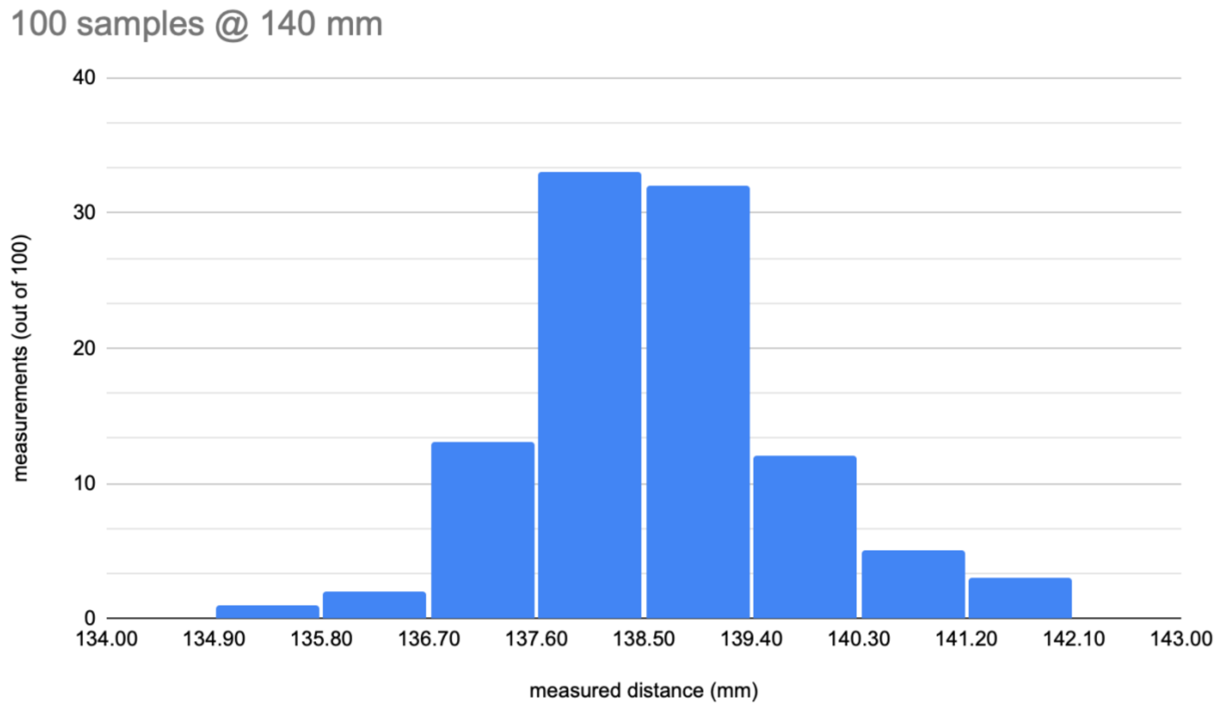
Note: accuracy was not good and there was not direct relation between minimal changes and sensor output



In order to assess measuring tolerance, I conducted 100 samplings within an effective range (calibration distance at 14 cm). The histogram chart below illustrates these measurements, with a minimum distance of 135 mm and a maximum of 142 mm. Additionally, the table provides the count of measured samples:

Measured distance (mm)	Number of time
135	1
136	2
137	13
138	32
139	32
140	12

141	5
142	3



3.3 Number of samples per 5 seconds

~86 samples

Each 0.05813 second

Frequency is: 17.2 Hz

*** I tested for various distances, and the signal rate varies from ~10 Hz to ~18 Hz.*

3.4. Min and max effective range

Analyzing the plots, it appears that the effective range for this ToF sensor lies between 5 and 15 cm. It's essential to note that these values are obtained under normal lighting conditions and with wood materials or paper. Variations may occur in different situations.

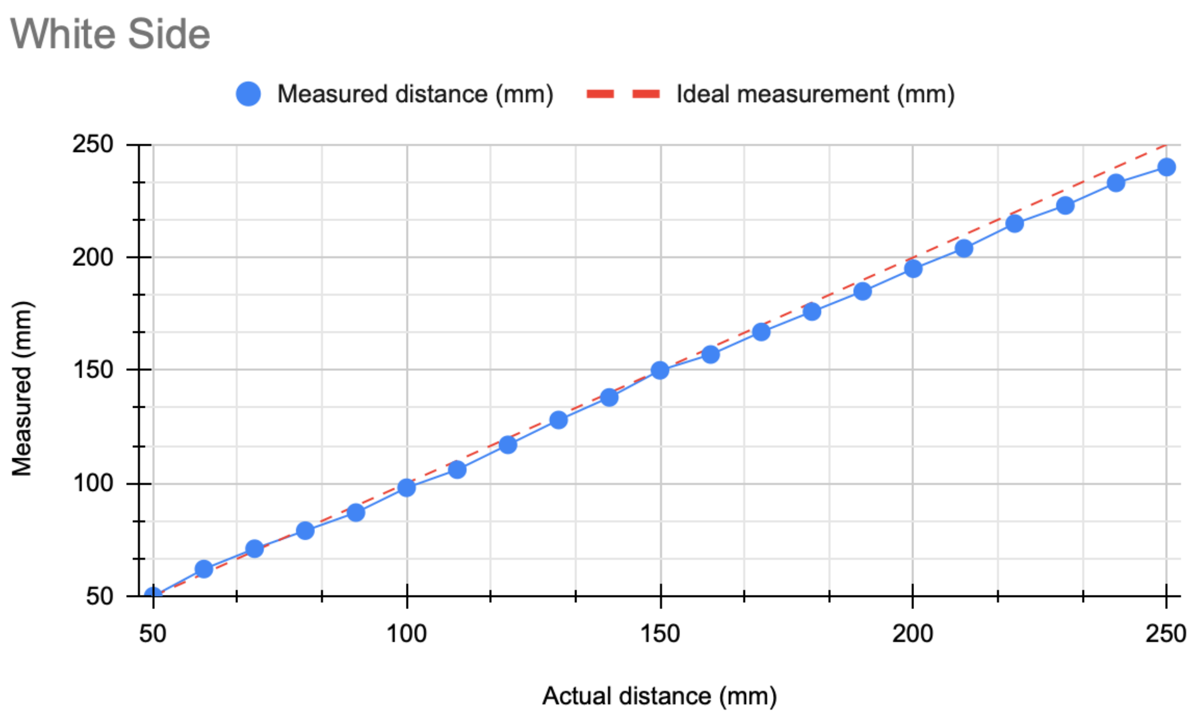
3.5. Effect of the color on measurements

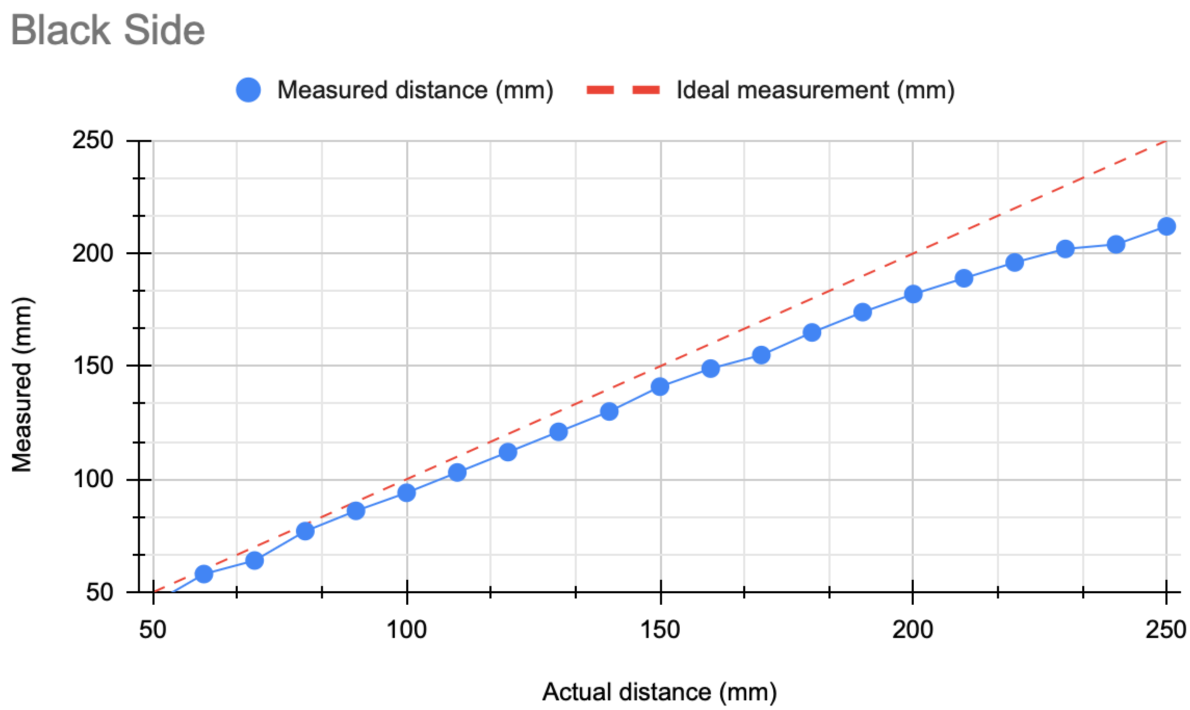
Generally, we can define the effect of color on measurement using the following basic rules:

- White Surfaces:

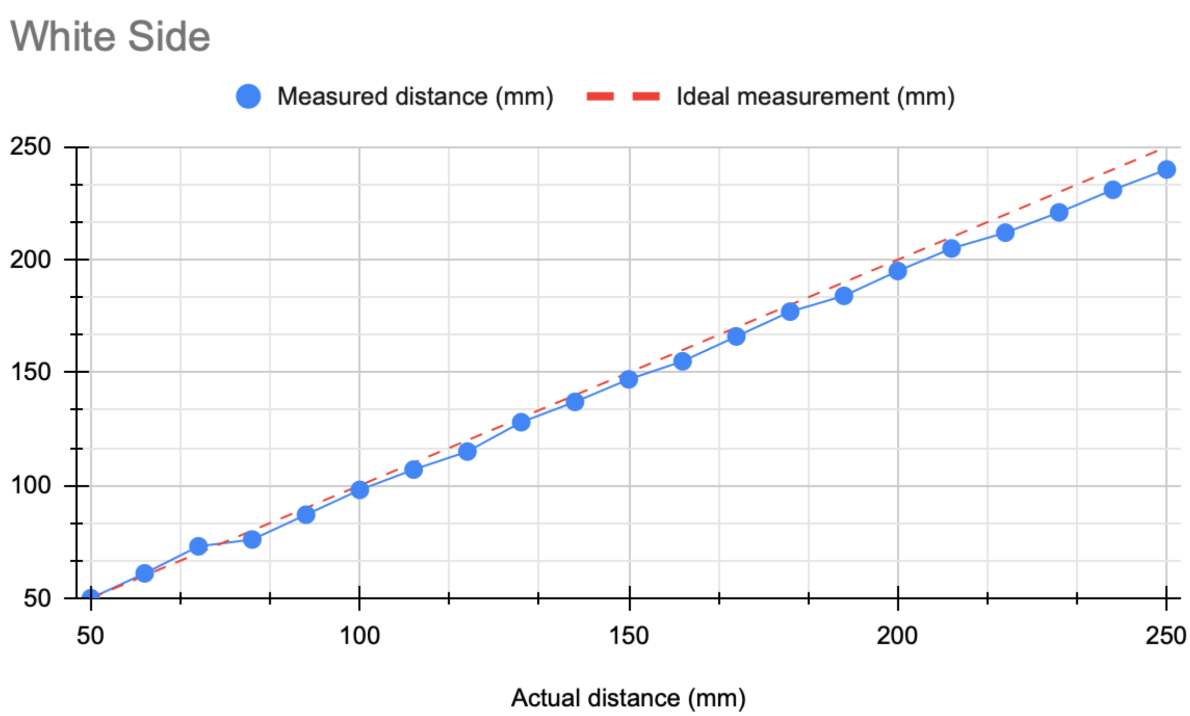
  - Reflectivity: White surfaces generally have high reflectivity in the infrared spectrum.
  - Effect: Because of the sensor's high reflectivity, white surfaces are likely to reflect the IR light it emits back to the sensor well.
  - Outcome: This can result in a strong and clear return signal, potentially leading to accurate distance measurements.
- Black Surfaces:
  - Reflectivity: Black surfaces typically have low reflectivity in the infrared spectrum.
  - Effect: The low reflectivity means that the IR light is less likely to be reflected back strongly from black surfaces.
  - Outcome: This can result in a weaker return signal, potentially leading to challenges in accurately measuring distances on dark-colored surfaces.

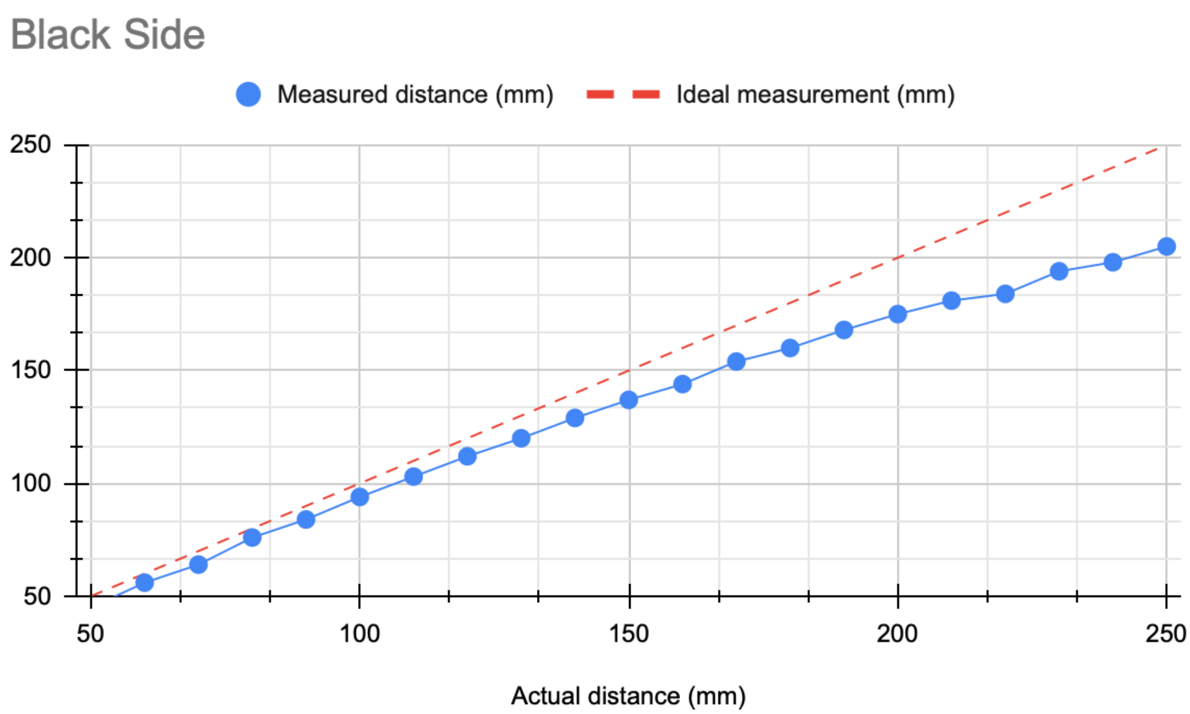
The below results are based on one-time calibration:





I verified the results after calibrating each side separately, implying distinct calibration for each color.





In conclusion, lighter colors show more accurate results compared with black. Moreover, we can see that the calibration for each color does not have a huge impact on the results. Even on the black side, the results got slightly worse (maybe it's a human error).

3.6. Effect of material on measurement

Generally, the effect of material on measurement can be summarized as follows:

- Wood:
  - The reflectivity of wood in the infrared spectrum can vary based on the type of wood and its surface finish.
  - In general, many types of wood have moderate to high reflectivity in the IR spectrum.
  - The sensor is likely to receive a relatively strong return signal from wood surfaces, leading to accurate distance measurements.
- Paper:
  - Paper is often reflective in the infrared spectrum, and its reflectivity depends on factors like color and composition.
  - White paper, commonly used in various applications, tends to have high reflectivity in the IR range.

    - The sensor is likely to receive a strong return signal from white paper, contributing to accurate distance measurements. Colored or darker paper may have lower reflectivity.
- Cotton:
    - Cotton, being a natural fiber, can have varying reflectivity based on factors like color, weave, and texture.
    - White or light-colored cotton fabrics may have moderate to high reflectivity in the IR spectrum.
    - The sensor is likely to perform well with white or light-colored cotton materials. Darker or highly textured cotton may have lower reflectivity, affecting the strength of the return signal.

4. Conclusion

- The results indicate that this sensor cannot ensure a stable measurement, and there is consistently at least a 1-2 mm tolerance (min: 1, max: 7).
- It performs well close to the sensor within the range of 5–15.
- Darker colors make the measurement accuracy worse.
- It's important to note that the sensor's angle has an effect on measurements.
- Although material affects distance measurement, it can be recalibrated based on the type of material.

5. Some facts from sensor's datasheet

- All measurements in the datasheet are based on gray (17% reflectance, N4.74 Munsell) and white (88% reflectance, N9.5 Munsell).
- Ranging accuracy:

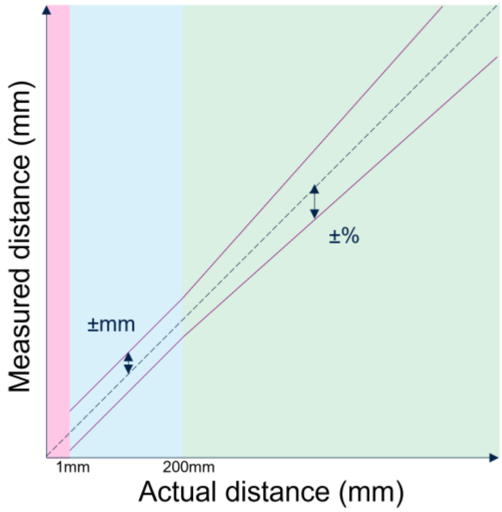
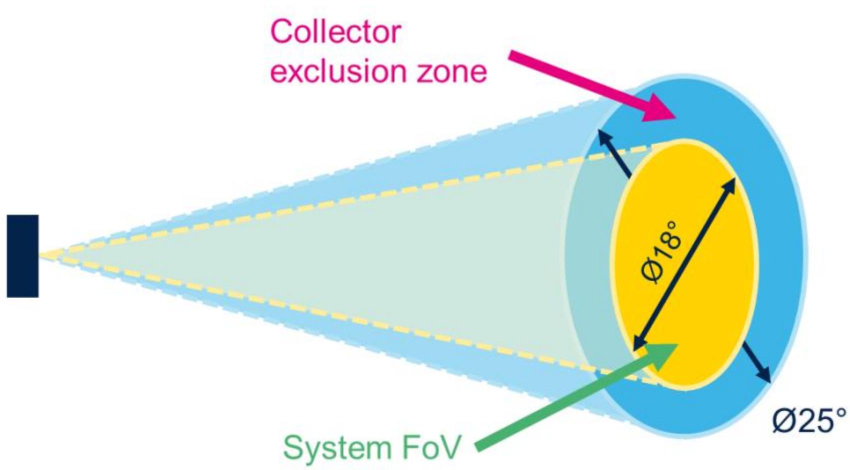
- ○ 

Table 15. Typical ranging accuracy with 33 ms timing budget

Target reflectance level, full FoV	Distance (mm)	Indoor (no infrared)	Outdoor overcast
White target (88%)	1-100	± 7 mm	± 8 mm
	101-200	± 8 mm	± 9 mm
	>200	± 3%	± 8%
Gray target (17%)	1-100	± 6 mm	± 7 mm
	101-200	± 8 mm	± 9 mm
	>200	± 4%	± 8%

- ○

- Temperature changes can cause ranging drift in this sensor. However, it reassures that this drift is treated as an offset (a constant correction) and not a gain (a proportional change).



-