Automotive Sensors and Networks
Distance sensors

1 LiDAR and ultrasonic sensor FOV

Firstly, our task is to determine the field of view of an ultrasonic and LiDAR sensors. The field of view (FOV) is measured for three different materials, namely cardboard, aluminum and foam. The measurements are taken at three different distances from the sensor y, which are 15 cm, 20 cm and 25 cm. The field of view is calculated from the following equation

$$\mathrm{FOV} = 2\arctan\left(\frac{x/2}{y}\right). \tag{1}$$

The object in front of the sensors is moving using a linear motor from one side to the other. Knowing the velocity of the linear motion v and the sample rate f of the sensors capturing the data, we can calculate the distance x

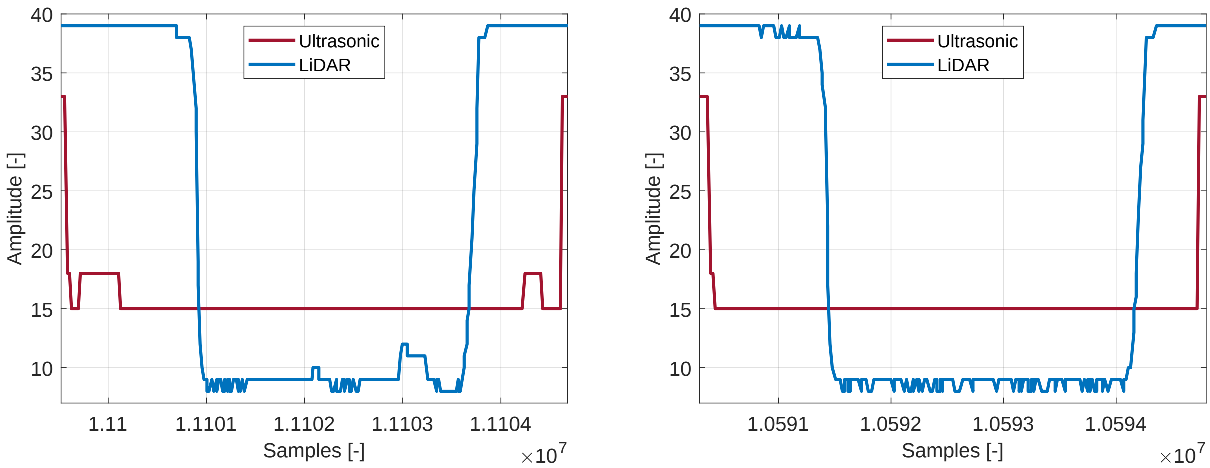
$$x = v\frac{N}{f} - w, \tag{2}$$

where N is the number of samples captured during the object detection by the sensor. The value w is the width of the moving object in front of the sensor.
The distance x is then used to calculate the angle FOV using (1). The resulting values of FOV are summarized in the following table.

	Cardboard			Aluminum			Foam		
Distance [cm]	15	20	25	15	20	25	15	20	25
Ultrasonic FOV [°]	30.6	37.6	33.6	32.7	44.3	41.6	24.1	40.6	37.4
LiDAR FOV [°]	6.1	3.7	3.7	9.5	2.9	3	7.2	2.9	3

Table 1: Field of view of the ultrasonic and LiDAR sensors for different materials measured at different distances.

We can see that the FOV angles for the ultrasonic sensor range from 30° to 40° apart from one measurement using the foam as a reflective material. This value range correspond to the FOV of standard ultrasonic sensors. For the LiDAR, the FOV angle is surprisingly small ranging from 3° to 10°. This value range can not be correct and is probably caused by inaccuracy of the measurement in the laboratory or badly working sensor. LiDAR sensors are a popular choice for capturing data these day and such FOV would make the sensor simply inapplicable in practical use. We can see a comparison of the LiDAR and the ultrasonic sensor detecting the aluminum object and the cardboard object from a distance of 15 cm in Figure 1.



(a) Aluminum from distance 15 cm.

(b) Carboard from distance 15 cm.

Figure 1: Comparison of the LiDAR and the ultrasonic sensor to objects made of different materials.

Comparing the computed values of FOV of the ultrasonic and LiDAR sensors with the standard expected value obtained from the data sheet, we have verified that the computed values approximately correspond to the expected values stated by the manufacturer.

2 SNR

Signal to noise ratio is usually regarded as a qualitative factor. The ultrasonic and the LiDAR sensors have different noise sources, considering that we do not take into account the noise introduced during the data transmission. The source of noise for the LiDAR is the light reflected from the objects detected by the sensor. The noise source for the ultrasonic sensor is mostly the sensor's electronics and the environment's noise.

3 Linearity error

Unfortuantely, we have not managed to measure the linearity error of both sensors due to time constraints and technical difficulties in the laboratory.

4 LiDAR

In this section, we will measure the field of view of a second LiDAR sensor named SCALA from Valeo used in the automotive industry. The sensor is placed on a flat surface and the edge of both the horizontal and vertical field of view is estimated moving an (arbitrary) object around the sensor and watching the live data stream from the sensor. The data stream is visualized using the software provided by the manufacturer.

4.1 Horizontal FOV

The horizontal field of view (FOV) of the LiDAR sensor can be calculated from a triangle formed by the sensor, the edge of the field of view and the center of the field of view. The formula is given by the following equation

$$\mathrm{FOV_h} = 2\arctan\left(\frac{x}{y}\right), \tag{3}$$

where x and y are the distances from the sensor to the edge of the field of view. Due to the space limitations in the laboratory, we measured the two distances only on one side of the sensor. We can however assume that the sensor is symmetric and the distances ought to be identical on the other side. The distances were measured using a tape measure and are

$$x = 310\,\mathrm{cm}, \qquad y = 120\,\mathrm{cm}.$$

The angle $\mathrm{FOV_h}$ is then approximately 138°.

4.2 Vertical FOV

The vertical field of view (FOV) of the LiDAR sensor can be calculated from a triangle formed by the sensor and the maximum and minimum heights of the field of view using the cosine rule. The formula is given by the following equation

$$\mathrm{FOV_v} = \arccos\left(\frac{f^2 + g^2 - (h_1 - h_2)^2}{2fg}\right), \tag{4}$$

where

$$f = \sqrt{x^2 + (h_2 - h_3)^2}, \qquad g = \sqrt{x^2 + (h_1 - h_3)^2}. \tag{5}$$

The value x is the distance from the sensor to the place, where the angle $\mathrm{FOV_v}$ is measured, h_1 is the maximum height, where the sensor measures an object, h_2 is the minimum height, where the sensor measures an object and h_3 is the height of the surface, where the sensor is placed. All three heights are measured with reference to the ground, where $h = 0$. The distances are

$$x = 270\,\mathrm{cm}, \qquad h_1 = 170\,\mathrm{cm}, \qquad h_2 = 120\,\mathrm{cm}, \qquad h_3 = 90\,\mathrm{cm}.$$

The angle $\mathrm{FOV_v}$ is then approximately 10°.

4.3 Object differentitation

In the last task of this section we determine an FOV angle α, which determines an angle, when two seperate objects become undistinguishable from each other in the data stream. The angle α can be calculated from the following equation

$$\alpha = 2 \arctan\left(\frac{c/2}{x}\right), \tag{6}$$

where x is the distance from the sensor to the two objects and c is the distance between the two objects when they become undistinguishable. The distances are

$$x = 140\,\mathrm{cm}, \qquad c = 6\,\mathrm{cm}.$$

and the angle α is then approximately $2.4°$.

5 Car bumper

Having a car bumper that is $l = 1.6\,\mathrm{m}$ wide, we want to determine the number of ultrasonic sensors mounted on the bumper, which are needed to avoid any dead angles on distances over $a = 20\,\mathrm{cm}$.
The width corresponding to a part of the bumper, that one sensor can fully cover is given by

$$d = 2\frac{a}{\tan\beta}, \tag{7}$$

where

$$\beta = \frac{1}{2}(180 - \mathrm{FOV}). \tag{8}$$

The width d is approximately $d = 14.6\,\mathrm{cm}$ and the required number of sensors mounted on the bumper is thus

$$N = \frac{l}{d} \approx 11. \tag{9}$$

6 Rotating LiDAR

Using the LiDAR sensor from above, we want to estimate the maximum reasonable rpm of a 2D rotating LiDAR sensor using its sample rate and FOV. We consider a LiDAR sensor with a sample rate of $f = 100\,\mathrm{Hz}$ and a slightly larger FOV of $10°$ compared to the calculated value from above. Having the same scenario as in the previous task, the required scanning angle is given by

$$\alpha = 180 - 2\arctan\left(\frac{a}{l/2}\right) = 152°. \tag{10}$$

Considering the sensor's FOV, the sensor turns $10°$ every sample. It takes the sensor $360\,\mathrm{ms}$ to make a full rotation. The maximum reasonable rpm is

$$\omega = \frac{1000}{360}60 \approx 168\,\mathrm{rpm}. \tag{11}$$

The scan time is then approximately $160\,\mathrm{ms}$. It shows that such sensor is not suitable for application in car assistants for the object detection due to its low sample rate. This is clearly apparent from the following simple case scenario.
We consider a car travelling at $130\,\mathrm{km\,h^{-1}}$, we want to compute the distance, that the car travels during the time it takes for the LiDAR sensor to make a one full rotation. The distance traveled during the scanning process is

$$s = vt = \frac{130}{3.6}0.160 \approx 5.8\,\mathrm{m} \tag{12}$$

and the distance traveled between the individual full scans is $13\,\mathrm{m}$. One can see that these two distances are too large for the sensor to safely detect any object in front of the car in time.

7 Conclusion

The LIDAR sensor utilized in the laboratory unfortunately offers a limited horizontal and vertical field of view. A broader horizontal FOV may be achieved with the rotating LIDAR sensor with a higher sample rate. Due to the limited sample rate, the LiDAR employed in the laboratory is unsuitable for integration into automotive assistance systems. One of the advantages of LIDAR sensors lies in low signal attenuation in comparison to ultrasonic sensors, which makes them a suitable choice for detection of objects at longer distances.
Ultrasonic sensors are widely utilized in the automotive industry as well. Their horizontal FOV highly differs, the measured FOV in the laboratory was in the range of 30° to 40°. With a higher FOV, the number of sensors required to cover the entire width of a car's bumper can be reduced representing a judicious choice for integration into automotive assistance systems.