Distance sensor in robotics

Tiberiu Bongiu
HTL SAALFELDEN
Higher Technical College for Mechatronics
Saalfelden, 5760 Austria
tiberiu.bongiu@htl-saaalfelden.at

Jakob Diegruber
HTL SAALFELDEN
Higher Technical College for Mechatronics
Saalfelden, 5760 Austria
jakob.diegruber@htl-saalfelden.at

Raffael Hasenbichler
HTL SAALFELDEN
Higher Technical College for Mechatronics
Saalfelden, 5760 Austria
raffael.hasenbichler@htl-saalfelden.at

Fabio Schnegg
HTL SAALFELDEN
Higher Technical College for Mechatronics
Saalfelden, 5760 Austria
fabio.schnegg@htl-saalfelden.at

Georg Schneider
HTL SAALFELDEN
Higher Technical College for Mechatronics
Saalfelden, 5760 Austria
georg.schneider@htl-saalfelden.at

Moritz Schörghofer
HTL SAALFELDEN
Higher Technical College for Mechatronics
Saalfelden, 5760 Austria
moritz.schoerghofer@htl-saalfelden.at

Abstract— **The exploration of other planets and celestial bodies relies heavily on robotic missions, where spacecraft equipped with scientific instruments and rovers are sent to investigate these distant worlds. However, there is one big problem: the robot cannot be modified on site. In space the machine is completely isolated, so it is impossible to maintain or alter it. Just as in our tournament, we have no ability to customize the robot after the start, so we must build the automaton properly. This presents a lot of challenges and complexities.**

I. Introduction

The range of application that automated robots are needed in has been growing bigger in the past decades. One of the many are space missions. But since the robots must be built on earth, it is hard to make the automaton fitting for the unknown territory. Therefore, it is particularly important to make the sensors suitable for every situation and every ground. Aerospace companies utilize distance sensors and black and white sensors in various ways for their moon missions to gather data, ensure safe navigation, and conduct scientific research. During the landing of robots on the moon it is important for the machine to know how far away the landing spot is. In the Botball® competition, we must also always know the distances to the reference points, so that our tasks can happen automatically and as intended. Also, recognizing the difference between black and white is especially important for the navigation of our robots. In our case, the machine orientates a black line and without these sensors it would be harder to guide the robot to specific locations.

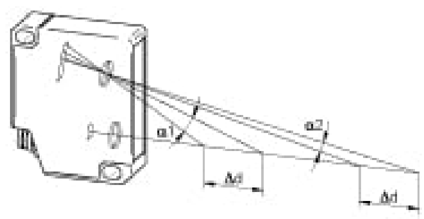
II. Distance Sensors

A. General usage

Distance Sensors are also used in several other occasions. They are used to determine fill levels of tanks or Breweries, to control processes in all sorts of applications, to detect slabs in rolling mills or to simply get the distance of objects you need to know for a certain process.

B. Principle

Even though there are many ways and principles to measure distances, three main ways to measure distances have established after time. Those are infrared-, ultrasonic- and laser sensors. Ultrasonic sensors use sound waves to measure how far away you are from an object. The infrared sensors use infrared light, which are electromagnetic waves, to determine whether an object is there or not. The laser-beam-sensor works through laser beams. The biggest advantage of laser beam sensors is the high speed of the laser beam. One common method that is also used in the sensor we have for the Botball® competition, is through infrared. The big advantage of the infrared sensor is the, compared to the ultrasonic sensor, small price. [3]



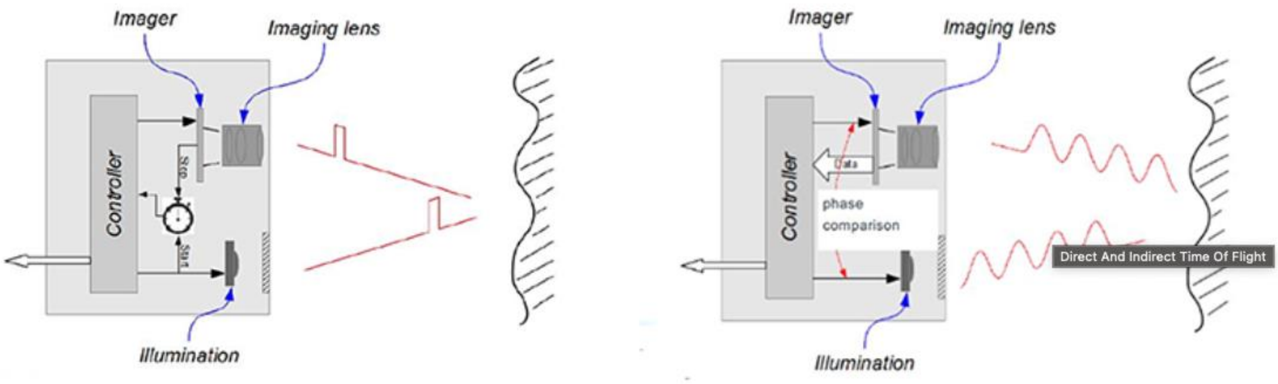
[1] Fig. 1: Triangulation principle

1) Triangulation principle

The Triangulation principle is a common principle to locate distances of objects through infrared. Here a laser beam strikes the object at a small point, and the sensor's receiver detects its position. The changing angle of incidence corresponds to the distance, altering the laser point's position on the receiver. An integrated microcontroller reads the photodiode line, accurately calculating the angle and distance to the object. The output is provided at the serial port or converted into a distance-proportional output current. The microcontroller ensures high linearity and precision, suppressing interfering reflections for reliable data from critical surfaces. The sensor adjusts to different colours, maintaining independence from the object's colour. A digital output activates when no object is within the measuring range or if insufficient light is received, such as when the sensor is dirty. The resolution and accuracy vary with distance, with the microcontroller correcting for non-linear behaviour, ensuring a linear output signal proportional to the distance. [1]

2) Time of flight

Time of flight measurement is the principle of the time taken by an object or a wave to travel a distance through a medium. The wave can be acoustic or electromagnetic, but most sensors that are based on this principal work through lasers. The distance is determined by means of the time delay Δt between when the light is emitted and when the reflected light is received.



[2] Fig. 2: time-of-flight measurement

As you can see in the illustration Fig. 2, there are direct and indirect time of flight measurements. The left one is a direct time of flight measurement. This means that the time taken for a signal to travel from a transmitter to a target and back to a receiver is directly measured. On the right-hand side, there is the indirect time of flight measurement. Here, the distance is inferred from the phase shift of the signal rather than directly measuring the time it takes for the signal to travel. The big advantage of this principle is the high accuracy. [4]

C. Common use

1) Infrared sensor

Infrared sensors are built in smartphones and tablets to detect when the device is held close to the user's face, automatically turning off the display to save power during phone calls. It is also good for detecting the presence or absence of objects, enabling tasks, such as automated counting, sorting, and inventory management. Infrared sensors also help robots to detect obstacles in their path and navigate them around safely. By continuously measuring the distance to objects in their surroundings, robots can adjust their route to avoid collisions. One big downside of these sensors is that they can be interfered by light, so the reflection can be recorded wrong, and the robot might crash into an undetected object. [5]

2) Ultrasonic sensor

One of the primary applications of ultrasonic sensors is the distance measurement. They are more common in parking assistance systems for cars to detect obstacles and assist drivers in parking manoeuvres. They are also used in tanks and containers for measuring liquid levels in utilizations such as fuel tanks, chemical storage tanks, and water tanks. They provide accurate and reliable measurements without the direct contact with the liquid. While infrared waves work in vacuum, the ultrasonic waves do not. Therefore, the infrared sensor is useable in space, for example at the NASA space robots. [6]

D. Distance sensors in Botball®

There are three distance sensors that are used in the Botball® competition. The “Top Hat” sensor is available in small and large. Those work through infrared and are a good option for line following. The other one is the Rangefinder Sensor “ET” that works through laser beams. The Rangefinder Sensor works based on the time-flight principle. [7]

1) Infrared sensor “Top Hat”

The “Top Hat” distance sensor in Botball® is available in two different variations. There is a small Top Hat sensor and a large Top Hat sensor. The only difference between these sensors is the maximum detection distance. This sensor has two uses. The first is a line-detector. Black materials typically absorb infrared and reflect extraordinarily little infrared back, and white materials typically absorb little infrared and reflect most infrared back. If this sensor is mounted at a fixed height above a surface, it is easy to distinguish a black line from a white surface. The second use is as a short-range distance sensor. The Top Hat sensor works best when calibrated to black and white, because factors as daylight or colour variations can differ the sensor output. The amount of infrared reflected depends on the surface texture, colour, and distance. That is why difficulties occur. [7]

We have measured the reflection of the infrared light on two different surfaces with the same distance between the surface and the sensor: [7]

TABLE I. SENSOR CHARACTERISTICS [7]

	Brown	White
Standard deviation	15,3	9,76
Median value	275,7	251,9

The results show that the sensor is accurate. However, there can be some variance between the measurements because of the light level. What we also recognized is that the sensor is more accurate on brighter surfaces and smaller distance measurements. If the infrared sensor is used on a black surface, then the measured value does not change when you get closer to it or further away. If the infrared sensor is used on a bright surface, then the value changes with the distance, until the maximum tested distance of two centimetres is reached. Above there is barely any change in value. When a bright light irritation is there, the measured data can be manipulated and black could be perceived as a brighter colour. Therefore, it is important to keep the light on a low level for accurate measurements. [7]

2) Rangefinder "ET"

This sensor works by sending out a modulated frequency infrared beam and measures the angle the reflected infrared light returns at and triangulates the distance to an object. Because of the modulated frequency, this sensor is making fewer errors due to changing lighting conditions. This sensor makes a great medium range distance sensor. The measured distances for this sensor should be between ten and 50 centimetres. [7]

To program the rangefinder sensor, we wrote the following code:

```
#define abstand_100 2900


drive_until_analog(0,abstand_100,-50);

int drive_until_analog(int number, int value, int v_drive)
{
cmpc(motor_r);
cmpc(motor_l);

while(analog(number)<value)
{
motor(motor_l,v_drive);
motor(motor_r,v_drive);
}

ao();

return 0;
}
```

Fig. 3: Rangefinder sensor code

This program says that the robot can move until it gets too close to an object. The distance where the robot should stop has to be measured. The value that the sensor shows at the wanted distance is the variable "value" in the program. The variable "number" represents the port number.

```
void follow_straight_line()
{


    while (analog(bw_l) >= black_l || analog(bw_r) >= black_r)
    {

        if(analog(bw_l) >= black_l && analog(bw_r) >= black_r)
        {
            move_at_velocity(motor_l,800);
            move_at_velocity(motor_r,-740);

        }else if (analog(bw_r) < black_r)
        {

            move_at_velocity(motor_l,1500);
            move_at_velocity(motor_r,-540);


        } else if ((bw_l) < black_l)
          {

              move_at_velocity(motor_l,600);
              move_at_velocity(motor_r,-1440);


          }
    }
  ao();
}
```

The following program is structured for the Top Hat sensor to follow indicate a line following program.

In this program, the robot needs to follow a black line; however, there can be deviations on one or more of the motors. To still guarantee a correct execution, our Top Hat sensors determine on which side the robot is going wrong and arrange a small turn in the other direction.

Fig. 4: Infrared sensor code

TABLE II. SENSOR CHARACTERISTICS [7]

	Small Top Hat	Large Top Hat	Rangefinder
Maximum detection distance	12mm	15mm	80cm
Light sensitivity wavelength	940-850 nm	940-850 nm	940-800 nm

E. Sensor Calibration

The calibration of the distance sensor works in a simple way. A distance measuring device, in our case a calliper, was used, that is as accurate as possible and an object that could be found in a real application are needed. The first step is to place the object in a distance in the front of the sensor, which commonly appears in practical applications. Then the value delivered by the sensor needs to be documented. This process is repeated with different distances until there are enough values, so that a large portion of the practical distance spectrum is covered for the sensor to work as accurate as possible.

1. *Calibration of the Rangefinder "ET"*

In order to calibrate the Rangefinder, we measured some points, to get a feeling for the sensor graph. Even though the sensor produces viable values between 5 and 75 cm distance, it is better to use it for distances between 10 and 40 cm, because the graph is steeper in this interval. This is mandatory, because changes in our sensor values, via light et. cetera, don't affect the outcome in a big manor, if they occur in the given interval. We first measured the sensor values given at different ranges and noted them in an Excel document. The next step was to create a Punctual XY diagram and to create a function which looks like the imaginary curve of the calibration points. We then picked 4 of the best points and created a Punctual XY diagram just with them. The next step was to flip the axes and create a new function for the flipped diagram. The function we got was $y = 153720 * x^{-1,213}$. We then calculated the sensor values with the equation we have gotten and achieved an average measurement uncertainty of -0,47 cm. This result is more than sufficient for our usage! Figure 5 shows the 4 points we used to determine the equation. Figure 6 shows the graph with all the measurements, and has the approved interval marked. We only use 4 points for our reversed function, because we need to be able to quickly check if another Rangefinder is good enough for our use and the more points you pick the longer it takes to do that. In Chapter 2) Rangefinder "ET" we stated that the ideal range for the use of the Rangefinder is 10 – 50 cm. This has been furthermore proven by our tests.

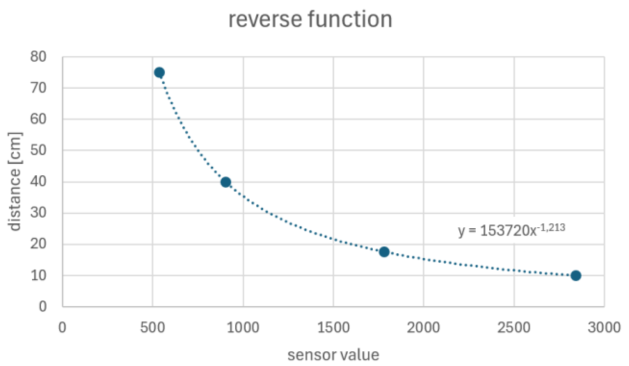


Fig. 5: reversed function diagram

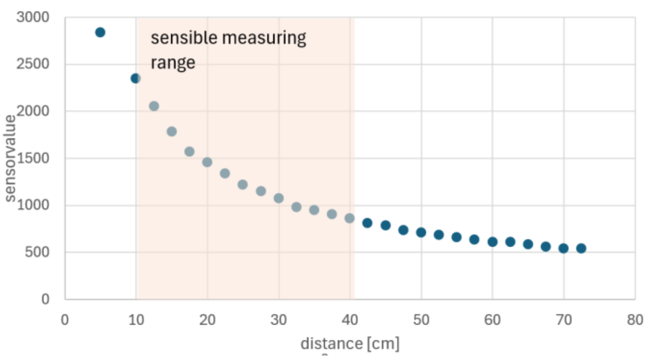


Fig. 6: measurements done by us

III. CONCLUSION

The measurement of the distance with a distance sensor is not an easy task. The time-of-flight principle is the most accurate principle for sensors to measure distances. That is why most distance-sensors work through the time-of-flight principle. Our Rangefinder sensor as well as our infrared sensor are both based on the time-of-flight principle. The advantage of the infrared sensor is that it can be used to recognize surfaces that reflect better or worse than others as we do in the Botball® competition to orientate ourselves with the help of the black orientation line. The disadvantage of the infrared sensor is the light sensitivity because it reacts very fragile to external light sources, so the sensor is not able to work well under heavy light irritation. The short distance which the sensor is dependent on can also be a downside of the infrared sensor. To equalize this, there is the rangefinder sensor, which works well at long distances.

REFERENCES

[1] Baumer: Functionality and technology of optical distance sensors [online] available at https://www.baumer.com/nl/en/service-support/function-principle/functionality-and-technology-of-optical-distance-sensors/a/Know-how_Function_optical-distance-sensors (Accessed February 10 2024)

[2] Terabee: time-of-flight principle[online] available at https://www.terabee.com/time-of-flight-principle (Accessed February 10 2024)

[3] H.R. Everett, Sensors for Mobile Robots, AK Peters, Ltd., Wellesley, MA, 1995..

[4] ST: time-of-flight-sensors [online] available at https://www.st.com/en/imaging-and-photonics-solutions/time-of-flight-sensors.html (Accessed February 17 2024)

[5] G. Benet, F. Blanes, J.E. Simó, P. Pérez "Using infrared sensors for distance measurement in mobile robots"

[6] Jiajun Ma "Obstacle Detection and Avoidance Using Ultrasonic Sensors in Autonomous Robots"

[7] Kipr.org: Sensor and Motor manual [online] available at Sensor_and_Motor_Manual_BB2013-no camera (kipr.org) (Accessed February 24 2024)

[8] Laser distance sensors for precise measurement and monitoring of distances [online] available at https://www.jenoptik.de/produkte/laser/laser-distanzsensoren/ldm (Accessed March 27 2024)