LIDAR Sensors
Advanced Sensor Usage in Botball - A Concept
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Abstract—Advanced sensor usage is of strong interest for Botball. This paper gives an overview of LIDAR sensors, their principle of operation and how they can be used for obstacle detection, landmark detection or navigation and path planning. The goal of this paper is to show how this technology can be implemented in future Botball competitions. Requirements for sensors for the usage as a part of Botball are listed as well.

The first chapter defines the term LIDAR and explains the principle of operation. Furthermore LIDAR sensors are introduced. The following chapter shows a possible concept of implementation into Botball and also lists requirement for possible sensors. The third chapter shows ways to implement LIDAR sensors into robotics. These implementations are about obstacle detection and simple path finding techniques, as well as landmark detection, as possible use cases for Botball. The final part summarizes the topics and recommends areas for future research.

Index Terms—LIDAR, Robotic, Botball, Path Planing, Obstacle Detection, Landmark Detection, Advanced Sensor Usage.

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1 Introduction

The term LIDAR is the abbreviation of light detection and ranging. The use of LIDAR started in the 60s and 70s and has a rapid development since around 10 years. LIDAR is a widely used method to accumulate data from the environment. It is used by cars to collect data of the environment while driving, to make topographic maps of a landscape from an airplane and various other applications. In general there are two types of systems. These are airborne and ground-based LIDAR systems. [2]

LIDAR is used, amongst others, in this applications: [3]

- Flood Modelling
- Pollution Modelling
- Mapping and Cartography
- Coastline Management
- Navigation
- Meteorology
- Geology
- Vehicles
- Imaging
- Robotics

This list shows that the operation area of LIDAR is wide spread. In this paper the focus is on robotics and specially how it may be used in Botball.

1.1 Principle of Operation

There are basically three measurement principles for LIDAR sensors. The time-of-flight approach (TOF), the phase approach and the triangulation method. The first and the last approach are explained and compared in this chapter.

1.1.1 *LIDAR with the Time-of-Flight Method*

This method is based, like RADAR, on the principle of measuring the time-of-flight. A single laser signal is shoot at a given angle and reflected by a target. The time between sending and receiving of the laser signal is measured. With this information it is possible to calculate the distance to the target. The formula is shown in 1, where l stands for the distance to the target and c is the speed of light. The formula is divided by two, because the signal has to travel the distance twice. [9]

$$l = \frac{c * \Delta t}{2 * n} \tag{1}$$

The relative position of the target can be determined by knowing the angle and the calculated distance. 1 shows a graphical representation of the principle of measuring the time-of-flight. [4]

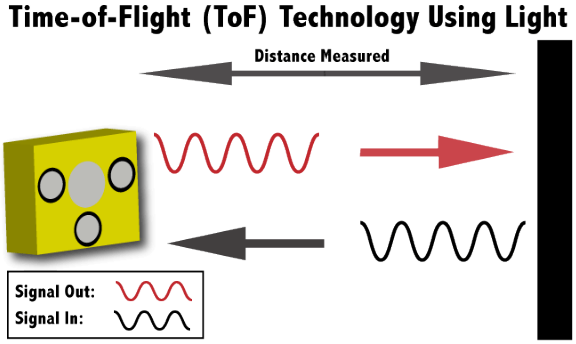

Fig. 1. Principle of LIDAR operation [5]

The sensor is spinning around its horizontal axis to scan on a given angle, e.g. 90 degree. This is repeated multiple times. (e.g. 10 measurements per second at an angle of 0 to 90 degree). The repetition is known as the scan rate. With all these data a 2D map of the environment can be continuously generated. Ground based LIDAR systems use a wavelength of 500 to 600 nm, while air based systems use a wavelength of 1000 to 1600 nm. Larger wavelength are good for penetrating objects (e.g. clouds), smaller wavelength is better to detect smaller objects. [8]

1.1.2 LIDAR with the Triangulation Method

Apart the time-of-flight there are other working principles. One is the triangulation approach. The triangulation approach is used to provide very accurate distance information in the near frame of the sensor. A disadvantage is that these sensor are mostly not eye safe and that the signal is affected by the surface of the reflecting object. [8] The principle of this method is described in 2. In this case an IR LED sends a infrared light signal through a lens. This light signal is reflected by an object. Until here it is the same approach as time-of-flight. But instead the travel time, the position of the reflected signal on a position sensitive IR detector is measured. With knowing the position of the reflected signal on the sensor the angle of the reflected signal can be calculated. With the angles and the method of triangulation the distance to the object is calculated. [7]

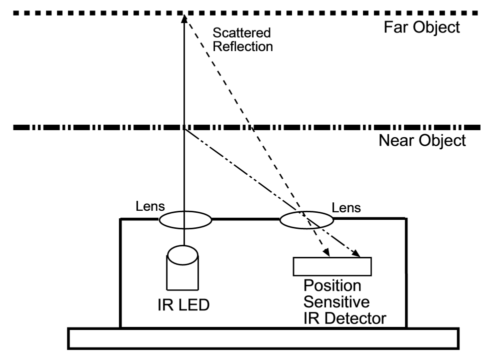

Fig. 2. Principle of the Triangulation Method [7]

1.1.3 Comparison of Time-of-Flight and Triangulation

There are several differences between these two concepts. The first is the way of measuring the distance information. The time-of-flight principle measures the travel time, while the triangulation method uses the angles of the reflected light. The triangulation approach is more accurate on short distances, cheaper and more robust. The time-of-flight method has a higher distance range, a better reaction time and no dead angle. [9] Especially the higher accuracy and the robustness makes triangulation LIDAR sensors interesting for robotic tasks. But additional drawbacks of the triangulation are that it is mostly not eye safe and that the measurement quality is dependent on the surface of the reflecting object.

1.2 LIDAR Sensors

Common LIDAR sensors are capable of making high resolution 3D images of their environment. This complexity is not necessary for robotics in most cases. Therefore a simple LIDAR sensor with a relative low resolution is sufficient for the usage in Botball. On the other hand high performance systems can cost far over 100,000 Euro and are big in size and weight. This is another reason why they are not usable for robotics and Botball in specific. On the market exist low performance LIDAR systems which are suitable for this use case.

2 Concept

This section gives an overview of what a possible sensor for Botball has to fulfil. A LIDAR system has a big number of specifications, only the most important ones are presented in this section. The second part introduces a possible concept of implementation for the use in Botball. This includes the necessary hardware parts, but also necessary software parts.

2.1 LIDAR Sensor for Botball

A possible LIDAR sensor for the use in Botball should at least fulfil the following requirements. [2]

Requirement	Value	Unit
Scan Angle	0 to 120	Degree
Scan Rate	10	Hz
X-Accuracy	5	mm
Y-Accuracy	5	mm
Resolution	10	mm

A scan angle of 0 to 90 degree is enough, since the robot (with exception of an omni-wheel driven robot) is only travelling in one direction. 10 Hz is also enough for the scan rate, because the speed of the robot is relatively low. The most important requirements are the accuracies in x and y direction. The better these resolutions are, the more accurate an obstacle can be detected. Last the resolution of 10 mm is necessary to have enough data points along the scan angle.
The following table gives an overview of available systems for robotics. [10]

Name	Manufacturer	Angle	Distance	Accuracy	Scan Rate	Price
RB-Pli-03	PulsedLight	—	—	+/-0.025m	1-500Hz	115$
RB-Rpk-01	RoboPeak	0-360°	0.2-6m	<0.5mm	5.5Hz	400$
URG-04LX-UG01	Hokuyo	0-240°	20-5600mm	+/-30mm	10Hz	1.150$
UTM-30LX-EW	Hokuyo	0-270°	0.1-30m	+/-30mm	400Hz	5.310$

2.2 Concept of Implementation

A possible concept for the implementation of a LIDAR sensor into Botball is shown in 3. The concept can be split in two parts, the hardware and the software. The hardware part consists of the sensor and the Wallaby-controller. The sensor and controller need to communicate with each other, e.g. via UART or USB (see 3).
The software part is done by the controller. The tasks of the software are to acquire data from the sensor and to bring them into the formats needed. These formats are polar (r and ϕ) and cartesian (x and y) coordinates. Possible inputs for the acquiration part are ϕ_{start}, ϕ_{end} and r.

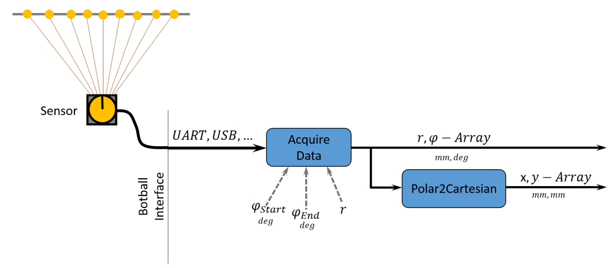

Fig. 3. Possible Concept for LIDAR sensor Implementation to Botball

The software part can be integrated into the standard library, that is handed out to the teams. This has the advantage of a easy use, even if some of the LIDAR functions are relatively complex. Possible modules that can also be implemented into the software are more complex functions, such like obstacle detection, landmark detection or path planning and map generation. A brief overview of this functions is given in the following section.

3 Implementation

For advanced autonomous driving and navigation of the robot it is necessary to implement two features which introduce more intelligence, more degree of freedom and accuracy. These two features are the so called obstacle detection on the one hand and avoidance and landmark detection algorithm on the other hand. Both features require an active sensor which in this case is the LIDAR sensor finder which scans the environment in a certain range and a certain accuracy. 4 presents an overview about the two tasks.

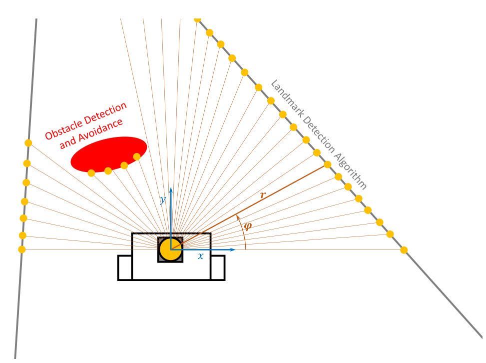

Fig. 4. Obstacle Detection & Avoidance and Landmark Detection Algorithm

3.1 Obstacle Detection

An important feature for navigating a mobile robot autonomous through a map is the possibility of detecting unknown static or dynamic obstacles. Therefore it is required to scan the environment in front of the robot and stop the robot if an obstacle is too close. Usually LIDAR sensors scan a wide area (e.g. 120 degree). This includes unnecessary information for the obstacle detection. An algorithm extract the data that which are within the collision area and checks if the measured radius of each point is within a minimum value r_{min}. Due to noises in the measurements one point is not enough for being an obstacle. Therefore at least five or ten points have to be within the critical area to be counted as an obstacle.

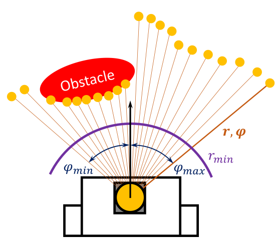

Fig. 5. Obstacle Detection

Because collisions can only occur in the direction of motion it is enough to look at a certain area where it is probable that collisions might occur. These areas are indicated with ϕ_{min} and ϕ_{max}.

3.2 Landmark Detection

The second feature that can be implemented with a LIDAR sensor is a landmark detection algorithm. In this case a special algorithm is shown, the so called RANSAC algorithm. It is able to detect straight lines (e.g. walls or similar objects). For further information see [6].

3.3 Navigation and Path Planing

Autonomous driving robots require an algorithm for planning a path. This algorithm requires knowledge about the actual position and knowledge about the area the robot is operating in. The map can either be created during driving or can be known beforehand. Anyway attention has to be paid to not crash into obstacles. Path planning algorithms are using either road maps or grid based maps.
A possible approach for Botball is the visibility map method. The path are defined by the geometry of the obstacles. In the case of a visibility graph method the paths are minimal length solutions and the edges of an obstacle result in the path itself. One example of the visibility graph method is shown in 6 where two obstacles are within the map. The aim of a path planner is to find the shortest way from A to B passing the obstacles. This is done by connecting each edge point of the obstacles with every visible edge point of the other obstacles and also the points A and B. [1]

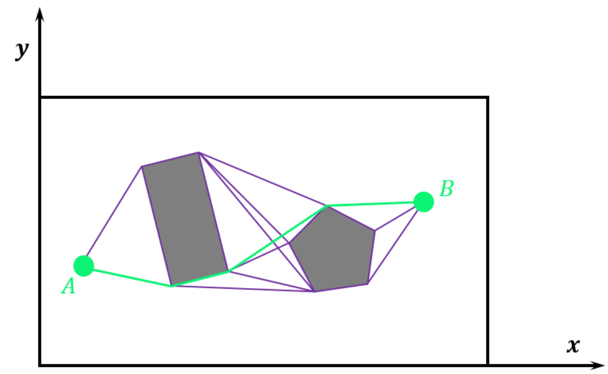

Fig. 6. Visibility Graph Method

Including the edges of the obstacles several possible paths from A to B are developed. In the example in 6 at least ten different solutions for getting from A to B are displayed. Therefore after establishing the paths it is necessary to select the shortest one. This can be done by using the Dijkstras algorithm which weights the distances between each edge point, checks several combination and tries to minimize the travelling distance. This algorithm will find the green line indicated in 6. Using this approach it is necessary to increase the size of the obstacles. Otherwise the robot would hit the obstacles. [1]

4 Conclusion

The first section gives a brief overview of LIDAR, its measurements principles and its history. Also it shows areas where LIDAR is used today. The second part of this chapter explains the functionality of LIDAR with a few words and compares high and low end LIDAR systems. A concept for the implementation in Botball is shows in section two. The concept lists the hardware and software parts. At the beginning of the section requirements are listed for a Botball LIDAR sensor. Section number three is all about the possible implementation of LIDAR in robotics and Botball in specific. For each of the three areas only one possible solution is briefly explained.

To implement a LIDAR sensor into the Botball ecosystem a more detailed concept needs to be worked out. This means the implementation of both, hardware and software. For example, which LIDAR is the best suited for Botball and how can it be connected with the controller. But also the software has to be detailed. This means it has to be worked out which algorithms are used and how to implement them into the environment.

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