__Research__

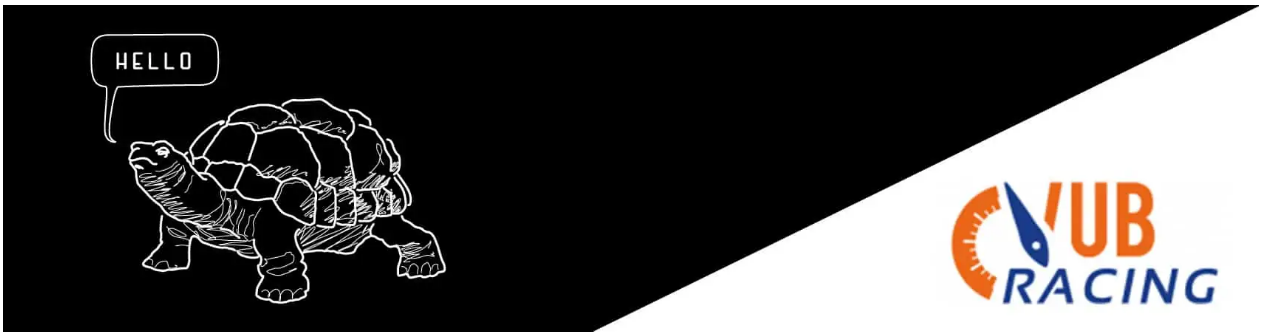
INTRODUCTION

As a young engineer passionate about cutting-edge technology, I was always fascinated by autonomous cars. The thought of a camera being able to capture the world not just in 2D images but also in 3D, blew my mind. And when I discovered the world of Formula Student and the challenges they face in terms of perception, I knew that this was the perfect opportunity for me to dive into this exciting field.

The goal of my Master's thesis is to explore the state-of-the-art techniques in the field of LiDAR perception and to see how they can be applied to the unique demands of Formula Student race cars. The challenge of detecting cones on a track, separating them from the background, and accurately localizing them, is a complex one. But, I am determined to rise to the challenge and to find the best solution for this problem.

I am eager to explore the different algorithms that exist for object detection using a point cloud as input, to compare their strengths and weaknesses, and to determine which one would be best suited for a Formula Student race car. The work will culminate in a comprehensive study of the perception pipeline, with a focus on the innovative algorithms.

APPLICATION



One of the goals of vub-racing is to participate to the future driverless [Formula Student] competions. For this research has to be made.

The race

General circuit arrangement

- closed loop tracks (layouts: skidpad, trackdrive, autocross, endurance)
- start/finish line is marked by four big orange cones
- left track : blue cones
- right track : yellow cones
- finish : big orange cones
- braking track : orange cones
- cone distance : max. 5m
- width track: min. 3m
- length lap: +/- 200 m to 500 m
- Straights: No longer than 80 m
- Constant Turns: up to 50 m diameter.
- Hairpin Turns: Minimum of 9 m outside diameter (of the turn)
- Miscellaneous: Chicanes, multiple turns, decreasing radius turns, etc

Dynamics events

Skidpad

D 4.1 Skidpad Track Layout

D 4.1.1 The skidpad track consists of two pairs of concentric circles in a figure of eight pattern.

D 4.1.2 The centers of these circles are 18.25 m apart. The inner circles are 15.25 m in diameter and the outer circles are 21.25 m in diameter.

D 4.1.3 16 cones are placed around the inside of each inner circle. 13 cones are positioned around the outside of each outer circle, in the pattern shown in the skidpad layout diagram.

D 4.1.4 Each circle is marked with a line, outside the inner circle and inside the outer circle.

D 4.1.5 The driving path is the 3 m wide path between the inner and outer circles. The vehicles enter and exit through gates on a 3 m wide path that is tangent to the circles where they meet.

D 4.1.6 The line between the centers of the circles defines the start/finish line. A lap is defined as traveling around one of the circles, starting and ending at the start/finish line.

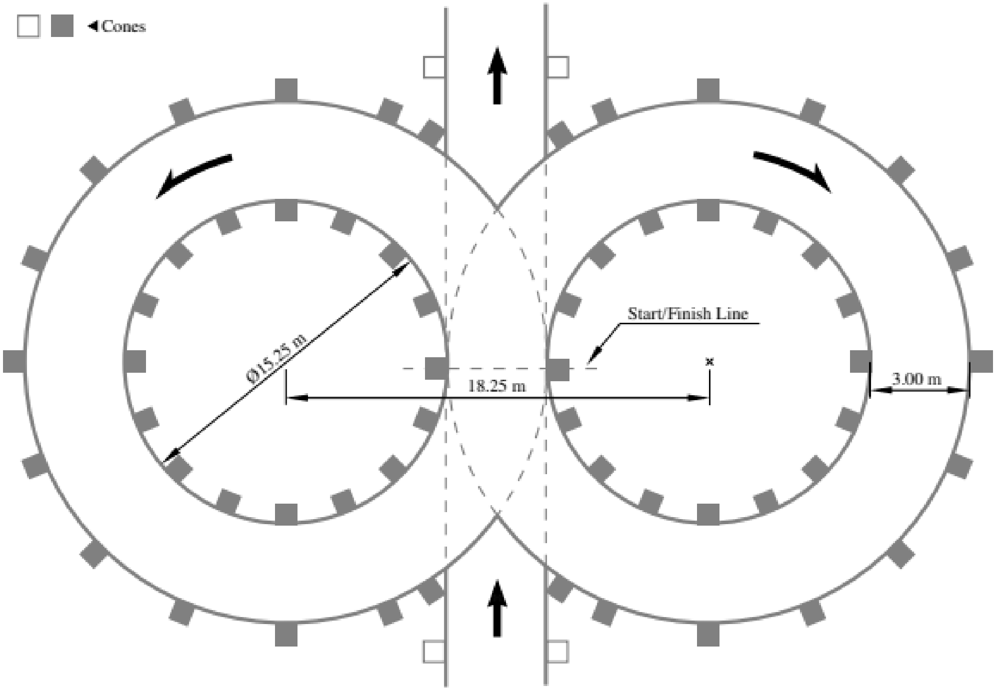


Figure 23: Skidpad Track Layout

Acceleration

D 5.1 Acceleration Track Layout

D 5.1.1 The acceleration track is a straight line with a length of 75 m from starting line to finish line. The track is at least 3 m wide. Cones are placed along the track at intervals of about 5 m. Cone locations are not marked on the pavement.

Autocross

D 6.1 Autocross Track Layout

D 6.1.1 The autocross track layout is a handling track built to the following guidelines:

- Straights: No longer than 80 m
- Constant Turns: up to 50 m diameter
- Hairpin Turns: Minimum of 9 m outside diameter (of the turn)
- Slaloms: Cones in a straight line with 7.5 m to 12 m spacing
- Miscellaneous: Chicanes, multiple turns, decreasing radius turns, etc. The minimum track width is 3 m.

D 6.1.2 The length of the autocross track is less than 1.5 km.

D 6.1.3 [DC ONLY] The autocross is using the same track as the trackdrive event (see D 8.1).

D 8.1 Trackdrive Tracklayout

D 8.1.1 The trackdrive layout is a closed loop circuit built to the following guidelines:

- Straights: No longer than 80 m
- Constant Turns: up to 50 m diameter
- Hairpin Turns: Minimum of 9 m outside diameter (of the turn)
- Miscellaneous: Chicanes, multiple turns, decreasing radius turns, etc.
- The minimum track width is 3 m

D 8.1.2 The length of one lap is approximately 200 m to 500 m.

Endurance

D 7.1 Endurance Track Layout

D 7.1.1 The endurance track layout is a closed lap circuit built to the following guidelines:

- Straights: No longer than 80 m

- Constant Turns: up to 50 m diameter
- Hairpin Turns: Minimum of 9 m outside diameter (of the turn)
- Slaloms: Cones in a straight line with 9 m to 15 m spacing
- Miscellaneous: Chicanes, multiple turns, decreasing radius turns, etc.
- The minimum track width is 3 m

D 7.1.2 The length of one lap of the endurance track is approximately 1 km.

D 7.1.3 The length of the complete endurance is approximately 22 km.

Extra Pictures:

small orange cone
single white stripe

small yellow cone
single black stripe

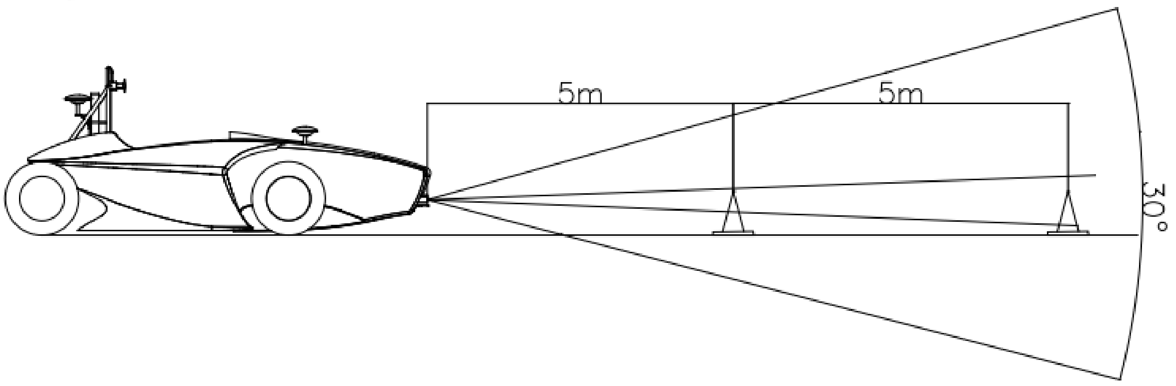
small blue cone
single white stripe

big orange cone
two white stripes

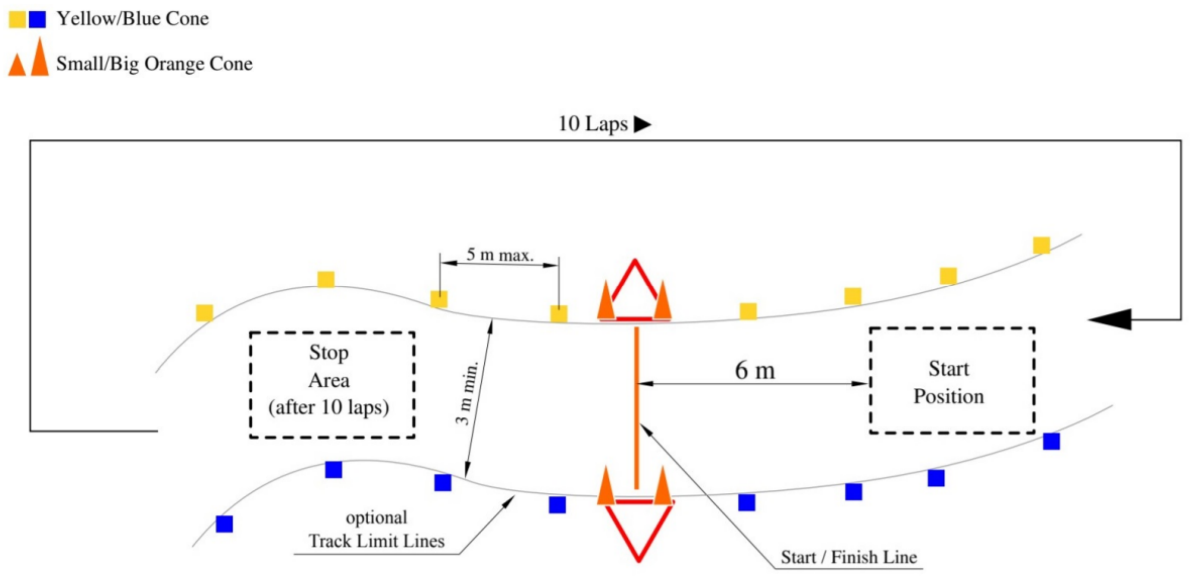
	small cones	big orange cone
dimensions:	228 mm × 228 mm × 325 mm	285 mm × 285 mm × 505 mm
weight:	0.45 kg	1.05 kg

Track limitations

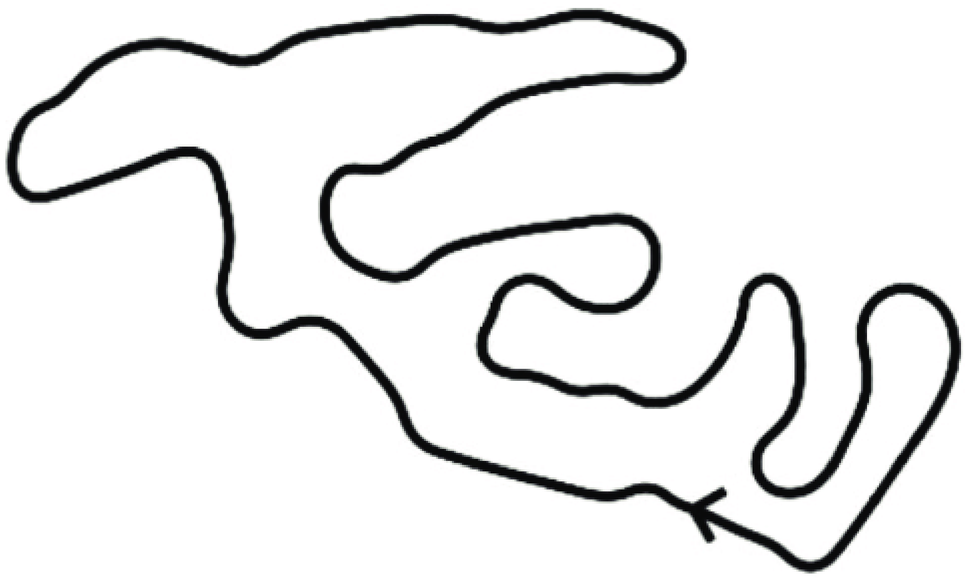
Cone distance



general track layout

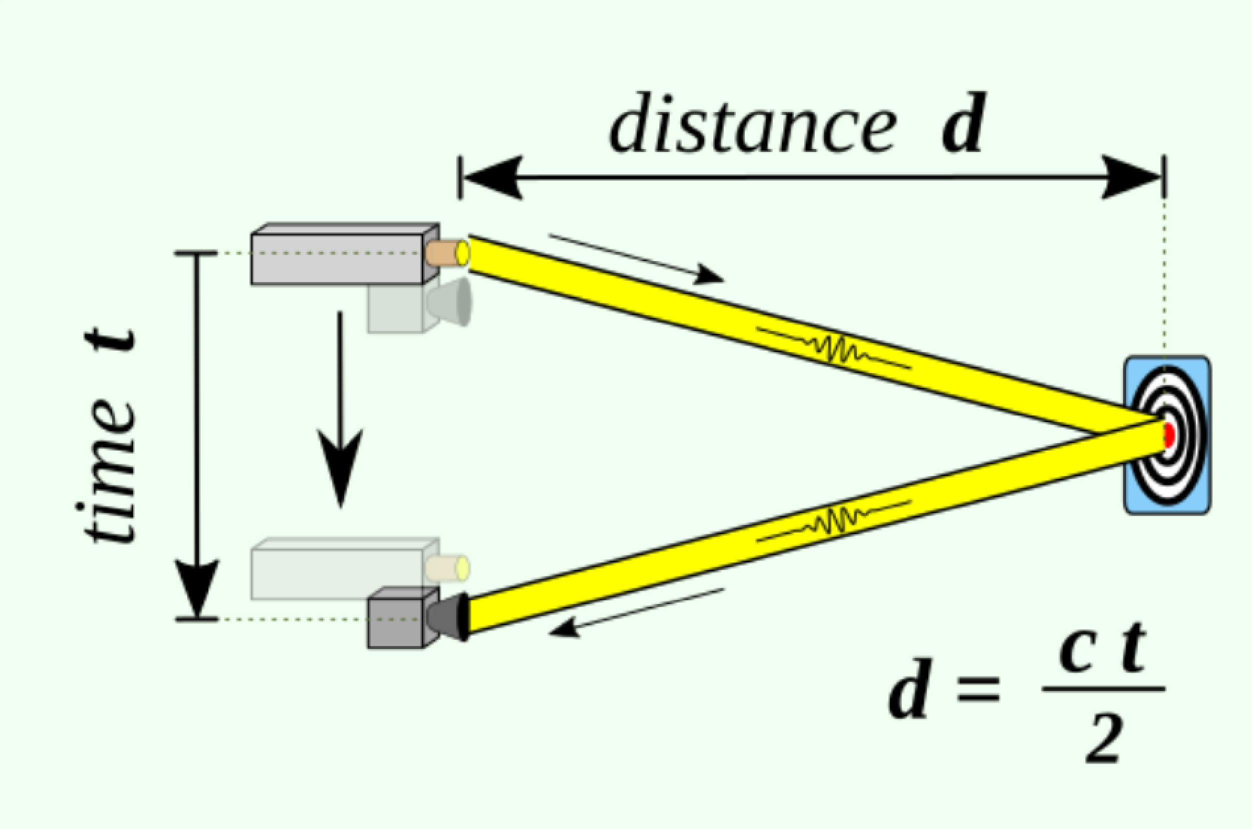


FSAE-Germany-Endurance-track



What is LIDAR ?

LIDAR TECHNOLOGY



LiDAR (Light Detection and Ranging) is a remote sensing technology that uses laser light to measure distances and create high-resolution 3D maps of objects and environments. It works by emitting laser pulses from a spinning sensor and measuring the time it takes for the laser light to bounce back to the sensor after hitting an object. The laser rangefinder then calculates the distance to the object based on the time of flight of the laser light.

The process of LiDAR technology

1. **Laser Pulse Emission**: A laser rangefinder in the LiDAR sensor emits short laser pulses at a high frequency (typically hundreds or thousands of pulses per second). The laser rangefinder can be either fixed or mounted on a spinning mechanism, allowing the LiDAR sensor to capture a 360-degree view of the environment.

2. **Light Propagation**: The laser light travels from the LiDAR sensor to the objects in the environment, where it bounces back to the sensor after hitting the objects.

3. **Time of Flight Measurement**: The LiDAR sensor measures the time it takes for the laser light to travel from the sensor to the object and back. The time of flight is used to calculate the distance to the object based on the speed of light (299,792,458 meters per second).

4. **Distance Calculation**: The LiDAR sensor uses the time of flight measurement to calculate the distance to the object. The distance is then recorded along with the position of the LiDAR sensor and the direction of the laser pulse, creating a 3D point cloud representing the objects in the environment.

5. **Point Cloud Creation**: The LiDAR sensor continues to emit laser pulses and measure the time of flight, generating a large number of 3D points that form a point cloud of the environment. The point cloud data can then be processed and analyzed to create 3D maps of the environment, detect objects, and perform other tasks.

6. **Data Processing**: The raw data collected by the LiDAR sensor must be processed and transformed into a useful format. This typically involves filtering and cleaning the data, removing extraneous information, and transforming the 3D points into a meaningful representation of the environment. For example, the data may be transformed into a grid or voxel representation, which provides a more compact representation of the environment while preserving the key features of the data.

7. **Object Detection and Recognition**: LiDAR data can be used to detect objects in the environment, such as vehicles, pedestrians, road signs, and obstacles. This typically involves using algorithms such as clustering, segmentation, and classification to identify and isolate objects of interest. Deep learning techniques, such as convolutional neural networks (CNNs), have also been used for object detection and recognition using LiDAR data.

8. **Mapping**: LiDAR data can be used to create high-resolution 3D maps of the environment. This typically involves transforming the 3D points into a

coordinate system, aligning and registering multiple scans, and fusing the data to produce a complete map of the environment. LiDAR mapping is used in a wide range of applications, including autonomous navigation, urban planning, and environmental monitoring.

Important considerations with LiDAR

To build a top-performing car, these considerations are key.

- **Real-Time Performance**: In order to be useful in many applications, LiDAR systems must be able to operate in real-time. This means that the data must be captured, processed, and analyzed quickly enough to be useful in a rapidly changing environment. LiDAR systems typically use specialized hardware and algorithms to achieve real-time performance, and there is ongoing research into improving the speed and efficiency of these systems.
    - **Algorithm selection**: The choice of object detection algorithm is crucial, as it will determine the accuracy and speed of the object detection process. The algorithm must be flexible, fast, light-weight and must be giving accurate outputs.
    - **Hardware selection**: We must consider factors such as computation speed, memory capacity, power consumption, robustness and compatibility with the chosen software and algorithms. A balance between performance and efficiency is key.
        - **Range and Accuracy**: Ensuring high enough range and accuracy.
        - **Field of view (FOV)**: Covering the required area and cones.
        - **Scan rate**: sufficient scan rate
        - **Data rate**: sufficient data rate
        - **Laser type and wavelength**: near-infrared (NIR), short-pulse or long-pulse
        - **Point density**: Generating enough points
        - **Size, weight, power consumption and connectivity**
- **Cost**: Considering hardware, software, and data processing/storage costs.

- **Integration**: Ensuring proper integration with power, control, sensors, and communication systems is required. LiDAR systems are often used in combination with other sensors, such as cameras, GPS/IMU, to provide a more complete picture.

Pro's and Con's of using LiDAR

Pros:

- **Accurate distance measurements**: LiDAR cameras use light beams to measure distances, making them very precise in determining distances, even in dynamic environments such as a race car track.
- **Provides 3D data**, which is more comprehensive compared to 2D cameras
- **Efficient object detection**: LiDAR cameras are great for detecting objects, especially those that have a distinctive shape, such as cones. It's also capable of detecting obstacles in real-time, providing valuable information for race car drivers.
- **Works in various lighting conditions**: Unlike regular cameras, LiDAR cameras are not affected by lighting conditions, making it useful in low-light environments, or in bright environments, where the sun is shining directly onto the track.

Cons:

- **Overwhelming data output**: LiDAR cameras can produce a large amount of data, which can be difficult to process and interpret.
- **Data processing demands**: LiDAR cameras generate large amounts of data, which can be complex and difficult to process, requiring advanced algorithms to filter and extract features.
- **Cost**: LiDAR cameras can be expensive compared to regular cameras, which can be a significant investment for a formula student team.
- **Prone to vibrations**: As the laser beams and the sensor need to remain stable for accurate data collection. Vibrations can cause measurement errors and impact the accuracy of the LiDAR system. Additional stabilizing platforms are often needed to stabilize the camera and algorithms may be needed to filter out noise and correct inaccuracies.
- **Calibration and maintenance**: LiDAR systems need regular calibration and maintenance to ensure they work correctly and accurately, which can be

time-consuming and difficult.

- **Difficulty in detecting transparent objects**: LiDAR cameras work by reflecting light, making it difficult for them to detect transparent objects.
- **Weather sensitivity**: Weather conditions such as rain, snow, and fog can deflect the light beams, making it difficult for LiDAR cameras to accurately detect objects.
- **Range limitations**: LiDAR cameras have a limited range, which is determined by the hardware used. This means that it may not be able to detect objects that are too close or far away.

CAMERA SPECS

The needed specifications for the Lidar camera can be determined by understanding the APPLICATION we will use it in.

Desired specifications

Type of camera: a **solid-state LiDAR** may be preferred over a scanning LiDAR due to its compact size, real-time capabilities, less complexer and high-resolution data.

Horizontal and vertical field of view: The field of view (FOV) requirements can be determined based on the width of the track, which is a minimum of 3m, and the distance between the cones, which is a maximum of 5m. A LiDAR camera with a wide horizontal FOV and a narrow vertical FOV would be ideal for capturing the track and the cones accurately. (a rough estimate of the **HFOV** angle in the range of **60 to 120** degrees and **VFOV of 30-40 degrees** could provide an adequate coverage of the track)

Framerate: Given the requirement for real-time processing of the data, it would be ideal to use a LiDAR camera with a high framerate, ideally in the range of **10-30 frames per second**.

Wavelength: The wavelength of the laser used in the LiDAR camera is an important consideration as it affects the range and accuracy of the camera. For high-precision mapping of the track, it would be ideal to use a LiDAR camera with a laser wavelength in the near-infrared (NIR) range, as it provides high accuracy and is less affected by weather conditions.

Range: Given the maximum distance between the cones and the maximum length of a straight, a LiDAR camera with **a range of at least 50-100 meters** would be ideal for mapping the entire circuit.

Precision and accuracy: For accurate mapping of the track, it is important to use a LiDAR camera with high precision and accuracy. This can be ensured by using a high-resolution camera, as well as using advanced algorithms for data processing and filtering.

Trade-offs must be made between the camera characteristics in order to meet cost restrictions and liability of the measurements.

(point density ?)

CAMERA CHOICE

product	**constructor**	**FOV**	**precision**	**price**
?	Xenomatics	?	?	$ $ $
Velabit	Velodyne	70°/30°	?	100$
Puck	Velodyne	?	?	$ $ $

Racha Akrour : zocht voor mogelijkheden bij firma's
Michael Vervaeke : hulp lidar

Sources

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- Past Competitions
- thesis
- object detection
- AMZ
- PointNet++
- rangenet++
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