Vision Based Cone Detection System for Formula Student Driverless Race Car

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Abstract

This paper presents an implementation of a cone detection system, under controlled environment, based only on image processing and feature detection of a video stream, as a first step for a fully autonomous system to be implemented on UFMG's Formula Tesla electric race car. The presentation video of this paper is at this link.

1. Introduction

Autonomous vehicles are treated by many as the future of transportation, but yet there are many difficulties that forbid a more comprehensive use of it due to lack of reliability.

A way to encourage students to enter this area is through universities driverless racing competitions, which has emerged in a few countries, where traditional university racing teams are starting to develop autonomous vehicles to compete. There are two possible categories: one with unknown tracks, and another with known tracks, where the car is allowed to map the track before the official race. This way, the car has to be able to recognize and map the track, which is delimited by cones.

To do so, a camera installed in the car records a real time video, providing information for a processing unit to analyse, filter and process the input, aiming to create the closest possible map of the track, allowing the car to race it through a safe path in the shortest time.

Formula Tesla is a UFMG team that builds an electric race car and competes in Formula SAE Brasil. Inspired by the development achieved in computer vision and autonomous driving, and by the introduction of the Driverless class to the Formula Student Germany competition in 2017, the desire emerged in the team to build a self-driving race car, aiming to introduce this new class in Formula SAE Brasil.

As a competition for university students, the environment the car is put every year is the closest possible from ideal, meaning planar track, no obstacles and presumably static, predefined racing courses delimited by same-sized, easy-to-find cones.

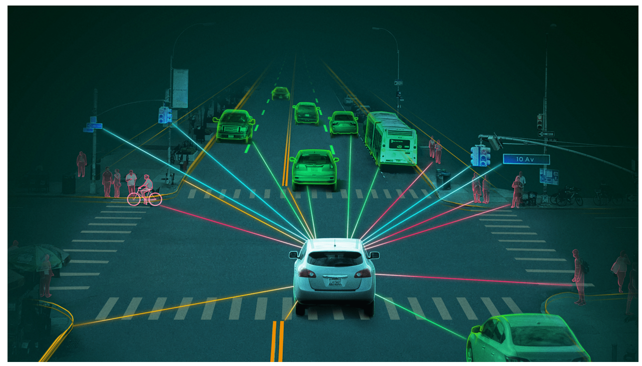

Figure 1. Representation of an autonomous vehicle vision.

2. Related Work

The greatest challenge to achieve real world autonomous vehicles is to find correct methods that provide safety to its movement, there being various studies about newer and more efficient methods than those being used nowadays.

Reconstruct from Top View: A 3D Lane Detection Approach based on Geometry Structure Prior is a paper by Chenguang Li [5], which approaches aspects of visual recognition of objects based on its geometrical shape, transforming an initial 2D model to a 3D one.

The main references [1–4,7–9] were from university racing teams' papers from countries that have already established an autonomous vehicle competition, notably from Germany, which was the first country to achieve this mark with the Formula Student Driverless.

These papers discuss different architectures for autonomous driving, such as combining camera and LiDAR for data acquisition and using YOLO (an real-time object detection algorithm) for cone detection.

3. Methods

As the racing track is not supposed to be a hard-test, there are no similar forms to mislead the algorithm, so cones can be accurately detected only with image processing and feature detection.

That being said, the method is composed of testing different image processing and feature detection techniques with different parameters, finding which ones fit better our scene.

With this method, it is expected that the car, as a fully autonomous system, could drive at a safe speed on a mapping lap to detect the cones. With the car and camera lacking information, would be possible to map the track to be raced, similarly to the track walk teams and drivers do before racing so they have better understanding of the racing track.

4. Experiments

Figure 2. Original monocular camera view.

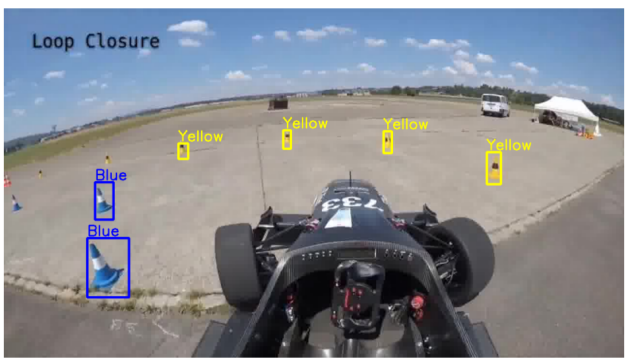

Figure 3. Bounding boxes around detected cones.

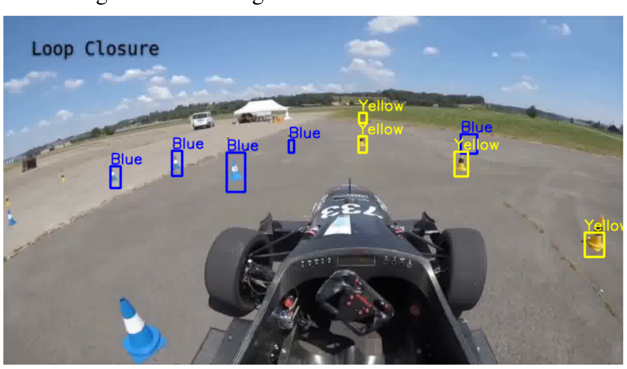

Figure 4. Few errors captured.

As the team's car was not ready for driving until the date of this paper, the input images, as in figure 2, used for testing were obtained from AMZ Racing's previous work, available at this link. This way, the car and the camera specifications were not available, lacking crucial information for a more detailed scene description.

Detecting 3D objects using images from a monocular camera is known to be an intrinsically ill-posed problem. But this scenario has a few key points that allow monocular cameras to be used: as said before, the environment is the closest possible from ideal, not having any obstacles to interfere in the quality of detection, and the cones are perfectly symmetric and have easily distinguishable colors and a standard size.

It was implemented an algorithm in Python 3.7 using OpenCV library that:

- thresholds blue and yellow colors in HSV scale;
- dilates and blurs to smooth the image;
- uses Canny edge detector to find approximate contours;
- detect convex hulls with appropriate dimensions for cone selection.

5. Results

With the algorithm described above, the cones were identified during most of the screen time, but a few errors were identified for a shorter period of time, as detecting ghost cones and missing others for a few frames as seen in figure 4.

6. Conclusion

As shown above, the results indicate that, with the chosen parameters, the developed method has an acceptable accuracy for identifying cones in the desired situation, and still having the possibility of being optimized.

7. Future Work

Possible works that can be done can be divided between 1) measurement methods, 2) optimization, and 3) machine learning.

7.1. Measurement Methods

At first, the video captured for AMZ's work [3] was the only data available to work with. Once there are a car, a camera and cones, it will be possible to determine all needed coordinates, as can be seen in the diagram on figure 5, obtaining both intrinsic and extrinsic matrices.

Given the objective of the project is to map a racing track with the cones three dimensional pose estimation, there are two main possibilities to do so:

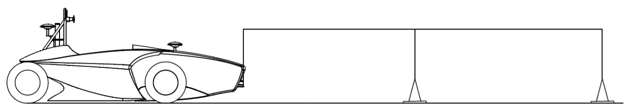

Figure 5. Scene Diagram.

7.1.1 Monocular Image

Given every cone has same standard dimensions and all coordinate systems are known, if a monocular camera is used, any cone in scene can have its three dimensional pose estimated by its bounding box dimensions. Resolution reductions for performance increasing could affect the algorithm accuracy as the boxes are used for measurement, and improvements should be made to reduce excessive margins between the cone itself and its bounding box, as seen in figure 4.

7.1.2 Stereo Image

If a stereo camera is used, by having the coordinate systems and the camera specifications, is possible to calculate any cone pose through the epipolar geometry in the scene. As only one class of object is wanted, with a shape that can be easily detected with features, a feature-based algorithm can be used, given the set of correspondences wanted is known to be sparse (only a few cones at a time).

7.2. Optimizations

As seen in figure 4, a few errors were detected using only image processing and feature detection with the chosen parameters. Given that, a more detailed analysis of the parameters, as well as of other algorithms and methods, could be done to achieve more accurate results.

As the car(camera) is moving while the cones are static, the optical flow could be used to track them, which could increase the accuracy of the obtained map.

7.3. Machine Learning

Last but not least, there can be implemented supervised Machine Learning (ML) algorithms.

Multiple images with one blue and white cone or one yellow and black cone or without any can be extracted from any frame of the video, generating a dataset to train and test cone detection ML algorithms. A larger dataset could be generated through image transformations from the original dataset.

7.3.1 From Scratch

A few ML algorithms could be used to train and test this dataset to classify if an image has one of the cones or no.

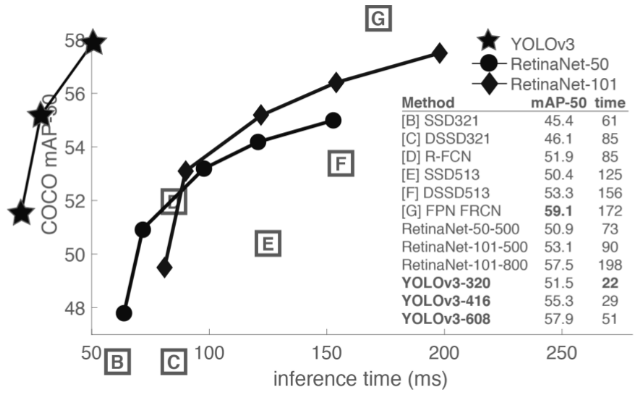

Figure 6. Comparison between object detectors.

As there are only two types of cones, could be used a very small bag of features to detect the cones on the image.

7.3.2 Ready to Use

There is also a possibility to use ready real time object detection algorithms, such as YOLO, You Only Look Once, which is an extremely fast and accurate general purpose detector as seen in figure 6 [6]. As this project requires only two objects to be detect, there is an even faster version of this detector for specific objects, called YOLO-Tiny that could be used.

References

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