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Object Detection in Autonomous Vehicles - A Case Study

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Abstract: ***This paper gives an overview of the object detection in autonomous vehicles and analyzes how robustness and uncertainty quantification can be integrated to enhance the model performance and reliability. Furthermore, it also discusses the ethical implications of deploying non-robust models in safety critical imaging applications.***

Keywords: Object Detection, Autonomous vehicles, Robust model, Uncertainty quantification

1. Introduction

Deep neural networks have shown wide adoption in various computer vision techniques including safety critical applications like autonomous vehicles, medical image segmentation and surgery assistance etc., The performance of the deep learning models is highly important not just for the safety critical tasks but also for the general computer vision applications. The last few years has witnessed strong research interest in applying AI to object detection in autonomous vehicles. This paper initially talks about what is autonomous driving, various levels of autonomous driving, basic building blocks of the autonomous vehicle architecture. Then it explains how object detection contributes to autonomous vehicle development and the various challenges involved in it. Then it gives an overview of the need of the robust deep learning models and the various ethical and societal impacts of non-robust deep learning models.

2. Autonomous Driving and Levels

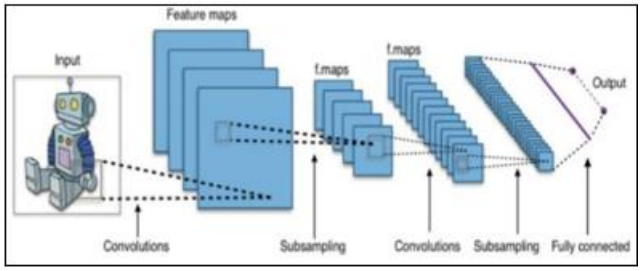


Figure 1: CNN Classification

Autonomous driving is one of the key research areas and well-funded research in the automotive industry right now in order to improve driving comfort and reduce injuries from vehicle crashes. Object detection is one of the critical components to support autonomous driving. Autonomous vehicles typically have multiple sensors such as RADAR, LIDAR and cameras. It will also incorporate contextual data from digital maps and vehicles to infrastructure networks.

Autonomous driving has multiple levels as described below

- Level- 0: Drivers will be performing all tasks. No autonomy at this level.
- Level- 1: Driver assisted features are included.
- Level- 2: Automated functions are included
- Level- 3: Driver should take control on notice
- Level- 4: Vehicle performs all driving functions under certain conditions
- Level- 5: Vehicle performs all driving functions in all conditions

Autonomous Vehicle Architecture

There are four different stages involved in the object detection and processing in the autonomous vehicles.

- **Sense:** In the first stage, the autonomous vehicle will use various sensors such as cameras, LIDAR, RADAR, positioning sensors for sensing the current driving environment
- **Understand:** In the second stage, it goes through the scene understanding phase where the captured data will be processed and the vehicle position, movements of other road users, surrounding environment will be understood.
- **Decide:** This is the decision making stage, aka control stage, where the information from the previous stage will be processed by the control mode and takes decisions to formulate driving strategies
- **Act:** Finally it is the time to take action to implement the decision strategies with the mechanical components such as steering wheel motor, brakes, accelerator motor.



3. Object Detection

Object detection is the crucial part in autonomous vehicle software development and architecture. Fast and accurate object detection algorithms are required to take actions in real time for latency critical applications. The algorithms are not just responsible for detecting objects in the captured images but also classify every object in the image and localize each object by segmentation or drawing bounding boxes around the object. Now it is clear that object detection is not a simple task but a very challenging and significantly harder task than the traditional image classification tasks. Faster R-CNN, YOLO and SSD (Single Shot Detection) are the most popular object detection techniques.

4. Challenges

There are multiple challenges involved in the autonomous vehicle object detection process including accurate detection, real-time processing, reliability etc., Robust deep learning models are required to address these challenges in autonomous vehicles where the output of the object detection directly impacts human lives. Object detection heavily relies on the data captured by the sensors and often these sensors introduce varying noise due to various environmental and thermal conditions. Deep learning models have to deal with such uncertainties and hence there is a need for robust deep learning models to save lives.

Deep learning models are vulnerable to adversarial attacks and modifying pixel values slightly could lead the image classifier to misclassify the objects. These slight modifications will not be noticed by the humans and are called as imperceptible attacks. Adversarial attacks are classified into two types: targeted attacks and non-targeted attacks. Both the attacks are white box attacks meaning that the perturbations are created with the model parameters.

When building deep learning models it is essential to consider the sources of uncertainties. Quantifying uncertainty helps us to make informed decisions and reduce the risk of making wrong decisions. There are two types of uncertainty namely aleatoric uncertainty and epistemic uncertainty. Aleatoric uncertainty refers to the randomness or noise inherent in the sensor data. Epistemic uncertainty occurs due to the lack of knowledge about the model or its parameters.

Object detection algorithms in autonomous vehicles have to identify the following objects with high confidence and accuracy: people, cars, motorcycles, background, lanes, roads, traffic signs, traffic signals.

Building Robust Models

Robust deep learning models have to be built to gain confidence from the general public and the users of the autonomous vehicles. Transparency, reliability and safety serves as the three fundamental pillars of trustworthiness to gain confidence among users and society.

Adversarial examples can be created with the help of optimization and the robustness of the deep learning models can be enhanced with the help of adversarial training.

Safety is the most critical requirement in the design and development of autonomous vehicles. Inherent errors and uncertainties in the output of the deep learning based models will introduce errors in the decision making and action implementation phases. Uncertainty quantification for the two sources of uncertainty (epistemic and aleatoric) in the deep learning models can be approached into sampling based and non-sampling based methods. Bayesian deep learning can be used to model uncertainties in deep neural networks. Conventional deep neural networks uses maximum likelihood regression to estimate deterministic network parameters whereas the Bayesian deep learning models weight parameters as stochastic variables that can be estimated by approximating their posterior probabilities. Sampling based methods are widely used as approximation methods.

5. Ethical Impacts

Using artificial intelligence in autonomous vehicles poses multiple ethical challenges and societal impacts. The key challenges are

- Accountability
- Decision making
- Transparency
- Data security
- Bias and
- Privacy

Autonomous vehicles capture data from various sensors and digital maps and these data can be misused by the companies collecting data leading to significant privacy risks. Deep understanding of cultural and societal contexts is required in the decision making process as the ethical behavior differs across cultures and contexts. Decision making is complex and challenging in diverse traffic scenarios. Cultural differences lead to varying prioritizations and complicates ethical decision making.

Determining liability in the event of accidents is a complex issue as responsibility lie with autonomous vehicle manufacturers, developers etc., Deep neural networks often operate as black boxes making it difficult to understand how decisions are made. This lack of transparency can undermine trust and accountability.

Artificial intelligence systems can make biased decisions due to the inherent bias present in the training data and/or the algorithms themselves. This can lead to unfair outcomes for certain groups and create social inequalities.

6. Conclusion

This paper explained about autonomous driving and the various levels involved in it. It highlighted the importance of robust and accurate object detection in the autonomous vehicles. The various challenges and ethical implications in deploying non-robust deep learning models have been explained along with the brief overview of building robust models and the need for it in the autonomous vehicles and in general for any AI based systems.

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