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**CENG 407**

# LITERATURE SEARCH REPORT

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## Abstract

In recent years, autonomous vehicles moved from an imagination to very realistic possibility. With the current technology, they can almost perform all driving tasks without any human activity. To accomplish these tasks, multiple disciplines and concepts need to be combined. This combination includes computer science, electrical engineering, artificial intelligence, mechanical engineering, etc. Since autonomous vehicles includes such variety concepts, it is developed by using various algorithms, techniques, and approaches.

Autonomous vehicles are generated using different equipments including sensors, radars, cameras, and communication systems. All these subsystems perform different tasks and with different implementations. In general, autonomous vehicles are used for self-parking, avoiding obstacles, go on a certain line, etc. However, it is not the first choice when it comes to providing safety.

On this project, we aimed to provide safety of an area using autonomous vehicle. There are many high security facilities which use soldiers, cameras, laser-beams, etc. However, if autonomous systems are used for security situations, many benefits would arise. Therefore, we will develop a system which takes tour around of the facility/area and detects are there any suspicious or dangerous objects. Therefore, it will make reconnaissance and surveillance around critical facilities. In this way, we believe that this system will prevent incoming military attacks and inform military when there is an emergency.

# 1. Introduction

Autonomous vehicles are actively developing and being used in the world day by day. In the Introduction part of our report, we will provide general information about autonomous vehicles. Autonomous vehicles are cars that can move without the need for any intervention, thanks to their unmanned driving and object detection systems. These vehicles can detect objects around them by using camera, radar and lidar technologies and help us to get clear images. Autonomous vehicles detect the positions of objects in the environment using various sensors. The vehicle is driven by examining the data from these various sensors in the computer system. Unmanned vehicles, which provide convenience and safer life to our lives, are becoming more and more common. Our aim in this project is developing a system which provides security using autonomous vehicle. While doing that, we will keep our soldiers safe and decrease the human power. It will detect dangerous objects which can be guns, remote control, suspicious people based on timing and other factors. We believe that it is an efficient approach for defense and military systems since it provides information in hazardous situations.

Autonomous Vehicles occurred of 5 diverse automation levels from zero to five.

**Level 0:** There is no driving automation at level 0. All driving is done by the driver.

**Level 1:** Autonomous system uses Driver Assistance when driver drives vehicle on the road at Level 1. For instance, if driver wants to park on the roadside, it helps to make easy parking.

**Level 2:** In level 2 which refers to Partial Automation, driver is generally not having the control of car, however, when there is an emergency, driver must take the control.

**Level 3:** In level 3 which known as Conditional Automation, there is a major change which car starts to use sensors such as LIDAR, RADAR, camera, etc. However, in critical situations, driver may need to take over the control.

**Level 4:** In level 4 which refers to High Automation, car starts to determine some critical decisions such as changing lanes, using signals, etc. Yet, if there is a traffic congestion, car may have trouble while deciding.

**Level 5:** Level 5 known as a Complete Automation which is the level that no human is needed. Therefore, pedals, brakes or steering wheels are discarded. Autonomous car is responsible for moving by itself.

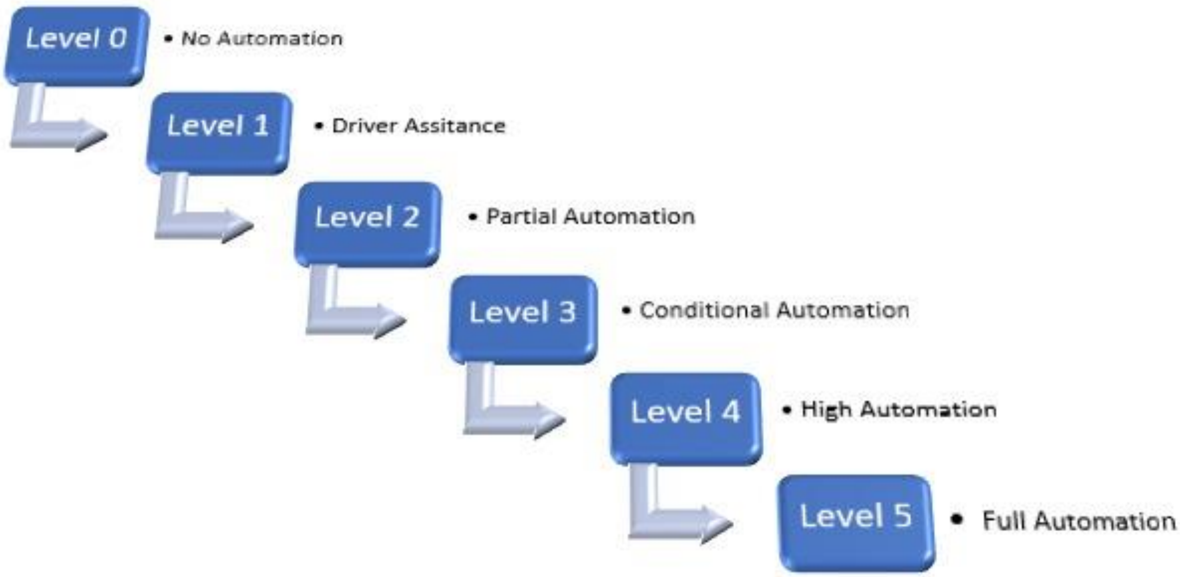


*Figure 1: Levels of Autonomous Cars*

In this Literature Review report, we have 9 sections which are given in order. In *1.Introduction* section, we described our project scope and what will be explained in the rest of the report. In *2.History of Autonomous Vehicles* section, we analyzed autonomous vehicles which are developed from 1925 to 2021. Afterwards, we provided samples from Defence Industry products in *3.Autonomous Vehicles in Defence Industry* section. Next, we described perception and provide summarized information related perception in *4.Object Detection with* Perception section. We also stated safety issues regarding autonomous vehicles in next section. Afterwards, in *6. Solution and Algorithms* section, we described detailed solutions, techniques and algorithms related to technology that we will be using in this project. Next, in 7. Previous Works and Articles section, we stated articles that we used while writing this literature review. We also shared which comparisons and techniques that we possibly use during the development of project. Then, we summarized solutions and techniques which are explained in the report. Finally, in 9.Conclusion section, we also stated summarized version of our project scope and what will be implementing during the development process.

## 2. History of Autonomous Vehicles

In **1925**, Francis Houdina developed the first sample of autonomous vehicles in the history. This development was a radio-operated automobile which was a 1926 Chandler. The vehicle had transmitting antenna on its tonneau. Also, it was controlled by another car which is following it using a transmitter. In this way, this automobile could travel through streets without any human sitting at the steering wheel. Francis Houdina published this invention as American Wonder which changed the automobile industry. [1]

In **1939**, Norman Bel Geddes released the idea of the first self-driving vehicle which uses electricity to be able to operate. The vehicle was self-driving by using radio-controlled electro-magnetic area where magnetized metal spikes hidden and embedded. The idea is known as FUTURAMA.[2]

In **1953**, RCA Labs developed the mini car which was guided by wires positioned on the lab's floor.[3]

In **1954**, General Motors introduced Firebird I the first gas turbine automobile in history. This development was crucial for self-driving history since it leads to Firebird II which was aired couple of years later.[4]

In **1956**, Firebird II was introduced by General Motors as "Laboratory on Wheels". It was designed to drive as an autonomous vehicle on electronic highways.[5] However, Firebird II was a concept car, therefore; it was never produced. General Motor aired a short musical which aims visualize self-driving cars and show people how can technology evolve in the future.[5]

In **1957**, RCA Labs developed self-driving car with an actual scale in Lincoln, Nebraska. Using embedded wires, signals were emitted, and they could expect to stay car within its line. [6]

In **1962**, Robert Fenton who is a professor at Electric-Electronic department of Ohio State University created a car which can control braking, steering and speed. The car used embedded roadway with wires for moving like previous developed systems.[6]

In **1969**, John McCarthy who is one of the founders of Artificial Intelligence concept published an article called "Computer Controlled Cars"[7]. He highlighted that  a computer could control car using television camera input. In this way, the chauffeur will be automatic. In the article, features that car would have, issues, cost and other additional information is given.

In **1977**, Japanese engineers improved the idea of General Motors by using a camera system to be able to process images of the road. However, the vehicle could not travel as much as fast.[2]

In **1980**, Mercedes-Benz which was vision-guided robotic van developed by Ernst Dickmanns from University of Munich. Vehicle was controlled by computer commands using computer vision with image sequences that are cought by four cameras. It could speed up to 63 km/h on roads without traffic.[3]

In **1987**, Germans improved the solution of Japanese engineers who completed their system in 1977. The vehicle called VaMoRs and it could speed up 175km/h without any human interaction.[8]

Between **2004-2007**, Defense Advanced Research Projects Agency (DARPA) organized a competition for American autonomous vehicles. The competition is called DARPA Grand Challenge. The competition served for military use; therefore, it was one of the most important organizations of the United States Department of Defense. There were several DARPA Grand Challenges through years and each of them have huge impacts on autonomous vehicle industry and military products. The first competition of DARPA Grand Challenge organized in 2004. In this first competition, none of the vehicles were able to finish the parkour. Two vehicles travelled the most distance which was 11.78 km. However, that was not enough, therefore, there was no winner and prize given. Hence, second DARPA Grand Challenge was organized in 2005. This time five vehicles could complete the parkour which was 212 km. Also, in 2005 race, vehicles passed through 100 sharp turns and 3 narrow tunnels. The third and last competition of DARPA Grand Urban Challenge event occurred in 2007. In this race, vehicles had some strict limitations and rules such as parkour complete time and distance. In the race, vehicles must operate even in rainy and foggy weather with blocked GPS. Team Tartan Racing won the race and received the prize of 2 million dollars. [9]

In **2009**, Google started to develop Waymo self-driving car project which aims to have empty driver seat. For that purpose, company actually tought an autonomous vehicle how to understand and perceive the environment. After many years, Google contionued to improve project and released two version of Waymo, which are Waymo One and Waymo Via. Waymo One aims to be used for daily services like going to market, school or job. Waymo Via focuses to be used for transportation services.[10]

In **2015**, Tesla released the feature of autopilot which provides self-steering, self-changing lines and adjusting speed. Although the car was not fully autonomous, it was a critical step to moving on fully autonomous ones.[6]

In **2016**, a company called Ottomotto developed Otto Truck which achieved the longest continuous traveling without human intervention as a semi-truck. The total route was 132 miles without any leading vehicle, driver, or any other human interaction.[11]

Between **2016-2021**, Tesla company is being one of the leading companies in autonomous vehicle industry. They improved the Autopilot technology which they published in 2005. One of the reasons behind their success is powerful sets of vision processing. They use Deep Neural Network to operate visual processing techniques. In addition to Autopilot technology, they also developed Autosteer+ and Start Summon technologies to have full of self-driving capability. [12]

In this section, we explained which samples do autonomous-vehicle industry have and how far we have come in this area. It can be seen that the autonomous vehicle industry includes variety of technologies, and vehicles can be used for different purposes. Since in our project we are aiming to use autonomous vehicles for providing security, in *3. Autonomous Vehicles in Defence Industry* section, we examined military approaches, products and algorithms that has been developed in recent years. Therefore, we focused on unmanned ground vehicles (UGV).

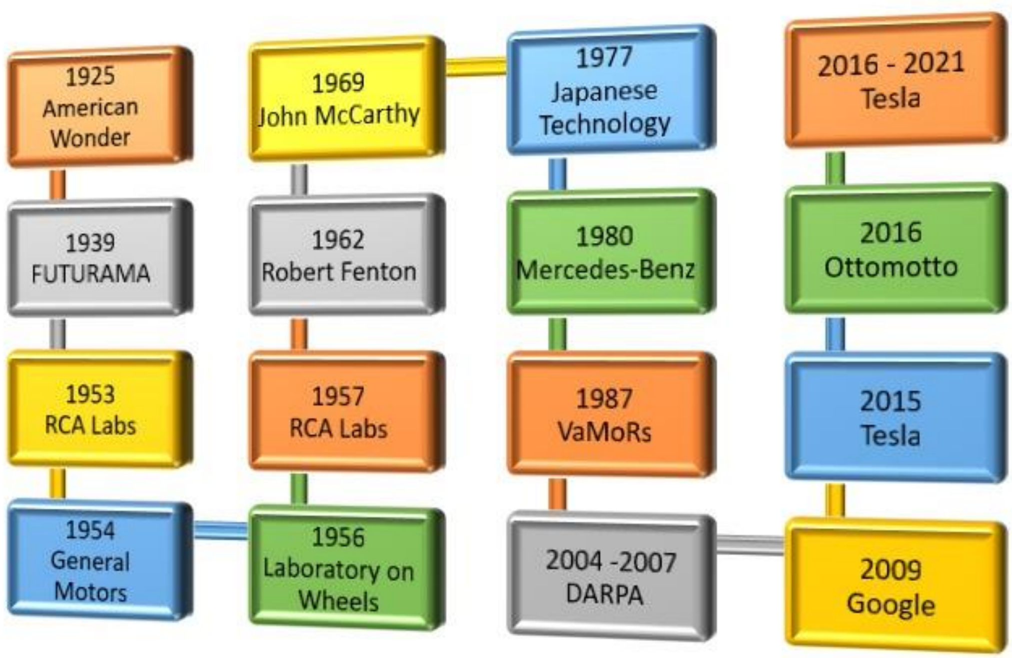


*Figure 2: History of Autonomous Cars*

## 3. Autonomous Vehicles in Defence Industry

We observed that Defence Industry companies has been using autonomous vehicles, drones, and many other autonomous systems recently. That is why, we aimed to develop a system which can be used for high security required facilities or protection of a certain area. In this section, we will provide examples of both Turkish and foreign countries' products that belong to autonomous-vehicle and UGV concepts. In below table, we summarized the vehicles that we explained in this section; hence, the summarize form can be observed in following figure.

| VEHICLE NAME | YEAR | DIMENSIONS | WEIGHT | DETECTION TYPE | RANGE | ARMED |
|---|---|---|---|---|---|---|
| TARANTULA UGV | 2018 | 500x222x210 cm | 2,000 kg | Unknown | 3 km | YES |
| ACROB UGV | 2021 | 65x31x14 cm | Unknown | Day/Night Cameras | 500 m | NO |
| O-İKA 2 UGV | 2019 | Unknown | 1100 kg | Mast-mounted Camera | Unknown | YES |
| ALPAN UGV | 2020 | 142x106x164 cm | 500 kg | Day/Night Cameras, LIDAR, RADAR | 3 km | YES |
| BARKAN UGV | 2021 | 140x90x110 cm | 500 kg | Day/Night Cameras, LIDAR, RADAR | Unknown | YES |
| URAN-9 UCGV | 2015 | 512x253x250 cm | 10,000 kg | Electro-optic and thermal cameras | 3 km | YES |
| Gladiator TUGV | 2005 | 178x112x135cm | 725 kg | Day/Night and Thermal Cameras | Unknown | YES |
| Miloš UGV | 2017 | 172x70x95 cm | 680 kg | Day/Night and Thermal Cameras | 3 km | YES |

*Figure 3: Summarize of UGVs*

## *3.1.* Turkish Defence Industry Products

### 3.1.1. Tarantula UGV

Tarantula is armed unmanned ground vehicle platform (UGV) which is created by ASELSAN and TEAS in 2018. It is actively used by Turkish Armed Foundation to operate many functions which are surveillance, patrol, defence, and other security services. Tarantula also has a controller which has up to 3 km range. By using the controller, it can shoot as well. It has electrical engine which provides 8 hours to operate. It has 2 tons weight and can carry 800 kg of load. [13] Additionally, Tarantula has length of 500 cm. Its width is 222 cm, and it has 210 cm height.[14]

### 3.1.2. ACROB UGV

In September 2021, Republic of Turkey Ministry of National Defense announced that ACROB UGV enter to the products which services for Turkish Armed Forces. ACROB was generated the company called Elektroland Defense. One of the most significant features of Acrob is being resistant to the different physical environments. Even more, it can climb stairs and other vertical obstacles on road. It is equipped with day/night colour cameras. It uses electricity to be powered and its controllers has maximum 500m range. It is also a small UGV with 31 cm width, 14 cm height and 65 cm length. [15]

### 3.1.3. O-İKA 2 UGV

In 2019, Turkish companies ASELSAN and Katmerciler developed a UGV named O-İKA 2. The vehicle is capable of detection, surveillance and using different weapon systems. As previous ones, O-İKA 2 has camera at both front and rear. Images taken with this camera can be transferred as well. Although the vehicle is autonomous, weapons can be used manually when there is an emergency. Therefore, vehicle can be remotely commanded or used autonomously based on the situation. O-İKA 2 has 1.1 tons weight. Currently, Land Forces Command has the user authority.[16]

#### 3.1.4. ALPAN and BARKAN UGVs

In 2020, Turkish company HAVELSAN introduced ALPAN UGV which was their first prototype vehicle. Afterwards, they added some subsystems and introduced BARKAN UGV in 2021. Both UGVs capable of handling different geographical conditions. They also have environmental sensors like LIDAR and RADAR. In addition, they are equipped with day/night camera and other image processing systems.[17] ALPAN has a length of 142 cm, and its width is 106 cm. Also, when it is unarmed, it has 164 cm height. ALPAN has 6 hours operation run time with around 10-15km/h velocity. In addition, it can be controlled from 3km range distance.[18] On the other hand, BARKAN has 500 kg weight. It can operate for 8 hours, and its velocity is 12 km/h at most. BARKAN has a length of 140 cm, width of 90 cm and height of 110 cm.[19]

### *3.2.* Foreign Defence Industry Products

#### 3.2.1. Uran-9 UCGV

Uran-9 UCGV (Unmanned Combat Ground Vehicle) is produced in Russia, 2015. The producer was Russian military equipment manufacturer JSC 766 UPTK. Uran-9 can speed up to 35 km/h. It was generated to provide fire support and make reconnaissance and surveillance in urban areas. Its weight is approximately 10,000 kg with 512 cm length, 253 cm width and 250 cm height. Therefore, this vehicle is one of the hugest ones compared to its competitors. Its missiles have the range of 0.4km to 6.km. It has both camera types which are electro-optic and thermal imaging. It can detect the suspicious situations up to 6 km distance in the afternoon. It decreases to 3 km at nights. Uran-9 can be used either manual or autonomous mode. The path finding algorithm is used to make vehicle autonomous. For manual mode, Uran-9 has a controller which can operate from a distance of 3 km. [20]

### 3.2.2. The Gladiator TUGV

The Gladiator which was the first tactical unmanned ground vehicle was developed to support the United States Marine Corps. It was designed by Marine Corps on February7, 2005. Then it was produced several hundred in production in 2007. The Gladiator TUGV is an unmanned, compact, robust, tele-operated, multi-purpose ground exploration, observation, and target detection vehicle system possessing a discovering and direct engagement capability. It provides the armed forces with remote observation, exploration, and target detection, biological, nuclear, and chemical reconnaissance in different parts of the battlefield, obstacle breaching, and direct fire capability to deactivate threats and reduce risk to the war warrior. Moreover, it supplies remote imagery software to relay images, including day and night images, and thermal images. It's weight is 725,75 kg with 1,78 m length, 1,12 m width, and 1,35 m height. Since its an unmanned ground vehicle, each Gladiator is equipped with a remote-control unit capable of displaying mission data, operational status, and mission observation.[21]

### 3.2.3. Miloš UGV

Miloš developed by the Military Technical Institute Belgrade in Serbia, 2017. It uses a day and night camera, thermal camera, and a laser ranger. It has one or two guns attached to its turret. Maximum total weight is around 700 kg or 300 kg of cargo. It has two cameras which provide day and night vision are installed on front and back for driving. Moreover, it has thermal camera that enables recognition up to 450 meters. It can recognize solder using charge coupled device up to 1000 meters. In its equipment is laser rangefinder for range up to 2000 meters. Miloš unmanned ground vehicle can negotiate gradients of 57.7% and side slopes of up to 46.6%. It can cross a maximum vertical obstacle of 200mm and a maximum trench width of 250mm. The UGV measures 1.72 m-long, 0.7 m-wide, and 0.95 m-high and has a curb weight of 680 kg, while the weights of the driving base and the battle station are 430 kg and 250 kg. The battle station can revolve in 360° at speeds between 0.05° per second and 48° per second, while the elevation range of the station is between -15° and 50°.[22]

# 4. Object Detection with Perception

## *4.1.* Requirements for Perception

### 4.1.1. Definition of Perception

In our project, we will develop a vehicle which will be able to make reconnaissance and surveillance around an urban environment. For that purpose, we must identify each object around facility. To do that, we will percept objects to understand what it is: a human, a riffle, a controller for a bomb, a suspicious car, etc. However, computers cannot handle this operation as fast as humans.

### 4.1.2. Goals for Perception

The objects can be separated in two main sections: Static and Dynamic. Static objects refer to objects which are stabilized and do not move. On the other hand, dynamic objects refer to continuously moving objects such as pedestrians, other cars, wheelers, etc. Object types can be observed from following figure.

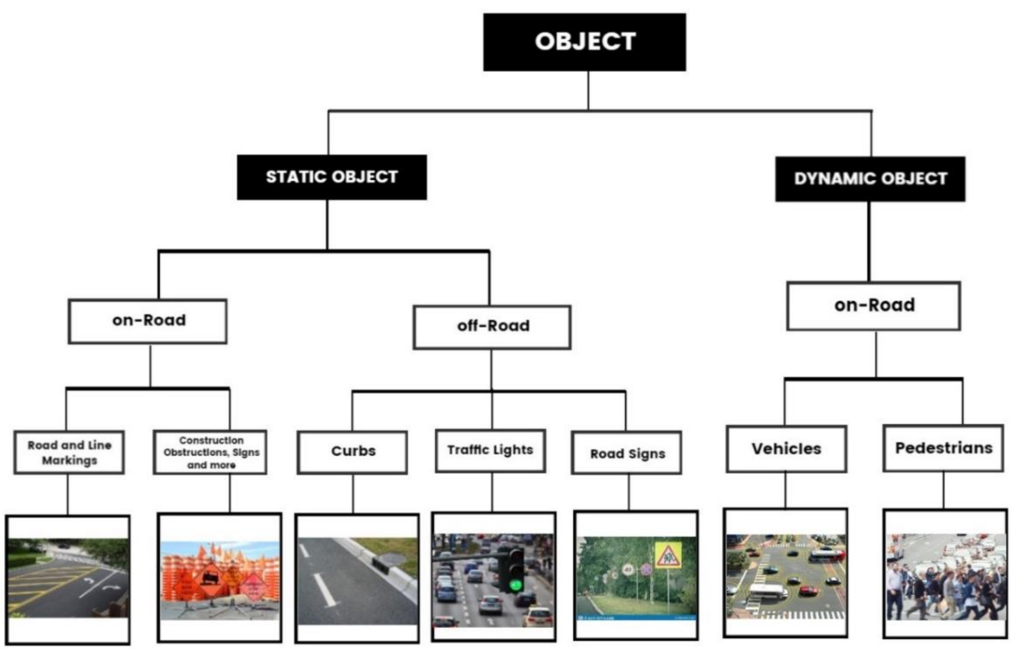


*Figure 4: Static and Dynamic Objects*

#### 4.1.3. Challenges of Perception

While implementing perception, many issues could arise. One of the biggest problems is having limited amount of labeled training data.[23] Since our priority is detecting dangerous objects, trained data must include these kinds of objects for sure. Our vehicle must be able to separate an umbrella and a riffle to provide incorrect warnings. To achieve this separation appropriately, we will use detection algorithms with modern machine learning techniques. Researchers are still implementing studies to equalize detection level of machines with human level. There are many researches that compare humans with computer vision algorithms which refers to deep neural networks(DNNs).[24]

#### 4.1.4. Solutions to Challenges of Perception

We can reach the best possible solution by combining radar, lidar and camera systems while detecting vision. Another vital solution is to enable the autonomous vehicle to perform better segmentation and detection by using large datasets and more training data.

#### 4.1.5. Sensors of Perception

In Perception, there are 3 well-known sensors which are LIDAR, RADAR and Camera. In this section we will be focusing on these sensors. Each of them has their own pros and cons.[25]

- **CAMERA**

  Camera is the oldest sensor technology used in vehicles. Also, it is the most similar sensor type to our eyes. [26] Cameras are great choice while detecting RGB information. Therefore, they have extremely high resolution which comes as an important benefit. However, if the weather is extreme like sunny or foggy, the results are not that great. In addition, contrast is another issue which is an important limitation of camera technology.

- **LIDAR**

LIDAR technology is known as laser imaging detection (light detection) and ranging. It is used for determining distance (range) by targeting object with lasers. For that purpose, it measures the difference of time between sending light and receiving back the reflected light.[27]
When we compare LIDAR with camera and RADAR, we observed that LIDAR is the only sensor that gives resolution at range which means the ability to receive appropriate and accurate detection of objects in space. Additionally, using LIDAR, we can receive great results day and night without any loss of performance unlike Cameras.[28]. In addition, LIDAR implement image analysis much simpler and faster than cameras. However, it has weaknesses, too. It does not have high amount of resolution; hence, it cannot detect objects through bad weather as well as RADAR does. Additionally, LIDAR cannot detect colors so it cannot replace cameras in this point. Therefore, it is very difficult to LIDAR detect any road signs, traffic lights or etc. since it cannot recognize colors.

- **RADAR**

RADAR technology is known as laser imaging detection (light detection) and ranging. It can be basically broken down into receiver and transmitter. Radio waves are reflected when they see an object.[27] Additionally, RADARS can work in bad weathers as well. In this point, we can say that they are better than cameras and LIDAR. However, they do not have range information and resolution at range. Additionally, it cannot detect objects as well as camera does. Therefore, it might have trouble while identifying what the object really is.

In below table, we summarize advantages and disadvantages of each sensor we described.

| | Name | Advantage | Disadvantage |
|---|---|---|---|
|  CAMERA | CAMERA | - Can detect colorful objects<br>- High resolution<br>- Low cost<br>- Can recognize 2D | - Bad results when in different weather conditions |
|  | LIDAR | - High-definition of 3D modeling<br>- Gives great results day and night | - Affacted from bad weather<br>- High cost<br>- Cannot recognize colors |
|  | RADAR | - Unaffected by weather conditions<br>- Low cost | - Low-definition modeling |

*Figure 5: Pros and Cons of Sensors*

It can be observed that, three techniques have their own weak and powerful sides. Therefore, it would be better if we can combine three of them. That is why, we can conclude that vehicles are just like humans. Humans do not have only a sensor. They see, touch, taste, smell and hear. When these abilities are working simultaneously, we say that this person is healthy.

# 5. Safety of Autonomous-Vehicles

Today's autonomous vehicles make their movements using sensors. They solve difficult tasks with machine learning. Although high-accuracy algorithms in Machine Learning have emerged recently, automotive software is still insufficient to solve problems such as security standards, interpretability, validation, and performance rankings.

The development of safety-critical systems for autonomous vehicles is based on strict safety methodologies, design, and analysis to prevent hazards in the event of a malfunction. There are 2 main safety standards used worldwide to address the safety of electrical and electronic components, these are ISO26262 and ISO/PAS 21448. Through these standards, they must apply software development, system, and hardware methodologies.

With the use of machine learning in such systems, it is an inevitable fact that these models reveal gaps in security standards in current engineering applications. Many examples of these gaps are discussed on the security of our machine learning, considering factors such as official verification and traceability of design code. (Salay, Queiroz and Czarnecki 2017).

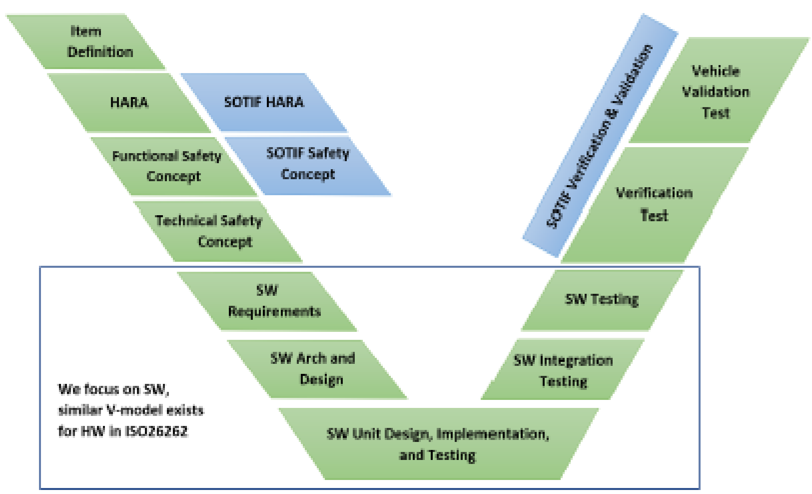


*Figure 6: Standarts for Safety of Autonomous Vehicles*

## 5.1. ISO 26262 Standard

The other name of ISO26262 is the E/E functional safety standard. This standard is the absence of irrational risks arising from defective E/E components to the safety of the vehicle. Requires a Hazard Analysis and Risk Assessment (HARA) to identify hazards at vehicle level. Potential dangers that may occur in the future direct the security engineers working in this field to the security targets used to create functional security requirements. These requirements lead to the system development process, which is divided into hardware and software development processes in the later process.

## 5.2. ISO/PAS 21448 Standard

It is ISO/PAS 21448 or SOTIF (Security Functionality) standard. The features of this standard are design features, development, and verification stages. This standard defines the performance limitations of the software (including machine learning components) and allows it according to the scenarios and inputs it belongs to. In such cases, this standard reduces the risks of applications that are known to be unsafe. Other risks of error become acceptable in this way. As a result, we are aiming to perform system which provides standards that we explained above.

# 6. Methods and Algorithms

## 6.1. Methods for Self-Driving

Self-driving cars may be the future of transportation, but we do not really know whether it is safer than nonautonomous driving or not. Automakers are spending billions each year to develop self-propelled cars. But it turned out from different studies that people are more concerned than enthusiastic about the appearance of this new technology

When autonomous vehicles are operated without automation and partially automated or highly automated, security becomes a major challenge between the interaction between human and autonomous vehicle. In the full automation mode, the reliability of the software and hardware come to the fore as a very critical issue.

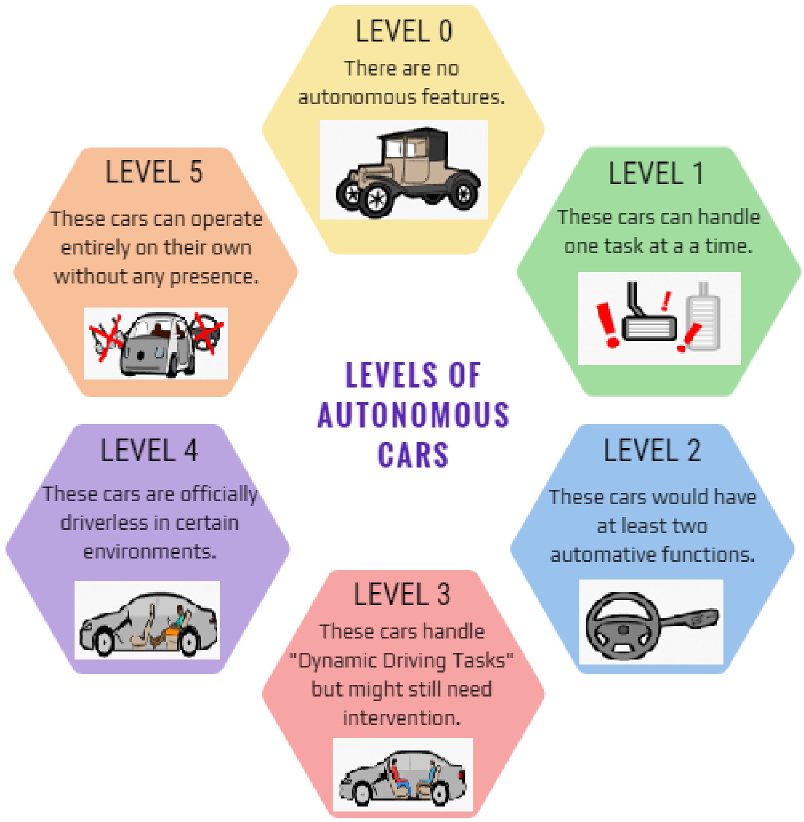


*Figure 7: Autonomous Levels*

These levels are very useful as with these we can keep track of what happens when we move from human-driven cars to fully automated ones. This transition will have enormous consequences for our lives, our work, and our future travels. As autonomous driving options are widespread, the most advanced detection, vision, and control technologies allow cars to detect and monitor all objects around the car, relying on real-time object measurements.

In the 5$^{th}$ level, it is used in the form of full autonomous. It has possibilities that can provide serious convenience to our lives in this transition. Autonomous driving options are common, so cars are the most advanced sensing, vision, and control technologies to detect and track all objects around the car based on real time object measurements. Vehicles perform autonomous driving with a multi-disciplinary engineering approach.

If a computer decides instead of us, we do not control the processes. Every computer and program may have a back door, and the question arising is what can be done if someone enters the computer that can save our lives.

## 6.2. **Methods for Detecting Objects**

Object Detection can be defined as identifying the object with boundaries. To be able to detect objects, there are some well-known algorithms and techniques. In this subsection, we analyzed these solutions and aimed to decide algorithm that we will use in our project. For all algorithms, strengths and weaknesses table is stated. The algorithms that we analyzed are stated in following figure.[29]

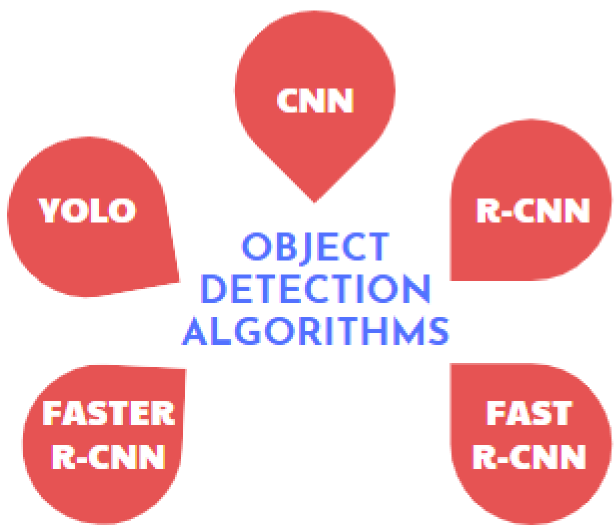


*Figure 8: Object Detection Algorithms*

### 6.2.1. **CNN**

CNN which is known as Convolutional Neural Network object detection algorithm is used for image recognition. In this method, we select different regions from different parts of an image and try to classify the presence of an object in that specific region. However, CNN algorithm can choose limited number of regions.

Therefore, since number of regions can be huge, this algorithm fails. That is why, alternative solutions are developed. [30] In following figure, strengths and weaknesses of CNN algorithm is given.

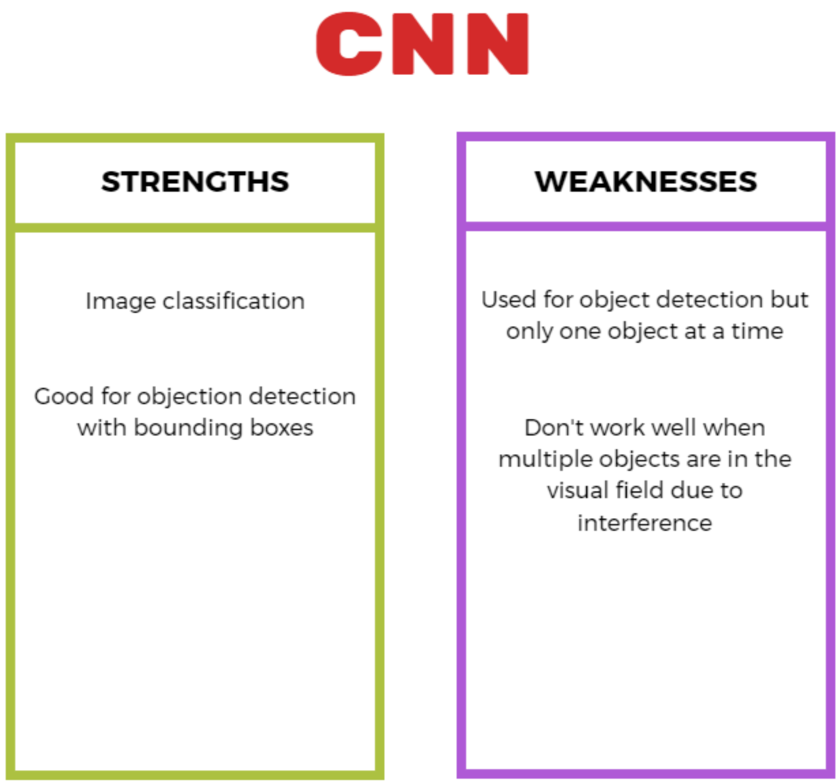


*Figure 9: Strengths and Weaknesses of CNN*

### 6.2.2. R-CNN

To discard the problem of choosing many regions, R-CNN which refers to Region Based Convolutional Neural Network uses selective search to indicate candidate regions. Therefore, it searches for possible target areas. After 2000 regions are indicated, each of them uses CNN separately and their bounding boxes and classes will be predicted. Since in selective search the number of 2000 is a fixed number, it makes algorithm slower. In selective search, algorithm first receives images as an input, then, it creates sub-segmentations which means we have multiple regions in image. Finally, it gathers similar regions together. These regions refer to final locations of objects.

In following figure, strengths and other weaknesses of CNN algorithm is given.[31]

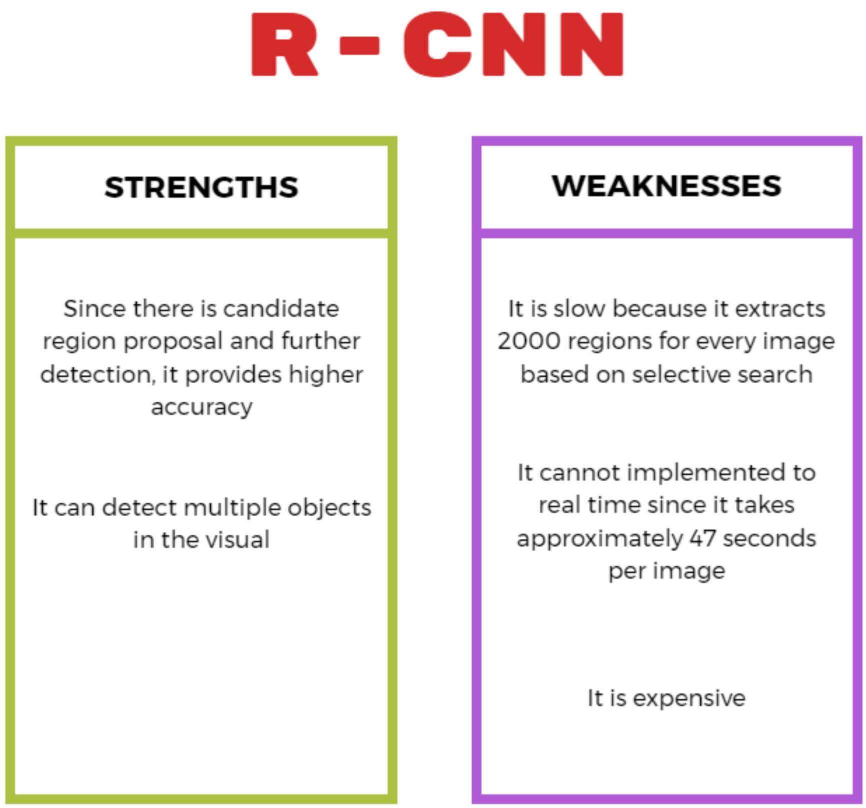


*Figure 10: Strengths and Weaknesses of R-CNN*

### 6.2.3. FAST R-CNN

As it is mentioned in its name, Fast R-CNN is the faster algorithm than R-CNN. It is because we do not have to feed 2000 regions each time. Instead, a CNN (convolution operation) is applied to an entire image and feature map is generated from it. After feature map is generated, ROI (Region of Interest) is created using selective search. For each object detection, ROI extracts a fixed-length feature vector from feature map.[32] Using this ROI feature vector, algorithm uses softmax function to predict the class of region and identifying bounding box's values.[30] In following figure, strengths and other weaknesses of CNN algorithm is given.

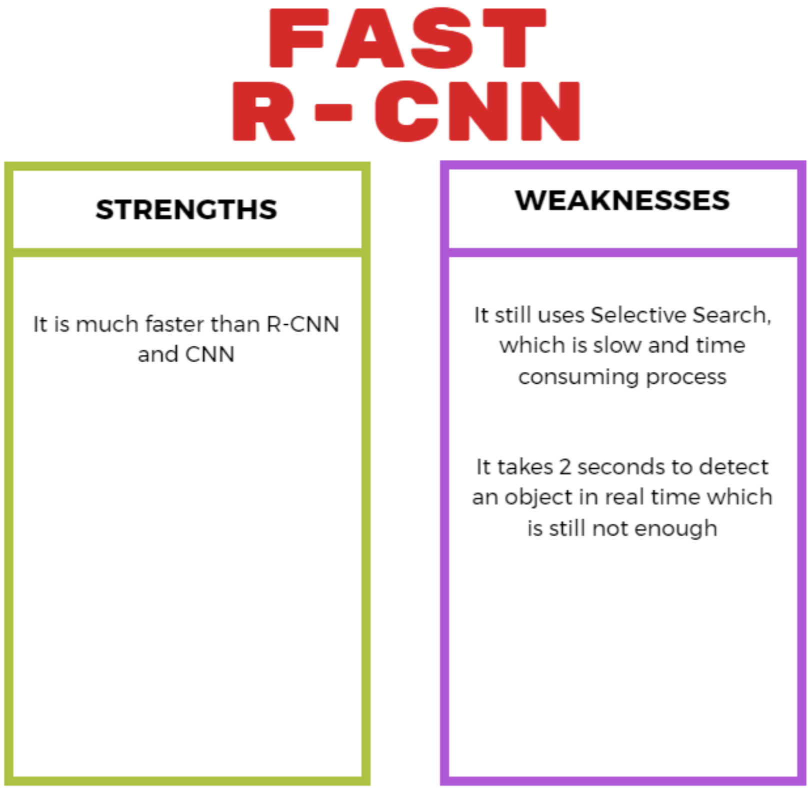


*Figure 11: Strengths and Weaknesses of Fast R-CNN*

### 6.2.4. FASTER R-CNN

Faster R-CNN is faster than Fast R-CNN, because it does not use selective search anymore. Instead of doing that, it uses Region Proposal Network which provides feature map directly. Therefore, we do not have to search for feature map any longer. In this way, algorithm works much faster.[30] In following figure, both strengths and weaknesses of Faster R-CNN algorithm are stated.

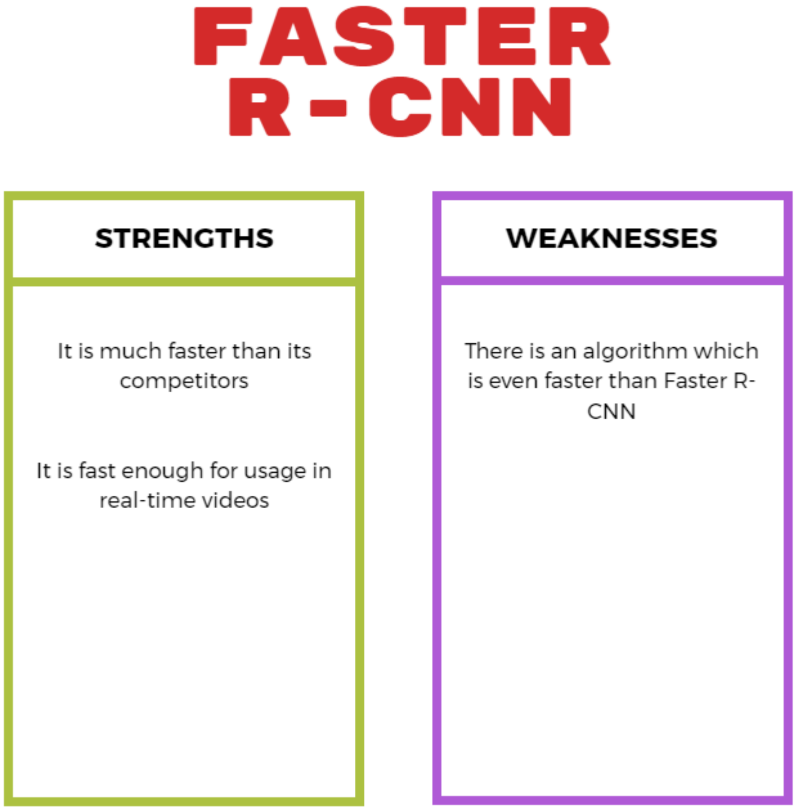


*Figure 12: Strengths and Weaknesses of Faster R-CNN*

#### 6.2.5. YOLO

YOLO (You Look Only Once) algorithm is very different from previous techniques. It is trained to implement bounding box prediction and classification at the same time. That is why, YOLO algorithm is even faster than Faster R-CNN algorithm. However, YOLO has similarity with previous algorithms as well. They all use bounding box regression. We stated that YOLO is fastest algorithm, yet, it has some drawbacks as well. If objects are close to each other YOLO may fail because each grid cannot have more than 2 bounding boxes. In addition, it has trouble with detecting small objects due to spatial limitations.[31]

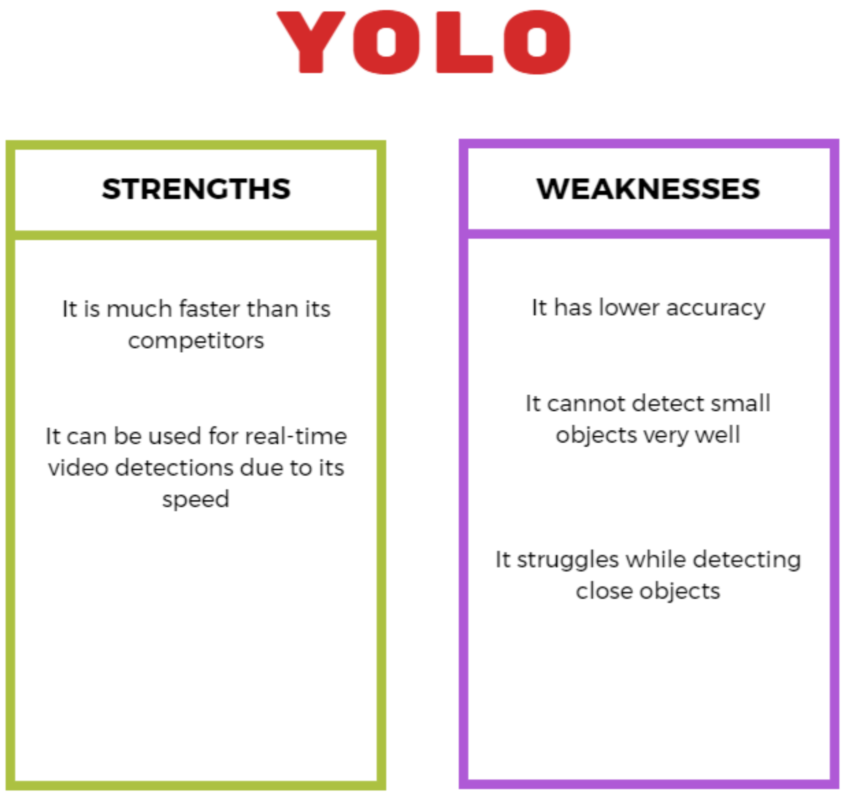


*Figure 13: Strengths and Weaknesses of YOLO*

When we examined all these algorithms, we had to decide which one is more important for us, speed, or accuracy. If we choose YOLO, we may have trouble with wrong or missing detections, and it would cause fatal problems. On the other hand, algorithm must work as much as fast since commanders must be warned as soon as possible. Therefore, we will look for best decision considering these issues. [33]

## 6.3. Comparison of Algorithms and Techniques

### 6.3.1. Comparison of Model Prediction Speeds

| MODEL | TIME TO PREDICT SINGLE IMAGE |
|---|---|
| VGG16 | 47s + region proposal time |
| Fast R-CNN | .3s + region proposal time |
| SimpleNet | .09s |
| Yolo | **.0222s** |

*Figure 14: Prediction Speeds for Deep Object Detectors*

In above table, Models are compared in terms of prediction speed. It can be observed that YOLO architecture predicts objects as the fastest.[34]

In above table, the VGG stands for the Visual Geometry Group of the VGG16 algorithm, and the value 16 in it means that there are 16 layers in total in the algorithm. There are 138 million parameters in this network. There is also SimpleNet which is an algorithm consisting of 13 layers using the CNN algorithm. In addition to above algorithms, there are other alternatives as well like MobileNets, SSD, etc. MobileNets are used to present an efficient class of vision models in embedded and mobile applications. It creates efficient parameters between latency and accuracy. They can be built lots of types such as embedding, recognizing, and classification. There is also SSD (Single-shot Detector) algorithm which predicts objects and find locations of them. At the end of the algorithm, we will receive probability of being object, location of object with coordinates, and width & height of bounding box as outputs. This algorithm is like YOLO since both find objects in single shot as it can be seen from how its named. Therefore, it can be stated that region proposal algorithms have better accuracy but slower run time. On the other hand, SSD and YOLO algorithms have good accuracy with faster run time.

### 6.3.2. Comparison of Sensors Under Different Weather Conditions

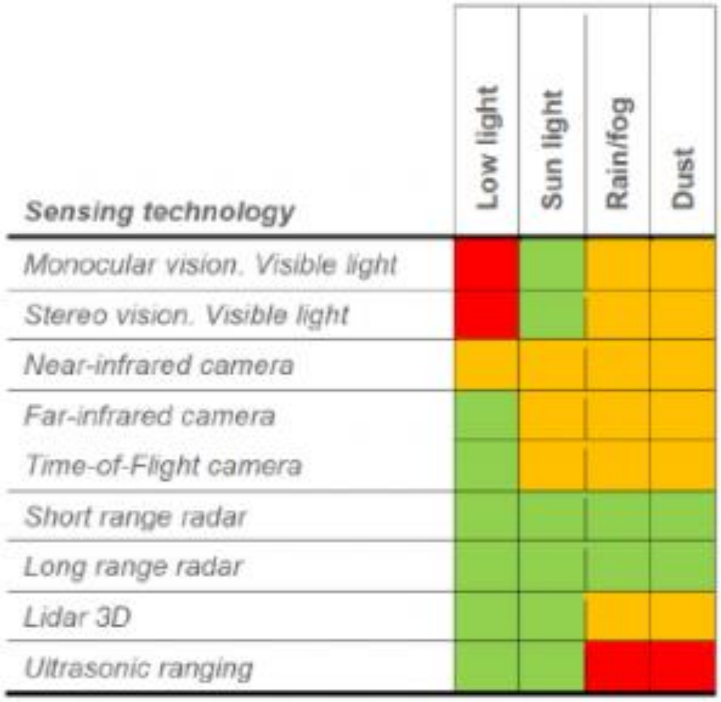


*Figure 15: Sensors with different weather conditions*

In above table, it is stated that each sensor acts differently based on weather conditions. Since in our project, we are aiming to use our vehicle in all seasons, we will be careful while choosing our sensor. In the table, red color refers to Bad, yellow color refers to Average, and green color refers to good results.[35]

### 6.3.3. Comparison between YOLO and other Object Detection Algorithms

In a review, researchers shared the results of object detection algorithms performance. The first related table is given at following figure.[36]

| Real-Time Detectors | Train | mAP | FPS |
|---|---|---|---|
| 100Hz DPM [31] | 2007 | 16.0 | 100 |
| 30Hz DPM [31] | 2007 | 26.1 | 30 |
| Fast YOLO | 2007+2012 | 52.7 | **155** |
| YOLO | 2007+2012 | **63.4** | 45 |
| Less Than Real-Time | | | |
| Fastest DPM [38] | 2007 | 30.4 | 15 |
| R-CNN Minus R [20] | 2007 | 53.5 | 6 |
| Fast R-CNN [14] | 2007+2012 | 70.0 | 0.5 |
| Faster R-CNN VGG-16[28] | 2007+2012 | 73.2 | 7 |
| Faster R-CNN ZF [28] | 2007+2012 | 62.1 | 18 |
| YOLO VGG-16 | 2007+2012 | 66.4 | 21 |

*Figure 16: Comparison between Object Detection Algorithms*

As it can be observed from above table, YOLO provides less accuracy compared to Fast R-CNN or Faster R-CNN algorithms. In addition, according to FPS values, we can state that YOLO algorithm works much faster than Faster R-CNN algorithm. There is another chart that supports above table:

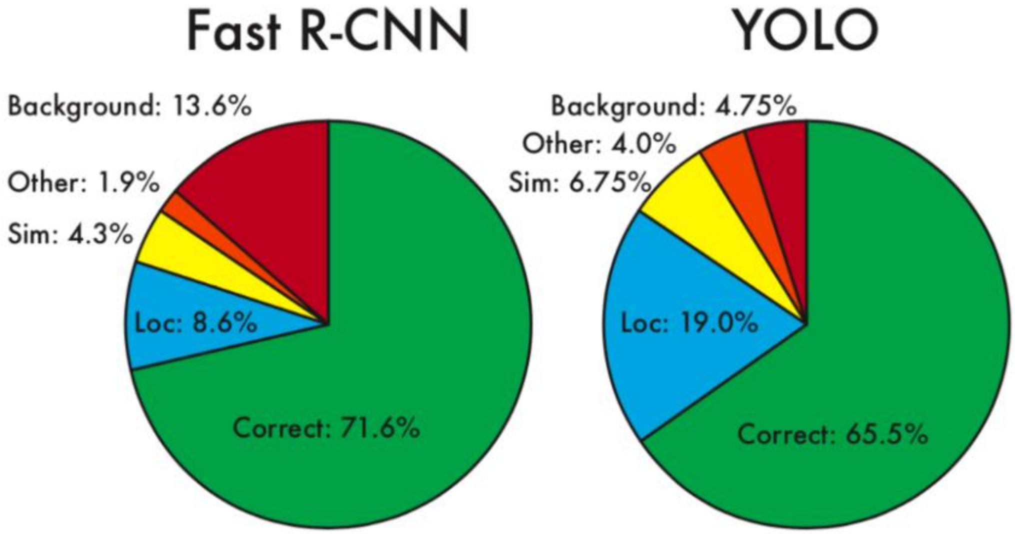


*Figure 17: Accuracy Comparison between Fast R-CNN and YOLO*

In above chart, it can be observed that Fast R-CNN gives more accurate results compared to YOLO algorithm. Therefore, when it comes to speed, YOLO algorithm is better. On the other hand, when it comes to accuracy, CNN methods work better. Hence, their combination gives good results as is shown in below figure.

| VOC 2012 test | mAP | aero | bike | bird | boat | bottle | bus | car | cat | chair | cow | table | dog | horse | mbike | person | plant | sheep | sofa | train | tv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MR_CNN_MORE_DATA [11] | **73.9** | **85.5** | **82.9** | **76.6** | **57.8** | **62.7** | **79.4** | 77.2 | 86.6 | **55.0** | **79.1** | **62.2** | 87.0 | **83.4** | **84.7** | 78.9 | 45.3 | 73.4 | 65.8 | 80.3 | 74.0 |
| HyperNet_VGG | 71.4 | 84.2 | 78.5 | 73.6 | 55.6 | 53.7 | 78.7 | **79.8** | 87.7 | 49.6 | 74.9 | 52.1 | 86.0 | 81.7 | 83.3 | **81.8** | **48.6** | **73.5** | 59.4 | 79.9 | 65.7 |
| HyperNet_SP | 71.3 | 84.1 | 78.3 | 73.3 | 55.5 | 53.6 | 78.6 | 79.6 | 87.5 | 49.5 | 74.9 | 52.1 | 85.6 | 81.6 | 83.2 | 81.6 | 48.4 | 73.2 | 59.3 | 79.7 | 65.6 |
| **Fast R-CNN + YOLO** | 70.7 | 83.4 | 78.5 | 73.5 | 55.8 | 43.4 | 79.1 | 73.1 | **89.4** | 49.4 | 75.5 | 57.0 | **87.5** | 80.9 | 81.0 | 74.7 | 41.8 | 71.5 | 68.5 | **82.1** | 67.2 |
| MR_CNN_S_CNN [11] | 70.7 | 85.0 | 79.6 | 71.5 | 55.3 | 57.7 | 76.0 | 73.9 | 84.6 | 50.5 | 74.3 | 61.7 | 85.5 | 79.9 | 81.7 | 76.4 | 41.0 | 69.0 | 61.2 | 77.7 | 72.1 |
| Faster R-CNN [28] | 70.4 | 84.9 | 79.8 | 74.3 | 53.9 | 49.8 | 77.5 | 75.9 | 88.5 | 45.6 | 77.1 | 55.3 | 86.9 | 81.7 | 80.9 | 79.6 | 40.1 | 72.6 | 60.9 | 81.2 | 61.5 |
| DEEP_ENS_COCO | 70.1 | 84.0 | 79.4 | 71.6 | 51.9 | 51.1 | 74.1 | 72.1 | 88.6 | 48.3 | 73.4 | 57.8 | 86.1 | 80.0 | 80.7 | 70.4 | 46.6 | 69.6 | **68.8** | 75.9 | 71.4 |
| NoC [29] | 68.8 | 82.8 | 79.0 | 71.6 | 52.3 | 53.7 | 74.1 | 69.0 | 84.9 | 46.9 | 74.3 | 53.1 | 85.0 | 81.3 | 79.5 | 72.2 | 38.9 | 72.4 | 59.5 | 76.7 | 68.1 |
| Fast R-CNN [14] | 68.4 | 82.3 | 78.4 | 70.8 | 52.3 | 38.7 | 77.8 | 71.6 | 89.3 | 44.2 | 73.0 | 55.0 | **87.5** | 80.5 | 80.8 | 72.0 | 35.1 | 68.3 | 65.7 | 80.4 | 64.2 |
| UMICH_FGS_STRUCT | 66.4 | 82.9 | 76.1 | 64.1 | 44.6 | 49.4 | 70.3 | 71.2 | 84.6 | 42.7 | 68.6 | 55.8 | 82.7 | 77.1 | 79.9 | 68.7 | 41.4 | 69.0 | 60.0 | 72.0 | 66.2 |
| NUS_NIN_C2000 [7] | 63.8 | 80.2 | 73.8 | 61.9 | 43.7 | 43.0 | 70.3 | 67.6 | 80.7 | 41.9 | 69.7 | 51.7 | 78.2 | 75.2 | 76.9 | 65.1 | 38.6 | 68.3 | 58.0 | 68.7 | 63.3 |
| BabyLearning [7] | 63.2 | 78.0 | 74.2 | 61.3 | 45.7 | 42.7 | 68.2 | 66.8 | 80.2 | 40.6 | 70.0 | 49.8 | 79.0 | 74.5 | 77.9 | 64.0 | 35.3 | 67.9 | 55.7 | 68.7 | 62.6 |
| NUS_NIN | 62.4 | 77.9 | 73.1 | 62.6 | 39.5 | 43.3 | 69.1 | 66.4 | 78.9 | 39.1 | 68.1 | 50.0 | 77.2 | 71.3 | 76.1 | 64.7 | 38.4 | 66.9 | 56.2 | 66.9 | 62.7 |
| R-CNN VGG BB [13] | 62.4 | 79.6 | 72.7 | 61.9 | 41.2 | 41.9 | 65.9 | 66.4 | 84.6 | 38.5 | 67.2 | 46.7 | 82.0 | 74.8 | 76.0 | 65.2 | 35.6 | 65.4 | 54.2 | 67.4 | 60.3 |
| R-CNN VGG [13] | 59.2 | 76.8 | 70.9 | 56.6 | 37.5 | 36.9 | 62.9 | 63.6 | 81.1 | 35.7 | 64.3 | 43.9 | 80.4 | 71.6 | 74.0 | 60.0 | 30.8 | 63.4 | 52.0 | 63.5 | 58.7 |
| **YOLO** | 57.9 | 77.0 | 67.2 | 57.7 | 38.3 | 22.7 | 68.3 | 55.9 | 81.4 | 36.2 | 60.8 | 48.5 | 77.2 | 72.3 | 71.3 | 63.5 | 28.9 | 52.2 | 54.8 | 73.9 | 50.8 |
| Feature Edit [33] | 56.3 | 74.6 | 69.1 | 54.4 | 39.1 | 33.1 | 65.2 | 62.7 | 69.7 | 30.8 | 56.0 | 44.6 | 70.0 | 64.4 | 71.1 | 60.2 | 33.3 | 61.3 | 46.4 | 61.7 | 57.8 |
| R-CNN BB [13] | 53.3 | 71.8 | 65.8 | 52.0 | 34.1 | 32.6 | 59.6 | 60.0 | 69.8 | 27.6 | 52.0 | 41.7 | 69.6 | 61.3 | 68.3 | 57.8 | 29.6 | 57.8 | 40.9 | 59.3 | 54.1 |
| SDS [16] | 50.7 | 69.7 | 58.4 | 48.5 | 28.3 | 28.8 | 61.3 | 57.5 | 70.8 | 24.1 | 50.7 | 35.9 | 64.9 | 59.1 | 65.8 | 57.1 | 26.0 | 58.8 | 38.6 | 58.9 | 50.7 |
| R-CNN [13] | 49.6 | 68.1 | 63.8 | 46.1 | 29.4 | 27.9 | 56.6 | 57.0 | 65.9 | 26.5 | 48.7 | 39.5 | 66.2 | 57.3 | 65.4 | 53.2 | 26.2 | 54.5 | 38.1 | 50.6 | 51.6 |

*Figure 18: Combination of YOLO and Fast R-CNN*

From above table, it is stated that YOLO itself is less successful than combination of Fast R-CNN and YOLO. We will choose the most appropriate technique by considering these tables and values.

# 7. Previous Works and Articles

[34] Gene Lewis. *Object Detection for Autonomous Vehicles,* pages 4-5, Stanford, CA, 2016.
This paper focuses on accuracy of object detection algorithms and comparison between them. It overviews which algorithm gives the best results while making predictions. It also reviews architecture, training algorithms, results of time prediction between models. As the article stated, YOLO model gives the fastest predict time among most popular models. We examined the time prediction results between models using this article and it will guide us while choosing our model.

[23] Bunyo Okumura, Michael R. James, Yusuke Kanzawa, Matthew Derry, Katsuhiro Sakai, Tomoki Nishi, Danil Prokhorov. *Challenges in Perception and Decision Making for Intelligent Automotive vehicles,* pages 1-12, Japan, 2016.
This paper overviews the challenges of perception for autonomous vehicles. It focuses on the difficulty while detecting objects and explained possible solutions. For that purpose, article explained that we can use classifiers for high-level decision making. It also examines classification successes under different road circumstances.

[24] Robert Geirhos, David H.J. Janssen, Heiko H. Schütt, Jonas Rauber, Matthias Bethge, and Felix A. Wichmann. *Comparing Deep Neural Network Against Humans Object Recognition When the Signal gets Weaker,* pages 15-17, Germany, 2018.
This paper focuses on a comparison between human-level classification performance with computer vision algorithms that refers to DNN. Additionally, in the paper, there are some experiments that compares well-known DNN algorithms like GoogLeNet, VGG-16 and AlexNet in each other. As a result of these comparisons writers decided that these 3 algorithms could be successful models for human feedforward visual detections. We observed that reaction of most popular models when different experiments are implemented. Therefore, we will be careful about the environment when choosing our model and algorithms.

[34] Enrique Marti, Miguel Angel de Miguel, Fernando Garcia, Member, IEEE, Joshue Perez. *A Review of Sensor Technologies for Perception in Automated Driving,* Pages 4, Spania, 2019.

This paper focuses on sensors which are used in automanous vehicles. In the paper, each sensor is explained in detail. Article presents their sensing setup as well. Additionally, article higlights that each sensor has its own weakness and strenght. Therefore, there is no winner among these sensors. Thanks to this research, we are informed about most popular sensor technologies, and it guided us regarding behaviour of sensors under different weather conditions.

[29] RuiJingXiaoQu, SongMen, WenLing, ZheJiang. *Comparison between Convolutional Neural Network and YOLO in image idendification,* Pages 1-3, China, 2019.

This article summarizes what are the most preferable object detection algorithm and it highlights their strengths and weaknesses. It seperates CNN and YOLO family and overviews each algorithm. Therefore, it also focuses on what are the difference between CNN and YOLO methods. We used this article while searching for algorithm to apply while detecting objects. Therefore, it guided us regarding our system's detection techniques.

[31] Danyang Cao, Zhixin Chen and Lei Gao. *An improved object detection algorithm based on multi-scaled and deformable convolutional neural networks,* Pages 1-4, China, 2020.

This article overviews what are the most popular object detection algorithms, what are their strengths and weaknesses and how they differ in each other. Therefore, it analyses the methods and compare them based on many features. This article guided us about what are advantages of R-CNN object detection algorithm other than enabled for multiple object detection simultaneously. We learnt that R-CNN also provides more accurate and reliable detections when compared to the other popular algorithms like YOLO and SSD. Therefore, we will be considering about this feature while developing detection part.

[36] Allen Wu. *Note for YOLOv1,* All Pages, China, 2018.

In this research, comparison of most popular object detection techniques is given. In paper, YOLO algorithm is summarized, and experimental comparisons are stated. According to paper, YOLO is appropriate choice in general cases. Comparisons are mainly based on accuracy speed, which are the most important factors for us. Therefore, thanks to this research, we observed different algorithms' performance and decide regarding our future solutions. Since both speed and accuracy factors are very significant for us, we will consider the comparison charts in our development process.

# 8. Summary

## 8.1. Technology Used

In Solutions for Self-Driving section, we explained there are 6 different levels of autonomous vehicles. In this section, we analyzed how exactly level 6 differs from remaining other levels.

In Solutions for Detecting Objects, we examined 5 types of algorithms. We examined the CNN object detection algorithm for image recognition. The CNN algorithm examines a limited number of specified regions. Using selective search, R-CNN selects candidate regions from 2000 regions at a time and collects similar regions together. With these regions it refers to the final positions of objects. Fast R-CNN applies a CNN to the entire image and generates a feature map from it. Then, it creates an ROI using selective search. Algorithm uses softmax function to predict the class of region and identifying bounding box's values using this ROI feature vector. Faster R-CNN uses Region Proposal Network instead of selective search. This makes the algorithm run faster. YOLO is the fastest running algorithm among these algorithms. This algorithm is trained to implement bounding box prediction and classification at the same time. They all use bounding box regression. These algorithms have advantages as well as disadvantages. We explained them in detail in the Solutions for Detecting Object section and compared them with each other.

# 9. Conclusion

In this literature review, we made research about Autonomous Vehicles as UGVs and summarize what we learnt and observed. This review does not contain the list of best algorithms or techniques, yet, it has comparisons between algorithms, definition of techniques and advantages, disadvantages tables, etc. While comparing these techniques and solutions, we observed that there are weaknesses and strengths of each algorithm since performance may depend on weather conditions, speed, computing power, sensor type, etc. Additionally, we looked deeper into the samples of autonomous vehicles, therefore, we analysed what other developers used and what kind of products come as a result. According to all of this information, we will choose techniques to develop our own system.

We'd like to state that, we are not going to develop a system which only autonomously move, we also add subsystems to our vehicle which enables our vehicle to make reconnaissance and surveillance around critical facilities. For that purpose, we are aiming to add a camera system which can continuously send real-time video to receiver. We are going to implement detection algorithms to that video and identify risky events. Even more, this vehicle can be also used for spying the enemy in battlefield. In this way, performance in battlefield or around a critical facility can be monitored or plans may be updated by commanders without risking any soldier's life. Additionally, when there is an emergency or necessary situation, commanders will be able to control the vehicle using controllers. Therefore, our vehicle can be operated either manual or autonomous mode. In conclusion, our system will be responsible of two main parts:

- Vehicle will be autonomously and manually operated.
- Suspicious events will be detected, and commander will be informed about these events immediately.

With this project, we are determined and excited to develop a national unmanned ground vehicle. With the ability to patrol autonomously, our soldiers will be safer.

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