2022-04

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https://doi.org/10.24382/pg97-j670
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**History**

Since the development of the first automotive vehicle manufactures and individuals have been continually attempting to automate some of the driving tasks as technology has evolved.

In 1925, inventor Francis Houdina [1] demonstrated a driver less radio-controlled vehicle through the streets of Manhattan. Using the radio-controlled link he was able to control the vehicle and even start the engine and sound the horn. He was stopped from using it when the operator lost control twice and crashed into other vehicles.

Between 1987-1995 a number of European motor manufacturers and suppliers worked on a €749 million Eureka project called Prometheus [2]. This looked at 10 different work streams and resulted in the development of a number of Advanced Driver Automated Systems (ADAS) features such as Adaptive Cruise Control, Advanced Emergency Braking, Lane Keeping Assist and Driver Status Monitoring. To date this is still the largest R&D project into driverless vehicles.

In 2004, the U.S. Defence Advanced Research Projects Agency (DARPA) held its first Grand Challenge [3]. Where prize of $1 Million was offered for the individual or team that could build an autonomous ground vehicle capable of traversing a 132 mile off-road desert course in under 10 hours. At the end of the 10 hours no vehicle had travelled more than 7 miles. The next year DARPA held the second event for $2 Million prize [4]. This time 5 vehicles completed the course with 23 of the 24 vehicles travelling further than 7 miles achieved in the previous year. In 2007 there was a 3rd challenge [5] to drive around a 96 kilometre urban environment. The vehicles had to obey traffic regulations and negotiate other robot participates and additional driven vehicles.

## Levels of driving automation

To help define the potentially different levels of autonomous vehicles the Society of Automotive Engineers (SAE) have defined six levels of automated driving ranging from Level 0 where all of the systems of the vehicle are controlled entirely by a human driver to Level 5 where the driver is not responsible for the motion of the vehicle [6].

In the SAE definition there is an important step which takes place between Level 2 and Level 3 in that the driver's responsibility to continuously monitor the road is removed. The driver **is** however, still responsible for the vehicle and is expected to take control when requested to do so. As an example, the Tesla's Autopilot system is classed as a Level 2 system in that it is '*intended for use with a fully attentive driver, who has their hands on the wheel and is prepared to take over at any moment.*' [7]

The mainstream automotive companies, including Tesla, are currently developing features which are incrementally working up the SAE scale. With the current development being focussed on Level 3 features where the main issues are

- how do you hand back control to the driver, and if you can't how do you get the vehicle into safe state?
- how do ensure that any sensor set you are using is robust and there is some level of redundancy?

The "disruptive" automotive companies such as Waymo, Cruise, Zoox, Aurora, Apple have set their sights on building Level 4/5 vehicles. This solves some of the interaction issues with the driver but there are a more complex set of problems to be solved.

## Autonomous Vehicle Building Blocks

Any of the features developed can be attributed to one or more of the four application building blocks given in [8].

***Localisation (Where am I? What is my dynamic state?)***

This is solved by combining the output of a dynamic Global Navigation Satellite System (dGNSS) [9] and an Inertial Measurement Unit (IMU). The dGNSS receives positional information from the one or more satellite constellations systems such as GPS, GLONASS, Galileo, Beidou and the position compared to a known base station location. The IMU measures the vehicle acceleration in x, y, z, pitch, roll and yaw using accelerometers and gyroscopes. Combining the two sets of vehicle state information within a Kalman filter can give a positional accuracy of the order 1 cm [10]. Some of the issues are

- dGNSS systems requires line of sight to the satellites so in an urban environment they can suffer from reduced number of satellites (you need to see at least 4 satellites) and signals reflected off buildings leading to positional inaccuracies [11].
- The sensors within the IMU are prone to drift and have to be realigned periodically using the dGNSS. So what happens when you come out of a tunnel and the IMU says one position and dGNSS says another?

***Perception (What are the objects around me? How are they going to move?)***

The Perception layer requires the ability to receive information from a number of different sensors systems which are going to be cameras, radars and lidars. All of these have to be fused together to generate an understanding of other road users/pedestrians/animals, their movements and the road/track the vehicle is on. Typically, this is where the Artificial Intelligence is used [12]. Some of the issues with this layer are

- All of the sensors have to be time synchronised so that detected objects appear at their correct location relative to each other and the vehicle.
- Perception generates a large amount of data for example an uncompressed video image from a 1080P camera will generate 6MB/Frame so 30 frames per second will generate 11GB/minute [13]. So, do you reduce the amount of information and use a "smart" sensor which provide just the object information?
- Before the sensor information can be fused together each sensors output will have to be transformed into a common reference frame, normally a bird's eye view of the vehicle. Each transform introduces distortions and assumes that the sensors are positioned accurately on the vehicle.
- Any sensor set used needs to be able to work in all environments and lighting conditions.
- This layer has to predict the movement of other vehicles, pedestrians and animals each with their own dynamic responses.

***Planning (Where can I move to? Where do I want to go?)***

Planning is split into three levels. *Global Planning* which works out the route to get you from Location A to Location B. *Local Planning* determines which lane you need to be in or where the vehicle needs to be positioned to get in the right lane for next exit. *Trajectory Generation* determines how the vehicle moves to achieve the Local Planning objective. It is the Trajectory Generation level that controls the vehicle speed, lateral movement and the position between it and other vehicles. It is the tuning of this level which determines the "feel" of the vehicle's response and will represent the motor company's key marque values. The issues with this layer are

- How do you map the world's roads to a high level of map accuracy to allow a vehicle to drive on it?
- How do you get updates in the road layout in the case of accidents and road works? Also, who is responsible for providing this information and how frequently are the maps updated?
- Local Planning needs to understand the local rules of the road and have the ability to resolve potential contradictions in these rules.
- There are also moral and ethical decisions to be made around some decisions that the vehicle might have to make in terms of the path it takes [14].

***Drive-by-wire (How do I control the vehicle?)***

The Drive-by-Wire system will receive a trajectory from Planning and then it has to determine how to steer and provide the correct amount of acceleration to follow this trajectory. This is perhaps the best understood layer as some of these issues have already been solved as part of the ADAS development. However, if we are looking at developing a Level 5 system then this will require the capability to control the vehicle in some extreme edge case conditions, for example

- It will need to control the vehicle if it goes into understeer or oversteer?
- Do we expect our autonomous vehicle to go rock crawling?

## Conclusion

The issues and decisions highlighted above are only a few of the design choices that have to be made to produce an autonomous vehicle. In addition, how is such a complex system validated? and the last big and perhaps most important question to ask is, whether there is an appetite within the general public, beyond general curiosity, to actually buy/use autonomous vehicles?

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