A Systems Approach to Parking Assist System: Investigating Test and Verification Methodology

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***Abstract*—This paper explores the parking assist system technology and how it has evolved over the years. It investigates the different types of subsystems and components that go into this small, yet complex system inside a vehicle and why this technology is needed. The system decomposition examines how everything is linked together and why all the subsystems and components are necessary for the system to function. The test and verification consider current test methods and explore existing equipment and software, especially for these cases. After discussing potential system requirements, a systems approach inclusive of both CATWOE (Customer, Actor, Transformation, World View, Owner, Environment) analysis and Systemigram methods is used to map out and get an overview of the system and its stakeholders. This paper presents a new approach to the way of looking at the parking assist system because taking all stakeholders and looking at the bigger picture is not considered in common practice. In a common analytical approach, engineers tend to focus on a separate part of the system without considering its interactions with the environment. Hence, looking at this problem from a systemic perspective is novel and constructive for this industry in the future.**

Keywords—Systems Thinking, PAS (Parking Assist System), ABS (Anti-lock Braking System), Systemigram, CATWOE.

I. Introduction

The roads are becoming increasingly busier and have been for many years and parking a vehicle in certain situations can be stressful no matter how experienced the driver is. Looking back in history, the first cars on the market were a lot smaller than the current design and were nowhere near as many vehicles on the road as we see today. Particularly in cities, the parking spaces can be tight and difficult to get into, however people are dependent on parking spaces. More people, more vehicles and tighter spaces unfortunately cause an increase in accidents. This happens not only on the roads, but in other places like parking lots and parking garages where the view around the vehicle is limited and the randomness of human behavior is responsible for a large percentage of accidents.

Parking assist technology has been around for many years and the first mainstream car to feature rear parking sensors was the Toyota Prius, although Toyota already had introduced ultrasonic back sensors as far back as 1982. The next technological development within the parking systems was the surrounding-view parking monitors/cameras, which Nissan first developed and introduced in 2007. The very first rear park assist system (semi-autonomous parking) was introduced in 2003 and has since then evolved into autonomous parking that is one of the latest features within parking technology [1].

II. Background and System Description

Looking into the modern car parking technology, one of the newest features that have been around for a few years is the semi-autonomous and autonomous parking assist system. The parking technology has evolved a lot over the last 20 years from when the rear parking sensors first were introduced. Today, most of the large car manufacturers provide parking assist technology in their new cars, or at least as a feature option that can be bought.

Although the parking assist system is small, it is a very complex system within the vehicle. There are many subsystems and components that must cooperate for the system to work as it should. In general, automatic parking systems consist of three main components: the target position designation, path planning and path tracking by active steering [17]. The subsystem includes sensors, cameras, control center, computers, and user-interface, to mention some. There are 3 main sensors used in modern parking system technology:

- Ultrasonic sensor (most common) – Emits soundwaves that humans cannot hear.
  Measures the distance using D =0.5 x Time x Speed of sound.
  The speed of sound varies in different temperatures and humidity; therefore, the car has temperature sensors that can compensate.
- Electromagnetic sensor – Emits radio waves at certain frequency. These reflect back when they hit an object and reach the car at a different frequency. The car is then able to detect the change in frequency and calculate the distance.
- Radar – Located behind the bumper bar at each corner of the car pointing out towards the side. Used for rear cross traffic alert.

Having eyes all around the car has become more common in newer cars as well. Reverse view camera, front camera and wide-angle camera on the wing mirrors are stitched together to produce a top view of the car and surroundings. This is also known as a 360-degree camera or birdsview [2].

The most used ultrasonic sensors only work from 3-5 meters from the car, whereas radar can go further down the road. Reverse Autonomous Emergency Braking (AEB) is usually implemented into the system and activates when there is an obstacle too close that the sensors detect or if the radar detects a moving vehicle or pedestrian [2] [10].

From the moment the parking assist system has been activated, it starts collecting data and calculating the needed distances. It also detects any obstacles via cameras and sensors as well as taking over the steering system. The cameras and sensors act as transmitters and receivers. These signals go into the computer, which then calculates the distance from objects etc. [8].

III. Problem Context

Over the years, cars have been getting bigger. Also, traffic and the number of vehicles on the road have increased over many years. There is a high demand for parking spaces and parking lots. Parking lots are where one of five motor vehicle accidents happen in the US. Some of the accidents happen between two cars crashing, however most of the accidents involve pedestrians walking in the parking lot. Some of the top causes of parking lot accidents includes drivers entering a parking lot and keeping an eye on a spot, not focusing on the surroundings such as other cars, pedestrians, or obstacles. Another reason is drivers who must back out of their spot, not being able to see all the surroundings. Pedestrians and other moving vehicles are at that point in the driver's blind zone [4].

Statistics from National Centre for Statistics and Analysis (NHTSA) from the year 2007 illustrate numbers of non-traffic fatalities and injuries (Figure 1).

Event	Fatalities	Injuries
Non-occupant in Non-traffic Crash: Backing Vehicle	99	2,000
Non-occupant Struck by Driverless Vehicle	5	<500
Non-occupant in Non-traffic Crash: Forward-Moving Vehicle	106	3,000
Total (approx)	210	5,000

Figure 1. NHTSA Non-traffic fatalities and injuries 2007 [4].

A safe and reliable parking assist system can provide a securer and less stressful parking experience for the driver and help avoid accidents and damages to other cars, obstacles, and people nearby. Sensor and radar systems provide the driver with 'eyes' surrounding the car that easily will alert or activate emergency brakes in unforeseen cases and human behavior. The test, verification, and validation of all the subsystems and the parking assist system as a whole need to be thoroughly executed to provide a reliable system for the user.

IV. System Decomposition

There are many components and subsystems that have to work together in order for the autonomous/semi-autonomous parking assist system to complete its task. There are various conditions the system must fulfil:

- Detect obstacles in the surrounding environment.
- Measure and estimate the distance to obstacles.
- Provide a planned route to park.
- Provide a real-time display to the driver during the parking sequence [5].

These conditions are done by separate interconnected subsystems, as seen in Figure 2.

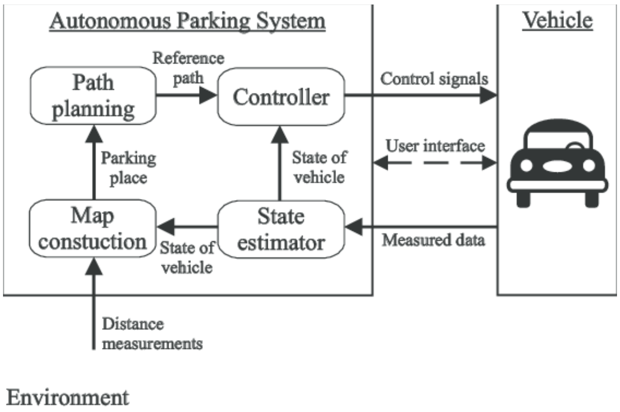

Figure 2. Components of the Parking Assist System [5]

According to Szadeczky-Kardoss and Kiss, the ABS sensors assembled on the vehicle detect the displacement of the wheels on the car. Furthermore, this data can be used to calculate an estimated position and orientation. This estimated state is then used by the mapping and controller modules. For the map to be developed, additional data is also required about the environment. Ultrasonic sensors (most commonly) are used to measure the distance to nearby objects and obstacles. Based on this data, a map can be assembled to near accuracy [5].

Throughout the path planning, a reference path is calculated, which connects the initial and the desired final configurations. In this path planning stage, there are certain constraints that need to be taken into consideration. This can be collision avoidance and the non-holonomic performance described in the model. Ultimately, the tracking control algorithm is used to track the reference path [5].

In Figure 3, the system environment for the parking system is illustrated. The inputs are sensor data that contains information on the vehicle state. For example, vehicle speed, steering position and information from environmental sensors that register objects on the right and left side of the vehicle. In terms of output, the system possesses an interface to the vehicle actors where the vehicle steering angle and velocity will be set [9].

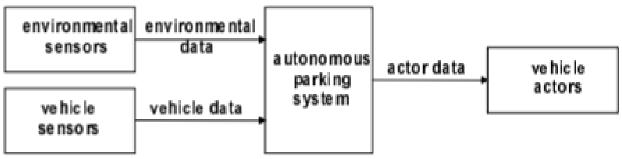

Figure 3. System Environment [9]

V. Test, Verification and Validation

Testing, verifying, and validating the parking assist system is one of the most important steps in the process of product development. This is where the subsystems and the system are tested to see if it fulfils the requirements or if certain things need to be improved. This step can also involve the safety of the product and determines the acceptable level.

A. *Parking Assist Test Company (VBOX Racelogic)*

VBOX Racelogic is a company that provides equipment for the manufacturers to make sure the parking assist system can be easily tested and validated. Using a VBOX 3i

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datalogger, RTK base station and survey trolley a parking space can be marked out and plotted to more than 2 cm accuracy. This makes an exact resemblance of the space which then can be uploaded to the VBOX test suite (Software) where the parking assist test can be configured and run. Another feature is that the user can set defined pass and fail conditions in the system to fit the user conditions.

The parking space only needs to be mapped out once, meaning the test can be run multiple times in the same space and variations can be minimized more easily [6].

When the test is running, real-time data can be seen on the screen, as shown in Figure 4. It illustrates the cars outline, the closest point of contact, as well as the pre-marked parking space. This gives the user an instant insight to the pass and fail status of each test, saving valuable testing time.

Figure 4. VBOX Test Suite Park Assist [6]

B. BMW X5 Parking Assist Test

The parking assist technology is one of the best technologies within parking features existing today. The technology has been around since 2015 and BMW, Mercedes-Benz, Tesla and Volvo have all introduced autonomous parking assist [1].

Looking into BMW's parking technology, a test on the parking features for a BMW X5 xDrive30d was performed by Paul Maric [2] where he went through all the features and put the system to test in an empty parking lot, using suitcases, himself and two other cars as obstacles. The two cars made it possible to create different scenarios like parallel parking, perpendicular and remote parking.

During these tests, the system is tested in its entirety, not each subsystem separately. When testing the perpendicular parking, the two extra cars were parked within the lines leaving one parking spot in between them. The car then drove slowly past the empty spot to estimate the size. After passing the spot, the car will either alert the driver that the spot was too small, or big enough, so the parking operation can commence. In this case, the spot was big enough. If the driver accepts, the car will automatically set itself to the reverse or drive and park within the lines. At this point, all the sensors are active and the driver should not do anything apart from hovering over the break as an emergency if something were to happen. The driver also gets a 360-degree view of the car from above, also known as birdsview, making it easy to see how the parking is going and that the car will be parked within the lines. Once the parking is complete, the car will alert the driver on the screen and the assisted car parking is complete.

Very similarly to the perpendicular parking, the parallel parking begins by measuring up the space in between two vehicles and the car will alert the driver if the space is suitable. The driver can then accept and start the parking sequence where the car then automatically will set itself into the needed gear and make its way into the space without hitting any of the other vehicles. If something was to interrupt the parking sequence whilst its running, for example a pedestrian walking behind the car, the parking will be paused and resumed when the obstacle is outside of the path.

As Paul Maric mentions, the exit assist may be needed in many cases when the parallel park feature has been used to get the vehicle into the spot. Similarly, starting the other parking assists, one selects exit assist, and it will have the driver confirm the direction of exit. The system will the reverse the car to clear room for the car in front, then drive out of the spot until the driver can take over [2].

Individual tests for the subsystems can also be performed. Regarding a senor test on a vehicle, a simple multimeter test can be used. Other practical tests can also be performed easily by putting the sensors to the test. Normally, objects are placed in certain locations then a scanning tool is used to see if the object is being correctly detected [7]. Placing an obstacle in front or behind the car and driving towards it will show if the sensors pick up on the obstacle in time and how the sensors beep at different distances.

Understanding how the system works can reduce the diagnostic times. Also, knowing what part of the system to test will help prevent installing parts that do not fix the problem and make the repair or improvement cheaper and quicker [3].

VI. DISCUSSION

Systems thinking gives the industry a new opportunity to see the bigger picture and seeing the system with all perspectives and stakeholders involved. When looking at the parking assist system, the main goal for this system is to park without hitting anything and park in a sufficiently large spot. For the system to work and reach its goal, we need reliability and accuracy.

The goal seems like a simple case to solve, and that may be if all the impacting factors are at the perfect state. This is, however, very rare and unlikely in a real-life situation. What makes the whole situation so complex is the randomness and human behavior that occurs. A case scenario could be driving on one of the busiest streets in Oslo wanting to parallel park along the street. In this case, we do not have an empty parking lot where nothing can go wrong. We have randomness and human behavior. There are cars everywhere, trams and tram tracks, buses and people and pets walking all over the place. This means there are many unforeseen situations that can occur and effect the parking assistance system. What happens if a person walks behind the car when parking? What happens if a car behind drives too close during an active parking sequence?

What would be some of the potential test criteria or requirements to have a successful and reliable product?

- Perform parallel and reverse parking without hitting anything.
- Measure and determine a suitable parking spot that will fit the car and allow room to exit and enter the car.

- Park within a time limit of 30 seconds (for example) from accepting and activating the parking.
- Emergency breaks in case of unforeseen behaviour.
- Perform parking assist on the exit of the parking spot.
- Provide clear instructions to the driver during the parking procedure.

Examining the types of components in the system, in order to fulfil these criteria, the sensors may not need to be the absolute best and most expensive to complete the same tasks. To perform a parking operation, all the subsystems must cooperate to achieve the goal and if the components are good enough to fulfil the set requirements with a reasonable margin, it should be acceptable.

VII. Systems Thinking Approach

A. *CATWOE from company perspective*

The CATWOE approach illustrates the different actors and stakeholders and their perception on a topic. In this case, the CATWOE approach is done from the company's perspective. This approach is from the systems thinking framework [16]. Perspectives are representations of an individual's truths based on their knowledge of the world, and we use multiple forms to contextualize and communicate these perspectives (i.e. verbal, written, graphical) [16]. Using the CATWOE approach can give an overview of what to focus on and perhaps a clearer understanding when making certain decisions and what to prioritize. An example could be making a user-interface that is so complicated that only software engineers would understand it. The user-interface could be very good; however, it is then important to remember who the customers are, who in this case are the drivers. The assumption should be that the divers are not software engineers, and the user-interface needs to be user friendly and easy to understand and comprehend for anyone.

Table I. CATWOE Company Perspective

ASPECT	DESCRIPTION
CUSTOMERS – who are the beneficiaries/victims?	Drivers.
ACTOR(S) – who are the implementers?	The car manufacturers (software, electronics, and test department).
TRANSFORMATION – what does the system do? What are the inputs and what transformation do they go through to become the output?	Signals and communication between different subsystems.
WORLD VIEW – what point of view justifies its existence to the customers? What point of view makes this system meaningful? The big picture and its impact.	Verify the subsystem. Validation of system that it works as it should.
OWNER – who has the authority to change the system?	Authorities like DMV (Department of Motor Vehicle in USA), DVLA (Driver and Vehicle Licensing Agency in England) or Biltilsynet in Norway can set requirements.
ENVIRONMENT – What are the external constraints?	Guidelines, rules, and regulation in the traffic. Randomness and human behavior.

Customer - Drivers would be the main customers of this product and will be most beneficial for them as they are the direct users. The general system technology would, however, be technology that car manufacturers would want to get and interoperate into their line of products to improve the overall performance and possibilities, and also keep up with the technological development.

Actors - The car manufacturers are the ones responsible for implementing the system and making sure the system works and fulfils certain criteria before being released into the final product stage. Within the car manufacturer structure, there are many departments, meaning the software and electrical department mostly will oversee implementing and assembling the system together. In addition, they will be working with the test department to perform tests that verify and validate the different subsystems, then also improve the system if needed. The Department of Motor Vehicles, or Biltilsynet in Norway, are not implementers but may, however, set requirements as to how safe the system must be.

Transformation - The main transformation for this system will be signals. The whole system is made up of sensors, radars, modules that calculate distance and a computer. Simply broken down, one example can be the sensor measuring the distance to the car behind it. This data is sent to the computer which then sends this to the brake system. The brake system can then perform an action of breaking when the car reaches a certain point.

World View – The world view aspect investigates what point of view justifies its existence to the customers and the meaningfulness of the system. For this case, verifying the subsystem and validating the car assist system and making sure it works as it should and fulfils the requirements is what justifies its existence to the customer.

Owner – The owners of the system or the authorities that have the power to influence or change the system in the case of car parking assistance is the DMV (Department of Motor Vehicles in USA), DVLA (Driver and Vehicle Licensing Agency in England) or Biltilsynet in Norway, to mention a few from different countries. They have the authority to make changes or set requirements and constraints to the system, if needed.

Environment – some of the external constraints for the system are guidelines, rules, and regulation in the traffic. Another external constraint can be randomness and human behavior.

B. *Systemigram*

The term "Systemigram" is derived from "Systemic Diagrams," and has been used to "bring context to the meaning of togetherness" [11] [13] [14]. A system diagram or Systemigram will be used to map the parking assist system. This systems thinking tool is used to explain the interactions between several, interrelated elements and is a great tool to get an overview over all the elements and decompose complex systems [12]. The Systemigram was developed by Boardman and provides a powerful tool for the analysis of systems first described in written form [15]. In this diagram, the mainstay is displayed with the dark and light green bubbles and the path lines are thicker than the rest. The mainstay shows the main steps in the process and shows how it goes from a PAS test to a verified PAS product. See Figure 5.

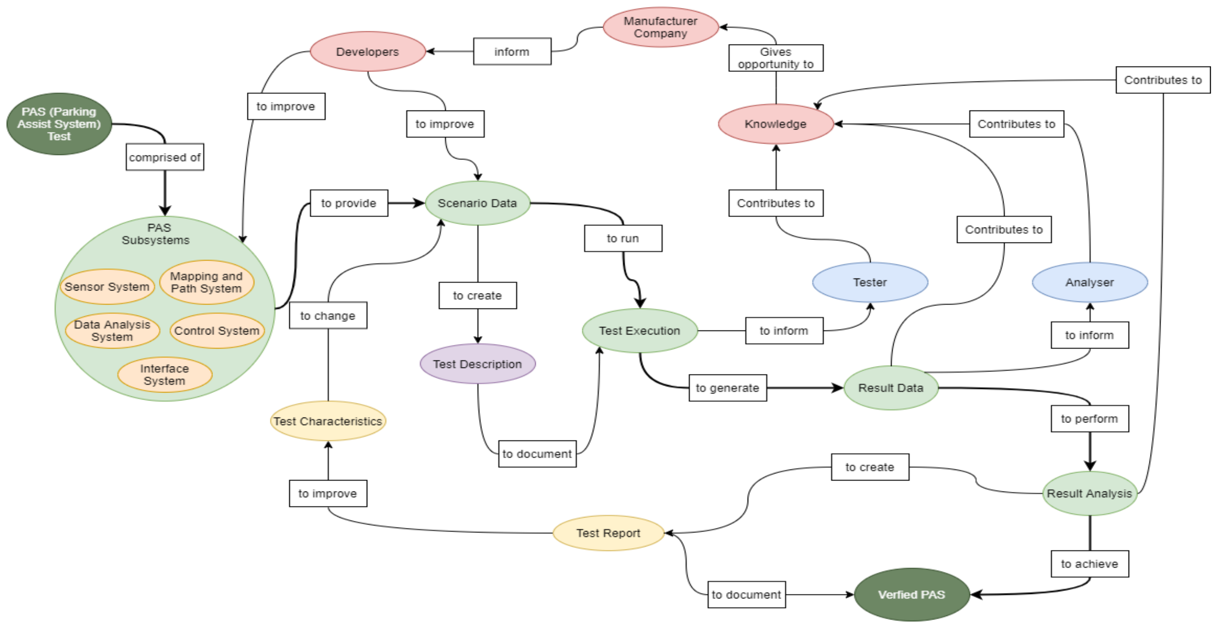

Figure 5. Systemigram of the PAS

VIII. CONCLUSION

The PAS technology is, as mentioned, a small system. However, car manufacturers have prioritized this technology and kept developing it together with the overall vehicle, but why? As explained in the problem context, a large percentage of accidents happen in parking lots and parking garages, not only to other vehicles, but people. Developing a smart parking assist systems in vehicles can help reduce the number of accidents, if not avoid them all together.

The tests and verification of these systems are done thoroughly and there are even companies that produce specific equipment and software for the testers or users to get a good overview and insight in every stage of the parking process. The new modern-day cars are full of parking sensors, radars and, in most cases, also equipped with 360-degree cameras and much more technology and features, such as Reverse AEB (Autonomous Emergency Braking), reverse assist, remote parking etc. Having all these features activated would reduce the risk of accidents as the car would pick up on everything the driver does not see, and even emergency brake, if needed.

The parking assist system technology has been and will be around for a long time. Looking at how much this small and complex technology has evolved since 2003 when the first rear parking sensors were introduced, it is safe to say it will not stop at semi- or autonomous parking assist and will be evolving into technology and new smart solutions we have not even thought of yet.

The purpose of this paper is to propose a new way of looking at a complex system. Using systems thinking approaches as CATWOE and Systemigram, we can look at the system with more perspective and with the involved stakeholders. Although each component and subsystem are important, they can give the system a new view when looking at it with a wider perspective and seeing the whole system.

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