ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

DESIGN AND VALIDATION OF AN AUTONOMOUS PARK SYSTEM CONCEPT BASED ON CUSTOMER CLINIC

M.Sc. THESIS

Onur ÖKSÜZ

Control and Automation Engineering Department

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AUGUST 2018

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

KULLANICI ODAKLI OTONOM BİR PARK SİSTEMİ TASARIMI VE VALİDASYONU

YÜKSEK LİSANS TEZİ

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Onur ÖKSÜZ, a M.Sc. student of İTU Graduate School of Science Engineering and Technology student ID **504101121** successfully defended the thesis entitled **"DESIGN AND VALIDATION OF AN AUTONOMOUS PARK SYSTEM CONCEPT BASED ON CUSTOMER CLINIC"**, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 07 August 2018
Date of Defense : 08 August 2018

To my family,

FOREWORD

Firstly, I would like to thank to my advisor Asst. Prof. Dr. Ali Fuat ERGENÇ for sharing his extensive knowledge and experiences throughout my master's degree.

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August 2018 Onur ÖKSÜZ
(Electrical Engineer)

LOCK FLAG

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ABBREVIATIONS

ABS	: Anti-lock Brake System
ADAS	: Advanced Driver-Assistance Systems
BCM	: Body Control Module
BLEM	: Bluetooth Low Energy Module
DAT	: Driver Assist Technologiy
ECM	: Engine Control Module
GDO	: Garage Door Opener
GPDR	: General Data Protection Regulation
GPS	: Global Positioning System
GSM	: Global System for Mobile communications
HAP	: Home Area Parking
HMI	: Human Machine Interface
iOS	: iPhone OS
kph	: Kilometer per hour
PCM	: Powertrain Control Module
PSCM	: Power Steering Control Module
SRD	: Smart Remote Device
SAE	: Society of Automotive Engineers
TCM	: Transmission Control Module
TCU	: Telematics Control Unit
Wi-Fi	: Wireless Fidelity

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DESIGN AND VALIDATION OF AN AUTONOMOUS PARK SYSTEM CONCEPT BASED ON CUSTOMER CLINIC

SUMMARY

Fast growing technology contributes to enrich every branch of industry as well as the automotive industry. The developments through the last decade in automotive industry are remarkable and majority of these automotive innovations featured electronics and software especially at electrification and driver assistance technologies. This leads to equip the vehicles with more electronics systems and convenience features day by day. The latest features are usually offered at first in the higher vehicle segments, and hence large user groups do not experience them. It does not take long until those features can be found in lower segments. This can be observed for automated parking assistance systems and driver assistance features, which are getting close to the autonomous driving.

The new automated parking assistance systems are making life easier for drivers to park in tight spots by pressing a button. The driver assistance features are capable of autonomizing the drives up to a certain level without the constant supervision of the driver. By merging the trends in these two feature domains, a new parking assistance feature called Home Area Parking (HAP) is aimed to be designed and validated in this thesis.

Firstly, active and passive park aid systems are investigated. Secondly, the autonomous vehicle definition and levels are examined. After that, the concept details defined and storyboard is created for the feature and for the main use cases. The details of each use case are defined in the sub-sections of the storyboard. In order to validate the designed feature, a customer clinic is organized. During the clinics, the feature is simulated by a human driver since the feature is not yet implemented. Preparation and execution steps are explained. The outcome of the clinic is summarized and the results are analyzed. Accordingly, boundary diagram is updated based on the analysis of the results.

Finally, conclusions of this study is oulined and recommendations for further improvement are laid out in the last section.

KULLANICI ODAKLI OTONOM BİR PARK SİSTEMİ TASARIMI VE VALİDASYONU

ÖZET

Gelişen teknoloji, endüstrinin her alanında olduğu gibi otomotiv alanında da yenilikler getirmiştir. Önceleri sadece mekanik sistemlerden oluşan otomobillerin yerini, gelişen teknoloji ile birlikte hem mekanik hem de elektronik sistemlerin birleşiminden oluşan otomobiller almaya başlamıştır. Başlarda hava yastıkları ve tekerleklerin kilitlenmesini önleyen fren sistemleri gibi daha temel güvenlik önlemleri geliştirilirken, özellikle programlama alanındaki gelişmelerle sürücünün hayatını kolaylaştıran konfor özellikleri geniş yer tutmaya başlamıştır. Bu konfor özellikleri yanlızca sürücüye rahatlık veren özellikler değil, aynı zamanda sürücünün seyir esnasında yerine getirmekte yükümlü olduğu görevlerin de bir kısmının yerine getirilmesinde yardımcı olan özelliklerdir. Son yıllarda özellikle bu alandaki sürücü yardım sistemlerindeki gelişmeler öne çıkmaktadır. Öncelikle üst segment araçlarda sunulan bu özellikler, günümüzde artık daha aşağı segmetlerde de kısa sürede yaygınlaşmaya başlanmasıyla daha geniş kitlelerin kullanımına sunulur hale gelmiştir. Örneğin, otomatik park sistemleri ve sürücü yardım sistemleri gibi özellikler artık küçük segmentlerdeki araçlarda dahi sunulmaya başlanmıştır.

Gelişmekte olan ileri sürücü yardım sistemleri, sadece sürücüye daha gelişmiş konfor özellikleri sağlamakla kalmaz, aynı zamanda emniyeti de arttırır. Örneğin, bir çarpışma riski ortaya çıkması durumunda sürücü refleksine gerek kalmadan otomatik bir şekilde frenleme yaparak sürücüye aktif olarak yardımcı olurlar. Avrupa ve Amerika Birleşik Devletleri’nde kısa süre içerisinde acil durum frenleme sistemi ve ön çarpışma uyarı sistemlerinin standart hale getirilmesi planlanmaktadır.

Otomatik park sistemleri, park etme işlemini oldukça kolay hale getirmektedir. Gün geçtikçe daha da gelişen sürücü yardım sistemleri, otonom sürüş sistemlerinin geliştirilmesine giden yolda önemli bir temel oluşturmaktadır. Bu tez de ise, otonom bir park sistemi konsepti tasarlanmış ve müşteri araştırması ile validasyonu sağlanması amaçlanmıştır.

İlk olarak günümüzde araçlarda sunulan mevcut park asistanı sistemleri araştırılmıştır. İki ana dala ayrılan, aktif ve pasif park sistemleri incelenmiştir. Pasif park sistemleri, geri görüş kamerası ve park sensörlerinden oluşmaktadır. Bu sistemler, yanlızca sürücüye aracın etrafinda bulunan obje ve engeller hakkında görsel ve işitsel bilgi verirler.

Aktif park sistemleri, sürücüye aktif bir şekilde yardımcı olmaktadırlar. Üç farklı aktif park sisteminden ilki olan, yarı otomatik park asistanı (Semi Assisted Parking assistance) yalnızca direksiyon hareketlerini kontrol ederek, aracin park yerine kolayca ve düzgün bir şekilde park edilmesinde sürücüye yardımcı olur. Tam otomatik park asistanı (Fully Assisted Parking assistance) ise direksiyon kontrolü yanında; gaz pedalı, vites değişimi ve frenleme gibi işlemleri de kontrol ederek aracın kendi kendine park etmesini sağlamaktadır. Uzaktan park etme asistanı (Remote Parking Assistance)

ise, dar park ceplerinde sürücünün aracı park etme işlemi tamamlanmadan aracı rahatca terk edebilmesini sağlar. Sürücü araçtan indikten sonra, uzaktan kumanda yardımı ile aracı ileri yada geri hareket ettirebilir. Bu işlem süresince sürücü aracın yakınında bulunmalıdır.

Üçüncü bölümde ise günümüzde otomotiv alanındaki en önemli yönelimlerden biri olan otonom araçlar incelenmiştir. Bu araçlar, araca entegre edilmiş birçok kamera ve sensörden gelen bilgileri işleyerek sürücünün yürüttüğü birçok fonksiyonu yerine getirmede sürücüye yardımcı olmakta ve hatta tamamen sürücüden devir almaktadır. SAE (Society of Automotive Engineers) organizyonu otonom araçları, araçların yerine getirebildikleri fonksiyonların kapsamına göre sıfırdan beşe kadar altı kategoride sınıflandırmıştır. Kontrolün tamamen sürücüde olduğu sistemlerden, sürücü kabini dahi olmayan araçlara kadar sıralanan bu kategoriler bu bölümde özetlenmiştir.

Dördüncü bölüm, otonom araçlar ve otomatik park asistanları alanındaki gelişmelerin birleştirilmesiyle ortaya çıkan otonom bir park konsepti olan “Home Area Parking” (HAP) konseptini konu almaktadır. Bu özellik, aracın bilinen bir park yerine, sürücüye ihtiyaç olmadan kendi kendine park etmesi prensibine dayanmaktadır. Sürücünün bu özelliği kullanmadan önce öğrenme prosedürünü uygulaması ve izlenmesi gereken rotayı öncelikle aracı kendi kullanarak araca kayıt ettirmesi gerekmektedir. Kayıt işleminin ardından, sürücü, uzaktan kumanda aracılığıyla aracını bilinen park yerine kendi kendine park etmek üzere gönderebilmektedir. Ayrıca, sürücü aracını park ettiği yerden, bilinen başka bir noktaya da geri çağırabilmektedir.

Bu özelliğin yalnızca özel mülk alanları içinde kullanılması öngörülmüştür ve umumi yolları içeren rotalar kapsam dışında tutulmuştur. Bu özelliğin, dördüncü bölümde öncelikle konsept detayları daha detaylı bir şekilde açıklanmıştır. Sistemin sınır şeması oluşturulmuştur. Sistemde bulunan alt sistemlerin görevleri kısaca açıklanmış ve alt sistemler ile diğer bileşenlerin etkileşimleri açıklanmıştır. Ardından bu özelliğin kullanılabileceği çeşitli mekan senaryolari incelenmiştir. Her bir mekanın karakteristik özellikleri belirlenmiş ve bu sistemin hangi senaryolarda kullanılabilir olup, hangi senaryolarda kullanılamayacağı sebepleriyle birlikte açıklanmıştır. Bir sonraki alt bölümde ise başlıca kullanım senaryoları incelenmiş ve resimli taslak olarak hazırlanan her bir kullanım senaryosu anlatılmıştır.

Beşinci bölümde ise tasarlanan konseptin validasyonu için kullanılacak olan müşteri araştırması yer almaktadır. Yeni ürünlerin geliştirilme sürecinde sıkça kullanılan bu araştırmalar, müşterilerin ürünler hakkındaki algılarını anlama ve ürünleri erken safhalarda müşterilerden gelen geri bildirimlere göre yeniden düzenlemeye veya optimize etmeye yarar. Araştırma için yapılan ön hazırlıklar, geri bildirim için hazırlanan anket, araştırmanın içeriği ve yürütme detayları bu bölümde açıklanmıştır. Henüz bu özellik geliştirilme aşamasında olup, gerçeklenmemiş olduğundan araştırma sırasında park asistanının otonom sürüş gerçekleştirmesi gereken yerlerde sistem simülasyonu başka bir sürücü tarafından gerçekleştirilmiştir. Dört hafta süren araştırma fazı ardından, araştırma sırasında katılımcılar tarafından doldurulan anket sonuçları incelenmiştir. Bunun yanı sıra, anket sonuçları ve araştırma sırasında gözlemlenen sonuçlar analiz edilmiştir. Elde edilen sonuçlara göre sınır şeması güncellenmiştir.

Son bölümde ise, tasarlanan otonom park konseptine ait araştırma sonuçları özetlenmiş ve validasyon neticesinde varılan çıkarımlar ortaya konulmuştur. Araştırmaya katılanlardan alınan pozitif geri dönüşler bu konseptin gerçekleştirilmesi için çalışmaların devam etmesini sağlamıştır. Ayrıca, konseptin geliştirilmesine yönelik öneriler ve daha detaylı araştırılması gereken alanlar belirtilerek sonlandırılmıştır.

1. INTRODUCTION

With the advent of the information technology in automotive industry after the 1980s, the systems in vehicles evolved from pure mechanics to combinations of mechanics and electronics [1]. Integration of electronic systems set the ground for safer, more comfortable, more luxurious and more environmentally friendly vehicles. Whereas these progresses were mainly focused on the essential features such as satellite navigation, anti-lock brakes in the early days, nowadays they are more focused on the comfort and driver assistance features.

There are several systems which which assist the driver in certain tasks like parking or automated braking in case of a collision risk. Currently, one of the major trends in the industry is autonomous driving. In the future, the autonomous vehicles will complete the long lasting validation drives and will take place in the traffic steadily. It is expected that consumers will start to own autonomous vehicles by 2030 [2]. In parallel to these movements, an autonomous parking concept Home Area Parking (HAP) is defined to provide advancements of autonomous driving for parking.

In the second section of the thesis, the history of the parking aid systems is investigated. Park aid systems started with passive systems such as rear view cameras and parking distance sensors that mainly inform the driver audibly and visually about the vehicle surroundings especially at the backside. While the passive systems are becoming nearly a standard equipment over a certain vehicle segment nowadays, the active park aid systems rose up. Semi Assisted Parking assistance supports the driver to get into the parking spot easily by controlling the steering, whereas, Fully Assisted Parking assistance can also handle the gearshifts and acceleration during parking. Remote Parking Assistance provides the flexibility to the driver to leave the vehicle before it is parked in tight parking spots or garages. The driver can remain around the vehicle and is able to move the vehicle backward or forwards by a remote device to get into or out of a parking spot.

Autonomous vehicles were investigated in the third section of the thesis. These vehicles are capable of processing the inputs from several sensors and cameras in the vehicle and able to drive itself based on these inputs without the necessity of a driver. As the sensor and camera technology is growing, the vehicles with certain autonomous capabilities are categorized in different levels from zero five, that are described in this section.

In the fourth section, an autonomous park system concept is developed by combining the technological advancements in autonomous driving and parking features. This feature concept is called Home Area Parking (HAP) and is intended to help the driver to park in a known parking spot autonomously. Additionally, it allows the driver to retrieve the vehicles from the known parking spot back to a pre-defined location within a certain distance. The aim of the feature and primary use cases were defined in a storyboard that consists of six sub-sections. Based on the initial assumpions, a boundary diagram is created. Accordingly, sub-systems and functions were defined and the interactions between them are explained.

Manufacturers take the advantage of customer surveys to predict a new product [3]. Therefore, the focus of the fifth section is the customer clinic in order to obtain initial feedback from the potential customers in several aspects such as target customers, customer perception, system scope and capabilities. Three main phases of the clinic are mentioned in this section: preparation, execution and results. After that, the results are analyzed and influencing factors based on the experiments during customer clinics such as road regulations, component limitations, system tolerances are summarized. Based on the analysis boundary diagram of the system is updated.

In the last section, the study of HAP concept is evaluated and the outcomes are summarized. Additionally, an outlook to the fields that are open for further improvement are mentioned.

2. PARK AID SYSTEMS

The history of the automotive industry started in the 1860s with the invention of internal combustion engine [4]. In the early days, focus was to transport people, however, industry evolved much faster after widening the focus on commercial and military vehicles. Due to the added conveniences in the daily life, the number of vehicles has been increasing steadily since decades. Increased number of vehicles gave rise to some problems such as parking and this made car manufacturers to focus on not only driving dynamics or fuel efficiency but also the convenience features that help drivers.

Parking remains as a daunting task for a significant number of drivers over the decades. Not only finding a parking spot but also getting into the spot might be tough sometimes especially in busy areas like city centers or narrow parking areas. Consequently, this led car manufacturers to invest and equip vehicles with different parking assistance features. These features can be classified in two major groups: passive park aid systems and active park aid systems.

2.1 Passive Park Aid Systems

Passive systems are mainly the systems that inform the driver audibly or visually about the surroundings. However, these systems do not take any action to help parking other than sensing the obstacles around the vehicle.

2.1.1 Rear View Cameras

The rear view camera is a type of video camera, which is assembled at the rear of the vehicle and the image is transferred to the center display in the vehicle. It helps the driver to see the objects directly behind the vehicle during reversing as shown in Figure 2.1. It was first used in 1950s for a concept vehicle [5]. Nevertheless, the application in a mass production car to feature them was in 1990s. After having parking sensor on the market, cameras were also combined with them to provide a clearer and more precise illustration of what is happening outside. There are usually overlays over the video to assist steering into a parking spot, as well. Overlays are dynamically adjusted by the steerig angle to indicate the backwards direction of the vehicle during reversing. Nowaydays, the cameras are not only used at the back but also used in the front and at the sides of the vehicle.

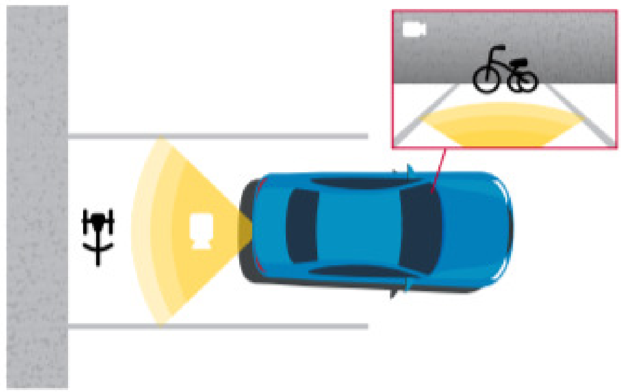


Figure 2.1 : Illustration of rear view camera function [6]

2.1.2 Parking sensors

Sensors used in parking systems were invented in the 1970s, however, the application in automotive as parking aid systems started in the 1990s [7]. These sensors are proximity sensors that sense the surroundings and estimate the distance between the car and obstacles around the vehicle. They are either electromagnetic or ultrasonic sensors. These systems alert the driver audibly and graphically about the obstacles while parking. A chime is played over the speakers in the vehicle when an object is decteted by the sensors and the frequency of the chime increases when the distance to the object decreases. There is usually a graphical illustration of the distance around the vehicle in the center stack display, as well. The sensors are located on the rear and front bumpers as shown in Figure 2.2. Usually four sensors are used in each direction. In some of the small vehicles, three sensors are also suffient to cover one direction.

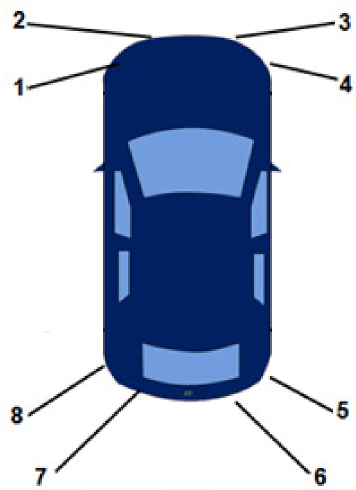


Figure 2.2 : Locations of the 8 sensors in the vehicle

2.2 Active Park Aid Systems

Active park aid systems do not only inform the driver about the surrounding objects but also actively help the driver to detect a suitable parking spot and park the vehicle in the found slot. These systems are sorted based on the levels of responsibilities taken over from the driver during parking.

2.2.1 Semi assisted parking assistance

Semi Assisted Parking assistance systems use the input from the sensors and determine whether the gap is large enough to park inside. After determining the parking spot, the steering is automatically controlled based on the parking algorithm, which constantly processes the inputs from twelve sensors around the vehicle. These sensors are located on the front and rear bumpers as shown in Figure 2.3. In order to cover not only the front and rear of the vehicle but also the sides, four of the twelwe sensors are located in each side by two. These sensors are especially required to support perpendicular parking to keep the distance to the sides under control. However, the driver has to operate gearshift, acceleration, brake and clutch. This system helps the driver to position the vehicle well in the parking slots and park in tight slots very easily. The system supports parallel and perpendicular parking as well as pull out assist when parallelly parked. Drivers do not usually need steering assist when the vehicle is perpendicularly parked since it is usually a straight drive out. Hence, it is not supported.

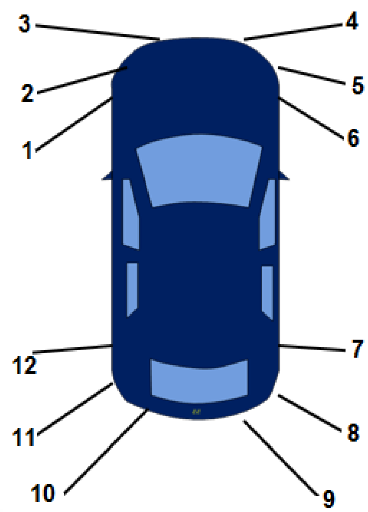


Figure 2.3 : Locations of the 12 sensors in the vehicle

2.2.2 Fully assisted parking assistance

Fully Assisted Parking assistance is a more advanced system compared to Semi Assisted Parking assistance. It is capable of handling not only the steering but also the gearshifting, acceleration and braking. The system can handle parallel and perpendicular parking. During the parking maneuvers, the driver keeps pressing the parking assistance button and can disrupt the maneuvers at any time by releasing the button. Therefore, the driver is still responsible from supervising the vehicle actions.

A special type of button, which is called dead man's switch, is used due to safety constraints and to maintain the responsibility with the driver. This type of switches have been in use extensively in the railway industry [8]. The working principle of the button requires constant pressure on it to operate the system [9]. If the pressure is reduced due to the fact that the driver becomes incapacitated becasuse of sickness or death, the system stops working. Opening the driver door or changing the steering angle sharply during parking maneuvers will also cause the cancellation of the operation. Additionally, the system immediately stops when an imminent danger of collision is sensed. This system can also help the driver to pull out from a parking position when the vehicle is parallelly parked. As explained before, pull out assist is also not supported by this feature.

2.2.3 Remote parking assistance

Remote Parking Assistance controls the vehicle's path into or out of a parking place by a remote device while the driver stands outside but nearby the car. This is comfortable and helpful for tight parking spots and garages, driving forward or backward directions. The user can easily open the driver's door for access and exiting without damaging the neighbouring vehicle and without getting clothing dirty. The driver has to stay around the vehicle and monitor the movements.

3. AUTONOMOUS VEHICLES

Autonomous vehicles are capable of driving themselves by sensing the surrounding via several onboard sensors and cameras without the need of any kind of human operation [10,11]. From the start of the 1950s until the 2000s, safety features were mainly based on passive systems like seat belts, airbags and antilock brakes [12]. Nowadays, vehicles are equipped with active safety features like Automatic Emergency Braking, Lane Centering Assist, Adaptive Cruise Control and Traffic Jam Assist, which are grouped under Advanced Driver Assistance Systems (ADAS) and assist the driver during the driving process. The evolution of the driver assistance technologies are leading to fully autonomous vehicles. Although the first self-sufficient and truly autonomous cars appeared in the 1980s, with Carnegie Mellon University's Navlab [11], there is no autonomous vehicle in the traffic today. However, it is expected customers will start using autonomous vehicles in the traffic by 2030 [2].

3.1 Advanteges of Autonomous Vehicles

On of the main reasons of having more and more organizations investing in autonomous vehicles is the advantages that will come along. Autonomous vehicles will not only help drivers to get rid of driving task but also to help the environment, economics and improved safety. Once the ratio of autonomous vehicles in traffic increases, they will collaborate to reduce the traffic congestion and optimize the traffic flow [12]. This will also bring efficiency in driving duration and fuel consumptions. The reduced driving duration will also mean more productive time for people. In addition to environmental and economical advantages, autonomous vehicles will also potentially reduce the accidents in the traffic. Human errors are playing a key role in traffic accidents. The statistics shows that the accident would be avoided up to 90 percent by utilizing more autonomous vehicles or vehicles with ADAS features on the roads [2].

3.2 Classification of Autonomous Vehicles

The Society of Automotive Engineers (SAE) has classified the autonomous vehicle levels based on the amount of tasks taken over from the driver. A classification system based on six different levels was published in 2014 by SAE International [13]. This classification is made according to the level of driver involvement instead of vehicle capabilities. A brief description of each level is mentioned below.

- Level 0: No automated actuations are possible and the human driver controls the vehicle. At this level only warnings are provided but no actions are taken to assist the driver.
- Level 1 (Driver Assistance): Vehicle control mainly stays with the driver and the vehicle is equipped with at least one ADAS feature which assists the driver in some occasions to have a shared control between the driver and the automated system. However, the automated system is not capable of taking the control itself and always requires driver supervision. Semi Assisted Parking assistance is an example for this level that leaves the control of the pedals to the driver and only takes over the steering maneuvers.
- Level 2 (Partial Automation): Vehicle is fully controlled by the system but the driver has to monitor and be ready to take over the control at any time. Therefore, driver has to keep the hands on the steering wheel during the drive although the vehicle is controlled by the system in order to ensure that the driver can take over the control immediately. As an example for this level, Fully Assisted Parking assistance can be considered. The vehicle parks itself by controlling the steering, braking, acceleration and the gear shifts. Nevertheless, the driver still has to keep pressing the parking button and monitor the environment in order to be able to take over control when needed.
- Level 3 (Conditional Automation): Vehicle is fully controlled by the system without requiring driver's constant attention under certain circumstances. Vehicle can manage situations like emergency braking and inform customer to get ready to take the control within a pre-defined time. The Traffic Jam Assist with Stop & Go can be used an example. This feature provides the comfort to the driver to leave the vehicle control to the feature up to a certain speed limit which is usually around 60 kph when the traffic is congested on the highway.

The vehicle continuously observes the surrounding vehicles and the lane markings to adjust the speed and hold the lane by handling acceleration, braking and steering.

- Level 4 (High Automation): At this level, no driver's attention is required during the pre-defined areas. During this time, the driver does not have to stay in the cockpit. Outside of these areas, the vehicle is also capable of putting itself in a safe state. The driver has the option to take the control if he/she wishes.
- Level 5 (Full Automation): No human intervention is required such as a robotic taxi that does not have a cockpit or a steering wheel in the vehicle. The humans in this kind of vehicles are only be the passenger and no influence on the vehicle control.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 3.1 : Summary table of Autonomous Vehicle Classifications by SAE [13]

4. AN AUTONOMOUS PARK SYSTEM CONCEPT - HOME AREA PARKING

Significant advancements during the last decade in parking features and driver assistance systems towards autonomous driving made out the subject of this thesis and resulted in an autonomous park system concept, which is called Home Area Parking (HAP).

4.1 Concept Description and Boundary Diagram

4.1.1 Concept description

The Home Area Parking concept is designed to park the vehicle into or out of a known parking place triggered by a smart remote device, which is working as a remote control and monitoring device for the user. HAP is a comfortable and helpful feature for tight parking spots and garages as well as for long and complex paths, driving in both directions forwards or backwards.

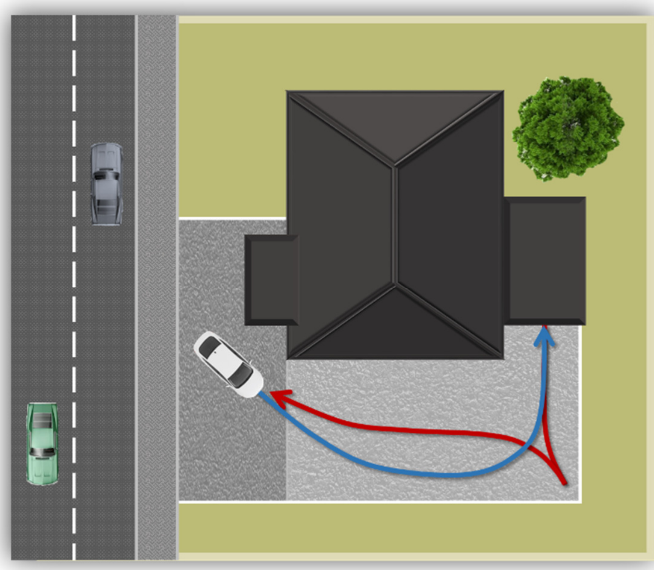


Figure 4.1 : Home Area Parking concept

The user does not have to constantly supervise the drive. He/she can leave the vehicle in a certain place and let the vehicle park itself. The user can also retrieve the vehicle at a convenient place. The feature scope is only planned for private properties at first due to the fact that the autonomous driving is not yet allowed because of ongoing legal regulations in Europe.

The HAP feature shall provide instructions and information to the driver on the center stack display and on smart remote device. Learning procedure will be activated via the Human Machine Interface (HMI) menu in the center stack. After learning procedure is initiated, user drives the vehicle from the initial position, which is called as drop off zone, to the parking position once and the vehicle records the path meanwhile. The chrachteristics of the path is planned to be saved by processing the image from the front camera, which is in use for advanced driver assistance features, in the vehicle during the learning procedure. The vehicle has to be brought to the same drop off zone within the allowed tolerances in order to let the vehicle find and follow the recorded route. This is presumed to be one meter around the vehicle and up 15° rotation from the pre-saved position.

GPS signal is not considered as main localization input since the the signal is not available in closed areas in case of feature usage in underground car parks. However, it is planned to use the GPS data to identify the vehicle location and filter the pre-saved routes around this location. By this way, the user can easily choose the pre-saved routes, which can be activated at the current location.

If the targeted parking position has an electrical garage door, it is also planned to incorporate the garage door operation capability by the system. When the vehicle is at final parking position, learning procedure is finalized by the driver. During the procedure, driver is informed visually on center stack. The procedure can be terminated at any time. The user has to repeat the learning procedure also for the backward route from the parking position to the initial position since the route and the vehicle orientation might be different. The position where the user wishes to pick up the vehicle is called pick up zone.

After the learning procedure is completed successfully, the user can call back the vehicle or command the vehicle to go to the parking position via the smart remote device. The smart remote device is the remote control interface for the user to give commands and get the status information about the parking progression. Since the smart phones and/or tablets are widely used nowadays, it is planned to create an application which is compatible with smart phones and tablets to utilize them as smart remote device instead of having a separate remote control device. By this way, the flexibility of using different communication protocols such as GSM, mobile data network, Wi-Fi or Bluetooth connection between the vehicle and the SRD is provided. Once the command is given, the vehicle will start driving and follow the recorded route up to the speed of 4 kph autonomously.

4.1.2 Boundary Diagram

Boundary diagrams is a graphical representation of a system and the interactions with elements of the system such as subsystems and actuators. By considering the current ADAS features implemented in new Ford Focus, an initial boundary diagram is created to represent how the HAP system is presumed to function.

The boundry diagram, consists of ten sub-systems and several actuators, sesnsors and cameras. The boundry diagram is shown in Figure4.2. Brief description of each sub system are mentioned below:

1. ABS: Anti-lock Braking System is responsible of brake controls and fulfilling the breaking requests from ADAS features such as Fully Assisted Parking.
2. PCM (ECM & TCM): Powertrain Control Module or the combination of Engine Control Module and Transmission Control Module are responsible from all engine related functions. It processes the command from the ADAS features and controls the vehicle speed, gearshifts and acceleration functions.
3. BCM: Body control module is one of the complex modules which manages several functions in the vehicle such as lighting, locking, security etc.
4. BLEM: Bluetooth Low Energy Module is used to communicate between SRD and the vehicle via Bluetooth and handle the HAP controls.
5. TCU: Telematics Control Unit works not only as a modem but also controls some functions such as cellphone interface, Wi-Fi hotspot, emergency call, remote lock/unlock, location services etc. TCU will also handle the GSM or mobile data network communication between the SRD and the vehicle.

6. In-vehicle HMI: User interface in the vehicle to interact with the driver and the passengers. The center stack display is planned to be used to host the HAP user interface.
7. SRD: A mobile phone or a tablet which can run the mobile application to use HAP user interface to send commands or monitor the HAP system.
8. GDO: Garage Door Opener is an electronic device which is capable of sending open and close commands to the garage doors via radio frequency signals.
9. DAT Domain Controller Module: This module is the main processor of the inputs from the several sensors and the cameras in the vehicle in order to integrate and control the sophisticated active and passive safety features.
10. PSCM: Power steering (control module) systems support the driver to rotate the steering wheel with less efforts by controlling the actuators. These actuators can also handle the rotation of the steering wheel as it is done in Semi Assisted Parking.

The front view camera and the twelve sensors provide the main inputs about the vehicle environment. Front view camera is usually located on the windshield and monitors the objects as well as the signs and lanes on the road. Most of ADAS features such as lane keeping detection, light object detection, Traffic Sign Recognition uses the input from the front view camera. Ultrasonic sensors, which are also used in Fully and Semi Assisted Parking features, are examined in Section 2.

The high level interface between the elements is shown in Figure 4.2. Commands from the SRD is transmitted to TCU module and the TCU transfers the HAP related commands to BLEM. Domain controller module receives the HAP related inputs from BLEM and accomadates the HAP controls. This module carries out the Lateral control, required speed calculation, path planning and environmental sensing functions. After domain controller's analysis of the commands and the inputs from the camera and the ultrasonic sensors, it determines the required speed and the path. This information is passed through to PSCM, ABS, PCM and BCM to get the vehicle ready for limited motive start. Limited motive start is a state that the vehicle capable of fullfiling not all but certain functions such as engine start, following the pre-saved route, controlling the exterior lights. These functions are mainly the ones which are required for autonomous driving. ABS, PSCM and PCM are controlling the vehicle to accelerate, to brake, to shuft the gears and to steer according to the route conducted by the domain controller.

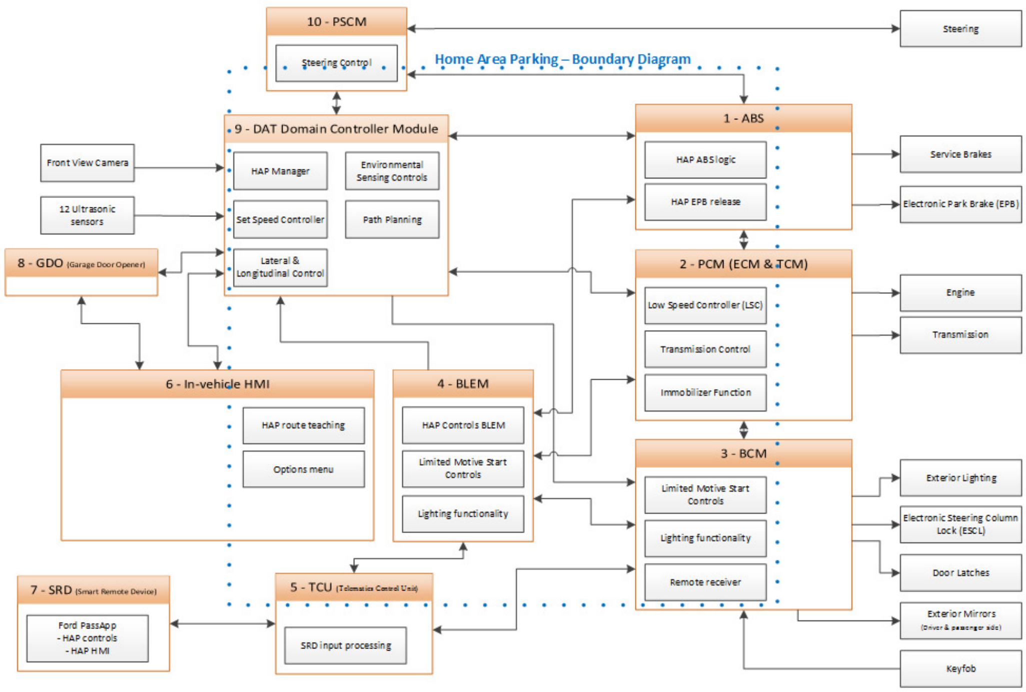


Figure 4.2 : Boundary diagram

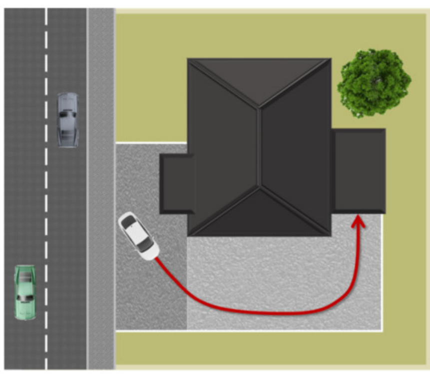
4.2 Potential Plot Scenarios

Potential plot scenarios where the HAP feature can be used are investigated and grouped in six categories. The variables in each plot are also listed in seven segments and can ben seen in Figure 4.3. Each segment has simple and complex cases ordered from left to right. Some of the complex cases will not be in the scope of this study as per concept definition such as public road involvement. These cases are highlited in red. The orange cases will be determined after the customer clinic results and kept out of scope for now, as well. The variables that are applicable in each scenario are highlighted in bold borders.

4.2.1 Single-family house

As a starting point, a single-family house with a garage next to that is considered. The ground, where the feature will be used, is only private ground and the vehicle might need to drive some curves to get into the garage from the entrance of the house.

Reaction to static objects is defined as “stop & abort” whereas reaction to dynamic ones is defined as “stop & wait”. The dynmanic objects are supposed to clear the route in a short time so that the vehicle can continue parking. However, the system is not design to drive around the static objects by itself. Therefore, the systems cancels the parking action and informes the user. Communication with the garage door could be either with or without. One or more garage doors are not making the scenario more complex as well as the gradient of the ground in this plot. Since the private ground is considered in this scenario, traffic rules are also not applicable. This plot is the most convenient use case for the feature and will also be used in the storyboard.



	Simple	→	Complex
Ground	Private only	Private & public	Public only
Turning	Without	With	
Reaction on static obstacle	Stop & abort	Override	Drive around
Reaction on moving obstacle	Stop & abort	Stop & wait	Drive around
Communication w/ garage door	Without	With	Double (gate and door)
Gradient	Flat	Inclined	
Knowledge of traffic rules	Without	With	
Legend	Within scope	To be checked	Out of scope

Figure 4.3 : Single-family house scenario

4.2.2 Multi-family house open parking space

In this plot, a multi-family house with inner parking area within the private ground is considered. The applicable variables are shown in bold borders below. The potential difference to the previous scenario is that there might be other traffic and pedestrians, which might cause delays to complete parking. Nonetheless, this scenario is in the scope of the feature.

	Simple	→	Complex
Ground	Private only	Private & public	Public only
Turning	Without	With	
Reaction on static obstacle	Stop & abort	Override	Drive around
Reaction on moving obstacle	Stop & abort	Stop & wait	Drive around
Communication w/ garage door	Without	With	Double (gate and door)
Gradient	Flat	Inclined	
Knowledge of traffic rules	Without	With	
Legend	Within scope	To be checked	Out of scope

Figure 4.4 : Muti-family house open parking space scenario

4.2.3 Multi-family house underground parking area

In this set up, a multi-family house with an underground parking area within the private ground is considered. The only difference from the previous one is that the garage door opening needs to be handled and the entrance of the garage is downhill. The angle of the gradient might cause false detection especially during transitioning between flat and inclined grounds. If the gradient is so high, the ultrasonic sensors might detect the uphill inclined ground as an obstacle. Nevertheless, this scenario is still simple and within the feature scope.

Simple → Complex

Ground	Private only	Private & public	Public only
Turning	Without	With	
Reaction on static obstacle	Stop & abort	Override	Drive around
Reaction on moving obstacle	Stop & abort	Stop & wait	Drive around
Communication w/ garage door	Without	With	Double (gate and door)
Gradient	Flat	Inclined	
Knowledge of traffic rules	Without	With	

Legend	Within scope	To be checked	Out of scope

Figure 4.5 : Multi-family house underground parking area scenario

4.2.4 Multi-family house underground parking area and entrance

The difference in this plot is that the entrance of the house is also under the ground. This time the vehicle drives on a flat surface and does not need to handle the garage door. This is similar to the second scenario without a garage door operation and will be in the scope of the study.

Simple → Complex

Ground	Private only	Private & public	Public only
Turning	Without	With	
Reaction on static obstacle	Stop & abort	Override	Drive around
Reaction on moving obstacle	Stop & abort	Stop & wait	Drive around
Communication w/ garage door	Without	With	Double (gate and door)
Gradient	Flat	Inclined	
Knowledge of traffic rules	Without	With	

Legend	Within scope	To be checked	Out of scope

Figure 4.6 : Multi-family house underground parking area and entrance scenario

However, the potential difficulty here might be with the route recognition since the colors and the surrounding objects like repetitive columns are very similar. Besides, parking lots might be also tricky since the vehicles parked in those slots might be different or not present there at every time the feature is used.

4.2.5 Multi-family house underground parking area with traffic light

Although there are not much differences in this scenario compared to the previous ones, it is not in the scope of the study since there is a traffic light that controls the right of way to enter or exit the underground garage. Hence, the system is not able to handle the traffic lights. That's why this plot is taken out of the scope.

	Simple →		Complex
Ground	Private only	Private & public	Public only
Turning	Without	With	
Reaction on static obstacle	Stop & abort	Override	Drive around
Reaction on moving obstacle	Stop & abort	Stop & wait	Drive around
Communication w/ garage door	Without	With	Double (gate and door)
Gradient	Flat	Inclined	
Knowledge of traffic rules	Without	With	
Legend	Within scope	To be checked	Out of scope

Figure 4.7 : Multi-family house underground parking area with traffic light

4.2.6 Multi-family house with route on public/private area

The entrance of the house and the garage are on the public road in this scenario. Therefore, the route has to be through the public road. This will keep this scenario out of the scope due to public road involvement.

	Simple →		Complex
Ground	Private only	Private & public	Public only
Turning	Without	With	
Reaction on static obstacle	Stop & abort	Override	Drive around
Reaction on moving obstacle	Stop & abort	Stop & wait	Drive around
Communication w/ garage door	Without	With	Double (gate and door)
Gradient	Flat	Inclined	
Knowledge of traffic rules	Without	With	
Legend	Within scope	To be checked	Out of scope

Figure 4.8 : Multi-family house with route on public/private area

As public roads may require different legal regulations, speed limits or right of ways depending on the area or country and it is not possible to identify all cases.

All in all, the feature is designed to be only used in private properties where the vehicle and pedestrian traffic is limited and not subject to road regulations. Otherwise, it would require additional technical solutions in cases of traffic lights on the route or obeying certain speed limits. These cases are not considered in the scope on this concept for now.

4.3 Home Area Parking Storyboard

In order to illustrate and define the high level use cases, a storyboard is created for the HAP feature. The reason of using the storyboard is to visualize the each step of a use case in sequence and to show the flow of actions step by step. The storyboard has six subsections. Each section itillustrates the vehicle movements and the driver interactions with the system for one use case.

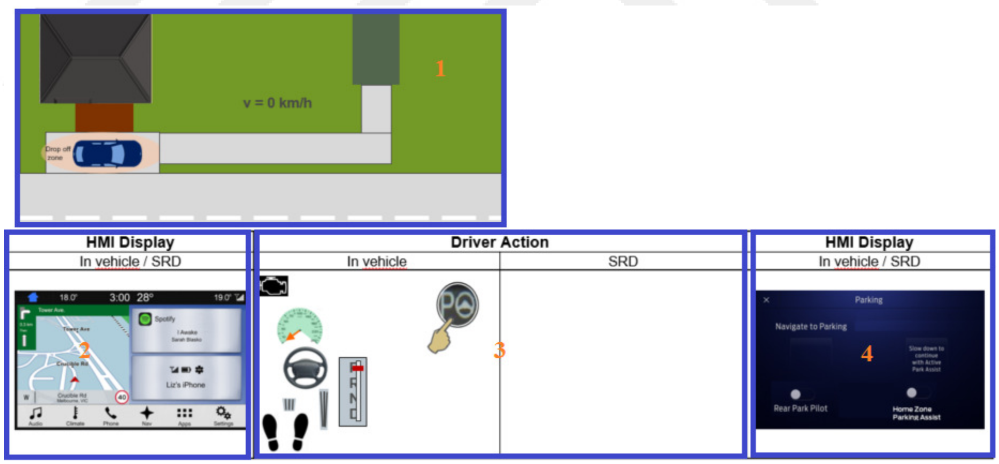


Figure 4.9 : Storyboard layout

The storyboard layout consists of four sections which are shown in Figure 4.9.

1. Pictorial representation in aerial view: This section illustrates the scenario, vehicle position and movements in the plot
2. Initial HMI state: This section shows the initial HMI state in the vehicle or on SRD at each slide
3. Trigger Actions: This section highlights the actions, which are required to move to the next state, taken in the vehicle and on SRD by driver or system.

4. Sequent HMI state: This section illustrates the next HMI state triggered by the actions shown in section 3 above.

Storyboard was based on a simple plot with single-family house where the user wishes to leave the vehicle in front of his/her house door and commands the vehicle to park in his/her private garage which is near of the house. As a first step, driver has to run the learning procedures so that the vehicle can record the start and end points as well as the route between those points.

4.3.1 Forward path learning procedure

In this section, the learning procedure, which is required before being able to use the feature, is visualized in the storyboard. The user has to drive the vehicle into the place where he/she likes to define as drop off zone with a certain orientation and has to stop the vehicle. The learning routine is activated in the HMI menu in vehicle center stack within the parking sub-menu. Since the feature is designed to be used in private properties only, a disclaimer message needs to be accepted by the user that the feature is activated in the private properties only.

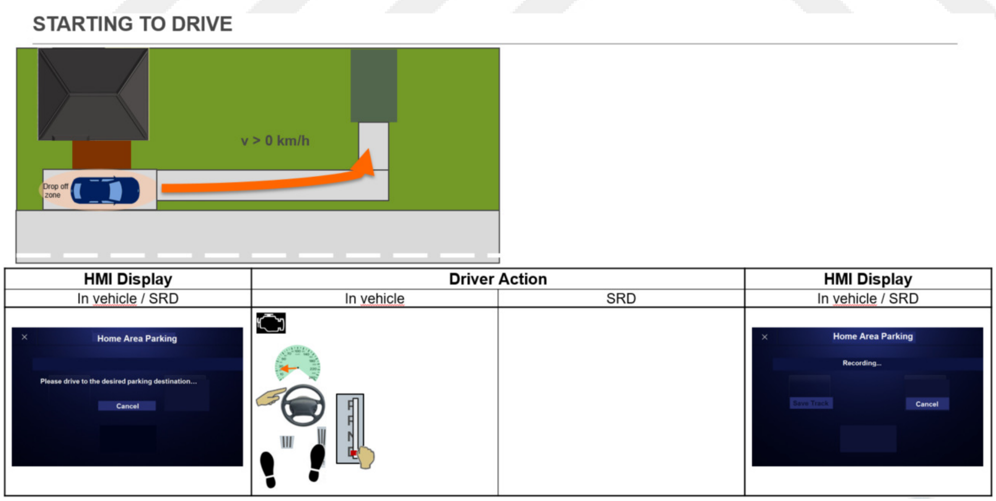


Figure 4.10 : An example storyboard slide from the forward path learning

After the initialization steps, the user presses the record button and starts driving the vehicle to the garage. While driving, the vehicle records the route from the start to the end point until the driver stops the vehicle and finlaizes the recording. Once the vehicle is stopped, the route can be saved and also the default name for the route can be renamed.

4.3.2 Backward path learning procedure

This routine mainly works the same way as forward path learning procedure, however, it has to be recorded again since the start point, the end point and the orientation might be different as well as the route between two points. Therefore, it has been illustrated in a separate section in the storyboard. An example slide from the backward path learning procedure storyboard is shown in Figure 4.11.

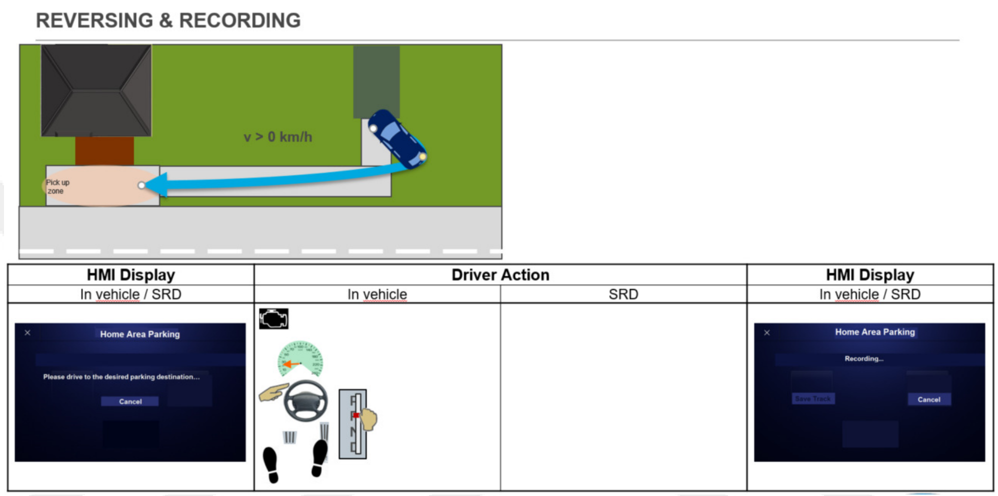


Figure 4.11 : An example storyboard slide from the backward path learning

4.3.3 Sending away to pre-saved parking place

After successful completion of the learning procedures, the feature can be used as intended. The user brings the vehicle in the drop off zone, leaves the vehicle and locks the doors. If the vehicle is in the drop off zone with the right orientation, the user can choose one of the pre-saved parking routes via the smart remote device menu. If not, the feature cannot be activated unless the vehicle is located in the right position. After selecting the preferred parking route, the user sets off the self-parking action by a finger gesture on the SRD in order to avoid setting off the self-parking actions unintentionally. Afterwards, the vehicle starts the engine, turns the hazard warning lights on to indicate the autonomous driving, shifts the gear and starts creeping at a maximum speed of 4 kph to the preferred parking place by following the pre-saved route. Meanwhile the SRD indicates that the parking is in progress. Once the vehicle arrives to the destination, vehicle shuts off the engine, turns off the hazard warning lights, shifts the gear to Park position and sends a notification that the parking is completed successfully to the SRD. During creeping, the vehicle is capable of shifting the gear and engage or disengage the parking brakes.

4.3.4 Calling back to pre-saved parking place

This section of the storyboard is designed in the same way as the previous section of sending away to the pre-saved parking place, however, the only difference is that the vehicle is supposed to be in parked state within the pre-saved zone and the user can directly call it back to the pick up zone by using SRD.

4.3.5 Removal of obstacles in the route during creeping

This section illustrates the situations in which the vehicle faces an obstacle through the pre-saved route. In such cases, it is determined that the vehicle first stops and waits up to 15 seconds in case the obstacle is not standstill and gets out of the route itself. If the obstacle still blocks the route more than 15 seconds, the vehicle sends a notification to the SRD so that the user has the chance to check and remove the obstacle or cancel the self-parking action. In case the obstacle is removed, then the vehicle continues to finish the self-parking action.

4.3.6 Driver Override in Case of Obstacle in the Route During Creeping

The only difference in this section from the previous one is that the user takes the option of cancelling the self-parking action after receiving the notification. In such cases, the vehicle stops the engine, turns off the hazard warning lights and goes into the parked state at the current position. The user has to park the vehicle manually or take the vehicle back to the drop off zone in order to be able to start HAP feature again.

5. CUSTOMER CLINIC

Customer clinic is a very useful method that can provide a direct feedback about a new product or a feature from the customers. It provides prominent information such as usability, demand in the market, customer perception, user experience, potential risks and the opportunities in the market for the new products as well as the existing products [14]. As it is quite important to have customer feedback during the development phase of a product, it is very often used in product development. Therefore, it will also be used in this phase of the Home Area Parking feature to verify the customer perception in general as well as the feature boundaries before having the final design.

5.1 Preparation

Since the system is still in the design phase and very open for improvement, the hardware design is postponed to be defined after the clinic results. This approach also helps in order to avoid prototype and re-design costs before the feature reaches a maturity level that can be marketed in the automotive industry. Therefore, a driver will simulate the autonomous driving sections of the feature during the customer clinic.

A new Ford Focus with shift by wire transmission was selected to be used in the customer clinics and can be seen in Figure 5.1. The reason is that the vehicle must be capable of shifting between gears itself and this is only possible with shift by wire transmission by which the gear shifts are handled electronically without any mechanical movements. A picture of the shif by wire knob is shown in Figure 5.2. Customer and vehicle interactions during the clinic were intended to be recorded inside and outside of the vehicle for further analysis. Hence, two cameras were installed in the vehicle. For this reason, informative stickers were also stuck on the vehicle in order to warn and allow surrounding individuals to use the right of privacy and get the recordings erased according to General Data Protection Regulation (GDPR).

Figure 5.1 : Picture of the vehicle used for the customer clinic

Figure 5.2 : Ford shift by wire knob (eShifter)

The participants were determined within the company due to competitiveness reasons and the insurance policies for the participants. The age distribution of the 23 participants is shown in Figure 5.3. Each participant has a unique plot for the customer clinic, which will contribute to experience the different scenarios and use cases.

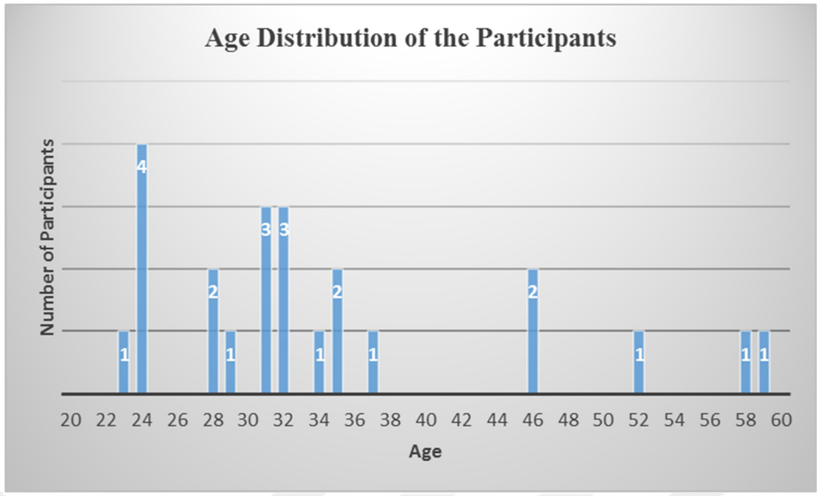


Figure 5.3 : Age distribution graph of the participants

After arranging the vehicle and the participant, the HMI demonstration and the communication between the vehicle and the SRD were the next challenges. In order to have a simple and efficient solution for these challenges, a HMI demonstration was developed by using the open source licensed QT software which is used for user interface developments and supported by several platforms like Android, iOS and Windows operating systems. A tablet, which is shown in Figure 5.4, was installed in the vehicle to replicate the display of the vehicle and provide demonstration of HAP HMI to the driver during the clinic.

Figure 5.4 : The HAP HMI demonstration on the tablet

On the other hand, a smart phone, which is shown in Figure 5.5, was also running the application which is adapted to provide HAP interface and keep the communication with the tablet via the Wi-Fi network which is hosted by another smart phone. The tablet and the SRD communicates bidirectionally and are able to send notifications to each other as defined in the storyboard.

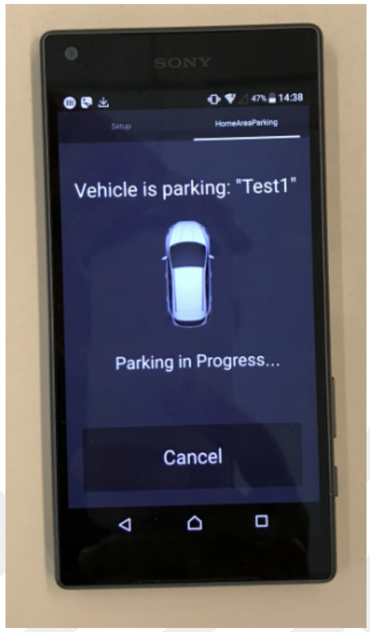


Figure 5.5 : The HAP HMI demonstration on SRD

5.2 Execution of the Customer Clinic

After setting up the equipment and the vehicle, customer clinics began. Before the first clinics, the steps that need to be followed were defined in order to have a comparable outcome from each customer clinic. Since the feature will be simulated by a driver, clinics decided to be run by two people: the presenter and the driver. The presenter role is mainly to accompany the participant throughout the clinic, explain the HAP feature and make the participant familiar with the HMI on the SRD and in the vehicle, which is shown in Figure 5.6. The driver role is to simulate the autonomous driving functions which the HAP feature is designed to have.

A questionnaire was also prepared to collect feedback about the feature from the participants at the end of the clinics. The questionnaire consists of four sections. It starts with generic questions about the participants and the feature. Then, the processes of teaching, sending away and calling back follow.

Figure 5.6 : Picture of the HMI tablet with HAP interface in the vehicle

After driving to the participant's location and meeting with him/her, the steps followed in the clinics were:

- Preparation
  - ➢ Pre-briefing the participant: Introduction of the clinic staff, information about the video recording and estimated clinic duration, getting the acknowledgement sheet signed by the participant.
  - ➢ Setting up the equipment: Installing the cameras, HAP HMI tablet in the vehicle, running the application in the smart phone, setting up the Wi-Fi connection for the communication between tablet and the SRD
  - ➢ Getting familiar with the area: Observation of the parking location, possible drop off zones and routes, checking the garage door whether it is mechanical or electrical.
  - ➢ Removal of the obstacles around: Making sure that there is no obstacle through the potential routes which could have an impact on the clinic operation.

- Introduction
  - Explanation of the feature to the participant: Briefing the participant what the feature intent is and the use cases that will be used during the clinic.
  - Explanation of the procedure and tolerance of the drop off zone: Explanation of the clinic flow, teaching and operation phases. Highlighting the importance of the drop off zone and the requirement to get into the same zone with the same orientation to be able to use the feature.
- Teaching
  - Participant takes driver seat, presenter takes passenger seat, and simulation driver sits in the back to observe the route driven by the participant.
  - Explanation HMI on the tablet and guiding the participant through the HMI screens.
  - Participant starts HAP feature on the tablet and follows the instructions
  - Participant positions the vehicle in drop off zone
  - Instructions on the tablet to initiate route recording
  - Participant drives to respective parking place
  - Saving the route and renaming
  - Starting teaching new route (for calling back) with the same way
  - Instructions on the tablet to initiate route recording
  - Participant drives back to desired pick up location
  - Saving the route and renaming
- Sending Away
  - Participant drives out of his/her private ground and then pretends like he/she is just coming back home
  - Participant stops in drop off zone
  - Everybody steps out of vehicle
  - Simulation driver takes the driver seat
  - Presenter explains the HMI on the smart phone

- Participant locks the vehicle and follows the instructions on the smart phone
- Once the participant commands to start on the smart phone, simulation driver drives to the parking place by following the pre-taught route with a speed up to 4kph
- Simulation driver sends notification to participant that the vehicle is driving to the parking place via the tablet in the vehicle
- Simulation driver sends notification that the vehicle has been parked in the desired location.

- Calling Back
  - Participant pretends he is about to leave home
  - Participant follows the instructions in the smart phone to call back the vehicle
  - Once the participant commands to start on the smart phone, simulation driver drives to the pick up zone by following the pre-taught route with a speed up to 4kph
  - Simulation driver sends notification to participant that the vehicle is driving to the pick up zone via the tablet in the vehicle
  - Simulation driver sends notification that the vehicle has been parked in the pick up location
- Sending Away (with Obstacle)
  - Same instructions are followed in the Sending Away section
  - Once the vehicle starts to drive to the parking position via the pre-taught route, presenter stops in front of the vehicle for more than 15 seconds.
  - The simulation driver sends the notification via the tablet to the participant that the vehicle detected an obstacle on the route.
  - Once the obstacle moves away, the vehicle continues to the parking position.
- Questionnaire & Feedback

5.3 Results of the Customer Clinic

The clinics were executed successfully based on the instructions above during 4 week's time successfully. It provided an invaluable insight of the target customers, customer perception of the feature, easiness of the usage as well as the fall backs of the design.

In order to collect some generic information about the participants, their driving habits and smart phone/tablet usages were questioned at the beginning. Based on the questionnaire the majority of the participants (22 out of 23) drives a vehicle every day and own a vehicle. Only one participant does not have a car but drives in weekly basis. All participants have a smart phone and are familiar with tablets and smart phones which made the clinics run smoothly. Besides, these results indicate that the majority of the participants are within the target customer group and their feedback is a prominent insight to refine the feature.

Other questions regarding to the HAP feature are summarized in Table 5.1 and the results are shown in Figure 5.7.

Table 5.1 : Table of questions regarding to HAP feature

Question number	Question
Question 1:	Participants were asked whether they have used any automated park aid systems before.
Question 2:	Participants were asked whether they liked the HAP feature
Question 3:	Participants were asked whether they find the HAP feature comfortable
Question 4:	Participants were asked whether they would use the HAP if they had in their vehicle
Question 5:	Participants were asked whether they would do any modification at their place of residence to be able to use the HAP (Eg: electric garage door)
Question 6:	Participants were asked whether they can use the HAP at their place of residence
Question 7:	Participants were asked whether they would order this feature if they bought a new Ford vehicle

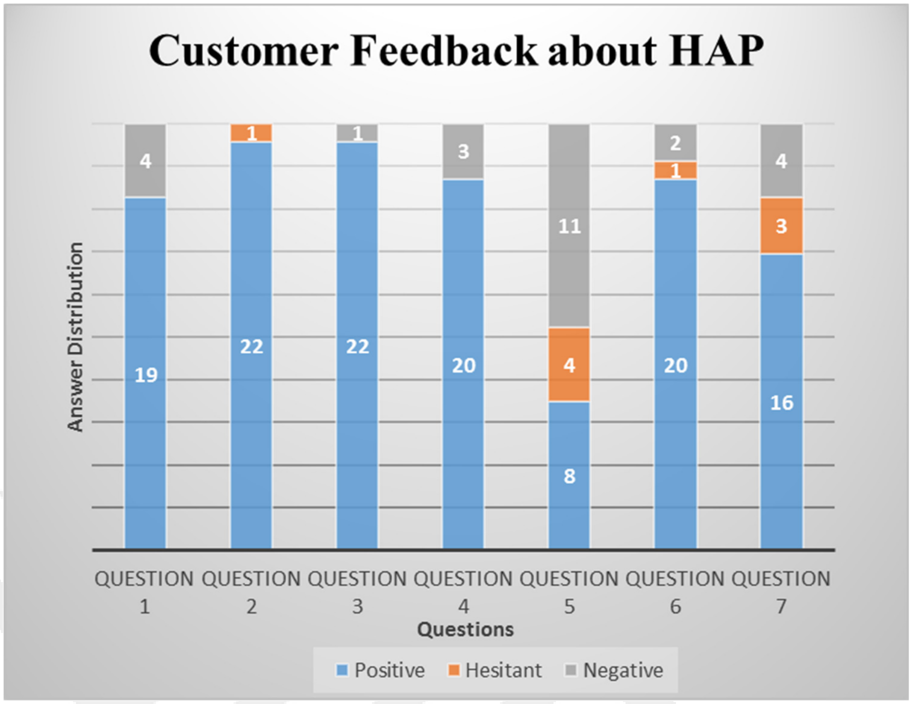


Figure 5.7 : Graphical illustration of the answers to questions in Table 4.1.

In addition to high-level outcomes in the Figure 5.7, a deeper glance on the results was examined to find the correlation between the answers and gain more meaningful results. In the first question, four participants who have never used an automated parking feature were at the age of 24 (3 participants) and 32. It is not possible to correlate the result with the age since there is another participant at similar age group who experienced the automated park aid systems. However, all these four participants liked the feature and found it comfortable.

The participant, who gave the only hesitant answer to second question, did not like the feature as he/she found it quite slow and is concerned about the potential accident risks when the vehicle is not controlled by the driver. Thus, he/she prefers to park himself/herself. In parallel to this feedback, he/she did not find it comfortable, which explains the result of the Question 3.

Three participants stated that they would not use the feature even if they had it in their vehicle. One of those answered this way since the participant is not able to use the feature as intended in his/her place of residence due to very short distance between the garage and the entrance. The other two participants at the age of 32 and 35 prefer to park themselves although their place of residence is suitable to use it. Especially, one of those liked the feature and found the feature comfortable but he/she still likes to park himself/herself.

The majority of the participants who was willing to use the feature accept to make modifications at their place of residence to be able to use the feature. One third of those, which are shown as hesitant participants, accepted only small modifications such as addting remote control to the existing electric garage door. Eleven participants, three of which did also not like the feature, did not accept to make any modifications.

Two of the participants answered the Question 6 negatively since they cannot use the feature due to the layout of their place of residence. One participant was hesitant about using the feature since he/she does not use the underground park and usually parks on the street near the building entrance.

The seventh question shows that the majority of the participants would order the feature, however, three participants are still hesitant. One of them stated that it depends on the price although he/she liked it and can use it at the place of residence. One of them is not able to use the feature and the last one did not state any reason for hesitation. Two of the four participants who would not order the feature are the ones who prefer to drive by themselves. One of the remaining two thinks that it would not be worthy to order when it is compared to advantages it provides with the current place of residence due to short distance between the drop off zone and the park place. Last one did not specify the reason not to order it although he/she liked the feature and can use the feature. Nevertheless, this participant marked the lowest pricing option in the questionnaire so it is most likely due to the same reason with the one before this participant who thinks that it would not be worthy to order when it is compared to advantages it provides.

The participants were also asked how much they would pay for the HAP and the distribution is shown in Figure 5.8. Only one participant, who did not find the feature comfortable, did not want to answer this question and did not want to buy the feature.

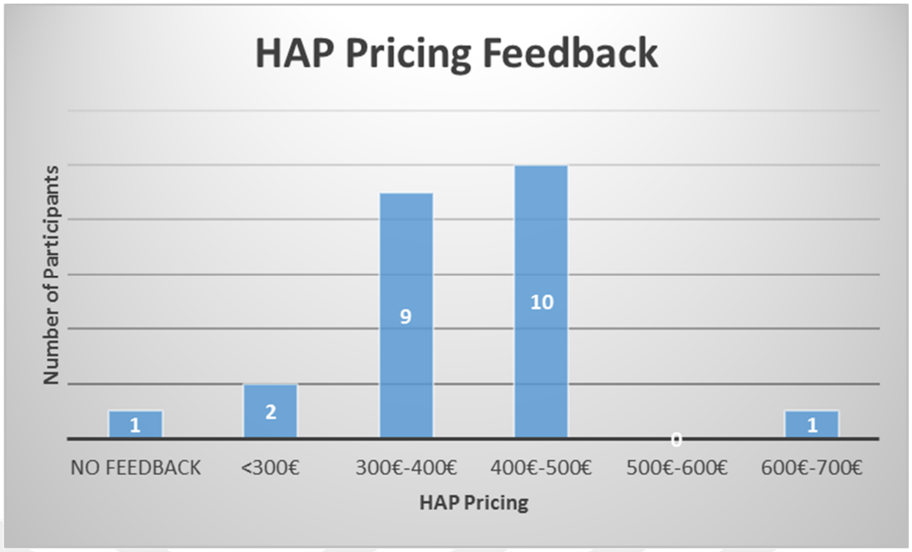


Figure 5.8 : HAP pricing feedback

In the questionnaire, there were also sub-sections for learning, sending away and calling back procedures in order to find out if there is any improvement required in the HMI or single pieces of the procedures.

Learning Procedure:

- All participants found it simple and easy.
- Majority of the participants (20/23) found the HMI menu self-explaining whereas three participants did not agree to this. One of them complained that the keyboard was not hidden automatically once the new name was entered and the user had to hide the keyboard to save the name. Similarly, the second one also referred to the renaming process. The third one complained that there was no notification that the renaming was successful.

Sending Away Procedure:

- All participants found it simple.
- Majority of the participants (22/23) found the HMI menu self-explaining whereas one participants did not find it self-explaining. The reason of this was that it is not possible to distinguish which routes are sending away or calling back routes in the saved routes list in case that the user did not name the routes clearly.

Calling Back Procedure:

- All participants found it simple.
- Majority of the participants (22/23) found the HMI menu self-explaining whereas one participants did not agree to this. The reason was that there was no optic or haptic feedback once the finger gesture to start calling back was performed correctly.

The complaints about the user interface and HMI menu was minor since only three participants criticized it and it was mainly about the renaming process. The potential root cause is that the user interface was created in order to meet the minimum requirements to operate the feature and was not designed by the HMI development team who has vast experiences on this topic. Therefore, this criticism will be addressed to HMI team for an improved design but is assumed to be minimized further once the final interface is designed together with the HMI development team and follows the same style as the other features and systems with integrity.

5.4 Analysis of the Results

In addition to the potential customer feedbacks about the HAP feature, the customer clinic also helps to validate the system design and the limitations which will be used to refine the system before proceeding to the next steps.

First of all, the customer clinics verified the initial assumption of not offering the feature on public roads again. The main reason is that public roads might have unpredictable vehicle, cyclist and pedestrian traffic which requires different right of ways depending on the scenario. The available systems in the vehicle are not capable of differentiating the objects around the vehicle to overcome this issue. Moreover, it would require a more complex algorithm to overcome this issue even if it was possible to recognize the objects around the vehicle. This would be possible once the autonomy level gets higher in a wider spectrum of the vehicles. In addition, the public roads may have different speed limits which might not be obeyed during the creeping action since the speed of the vehicle is limited. On the other hand, having unpredictable traffic on public roads might cause system interruptions in many cases due to detected objects around and might disturb the user with many notifications that the parking maneuver is paused. Also the other road users might be disturbed by the creeping vehicle that stops all the time. This might also affect the customer satisfaction and cause the deviation from the initial idea of comfortable parking experience without driver supervision.

Secondly, the sustainability of the connection between the vehicle and the SRD was a significant risk of not being able to use the feature. During the clinics, it was not a problem since the participants were also staying around the vehicle within the Wi-Fi hotspot range to observe the vehicle behaviors and the connection remained stable. However, it is very likely that the connection will be lost in some of the real use cases where the garage and the entrance of the house are in different ground levels. In order to overcome this problem, it is suggested to use more than one communication protocol. As an example, Bluetooth with a combination of GSM network or mobile network so that Bluetooth can be the primary protocol to stay connected within the 100m range and GSM or mobile network can take over in longer distances if available. However, this might also not be sufficient in some use cases as the Bluetooth range can be affected due to Wi-Fi signals, microwaves, walls, bodies, electronic devices etc. Another solution would be to have Wi-Fi coverage through the entire route. Depending on the communication protocol and the usable bandwidth, the images from the built-in cameras can also be transmitted directly to the SRD to provide information about the progress. All in all, it is suggested to continue parking in case of lost communication after the parking maneuver is started and inform the driver that the communication is interrupted so that the driver gets the possibility to come closer and go back in the connection range. In case of facing an obstacle during lost communication, vehicle stop and waits for the time out as always and cancels if the time is out and the obstacle is not removed. Driver gets the notifications once the connection is established again.

One of the other communication challenge is with the garage door opening mechanism. During the clinics most of the garage doors were either manual or manually operated electrical doors via a lock or a rope. However, the concept requires an electrical garage door which can be opened/closed by the HAP system. In order to ensure the usage of the feature with garage doors, a universal garage door opener is required in the vehicle. Based on the investigations so far, there are several companies and several systems used on European markets, which makes it difficult to have a universal opener. Only in Germany market, there are 21 companies who are registered to an organization, that is specialized for door systems and called BAS.T [15]. In contrast to the EU, a garage opener company called HomeLink has almost 90% market share in the United States of America. In case of difficulty to have a universal garage opener, it could be an option to limit the support to the majority of the opener protocols and get this assembled in the customer service division instead of the manufacturing plant. Alternatively, vehicles might be built with a certain opener system and a converter is required to be used by the customer in order to adjust the opener systems in the garage. However, the clinic results show that the customers do not tend to do major modifications at their place of residence to use the feature. Therefore, a result of the clininc, it was decided to handled it in a separate investigation to determine the optimal option. The reason of this is that it has a very small interface in the overall system by only executing the open and close commands in the vehicle.

Another issue which was also observed during the clinic is the minimum distance around the vehicle and surroundings. In some of the use cases, the vehicle has to be driven through very narrow areas where the distance between the vehicle and the walls or other objects is less than 30 cm and this causes to have a constant sensor warning with the indication of red zone. Therefore, it might cause interruptions if the vehicle has to continue with less than 30 cm distance around. This could be solved by adjusting the indication algorithm to reduce the red zone definition to a minimum value depending on the vehicle dimensions for the HAP since it is a known parking slot and the collision risk lower than a random slot. This solution will also address the concerns of potential false detections in case the route is going from a flat ground through uphill inclined ground.

During the clinics, another important outcome was the elevation difference along the route. In one of the plots, the route was through a flattened narrow way to the garage. However, one side of this way was inclined downhill. The vehicle is not able to detect this since the ultrasonics are detecting the vehicle plane and any deviation from the route might cause accidents. Therefore, it was verified that the vehicle should stop and ask for user help in case of an obstacle instead of driving around it. Using four cameras at each side of the vehicle might be a solution for detecting the gradient on the ground. This needs to be tested with the first prototype of the HAP system.

Clinics also showed that some of the participants uses full lock steering in narrow areas and for sharp turns. However, the automated parking aid system is not able to achieve the full steering angle. Therefore, the vehicle might not be able to follow the same route due to lack of full lock steering. In order to avoid this situation, the system has to limit the steering angle to the highest possible angle or notify the user that full lock steering has to be avoided.

In order to improve the system behavior in case of facing an obstacle and add more flexibility to the feature, the obstacle avoidance algorithms are investigated. Since the route is defined by the customer and the mapping of the private ground might be varying from one plot to another, mapping based algorithms are excluded. When sensor detection based algorithms are investigated, Bug algorithm is found out to be the most suitable algorithm for the HAP use cases that the vehicle follows the edge of the object and calculates a new path but after each step trying to adjust the path to back to the original path [16]. This provides the advange of sticking to the route taught by the user.

As an outcome of the clinics, the longest one way route was around 80m. Therefore, it is estimated that the maximum limit of 100m of a one-way route could be sufficient. Although speed limitation during teaching was not considered at the beginning, clinics showed that the participants usually drive less than 15 kph. However, the speed limitation is also required to allow the system to process the image from the cameras to extract the specific characteristics and landmarkings in order to save the route. Therefore, a speed limit of 15 kph during teaching is foreseen and needs to be verified again. Considering the memory constraints and clinics outcomes, it is planned to reserve the memory size to be able to support six routes up to 100m each. Although it was not planned to have a limit before the clinics, it was observed that the memory needed to save each route is not a negligible amount based on the data sizes from the front camera available in the vehicle and all of the participant have only one designated parking lot for their usage. All in all, six routes is assumed to have sufficient flexibility to the customers.

5.5 Boundary Diagram

After the analysis of the clinic results, boundary diagram is updated based on the outcomes. The results showed that the system, which consists of front camera and twelve ultrasonic sensors, might not be sufficient to localize the parking path and detect all the risk factors in some scenarios. When the vehicle has to reverse to follow the route, vehicle might not be able to use front camera as localization input in case of going out of a garage. The camera will face to the wall and will not be able to localize the vehicle location for a while. Moreover, twelve sensors might also not detect the moving objects especially at the sides. Therefore, it is required to have surround view cameras in all four directions to be able to localize the route and capture all around the vehicle at the same time. Moreover, some of upcoming ADAS features require four corner radars to detect the cross traffic and the blind spots, too. These radars are not presumed to be used as a must. However, they can be integrated to the HAP system to increase the the reliability and detect an object earlier than the ultrasonics or the surround view cameras do. The remaining system interface remains the same.

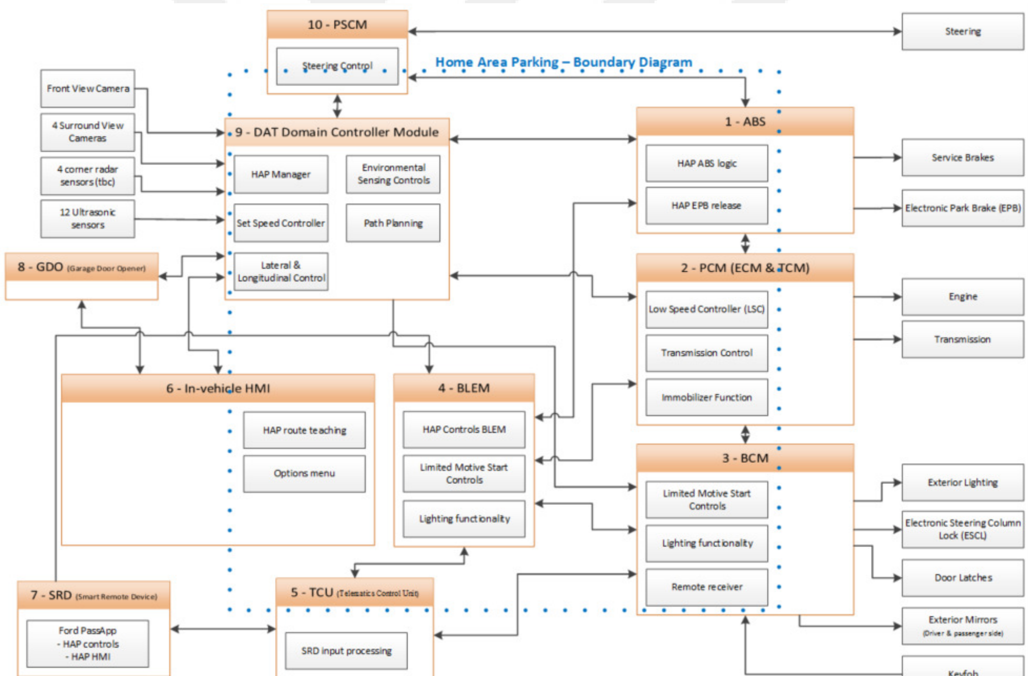


Figure 5.9 : Updated boundary diagram

6. CONCLUSIONS AND RECOMMENDATIONS

Considering advancements in autonomous driving as well as the advancements and the needs in automated parking systems, a new autonomous park system concept – Home Area Parking – is proposed in this thesis for a future vehicle model. Before investing in realization of the system and releasing the feature in the market, a validation through a customer clinic is executed.

Firstly, the possible scenarios are listed and categorized. After categorization, all scenarios were classified one by one whether this feature may be used or not. Accordingly, the use cases of the feature are defined and illustrated in a storyboard. Then, a customer clinic is organized to validate the designed system.

Based on the clinic results, the majority of the potential customers like the feature and find it comfortable. Approximately, two thirds of them stated that they would order the feature. Experiences through the clinics showed that the system should be designed with four cameras to collect constant information from all sides and avoid overlooking any risk items such as a moving objects around the vehicle. The limitation of the maximum route length and number is also recommended.

The points which are open for further investigation and development are the communication protocol between the vehicle and the SRD, garage door opener protocol and the illustration of the parking progress or live streaming the camera images.

Additionally, the feature may be enhanced with a scheduling option in order to provide the comfort to the customer to schedule his/her vehicle to be ready at the pick up location at a certain time and day. Besides, the user can also configure default setting such as engine shut off after arrival to drop off zone, changing the lock status, turning on the air conditioning, heated windshield, heated seats or heated steering wheel.

The next level of HAP would be autonomous valet parking that does not require a learning procedure beforehand and is able to find parking places itself.

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