Title	Designing framework for human-autonomous vehicle interaction
Sub Title	
Author	Costa, Giorgio(Sugiura, Kazunori) 杉浦, 一徳
Publisher	慶應義塾大学大学院メディアデザイン研究科
Publication year	2017
Jtitle	
JaLC DOI	
Abstract	
Notes	修士学位論文. 2017年度メディアデザイン学 第568号
Genre	Thesis or Dissertation
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO40001001-00002017-0568

Master's Thesis
Academic Year 2017

Designing Framework for Human - Autonomous Vehicle Interaction

Keio University Graduate School of Media Design

Giorgio Costa

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
MASTER of Media Design

Giorgio Costa

Thesis Committee:

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Abstract of Master's Thesis of Academic Year 2017

Designing Framework for Human - Autonomous Vehicle Interaction

Category: Design Research

Summary

This research is focused on the communication between autonomous vehicles and human road users, such as drivers, pedestrians and bikers.

Autonomous vehicles lack by definition of the human touch and visual feedback that defines the interaction between human road users. Generating a sense of distrust and skepticism, this gap can be identified as one of the crucial problems affecting the massive roll out of the autonomous driving technology, that has almost reached the state of the art for what concerns its technical development.

In order to overcome this issue, after a theoretical research phase that includes a collaboration with Professor Takaaki Sugiura from Mitsubishi Research Institute, an original concept is proposed, which aims to recreate through icons, text, sounds and lights, the human-to-human interaction, otherwise lost.

The system, positively received by the users during its testing phases, can dramatically improve the acceptance of autonomous vehicles and ultimately give a strong push on road safety, especially in crowded urban areas that show a strong presence of vulnerable road users, such as bikers and pedestrians of any age, including children, seniors and disabled people.

Keywords:

Autonomous Drive, Cars, Urban Mobility, Vehicle to Human Interaction

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Chapter 1

Introduction

1.1. Introduction

An autonomous vehicle, hereinafter referred to as ”AV”, is a vehicle capable of driving itself from point A to point B, with or without passengers inside, without the need of a human driver’s intervention.

An AV can operate at different levels of autonomy, and provide to a rather simple driving assistance to a complete autonomous driving experience.

The development of such vehicles started more or less 30 years ago, but only in recent times, in the first decade of 21st century, it has reached the level of real operability outside testing facilities.

AVs make the most of already existing technologies, such as different kinds of sensors (LIDARs, RADARs, stereoscopic cameras, etc.) and cross them together to reproduce a mapping of the surrounding world, in which they will move taking into consideration the presence of other users (other vehicles, pedestrians, bikers, etc.)

In a first phase of the AVs roll out, which includes the trials currently undergoing in many cities around the globe, their approach to other users is strongly adaptive, as they need to adapt to an already existing environment, mostly dominated by human drivers, with a human way of operating vehicles and a human reaction to external stimuli.

In a second stage, or in a potentially isolated environment in parallel to the cities in which we currently live in, the experience provided by AVs would be taken to a much more enhanced level, being remotely controlled by a unified control system, capable of predicting the behavior of all the users of the system.

In both cases, even if technology already allows AVs to operate safely and conveniently, the interaction with other human users of the road, including drivers, pedestrians and bikers remains a very critical point.

Several studies, such as the ”Global Automotive Consumer Study” [1] published by Deloitte in January 2017, show a strong distrust from users towards the autonomous driving technology, despite a proved increase of road safety when AVs are operating, as such vehicles can react more promptly than human drivers and being certainly more respectful than rules and limits.

The reason behind such a strong sense of distrust and vulnerability can be found in the fact that humans are traditionally used to interact with vehicles operated by other humans, who not only drive and react in the exact way we would do ourselves, but also provide several visual feedbacks to other road users.

This is fundamental to smoothen the interaction with other drivers, for example at unregulated junction, during parkings, lane shifting and so on, but also (and most importantly) reassuring the vulnerable users in situation like crossing a street, or when in proximity of a maneuvering vehicle.

In order to validate this assumption, a live fieldwork has been set up, to evaluate the interaction between a designated driver and other users of the road. The experimentation, conducted in the urban areas of Shinjuku (Tokyo) and Yotsuya (Tokyo) has proved how human users tend to naturally look for other humans' feedback when feeling vulnerable and exposed to an uncertain situation.

With the help of a driver, unaware of the purpose of the experimentation, the number of interactions (eye contact, hand/head gestures, usage of lights and horn) between the driver and other road users has been counted during two driving cycles, and two different driving styles.

Specifically, the experimentation's goal was observing how road users tend to interact with each other, and verifying that the more uncertainty is perceived, the more visual feedback is necessary for road users to feel safe and drive or walk with ease.

40% of the pedestrians have engaged in a visual interaction with the driver when operating the vehicle smoothly, and 50% when operating it more aggressively (higher speed and rougher driving style). At such speeds 1 out of 12 times and 1 out of 10 times respectively, drivers and other users have visually interacted with each other. Especially vulnerable users (senior pedestrians or bikers) have shown the strongest need to create a visual connection, as an above-the-average 53% eye interaction was counted in the smooth driving cycle, and up to 65% during the aggressive one.

Such results have reinforced the assumption that visual feedbacks (deliberate or subconscious) play an important role in the urban vehicle-to-user interactions and need to be well examined in the light of the upcoming massive roll out of AVs, which cannot provide, by nature, any sort of human feedback to the users in their surroundings.

The main goal of this research has therefore become the definition of a concept of an autonomous vehicle that can provide quick information to other road users in its proximity, using icons, text, sounds and lights combined, to recreate the above mentioned sense of human-to-human connection, even in presence of a fully robotized vehicle.

The concept proposed makes the most of already existing technologies to provide an economically feasible system that can be implemented in autonomous vehicles effortlessly and effectively.

Using the internal 3D mapping of objects and people that any AV already necessarily perform as a main operation to detect the surroundings and being able to move, the system targets specific road users, simultaneously, providing information about the intention of the vehicle. A layer of low-definition LED is used to display text and icons behind the translucent surface of bonnet, side fenders, tailgate and side of the vehicle.

At the same time several users can receive visual indications from the AV, combined with a simple sound signalization, similar to the repetitive sounds implemented in blind-people crossing assistance, in order to quickly be alerted of a potential danger, or to be given practical indication of what the Av is about to do. Also a specific color of running light (purple), distinguished from the already existing range of vehicular signalization and colors is implemented, to immediately recognize the vehicle as an AV.

To help the evaluation of the reception of such a concept vehicle, a visual prototype has been set up, using an actual car with polystyrene boards mounted on it, recreating the potential interactions with vehicles and other road users.

The four main kinds of information implemented in the prototype can be summarized as ”safety information”, ”driving intention”, ”vehicle status” and ”friendly communication”. The four areas have been chosen to replicate the majority of the messages that users of the road usually communicate to each other (deliberately or subconsciously), recreating as much as possible the human-to-human feedback, including the empathic and kind feeling that makes the human communication immediate and smooth.

At the end of this activity, a poll of 50 users has been chosen to validate the effectiveness of the prototype, and to collect suggestions to improve the concept, through questionnaire with closed and open answers.

The target of this concept car is potentially any user of the road, as beside some restricted categories of users, anyone of us is in fact a potential user of the road, both as driver or pedestrian/biker. In order to reach this broad surveying target, an evaluation of the Japanese population has been made, dividing it in five age ranges, and submitting the questionnaires according to the percentage of users in each specific range.

The answers collected have shown an overall encouraging reception by the users, who mostly have found the idea interesting or very interesting (84%) and the general sense of safety introduced by this technology was the most appreciated aspect of its implementation (80%). Surveyed users have also found the concept more useful for vulnerable users of the road (pedestrians and bikers, respectively 70% and 60% of effectiveness) than other drivers (54%).

However, also several concerns have come out of the questionnaires, especially regarding the real accessibility and universality of the service. The text shown, for example, is regarded as potentially hard to read by the majority of the users (63%) who also criticize the possibility of showing one language at a time (56%), if not all the road users can speak the same language. Icons and sounds have been ultimately regarded as the most effective way of communication, due to their quick understandability and higher universality. From the open answers, it once again appeared clear that users want a service that is automatic and fast to use, with no need to study before using it and that the system must be able to reach as many users as possible without creating confusion, and crossing cultural and linguistic barriers.

In conclusion, thanks to the users' feedback the concept has been improved to include an automatic adaptation to the cultural background in which the vehicle operates (e.g. utilizing signalization and sounds already introduced in that specific geographic area) and giving more relevance to icons and sounds, more than written text. Also, as a future development, it would be interesting to further expand the potential of directional sound systems, capable of delivering sounds to specific users with a very reduced dispersion angle, in order to reduce the interference in message delivery, and contain the urban noise pollution at the same time.

The final user test, performed in the areas of Yotsuya and Nakameguro (Tokyo) with a real vehicle equipped with a prototypical signalization apparatus, has ultimately proved the good reception of this technology, with an overall 21% of the users showing an increased rate of confidence when interacting with the vehicle, in comparison to the testing phases in which the signalization was not installed.

The road to a widespread diffusion of autonomous vehicles may seem far away, but it will be in fact closer than most can imagine. From 2025 on, a 63% year-to-year growth [2] in the sales of AV is expected to take place worldwide.

This research intends to give a positive contribution to the activities that will take place in preparation of such a massive roll out.

In particular, it aims to raise awareness on a subject, the vehicle-human communication, that despite appearing collateral at a first glance, is in fact one of the core problems of autonomous driving technology nowadays.

Overcoming it, will not only represent a key moment in the long path of the automation of mobility per se, but a chance to implement tangibly users-friendly systems, with the ultimate goal of reducing fatalities, and making tomorrow's roads safer than ever before.

Chapter 2

Related Works

2.1. Background

Autonomous drive has been made possible by the crossover of several different technologies that throughout the years have been tested and refined, and already used in other branches of technologies and/or transportation. [3] (Figure 2.1)

2.1.1 Hardware

LIDAR, Acronym of “Light Detection and Ranging”, is an instrument placed over the vehicle and sometimes on front and rear bumpers. Its purpose is detecting the surroundings and providing a tridimensional mapping that includes all the moving and fixed obstacles around. LIDARs operate, as the name itself suggest, by emitting a laser light and subsequently calculating the delay between the emission and the comeback after hitting the object’s surface towards which the LIDAR has been pointed. To create a 360° mapping, the LIDAR continuously spins, mechanically moved by an electric engine.

LIDARs allow to create an accurate tridimensional rendering that cannot, anyway, be enriched by fundamental details necessary for its evaluation. For example, a LIDAR will recognize the shape of a man, but won’t be able to understand if the object is a real person or a mannequin. Also, as operating through light adverse weather conditions, such as fog or heavy rain, may decrease the sensor’s operability.

RADARs, already implemented in cars to allow the vehicle's auto breaking function, as well as adaptive cruise control functionality, radars will detect the surroundings providing a rough yet highly reliable feedback that won't be affected by adverse weather conditions. Radars are in fact using radio waves that can easily pass through fog and rain, "bouncing"only on thick objects.

Proximity sensors (using infrareds or ultrasounds) are placed on sides and bumpers of a car to evaluate very precisely the proximity to vehicles moving around, and to perform parking maneuvers.

CAMERAS Monocular and binocular view cameras are currently fitted in vehicles to operate safety systems such as the LDWS (Lane Departure Warning System) or to provide a high-resolution view of blind spots when parking on reverse.

Cameras will integrate the information coming from LIDARs and RADARs by adding objects, people and animals'recognition and as an additional safety sensor.

Central Unit The core of autonomous drive will be, after all, a computer. The cars themselves in fact, will not be extremely different from what we are currently used to drive, at least at an early stage of the AV's rollout. Both internal combustion engine based cars and electric ones can in fact be converted to autonomous drive, with a central control unit in charge of operating gas, brake and steering wheel in place of a human driver.

Safety will of course be a priority when developing AVs, so a certain quantum of redundancy of these systems will be necessary. Similarly to what already happens with airplanes, up to three system in parallel will be implemented to annihilate any possible problem in case of a sudden shutdown.

GPS An important role will be played by GPS positioning, as the system will be constantly monitoring the position of the vehicle to make it reach its destination. In some countries (like Japan) a system called QZSS (Quasi Zenith Satellite System) will enhance the current GPS precision by adding a fourth satellite orbiting at xxx kilometers of altitude that will boost the positioning precision level to centimeters.

2.1.2 Software and Connectivity

V2V and V2I communication AVs are born to communicate among each other, sharing information about their position and planned route with other vehicles, including details on their system status. This is fundamental, for example, for the vehicles to evaluate which route could be the least congested, in relationship to the presence of other users on the same road and their desired destination. Also, AVs will be fully interconnected with road infrastructures.

It is important to understand that AVs will initially be introduced as "adaptive vehicles"capable of monitoring the surroundings and driving themselves in different scenarios, but on a second phase, the most radical one, AVs will be all managed remotely. A sort of "Big Brother", represented by a centralized operating central will in fact manage and optimize road fluxes, virtually annihilating road congestion.

Ultimately, AVs will not be independent units, but they will be engineered to be part of a wider system, capable of managing fluxes and harmonizing all the road users'behaviors, granting safety and convenience for all.

2.1.3 The 5 levels of autonomy

AVs are not classified according the traditional vehicles'categories. SAE International, a consortium of Automotive Engineers has released in 2014 a standardized classification for AVs [4], that keeps in consideration "how autonomous"they are, on a scale from 0 to 5, later confirmed and reviewed by the National Highway Traffic Safety Administration Agency (NHTSA) in 2016 [5]. This standard has been adopted internationally and is being used during the development of such vehicles as a form of common benchmark.

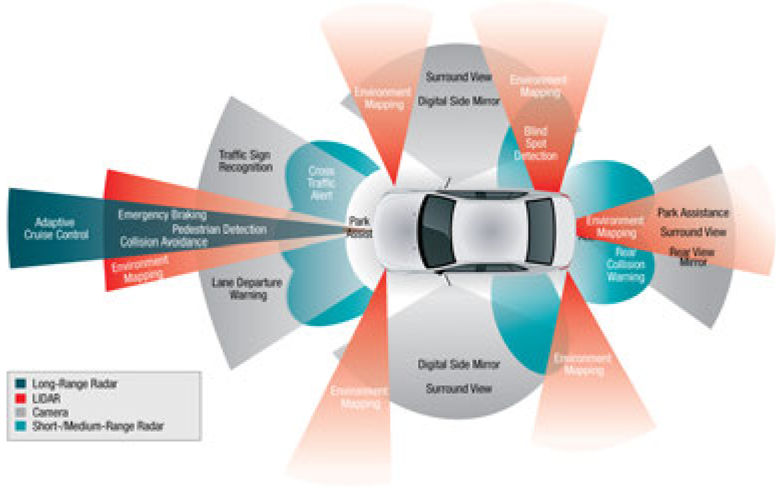

Figure 2.1: Sensors and their position. Source: Texas Instruments

Level 0: The vehicle is not autonomous, and requires drivers to operate it full time. Some advices (such as lane departure or proximity information) can be issued, if such systems are implemented.

Level 1: The vehicle includes some sort of driving automation but is not capable of moving without a driver. Driving automation can be represented by active systems such as ACC (Adaptive Cruise Control) or automated parking, but full responsibility is tribute to the driver that must be ready to intervene at any time.

Level 2: The vehicle is capable of driving itself without the driver intervention, but he/she will still be fully responsible of detecting obstacles or dangerous situations and is required to disable immediately the autonomous drive. This can be considered the first step of a really autonomous car and level 2 vehicles are already circulating on our roads on a daily basis and can be easily purchased by anyone.

Level 3: Similar to level 2, but the driver can decrease his /her level of attention in some specific environments in which driving is more linear and less exposed to dangers (such as highways where vehicles only move in column). Level 3 still requires the driver to intervene in case of emergency.

Level 4: Fully autonomous vehicles. The driver is not required to intervene, unless in adverse weather conditions or particularly complex road situations. When autonomous drive is engaged, the driver can also not pay attention and leave the commands.

Level 5: Fully autonomous vehicle, capable of driving itself in any weather condition or road environment, traditional commands such as steering wheel or pedals can be removed as the driver is never required to intervene.

2.1.4 Schedule and forecasts

AVs can be classified in five different categories according to their level self-driving capability [2], and we can forecast the Level 3 ones leading the sales for several years from now. In real life these vehicles will represent a gradual shift from manual to autonomous ones and they will be economically more sustainable than their fully autonomous counterparts. However, level 4 and 5 will face a dramatic growth, with a 43% year-over-year growing rate between 2025 and 2035

Between 2020 and 2040 their average year-over-ear growing rate will be over 60% and their overall market penetration will grow accordingly, but it's important to point out that manual vehicles will still represent the majority of vehicles sold at least until 2040.

Global sales of level 4 and 5 AVs will reach approximately 600.000 units in 2025, which is expected to represent a turning point for AVs worldwide, when United States and Europe will take the lead on this kind of market, while other geographical areas such as Southern American and India will lag far behind.

This number is expected to grow until nearly 21 million units yearly sold in 2035, with at total sales to date of 75 million cars.

We can expect 2020 to be a remarkable deadline in terms of technology roll out, with many projects reaching their maturity and release to the public, but 5 more years will be needed to really see the sales of AVs take a dramatically rising trend and 2025 will reasonably represent the real turning point.

2.1.5 Social Impact

One of the core advantages of AVs is their capability of moving passengers more safely: at the current state of development, statistics have shown a lower level of accidentality in comparison to traditional cars in the same areas of testing.

Google's WAYMO, at January 2017, has been ridden for more than 3 million kilometers in four areas of the United States: Mountain View (CA), Austin (TX), Phoenix (AZ) and Kirkland (WA) reporting 11 mild accidents with no injuries. In only one case the AV has been found responsible for a wrong maneuver. [6]

Tesla models S and X have been ridden on a daily basis using AutoPilot for more than 222 million miles (as of October 2016). The system could collect several data and one fatality has been reported. On May 6th 2016 a truck collided with a Model S that failed to detect the turning vehicle at a highway intersection. The impact could not be avoided as the car did not apply brakes while the driver was distracted by watching a movie on a portable DVD player. [7]

There are, in fact, two different approaches to autonomous drive: the one by Tesla, that already implements level 3 autonomy in its models, with drivers able to use the AutoPilot system and the cars can most of the time still be used traditionally with steering and pedals, and the one from Google with no steering wheel and pedals, and ultimately no controls applicable by the driver.

In this case the full responsibility of a crash would be attributed to the car. Only level 4 or 5 AVs can afford this kind of approach, as they are not in need of a human intervention to be operated. As scary as it may seem, this approach has for now showed more safety potential. The reason behind this is that people tend to get distracted while delegating to the vehicle. Their threshold of attention is too low when taking commands again, with the risk of making their intervention rude and ultimately dangerous.

At present, one-quarter of the Japanese population is over 65. This figure, which is higher in rural areas, is bound to increase up to 40% by 2060.

According to the National Police Agency, 4.36 fatal car accidents occurred per 100.000 drivers in 2015. The figure gets higher with the age of drivers: 6.99 for those aged 75 to 79; 11.53 for those from 80 to 84 and 18.17 among drivers 85 and older.

At the end of 2015, 4.78 million Japanese licensed drivers were 75 and older, which represent an increase of 300.000 people (6.8%), from a year earlier.

As a typical example of negligence performed by elderly drivers, we can find mistaking the acceleration and braking pedals, resulting in unexpected loss of control of the vehicle. Also, according to the transport ministry, 69% of those who drove their vehicles the wrong way on expressways, between 2011 and 2014, were 65 and older, and 9% of them suspected of suffering from senile dementia. [8]

The number of elderly drivers is expected to increase due to the aging of the population, and the problems related to unsafe drive, such as fatalities occurring in rural areas where there is no alternative for people to move, are expected to increase.

As a part of a trial project, which aims to hit the fully operating circulation in 2020, Softbank and Yahoo! partnered to develop a self driving bus, targeting elderly people living in rural areas of Japan who are currently cut off any chance to move freely, due to the difficulty of driving cars at a certain age. [9]

The project, covering also aims to help those kids who live in remote areas and need to commute to school everyday, who currently have to rely on parent's help.

Another experimentation has already started in Chiba prefecture, where DeNA and a French company called EasyMile teamed to offer a trial service of autonomous shuttle buses in order to cover routes to/from a mall, launching the "RobotShuttle" who targets elderly people who can not reach the mall easily, also thanks to its highly accessible structure and simplified command input system. [10]

Giving the chance to move to people who were previously unable to be independent, is not just creating a positive social value, but it is also representing a way to increase productivity by reducing times and costs of transportation in difficult contexts.

For example, we can expect school buses, which are a typical example of car pooling, to become one of the first appliances of AVs, leading to an increased mobility for children before/after school, relieving the parents from the need to always take their kids to school, especially in remote rural areas. However, there is concern whether children should be allowed to ride AVs themselves or not.

Legislation varies from country to country and it involves the area of parental responsibility. In many cases, children are already allowed to ride buses and public transportation by themselves after parental authorization, but this is strongly connected to the specific cultural environment. Just as an example, in Japan very young kids (6/7 years old) are used to walk to school, while in Europe this would legally result in abandonment of minors and make the parents face severe legal consequences.

Therefore the relationship between children is still strongly influenced by the social/cultural/legal context and we may expect still a strong parental influence to regulate the usage of such vehicles, even if technically possible.

In opposition, adult people without a driving license may strongly benefit from the introduction of AVs, as level 5 autonomous vehicles do not require any human intervention to be operated. In California, for example, one of the main testing fields for such vehicles, from October 2016 users without any driving license are allowed to ride prototypes in public circulation.

It is foreseeable that the number of adults with a driver's license will strongly decrease by twenty years, as shared fleets of AVs and in general the shared transportation, are already offering a valid alternative to owning and driving one's own car. Of course only level 5 AVs can be ridden without a license, as lower levels of autonomy still imply the handling of steering wheels and pedals.

It is remarkable how AVs are bound to change disabled people's life. Currently people with major physical handicap can still drive a car, but only under certain conditions through commands' adaptation. Commonly, people with injured lower body parts can use brake and accelerator with their hands through some tailor-made leverage systems and also people with motion deficit in their upper body can enhance their driving through simplified commands and adaptations on the steering wheel.

Those with severe cognitive deficits and/or blind ones are currently unable to perform any sort of driving by themselves and their level of autonomy is very low.

AVs are capable of dramatically improving the quality of life of such people and in 2015 Steve Mahan, a blind voluntary tester for Google, has performed the very first ride by himself in a car. [11] After the ride, the man stated: "This is a hope of independence. These cars will change the life prospects of people such as myself. I want very much to become a member of the driving public again."spreading a sense of positivity and hope through the whole blind community.

Despite the collective imagination, one of the most important applications of autonomous drive will be the transportation of freights. The main reason behind this potentially huge application of AVs is a strong lack of truck drivers all over the world. In the US only, at present, a shortage of 48.000 drivers is estimated, and this may reach 175.000 by 2024. [12] This job is pretty tough and less and less people are willing to start a career in these sector, that overall grants no high revenues and requires high responsibilities and exhausting turns of work. Let's not forget that human drivers need nocturnal rest and cannot work for more than a certain amount of hours, while AVs could do the heavy job relentlessly.

In the US only, according to federal statistics, 4000 people die every year in more than 400.000 crashes involving heavy trucks, almost all of them caused by human errors. AVs would provide a significant contribution to the decrease of fatalities.

As the founder of Otto powerfully summarized: ”You can imagine a future where trucks are essentially a virtual train on a software rail.”

Trucks could be in fact sent even without people inside on long and mostly straight courses such as the never-ending American highways, in long caravans. This would represent the perfect situation for AVs to operate, as their level of interaction with pedestrians or non-autonomous vehicles would be minimum, and overall their adoption safe and profitable.

In some countries the driving automation of trucks will be tightly linked to new forms of electrification that are intended to drastically modify the way we intend highways as corridors for freights. In Sweden, an experimentation financed by the local government, in partnership with Siemens and Scania, is aiming to fully electrify the freight transportation by implementing several kilometers of aerial cable lines to provide power for trucks.

As batteries of EVs are still not able to reach significant mileage on long distances, this could represent the perfect solution to achieve a zero-impact freight transportation without compromising route flexibility and cargo capacity.

2.1.6 Shared Mobility

Local public transportation systems are composed by vehicles capable of moving a remarkable number of users on a fixed route, sharing a common riding space, usually at a rather reasonable riding cost.

Public transportation commonly includes trains, subways, light rails, tramways, buses, cable cars and sometimes ferries or other special vehicles like monorails or trolleybuses.

This kind transportation is the most convenient in terms of co2 emissions per person moved, and very often it also represent the cheapest way to move in towns.

The disadvantages of public transportation are a lack of private space, a potential long waiting time, and the presence of a fixed route, which makes the transportation inconvenient in not well served areas, requiring an additional vehicle to integrate the commuting.

From town to town, public transportation can represent the main mean of transportation or an integration of private commuting. The development of efficient networks (especially subways, which are fast and not affected by traffic jams) requires time and a strong investments from local governments and not all the cities can rely on good public transportation.

For example, Los Angeles is one of the worst performing city in the US with only 11 percent of public transportation ridership, while New York City is the leading city with more than 55 percent.

A taxi is a vehicle that operates the service of carrying passengers from point A to point B, driven by a human operator, providing a non-shared ride. In opposition to public transportation, the taxi offers a private space and a dedicated route, becoming one the most comfortable ways of commuting, but also rather expensive in comparison to subways or buses.

Taxi drivers are professionals who get their revenue from driving and they are required to obtain a license for providing their service which is paid based on driven kilometers and sometimes adjusted by riding time or at special fees.

Car Sharing is a service that allows customers to drive themselves a car without owning it, and being at disposal of different users with a quick turnover. According to different possible setups, the cars can be picked up and returned in the same station or in any other parking spot within the operating area. Car sharing pricing is mostly based on time and/or kilometers driven, often including fuel and other advantages such as the entrance on restricted areas or lanes and no parking fee.

In Japan, the most popular car sharing companies are currently TimesCar24, CareCo and Orix, offering a total of xxx vehicles and xxx pickup/return stations. The policy of these companies is allowing customers to pickup and return the vehicle in a dedicated parking lot, with the users in charge of most of the expenses while the vehicle is rented. The rent can not be in fact terminated unless the car is returned to its original location and this makes these services much more similar to a short-time rental in comparison to a real car sharing.

In other areas such as Canada, US and Europe, the leading car sharing company is Car2Go, offering a convenient pickup/return service which is based on GPS positioning and does not require the car to be returned in the same pickup station.

Once the car is left, another user can pick it up and driving it somewhere else, making the service very flexible, with minimum dead times, but creating the need to control potential unbalance of the fleet as the cars could become all concentrated in some areas.

A different form of car sharing is instead provided by a Californian company called GetAround. With a peer-to-peer approach the company allows registered users to put their own cars on rent for short time and accessing other people's cars in return. This approach is sponsored by the company as ”social car sharing”, in which the resources are put in common by all the users, with additional fees paid to the company only to manage the server and the dedicated app. In this case, in fact, the company does not physically own any of the vehicles and only operates as an intermediary between different users.

Car pooling services are instead offering a paid ride, performed by a private user who does not have a taxi license and uses his/her own car. There are two approaches that we will evaluate: the one from Uber and the one from BlaBla Car.

The most famous car pooling company is Uber, with more than xxx users all around the globe. Uber user willuse their vehicles to give rides, based on app requests, after a payment. This service can be somehow considered an unlicensed taxi service and in fact Uber spread criticism in some areas where the taxi lobby felt threatened by a potentially unregulated service performed by non professional users.

A quite different approach is instead adopted by BlaBlaCar, a company that allows its users to split the cost of an already planned trip. For example,if I am planning to go from Rome to Milan, I can find other users interested in the same route and willing to split the cost with me. The more people I can carry, the more i will reduce the cost and lower the co2 emissions per person.

Car pooling services offer, in the end, the most offensive commercial impact on transportation, but a remarkable amount of side effects could limit their expansion and reliability. Mostly, the lack of trust when entering some stranger's car is still very (understandably) strong as people could feel unsafe or at risk next to a non professional driver.

In this context how do AVs fit in? They have a strong predisposition to being used as car-sharing vehicles and the reason behind this is pretty simple: car sharing fleets need operators to redistribute the vehicles when these are not in use and they all get concentrated in some areas (for example in a very central area during working hours) leaving the suburbs in a shortage of cars for several hours a day.

An AV can, by definition, drive itself without any passenger inside, so it can easily be recalled on demand, redistributing the fleet remotely without any effort from the company that manages the car sharing.

Also, customers can recall vehicles on demand and without the need of another, potentially unreliable or inexperienced driver. The parking time will also stop being a problem, as AVs can leave their users anywhere and then going to park themselves somewhere else.

AVs will combine all the advantages of carsharing, car pooling and taxi services and their adoption in sharing fleets will be the first form of massive roll out, more than private ownership.

2.2. Notable projects

2.2.1 Early Development

An autonomous vehicle is a vehicle capable of driving itself, with or without occupants inside, moving from place A to place B, with different possible levels of automation. We will refer to Autonomous Vehicles as “AVs”further on.

The early steps of autonomous drive go back to 1920 when early attempts have been done to experiment the implementation of this technology, but the first tangible results could be observed in 1984 with Carnegie Mellon University’s “Navlab” and Bundeswehr University Munich’s “Eureka Project”in 1987. [13] These two experimentations can be considered the ancestors of today’s AVs

In a time range of more than thirty years, many technological advancements have been achieved, and from early experimentations, we currently are at a point of having all the technology needed for a massive rollout.

The next big challenge will not, in fact, developing more complex systems, but trying to make this technology economically sustainable and most of all harmonizing all the regulatory matters and adapting our cities for AVs to circulate safely and massively.

2.2.2 WAYMO

[14] Formerly known as Google self-driving project, Google started testing its first autonomous driving vehicles back in 2009. An initial fleet of Toyota Prius, Audi TT and Lexus RX, adapted to autonomous drive, was rolled out in 2012, when regulations officially allowed the first tests.

In 2014 the first WAYMO self-built units (simply known as "Google Car") were presented to the public. These prototypes showed the very radical approach that Google is having towards AVs: they don't have nor pedals or steering wheel and can only be programed through an input device such as a tablet or a pc. The reason behind this choice is avoiding potentially dangerous situations when shifting from autonomous drive to piloted one. Tests have in fact revealed that when drivers are requested to intervene their level of attention may have lowered too much and could not be able to safely perform emergency maneuvers, making their intervention virtually counter-productive.

In 2016 google announced a partnership with FCA, and a fleet of 100 Chrysler Pacifica has been rolled out as nearly production-ready testing vehicle.

2.2.3 Tesla Autopilot

[15] Californian car-maker Tesla Motors has started its operations in 2003 and its first production vehicle, the Roadster, was released in 2008.

With a radical approach towards the concept of automotive itself, Tesla only provides electric vehicles, capable of level 4 self driving. Tesla Autopilot, released in 2014 and already available at its version 2.0 on the Model S and Model X cars, allows drivers to fully delegate to the vehicle's driving assistant most of the driving functionalities and by the end of 2017, Tesla Autopilot is expected to reach level 5 of autonomy.

The reason behind an early rollout of this technology is gathering as much feedback as possible from real-life users. Tesla cars are in fact connected to the company' s serves allowing live-feedback. By November 2016, 500 million kilometers have been driven by Tesla Autopilots all over the world.

2.2.4 Intel GO (in partnership with BMW)

Worldwide microchip leader Intel intends to play a key role in the development of autonomous drive and the goal of the company is creating a shareable platform of sensors, operating system and infrastructure that can be adopted by different car makers with full interoperability, reducing the cost of development and set up. [16]

Intel GO is particularly focused on V2V and V2I communication as a normally operating vehicle will generate 4000GB of data every day, that will be shared with the centralized infrastructure. To facilitate the remarkably high amount of data sharing, Intel GO has predisposition for 5G multichannel communication (standards for 5G are still not universally being defined, so the system is aiming to operate under different possible future scenarios).

2.2.5 nuTonomy

Established in 2013 in Boston as an MIT-funded startup, nuTonomy is the first company in the world to run a fleet of autonomous taxis. As a trial project, in fact, from August 2016 is possible to test-ride taxis on the streets of Singapore. [17]

The fleet is composed of Mitsubishi i-Miev and Renault Zoe cars and is planning to start its open-to-the-public operations in 2019.

2.2.6 Uber, Lyft and Otto

AVs have a strong predisposition to be shared and used as a fleet, more than being purchased and used by privates. The reason behind this is the possibility for them to be used also when passengers are not inside the vehicle itself, which allows anyone to recall the vehicle remotely, on demand. The concept itself of Taxi, will likely be part of our past, in a few years.

Companies of car sharing and car pooling such as Uber or Lyft are researching abou the possibility to add AVs to their offer.

Otto, a start-up company founded by Uber has developed level 4 self driving technology to allow automated deliveries with large trucks. As a first tangible result on October 2016 the first fully automated truck delivery (a lot of 50.000 Budweiser beers) has been performed in Colorado, over a 120 miles course. [18]

Otto has six trucks composing its fleet and in two years the company is expecting to rollout the service more massively.

2.2.7 DeNa, partnership with Yamato and ZMP

Software company DeNa and Yamato Transport are jointly testing a driverless delivery service in Japan. The goal of the companies is providing a fleet of door-to-door delivering that does not require any human intervention through all the phases of the process. [19]

A minivan (Nissan NV200) will drive itself to destination, carrying multiple items in different drawers, placed in its generous cargo compartment. Once reached the final destination, the recipient will open the door and pick his/her item, secured by a personal code.

Starting in March 2017, this joint-ventured project opens one of the most promising scenarios for the Japanese development of AVs.

The Olympic Games will represent a turning point for Japan under several aspects of its economic and cultural life, and AVs will be part of this vibrant scenario, bringing back and forth viewers and athletes to/from the sporting facilities spread all over Tokyo.

DeNa and ZMP have in fact jointly funded a project called “Robot Taxi”that, similarly to what nuTonomy is testing in Singapore, will serve the city of Tokyo with on-demand pickups, managed through a smartphone app.

The clear goal of the company is launching the public service in 2020, and further expand its operation to other Japanese cities and International markets, subsequently. [20]

2.2.8 Dynamic Map Planning - Tokyo 2020

Financed by the Japanese Government, several companies including Mitsubishi Electric, Mitsubishi Research Institute,Aisan Technology,PASCO,TOYOTA Mapmaster, Increment P and Zenrin, are currently 3D-mapping all the streets of Japan in order to allow AVs to circulate more safely and smoothly by 2020. [21]

By that time 789.000 miles of roads and 18.600 miles of expressways will be fully mapped, with a precision rate up to 20 times the ones achieved by Google Maps or similar.

2.2.9 Prototypes for vehicle-to-users communication

This field of research is still widely unexplored, however some car makers and research institutes have started approaching the topic with their own proposals.

It is the case of Nissan [22], that implemented a system of external ”intention indication” to inform the users in the surroundings. The prototype, called IDS (Figure 2.2) uses an LED fascia all around the car to show to the users that they have been detected, using low-range sensors and also a frontal LED panel to show messages to pedestrians. The IDS Concept also aims to advise pedestrians and bikers in the proximity about the intention of the vehicle (e.g. the intention to stop or change lane) and it is focused on short-range interaction, not targeting other drivers or giving indications on long distance.

Another prototype, developed by Duke University [23](Figure 2.3), uses a wide LED panel in front of the vehicle, to show icons targeting pedestrians at crossings. In this experimentation, the only way of communicating with pedestrians in the proximity is using standardized icons, resembling the ones implemented in road signs or traffic lights. Other road users are not targeted, but the wide dimension of the LED screen aims to create an effective way of alerting pedestrians about the intention of the vehicle.

Figure 2.2: Nissan IDS Concept

Figure 2.3: Duke University experimentation

Students Yoichi Ochiai and Keisuke Toyoshima from Tsukuba University have created a prototype called ”Homunculus” [24] (Figure 2.4), which uses motion tracking and haptic sensor installed in the interior of the vehicle and through a system of projection and eyes-like signalization, the gestures and expressions of the driver can be reproduced outside the vehicle. Homunculus aims to reproduce the visual communication that drivers and pedestrians have in real life and enhance the reciprocal feedback even in difficult visual conditions. When the driver moves his eyes to visually target someone outside the vehicle and/or moves the hands to target that user with a gesture the car detects it and reproduces it accordingly.

Design professor Hachiya Kazuhiko has developed, in 1996, a car accessory to be mounted on the roof of the vehicle called ”ThanksTail” (Figure2.4), which is able to reproduce the gentle movements of a wagging tail when the driver intends to communicate something to the surrounding users, such as expressing gratitude or apologizing for a wrong maneuver, commanded through a joystick installed on the dashboard.

Figure 2.4: Signalization with anthropomorphic and zoomorphic elements

Chapter 3

Definition of Issues

3.1. The Mitsubishi Research Institute experience

After the initial research phase, based mostly on a theoretical approach (reading publications, conferences etc.), it was fundamental to understand more in depth the reasons why AVs, despite being able to provide a higher level of safety, were so poorly received by the public and treated with skepticism.

Even after attending various conferences held by BMW, Google, De:NA and other companies involved in the development of AVs in Japan, the research still seemed to be not on point. It became necessary to discuss in person with someone actively involved in the field of AVs, to gather a meaningful feedback. Professor Takaaki Sugiura from Mitsubishi Research Institute has kindly disclosed his knowledge on the topic, based on his personal research activity at the MRI, in a series of weekly meetings.

Specifically, he explained how the MRI has encountered crucial issues when dealing with pedestrians and vulnerable users of the road. According to their experience during testing phases, the most critical part was making these vehicles accepted by the community when the visual feedback with a driver was not existing. When no humans were present inside the car, in fact, pedestrians would perceive the vehicle as completely out of control, and most of them would not dare to start crossing in front of it.

For this reason MRI has also interviewed associations of relatives of victims of the road, receiving a very negative feedback, as these people would largely find this technology morally unacceptable. In case of a deadly accident, in fact, only the car company could be blamed for a failure of the system, and no human would be found guilty and charged for the fatality.

Strong concerns were also raised by the users over the fact that such vehicles, operating in residential areas at low speeds and silently, could put in danger the kids playing nearby if failing to detect their presence.

The researches of MRI, still ongoing on this topic, have given a decisive input to properly define the issues related to this technology, and which could have been a meaningful area of research to improve its reception. It became clearer how this technology was still in need of a much stronger empathic connection with real human users, and Professor Sugiura helped to define a way to evaluate the specific issues, in particular distinguishing two main scenarios: one with AVs and manual ones coexisting and one with only AVs allowed in the circulation (this topic will be further explained in the following paragraph). Most of the publications on this matters were in fact quite confused about the context in which AVs operate, and it was important to find more clarity.

He also provided a strong support to this research when coming up with the concept itself. During this phase some brainstorming activity was done together in order to define meaningful characteristics that a concept that could overcome these issues should have, and others that should instead be rejected. For example, we evaluated how wearable technologies could have been used to provide signalization to the users, but we decided to drop it as it would have been ineffective.

Ultimately, the useful insights gathered during the meetings held with Professor Sugiura represented the first fundamental steps of the subsequent research and development of the concept, that will be explained in detail in chapter four.

3.2. AV's impact and acceptance in different scenarios

Regardless of their level of technical development, the impact and acceptance of AVs must be evaluated in two distinct cases: a first one (scenario A) in which manual vehicles are cut out of the circulation, and a second one (scenario B) in which such vehicles are still part of the environment. The technology that supports AVs is already at a very good point for what concerns the functionality of the vehicle itself, but the introduction in a preexisting driving environment certainly makes thing more complicated than on paper.

When interacting with manual vehicles, AVs will adopt an adaptive driving style that will take into consideration the other vehicles' reaction and drive accordingly, with no much space for pre-determined operations and management of routes. When operating in a fully isolated environment, instead, AVs will make the most of their V2X (Vehicle to X) communication skills. The acronym "V2X" (vehicle to X communication) represents the capability of vehicles to be automatically connected to other cars, users, infrastructures, networks, as the "X" stand for a generic element of the system. AVs are engineered to continuously communicate among each other and to be connected to the road infrastructure. Tomorrow's cities will somehow represent a large-scaled example of IOT (Internet of Things) which means that most of its components, like pedestrians, cars, traffic lights, signals and so on, will be part of the same interconnected ecosystem.

Vehicle-to-Vehicle (V2V) communication allows cars to share data in real time, regarding their position, speed and other driving parameters. The main application of this technology is mostly giving an anticipated feedback of the road conditions to the driver, otherwise impossible to gather. As a practical example, if an accident happens after a bend, or if the traffic has to stop suddenly creating a queue, the vehicles around will be immediately alerted, way before a visual feedback is achievable by a human driver.

This technology clearly represents an important support to improve road safety as both AVs and manual vehicles will be able to react at their best to a potentially dangerous situation.

When it comes to AVs, V2V will provide an important additional support for the vehicles to decide how to behave. For example, when approaching a crossing or shifting lanes, AVs may be able to determine with even more safety which maneuvers are the most appropriate to perform, considering the other vehicle's intention before they start moving.

Paired to V2V communication, the Vehicle to Infrastructure connection allows vehicles to communicate data about their current position, speed and driving status, and also planned routes before they actually hit the road.

The most basic implementations of V2I are, for example, the toll collection on highways or the access-control to restricted areas or lanes. V2I is already implemented in existing vehicles at a rather basic level, but future developments will be a total turning point.

Considering the city as an interconnected ecosystem, means that the remote infrastructure (collecting data from all the road users) will be able to automatically optimize the traffic fluxes and virtually annihilate any form of congestion.

The main application of V2I will be, in fact, the collection of data from users and the optimization of fluxes, using algorithms to determine the best route for each vehicle in order to reduce traffic and pollution. Even before the introduction of AVs we can perceive the benefit of this kind of approach when we plan our routes on systems like Google Maps, that can take into consideration the current traffic situation and suggest a better alternative. It is important to mention that V2I communication will not only be applicable to AVs, but also manual vehicles can get benefit from it, making it a very important transitioning technology that will help the harmonization of all the road users.

Users could be able to communicate their own plans to the road infrastructure, even before jumping on a vehicle and setting their desired destination. Nowadays a simple calendar tool in our smartphone is enough to automatically make the infrastructure aware of our commuting habits for the week to come.

A V2I-based flux management would ultimately operate as a ”Big Brother”, capable of automatically giving directions to cars, buses, trains, pedestrians and so on. The most important aspect of this process is shifting the perspective from an adaptive approach to a predictive one, capable of operating vehicles and infrastructures (AVs, trains, buses, but also traffic lights, illumination, road signs, etc.) according to the real users' necessities, and planning everything in advance, dramatically reducing the waiting times and optimizing the usage of resources.

3.3. Scenario A: Isolated Environment

Private areas, small islands or just insulated contexts can become the first tangible example of real ”Autonomous Cities”.

3.3.1 Traffic Management and Interconnected Transportation

The main difference between a regular city and a fully autonomous one is the automatic management of road fluxes. Driving would still be an adaptive operation, that keeps in considerations external elements such as pedestrians, cyclists or others, but overall the remote infrastructure will manage the routes of single vehicles in order to avoid congestions and virtually annihilating any traffic jam. Traffic lights, traditionally the main external input given from the infrastructure to the drivers could become completely unnecessary except for those who regulate pedestrian crossings.

As the remote infrastructure can be informed in advance of the people's moving habits, traffic fluxes could be optimized to be more spread all over the road network and not congesting always the same roads, with the advantage of a strongly reduced waiting time at junctions and roundabouts.

The management of lanes could become much more flexible than today. In fact, without any need to respect traditional road signs and circulation ways, lanes can be split according to specific congestion necessities. For example a two-ways road could become a one way road with double lane and vice-versa, if the traffic situation required it. This is something already happening in some highways, where the number of usable lanes or the traffic limits can be adjusted in real time, but the concept would become much more widespread and adopted within the whole urban environment.

More than today, autonomous cities would rely on a sharing based transportation. A strong integration could take place between AVs and MRT (Massive Rail Transportation). The two systems can in fact be considered two extensions of the same concept. AVs can reach the level of being extremely controlled by the centralized remote infrastructure, and we can find a strong parallelism with a train-dispatching facility and the central units who manage the fluxes of AVs.

Railway and vehicular fluxes can be fully interconnected, evaluated and optimized by the same system, which could allocate, for example, the necessary number of trains only when needed on a specific route, according to the commuting necessities of the already involved users of the road who are riding AVs.

3.3.2 Sharing

Currently cars are mostly owned by private users who drive them exclusively with family members and friends and despite a clearly rising trend of car sharing and car pooling programs, we still rely strongly on this kind of traditional setup. In a city driven by AVs the sharing concept would be taken to the next level. Psychologically AV users feel much less in control of the vehicles themselves and the sense of ownership would be strongly reduced. Considering that AVs are natively meant to be part of sharing fleets, such vehicles can be considered part of a totally shared transportation system that also includes bus and trains, but with a much more flexible and convenient setup.

3.3.3 City Structure

Cars are usually parked close to the places where people are willing to go and stored close to one's house in residential areas. The reason is pretty obvious, as the main purpose of a car is moving people from A to B, it is necessary to minimize the walking distance between initial and final destination to make the usage of the car meaningful and optimized.

In a foreseeable environment in which only AVs can circulate, we can expect a completely different setup, as the vehicles can be recalled on demand, only when needed, and can be stored remotely. AVs can in fact also drive themselves without any passenger inside, so dedicated parking areas, far from the city center, would make the parking areas in the city virtually unnecessary.The strong predisposition to sharing, would also decrease the specific necessity of keeping a car parked in one's house, as the legal property of the vehicle may be not related to a specific user, being part of a sharing fleet.

AVs will also massively come as electric vehicles, which means that they will be in need of being recharged often. In some cases we may expect wireless recharging lanes, as already experimented in countries like Sweden, that allow vehicles to recharge while moving, without any need to stop. In other cases, however, wireless recharging docks can be installed in parking lots to recharge the vehicles without the intervention of a human to plug and unplug the vehicle.

Road illumination in a context where only AVs can circulate would be only needed for pedestrians or cyclists. Such vehicles are in fact perfectly able to drive in full darkness and the road illumination can be activated on demand with motion sensors when people are around, basically for safety purposes, and anyway kept active at a lower power level for energy saving. As a reference, Ford has already tested a fleet of autonomous Fusion sedans in complete darkness, which have shown no issues with running immersed total darkness.

Road signs would become unnecessary for cars and only dedicated to pedestrians to signalize the presence of crossing and other potentially hazardous situations.

AVs in this environment are in fact guided by their internal mapping system and directed by the remote infrastructure. Something similar can actually already be evidenced in driver-less trains (e.g. Yurikamome Line in Tokyo) where no signs are needed along the route, as the system is already aware of all the driving necessities and the only signalization needed is for pedestrian evacuation in case of an emergency.

3.3.4 Users' Interactions

In a fully isolated environment, no manual vehicles are included in the circulation and no risk of conflict exists. As AVs are capable of communicating with each other, and also to connect to the remote infrastructure, the only variables left outside this interconnected environment are pedestrians, cyclists and animals.

In this environment, in which road signs will be adapted to the new circulation rules, more flexible and dynamic, pedestrians and the other must receive quick information from incoming vehicles in order not to be exposed to dangers when crossing roads. In the eventuality of no manual vehicles running, citizens will be strongly exposed to non-human behaviors and should not expect any sort of interaction with human drivers anymore, which implies a strong necessity of being guided through the process of understanding AVs' behavior.

3.4. Scenario B: AVs and manual vehicles coexisting

In the second of the two cases considered, with AVs and manual vehicles coexisting, all the other road users, including drivers, may find these vehicles scary and potentially dangerous, even if their safety level is in fact higher than manual ones.

One of the reasons, for example, is the lack of visual feedback from a human driver. We are all used to check, also involuntarily, if a car is actually going to stop when we cross a road. By briefly looking at the driver's eyes we can understand if he/she is aware of our presence and is keen to drive accordingly. Also, a car without a driver or even no occupants inside, may make people feel uncomfortable, giving the sense of a total lack of control and danger.

In some specific cases, like relatives of people who died in a car accident, the idea of a car that can drive around without the responsibility of a human driver will be totally unacceptable.

Last but not least, humans are used to other humans' driving style. Some maneuvers, some courtesies, some unwritten rules and communication protocols are part of our daily driving experience and may be very hard to eradicate.

As a practical example we could quote a feedback from Google's activities. When human drivers approach a road intersection without traffic light, they will gradually move forward departing from the Stop line, in order to gather more visual radius to understand if another vehicle is approaching. On the other hand, cars coming from the main road will be aware of the driver's intention and may eventually facilitate the maneuver, slowing down or giving him/her a signal (horn, lights, a hand gesture,etc.)

An AV will just stand still and wait for the road to be clear to enter the circulation, as its cameras are capable of detecting incoming vehicles even without the need of leaning forward.

This is the typical case in which a human behavior and a computer-based one would conflict. As not being able to understand what the AV is about to do, drivers around will feel uncomfortable and eventually in need to brake suddenly, fearing that the AV may move unexpectedly.

For this reason Google's AVs have been reprogrammed to simulate the human "leaning" even if not at all necessary for the drive itself.

As a matter of fact, it is pretty clear that a difficult path will be convincing people of the benefits that AVs will introduce, while in already developed societies

3.4.1 Statistics

As interest around AVs is growing, a strong skepticism remains, mostly for the reasons proposed up above. In order to understand the phenomenon with a statistical approach , a few data will be proposed (combined together, marked as A,B,C,D,E) as five recent surveys examined the public's attitudes toward AVs, four in the United States and one in Canada. [25]

- What's your attitude toward AVs?

  A: 34% say the prospect of the wide use of AVs makes them excited, 57% say it makes them worried.

- Will AVs reduce crashes and fatalities?

  A: 35% yes, 46% no.

- Would you ride in an AV?

  B: 17% would use an AV if one were available today, 75% would not use.

  A: 33% would be likely to ride in one in the next 10 years, 46% not likely.

- How comfortable would you be riding in an AV?

  C: 27% comfortable riding in an AV, 42% not comfortable.

  D: 32% not concerned about riding in an AV, 68% concerned.

  B: 22% would find them very relaxing, 41% very stressful.

- Would you buy an AV?

  E: 16% would buy an AV as soon as they are available, 35% would wait until they were more comfortable with AVs, 49% would never buy or buy only if there were no non-AV cars.

  C: 21% would be likely to buy an AV, 51% would not.

- How much automation do you prefer?

  E:

  11% Level 1

  27% Level 2

  20% Level 3

  26% Level 5 with the option for a driver to take control if desired

  13% Level 5

  D:

  44% no self-driving

  41% partially self-driving

  17% completely self-driving

- Should AVs allow a driver to take control if desired?

  E: 80% yes, 20% no.

  D: 96% yes, 4% no.

2

3.4.2 The missing link: Vehicle to User communication (V2U)

Statistics have shown interest by users but also a very strong lack of trust when it comes to fully delegate to the vehicle the main driving operations. Not only riders are skeptical, but also other road users, who find this technology disquieting at times, feeling vulnerable and exposed to a danger.

The reason behind this issues, is a strong lack of communication between the different road users (Figure 3.1). Making communication smoother and more effective would be a big step forward in the process of integrating pre-existing manual vehicles and AVs.

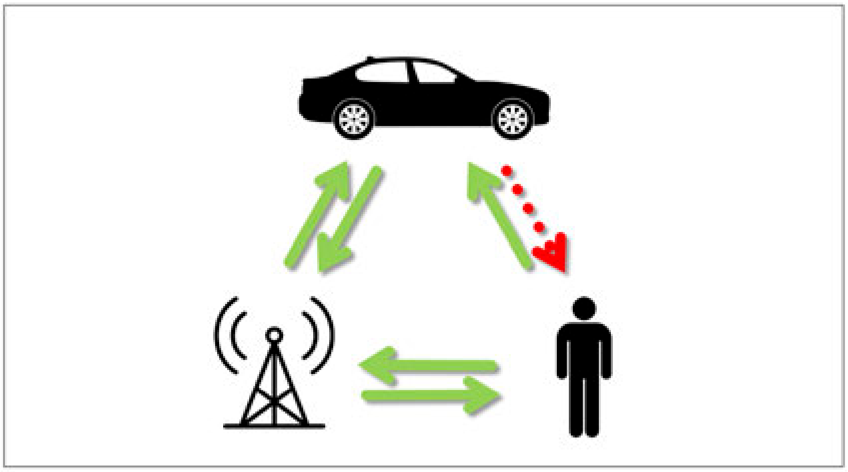

Figure 3.1: Vehicle, infrastructure and users' connection

3.5. Proposal

In both scenarios we can see how AVs will have a hard time dealing with public acceptance, especially in the light of the lack of vehicle-to-user communication that creates a sense of discomfort among the final users, also due to the robotized driving style that would not match the existing habits of human drivers.

In both scenarios human beings will still be part of the system. In an isolated environment, however, the problem is expected to be lower: AVs would not conflict with other vehicles, but likely "cooperate" with other AVs to make their driving cycle smoother. However, pedestrians and bikers would still require an extra-care as vulnerable users of the system.

The most complicated scenario is the one in which manual vehicles are allowed to circulate together with AVs. This is what we can expect to take place in most of the cities in which we currently live in, when AVs will be introduced, and dealing with this environment requires a much stronger effort from IT companies and car makers.

This research aims to provide a concept to overcome these difficulties by implementing a vehicle-to-user communication technology that can recreate the human-to-human interaction, otherwise lost with AVs.

The proposal, whose technical working principle will be further explained in chapter four, consists of a series of visual and sounds feedback coming from the AV, that combined together would alert the other users of the road (pedestrians and bikers, and also drivers in the scenario B) to make them aware of the driving intention of the autonomous vehicle, otherwise impossible.

The system aims to mentor drivers through several phases of the driving process of the AV (e.g. crossing junctions or lane changing), as well as pedestrians and bikers through situation of human-vehicle interaction (e.g. zebra crossings, parkings), creating a much higher sense of mutual understanding and breaking the barriers of skepticism that studies have found to be still remarkably high.

Chapter 4

Concept

4.1. A Framework for Human - Autonomous Vehicle Interaction

To overcome the strong lack of communication between AVs and road users, that is ultimately slowing down their adoption in real life situations, the technologies already implemented in AVs should be also used to manage a system of external visual information.

In particular, the LIDAR fitted in any AV is capable of creating a 3D mapping of the surroundings that includes, of course, any road user nearby(Figure 4.1). The possibility of detecting people, animals and other objects in the surrounding can, as a matter of fact, allow a direct and focused communication to explain what the vehicle is about to do, relieving the stress created by the lack of inter-human visual connection with simple led-wall panels fitted under translucent parts of the car's body (doors, bonnet, tailgate, fenders). LED lights have immediately been identified as the most effective way of creating a visual signalization on a vehicle due to the fact that the interaction occurs at relatively long distance (at least one meter from the vehicle) so a very high definition was not required, and an LCD display or projector would have been an unnecessarily sophisticated technology. One of the first point taken into consideration was in fact the economic sustainability and the necessity of not developing a whole new technology in order to

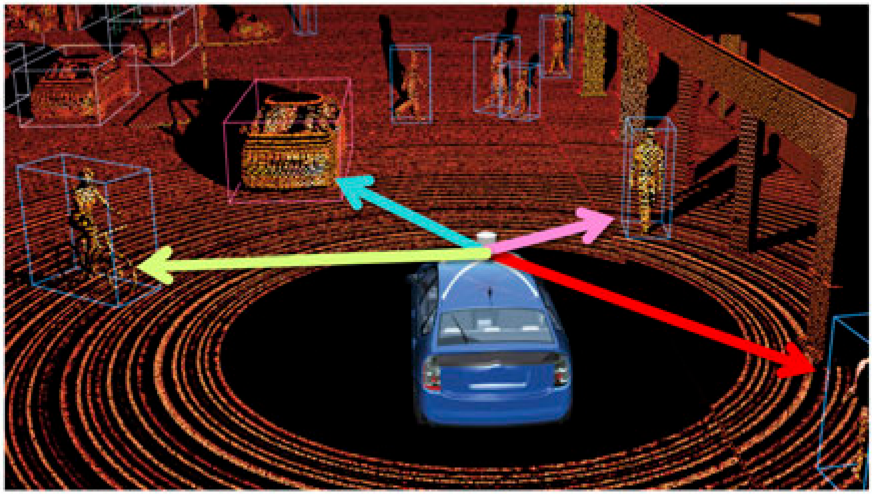

Figure 4.1: 3D Mapping view

reach the final goal.

When an AV fitted with such technology is approaching a road junction or crossing, it could automatically target the involved users and inform them properly, showing visual signalization when it is about to stop or start. The vehicle could show on its back an indication of its status, such as ”Waiting for clear road, please wait.” (Figure 4.3) while showing to the incoming vehicles a request of way such as: ”Entering the circulation. Please slow down.”

Low-speed driving also creates additional risk to pedestrians as most of the AVs will be based on electric platforms, which means very low engine sound. In parking phase pedestrians could not understand that the vehicle is moving and this issue has been already evaluated in current hybrids and EVs, making necessary a ”fake engine sound” to increase the perception of the moving vehicle at low speed.

In the case of AVs this issue would be even worse as no drivers or passengers could be inside of it, creating an additional difficulty for pedestrians who can not understand if the vehicle is on or off, and/or ready to move and depart.

In such a condition a countdown indication like ”Departing in 30s, please stand back!”, in addition to a sound alert, becomes absolutely necessary in order to avoid dangers. At low speed, it is also possible to smoothen interaction with humans and AVs, showing friendly messages like ”Hello, or Have a Nice Day!”(Figure 4.7)

One of the most complex situations concerning V2U communication is the approach of zebra crossings, not regulated by a traffic light. Pedestrians legitimately feel scared to take the initiative of passing while an AV is approaching, as they can not gather an immediate feedback about the intention of the vehicle to stop or not. Just imagine a car driven by no one, and blindly trust that this will actually stop while one is passing the road.

In this case, a written alert (Figure 4.2) paired with an audio recall, would dramatically increase the confidence of pedestrians and could easily be addressed to single users as the car can recognize the direction they are coming from. At the beginning of the concept ideation, the informations shown were textually more elaborated, but it became clear after confronting with my supervisors and evaluating other studies on this matter (such as the Nissan IDS concept [22]) that the text needed to be shrunk as much as possible. For example when inviting a pedestrian to cross, instead of a sentence like ”Please keep crossing”, something more simplified like ”Go! > > >” or a simple ” どうぞ > > >” would be much more immediate and effective.

It became clear that many users could not read well, or need too much time to fully understand written messages, but still it was decided not to drop the written text because the amount of information shown by simple icons would be too limited. Icons also have the limit of needing a decoding phase, while text generally reaches the users more directly. Text and icons should be ultimately combined together in order to mutually integrate each other to provide as much visual feedback as possible, respecting the principles of universality and accessibility.

As several pedestrians can be involved at the same time, the car can even address different messages to different users in order to synchronize the action. Bikers as well are targeted, especially in maneuvers like changing lane of giving way, always risky for the bikers' safety (Figure 4.4).

In the initial phases of the ideation, the usage of wearable devices was taken into consideration, with the vehicle potentially capable to address a haptic feedback to the surrounding users in order to attract their attention. This technology was subsequently dropped because it became clear that it would have distracted the users (instead of paying attention to the road, pedestrians or bikers would have raised their wrists to check a buzzing smartwatch) and creating a situation of danger instead of giving a real help.

Throughout the process, the "polestar" was trying to disconnect humans from their electronic devices, and recreate the dear-old visual communication that would be lost when interacting with an AV, without any intermediate filter.

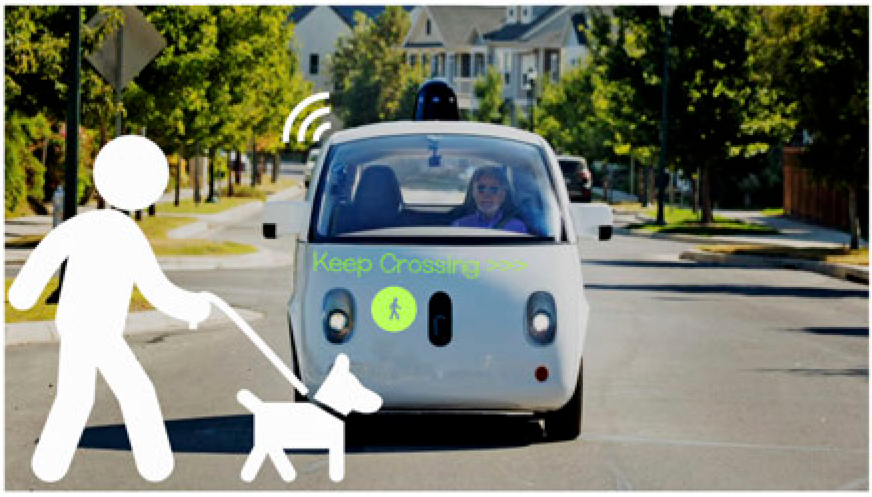

Figure 4.2: Communication to pedestrians - zebra crossing alert

In addition to this kind of signalization, a color to the existing red/am-

Figure 4.3: Communication at intersections - Rear visual alert

Figure 4.4: Communication to bikers - Lane shifting assist

ber/white lights used on the back and front of cars is added to the range to identify a running AV. For example, a blue or purple light would immediately identify AVs giving other drivers an idea of which kind of behavior expect from the car nearby. Ultimately, the purple color has been selected, as it is not part of the existing palette used for vehicular signalization (amber, white, red, blue) and can allow AVs to be identified immediately, without confounding them with other vehicles (e.g. police cars).

The concept of V2U communication is aiming to close the gap of information between the driving status of the vehicle and the final user, making the process smooth and trustful, reducing other users' uncertainty.

4.1.1 Feasibility, Universality

Figure 4.5: Signalization to human drivers using LED

A key advantage of the above described communication system would be its economic sustainability. The additional hardware needed, in fact, would not be more than some layers of low-resolution LED lights in flexible stripes, already implemented in several application such as led-walls or public transportation banners. (Figures 4.5, 4.6)

Instead of opaque plastic panels for bumpers, fenders and side protections, translucent ones would allow the led shine through, and the final design of the car could

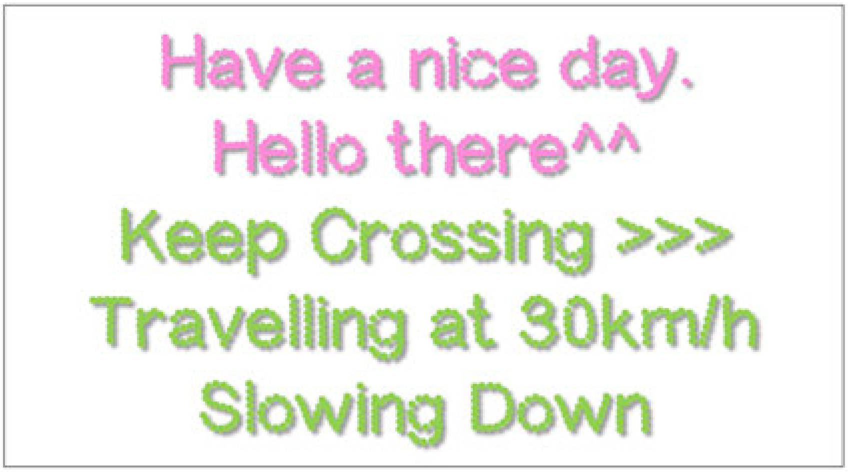

Figure 4.6: Signalization to pedestrians using LED

be kept virtually unmodified. (Figure 4.8) In terms of software implementation,

Figure 4.7: Bonnet and fenders fitted with LEDs and sound signalization

the already existing 3D mapping would provide the core of the system, which is already capable of fully distinguishing the different road users (cars, pedestrians, kids, animals, bicycles, etc.) and only an additional processing unit is needed to

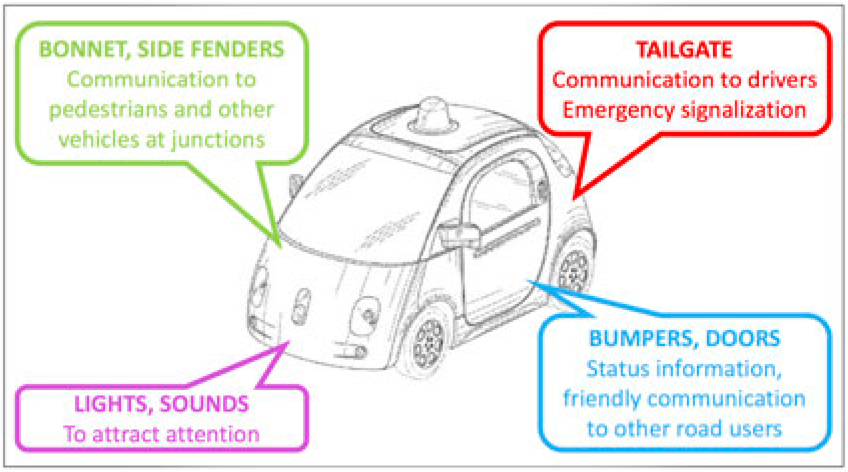

Figure 4.8: Communicating surfaces

generate sounds and visual information with dedicated targets

This system is aiming to provide a foxy solution to a big problem, using old and cheap technologies in pair with the most sophisticated ones already implemented in AVs, in a totally new and effective way.

Universality plays a key role in this process, as the vehicle must be able to communicate to every user in a quick and effective way, passing over cultural and language barriers. The adoption of only text would create problems to those who don't speak the local language, those who cannot read or just being difficult to read from afar. Using text is important to show elaborate information, such as the status of the vehicle when parked and to provide guidance to the people around, but it must be integrated with a set of icons that can be recognized by everyone easily. Road signs and the illuminated indications on a car instrument panel (Figure 4.9) are icons that people are already used to interpret quickly.

Universality is an issue in different fields, as a peculiar example we could observe how in Japan, in 2017, the makers of ”washlets” (toilet with integrated bidet function) had to define an industrial standard for people not to get confused with too many models and symbols on sale. [26]

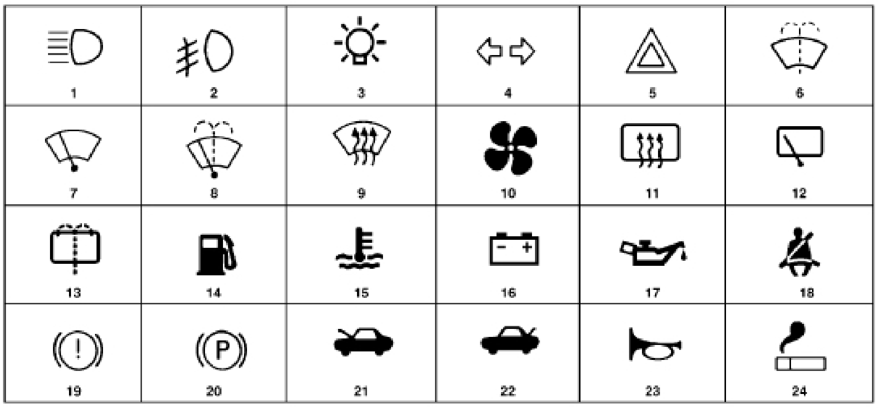

Figure 4.9: Example of standardized car symbols, internationally adopted

4.1.2 Comparison with existing prototypes

As previously mentioned among the related works (page 24), some makers and institutions have tried to bring a positive contribution in this field of research, with some prototypes.

Comparing the concept proposed with Nissan’S IDS, we can see how the indications on the front are mono-directional and can only target pedestrians, not other road users such as cyclists and drivers. Also they lack of a standardized communication protocol as not showing any icon that can be easily recognized regardless of the users’ language skills. Sounds are also not used, making the communication only effective at short distance and potentially failing to catch attention of distracted users.

In the case of the prototype developed by Duke University, the communication is smoother and standardized, but it lacks of important additional information, resulting too basic and again not targeting other road users. The results of their experimentation also showed that despite pedestrians looking at the icons, they failed to meaningfully attract attention and not providing a real benefit to the users.

4.2. Physical Prototype

A visual prototype has been set up in order to visualize the potential of this proposal. Using plastic cardboards installed on the vehicle I could recreate in real life a concept aiming to show the potential interaction between the car and the other road users. The first interaction shown is the crossing of pedestrians, in which the car shows two different messages and icons: "Keep Crossing > > >" (Figures 4.10, 4.11, 4.12) and "GIVE WAY!"(Figures 4.13, 4.14) and aims to replace the role of traffic lights when not present.

Figure 4.10: Green light replacement

Figure 4.11: Pedestrian invited to cross the street

Figure 4.12: Pedestrian invited to cross the street

Figure 4.13: Red light replacement

The second interaction created is the one with pedestrian walking by the car

Figure 4.14: Pedestrians invited to stop crossing and give way to the vehicle

at a very low speed, or standing next to the vehicle without paying much attention to the situation (Figure 4.15). In this case we could experience the vehicle departing without notice and creating potential danger to the people around: an icon and a written text ”Departing in 30sec.” (Figure 4.16), combined with a gentle sound, invite the people to stand clear and let the vehicle proceed with its maneuver.

Also, as a form of courtesy and a way to spread friendliness, harmonizing the communication with all the subjects of the road, the vehicle can show messages such as ”Hello b or ”Have a nice day!” (Figures 4.17, 4.18) which have no immediate practical purpose, but aim to reinforce the sense of trust between robotized vehicle and humans introducing a gentle human touch. The third main area of communication targets drivers on the back of the vehicle. In this case, for example, a sign ”Hold on..” (Figure 4.19) invites the driver to wait while something is happening in front of the car, where he/she cannot see. Possible situations in which this messages is in use could be a junction, when the vehicle stops and wait to have a clear way, or when someone is crossing the road in front of it. In this case it is important to alert the drivers behind that they should pass-by risking to hit the pedestrians crossing out of their viewing angle. Another case is lane changing where autonomous cars tend to be very ”timid” in comparison to human drivers and an additional signalization helps smoothening the shifting.

Figure 4.15: Distracted pedestrian alerted by the car with text, sound and icon on the side

Figure 4.16: Text showing the vehicle's status

Figure 4.17: Vehicle showing friendly messages

Figure 4.18: Friendly interaction with pedestrians

Figure 4.19: Message targeting drivers waiting behind the car

Chapter 5

Evaluation

5.1. Validation of hypothesis: real-life fieldwork

The goal of a driving fieldwork activity, set up in Tokyo during the month of May 2017 in the area of Shinjuku/Yotsuya, was validating the hypothesis that road users (especially the most vulnerable ones like pedestrians or bikers) would look for a visual connection when feeling threatened by a potentially hazardous interaction with a moving vehicle.

The experiment was also aiming to clarify the linkage between different driving styles and users' reactions. Specifically, to better understand how important the visual connection is regarded by the users, and if they would show a stronger necessity to interact with the driver when exposed to a more intense external stimulus.

To validate the data already acquired from various sources during the theoretical phase of the research, the real-life behavior of human beings, both pedestrians and drivers, has been evaluated in different situations and using a camera phone and a counter, the reactions in specific settings have been recorded:

- Junction with traffic light (wide road)
- Junction without traffic light (local road)

- Pedestrians crossing without traffic light
- Pedestrians passing by parked vehicles

5.1.1 Methodology, Findings

The observation took place on May 13th 2017 in the neighborhood of Shinjuku Nicchome/Sanchome and the area of Yotsuya Sanchome. The weather was cloudy and partially rainy, the fieldwork took place between 8:00 and 13:00, and from 15:00 to 17:00.

The experiment involved a driver who has been asked to drive in the above mentioned driving conditions with two different driving styles, one smoother and slower, the second one slightly faster and more aggressive.

In particular, it was focused on low speed driving and the purpose was finding as many interactions with other users as possible, in order to understand how driver and people around would have interacted.

The driver's age is 31, with 13 years of driving experience in Tokyo, and he was not aware of the purpose of the observation, in order to not influence his driving style.

A mechanical counter has been used to count the number of interactions while taking note of any driver-user communication action.

Interaction: anytime the driver crossed another vehicle at a junction or a pedestrian/biker crossing the street.

Communication: it includes head and hand gesture, eye contact, the usage of full beam flash or horn.

Results:

Figure 5.1: Driver to Pedestrian hand gesture

Observation	Smooth Driving	Aggressive Driving
Duration	2.5 hours	2.5 hours
Average Speed	16.1	20.4
Kilometers	40.3	51.2
Interaction (TOTAL)	253	245
Interaction (Eye contact)	100	123
Interaction (Head or hand gesture)	21	25
Interaction (Full beam flash)	10	10
Interaction (Horn)	0	2

5.1.2 Data Evaluation

During the smooth driving cycle, two seniors citizens stopped us raising their hand, in order to cross the street, deliberately asking us to slow down the vehicle. Seniors pedestrians also have shown a higher eye-contact with the driver, reaching 53% in comparison to the average 40% of the other road users.

In the second driving cycle, with slightly more aggressive driving style, in 3 occasion families with children looked at the driver with a bad look, and communicated some disappointment. Senior pedestrians in this situation have shown a higher level of interaction, remarkably high, with 65% of eye contact.

The fieldwork was very meaningful to validate the hypothesis of the need of visual driver-to-user interaction in a real life situation. The reason of an increased interaction when the speed of the car was higher, proved that when people lack confidence and they feel vulnerable or unsafe, they tend to immediately look for a visual connection in order to be able to take control over the situation, and to potentially mitigate any damage caused by improper driving style.

I also could understand, how from the driver's perspective it was important to find a visual contact in order to evaluate potentially dangerous situations. The driver has in fact, in many cases used his gesture to ask for a stop, or to ask other drivers to let him pass, or just as a sort of courtesy bowed his head (Figure 5.1).

The four main messages exchanged within users have shown to be the following:
"Please Go"
"Stop!"
"Sorry"
"Thank you!"

5.2. Characteristics Evaluation

The proposed concept differs from a regular vehicle, and also existing AVs, for its distinctive feature of providing visual and audio feedback to the users in its surroundings, about its driving intention, and alerting users in emergency situations, providing also information on the vehicle's status and friendly signalizations. As described in chapter four, the signalization is achieved through the usage of four elements: icons, text, sounds and lights, combined together.

The tangible value proposition for the final users is the possibility to be aware of the Av's intention and avoid the sense of uncertainty related to some potentially hazardous situations (like crossing a street) that would negatively affect its real-life usability.

Comparing the value proposition with what other concepts can do, we can see how they focus on pedestrian interaction, targeting only one user at a time, with a much more basic interface. It's the case of Nissan with the IDs concept [22], which provides a signalization about the detection of pedestrians and bikers using proximity sensors, as well as a frontal LED signalization for pedestrians, and a concept proposed by Duke University [23] with icons shown on the front of the vehicle to provide zebra-crossing assistance. The following chart briefly summarizes the functionality of the three concepts compared, and the target users reached.

FEATURE	Concept Proposed	Nissan IDS	Duke University
Icons	◯	X	◯
Text	◯	◯	X
Sounds	◯	X	X
Additional AV lights	◯	X	X
Target: Pedestrians	◯	◯	◯
Target: Bikers	◯	X	◯
Target: Drivers	◯	X	X

The following enumeration focuses instead on the specific components of the vehicle and the usage cases in which they can find actual implementation, aiming to evaluate which advantage they can provide to the final users.

- TAILGATE LED DISPLAY installed on the tailgate of the vehicle. It is capable of showing both text and icons. The target of rear signalization are other drivers and bikers. The LED display would activate when changing lane, or inviting a vehicle or bike to pass by. At junctions, to alert the drivers on the back of the AV of what is happening (e.g. the AVs is waiting to have clear way, or is about to enter the circulation) and whenever a pedestrian is passing in front of the vehicle, to alert other drivers not to pass by, reducing the risk of accidents. Also, in case of emergency, such as a sudden stop or an evasive maneuver, it would enhance the stop-lights signalization, recalling the attention of drivers more quickly.

The system can also be used to display to the rear users other kinds of friendly information such as memo of the speed limit ”Please slow down.” or ”Fasten your safety belt!”. Potentially it can be used for several kinds of signalization, also according to the specific environment in which the AV is operating, such as important news regarding the circulation or various topics.

- FENDER LED DISPLAY, installed above the front wheels, behind the surface of the side fenders. This display shows icons to regulate the circulation at junctions. The icons are targeting other drivers or bikers about the intention of the AV which is about to enter the circulation. The indication is shown to users moving perpendicularly to the direction of the AV and can request them to stop or proceed according to the specific situation and speed. The reason to implement this signalization is avoiding that perpendicularly driving vehicles would suddenly stop or speeding up. In fact, as finding the interaction with AVs unclear, drivers show the tendency to avoid it as much as possible, sometimes creating situation of severe danger. LED displays on the fenders can also show friendly messages to pedestrians and bikers at low speed such as ”Hello!” or ”Have a nice dayb.
- SIDE LED DISPLAY, installed on the side doors, This displays provide indication about the status of the vehicle, such as the battery/charging status of the car, as well as its availability in the case of car sharing fleets. In pair with the fender signalization it can also show friendly messages to pedestrians and bikers at low speed such as ”Hello!” or ”Have a nice dayb.
- FRONT LED DISPLAY, installed under the translucent surface of the bonnet, represent a key component of the system. It allows the communication with pedestrians, passing in front of the car at regulated or unregulated zebra crossing, or when crossing the street without any road signalization. The display will show two icons, resembling the pedestrian green and red lights, to visually replace the traffic light when. According to the speed and the condition of the vehicle, the system will give a positive feedback to the

pedestrians, who will be invited to keep crossing, or requested to stop.

Together with the two icons, also a written text will be shown, in order to provider a more consistent information to the final user, with indications like ”Keep Crossing > > >” or ”STOP! Give way!”.

- LOUDSPEAKER Replacing the classic horn, the loudspeaker targets pedestrians and bikers, emitting three different kinds of sound. The first, plain one, is used when giving information on the vehicle status or friendly messages to pedestrians. It will be a gentle and quick sound, useful to recall attention without being invasive. The second one, similar to the jingle used for blind-crossing assistance, will alert of a positive feedback from the AV when pedestrians and bikers are invited to cross the street. The third one, instead, will be louder and more ”dramatic” and paired with the ”STOP! Give way!” signalization, when pedestrians and bikers should not pass.

  As a form of cost-reduction, it is worth to mention that most AVs are based on electric vehicles that in many cases already feature a loudspeaker. The loudspeaker is used for ”dubbing” the engine sound to avoid risks to pedestrians at low speed, that may be unaware if the vehicle’s movement (EVs are generally too silent at low speed) and in such a case there would be no need of adding another one, wasting money.

- PURPLE LIGHTS, in replacement of the classic DRL (Daylight Running Lights) or in combination with them, must be lit whenever it is operating.

  The functionality of these lights is the immediate recognition of the vehicle as an AV also from long distance, for users to know in advance which kind of behavior they should expect from the incoming vehicle.

  The reason behind the choice of purple light is that red, amber and white colors are already used as a light signalization in existing vehicles and they would not be effective. Green has been rejected as a potential color because already used in traffic lights, while blue is traditionally linked to public service vehicles (police, ambulance, etc.) or truck side-lights.

5.3. Evaluation of the concept: users' questionnaire

After validating the hypothesis, creating a visual prototype and evaluating the functionality of the system, a questionnaire has been set up in order to validate the effectiveness and the reception of the proposed concept among the final users. The field duration was of two weeks and conducted in the month of May 2017. The goal was understanding whether people could find this concept useful and if they had any additional suggestion that could be used to further implementing my proposal.It was important finding a connection with real people, immersed in their daily life environment.

5.3.1 Methodology, Findings

The Vehicle to User communication targets potentially any road user in a urban environment. This means that in order to collect meaningful results from a questionnaire, I had to evaluate the structure of the Japanese society and to replicate on a smaller sample the same aging range. (Figure 5.2) I preferred to only submit the questionnaire to long time residents in Tokyo, to have a more homogeneous cultural background and living habits. From the data collected, I could sort the Japanese population in five main age ranges, setting up a target of 50 questionnaires compiled. 47 out of 50 surveys have been filled to date. I have found the designated people through personal connections, reaching a variegate poll of users. Google Docs has been used as a platform to elaborate the answers.

Age	Percentage	Questionnaires Submitted
0-19	17.5%	9
20-29	10.1%	5
30-44	19.8%	10
45-64	25.7%	13
65 and over	26.9%	13

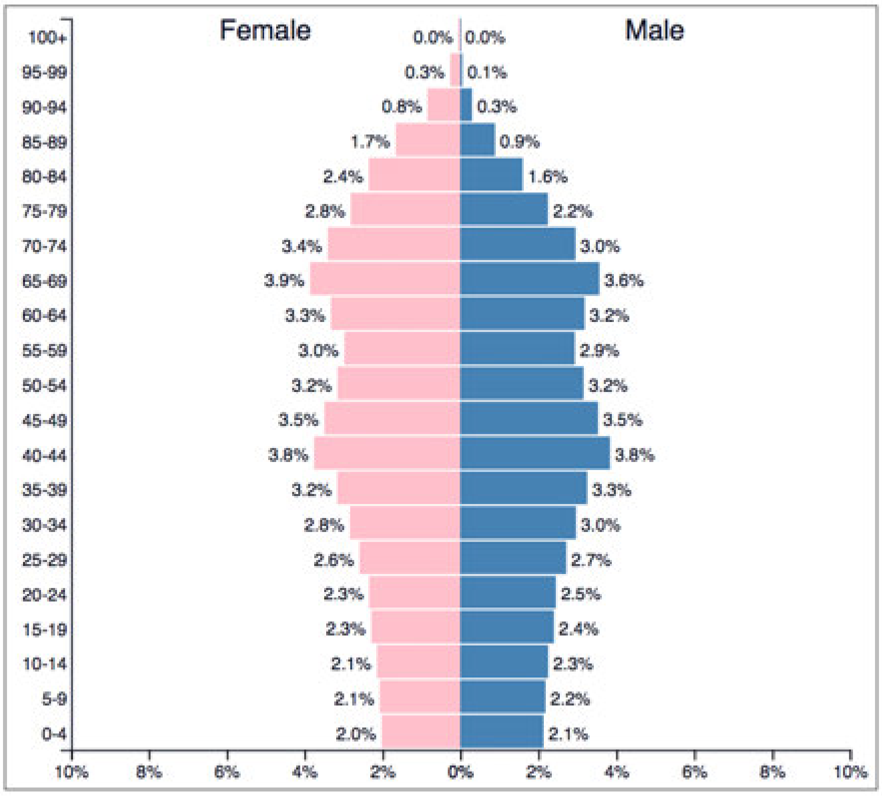

Figure 5.2: Japanese population by age

The questionnaire contained 13 multiple choice questions and 1 open-answer question, and the proposed concept was revealed only before the final 8 questions, in order to gather a honest feedback from the users about their background and potentially fears or doubts about AVs. The results are summarized as below:

- What is your general attitude towards AVs? AV(自動運転車) についてどう考えていますか。
  10% very positive, 23.4% positive, 34% neutral, 27.7% negative 4.9% very negative.

- As a pedestrian, would you feel vulnerable in presence of an AV? 歩行者として自動運転車の安全性に不安を感じますか。
  70.2% YES, 29.8% NO.

- As a biker, would you feel vulnerable in presence of an AV? 自転車を運転

される方にお伺いします。自動運転車の安全性に不安を感じますか。
36.2% YES, 21.3% NO, 42.6% I never use a bicycle. Overall 63% of the bikers YES, 37% of the bikers NO.

- As a car driver, would you feel vulnerable in presence of an AV? 自動車を運転する方にお伺いします。自動運転車の安全性に不安を感じますか。
27.7% YES, 21.3% NO, 51.1% does not drive/does not drive anymore. Overall 55% of the drivers YES, 45% of the drivers NO.

- Which of these occurrences concern you the most of an AV ? (Pick exactly two answers) 自動運転車の安全性に不安を感じる要因として当てはまるものを次の候補から選んでください。2 つ選択してください。

  An AV could cause a road accident: 74.5%
  An AV could run over a pedestrian or biker:70.2%
  An AV could increase the road congestion:29.8%
  An AV could be harmful for the environment:12.8%
  AN AV could be hijacked:12.8%

- Do you think AVs would be safer if they could communicate their intention (e.g. intention to stop at a crossing, or to pass at a junction) to other road users in the surroundings? 自動運転車が歩行者や一般ドライバーとコミュニケーションをとれた場合、より安全だと感じますか。例えば交差点で停止、または通過する際に、何らかのサインが自動運転車から送信されるようなケースを想定しています。

  34% much safer, 46.8% safer, 12.8% same, 6.4% less safe 0% much less safe.

Only at this point of the questionnaire, the concept is revealed to the interviewed people. After warming up with the first set of generic questions, the users will feel more into the topic and ready to provide a meaningful feedback, without being conditioned in advance by the proposed concept.

- What do you think about the concept proposed? Do you find the idea interesting? 今回提案されているソリーションについて興味はありますか。

  51.1% very interesting, 34% interesting, 12.8% neutral, 2.1% not much interesting 0% not interesting at all.

- Do you believe the concept proposed could increase the general safety of AVs? 今回提案されているソリューションによって自動運転車の安全性は向上すると思いますか。

  31.9% very much, 48.9% yes, 14.9% neutral, 4.3% not much 0% not at all.

- Do you believe the concept proposed could help drivers when driving in proximity of an AV? 今回提案されているソリューション一般ドライバーの運転にとって有益だと思いますか。

  19.1% very much, 34% yes, 34% neutral, 10.6% not much 2.3% not at all.

- Do you believe the concept proposed could help cyclists when riding their bike in proximity of an AV? 今回提案されているソリューションはサイクリスト (自転車の運転者) にとって有益だと思いますか。

  36.2% very much, 23.4% yes, 25.5% neutral, 14.9% not much 0% not at all.

- Do you believe the concept proposed could help pedestrians when crossing the street or being in proximity of an AV? 今回提案されているソリューションは歩行者にとって有益だと思いますか。

  38.3% very much, 31.9% yes, 19.1% neutral, 10.6% not much 0% not at all.

- Which is the most effective mean of communication, in your opinion? (Pick exactly 2 answers) 番効果がないと思うのは次のうちどれですか。二つ選択してください。
  Icons:68.1%
  Written Text:57.4%
  Sounds:42.6%
  Light signalization:31.9%

- Which of these options are most likely to turn out to be true? (Pick exactly 3 answers)

  Text can be hard to read: 57.4%
  Text can be shown only in one language: 55.3%
  Icons can be hard to decode:23.4%
  The system can create confusion:12.8%

The signalization can’t be viewed from afar:21.3%
The sounds are confusing 23.4%
The system is too expensive 2.1%
The system is useless 4.3%
The system is dangerous 0

- Considering the concept proposed, could you provide a feedback about it, and explain any improvement that could be implemented? (Free answer) 今回提案されているソリューションについてどう思いますか。改善策等についてフィードバックを頂けすと幸いです。

At this point, a series of free answers have been collected. Most of them have shown a positive feedback about the concept proposed, but some also introduced potential improvements, and have shown skepticism that can be summarized as below:

”I like the concept, but make sure that text and icons are really visible, because they could be too small.”

”I think text can be a problem because people don’t necessarily speak the same language.”

”I think people may need to study before getting used to this technology. They may need a course to know which kind of signalization is coming out of the car.”

”I think drivers could be confused and have too much information when they are driving around your AV.”

”I think sounds are important and useful, especially for blind people, but too many sounds can create confusion, and pedestrians may not be able to understand from which vehicle they are coming from.”

”I think the concept is very useful but young kids can’t read and maybe a voice to give indications could be more effective”

”I think that you could also introduce a more advanced technology, for example sending notification to smartphones or smartwatches of the people nearby”

”I think that if there are many vehicles on the street you may have too many information altogether”

5.3.2 Data Evaluation

After collecting data from the questionnaire (47 complete questionnaires out of 50), a positive feedback from the community have shown. The concept has been overall well received, as a total of 85.1% of the targeted people have found him/herself interested or very much interested in this technology, and 80.8% believe in this kind of technology as a way to make AVs safer and well received by the population.

Considering which target users would gather the most benefit from it, pedestrians and bikers respectively scored 70.2% and 59.6% of approval, while drivers scored a lower 53.1%.

In accordance to this data, the surveyed people showed to be worried more as a pedestrian (70.2%) and bikers (63%) than as drivers (55%) when in presence of an automated vehicle operating in their surroundings.

These data reinforced my assumption that the more vulnerable the user is, the more a human connection is needed in order to feel safe and at ease.

Regarding the functionality of the system, the questionnaires aimed to expose what the community thought about its real effectiveness. Most of the users have found icons the most effective way to express intention to other road users (68.1%) and text is also well received as a mean of communication, appreciated by 57.4%. Sounds are approved by 42.6% of the users, while lights as a way to immediately distinguish the AV from afar did not reach a high score, as only 31.9% of the users find them useful.

Also, it was necessary to check which could have been perceived as the strongest weaknesses of the system, as during the creation of the concept some warnings came out about these topics.

Accessibility and universality of the system are the two main concerns of the users. Despite being highly informative, 57.4% of the users found that text may be hard to read and understand quickly, and there is concern also over the fact that it can be displayed in only one language at a time (55.3%). Also icons are, however, regarded as possibly hard to understand from 23.4% of the users.

Interestingly, a small percentage of the users have found the concept useless or dangerous, and evaluating the open answers about which could have been a potential problem and/or improvement proposed, the surveyed people mostly focused their concern or demand towards the easiness and clarity of use, but not rejecting the concept per se.

5.4. Users' Test

After receiving a feedback from the users about the reception of the concept proposed, a users' test has been set up in order to verify the real-life effectiveness of the concept vehicle. In particular, as users have shown a strong interest in the communication between autonomous vehicle and pedestrians, the test mainly aimed to verify if such users could be targeted with sound and visual indications coming out of a vehicle effectively.

5.4.1 Methodology, Findings

The test has been conducted in July 2017 in two different urban areas of Tokyo: Yotsuya Sanchome and the residential area of Naka Meguro (Figure 5.3). These areas have been selected to have a setting in which the test could be performed without interfering with high speed circulation, and having a remarkable number of pedestrian crossing to observe. The test has been conducted in a clear weather conditions and driving performed by the same driver chosen for the hypothesis-validation test. The prototype previously set up to visualize the potential of the

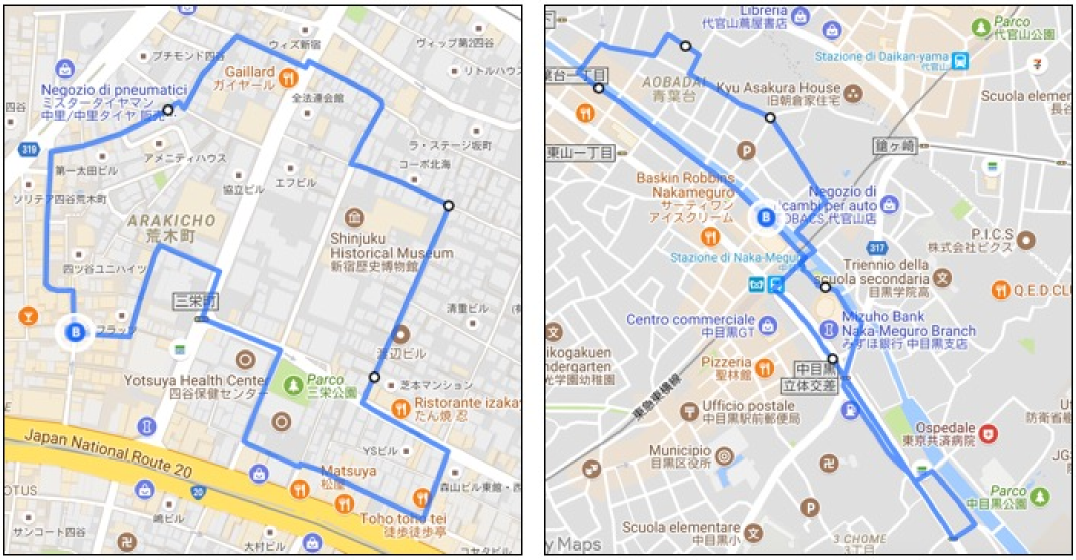

Figure 5.3: Testing areas and routes

system has been modified to reach a higher level of functionality, also in accordance to the feedback received during the research.

The text has been in fact adapted to the Japanese usage instead of English and it showed more simple and wider indication to alert pedestrians when to stop " 止まれ！" and when to proceed with the crossing " どうぞ。". Visual predominance has been given to icons that have been installed in a 25% diagonal increase format on the front of the vehicle, and mounted in a higher position (Figure 5.4).

In order to reproduce the visual effect of an autonomous vehicle, nullifying the human-to-human interaction with pedestrians, the driver has been asked to wear a dark shirt and sunglasses, to slide his seat backwards as much as possible to stay in he shadow, and to not show his hands while performing the test. He has also been denied to perform any visual interaction with pedestrians, in order not to corrupt the result of the test. Such methodology made the driver much less visible in comparison to a regular driving cycle, where pedestrians could visually relate to him in a natural way (Figure 5.5) and reproduced more closely the visual feeling of an AV.

The driving cycle has been specifically conducted in a very repetitive sequence in order to maximize the comparability between the two different situations (signalization installed, signalization not installed) and it was performed at a low speed of 10 km/h with no acceleration or deceleration, unless the pedestrians decided to pass in front of the vehicle. The interaction observed was the approach to a zebra crossing not regulated by a traffic light. The car, driving at a low speed, allowed users to choose safely whether to pass or not. Being on a zebra crossing the pedestrians were legitimate to pass and to expect the driver to stop, but the lack of visual feedback from the driver would create discomfort and could make them avoid the interaction. In case of positive response from the user (if he/she started crossing) the driver would reach full stop or slow down to make the pedestrian cross safely.

The goal of the test was understanding if approaching a crossing with the visualization installed could effectively change the users' behavior and make them decide differently to what they would have done in a normal situation. In ad-

Figure 5.4: Signalization with Japanese text

Figure 5.5: Visual interference decrease

dition to icons and text, a sound was emitted by a speaker hidden behind the cardboards (Figure 5.6). The Bluetooth speaker was installed with tape and connected to a smartphone inside the vehicle, and a specific sound was reproduced accordingly to the icon shown (green/red) every time the vehicle approached a crossing. The sounds have been recorded from traffic lights situated in the same geographical area before the beginning of the test.

The sound for red light is a slow tune, faster and more frantic for green light. In some Japanese traffic lights the traditional song "通りゃんせ", which literally means "Let me pass" is played. However, in this case a more neutral tune has been implemented, not to overcome the information provided by icon and text, attracting (or distracting) the users too much.

Sounds ultimately turned out to be a good way to attract users' as these have shown a good response, turning their head towards the vehicle whenever sounds were reproduced. Especially in a prototype phase, with visual resources more limited (no animation, no back light) sounds provided a good help to capture the pedestrians' attention. The following charts report the data acquired during the test in the two different areas. The driving cycle's was of 3 hours in the area of Yotsuya Sanchome and 3 hours in the area of Naka Meguro.

Figure 5.6: Bluetooth speaker recreating traffic lights' sounds

Yotsuya Sanchome (Case A):

	NO signalization	Green Light	Red Light
Duration	1 hrs	1 hrs	1 hrs
Total Interactions	27	23	34
Pedestrian started crossing	12	14	7
Pedestrian did not cross	15	9	27
Pedestrian started crossing (%)	44%	61%	20%
Pedestrian did not cross (%)	56%	39%	80%

Naka Meguro (Case B):

	NO signalization	Green Light	Red Light
Duration	1 hrs	1 hrs	1 hrs
Total Interactions	25	30	27
Pedestrian started crossing	10	19	5
Pedestrian did not cross	15	11	22
Pedestrian started crossing (%)	40%	63%	19%
Pedestrian did not cross (%)	60%	37%	81%

The test showed how pedestrians tended, in lack of any indication, to be conservative about their behavior and mostly avoid to cross, even if the vehicle was proceeding at low speed (10 km/h) and in presence of a zebra crossing. In Case A 56% of the users chose not to cross, 60% in Case B.

When the vehicle was fitted with a green light replacement signalization, paired to a sound, the number of pedestrians who confidently decided to pass increased by 17% in case A, and 23% in case B.

Overall, the crossing confidence increased by 20% when the system was in function.

During the test, the sound turned out to play a remarkable role in capturing the attention of the people who noticed the signalization, understood it, and decided to proceed with the crossing. When showing the red light indication, the results have evidenced a similar rate of reception, as in case A the number of stopping pedestrians increased by 24% and in case B by 21%.

Overall, the rate of pedestrian stopped increased by 22.5% when the system was applied.

5.4.2 Data Evaluation

The live test has shown an encouraging rate of confidence increase (21%) of the users interacting with the vehicle. It proved that a system outputting sounds, icons and text can represent a good way to attract attention and communicate to the surrounding users, when the visual feedback from the driver is cut out.

A very simplified and intelligible users' interface, strongly linked to the cultural background in which the vehicle is operating (already known icons, sounds, texts), turns out to be one of the killer-features of this technology. Even when driving with a prototypical signalization attached to the vehicle, users did not appear disturbed or surprised, and reacted naturally to the external stimulus.

In order to evaluate consistently these results, and also in the light of future developments of such technology, it is however important to point out some facts:

- The vehicle featured a non dynamic visual signalization. The limitations of this testing apparatus is that only one user at a time can be singularly targeted and that the visualization may reasonably be less effective than an LED and back-lit one. Future developments of the physical product would likely increase such results.

- The users have been tested without being aware of the functionality of the product. This has highlighted how a very simple interface does not need explanation and can effectively target a generalist public and that the road of simplicity is a winning one. Despite this positive result, in case of a massive trial of such vehicle, an awareness-increasing campaign would be rolled out, making users more conscious about the detailed functionality of the product, and able to maximize the benefits of its introduction.

- The test has been conducted on public roads and at a speed low enough not to compromise the safety of people walking around the vehicle. In order to verify the reception of this technology at higher speeds or more complicated driving conditions, and especially targeting other users (bikers, drivers) an initial testing phase on closed circuit would be recommended. One of the main prerogative of the system, is in fact the possibility to target several users at a time and not only pedestrian interaction.

- Despite questionnaires evidencing that sounds are the third most effective mean of communication, during the testing at low speed, users reacted particularly well to the audio stimulus. Considering the hybrid/electric nature of most of AV, and the regulatory issues related (in many areas EVs are required to have a fake engine sound to attract attention) the system could be integrated and provide a more consistent signalization at low speeds.

In the following chapter, based on the users' feedback and tests, some improvements to the product and future works will be proposed, in order to open a window on the potential scenarios that the development of this technology could show, becoming even more user-friendly and effective.

Chapter 6

Conclusion

At the end of the surveying activity, it became clear that the interest towards AVs, as expected, conflicts with the fear of these vehicles to be unsafe for the final users, even if statistics prove that the number of fatalities could actually be reduced by their introduction. The concept proposes to overcome this lack of trust, showing a good potential and generating interest in those users who would be skeptical without any communication from the vehicles.

The final user test has then shown a good improvement of the users confidence when the system is installed, providing a 21% average increase of users' confidence when crossing the street in presence of the prototype vehicle.

When really implementing this kind of system, however, some practical issues would come out, and the surveying activity with feedback from the users, conjuncted with the users, has turned out to be a meaningful source for improvements to be implemented.

6.1. Improvements and future works

Most users have raised concerns over the possibility the written text may be small and difficult to read from afar and that the vehicle can show only one language at a time. Such concerns are important to take in consideration and text should probably be regarded as the second mean of communication in terms of importance after icons, that can be displayed in a bigger size and have a potentially wider understandability. Icons are also more self-explaining and require less knowledge of the system to be quickly understood. They also can be shown in a bigger size, resulting more visible from a long distance.

When the interactions involve pedestrians or other vehicle coming from afar, the primary relevance should then be given to icons and lights, even if providing a more basic kind of information. Their size and brightness should be comparable to what traffic light are able to display and the usage of symbols must be carefully evaluated, also taking into consideration the cultural environment in which the vehicle is operating. Another improvement is the dynamic adjustment of font and icon size, brightness and lines of content shown according to the speed of the vehicle. At low speed, for example, is also possible to show messages in two languages as the characters can be smaller and having two lines of text instead of one (e.g. Japanese and English), while brightness should be lowered not to make the message blinding for users. Example:

- Speed 70km/h: No text, icon size 100%, icon brightness 100%
- Speed 50km/h: One line of text in local language, icon size 70%, icon brightness 70%
- Speed 30km/h: Two lines of text (local, English), icon size 50%, icon brightness 70%

Text messages, however, should not be dismissed from the vehicle and should in any case integrate the communication, as low-speed interactions still allow users to read properly, and icons cannot fully replace the range of information that text can show. In some cases, for example when showing vehicle status of a parking car, when giving friendly messages, and when communicating to drivers on the back who are in a range of just 2-3 meters, text can be a very meaningful way of communicating and will not negatively affect the overall usage experience.

Also sounds, overall appreciated by the users, are regarded as potentially misunderstandable, if the system became widely adopted by several vehicles, as users may be unable to distinguish the source of the information immediately, with a negative repercussion on safety. One of the cases could be vehicles in column that would emit too many noises at the same time. V2V communication, in this case, would help harmonizing the information provided to the external users avoiding redundancy and preventing the vehicle to show too many messages at the same time.

During the user test (described at paragraph 5.4) sounds have successfully captured the attention of the users, showing a good communication potential. When running at low speed, a hybrid or electric vehicle (most of the AVs are based on this technology) is particularly silent. A system of sounds emitted to communicate to the users could provide an additional support to mitigate the negative effects on pedestrians safety that electrification has brought to the world of automotive. Some users have also pointed out that kids could be targeted with sounds instead of a visual feedback, as it could be more understandable even without being aware of the meaning of icons and text.

Sounds can, ultimately, represent a good solution to smoothen the communication between vehicles and users and to enhance accessibility and universality.

Another point is finding a standardized communication register, and a way to make this technology known by the population effectively. The icons should resemble the ones implemented in already existing road signalization, according to the area in which the system is operating. For example, traffic lights in different cities may be different and the vehicle should show this indication accordingly. (Pictures 6.2, 6.3) The localization of information register, creating a cultural boundary to the area in which the vehicle is operating, increases the chances of effectively reaching the final users.

The sounds themselves, as users have found potentially difficult to understand quickly, should be strictly related to the operating environment. For example, using the same sounds already in use for blind crossers assistance is important do decrease the number of new information that the final users have to learn before interacting with the AVs. Despite being semantically in contrast, the concept

Figure 6.1: Text and icons adjusted according to the speed of the vehicle

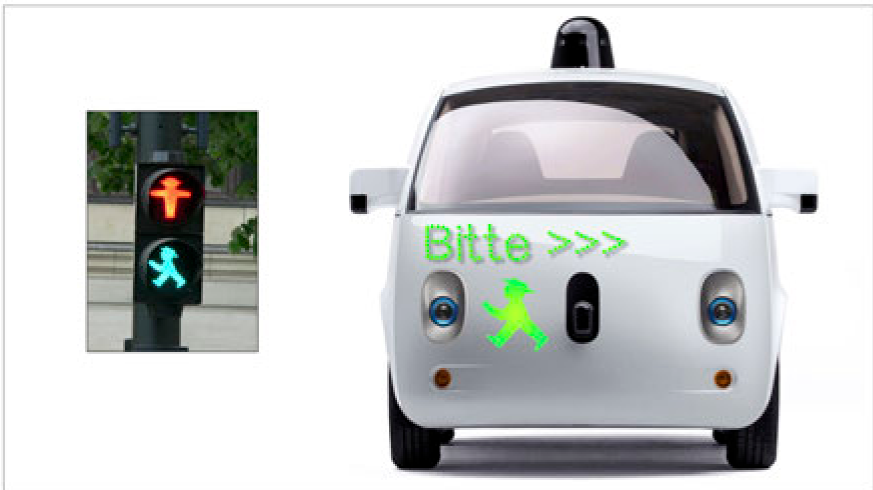

Figure 6.2: Distinctive pedestrian traffic lights in Berlin, reported on the vehicle

should ultimately embrace at the same time the prerogatives of being universal and localized at the same time. Universality implies that all the users in a specific cultural environment must be able to understand the messages provided by the vehicle, while these should be adapted and localized according to the specific community in which the vehicle is operating

Figure 6.3: Distinctive Japanese stop sign, reported on the vehicle

GPS positioning can play an important role in such a context. The communication must be universal, in terms of reception by all the population in a specific environment, but the information would be more effective if localized, and GPS could automatically detect where the vehicle is operating, providing information according to what the environment already shows to the people around (traffic lights, road signs, language, etc.)

Another kind of issues, related to the way the AV would be programmed to behave in case of an uncertain situation (for example, a pedestrian waiting on the pedestrian crossing but not moving forward, or a vehicle that cannot decide in which lane it intends to drive) should be taken in consideration. Even if the driving behavior itself is not strictly part of the ”information layer” evaluated in this research, in this kind of situation the vehicle would provide an information about its intention but not being able of receiving a contrary feedback and operate accordingly. In this cases the vehicle could be programmed to wait for some time, but ultimately perform a determined evasive maneuver if the other user does not perform any action.

However, this opens a window on a future field of research that could aim to not only create a visual communication from the vehicle to the users, but also from the external users to the vehicle itself, that could be capable of detecting more precisely the intentions of the surrounding human users.

The apparatus of an AV is in fact already distinguishing pedestrian from trees or road signs, kids from animals and so on. All the users of the road can be detected and recognized, and this represent the base of the working principle of an AV and of the concept proposed. But if the cameras installed on the AV could be refined to the point of distinguishing facial expressions or gesture in long distance, the AV could also adjust its behavior accordingly.

For example, a pedestrian raising his/her hand could make the vehicle stop on demand, or if engaged in another activity (e.g. talking on the phone, the vehicle would just skip his/her presence and move forward without interacting unnecessarily.

A whole new area to explore, that also turned out to become a possible future development of the product, is the implementation of directional speakers instead of regular ones (Figure 6.4). A directional (also known as "parametric") speaker can be regarded as a "laser sound" generator, that can transmit sound to a specific user with a very low dispersion angle.

The advantages of directional sound are two: the possibility of targeting different users at the same time with different sounds and reducing the noise pollution that the vehicle can generate, with potential conflict with other similar systems.

At the moment such technology is still not widely adopted, and pricier than a simple loudspeaker. As keeping the price of this system as low as possible is one of the prerogative of the concept proposed, directional sound technology could be implemented in the future, when such speakers will become more economically compatible and also the technology will reach a point of functionality where the dispersion angle is so reduced, that it really worth investing resources in its implementation, as well as practically installable in a vehicle (waterproofness, durability, etc.).

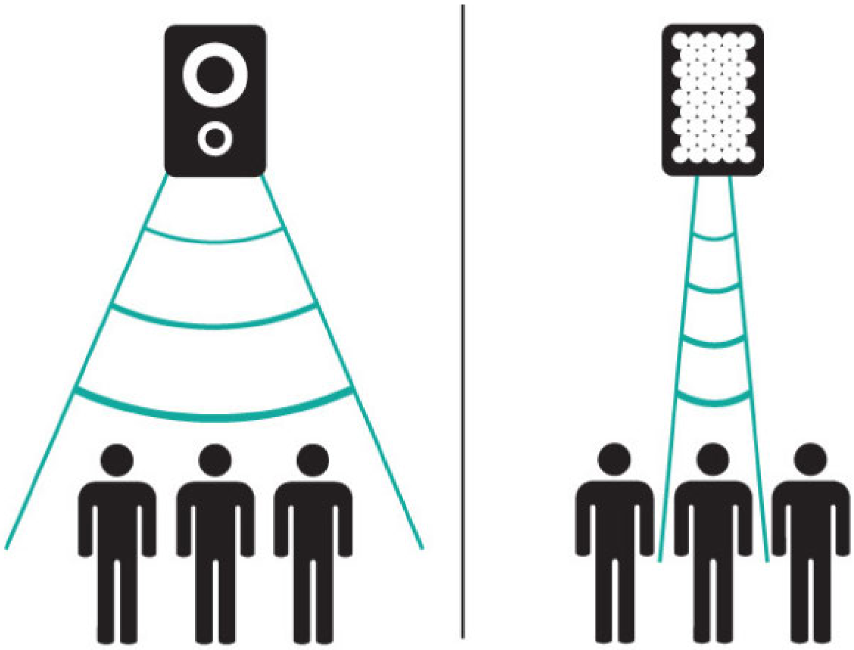

Figure 6.4: General principle of working of directional speakers

Acknowledgements

This research is dedicated to those who have supported me, materially and morally, whenever I doubted of myself.

It is dedicated to my family and friends, to the generous people who have passed through my life, and to those who are bound to stay.

And it is also dedicated to myself: may it be a turning point for my career, the first step of a happy life!

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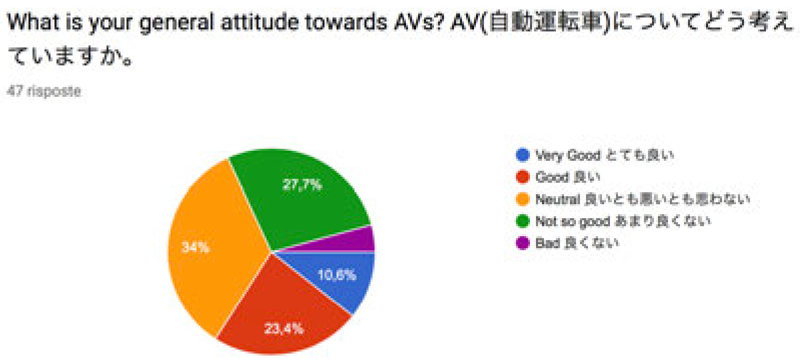
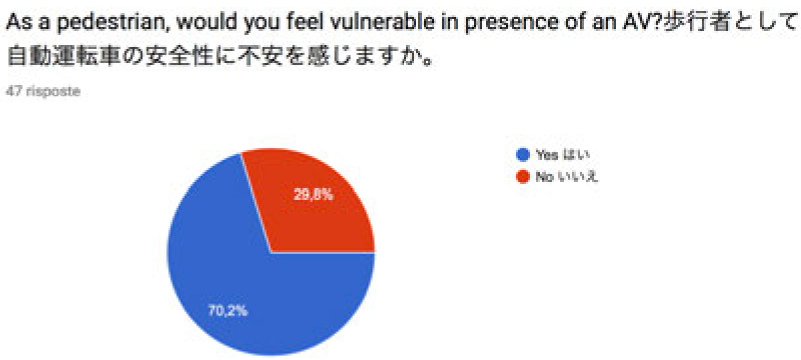
Appendix

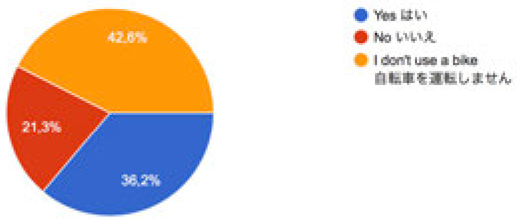
A. Results of final survey. Source: Google Docs web platform





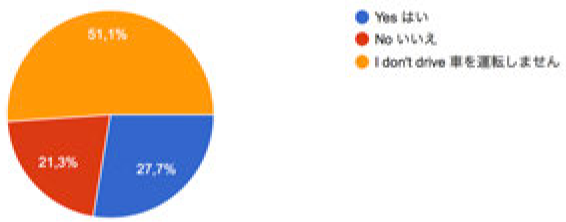
As a biker, would you feel vulnerable in presence of an AV?自転車を運転される方にお伺いします。自動運転車の安全性に不安を感じますか。

47 risposte



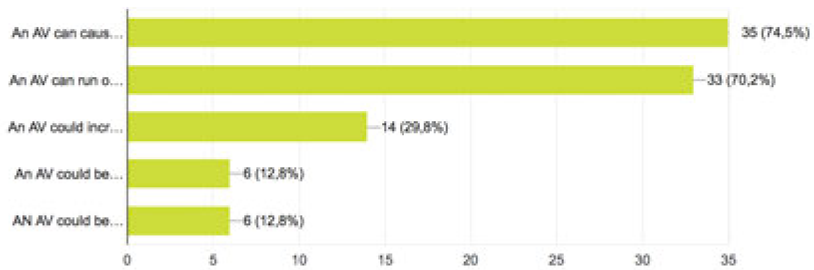
As a car driver, would you feel vulnerable in presence of an AV?自動車を運転する方にお伺いします。自動運転車の安全性に不安を感じますか。

47 risposte



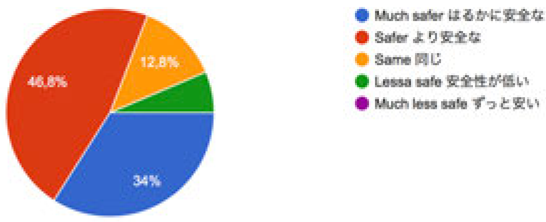
Which of these occurrences concern you the most of an AV ? (Pick exactly two answers)自動運転車の安全性に不安を感じる要因として当てはまるものを次の候補から選んでください。2つ選択してください。

47 risposte



Do you think AVs would be safer if they could communicate their intention (e.g. intention to stop at a crossing, or to pass at a junction) to other road users in the surroundings? 自動運転車が歩行者や一般ドライバーとコミュニケーションをとれた場合、より安全だと感じますか。例えば交差点で停止、または通過する際に、何らかのサインが自動運転車から送信されるようなケースを想定しています。

47 risposte

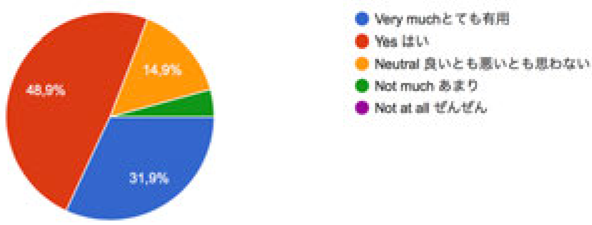


What do you think about the concept proposed? Do you find the idea interesting?今回提案されているソリューションについて興味はありますか。

47 risposte

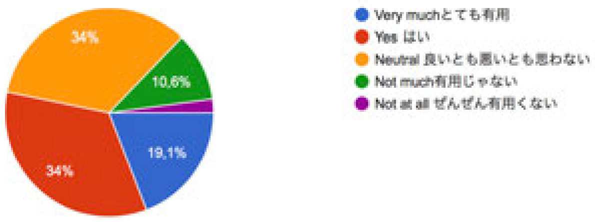
Do you believe the concept proposed could increase the general safety of AVs?今回提案されているソリューションによって自動運転車の安全性は向上すると思いますか。

47 risposte



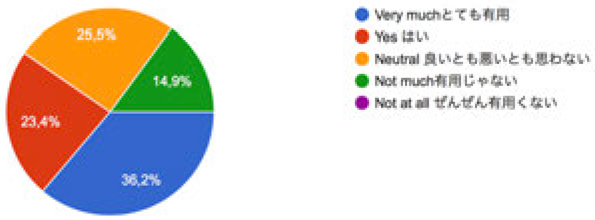
Do you believe the concept proposed could help drivers when driving in proximity of an AV?今回提案されているソリューションは一般ドライバーの運転にとって有益だと思いますか。

47 risposte



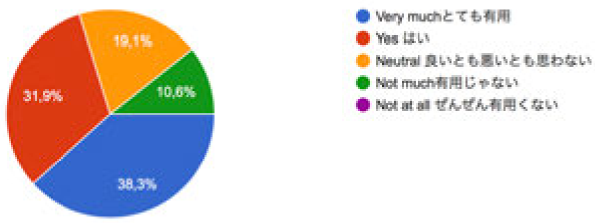
Do you believe the concept proposed could help cyclists when riding their bike in proximity of an AV?今回提案されているソリューションはサイクリスト(自転車の運転者)にとって有益だと思いますか。

47 risposte



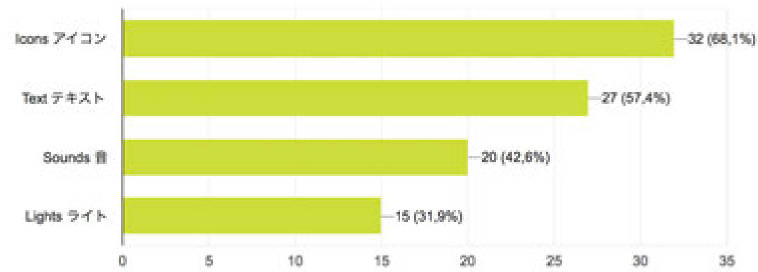
Do you believe the concept proposed could help pedestrians when crossing the street or being in proximity of an AV?今回提案されているソリューションは歩行者にとって有益だと思いますか。

47 risposte



Which is the most effective mean of communication, in your opinion? (Pick exactly 2 answers) 一番の効果があると感じるコミュニケーションツールは次のうちどれですか。二つ選択してください。

47 risposte



Which of these options are most likely to turn out to be true? (Pick exactly 2 answers)一番効果がないと思うのは次のうちどれですか。二つ選択してください。

47 risposte