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Diploma Thesis

Concept Design for Pedestrian-Vehicle Communication in the Age of Autonomous Driving

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Matriculation Number: 384573
May 6, 2018

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Acknowledgements

First of all I would first like to thank Prof. Dr. Sebastian Möller of Fakultät IV and Prof. Dr.-Ing. Matthias Rötting of Fakultät V at Technische Universität Berlin for giving me opportunity to carry out state of the art research in this field. Special thanks to Ms. Yuan Liu for her support and guidance. The door to all their office was always open whenever I ran into a trouble spot or had a question about my research or writing. She consistently allowed this paper to be my own work, but steered me in the right the direction whenever she thought I needed it.

I would also like to thank my former company to give me the flexibility to work on my research and provide the asset for helping me set and conduct the user study. Thanks to my former manager Ricardo Camacho's support, my friends Menghan, Ni's advice during my thesis work. Thanks to all the volunteered participants who were involved in this research, without their passionate participation and input, the validation survey could not have been successfully conducted.

Finally, I must express my very profound gratitude to my parents, my brother and to all my friends, especially to Yiping and Yiwen, for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Author

Yuan LYU

Hereby I declare that I wrote this thesis myself with the help of no more than the mentioned literature and auxiliary means.

Berlin, May 6, 2018

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(Signature [Yuan LYU])

Abstract

Important factors that are calculated into pedestrian's decision to cross the road include not only the vehicle's speed but also the interactions with the driver (e.g., eye-contact, gestures, or head movement). However, with the rapid development of autonomous vehicle(AV), how will pedestrians make the decision in road crossing without human driver involved?

The purpose of this research was to investigate the usability of the designed communication concept that explicitly communicate intent of autonomous vehicle to pedestrians, focusing on conflict situations. The research relied on three-phase design process with focus group, participatory design and the user study approaches. The first two approaches aimed to gain insight on designing the communication concept, Based on the outcomes, we developed prototype videos and assessed them in the user study. Qualitative and quantitative data were collected in the form of post-study interview and questionnaire to explain the participant's experience on designed concept.

The results indicate that in the AV-pedestrian communication concept: 1)the interface with relevant traffic light signal can be an effective signal to help pedestrians making the cross decision; 2)the explicit time expression is rather preferred when there is a certain crossing time period, especially for younger pedestrians; 3)virtual driver could help pedestrians to distinguish vehicle's driving mode, and it can increase perceived safety of AV for elder pedestrians.

Keywords: Automated vehicle(AV), human-machine interaction, focus group, participatory design, usability, AV-pedestrian communication.

Zusammenfassung

Wichtige Faktoren, die bei der Entscheidung des Fußgängers die Straße zu überqueren mit einbezogen werden, umfassen nicht nur die Geschwindigkeit des Fahrzeugs, sondern auch Interaktionen mit dem Fahrer (z. B. Augenkontakt, Gesten oder Kopfbewegungen). Wie aber werden Fußgänger bei den sich rasant entwickelnden autonomen Fahrzeugen (AV) diese Entscheidung treffen, ohne die Beteiligung eines menschlichen Fahrers?

Das Ziel dieser Forschung war, die Verwendbarkeit des entworfenen Kommunikationskonzeptes zu untersuchen, das die Absichten des autonomen Fahrzeugs an Fußgänger kommuniziert. Dabei wurde der Fokus auf Konfliktsituationen gelegt. Die Untersuchung basierte auf einem dreiphasigen Designprozess mit Fokusgruppen, partizipativem Design und Nutzerstudien. Die ersten beiden Ansätze hatten zum Ziel, einen Einblick für die Gestaltung des Kommunikationskonzepts zu gewinnen. Basierend auf den Ergebnissen entwickelten wir Prototypenvideos und bewerteten sie in der Nutzerstudie. Qualitative und quantitative Daten wurden in Form von Nachbefragungen und Fragebögen gesammelt, um die Erfahrungen des Teilnehmers mit dem entwickelten Konzept zu erklären.

Die Ergebnisse zeigen, dass in diesem AV-Fußgänger-Kommunikationskonzept: 1) die Schnittstelle mit dem relevanten Ampelsignal ein effektives Signal sein kann, um Passanten bei der Kreuzungsentscheidung zu helfen; 2) die explizite Zeitanzeige eher bevorzugt wird, wenn es eine bestimmte Querungszeit gibt, insbesondere von jüngeren Fußgängern; 3) ein virtueller Fahrer Fußgängern helfen könnte, den Fahrmodus des Fahrzeugs einzuschätzen, und er die empfundene Sicherheit von AV für ältere Fußgänger erhöhen kann.

Schlüsselwörter: Automated Vehicle (AV), Mensch-Maschine-Interaktion, Fokusgruppe, partizipatives Design, Usability, AV-Fußgängerkommunikation.

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1 Introduction

This chapter presents the motivation for the master's thesis project along with its background about relevant terms, technologies, and standards in the field of autonomous vehicle and its pedestrian-vehicle communication. In the end, it gives the outline of this paper.

1.1 Motivation

Autonomous vehicles (AV) are an emerging technology that over the last few years has been implemented in advanced testing programs on public roads. The technology is alternatively referred to as referred to as an autonomous vehicle, driverless car or self-driving car. Omar Rahim, the president of a British technology company Energi Mine, earlier said in an interview with The Mirror[2] that for at least 25 years, drones equipped with sophisticated artificial intelligence will completely replace human drivers. By then, human beings will be banned from driving in order to reduce thousands of traffic accidents.

Currently, almost all major automotive manufacturers are investing heavily in the autonomous vehicle research. The market for autonomous vehicles is expected to reach nearly US$42 billion by 2025[3]. IHS Automotive predicts global sales of nearly 21 million driverless vehicles (AVs) in 2035 [4]. McKinsey&Co. estimate that self-driving vehicles would eliminate 90% of the vehicle accidents in the United States and save up to US$190 billion of the expenses related to damages and health costs, while also saving thousands of lives[5]. The vehicle safety also means the lower insurance costs for industries and governments. Autonomous vehicle will bring tremendous benefits on traffic efficiency, make it more streamlined and less of congestions, efficiently use road space and increase roadway capacity, and save fuel for the vehicle itself.

As the year 2007 saw the completion of the first benchmark test for autonomous driving in realistic urban environments. And since now the companies which research such as such as Google's self-driving car has already covered thousands of miles of real-road driving[6]. With more and more researches, investments, and promotions on the autonomous vehicle technology, even though people see the big impact of this new technology, but there is still a large number of problems when we bring AVs and use them in the real traffic, especially with their surroundings on the road. The American Automobile Association(AAA) released a survey in March 2017 that found that 75% of respondents were afraid of using driverless cars, and 54% of respondents said that if there is a driver on the road during driving When the car is on the road, they will feel uneasy. Only 10% of respondents said they feel safer[7]. Even a shocking news on March 2018, *A woman in Arizona has died after being hit by a self-driving car operated by Uber in Tempe, Arizona...The victim was walking outside of a crosswalk when she was hit, police said.*[8] The incident appears to be the first time a pedestrian has been killed by an autonomous vehicle, and this brings one serious question: Can autonomous vehicle guarantee the pedestrian's safety when pedestrian crossing?

In terms of pedestrian findings during crossing in the traditional vehicle-pedestrian communication [9, 10, 11] that the human driver and their relevant behaviors impact pedestrian's cross decision. Since there is no human driver required during autonomous driving mode, the vehicle will possess the ability to sense the environment around them and navigate by itself. It is essential that the autonomous vehicle should able to transmit their status and intent to the pedestrian when they encountered each other, and the effectiveness and efficiency of this transition are particularly important for the pedestrian. Besides the technical and engineering matters to design and program this vehicle to avoid hitting pedestrians, it is also necessary to communicate them to the pedestrians to avoid conflict situations and fill up the absence of the human driver. Although the technology for vehicles to drive autonomously is being heavily researched, but how an autonomous vehicle would deal with pedestrian crossing in a good way is relatively unclear. Hence, the study of autonomous vehicle interaction with pedestrians is indispensable. In response to this overarching challenge, the work in this thesis focuses on the concept design of pedestrian-vehicle communication in the age of autonomous driving. And in the context of autonomous vehicle-pedestrian communication, we defined the AV is fully autonomous driven without the human driver inside, and the encountered situation is when one pedestrian wants to cross in front of the car.

1.2 Background

1.2.1 Autonomous Vehicles

An autonomous vehicle (AV) is a vehicle that is able to take over the control of the vehicle's operations[12], which means it capable of sensing and understanding its environment and navigating around without the need of a human input[13]. Advanced control systems interpret sensory information from a variety of technologies like radar, laser light, GPS and computer vision to identify navigation paths, other vehicles, pedestrians, obstacles and signages [14].

Society of Automobile Engineers (SAE) International classifies autonomous vehicle into six different levels, as summarized belows, Level 0 does not included in autonomous mode, Levels 1-3 require a licensed driver, but levels 4 and 5 allow driverless operation, which is necessary for many predicted benefits[15]:

- Level 0 — No automation: the driver is in control of the vehicle and responds to the automated systems in the vehicle.
- Level 1 — Driver assistance: the automated system and the driver share the driving responsibility. The driver is expected to take full control of the vehicle at any moment.
- Level 2 — Partial automation: the system takes full control of the vehicle operation. The driver must monitor the driving at all times and be prepared to take control of the vehicle.
- Level 3 — Conditional automation: The driver can disengage from driving tasks and the vehicle will inform the driver to take over the driving control in some limited time.
- Level 4 — High automation: vehicles operate autonomously for entire trips and driver attention is not required. Human-assistance is required only in specific circumstances.
- Level 5 — Full automation: fully autonomous system where the vehicle's performance is equal to human driver in any driving scenario. No driver assistance is required at any stage of the vehicle operation.

In this paper, ‘driverless vehicles’ and ‘autonomous vehicles’ refer to Level 5 autonomous vehicles where a human is not required in the driving loop of the vehicle.

1.2.2 Traditional vehicle-pedestrian communication

The communication between pedestrians and drivers starts well before the actual crossing action as reported by Varhelyi[9]. Apart from pedestrian, the drivers also make their decision (to yield or drive by) before the crosswalk. The research from A. Katz[16] indicated that the driver’s decision was biased by the approaching speed, distance between pedestrian and vehicle, and the number of the pedestrian. A driver’s reaction to yield after noticing a pedestrian trying to cross a road is normally by smooth and slow deceleration of the vehicle depending on the clarity of the pedestrian’s intentions. Schmidt and Färber [11] showed that pedestrian’s intention to cross a road is transmitted by their body language. Body language can include head, leg and body movements, for instance, turning of the body and so on.

The behavior of the vehicle in traditional communication totally depends on the operation of the driver, and the pedestrian can make their cross decision either by analysis the car’s movement or by connecting with the driver. And their behavior could also influence the driver’s decision. However, there is no tacit communication with driver can take place in the case of driverless vehicles. The traditional process of cross intent communication with the driver which relies on eye contact and body gesture stalls. But Rothenbücher et al. [17] notes that pedestrians are highly capable of interacting with vehicles, in situations like night time and poor weather, when the driver cannot be seen by a pedestrian. This might suggest the presence of cues that pedestrian may handle the situation rather than only have the tacit communication with drivers.

1.2.3 Vehicle-to-Pedestrian Communication

To reduce unimpaired vehicle crashes, a connected vehicle system had been researching and testing by U.S. Department of Transportation(USDOT) for the past decade, this can sense the environment around them and communicate that information to other vehicles, infrastructure, and our personal mobile devices. And it will enable safety, mobility, and environmental advancements that current technologies are unable to provide. The three major approaches to communication includes: Vehicle to vehicle (V2V), Vehicle to infrastructure (V2I), and Vehicle to pedestrian (V2P)[18]. Among them, V2P approach encompasses a broad set of road users including people walking, children being pushed in strollers, people using wheelchairs or other mobility devices, passengers embarking and disembarking buses and trains, and people riding bicycles.

Pedestrian detection systems can also be implemented in vehicles, in the infrastructure, or with pedestrians themselves to provide warnings to drivers, pedestrians, or both[18]. Due to the in-vehicle warning systems to drivers are becoming more and more commonplace (for example, blind spot warning, forward collision warning). And regarding the pedestrian’s habit during cross decision making in Section 1.2.2, we believe that the ”in-vehicle” system to communicate with the pedestrian should also be designed instead of using handheld devices for pedestrian to receive information from the autonomous vehicle.

1.2.4 Human Machine Interaction

Human-machine interaction is described as the interaction and communication between human users and a machine, a dynamic technical system, via a human-machine interface[19]. This can also be called Human-computer interaction(HCI) but apart from the computer-based software, the term "machine" here also indicates any kind of dynamic technical systems related in diverse application domains, autonomous vehicle technology is one of them. Therefore this AV-pedestrian communication can be considered as Human-machine interaction, hence it is important to understand how to do design in human-machine interaction field.

Human-machine interface can be described as the point of communication between the human user and the machine itself. This is not only refers to the user-visible part(vision-based), but also the auditory feedback(audio Based), machine environment, etc. The user communicates with the system through the interface and operates it, this interface can be as small as radio buttons, as large as the in-plane dashboard or traffic monitoring center. The design of human-machine interface should include the user's understanding of the system (mental model), and it is mainly for the usability of the system.

Mental Modal

A mental model is an explanation of someone's thought process about how something works in the real world, it can be described as "the mechanisms whereby humans are able to generate descriptions of system purpose and form"[20]. A mental model is a kind of simplified internal symbol of external reality, and modified and complemented with increased experience of the system to play a major role in cognition, reasoning and decision-making. In human-machine interface design, the mental model generally involves how humans understand and interpret the current state of the system and how to predict its future state.

It is important to design the AV-pedestrian communication with the pedestrians' established mental models towards traffic crossing context in this study. Additionally, attempting any concepts under this topic could also help on developing the intuitive and better mental models.

Usability

According to its ISO FDIS 9241-11 standard (Guidance on Usability, 1997)[21], usability is described as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". In human-machine interaction, the focus of usability is make the system meet user's needs and habits. Therefore it is important to understand users' needs and how they think while experienced the system.

J.Nielsen indicates that usability is part of "usefulness" of system acceptability(Figure 1.1), and it has been divided in 5 attributes:

- Guessability: The ability of first time users to guess what functions are doing.
- Learnability: How easy is it for users to accomplish basic tasks the first time they encounter the design?
- Efficiency: Once users have learned the design, how quickly can they perform tasks?
- Memorability: When users return to the design after a period of not using it, how easily can they reestablish proficiency?
- Errors: How many errors do users make, how severe are these errors, and how easily can they recover from the errors?

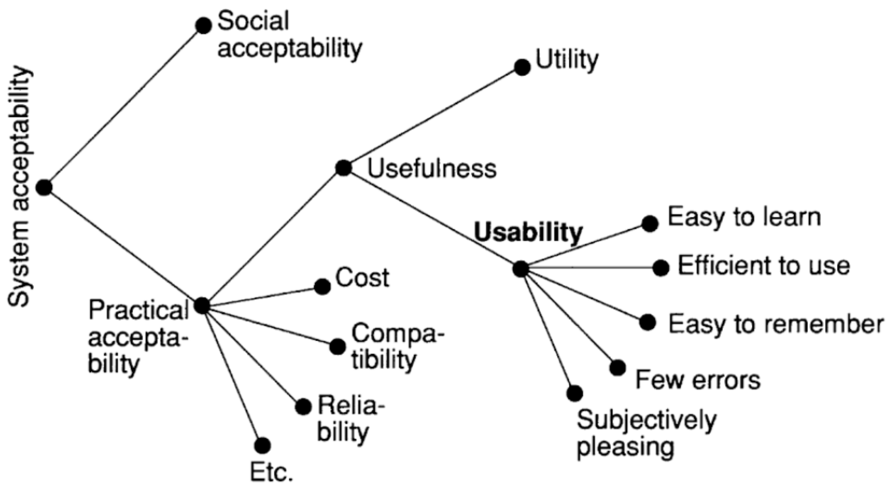


Figure 1.1: A model of the attributes of system acceptability[1]

- Satisfaction: How pleasant is it to use the design?

These are the attributes of usability and can each be studied to understand how the user and system interact and how the system compares to others. When design for good usability, a further 10-parameter usability definition from Jordan[22] describes below:

- Consistency: Tasks that are similar should be performed in the same way.
- Compatibility: How the user expects something to work based on other products or situations.
- Consideration of user recourses: The attention and cognitive power a user can apply is limited. Products should use more than needed.
- Feedback: When an action is preformed the user should be given feedback of the new state the product is in.
- Error prevention and recovery: The product should minimize the risk of errors and help users undo mistakes.
- User control: The product should maximize the users control over the product.
- Visual clarity: Interpreting the information from the product should be easy.
- Prioritization of functionality and information: Functions should be prioritized where the highest priority functions are the easiest to find and use.
- Appropriate transfer of technology: The technological level of the product should be decided of what is helpful for the user.
- Explicitness: The product should have oblivious cues for how to operate the product.

1.3 Outline

This master thesis is separated into 8 chapters.

Chapter 1 Introduction: This chapter presents the motivation for the master's thesis project along with its background and outline of this paper.(6 pages)

Chapter 2 Related Work: This chapter is intended to give an introduction about the relevant state of arts in the field of AV-pedestrian communication, and previous work. In addition, it also contains the intro-theory that has been central to the design methodology in this research.(8 pages)

Chapter 3 Focus Group: This chapter describes the relevant sections regarding focus group study, it is composed by aim of FG, participants, procedure and its key findings.(9 pages)

Chapter 4 Participatory Design: This chapter gives a description on the participatory design(PD) session, which includes aim of PD, method, participants, procedure and its key findings. (8 pages)

Chapter 5 User Study: This chapter presents the sections involved in user study(user study design, measurement, setup, participation, and procedure). In the end, how to deal with measured data as a transition to the next chapter. (7 pages)

Chapter 6 This chapter demonstrates the result of the user study qualitatively and quantitatively. (15 pages)

Chapter 7 Discussion: This chapter discusses the reflection of used methodology, the implications on the result of user study, and the limitation during this research.(5 pages)

Chapter 8 Conclusion and Future Work: This chapter summarizes the thesis, describes the problems that occurred and gives an outlook about future work.(2 pages)

2 Related Work

This chapter is intended to give an introduction about relevant terms, technologies and standards in the field of autonomous vehicle and its pedestrian-vehicle communication. In addition, it also contains the intro-theory that has been central to the design methodology in this research.

2.1 State Of Art

Concepts for future vehicle-pedestrian communication have been developed and prototyped by few companies and research institutes. Most of the concepts involve some form of visual communication either in the form of LED displays or projectors(shown as Figure2.1).

Google
Google has published their patent[23] about their AV to pedestrian communication concept, in the patent document it shows the signal at the radiator grill of the AV, combined with text and symbol to express to pedestrian that "you are safe to cross", at the meantime, the signal will be also displayed on the door of the AV on both side.

Mercedes-Benz Luxury in Motion
Mercedes-Benz has made an effort to be in the forefront of AVs with their concept car Luxury in Motion F 015 (Mercedes, 2015)[24]. This vehicle shows of a number of ideas that were described in the previous section, including LED lights for communicating in the front and rear, and projected laser messages (see Figure 9). This concept also provides verbal communication to the pedestrian.

Nissan IDS Concept Vehicle
Nissan has announced a concept vehicle called Nissan IDS Concept[25], which present Nissan's future vision of their autonomous driving. While this IDS Concept vehicle detected pedestrian surrounded, there will be an intention indicator around the vehicle which could flow pedestrian's movement. In order to communicate with pedestrian who wants to cross in front of this IDS concept vehicle, a small screen which set in bottom of the windshield with message display "stopping" and "after you".

Ford Fusion Autonomous Vehicle
Ford Motor Company partnered with Virginia Tech Transportation Institute, designed a method for communicating a vehicle's intent to pedestrian by using light signals. Considered as the most effective form in visual protocol and standardized turning and braking light indicator in current traffic communication, light signals in this concept were conduced in three conditions: autonomous drive mode, beginning to yield, or about to accelerate from a stop[26]:

- Yield: Two white lights that move side to side, indicating vehicle is about to yield to a full stop
- Active autonomous driving mode: Solid white light to indicate vehicle is driving autonomously
- Start to go: Rapidly blinking white light to indicate vehicle is beginning to accelerate from a stop

All the light signals were placed on the top of the windshield. The research team also designed a way to tested it as self-driving vehicle in the real traffic, the driver wear a seat costume whiling driving pretend that this is s driver-less car. They believe this is necessary to simulate the communication experience between pedestrian and actual autonomous vehicle.

Semcon's Car
Semcon's Car[27] concept was conducted together with Semcon automotive company and research institute Viktoria Swedish ICT. It displays lights in front of Radiator grill and head lights to communicate pedestrian as a global standard ideation, to make it readily understood by everyone. Due to it looks like the vehicle is smiling to you, they also called this as Semcon Smiling Car Concept. This concept take as a solution based on people's habit from the crossing situation. When the autonomous vehicle detect the pedestrian, the smile message sent to pedestrian and confirmed that the car will stop for the them. They also recommends a clear audio signal along with the smile since the majority of self-driving cars will be electric and silent.

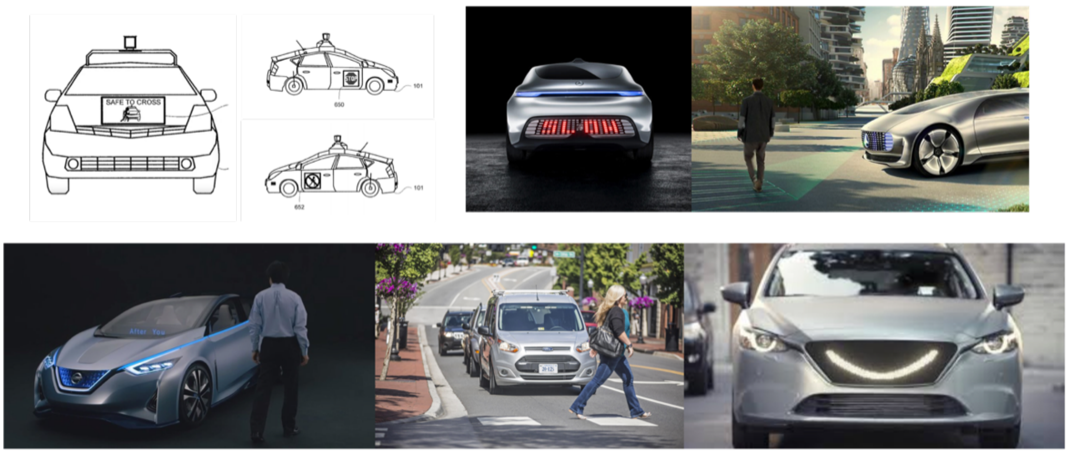


Figure 2.1: Existing or conceptual solutions for interaction between vehicles and pedestrians: (a)Google; (b)Mercedes-Benz Luxury in Motion; (c)Nissan IDS Concept Vehicle; (d)Ford Fusion Autonomous Vehicle; (e)Semcon's Car

2.2 Previous Work

The previous work was done by another bachelor student in our research group. He did a focus group and a survey study towards pedestrian's attitude towards future Car-to-Pedestrian communication of autonomous vehicle.

Figure 2.2 gives the example about four cross situations which were selected during the previous study. These 4 cross situation pictures were also used in the following focus group (Chapter 3) and participatory design session (Chapter 4) in this research.

Figure 2.2: Selected cross situations which require communication (a)Situation 1: crossing road without traffic lights & zebra-crossing (b) Situation 2: crossing when vehicle is turning (c) Situation 3: crossing in zebra-crossing (d) Situation 4: crossing when vehicle is driving in/off garages/parking lot

According to his survey research, there were several key findings he explored from over 200 respondents in bellowing:

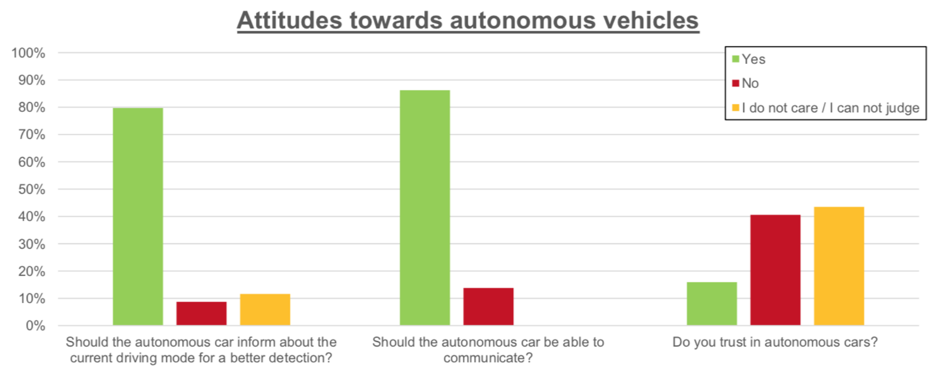


Figure 2.3: Attitude towards autonomous vehicle

- In Figure 2.3 pedestrians' attitude towards autonomous vehicle, the result shows that 80% respondent want to be informed about the current driving mode, and more than 85% respondent want a communication of autonomous cars in traffic situations.

- Figure 2.5 represents the result of pedestrians preferred displayed areas for all situations. We could see clearly that the windshield had the highest and most balanced respondents, the radiator grill and the panel on the car stands the other two top choices. Besides, the respondent on *projecting pictures onto the road* or give signals *with headlamps* are preferred in the situation 4(crossing when vehicle is driving in/off garages/parking lot).

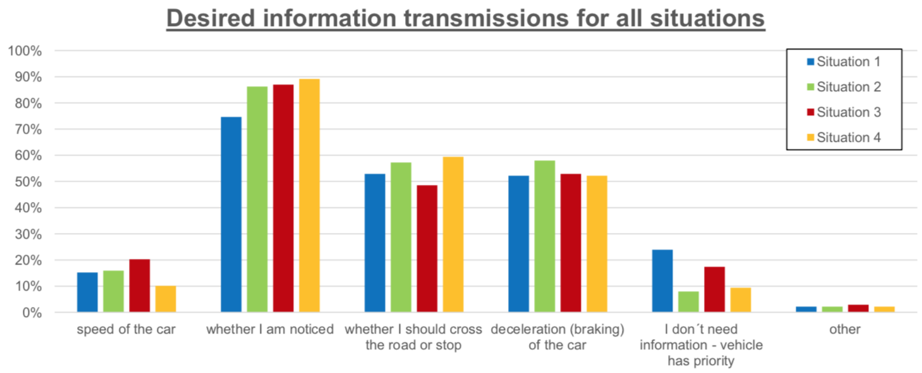


Figure 2.4: Desired information transmissions for all situations: Which information should be transmitted by the autonomous car?

- In Figure 2.4 Desired information transmissions for all situations, the respondent result shows that the "whether I am noticed", "deceleration", and "whether I should cross or stop" make up the majority 3 type of the information.
- Besides, when it comes to the question *Which type of transmission would you prefer in every situation?*, the preferred type of transmission are graphics and light signals, but it depends on the situations.

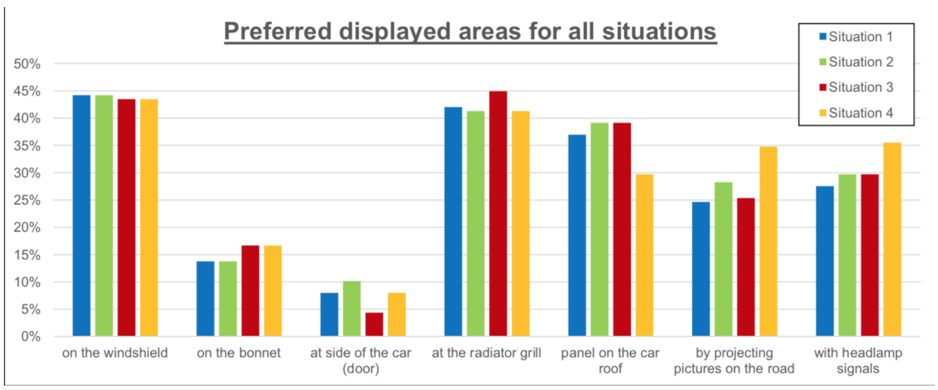


Figure 2.5: Preferred displayed areas for all situations: At which area of the car would be the information transmission most useful for you?

This previous study plays the foundational work in thesis concept design research, and its result continuously contributed to the following study and being a reference for the design process.

2.3 Research Methodology

This section presents the research methods we used in this thesis along with its role in this concept design methodology and their correlations.

To understand the pedestrian and how she or he will experience the communication with the autonomous vehicle, it is important to understand how the human mind works and how it interprets the world around it. Considering this as a key activity of this design research, the focus group study takes into the first method at the beginning of the research period, which is also be considered based on the previous study.

2.3.1 Focus Group

Focus Group(FG) is a commonly used research method in product usability studies, especially in finding the user needs. It first appeared in the 1950s, and proposed the use of this method by American sociologists Robert Merton and Kendall, who published *The focused interview; a manual of problems and procedures.* in the *American Journal of Sociology*[28]. Morton believes that by using this method can find the exact reason why people are admitting to a particular thing or behavior.

The Focus Group study is a round-table discussion meeting, which typically composed of 5 to 8 people, but the size can be ranged as few as 4 to as many as 12[29]. It is different from a question-and-answer type of interview. Because it is a multi-person discussion, under the auspices of the experienced moderators, the interviewees in the focus group have an interaction with each other. The reaction of one person can become a stimulus to other people. This interaction will produce more than the same. The number of people who provide a single statement can provide more information.

The Focus Group study is qualitative and instructive[30]. Bases on that, in this thesis research, we use focus group study to verify the previous traffic situations which need this autonomous vehicle-pedestrian communication, collect the communication approach in normal driving mode and autonomous driving mode, figure out the pedestrian needs during communicating and other relevant factors. The result from focus group study will be the reference to design the design tasks in the following participatory design session and contribute to the following design process as well.

2.3.2 Participatory Design

Participatory design (PD) is a set of theories, practices, and studies related to end-users as full participants in activities leading to software and hardware computer products and computer-based activities [31]. Literally, it is a concept that brings users deeply into the design process.

The field is extraordinarily diverse, drawing on fields such as user-centered design, graphic design, software engineering, architecture, public policy, psychology, anthropology, sociology, labor studies, communication studies, and political science, and from localized experiences in diverse national and cultural contexts [32]. Through the continuous practice and promotion of the practitioners in the field of anthropology and user experience(UE), this method has been recognized and applied in the product design circles in northern Europe and North America in recent decades. "with a more human, creative, and effective relationship between those involved in technology's design and its use, and in that way between technology and the human activities that provide technological systems with their reason for being" (Suchman, 1993)[33].

From the PD theory, it is not just a method during the design process but a mindset and mentality. Participating in the design of the stakeholders, mainly product end users, also can include potential users. In this thesis research the end users and potential users are the pedestrian who is or who might encounter with autonomous vehicle in the road traffic.

Some may state that we could consider our approach as a "user-centered approach". On the one hand, Mica R Endsley and Debra G.Jones explained in their book *Designing for Situation Awareness: An Approach to User-Centered Design(2016)*[34] that user centered design approach is a core set of principles and a methodology for engineers and designers who are seeking to nourish the situation awareness(SA)[1] of their system's users, such as the operators of automobiles, ships. On the other hand, Abras, Maloney-Krichmar, and Preece (2004)[35] consider PD as a form of user-centered approach. PD is "a maturing field of research and an evolving practice"(Kensing & Blomberg, 1998), thus difficult to define clearly. Asaro (2000)[36] showed that "despite their differences, the approaches ultimately converged on a set of shared concerns and very similar practices".

Therefore in our PD session, compared to the traditional participant's role, the researcher and designer change subtly: participants become the designer of this autonomous vehicle-pedestrian communication system, while actual designers and researchers in PD session more played a coordinator, cooperate and observer, perceptual get the first-hand data of the participants. As the main organizer of PD, researchers have been able to excavate the pedestrian's awareness and demand towards this communication from a richer perspective. Only when pedestrians express their ideas thoroughly can we truly understand them and design with their empathy, and then truly connected with pedestrians. This requires us to provide certain design tasks and some special materials to help pedestrians express more clear, creative and deeper ideas during PD session.

2.3.3 User Study

To assess the design we created so far, a user study evaluated by the qualitative research and quantitative research were designed as the third phase.

2.3.4 Interview

Interviews is one of the basic methods which often used in qualitative research to understand how users think. By means of an interview, the interviewer is able to collect data on a subject's experienced feelings, opinions, experiences, etc.

There are three broad types of interviews: unstructured, semi-structured and structured. Which of these is chosen depends on the research questions and the type of information that needs to be gathered.

- Structured interview: Before this interview, the interviewee or the user researcher outlines the problem in advance. The problem form, the answer method, and the

[1] SA is being aware of what is happening around you and understanding what that information means to you now and in the future. This awareness is usually defined in terms of what information is important for a particular job or goal.[34] The goal of this concept design is to make sure that pedestrian could cross road safely.

interview process are fixed procedures, thus it is not very arbitrary. The format is similar to the conversational survey, but most questions are still open questions.

- Semi-structured interview: Semi-structured interviews follows a pre-designed outline which addresses the topic through a number of open or defined questions. It is not as formal as structured interviews: according to these key points, the interview process can be flexible to ask follow-up questions about any subjects of interest.
- Unstructured interview: The unstructured interview is typically used when the interviewer has not much information about the topic that is being investigated. There do not require for a standardized processes and a fixed sequence of questions, and the dialogue process is relatively natural, allowing respondents to express their opinions as much as possible.

In this thesis, the semi-structured interview was used as the post-study interview method in the user study, the interview outline describes in Chapter 5 and the results are shown in the Chapter 6.

2.3.5 Questionnaire

It has been observed that questionnaires are the most frequently used tools for usability evaluation. It used to collect user attitudes, behaviors and characteristics under specific questions. Given the uniform format of the questionnaire, this method is quantifiable and comparable.

The questionnaire method originated from the attitude scales in psychometrics. When it is necessary to test the user's subjective indicators of the product, such as the preferences of the interface layout, the view of the interactive system, the overall evaluation of the product, etc. Measuring usability with questionnaire method commonly uses Likert scale, semantic differential scales, which are certified widely and simple to use. Based on that, the statistical data from the large-scale questionnaire can be considered to obtain stable and valid results and reveal some relevant phenomenons.

Questionnaire and interview methods can be combined within user study to complement each other and provide a better understanding of the view of pedestrian towards our design and its reasons behind.

To sum up, the three phases in this methodology we describes as "understand", "create", and "assess", the overview structure shows in Figure 2.6.

2.4 Tools

2.4.1 Unity

Unity is the multipurpose game development platform, which could build high-quality 3D and 2D games, deploy them across mobile, desktop, VR/AR, consoles or the Web, and connect with loyal and enthusiastic players and customers. It includes drag-and-drop functionality and scripting using C#. In this study, Unity was used for simulating the 3D urban crossing situation based on pedestrian's first perspective, the car movement and animated effect were defined by C# script. In the end, the created prototype was used for user study in Chapter 5.

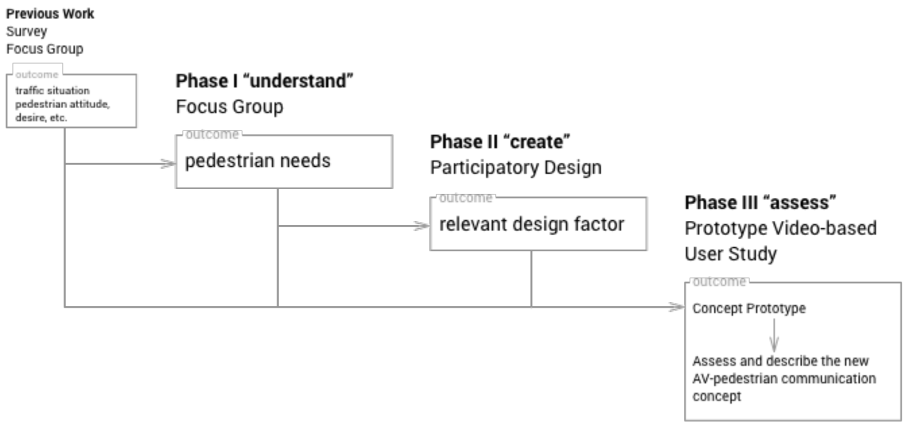


Figure 2.6: Methodology Structure in this research

2.4.2 Tableau

Tableau is an interactive data visualization tool that can be used to create customized dashboards and generate compelling business insights. In this thesis study, we use Tableau to calculate the MEAN and SD value as well generate box-whisker plot of our user study questionnaire data. Most Figures presented in Chapter 6 are created by Tableau.

3 Focus Group

3.1 Aims of the Focus Group

Due to there was a previous focus group conducted by another student as his bachelor study, the purpose of this study was to explore deeper based on the previous results of pedestrians' opinion about their attitude on autonomous vehicles, the communication between pedestrian and autonomous vehicle, their situational awareness for car-to-pedestrian communication and their needs in different urban traffic scenarios. Besides, the shared concern for this communication design was also discussed in the focus group study.

The result from focus group study should be used as the input for the following participatory design session.

3.2 Participants

This qualitative study was conducted during the autumn of 2017, recruitment took place in Berlin, Germany. After posting the recruiting announcement by different platforms, for instance, university research recruitment portal, facebook pages, off-line posts in the campus, potential participants were invited to our focus group room at TU Berlin. And we informed that this focus group study was required participants discuss in English in the recruiting post.

The two focus group were conducted after the recruiting, both focus groups were recruited with 9 participants, but 3 of them did not participant the second one, therefore the first one composed with 9 participants and the second one composed with 6 participants, all of them provided the informed consent about recording during study and their data using before we started.

Participants varied in age(from 20 to 39, MEAN = 28.87), gender(6 female and 9 male). Since the summer vacation period in the meantime and the territorial limitation, most participants were German(80%) but we keep the diverse range in the professions in order to collect answers from the different view. Participants were rewarded with 15 EUROs or 2 Hours certification for Human Factor student in TU Berlin.

3.3 Focus Group Procedure

Due to there was a previous focus group conducted by another student as his bachelor study, and the results about pedestrian's attitude, different needs based on different urban situations were quite complete, therefore we expected that the further focus group discussions from new participants could have additive insights based on the previous one rather than doing repeating work.

We designed two meetings in the focus group study, which was conducted in two stages. The discussion of the first focus group meeting(FG1) based on the results from the previous focus group. After we reviewed the results, we designed some new questions to explore the topics in this thesis research and modified some previous questions to make data more complete.

Before the first official focus group meeting, we did a pilot research with 4 voluntary participants to make sure that our questions were understandable enough, the discussions for each question were valid for our exploration. And it is always good for the moderator to practice his or her capabilities of questioning skill and field controlling(to suppress the powerful user, make the weak user speak more, etc.).

In the FG1, at the beginning, we presented what is the conflict[1] problem we might have in the normal pedestrian-vehicle communication, and ask *"In which kind of situations did you face such a problem? How did you try to communicate in such cases?"* to collect the situations we need in this study, and to verify if the situations we used in the previous study still valid and suitable for this thesis research. The decision making for normal pedestrian-vehicle communication were explored next, and the pedestrians' mental activity of different eye-contact condition with the driver were also collected(Figure 3.1 shows the three conditions we used in the first focus group meeting). Later on, we explained the difference of pedestrian-vehicle communication between normal driving way and autonomous driving way, discussed the situations again to double verify the needed situations and distinguish non-needed situations for pedestrian and autonomous vehicle communication, the reasons behind their opinion were also collected.

(a) (b) (c)

Figure 3.1: Selected conditions while crossing (a)Condition 1. driver has eye-contact with you (b)Condition 2. driver in the coming car is distracted/sleepy (c)Condition 3. you cannot see the driver in the coming car clearly

After the field discussion, we divided participants into two groups. Considering the time schedule of the focus group meeting, the group-discuss session was designed to collect pedestrians' opinion in a more efficient way. In the FG1 group discussion, each group held one concept of pedestrian's difference as well two situations to discuss the needed transmitted information, reasonable form for the transmitted information, and the possible communication procedure of pedestrian and the autonomous vehicle itself.

Table 3.1 presents the questions and group setting in two focus group meetings. Group A mainly focus on the concept for different types of pedestrian(normal pedestrian, distracted, disabled/elder pedestrian or kid, etc,.), the situations are 1: crossing road without traffic lights & zebra-crossing and 2: crossing when the vehicle is driving in/off garages/parking

[1]Conflict: There are situations in road traffic, in which the pedestrian does not know about the vehicle/-driver's intention.

lot. For the participants in group B, they had the discussion for different pedestrian's cluster(single pedestrian or multiple pedestrians), and the situations are crossing when the vehicle is turning and crossing in zebra-crossing. The picture of each situation are provided during discussion to help participants imagine that situations.

Table 3.1: Focus Group - Group Discussion

		Group A		Group B	
	Questions	Situation	Pedestrians' difference	Situation	Pedestrians' difference
FG1	1. What kind of information is required to communicate? 2. If there are {Pedestrians' difference} in these situations, in which way could these information be transmitted in the respective situation? 3. How could the communication (procedure) look like? How should autonomous vehicle and pedestrian behave?	situation 1&2	different types: normal pedestrian, distracted, disabled/elder pedestrian or kid, etc,.	situation 3&4	different cluster: single or multiple pedestrians(from different culture)
FG2	1. Which (types of) information is required to communicate? 2. In which form could each (type of) information be presented by the autonomous car? 3. How could the communication (procedure) look like?	situation 1&2	-	situation 3&4	-

The second focus group(FG2) meeting was a fast iteration of the first one(FG1), the whole meeting also included field discuss session and group-discuss session. The questions were modified after we collected the first focus group's data. In the second meeting, the participants' perceptions concerning the arise problem of the autonomous vehicle come into urban traffic, pedestrians' attitude and their expectation towards the autonomous vehicle. The conflict situation was discussed again, as well the normal vehicle-pedestrian communication form, relevant indicators and factors for cross decision making. After that, we asked participants to write down the needed transmitted information from the autonomous vehicle, the listed result came from the discussion between two neighbors. Before the group discussion, we also collected participants' views of *"How (In which way) could autonomous car get better reliant/trust from pedestrians?"*. Besides, we spent a bit time and gave a short introduction about the current pedestrian-vehicle communication concepts in the age of autonomous driving, which were surmised from companies and institutes. During the introduction, we provided the information type, information form and procedure of each concept to help participants understand better about the question we wanted to ask in the group discussion. After that, we also analyzed together about the advantages and disadvantages of those concepts we introduced.

In the FG2 group discussion, we basically set the same structure of questions and situation conditions, which also presents in Table 3.1. Two groups discussed the needed transmitted information, reasonable form for the transmitted information, and the possible communication procedure of pedestrian and the autonomous vehicle itself. Group A had the situation 1 and situation 2, group B had situation 3 and situation 4. To help participants put themselves more into the situations, besides the pictures from the first group discussion, the video of each crossing based on the first perspective were also displayed in addition. We removed the pedestrian difference as the condition this time to get more general output from participants. On the other hand, we could compare the results we had from two focus group meetings, to explore the similarity and difference within or without this different pedestrian condition.

The expectation of the future pedestrian-vehicle communication *"What in your opinion is the most optimized way for vehicle-pedestrian communication and what do you expect to realize for future V-P communication?"* as the close discussion for the whole focus group study.

3.4 Data Collection and Analysis

In the consent of focus group study, the video and voice recording was informed to all participants. With their agreement, the discussion recording was transcribed to the script for each meeting, afterwards we went through several phases of analysis. In addition, the material they created were also collected for the analysis (for instance, notes, handwriting, graphs, etc.). Figure 3.2 represents some pictures from the focus group study.

As we involved two meetings in focus group study: FG1 and FG2, data analysis was conducted in three stages. After the FG1, a preliminary analysis from the script was conducted in order to get a general sense of the data and reflect on its meaning. The data was divided into segments or units that reflected relevant insights, attitudes, and experiences of participants. Next, the retrospection of the data from FG1 needed to be done before the FG2. The result provided the segments or units which needed to be obtained more and the supplement was defined and collected during FG2. The preliminary analysis and segment analysis of FG2's script was also performed. Finally, with performed more detailed analysis and divided segments or units from FG1 and FG2, a conclusion of this process of analysis a list of topics was generated, and the topics were compiled into categories that were labeled as key findings.

In the last analysis stage, data across all focus group meetings was again analyzed for organizing them into categories. Then these categories or key findings were analyzed to determine the interconnectedness of issues and conditions that may have given rise to the categories.

Finally, a picture of the pedestrians' needs and their expectation of communicating with autonomous vehicle emerged. Data from all listed questions we discussed in focus group was analyzed for major themes, and data from each focus group meeting was also analyzed separately to identify the similarity and difference of the common questions.

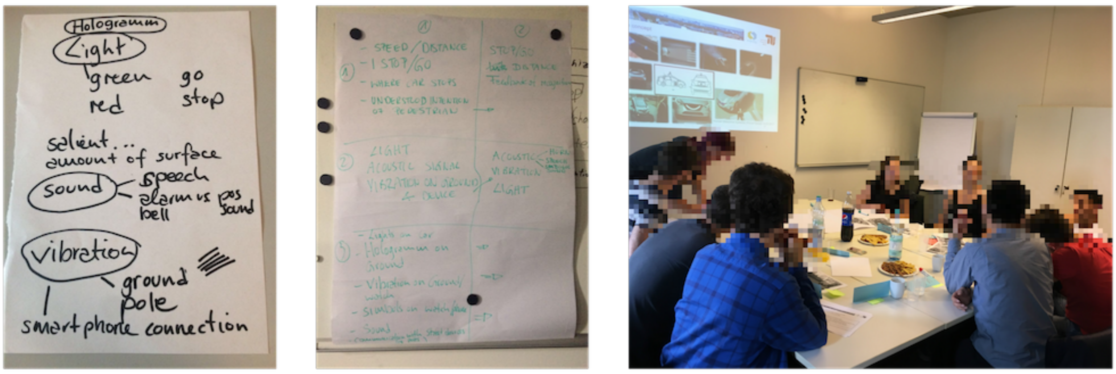


Figure 3.2: Pictures from focus group

It is important to note that the outputs from the focus group study can become the relevant inputs for the following participatory design in Chapter 4.

3.5 Key Findings

After the focus group data analysis, a number of key findings related to pedestrians' insights of pedestrian-vehicle communication under normal driving and autonomous driving. These findings include: 1) Conflict situation, 1) Decision making and communication approach, 3) Needed transmitted information and 4)Problems and expectation while communicating with AV. These findings are elaborated below.

To provide a better understanding of the audience, we present our results with the brief summary, some bulleted list, and its expended description. And additionally combined with actual words from focus group participants together in this paper.

It is necessary to mention that we did not choose the direct comment from participants randomly. All those words or comments we input in this thesis represent the standpoint or insights which were highly agreed by most participants. Therefore, even though some of the participants said in a different way or use different words, but the idea behind stayed tight together. And for those comments we chose were mainly because they expressed more typically for each subject. The following part explained our key findings from the focus group study in details.

Conflict Situation
The processed conflict situations we collected from focus group script are listed in Table 3.2 below:

Table 3.2: Collection of Conflict situations

	FG1	**FG2**
Conflict Situations	- pedestrian cross without the traffic light (like midblock or some small intersections) - pedestrian cross by breaking the rules even with the traffic light - pedestrian encountered the car which is driving back or turning - pedestrian cross without the clear priorities - pedestrian cross without situation awareness(for example, using mobile while crossing)	- pedestrian crossed when the car is turning right - pedestrian crossed in different driving cultures (like different regulations under zebra crossing) - pedestrian encountered the car in the traffic jam (mostly with multiple pedestrians and multiple cars) - pedestrian encountered the car in the parking lot or some other places without clear priorities

Come back to the discussion in the focus group, the unclear priority of crossing take into the majority reason behind the situation, such as crossing without the traffic light, pedestrian encountered the car in parking lot or other places. As these two we could classify with Situation 1(crossing road without traffic lights & zebra-crossing) and Situation 4(crossing when vehicle is driving in/off garages/parking lot) in the previous work. And encountering a car which is driving back for pedestrian also mainly happened in the parking lot or open area. Then the rest pedestrian encountering or crossing when the car is turning can be also classified as Situation 2(crossing when vehicle is turning).

One interesting finding pointed by participants is the traffic regulation regarding zebra crossing among different countries. Some participants mentioned that not like in Germany that pedestrian had priority to cross at zebra crossing(where there is a zebra crossing, there is no traffic light in Germany), in some countries, the zebra crossing just as an indicator for driver that they should slow down to aware the situation but yield for pedestrian is not compulsory, the actual crossing commend might from traffic light. *"I think if you switch to another country, you have to check the law and access, so in Germany or Australia it might bit different...like in zebra area, If you go as a pedestrian but the car has the right to go first, then the pedestrian has to wait"* one participant said. Considering the pedestrian's behavior on zebra crossing might bias by their different background, Situation 3(crossing in zebra-crossing) still counts as a conflict situation.

There were also few complicated situations from the discussion: pedestrian cross by breaking the rules, pedestrian encountered the car in the traffic jam. The most common situation happened in the first case was pedestrian crossed when the traffic light just turned to red. Normally there was not only one pedestrian either one vehicle in the traffic jam, thus the more common reason to lead this as a conflict because of the unclear and inefficient intention catching both from pedestrian and driver side. And regarding the pedestrian using their mobile while crossing has become more and more common, this could happen in every situation we mentioned above.

To sum up, according to the result of focus group study, we preliminary agreed that besides the complicated situations, the situations we used in the previous study were basically covered the result from focus group, which means the 4 situations in Figure 2.2 are still valid to use them as the context in the following design process.

Decision making and communication approach

When the participants talked about their design making in normal cross situations, there are several things they taking care of: 1) figure out whether the car or driver has recognized them; 2) figure out the car or driver's intention based on car's speed or light sign, gestures either hands from driver, and so on; 3) show their intention to the car or the driver whether they are going to cross or not; and 4) paying more attention in more complicated case such as crowded places or dark place, and watch the behaviors from other pedestrians.

The discussed of the communication while they met the conflict problem show the similar result, we list in two different types and divide based on the communicated carrier: the indicator/behavior of the car itself, and the communication with the driver.

For the indicator or behavior of the car itself category, many participants reflected that they mainly cross based on their experiences. From it, the distance between the car and themselves, the speed of the car are two core factors they refer to: How far and how fast is the car can ensure that I am able to cross safely is the first question before they made the cross decision. Besides, the communication with car itself also includes the headlight and horn from the car, but they are also relevant to the distance and car's speed. For example, most participants said they received a light warning from the car with the speed when they were trying to cross the street, and some of them also commented the similar situation about the horn.

When it comes to the communication with the driver, the outcome of the communication approach includes eye-contact, gesture/hand-movement, head-node or facial expression, even speech from driver sometimes.

Among the listed communicated approaches with driver, the eye-contact condition with driver plays an important approach when pedestrian make the cross decision. In the FG1 discussion, the different eye-contact condition drives the different mental activities of pedestrian.

For the first condition which presents in the Figure 3.1 (a), when the pedestrian has the eye-contact with driver. When they can clearly see the driver and have eye-contact, most of the participants mentioned that they feel quite safe even if they have no cross intention. "if there is eye-contact, at least driver they are paying attention to the environment" they said. But besides that, most of them also mentioned that they will decide to cross not only based on the eye-contact but also something else, for example, the car's speed, the gesture or head node from the driver, etc. One participant said, "I will always look like if the driver makes a gesture or hand sign or something more".

For the condition 2(Figure 3.1 (b)), all the participants had the agreement that this situation is dangerous. Most of them chose to wait and let the car go first, and one participant said *"I would not cross even if the car is slow"*.

As for the condition 3(Figure 3.1 (c)): you cannot see the driver in the coming car clearly, the discussion outcome indicated that the only factor for helping them to decide cross or not cross is to see the behavior of the car, which is basically the similar answer we had with the previous section "the indicator from the car". Some comments from participants:

"If the car is slowing down or stop, I supposedly walk"

"If they come with speed, you can be sure that they won't stop for you."(FG1)

Needed transmitted information

Based on the previous discussion, the introduction of the autonomous vehicle, the needed transmitted information in AV-pedestrian communication came on the desk. We listed and analyzed all the information they mentioned in two focus group meetings, as well the group discussion under different conditions. The sorted them into different categories and named each of them. In total 8 categories of needed transmitted information were summarized. Since the given context during the discussion, therefore the pedestrian in the description below represents the pedestrian who has cross needs when encountering an autonomous vehicle:

- **Vehicle's Status:** whether this car is automated driving; whether the inside automated system is running good(everything is under control) or being hacked, etc.
- **Recognition:** whether the car is recognized pedestrian.
- **Vehicle's Intention/next movement:** whether the car is going to yield or stop for the pedestrian; where is the car going to turn(right or left); is the car going to change the lane or not, etc.
- **Vehicle's Speed information:**includes the vehicle's current speed and its changing(acceleration or deceleration).
- **Distance information:** how far is the distance between the pedestrian and the moving vehicle(the implicit reflects "whether this distance safe for pedestrian to cross").
- **Pedestrian's Safety:** pedestrian wants to make sure that he or she will be safe with the following movement(either cross or not cross), and wants to receive the guarantee that the car won't hit him or her.
- **Communicate Validation:** to make sure this is a valid communicate between pedestrian and AV, the confirmation that pedestrian has received information and request for pedestrian's intention can be provided.
- **Traffic situation:** the hidden objects out of pedestrian's view sight can be provided as assistant information, for example, there is another car behind the Autonomous Vehicle but he or she cannot see during crossing.

The outcome done by preliminary sorting of the needed transmitted information for AV-pedestrian communication is used for designing tasks in the following participatory design session in Chapter 4.

Problems and expectation while communicating with AV
In the question of *"What information do you think should be transmitted between autonomous vehicle and pedestrian? What problems could arise when communicate?"*, there were four big topics regarding the second part we summarized from the discuss result, which was explained in below:

- **Weather condition:** If the autonomous vehicle is going to provide some signals for pedestrian to communicate, does the sign can be seen clearly in bad weather, for instance, darkness, rainy or snowy, foggy, etc.
- **Different type of pedestrian:** There are different kinds of pedestrian on the road traffic, besides the normal pedestrian who doesn't have disabilities, the blind people or deaf people could also be the pedestrian who need to communicate with the autonomous vehicle. The communication with kids or elder people who cannot move properly can also be the different case, even with animals.
- **Single / multiple pedestrian:** In the real urban traffic, the crossing does not only happened on single pedestrian but also a group of pedestrians, in the second case, how should the system manage to communicate with multiple pedestrians walk around the vehicle.
- **Cultural difference:** There is no doubt that different countries have different driving cultures, the relevant sign for communicating either on traffic signal or gestures or other relevant factors are also different. Therefore the cultural difference could be one problem for future pedestrian-vehicle communication as well.

When the participants talked about their expectation of the pedestrian-vehicle communication for the autonomous vehicle in the future, the data shows the relevance of the problems they discussed before. For dealing with visibility in different weather conditions and usable for different type of pedestrian, all participants agreed that this communication should be designed as multi-model interaction[2]: *"They need to mixture the different types of feedback, like sound, vibration, symbols, or lights, you cannot really focus on just one"*, one participant commented. As the visual communication might be the core communicated approach they mentioned during the discussion, it will be helpful when they are in the daily noisy traffic situation. However, when they had vision problems in bad weather conditions, one good solution is to provide auditory feedback as an assist. Furthermore, transmitting information with multiple channels can also be useful for disabled people(blind, color-blind, deaf, etc,.). Therefore participants believed it is fair to expect future pedestrian-vehicle communication with multiple forms to transmitted needed information, at least in visual-auditory modality.

From the discussion, one expectation of autonomous vehicle communicating with the pedestrian on the road traffic is to make it effective enough, even with the pedestrian group. On the one hand, they agreed that when there are too many communications needed in the

[2]Multimodal interaction provides the user with multiple modes of interacting with a system. A multi-modal interface provides several distinct tools for input and output of data. For example, a multimodal question answering system employs multiple modalities (such as text and photo) at both question (input) and answer (output) level.[37]

traffic, especially the pedestrians have different needs for crossing, it is better to have the vehicle communicate with all pedestrians at the same time instead of figure out with every signal pedestrian's intention. One pedestrian actually came out with following speech:

"if there is a group standing on the zebra crossing, for the car you cannot pay attention to every single gesture or hand sign, because there are too many people, maybe they also have different intention, in that case it would be better to show the car's intention to all of them, like saying "I'm driving now or I will turn right next"."

The position of transmitted information from the autonomous vehicle could help dealing the communication with multi-pedestrians as well. Most participants noted, if there will be a screen for providing needed information, no matter where does pedestrian stand around the vehicle, it should be transmissible for pedestrians to get the information. *"I think the screen in the front is important, and when the car turning around, it should also have something on the side, maybe on the roof, you could have 360 degrees (screen), then the car can give information to every side"*.

As for the cultural difference, the participants expect that there should be a standard which is international for people from different countries are able to understand. Besides, this communication system should be respectful for the local regulation at the meantime, so it can be easier to promote and adapt in different countries.

The outcome of the needed transmitted information for pedestrian communicated with the autonomous vehicle is used as reference or guideline to help participants design their prototype in the following participatory design session in Chapter 4.

4 Participatory Design

4.1 Aim of the Participatory Design

Considering the end user of this communication system would be any pedestrians in road traffic, to gather better about what are the insights from their perspective and how should this communication work or look like, we used participatory design to let pedestrian design this vehicle-to-pedestrian communication themselves. The relevant design will be the reference to our design concept and evaluated in the following user study.

4.2 Method

We used PICTIVE[38] method in our participatory design(PD) session. Additionally, to help participants express their idea more broadly, we also provided the paper vehicle model for each participant.

4.3 Participants

The participatory design(PD) session in this research was conducted right after the focus group study, and it also took place in Berlin, Germany. It was organized with 8 participants(6 males and 2 females) aged from 24 to 28 years in total, the participants included students and employees who have Human-Computer Interaction Design(HCID) and other subject backgrounds. Each PD session involved 4 participants, and their backgrounds were varied. Apart from focus group study, the participating of this PD study was volunteered, all of them provided the informed consent about recording during the study and their data using before we started.

4.4 Participatory Design Session Procedure

We planned to conduct two PD sessions in this phase: PD1 and PD2, and each PD session were composed of several design tasks. The tasks we designed for participants to contribute were mainly referred to the result of previous focus group study, and the order of these tasks could help participants transfer their design idea to the design deliverable step by step. Therefore from their output of each task, the early stage of this pedestrian-vehicle communication towards autonomous car can be exposed. And those outputs can certainly contribute to the following design process in our research.

To optimize the participants' engagement during PD session, and also to reduce the possibility of repeated design ideas behind, we aligned the different conditions under each design tasks for the participants. After each task, we set a short recapitulation part, the participant presents his or her design ideas to others, this can not only help the researcher to understand participants' design better but also help themselves to do the retrospection. Additionally, other participants could also get inspired from this recapitulation and be more creative in next task.

In PD1, to guide our participants into the design context smoothly, we provided the introductory overview of modalities, Vehicle-to-Pedestrian(V2P) Communication and Autonomous Driving as a start. The basic introduction of modalities under human-computer interaction design was considered as a correct guidance to some participants who have no idea to start designing. Then briefed V2P Communication and the autonomous vehicle is to help them understand the design context for their tasks: thinking as a pedestrian, and designing a communication for an autonomous vehicle which has no human driver inside. Before we provided the referred design tips from focus group result, a quick discussion was conducted in *"What would be the concerns of designing information transfer from autonomous vehicle to the pedestrian?"* and *"If an autonomous-driving company wants to develop a mode for AV to communicate with the pedestrian, what advice do you have for them?"*. We believed that this could help participants engage more into the topic rather than only receiving the requirements from us.

We set 3 design tasks in PD1, the structure and task description presents in Table 4.1 below. The first design task called *Information Format Exploration.* This task is designed to explore the desired information form from pedestrian, how should this information be transmitted by the autonomous vehicle in their mind. Each participant received 2 types of needed information we collected from focus group and spent 10 to 20 minutes to design the information formats as many as possible. The format should include the content of the information, used modality, and its placement. The participants were allowed to use any materials we provided to express their ideas but the paper vehicle model. Therefore we presented the potential placements of the car with a picture to make sure that everyone understands the placement of every format during the short recapitulation.

Table 4.1: PD1 Design Task Structure

	Aim of the task	Given Context	Task Description
Task 1 Information Format Exploration	Help participant explores the format of information between AV-Pedestrian communication, and collect them for the following tasks.	- 2 types of information per participant	Task 1: Please create the information format to express the given information. If there is an Autonomous Vehicle going to tell this information to you, what kind of form do you think that would be? The output should includes content(concrete the information), modality(how it present) and placement(where should it display).
Task 2 Accurate Your Design	Find out the matched information format with different road situation for AV-Pedestrian communication, help the participant to design more accurate step by step.	- 1 traffic situation per participant - all types of information and its formats created from Task 1	Task 2.1 Information Selection: Please pick the information format you want to use in your communication design concept from all we concluded in Task 1 depends on the given road situation. Task 2.2 Information Adjustment: Based on what you chose, please try to make them more accurate. Please combine and adjust them, and give a clear communication concept.
Task 3 Prototype Your Design	Task 3: Set the design within the given road situation and prototype with paper vehicle model to help the participant figuring out how does their designed AV-pedestrian communication work	- 1 traffic situation per participant - all types of information and its formats created from Task 1&2	Based on what you designed so far, try to make your design more complete. Please set all your ideas on the AV model, with the materials you made from Task 1&2 or created something new.

With the information format created generally, a transition to the next design task *Accurate Your Design* is setting the traffic situation context for participants. After introducing the 4 traffic situations(Figure 2.2) and watching the relevant cross videos with the first perspective, every participant got one traffic situation as their design context. There were 2 sub-tasks included in(task description in Table 4.1): *Information Selection*(5 minutes) and *Information Adjustment*(15 minutes), and the reason regarding their choices and designed concept were explained in the recapitulation.

In the end, we came up with the last design task *Prototyping Your Design*, participants placed their designed information format on the paper vehicle model based on the given traffic situation, they could use any format from previous tasks, adjusted it or create something new. The paper vehicle model used here mainly as an auxiliary mean to help participants realize the problems which they may miss during designing only on the 2D level. In addition, it also helped researchers and other audiences picture the whole communication during presenting and understand the design concept in a vivid and animated way. Figure 4.1 shows participants presenting their design with the paper prototype.

Figure 4.1: Participant was presenting his or her design concept

The PD2 basically follows the design structure in PD1, while adjusted some task details based on the feedback and reflection of PD1. First we move the traffic situation introduction part before the Task 1, and re-sort the information type in 5 categories(See description below) instead of previous 8 information type in Section 3.5.

- Vehicle‘s driving mode information: whether AV is in autonomous driving mode or not?
- Recognition information: whether AV has recognized pedestrian or not?
- Vehicle‘s intention information: whether AV is going to decelerate or accelerate?
- Vehicle‘s intention information: whether AV is going to turning right/left or not?
- Pedestrian‘s safety information: whether it is safe for pedestrian to get across? or whether the vehicle is able to stop enough for pedestrian safely cross?

The reason behind is to make participants think into the traffic context at the beginning, therefore in Task 1 they could create their design by considering those 4 situations(Figure 2.2) either separately or after classified. Among the new 5 information types, we set the information "Vehicle‘s driving mode information" as the basic one which was given to every participant and split the rest 4, then each participant still needed to create 2 types of information in Task 1.

According to the design outputs among different traffic situations in PD1, we found that the core factor which influences the design was the speed and distance of the vehicle, therefore we combined the Task 2 and Task 3 together as one to emphasize the prototype part with different vehicle’s conditions(able to yield for pedestrian cross or not able to yield). In addition, by thinking about it is very common that vehicle encounter several pedestrians at one moment in real traffic, we also set this as the design context in prototype task.

Hence the design context included two variables: vehicle's conditions and the amount of pedestrian, each of them included 2 different cases, so there were 4 design cases(Table 4.2) in total. Before we started the last prototype task, to help participants distinguish the design differences between single pedestrian and multiple pedestrians, a short discussion about the concerns and design advice for autonomous vehicle dealing with multiple pedestrians was conducted. And to avoid too complicated context, we simply assigned the traffic situation as Situation 1: crossing road without traffic lights & zebra-crossing.

Table 4.2: Design Cases in PD2

		Design Case			
		1	2	3	4
Vehicle's Condition	able to yield for pedestrian	✓	✓		
	not able to yield for pedestrian			✓	✓
Amount of Pedestrian	single pedestrian	✓		✓	
	multiple pedestrians		✓		✓

4.5 Data Collection and Analysis

From each PD session, the video and voice recording were collected during the whole session and the recorded video of individual presenting after last prototype task. All participant-created design outputs were collected with their agreement. The recapitulation part can be considered as an adjusted think-aloud protocol[39]. Therefore besides the discussion recording, the recapitulation part was also transcribed to the script as we did in focus group study, and the relevant outputs were attached in via pictures we took. We went through each design task and summarized separately. Afterwards, the collected design concepts, design features, and design elements were analyzed.

4.6 Key Findings

The following content describes our findings from PD session.

4.6.1 Design Concept

Since the foundational design concept we provided is to have the vehicle-to-pedestrian communication, therefore the third party devices(like mobile phone, wearable devices and so on) or any other infrastructures were not considered from participants' designs. Based on that, all the participants designed the communication by transmitting the information from the vehicle itself. This lead to the placement of the information directly presenting on or from the vehicle such as an interface display or a in-car acoustic signal. Therefore the responsibility of communicating with the pedestrian mainly relies on the autonomous vehicle.

Besides the AV's movement(deceleration, stop, acceleration, turn, etc,.) as a sign to transmit information from the car, the major modalities for participant-designed information we found were visual and auditory. The visual modality from their design primarily leverages perceived visual signals used by colors, patterns and text. The auditory modality aims to capture pedestrians awareness by acoustic signal or engine sound(if the autonomous vehicle is driving electrically), and the assistant verbal signal for people who has vision problem. Apart from those two modalities, there was two participants considered the haptic design as their third modality(one got inspired from another), *by sending directional pressure waves from AV to pedestrian to make them feel a vibration through, if it's possible* he mentioned. Due to not all participants used auditory modality in their final prototype design, and most auditory communications play as an assist approach, we prioritized the visual modality in the AV-pedestrian communication design concept.

According to the final prototype task in PD1 and PD2, we also clarified the concept in two contexts by the amount of the pedestrian during communicating. For communicating with signal pedestrian context, we found that all the designed communication started before the actual crossing action, this was the same result with the traditional vehicle-pedestrian communication in Chapter 1.2.2. And the information should also be adjusted and changeable based on pedestrian's behavior, for example, pedestrian did not move or cross if the car yielded for them, or pedestrian try to cross in a dangerous case(car was not able to stop). Same as the multiple pedestrians, but since it is hard to catch each pedestrian's intention, the main focus is to present the intent of the vehicle and make them decide by themselves. In terms of this, the information presenting must reach a consensus among diverse pedestrian. The diversity should cover the pedestrian from different countries, speak different languages and has different capabilities(such as kids, elder people and disabled, etc,.).

By comparing and analyzing all the designs under two contexts, we found that no matter the autonomous vehicle has communicated with single pedestrian or multiple pedestrians, the design from participants shows a core message that the transmitted information should be explicit and universal, especially for the information regarding the intent of the vehicle. Considering the traffic efficiency from vehicle's perspective, some participants set a certain cross time when the car yield for pedestrian crossing. This can be considered as the traffic light system for pedestrian crossing in reality, and it could also be used in the case when the conflict happened(if the pedestrian does not react or no willing to cross). And it is also important to increase the pedestrians' trust towards autonomous vehicle during they perceived the information.

4.6.2 Design Feature

Placement
From 2 PD sessions, all the participants placed part of their design on the windshield in their prototype. This matched with the survey result from previous work in Chapter 2.2. The windshield was being used as a displayed interface in their prototype for pedestrian perceiving information, and the some participants actually set a stable LED strip around the windshield to transmit different intent of AV by using different colors. In addition, 4 out of 8 participants placed their designed indicator around headlight of the vehicle, and 2 used the existing headlight blinking to communicate with pedestrian as they believed it is the most visible lights. *"Since the distance is quite close, the headlights with color are designed for children who can not see that high position."(design context with Situation 4: crossing when vehicle is driving in/off garages/parking lot)* One participant commented during presenting.

Signal Form
Even though there were many different information formats were explored at the beginning of each PD session, but the majority communication design in the final prototype task pre-

sented by the colors and patterns. The result also indicates a reflection of the result in design concept *"that the transmitted information should be explicit and universal."*. The benefit of designing with colors which are used in the current traffic regulation(Green: cross, Red: stop, Yellow: attention) is extremely obvious, all the road users already knew the meaning behind and this is not biased. The participants discussed during PD said *"there should be a standard...for example, the traffic lights is always the same, the red is always stop, green is go... those international signs not like simply word, you can easily distinguish even you don't speak that language"*. And compared to display with colored text, the colored pattern can be more visible and obvious, as well faster to capture its meaning while using a familiarized one on many occasions(such as communicate with distance and avoid the language barriers). In particular, some participants used the pedestrian cross symbols of the traffic system was also inspired us and was more appropriate for the analyzed design concept above.

Other Feature

As we explored all the possible information formats based on its categories, while all the designed communications in the final prototype task were presented in a combination. Among those, the intent of vehicle makes up the mandatory information from the design. Some participants think the information about autonomous mode should be obliged while some not. But most pedestrians might speculate that this vehicle is an autonomous one when it communicated with them in an uncommon way.

4.6.3 Design Elements

After analyzed the design concept and design features behind the result of PD session, a number of design elements related to AV-pedestrian communication were extracted. These design elements include: 1) Visual indicator, 2) virtual driver, 3) pedestrian symbol, and 4) numeric countdown. These elements described in Table 4.3.

Table 4.3: Extracted design elements from PD session

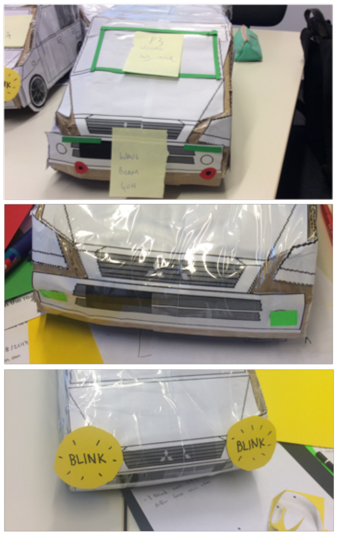
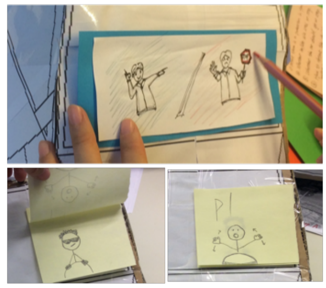
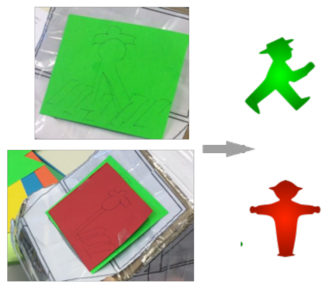
Design Element	Description	Examples
Visual Indicator	The visual indicator created in PD session was mainly represented by the LED light, either in strip or in patterns. By using different colors to transmit the relevant information, for example, green indicator intends to "safe to cross", and red intend to make the warning awareness to pedestrian. These indicators normally placed on the vehicle part which is obvious to notice by pedestrian, such as windshield, somewhere at radiator grill. Besides, providing a light signal at headlight was also intended to request pedestrian's awareness the intent of the vehicle.	

Table 4.3: Extracted design elements from PD session

Design Element	**Description**	**Examples**
Virtual Driver	The virtual driver shows on the windshield could be a replacement to the absence of the human driver. On the one hand, this can transmit a information that this car is driven automated without human operated when pedestrian seeing a virtual driver on the windshield. A smiled virtual driver may build a trust of pedestrian towards autonomous vehicle even it is operated by the machine itself. On the other hand, by animated virtual driver with gestures, head node, and even eye contact with pedestrian, these communication approaches between autonomous vehicle and pedestrian simulated well the traditional driver-pedestrian communication.	
Pedestrian Symbol	The pedestrian symbol which is used here is to convey an explicit intention of AV that "you are safe to cross"(green walk-man) or "dangerous! you should not cross"(red symbol). As we mentioned above, there is no doubt that the pedestrian symbol can be a clear signal which is universal enough for all road users in the current traffic system. Therefore we do not need to train the pedestrian to get to know an additional signal and its meaning in this AV-pedestrian communication.	
Numeric Countdown	The numeric countdown element reflects the settled crossing time period for pedestrian. This numeric time countdown concept was also used as the traffic light in some counties such as America, China, South Korea, etc,. The trigged timing of this countdown element starts from the vehicle stopped for the pedestrian, and the number presents how much time left for pedestrian crossing. During the greened number displays, pedestrian can cross. Once it reached to 0, the countdown number will become red, which gives a warning to pedestrian that "you should not cross now".	

In the end, grounded on the findings we collected from PD session, we designed this AV-pedestrian communication mainly refer to the traffic light concept for pedestrian crossing, set a certain cross time for pedestrian with autonomous vehicle. The relevant design elements includes pedestrian symbol which used in real traffic system, and the numeric time countdown as a signal to help pedestrian perceive the time period for crossing. We designed those elements display on the windshield with colors. As the majority design involved visual indicator(LED signal), hence we placed it in the position around the windshield and headlight as the basic design element during the whole communication, and the color should be synchronized with others. Considering the interacted virtual driver might lead the information overloading with the traffic signal concept at the same time[40, 41], and it take time to implement in the prototype, the virtual driver element was just used to increase pedestrian's trust towards autonomous vehicle during communicating. The design concept and adjusted design elements will be implemented as the prototype and evaluated in the following user study in Chapter 5.

5 User Study

5.1 Aims of the User Study

The user study surveyed perceptions of the virtual driver element and settled cross time concept(adjusted traffic light system on autonomous vehicle), focusing particularly on the period that the autonomous vehicle is going to stop and during the stop respectively, and on general attitudes towards these design concept combinations reflecting relevant usability attributes to them being used in the real urban traffic situation. Given this focus, it was of particular interest to examine the perception in a certain period: before the vehicle is stopping, during vehicle is stopping, and the whole interaction period in general.

5.2 User Study Design

As we mentioned the aims of this study, this user study was designed in 3 parts, (1) During AV is approaching pedestrian(before AV is stopping), (2) During AV is stopping, (3) The whole V2P communication. Figure 5.1 shows our proposed prototype video for autonomous V2P communication design concept in user study(USV).

AV's Status	Signal Type	Vitual Cue				Auditory Cue
		LED Light	Virtual Driver	Numeric Time Countdown	Pedestrian Symbol	
Before Stopping	USV_1_1	✓				
	USV_1_2	✓	✓			
During Stopping	USV_2_1	✓		✓		
	USV_2_2	✓			✓	
Before Stopping & During Stopping	USV_3_1	✓		✓		✓
	USV_3_2	✓			✓	✓
	USV_3_3	✓	✓	✓		✓
	USV_3_4	✓	✓		✓	✓

Figure 5.1: User Study Video(USV)

In the part (1) before AV is stopping, our main focus is to discover how virtual driver affects their understanding on the different information. We designed this part with AB test to figure it out. Firstly, showing them the prototype video with the signal only includes LED light indicators around the car(UEV_1_1), this LED concept we take as a baseline V2P communication in the whole study. Another prototype video presents the signal with the LED light indicator and virtual driver concept(UEV_1_2).

In the part (2) during AV is stopping, we mainly explore the usability difference between pedestrian symbol signal and numerical time countdown signal. Besides, from our design principle, the AV will always stop for pedestrian first, therefore we also want to test which signal will help pedestrian cross faster in crossing case. Hence the reaction time should be recorded for different signals in this part, and the order of the signal should be randomized. Besides, we defined the failed behavior should include they did not choose to cross till the end and they missed the cross signal but cross during the warning signal.

The first two parts are aimed to help participants get familiar with the signal. Then the part (3) shows the whole communication concept includes before the AV has stopped and during the stopping period. To express design concept better, this part we also combined with the auditory signal to make the V2P communication more complete.

All participants will play a role as a pedestrian in this user study, and we present our prototype video with big size screen with reasonable height for them to simulate the real urban traffic crossing situation.

5.3 Prototype Implementation

The prototype was developed by Unity, a cross-platform game engine, that provided features to render the virtual environment for the purpose of the user study. The virtual scene was set in an urban scenario. The crosswalk situation was built with standard virtual assets provided by Unity. Since the majority of the autonomous vehicle is driving electrically, we did not add the vehicle's engine sound but auditory signal into the prototype.

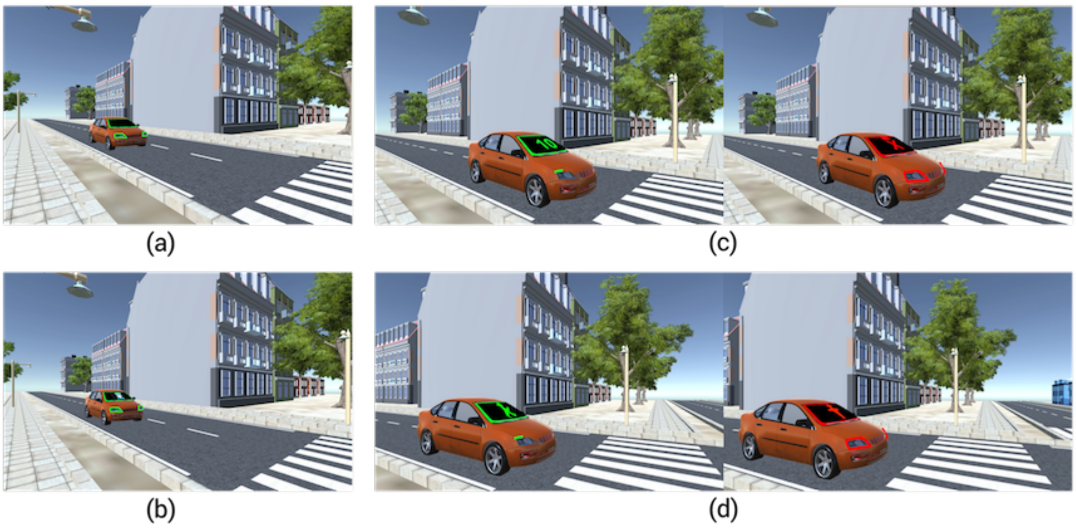


Figure 5.2: User Study Video(USV): (a) The basic LED signal (b) Virtual driver and LED signal (c) Numeric time countdown and LED signal (d) Pedestrian symbol and LED signal

In the unity project, we set the participant standpoint at the beginning of the crosswalk (as shown in Figure 5.2 (a)), ready to cross the zebra-crossing. Regarding this zebra-crossing scenario, we developed that the vehicle always stops for pedestrian first. And we set the view height as 1.6 meters to simulate better this scene is from their first perspective. A vehicle approached the crosswalk from the pedestrian's left-hand side and the participants were asked to cross the zebra-crossing safely. As for the auditory signal, considered the settled cross time concept and visual signal we used both are relevant traffic light signals, thus we simply used the traffic light sound we found on Internet which recorded from the real traffic system, added on the vehicle itself to represent the sound comes from the vehicle itself. The prototype video had same vehicle movement and signal trigger point as described below:

- The vehicle accelerates a speed from 0 to 30km/h, and it starts to display the USV_1_1 or USV_1_2 signal when the vehicle starts decelerating.
- The vehicle starts to display the USV_2_1 or USV_2_2 signal when the vehicle's speed decelerates to 0, which means it fully stops in front of the zebra crossing.

After we implemented the virtual scene in Unity, we run the game project and using mouse movement to simulate pedestrian's sight movement. At the meantime, we recorded the game screen as well sound effect as our prototype video. Finally, we trim them for each user study part respectively, and make sure they have same video length in each part.

5.4 Questionnaire Design

The questionnaire we designed for user study mainly referred to the CSUQ[42] and SUS[43]. It aims to figure out pedestrians' satisfaction and measure usability among different design elements, thus it should be done as the post-experiment questionnaire.

For virtual driver design concept, the assessment includes information acknowledgment and usability. As questionnaire statement shows in Table 5.1, we defined measurement mainly from focus group result "expected information from pedestrian" to figure out if this concept matched their requirement.

Table 5.1: User Study Questionnaire: USQ_1

	Definition	Statement
Information Acknowledgment	Vehicle's status	I think the signal is telling me that "this car is autonomous driving car or driverless car"
	Recognition	I think the signal is telling me that "this car has seen or recognized me"
	Vehicle's speed	I think the signal is telling me that "this car is decelerating or slowing down"
	Vehicle's intention	I think the signal is telling me that "this car will stop for me"
	Pedestrian's Safety	I think the signal is telling that "I am safe to cross"
	Additional	Besides the listed information, what else do you think the signal is telling you?
Usability	Visual Clarity	The signal (such as LED lights, on-screen signal and other indicators) provided was clear.
		The signal provided was easy to understand.
		The position of signal presents was obvious to notice.
	Effectiveness	The signal was effective in helping me to decide cross or not cross
	Satisfaction	I am satisfied with this provided signal.

Table 5.2 shows the questionnaire in user study part (2), includes efficiency and usability assessment. The core design purpose during vehicle is stopping is to let pedestrian cross first when they have crossing needs, therefore we also measured efficiency in this part.

Table 5.2: User Study Questionnaire: USQ_2

	Definition	Statement
Efficiency	Reaction Time	Task: Stop the video when you decide to cross
Usability	Visual Clarity	The signal (such as LED lights, on-screen signal and other indicators) provided was clear.
		The signal provided was easy to understand.
		The position of signal presents was obvious to notice.
	Effectiveness	The signal was effective in helping me to decide cross or not cross
	Satisfaction	I am satisfied with this provided signal.

For the measurement in user study part (3) the who communication, besides the basic usability section we designed in USQ_1 and USQ_2, we also add learning, capability, and emotion into the questionnaire. Among those three additional measurements, learning section refer to CSUQ[42] as a measurement about if the communication signal is easy to learn and use. And capability is to evaluate does this communication concept designed for different kinds of pedestrian and different crossing scenarios, which is the two big concern from the focus group and participatory design discussion. Finally, the emotion section is the feedback from the pilot study. Table 5.3 below gives the final statement about User Study Questionnaire in part (3)(USQ_3).

Table 5.3: User Study Questionnaire: USQ_3

Definition	Statement
Visual Clarity (plus auditory)	Overall, the signal(such as LED lights, on-screen signal and other indicators) provided in this V2P communication was clear.
	Overall, the signal provided in this V2P communication was easy to understand.
	Overall, the position of signal presents in this V2P communication was obvious to notice.
Learnability	Overall, I believe I could get used to the signal in this V2P communicationin real urban traffic situation very quickly:
Effectiveness	Overall, the signal in this V2P communication was effective in helping me to decide cross or not cross
Capability	Overall, I think this V2P communication was designed for all kinds of pedestrian(kids, elders, disabled, etc,.)
	Overall, I think this V2P communication can be used in different urban traffic scenarios(zebra crossing, mid-block, open area, etc,.)
Emotion	Overall, the signal in this V2P communication was pleasant.
	Overall, I feel comfortable with this V2P communication.
Satisfaction	Overall, I am satisfied with this V2P communication.

5.5 Post-Study Interview

As we mentioned in Chapter 2, the semi-structured interview was used as the post-study interview. After watching the 4 prototype videos in the Part (3) study, the post-study interview allowed participants to choose the most and least effective one among them, and further explain the different feelings they experienced with 4 prototype concepts, such as their preference part and reasons, their concerns and advice, etc.

5.6 Pilot Study

A pilot study was conducted before the laboratory study sessions with recruited participants. We did 2 round pilot study, In the 2 round pilot study, we went through each step in the preliminary experiment procedure and ended up with the feedback as below.

- Each concept video should be only shown to participant once during the experiment but they could ask for re-watch them after the whole study but before the post study interview.
- Measure also emotional feeling among different prototype videos in USQ_3(Table 5.3).

5.7 Participants

A total of 20 participants took part in this user study, includes 9 female(45%) and 11 male(55%). The range of age is from 17 to 56 years old(MEAN = 31.6). The majority of participants between the age of 20 to 29(20s) account for 45%, the percentage of the 30s, 40s and 50s makes up 25%, 15% and 10% respectively, while only one participant in the age from 10 to 19(10s), represent 5%. Figure 5.3 shows the demographic information overview of the participants. Besides, we also kept the diversity of their nationality and their studying or working fields. All the Participation was rewarded with sweeties, and they are allowed to stop this study anytime or recall their data afterwards.

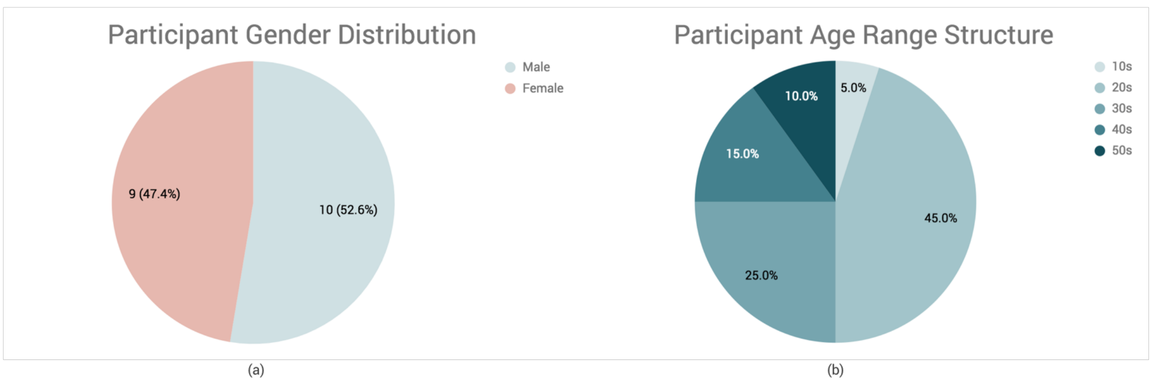


Figure 5.3: Demographic information overview of the participants

5.8 Procedure

Each user study lasted approximately 30 to 45 minutes and comprised seven steps as listed below.

1. Welcome and Introduction to the Procedure
2. Participant Consent Form
3. Demographic Survey
4. Part (1) prototype video watching and User Study Questionnaire 1
5. Part (2) task with prototype video and User Study Questionnaire 2
6. Part (3) prototype video watching and User Study Questionnaire 3
7. Post-Study Interview (10min)

Once they had been welcomed, a short introduction of this study will be explained to participants. Then, they signed the consent to the user study procedure and data privacy, filled out a demographic questionnaire. The driver-less level 5 and vehicle's status were extremely mentioned to all participants. And inform them all the video will be only shown once during the study, they can ask for re-watching after the study.

After the preparation, a short scenario description was explained before each part started by researcher. We set up the prototype video with big size screen to simulate participant in the real urban traffic scenario(See as Figure 5.4). In part (1), participants stood in front of the big screen to watch the USV_1_1 and USV_1_2. Those 2 prototype videos express the V2P communication signal concept in the period before the AV has stopped, and they filled out the User Study Questionnaire 1(USQ_1) after seeing each prototype video.

Figure 5.4: Sample of the participants in User study

In part (2), we briefed the participant of the task we were testing, as well the test scenario (during AV is stopping). They operated the prototype video by themselves: Press space button on the keyboard to start receiving signal, when they think "I'm ready to cross" press space button again. The researcher recorded time duration between participant's two press actions as their reaction time. The prototype video shown in this part are USV_2_1 and USV_2_2, the order was randomized, and after each task they completed the USQ_2.

Afterward, the part (3) was started. The participants watched the USV_3 series with auditory signal. The speaker also set up with the screen together to simulate the sounds came from the vehicle itself. The participants received instruction of this part and watched 4 prototype videos with random order. And the participants filled out the questionnaire USQ_3 four times after each video. Once they had completed the prototype video watching and questionnaire, researcher did the post-study interview with participants and they were rewarded with sweets and drinks.

5.9 Data Collection and Analysis

In the user study, we collected data responses to user study questionnaires(USQ) among part (1) Before AV is stopping(USQ_1), (2) During AV is stopping(USQ_2) and (3) The whole V2P communication(USQ_3). For the 7-point Likert scale data, the mean value, as well as the standard deviation, were looked at. The data was then plotted by the Tableau software, which graphically interpreted in the box-whisker plot. The reaction time in part (2) was also recorded and plotted in box-whisker plot (unit in hundredth of a second). The average value(MEAN) and the standard deviation(SD) of each statement ratings were calculated and compared. The results were compared between and among the different prototype video.

According to the Figure 5.3 (b), 50% participants are from 10s and 20s, and the rest are from 30s to 50s. Therefore two age groups were divided from 30 years old: under 30, equal&above 30. The difference of their data in USQ_3 was also plotted in Tableau and analyzed.

Qualitative feedback, comments, and suggestions were collected through the post-study interviews which were audio-recorded. The recorded interview data were selectively transcribed and analyzed in categories.

6 Results

To have an overview of the User Study Questionnaire responses, we compiled the questionnaire data and produced some preliminary results by calculating the mean values and of the dependent measures among the participants. In the following Figures, to provide a better data overview, most of them combined box-whisker plot with the bottom-table includes calculated MEAN and SD values together.

Among the box-whisker plot, the X-axis shows the dependent measures and the Y-axis indicates the 7-point Likert scale of the corresponding test signal concepts of each dependent variable. The scores from one to seven correspond to the 7-point Likert scales from "strongly disagree" to "strongly agree". By choosing 1 means they did not agree with the statement we mentioned in the questionnaire and by rating 7 means that they fully agree with the statement in that section. The higher number they rated, the more positive attitude they hold to it.

What follows is the extended description of the data results from User Study Questionnaire respectively. In general, we gave the separated explanation for each definite section but also combined several sections together when their outputs expressed a bit of correlation. Ultimately, the analyzed post-study interview provides the qualitative feedback from the participants, to help to figure out the causes behind the quantitative data from the 7-point scale.

6.1 Part (1) Before AV is stopping

In this part, the prototype video displays the LED light signal which was shown as the result marked as USV_1_1 and the prototype with virtual driver and LED light signal was shown as the result marked as USV_1_2.

Figure 6.1 represent the data itself in box plot as well the MEAN and SD values we calculated of the corresponding test signal concepts of each dependent variable.

The MEAN and SD value we calculated also lists in the bottom table of Figure 6.1. According to the list numbers, we can see in general, the MEAN value of USV_1_2 is higher than the MEAN value of USV_1_1, except in the question of Recognition and Position.

6.1.1 Acknowledge Information

Vehicle's Status

In the box plot of Figure 6.1, we could see that the distribution of USV_1_2 skewed towards to the "strongly agree" side, the upper whisker and upper hinge both equal to 7, and the lower hinge = 3.5, which means most of participants rated their agreement level from 3.5 to 7. The median agreement level is 5. And three participants rated their agreement level below 3.5 for the virtual driver and LED light signal. For the plot result of USV_1_1, even it has same lower whisker with USV_1_2(1) as well upper whisker(7) but most participants rated from 2(lower hinge) to 5(upper hinge), and the median agreement level is 3.

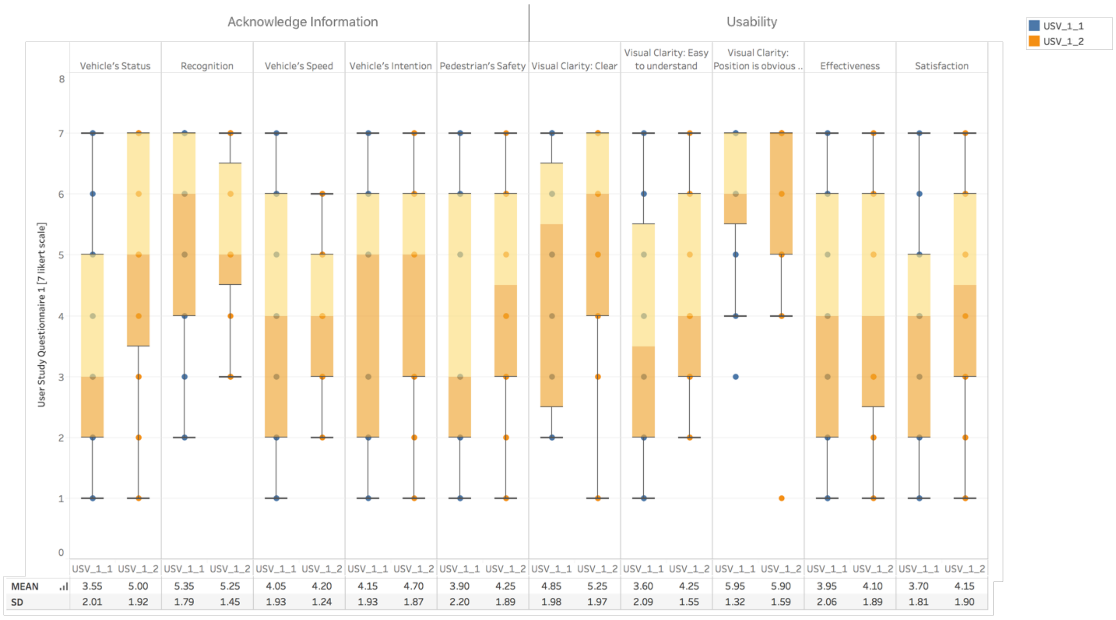


Figure 6.1: Box-whisker Plot of USQ_1(USV_1_1: LED light signal; USV_1_2: Virtual driver and LED light signal.)

Recognition
The result of this Recognition statement shows that the participants had the Small agreement gap between USV_1_1(MEAN = 5.35) and USV_1_2(MEAn = 5.25). From the box-plot, most participants gave their rates from 4(lower hinge) to 7(upper hinge) on USV_1_1, which is more various than the rates on USV_1_2(lower hinge = 4.5, upper hinge = 6.5). However, for the USV_1_2, the median value is 5 which is 1 point lower than the median of USV_1_1.

Vehicle's Speed & Vehicle's intention
We cannot deny to say that the car's movement in the prototype video somehow influenced the result of the questions on Vehicle's Speed and Vehicle's Intention, the median of agreement level are similar between USV_1_1 and USV_1_2(Vehicle's Speed: Median = 4; Vehicle's Intention: Median = 5). However, from the MEAN result in the bottom-table, the LED signal combined with virtual driver(USV_1_2) still has the higher rate(Vehicle's Speed: MEAN = 4.20; Vehicle's Intention: MEAN = 4.70) than without(Vehicle's Speed: MEAN = 4.05; Vehicle's Intention: MEAN = 4.15). Furthermore, the scores of USV_1_1 are more variable than USV_1_2, which also indicated by the SD values(Vehicle's Speed: upper whisker = 6, upper hinge = 5, lower hinge = 3, lower whisker = 2; Vehicle's Intention: upper whisker = 7, upper hinge = 6, lower hinge = 3, lower whisker = 1).

Pedestrian's Safety
When it comes to transmitted information "I am safe to cross", for the virtual driver and LED light signal(USV_1_2), the MEAN = 4.25, SD = 1.89; and only for the LED light signal(USV_1_1), the MEAN = 3.90, SD = 2.20. From the box plot, in this section, we could

see that the most participants rates their agreement level up to 6(upper hinge), but the lower hinge = 3 for the USV_1_2, and the lower hinge for USV_1_1 is just from 2. From the median value, 50% participants rated USV_1_1 from 2 to 3 but the agreement level range for USV_1_2 is from 3 to 4.5.

6.1.2 Usability

Visual Clarity

There are three statements in the Visual Clarity section: *" signal(such as LED lights, on-screen signal and other indicators)provided was clear, understandable, and whether the presented position is obvious to notice or not.", "The signal provided was easy to understand.", and "The position of signal presents was obvious to notice."*. In the first two statements, as we can see from the Figure 6.1, there are both 0.5 point gap between USV_1_2 and USV_1_1, and USV_1_2 stands the higher rate. Besides, the plot of USV_1_2 is skewed to the highly agreed side for Visual Clarity: Clear statement. However, the SD values are quite similar in Visual Clarity: Clear (USV_1_1: 1.98, USV_1_2: 1.97) while there is the difference in Visual Clarity: Easy to understand(USV_1_1: 2.09, USV_1_2: 1.55).

"The position of signal presents was obvious to notice" has the highest average agreement score not only in the usability section but in all USQ_1 questions, which reaches to 5.95 and 5.90 for USV_1_1 and USV_1_2 respectively. We could also see from the box plot that both of them are top-skewed: for USV_1_1, most participants rates their agreement level of this statement from 5.5(lower hinge) to 7(upper hinge), and the median value = 6. As for USV_1_2, most participants gave their agreement level from 5(lower hinge) to 7(upper hinge), but the median value also reaches to 7. There were several rating lower than 5.5 for USV_1_1, and there was one extreme case for USV_1_2: he or she just gave the 1 as the agreement level.

Effectiveness

The effectiveness section did not show the big difference between USV_1_1 and USV_1_2 according to the Figure 6.1. Even though the USV_1_2(MEAN = 4.10) has higher MEAN value than USV_1_1(MEAN = 3.95), but their median placed in the same point(both equals 4) in the box plot. Additionally, their plots looks similar from the view (USV_1_1: upper whisker = 7, upper hinge = 6, lower hinge = 2, lower whisker = 1; USV_1_2: upper whisker = 7, upper hinge = 6, lower hinge = 2.5, lower whisker = 1), which means most participants gave their rates between 2 to 6, either to the LED signal with virtual driver or without.

Satisfaction

As the last section in USQ_1: Satisfaction, it is clear to see from the box plot that the median of USV_1_2 is 0.5 point higher than the median of USV_1_1(4). For the USV_1_1, most participants chose their satisfaction scale from 2(lower hinge) to 5(upper hinge), while they rate their satisfaction of USV_1_2 from 3(lower hinge) to 6(upper hinge) conversely. However, the ranges of those two signals in part (1) are quite similar, their upper whisker both equals 7 and lower whisker equals 1, and it also shows by the listed SD value(USV_1_1: 1.81, USV_1_2: 1.90).

6.2 Part (2) During AV is stopping

6.2.1 Reaction Time

In part (2) USQ_2 result, we first collect the reaction time and calculate the Mean and SD value for numeric time countdown signal(USV_2_1) and pedestrian symbol signal(USV_2_2). Based on the task we defined in User Study Design, among 20 participants, all participants cross successfully when they received signal USV_2_2, the task completion was 100%. However, there were 2 participants failed the task when they received signal USV_2_1, therefore the task completion was 90% and the valid samples were 18. Table 6.1 clearly lists the data about this efficiency section as well the MEAN and SD value we calculated. In Table 6.1, when participants received the signal USV_2_1, numeric time countdown on windshield, the MEAN(18) = 3.77s, SD(18) = 1.77; when they received the signal USV_2_2, pedestrian symbol on windshield, the MEAN(20) = 3.25s, SD(20) = 2.15.

	1	2	3	5	4	6	8	9	7	10	11	12	13	14	15	16	17	18	19	20	MEAN	SD
USV_2_1	1.51	5.06	5.19	4.34	5.91	1.9	3.09	3.75	2.94	1.65	3.53	-	2.26	2.36	4.49	3.53	3.56	3.94	8.79	-	3.77	1.77
USV_2_2	1.47	2.15	9.77	2.79	2.7	0.94	2.12	5.76	1.42	2.28	5.11	5.47	1.73	2.5	4.05	1.5	2.19	1.69	5.26	4.1	3.25	2.15

Table 6.1: Reaction Time.

We visualized those data in box-whisker plot in a horizontal way. As shown in Figure 6.2 Box-whisker Plot of USQ_2 Reaction Time. The X axis is the reaction time, from 0 to 10 seconds. The Y axis represents the signal type participants received: USV_2_1(numeric time countdown and LED light signal), USV_2_2(pedestrian symbol and LED light signal). The signal types consist of the following numbers of samples: USV_2_1, n = 18; USV_2_2, n = 20.

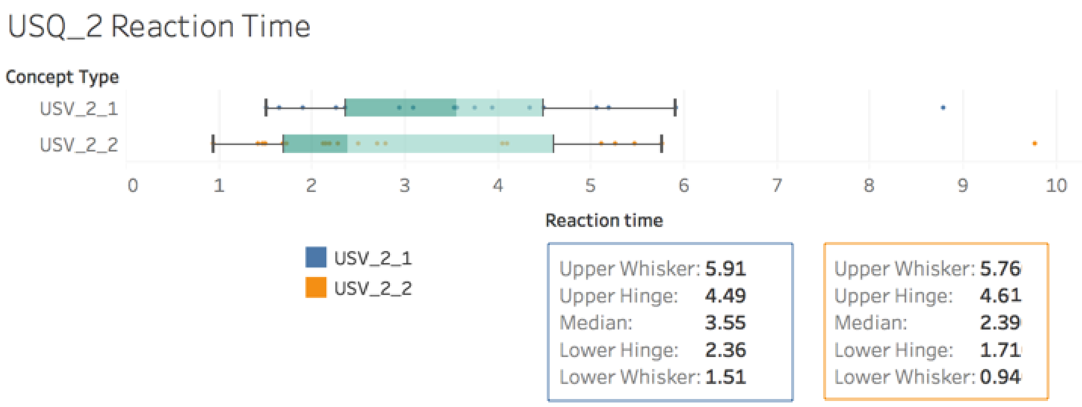


Figure 6.2: Box-whisker Plot of USQ_2 Reaction Time (USV_2_1: Numeric time countdown and LED light signal; USV_2_2: Pedestrian symbol and LED light signal.)

According to the Figure 6.2, we could clearly see, compared to the results of USV_2_1, the participants had less reaction time when they received the pedestrian symbol signal(USV_2_2). The box plot shows that the median reaction time of USV_2_1 is 3.55s, and for USV_2_2, the median reaction time is 2.39s. For the USV_2_1, the reaction times of most participants are between 2.36s to 4.49s.

For the USV_2_2, most participants made the cross decision from 1.71s to 4.61s. The participants could make the cross decision faster under the USV_2_2 case but the reaction time range of USV_2_1 is less various than the range of USV_2_2.

6.2.2 Usability

Figure 6.3 shows the box-whisker plot result and the MEAN, SD value we calculated of USQ_2 usability part, the X axis shows the dependent measures divided by the different concept type and the Y axis indicates the 7-point Likert scale of the agreement level for each dependent variable.

According to the numbers listed in the bottom of Figure 6.3, we could see the MEAN values of USV_2_1 is higher than the MEAN values of USV_2_2 except Virtual Clarify: Easy to understand section(USV_2_1: MEAN = 5.55, Median = 6; USV_2_2: MEAN = 5.75, Median = 7). In the Virtual Clarify: Clear part, even USV_2_1's MEAN(6.05) is higher than USV_2_2's (5.75), but in the box plot, the median of USV_2_1(6.5) is lower than USV_2_2(7).

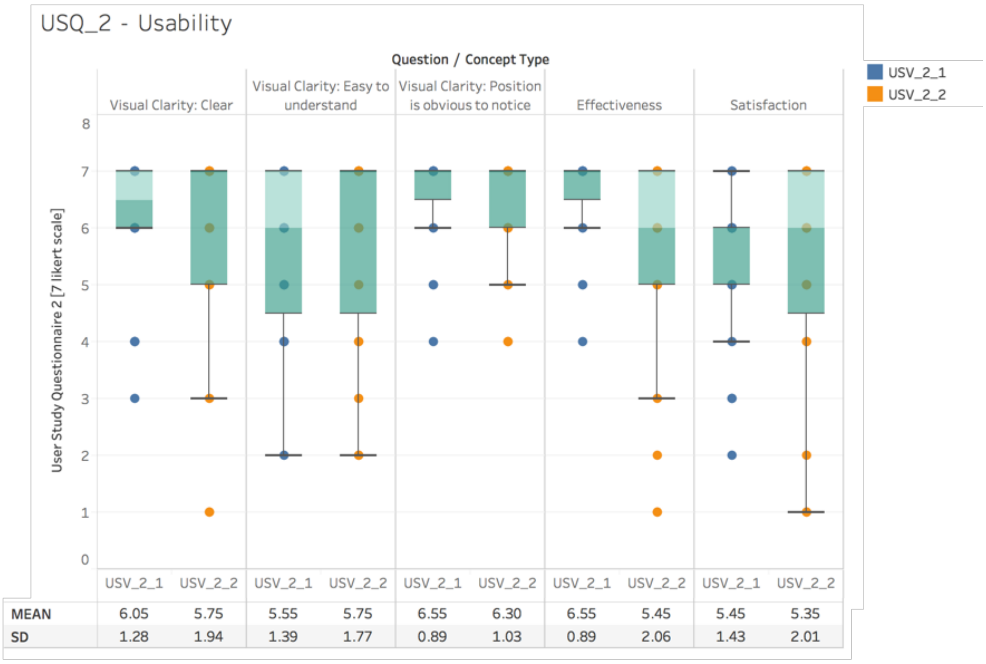


Figure 6.3: Box-whisker plot of USQ_2 (USV_2_1: Numeric time countdown and LED light signal; USV_2_2: Pedestrian symbol and LED light signal.)

In Effectiveness section, the signal of LED light and numeric time countdown(USV_2_1: MEAN = 6.55, SD = 0.89) has higher agreement score than the signal of pedestrian symbol and LED light(USV_2_2: MEAN = 5.75, SD = 2.06). The result was more clear in the box-whisker plot. For USV_2_1, half participants gave their rates to 7(upper whisker = 7, upper hinge = 7, median = 7, lower hinge = 6.5, lower whisker = 6), only few rated below 6. As for USV_2_2, most participants rated their agreement level of effectiveness statement from 5(lower hinge) to 7(upper hinge), and the median score is just 6. Even few participants gave their rating below 3.

Overall, all the box plots are skewed to the "strongly agree" side except the satisfaction of USV_2_1. However, in the Satisfaction section, the results are quite similar from the median value(USV_2_1: 6; USV_2_2: 6) in box plot and MEAN value(USV_2_1: 5.45; USV_2_2: 5.35), but the data range of USV_2_2 is much more various than USV_2_1's. Most participants rated USV_2_1 signal between 5(lower hinge) and 6(upper hinge), only a few rated below 4(lower whisker). But the ratings of USV_2_2 are through 1(lower whisker) to 7(upper hinge) in general, and the lower hinge is 4.5.

6.3 Part (3) The whole C2P communication

In part (3) The whole C2P communication, the data result will be explained by categories: Virtual Clarity(plus auditory), Learnability, Effectiveness, Capability, Emotion, and Satisfaction. The results in the different age group will also be described in each category respectively. The general data will be presented in Figure 6.4 and Figure 6.5 together as the overview. And the box-plots of different age groups(Under 30, Equal&Above 30) will be presented in Figure 6.6, 6.7 and 6.8.

Figure 6.4 lists the MEAN and SD values we calculated from 7-point Likert scale result among different concepts, the higher MEAN value is, the higher positive attitude or agreement they had; the lower SD value is, the more of the scales are very close to the average. And Figure 6.5 integrates all results among all asked questions within different concepts in one box-whisker plot.

From the Figure 6.4, we could clearly see that the USV_3_3 generally had the highest MEAN and Lowest SD value among those 4 prototype videos we provided, which are in the section of virtual clarity, learning, effectiveness and the capability for using on different urban traffic scenarios.

		USV_3_1		USV_3_2		USV_3_3		USV_3_4	
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Virtual Clarity (plus auditory)	Overall, the signal(such as LED lights, on-screen signal and other indicators)provided in this C2P communication was clear.	5.95	1.47	5.84	1.17	**6.16**	**0.96**	6.05	1.22
	Overall, the signal provided in this C2P communication was easy to understand.	5.79	1.40	5.79	1.18	**6.11**	**0.94**	5.84	1.30
	Overall, the position of signal presents in this C2P communication was obvious to notice.	6.11	0.88	6.21	0.98	**6.53**	**0.70**	6.16	0.96
Learnability	Overall, I believe I could get used to the signal in this C2P communication in real urban traffic situation very quickly:	5.53	1.43	5.32	1.38	**5.79**	**1.27**	5.53	1.43
Effectiveness	Overall, the signal in this C2P communication was effective in helping me to decide cross or not cross	5.63	1.50	5.89	1.20	**6.00**	**1.00**	5.68	1.29
Capability	Overall, I think this C2P communication was designed for all kinds of pedestrian(kids, elders, disabled, etc,.)	4.16	2.01	**4.58**	**1.64**	4.11	1.97	**4.58**	1.80
	Overall, I think this C2P communication can be used in different urban traffic scenarios(zebra crossing, mid-block, open area, etc,.)	4.95	1.58	5.05	1.51	**5.11**	**1.49**	5.05	1.54
Emotion	Overall, the signal in this C2P communication was pleasant.	4.79	1.72	**5.11**	**1.49**	4.89	1.66	4.89	1.70
	Overall, I feel comfortable with this C2P communication.	5.32	1.60	5.32	**1.57**	5.11	1.82	**5.42**	1.68
Satisfaction	Overall, I am satisfied with this C2P communication.	5.26	1.66	**5.32**	**1.45**	5.21	1.58	**5.32**	**1.45**

Figure 6.4: Mean and SD of USQ_3(USV_3_1: numeric time countdown and LED light signal; USV_3_2: pedestrian symbol and LED light signal; USV_3_3: virtual driver, time countdown and LED light signal; USV_3_4: virtual driver, pedestrian symbol and LED light signal.)

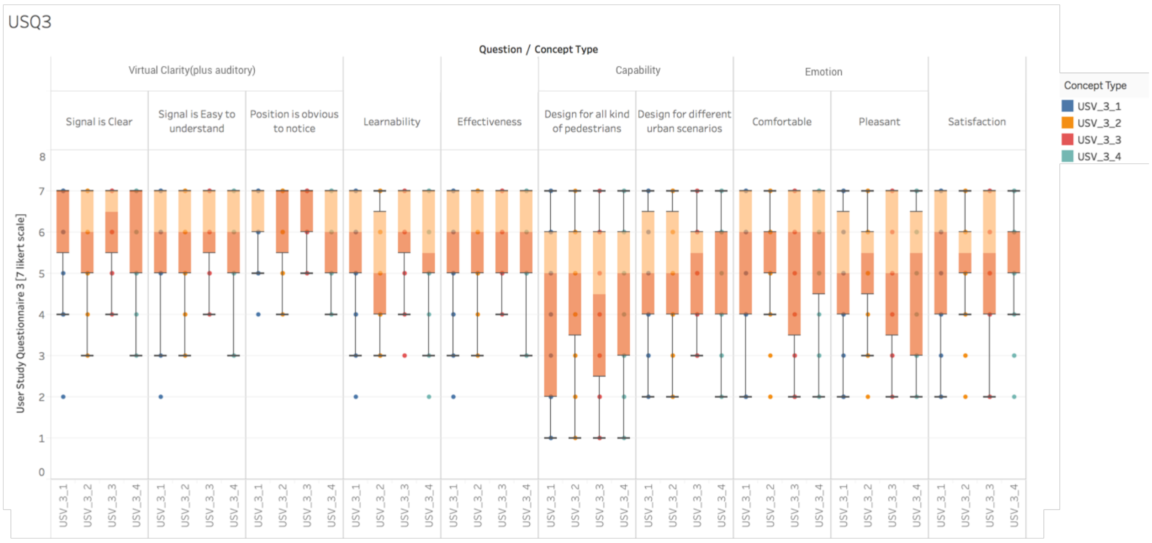


Figure 6.5: Overview Box-whisker Plot of USQ_3 (USV_3_1: numeric time countdown and LED light signal; USV_3_2: pedestrian symbol and LED light signal; USV_3_3: virtual driver, time countdown and LED light signal; USV_3_4: virtual driver, pedestrian symbol and LED light signal.)

Virtual Clarity(plus auditory)

According to the Figure 6.5, all the box plots in Virtual Clarity(plus auditory) skewed to the "strongly agree" side. There is no clear clue indicated the difference among 4 concepts from the overview box plot, but in the Figure 6.4, USV_3_3 got the highest MEAN and lowest SD values compared to others(signal is clear: MEAN = 6.16 , SD = 0.96; signal is easy to understand: MEAN = 6.11, SD = 0.94; position is obvious to notice: MEAN = 6.53, SD = 0.70).

However, in Figure 6.6, we could see all the plots from "Under 30" age group had higher median value than the "Equal&Above 30" group, no matter for which concept type. Among 12 pairs of plots in 3 statements, most plots of younger group were less various compared to the elder group. Even in the "signal is clear" statement, most younger participants rated 7(upper whisker = upper hinge = median = lower hinge = lower whisker = 7) for USV_3_1 and USV_3_4, only one participant gave 6 as his or her answer. The same situation also happened in the "position is obvious to notice" statement but for the concept USV_3_3.

Learnability

When looking at the result in Learnability category, USV_3_3 still had the highest MENA value(5.79) and lowest SD value(1.27) in Figure 6.4. Among the rest 3 concepts, the MEAN of USV_3_2(5.32) was the lowest one, which was also reflected in the Figure 6.5. Besides the plot of USV_3_2(upper whisker = 7, upper hinge = 6.5), the other concepts' plot all skewed to the "strongly agree" side(upper whisker = upper hinge = 7).

The weakness of USV_3_2 in Learnability also shows in Figure 6.7. According to the plots, the median value of USV_3_2 from younger participant group equals 5, which is the same value as the lower whisker of USV_3_3, as well the lower hinge of USV_3_1 and USV_3_4 from the same age group. The data range of USV_3_2 from younger age group was also obviously

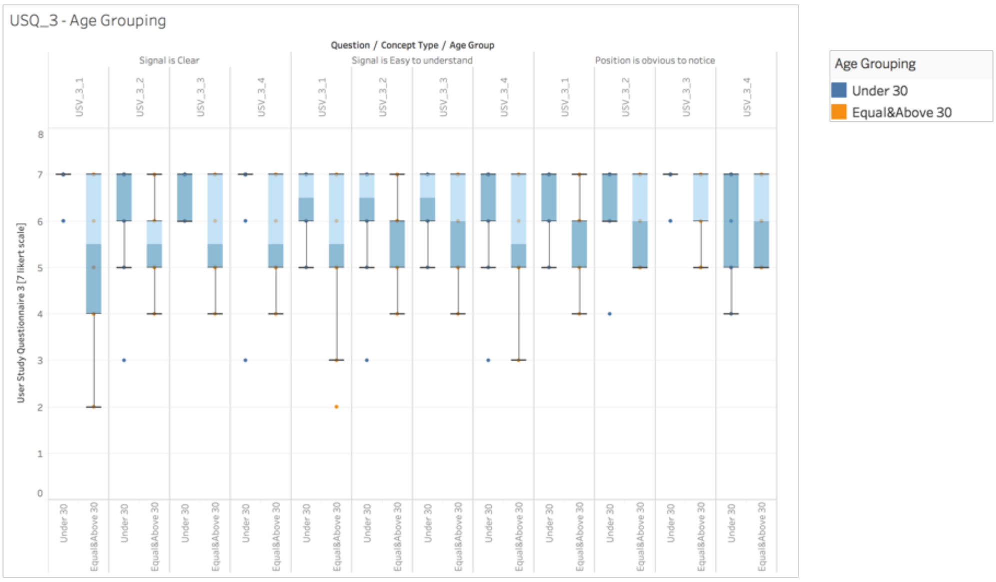


Figure 6.6: Age-grouped Box-whisker Plot of USQ_3 in Virtual Clarity((plus auditory)

larger than others(upper whisker = upper hinge = 7, lower hinge = 4, lower whisker = 3).

In addition, all the plots from "Under 30" age group were skewed to the "strongly agree" side(upper whisker = upper hinge = 7 in USV_3_1, USV_3_2, USV_3_3, USV_3_4). But for the "Equal&Above 30" age group, the plots of the concepts without virtual driver(USV_3_1 & USV_3_2: upper whisker = 7, upper hinge = 6) did not skewed as the younger group.

Effectiveness

From the Figure 6.5, there is no big difference among the 4 box plots in Effective category: All the plots were skewed to the "strongly agree" side, and had the same upper whisker(7), upper hinge(7), median(6), lower hinge(5). The only difference here is the different lower whisker values, only USV_3_3 got 4 and the rest three all had 3.

Even the plots of Effectiveness in Figure 6.5 shows similar result, given the calculated MEAN numbers in Figure 6.4: MEAN = 5.63(USV_3_1), 5.89(USV_3_2), 6.00(USV_3_3), 5.68(USV_3_4), we could see the USV_3_3 had the highest MEAN among 4 concepts, and it also got the lowest SD(1.00).

When we plotted the data by age group, one interesting thing was the median difference between two age groups: the 7-point Likert scale from the younger group had higher median than the elder group in every concept. For USV_3_1, median = 6.5(Under 30), 5.5(Equal&Above 30). And from the plot, the data range of elder group(upper whisker = upper hinge = 7, lower hinge = 4, lower whisker = 2) was more various compared to the younger group(upper whisker = upper hinge = 7, lower hinge = 6, lower whisker = 5). For USV_3_2 and USV_3_4, the median value of younger group was 7 and 6.5 respectively, and the median value of elder group for both concepts equaled 5. As for USV_3_3, median = 6.5(Under 30), 5.5(Equal&Above 30). But compared to the plot of USV_3_1, the data range of elder group was less various(upper whisker = upper hinge = 7, lower hinge = 5, lower whisker = 4).

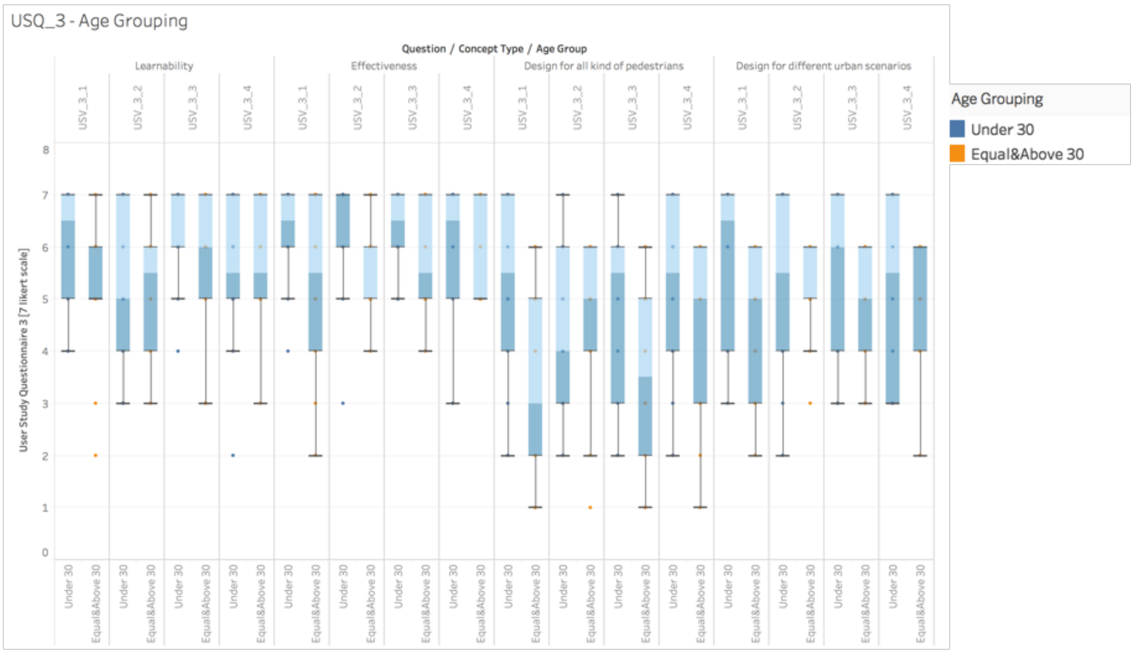


Figure 6.7: Age-grouped Box-whisker Plot of USQ_3 in Learnability, Effectiveness, and Capability

Capability
We set 2 statements related to Capability: design for all kinds of pedestrians and design for different urban scenarios.

For the "design for all kinds of pedestrians", the listed number in Figure 6.4 shows the concepts with traffic light signal had more positive feedback: MEAN = 4.16(USV_3_1), 4.58(USV_3_2), 4.11(USV_3_3), 4.58(USV_3_4). Even the difference of the median, upper whisker and upper hinge value in Figure 6.5 were not that obvious, but the data range of USV_3_2 and USV_3_4 were less various compared to the concepts with numeric time countdown(USV_3_1 and USV_3_3). Most participants rated USV_3_1 from 2(lower hinge) to 6(upper hinge), rated USV_3_3 from 2.5(lower hinge). But for USV_3_2 and USV_3_4, the lower hinges were one point higher compared above two, which means most participants gave their rates from 3 or 3.5 for the concepts with pedestrian symbol signal.

When it comes to the result grouped by age in Figure 6.7, obviously, the feedback from elder group of USV_3_1 and USV_3_3 were less positive compared to the younger group. For the participants who are under 30, most of them rated USV_3_1 from 4(lower hinge) to 7(upper hinge), and the median value equals 5.5. Most of them rated USV_3_3 from 3(lower hinge) to 6(upper hinge), and the median was the same(5.5). As for the group who is equal or above 30 years old, most of them gave their rating from 2(lower hinge) to 5(upper hinge), the median is just 3, which means half participants from that group rated either 2 or 3 for USV_3_1. As well there was a similar result for USV_3_3, but its median rate(3.5) was between 3 and 4.

The USV_3_3 still had the highest MEAN(5.11) and lowest SD(1.49) among 4 concepts in "design for different urban scenarios" statement, but generally there was no big difference according to the listed number in Figure 6.4. And in the Figure 6.5, the two medians of virtual driver concepts(USV_3_3: 5.5, USV_3_4: 6) were higher than without(Median = 5 for USV_3_1 and USV_3_2). Half participants rated USV_3_1 and USV_3_2 either 4(lower hinge) or 5(median), while most participants agreed on USV_3_4 from 4(lower hinge) to 6(median = upper hinge = 6). The data range of USV_3_3 was the least various one(lower whisker = 3, lower hinge = 4, median = 5.5, upper hinge = 6, upper whisker = 7).

Regarding the relevant plots in Figure 6.7, all positively skewed plots are from younger participant group(upper whisker = upper hinge = 7), while the upper whisker and upper hinge were also same in elder group but equal 6. Except the data set of USV_3_4, the younger group always got higher median than elder group and the median values from elder group were all equal 5. The median data of younger-age was different(USV_3_1: median = 6.5; USV_3_2: median = 5.5; USV_3_3, median = 6). For the two plots of USV_3_4, all younger participants rated from 3(upper whisker = upper hinge = 3), up to 7(upper whisker = upper hinge = 7), and their median rate was between 5 and 6(median = 5.5). Most "Equal&Above 30" participants rated USV_3_4 among 4(lower hinge), 5 or 6(upper hinge), and only several of them rated between 2(lower whisker) and 4(lower hinge).

Emotion

There were also 2 statements in Emotion category: pedestrians' feeling on pleasantness and comfort among 4 different concepts.

According to the numbers of pleasant statement in Figure 6.4, the MEAN of USV_3_2 was the highest one(5.11) while the rest of their MEANs were quite similar: MEAN = 4.79(USV_3_1), 4.89(USV_3_3), 4.89(USV_3_4). The SD data was reflected in the plot overview in Figure 6.5 as well. Among those 4 plots, the one of USV_3_2 had the least various data range: upper whisker = 7, upper hinge = 6, lower hinge = 4.5, lower whisker = 3. However, the plot of USV_3_3 was the one which skewed towards to "strongly agree"(upper whisker = upper hinge = 7).

Meanwhile, in Figure 6.8, the two age-grouped plots of USV_3_3 were all positive skewed (upper whisker = upper hinge = 7), while the data range was different between two age groups(Under 30: upper whisker = upper hinge = 7, lower hinge = 4, lower whisker = 3; Equal&Above 30: upper whisker = upper hinge = 7, lower hinge = 3, lower whisker = 2). As for the rest 3 concepts, the plots from younger participant group were skewed towards to "strongly agree" side, but the plots of elder group were not. For USV_3_1, all participants who are younger than 30 years old rated between 4(lower whisker = lower hinge = 4) to 7(upper whisker = upper hinge = 7), and half of them gave their rates up to 6(median). Most elder participants rated USV_3_1 from 2(lower hinge) to 5(upper hinge). Compared to the USV_3_1 concept, most ratings from elder participants were either 5(lower hinge) or 6(upper hinge), only one elder participant rated 3(outlier). As for USV_3_4, the median shows the same value(5.5), but the data range were different(Under 30: upper whisker = upper hinge = 7, lower whisker = lower hinge = 3; Equal&Above 30: upper whisker = 7, upper hinge = 6, lower hinge= 4, lower whisker = 2).

As for the participants' comfort feeling, from the result in Figure 6.4, we could see that they felt more comfortable to USV_3_4 among 4 concepts : MEAN = 5.32(USV_3_1), 5.32(USV_3_2), 5.11(USV_3_3), 5.42(USV_3_4). While the lowest SD came from the data of USV_3_2(1.57), which was also visualized in Figure 6.5. Meanwhile, for USV_3_2, most rates were given either 5(lower hinge) or 7(upper hinge = median = 7), and only a few rates were

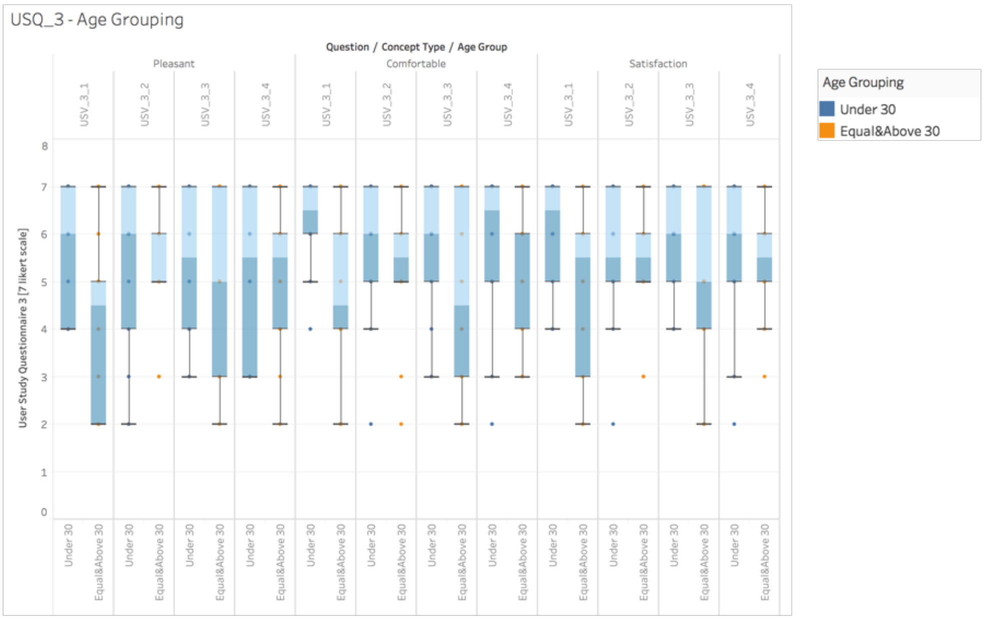


Figure 6.8: Age-grouped Box-whisker Plot of USQ_3 in Emotion and Satisfaction

below 4(lower whisker).

The plots grouped by age in Figure 6.8 has the similar result with "Pleasant" statement. All the plots of younger age group were "strongly agree" skewed(upper whisker = upper hinge = 7), and their median values were either 6 or 6.5, which were all higher than the medians in elder age group(USV_3_1: median = 4.5; USV_3_2: median = 5.5; USV_3_3, median = 4.5; USV_3_4, median = 6). Given the analysis between the concept with numeric time countdown(USV_3_1 & USV_3_3) and pedestrian symbol(USV_3_1 & USV_3_3), there is no obvious difference from the data of younger group but the participants from the group "Equal&Above 30". From the elder-plot, the median rate of USV_3_1 was between 4 and 5(median = 4.5), the same median shows in USV_3_3 as well but the upper whisker and upper hinge went up to 7. When it comes to the concepts with the pedestrian symbol, the median rate of USV_3_2 was between 5 and 6(median = 5.5), and the median value of USV_3_4 was 6.

Satisfaction

According to Figure 6.4, the concept which presented pedestrian symbol signal(USV_3_2 and USV_3_4) had the same MEAN and SD value(MEAN = 5.32, SD = 1.45). Although this was the highest MEAN in Satisfaction category, the other two MEAN values were quite similar: USV_3_1(5.26) and USV_3_3(5.21).

Nevertheless, the 2 plots of numeric time countdown concepts were both skewed to the positive side according to Figure 6.5(upper whisker = upper hinge = 7). Besides that, the rest factors in the plot were quite same(lower hinge = 4, lower whisker = 2) but the median value(USV_3_1: 6, USV_3_3: 5.5). The similar situation also happened on the 2 concepts with pedestrian symbol signal: USV_3_2 and USV_3_4(higher whisker = 7, higher hinge = 6, lower hinge = 5, lower whisker = 4). The median values between them were also different (USV_3_2: 5.5, USV_3_4: 6).

Based on the integrated Figure 6.8, it is obvious to see that all plots from "Under 30" age group were skewed towards the positive side(upper whisker = upper hinge = 7). And among them, USV_3_1 owns the highest median value(6.5), USV_3_2 had the lowest median(5.5), and USV_3_3 and USV_3_4 both had median = 6. Instead of 4 skewed "Under 30" plots, 3 out of 4 plots from elder group were not skewed to the "strongly agree" side. And even the plot of USV_3_3 within elder age-group was skewed towards "strongly agree", the median shows the lowest one(5) among 8 sets of data in this category.

Overall, in Satisfaction category, except the equivalent median of USV_3_2(5.5), the younger group displayed the higher median generally than elder age group.

6.4 Post Study Interview

In the post-study interview, firstly we asked about the most and the least effective design while using in the real urban traffic. And the relevant interview questions follow based on the answer they gave.

Figure 6.9 reflects the percentage of participants' opinion about effectiveness among 4 different design concepts. According to Figure 6.9 (a), we could see clearly that half of the participants believed that the USV_3_1 will be the most effective communication when it used in the real urban traffic. 30% of participants think the USV_3_4 will be the most effective one. The USV_3_2 and USV_3_3 both constitute 10%. However, in Figure 6.9 (b): which would be the least effective one among those 4 communication concepts, compared to 5% composed from USV_3_3, USV_3_2 plays the majority choice, account for 45%. The USV_3_1 and USV_3_4 take up 30% and 20% respectively.

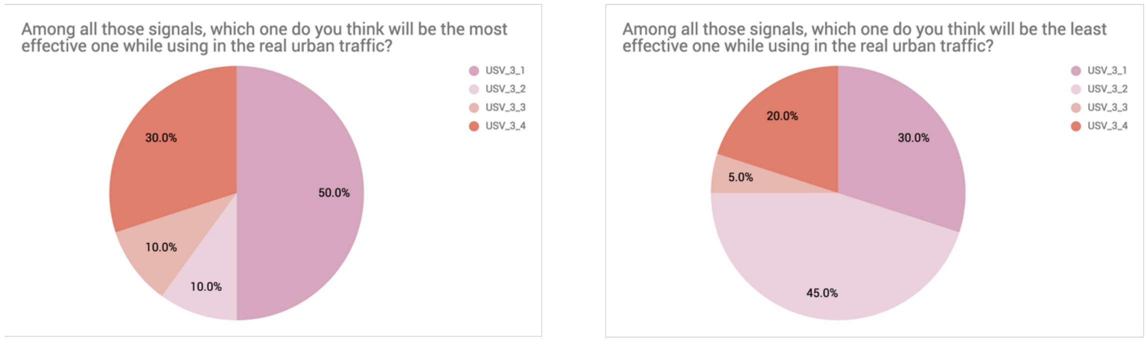
The audio recordings of the post-study interview from each participant were reviewed and selected transcribed. With the notes we took during the interview and their answers of relevant questions, there are four categories we highlight from the results: 1) Numeric time countdown vs pedestrian symbol, 2) Attitude of Virtual Driver, 3) Concerns when used in real traffic, 4) Suggestions for improvement. The extended description of those categories reflects the quantitative result above in this Chapter as well the result in Figure 6.9.

Same as the focus group and participatory design analysis in Chapter 3, 4, to provide better understanding and appreciation for the audience, the original words used by participants were also presented together in following, and those comments stand as the majority viewpoint or the extreme case from participants.

6.4.1 Numeric time countdown vs Pedestrian symbol

According to the Figure 6.9 (a), USV_3_1 and USV_3_3 account for 60% together as the most effective choice from participants, and both of them used numeric time countdown signal while communicating. All the participants who prefer them because they can make their cross decision better with those displayed numbers: they can choose to cross if there is enough time left, and if there were just a few seconds left they probably would not take the risk. In that case, it will also help the elderly people or disabled people assuming if they can manage crossing on time or not. On the other hand, they believed that this could be a good option to avoiding too many stops for the driving vehicles.

"Instead of having the pedestrian symbol signal, it makes more sense to me to have ... the numbers in green, because green, of course, goes and then with the numbers, you will know how long you have to cross the street."



(a) (b)

Figure 6.9: Result of the "most/least effective" question in Post-study Interview. (a)the most effective concept among 4; (b)the least effective concept among 4.

Besides, one participant mentioned that it is more convenient for colorblind people to see the numeric time countdown rather than distinguish the symbols for crossing.

Nevertheless, for participants who did not choose the one with numeric time countdown signal, the most common reason for them is whether the children will be able to understand the numeric signal at the beginning. Two participants did not feel comfortable or pleasant with numeric time countdown, *"I don't feel good because it's like pushing me to cross, why the car can define how long do I have to cross."* they said. And for all the above reasons, some participants prefer to choose the most effective one used by the pedestrian symbol signal, which they think is more understandable, acceptable and adaptable compared to another one.

"I was thinking about whether it's suitable for all kind of people that we have in the urban areas like if someone is quite young and did not understand quickly... The signs that had been used already for traffic lights(pedestrian symbol) are easier for me, at least from my point of view, for people to adapt to."

Regarding the least effective choice, given one choice was quite difficult for few participants during the interview, they think either numeric time countdown or pedestrian symbol signal both can be effective enough in the real urban traffic. One of them says *"The pedestrian symbol is really good I think, because it used the one which can be understood by everyone. And for another one, I am not sure when I saw this numbers displays on the car(windshield) at the first time, but you can get used to it very fast, which is also pretty nice."*.

6.4.2 Attitude of Virtual Driver

In the Figure 6.9 (a) the most effective communication signal, the design with virtual driver composed 40%(USV_3_3 and USV_3_4), and it accounted for 25% as the least effective choice in Figure 6.9 (b).

There was no clear clue about the feedback of the virtual driver signal from the interview. Some participants preferred to have the virtual driver on the windshield because compared to the other two without the virtual driver, it can make them trust the autonomous vehicle more. One participant commented directly *"First I would be a little scared"* when he or she saw the LED signal communication without the virtual driver in the front. And later on, when he or she saw the prototype video with the virtual driver, the commented changed *"I feel better about this(signal with virtual driver).".* Some other participants also said *"It somehow makes me feel safer.".* Besides, they also mentioned that the virtual driver on the windshield can help them to distinguish autonomous vehicle and normal vehicle on the road, especially when they appeared in the traffic at the same time. One participant said,*"I guess the sign of the driver can help a lot to understand the autonomous car, because otherwise it's really difficult to distinguish".*

However, in spite of the positive attitudes from participants, some of them also pointed that there is no necessity for them to have the virtual driver during communicating. From their answers, they considered the virtual driver as a bonus approach(*"It is nice to have."*) but not very important for them to communicate with the driverless car. *"I think the virtual driver is not important for me, as long as the car stops and let me cross, it doesn't matter if I knew whether it drives autonomous or not.".* Furthermore, few participants mentioned that he or she was confused about this virtual driver at the beginning, and there was one participant felt a bit scared of the virtual driver.

6.4.3 Concerns when used in real urban traffic

When we asked "What would be your concern if we bring this design to the real urban traffic", the weather condition still came out as one of the most problems they mentioned during the interview. They were wondering whether the visual cues still can be seen when it is a pretty light situation or other occasions. *"I could imagine that this might be worked in the rain or in the night, in terms of the big shape and colored light. But if it's very sunny, will it be declared from the windshield as well?"*

Secondly, most participants questioned about the auditory signal we added around the vehicle. On the one hand, they believed that this could lead to more noises on the street, on the other hand, they doubted if this could work well in the busy cities where is already too noisy on the street. Considering the communication needs of people who have the vision problem, they understood that it should have combined acoustic cue during communication, but the noise on the street is the concern which cannot be ignored. *"Thinking about that if there are several autonomous vehicles together and giving those auditory signals on the street, that would be a mess."*

The above comment also reflects the concern of the existing problem for multiple autonomous vehicles either mixed with normal vehicles on the street. *"the concern is that if so here we have only one car. But if we have so many cars and especially when you want to think about these beeping. And that's would be definitely one problem especially for big cities."* another participant said.

And from the Chapter 6.4.1, the comment from some participants made the concern about the numeric time countdown, they said it could be a misunderstanding for kids or even people who have reading problems at the beginning. The time period for crossing is one another topic. They noticed that the 10 seconds we used in the prototype video might not be enough for elder people or disabled. Besides, the international standardization is also one of the big concerns. All participants agreed that they could understand the signal but it should also be adapted to different countries as well.

In the Chapter 5, even we got the highest scale result from "The position of signal presents was obvious to notice." statement in the questionnaire, and most participants agreed that they are satisfied with the position of the signals. Nevertheless, some participants pointed out that the LED lights which placed around the headlight of the car were a bit confused. Based on the pedestrians' perspective, when the car flashes their headlight on the road, it means giving some warnings or request for attention in the traditional approach. Due to that reason, the placement around headlight also became as one of their concerns.

In the end, we cannot deny that there is always someone who will break the rules, especially traffic rules. The participants also mentioned that even some regulations were defined in this communication, like giving a certain time for the pedestrian to cross, but it is not possible to avoid the rule breakers. *"What if people cross after the settled time?"* was also one concern point came from participants.

6.4.4 Suggestions for improvement

Following the concern, we collected participants' suggestions towards the improvement of presented prototypes as well the future pedestrian-vehicle communication.

For the participants who did not choose the numeric time countdown as the most effective one, most of them say that it would be better if this signal can be combined with pedestrian symbol together. They admitted that the numeric time countdown signal can be learned and get used to it very quickly, and it is helpful for guaranteeing the traffic efficiency. While it is also obvious that the pedestrian symbol signal can be more international and acceptable in some cases. The better solution is to take their advantages and have both of them display at the same time.

"And for crossing the street I personally like the pedestrian sign. But if we can combine it with the numbers like the counting down numbers, that would be great.", one participant mentioned.

Additionally, the placement also plays a part of improvement from the interview. Some participants suggested that it is nice to have the additional display on the sides of the AV, *"Maybe on the glass of side-door can also help for the pedestrian who is standing next to the car."*. This improvement can be used to deal with the situation which has multiple pedestrians around the vehicle. In addition, it can also be helpful to avoid people cannot see the front information when it is too bright.

In terms of defining crossing time period, some participants suggested *"Maybe it can be freeze when the car detected someone who is crossing in front of them."*, one participant even thought about the time period can be adjusted depends on different pedestrians or their group size, if the technology became mature enough.

Improvement of the auditory signal was also mentioned by participants. According to the feedback, some of them felt that the sound we used in the prototype video is a bit aggressive, therefore instead of that, they prefer to have a less aggressive one. There was a similar comment from the same participant in the last paragraph: *"this can also be adjusted. If the technology can even distinguish the blind people, the car offers the sound, if that's normal pedestrian, they don't. And the volume can be different on different streets."*

Overall, most the participants felt that the presented prototypes can be useful and effective enough as the first pilot approach tested in the real urban traffic. But it could be better with the improvements they provided above.

7 Discussion

In this chapter, we discuss high-level subjects which spring from our findings and reflect on how pedestrian-vehicle communication in the age of autonomous driving could be designed.

7.1 Reflection on methodology

The methodology in this research follows three phases 1) Focus group study, 2) Participatory design session, and 3) User study. In the following section, we reflect our findings in the proposed design methods, consolidating its validity and proposing implication for future design sprint.

Focus Group Study
The discovery from the focus group sessions collected bullets and provided valuable insight into the current communicated approach for crossing, the pedestrians' needs as well as the expectation of the future pedestrian-vehicle communication. The result helped to verify the selected situations, understand pedestrians basically and define the research scope in this thesis. In particular, the required information during communicating primarily collected and played an important foundational work for the next phase.

Participatory Design Session
The outputs from PD session have been extremely influential on and to the following communication concept as well as the user study design. Design elements of this vehicle-pedestrian communication system were mainly referred by learning and interpreting the pedestrians. From the focus group result, recalibration of the design situations and collection of user needs during communicating enabled a clear and consistent presentation of the context and design tasks to participants in the PD session.

However, Sumner and Stolze[44] mentioned that the participatory designers' work have been cautioned to think as "evolution, not revolution". The given mock-up of the vehicle and the material were used might be the barrier for participants while prototyping. For instance, only 1 out of 8 participants came up with the haptic modality for future vehicle-pedestrian communication besides the visual and auditory modality.

User Study
The prototype videos were created based upon the results of previous researches as well as the user study setup. The pilot study was done before conducting the formal user studies with 20 participants. Initially, due to the lack of field study capacity, we planned to test out concepts with VR simulation, which is also cheaper than the Wizard-Of-Oz[45] approaches used to study interaction between pedestrians and autonomous vehicles[17]. However, considering the convenience of participants and better controllable for researcher during the user study, the video-based method is obvious a quick-win approach to obtain the attitude towards our concept design.

There is no doubt that we might gain more significant results if we had taken an iterative method when designing the prototypes. The between-subject control of the independent concept would be adjusted the results, for instance, the within-subject control makes participants get to know there is a settled time for crossing faster, then considered this more to the weakness of traffic light signal. This can also be the improvement if adequate significance was not achieved in the study of the initial designs. Moreover, it is probable that setting one more concept with combined numeric time countdown and traffic light signal at the same time might also help us to determine the direction of the future design.

7.2 Implication for design

The propose of this research is to design the concept of autonomous vehicle-pedestrian communication and to explore the pedestrians' attitude about different design elements. The scope and the evaluation in user study have been considered mainly between one pedestrian and one autonomous vehicle. Our results nevertheless raise some questions that are discussed hereafter.

Communication Concept
Research from the Bonnefon in USA[6] revealed participants would rather that an autonomous vehicle was programmed to prioritize the safety of pedestrians, if they outnumbered the vehicle's passengers. Given the end user of this communication is pedestrian, and the context is in the crossing situation with approaching vehicle without human-driver inside, the result of this concept design perceived generally positive feedback. The data from post-study interview initially suggest that most participants agreed that this would be an effective approach not only to guarantee the safety of pedestrian but also increase the efficiency of the traffic. Since the findings from the University of Calgary [46] suggest that participants preferred to receive explicit information about vehicle' awareness and intent via interfaces as opposed to only receiving information from the vehicle's movement. The design elements which were used for transmitting cross information in our research advise that the symbols in traffic system can be extremely helpful to help pedestrian make the cross decision. Meanwhile, our findings emphasize the explicit time expression is rather needed when there is a certain crossing time period.

Design Element
LED signal Using LED signal with colors to transmit information(for example, pedestrian has been recognized, the car is slowing down, etc,.) as the basic design in this research. This may build the basis for the development of the effectiveness towards communicating with an autonomous vehicle. Instead of the pedestrian rely on vehicle speed and distance to judge both the awareness and the intent of the car in the traditional vehicle-pedestrian communication[9], the colored LED bar placed around would be particularly beneficial in the future approach. And out findings also suggest it may help to sighted people during the crossing.
Virtual Driver signal The survey study of Schoettle and SivakS[47] pointed a large percentage(90.1%) of respondents said they had some level concerns("very/moderately/slightly concerned") that self-driving vehicles would not drive as well as human drivers. In that sense, we suggest that a virtual driver could be considered as a signal to decrease pedestri-

ans' concern while encountering with an autonomous vehicle. Our findings of virtual driver element do not point to a specific threshold but rather a good indicator to distinguish driving mode as an additional cue in this communication, and help to improve the satisfaction of some participants during communicating with AV.

Numeric time countdown & Pedestrian symbol signal The two different traffic signals we used for crossing intent are both existing in the traffic system already: numeric time countdown and pedestrian symbol. The results of this study preliminarily indicate that both of them can be effective and satisfied by most participants, but the pedestrian preferred to receive numeric signal rather than the normal cross symbol when the autonomous vehicle let them cross in a certain time period. There were also several researches regarding influence on pedestrian of the numeric countdown signal using in the real traffic system. In 2005, JP Singer and N Lerner[48] compared the difference of pedestrian behavior among countdown signal(only), normal traffic signal(flashed traffic icon), and combined signal(countdown and traffic icon), the results show that the countdown signal works best on reducing the behavioral decision-making confusion. The findings of Pulugurtha [49] in 2010 and Huitema[50] in 2014 indicate that the countdown signal in intersections can make better decision for pedestrian, and decrease the number of pedestrian collision accidents. As explained previously, with the traffic light signal citing its familiarity and universality as reasons for its better emotional feedback, the capability to diverse pedestrian and more positive satisfaction. While the numeric time countdown performed better effectiveness by providing more explicit information under the certain time condition. However, the difference between these two signals do not necessarily contradict each other: they suggest that the future pedestrian-vehicle communication with autonomous vehicle can be effective and helpful on the pedestrian crossing by using traffic light symbols.

Auditory signal Our finding in the user study that it is good to have the auditory signal in this pedestrian-vehicle communication is not surprising, the FG study and PD both pointed out that acoustic cue might be necessary to communicate with the blind pedestrian. Besides, another good-to-have point considered as most autonomous vehicles are electric cars and may drive relatively silent. EU regulations require electric vehicles to be equipped with Acoustic Vehicle Alerting Systems (AVAS) to generate artificial audio cues for vehicle detection[51]. But some participants mentioned that it might not work in the big city(with street noise), either beeping in the situation with multiple AVs. This is consistent with the findings of the research from the University of Calgary[46].

Signal Placement

As we mentioned in Chapter 6, among all quantitative results of USQ, as well the post-study interview, the statement *"The position of signal presents was obvious to notice."* gained the positive light feedback from participants. This suggests that the windshield can be taken as the core display position of the car itself. However, the placement of LED signal around car's headlight should be considered more serious to avoid misunderstanding.

Overall, the communication concept would be implicitly understood and learned by a person without specifically being engaged and trained. And the visual signals we designed in this research is an explicit way of communicating intent for car-to-pedestrian.

7.3 Implications of Age Grouping Difference

Age-group differences pervaded the user study questionnaire: the younger adults are more positive of this communication concept since these are more likely to make the crossing effective while encountering an autonomous vehicle in the real traffic, especially on the numeric time countdown signal. And the virtual driver signal considered as more satisfied for the participant who is not below 30.

Given the approaching vehicle without human-driver inside in the crossing situation, the most important aspect of age difference is that how the majority of the people in different age range hold their attitude towards this autonomous driving technology. The findings of the survey from Schoettle and Sivak[47] indicated that younger people were more likely to expect less traffic congestion, shorter travel time, and lower insurance rates with self-driving vehicles. And the replicated result from [52] also pointed that age differences affected the more extreme attitudes with younger participants more often accepting autonomous cars and less often outright opposing them than older participants. This could be one of the reasons why few over-30-participant mentioned that they feel safer when there is a driver displaying on the windshield and to the oppose *"I would be a little scared"*.

Another possible reason could address this age difference is the design consideration based on kids' perspective. Since most participants in the elder-age group in our user study have already become parents, can this pedestrian-vehicle communication be understood by their kids and taking care their safety remind them being more serious than the younger group. Children need to know whether the vehicle they are encountering is autonomous, the concrete and easily read messages during communicating with the self-driving car was also revealed in the research [53]. In another word, despite the numeric time countdown signal provides explicit time duration, the pedestrian symbol could be more approved and crucial to help pedestrian make the cross decision in such situation, no matter what age they have.

Reviewed in the PD session, the participants aged from 24 to 28 years old. Even though they played as the end user in this pedestrian-vehicle communication while prototyping, the design ideas might not stand as the incorporated insight from all pedestrians but their specific age group. And thus this might explain younger participants rating among all concepts we designed as being more positive.

7.4 Limitations

The limitations of this study include a couple of aspects. Firstly, the limitation of participants' background among focus group, participatory design, and final user study. Secondly, due to the limitation of time, space and costs, the user study was only conducted in the laboratory but field, and it only applies to a small number of sample. Last but not the least, the prototype videos we used in user study were limited by the time and capacity.

In the focus group, the majority of participants are German, the other parts were more or less diverse besides the nationality. In participatory design study, the majority of participants are students, which means the core design elements came from them may represent better for the younger generation. As for the user study, all the participants were employees in one industry even though they work as the different occupation. All above background limitations can be addressed by repeating the study with diverse participants.

The prototype videos in the laboratory study set the boundary to the pedestrian that they are only allowed to aware the situation with the settled perspective, and wait for the anticipated vehicle approaching. There is no actual cross movement either in different urban situations. A single vehicle type and setting were assessed. Moreover, the video-clips were too short to notice the difference between each other. For example, when we played two traffic light concepts within or without virtual driver(USV_3_2 and USV_3_4) next to each other, some participants cannot really distinguish the difference between at the first time. The non-animated virtual driver signal we used in the prototype videos can also be one of the limitations, which could influence the pedestrians' attitude or awareness towards this virtual driver concept behind.

Given those considerations, the methodology in this thesis study is more suitable for designing relevant elements and defining the concept rapidly that can be used for further investigation rather than the post-validation in the end.

8 Conclusion and Future Work

The major contributions of this research include: 1) in-depth knowledge on how autonomous vehicle may communicate with pedestrians, 2) the video-based prototype addressing this pedestrian-vehicle communication, and 3) a method for the concept design of such a new technology system.

Based on the previous focus group and questionnaire study towards future vehicle-pedestrian communication, we created a design methodology and framework for our following exploratory research. We conducted the field focus group study and participatory design session step by step, the results of which contributed to the design concept and laboratory user studies. We evaluated the design concept by implementing 3D prototypes and produced them as video clips(USV), and conducted the user study to assess the relevant usability factors by user study questionnaire(USQ) and post-study interview.

The result of the user study questionnaire research and the post-study interview have demonstrated that pedestrians' perceived safety might increase when providing a virtual driver instead of displaying patterned signals only during the autonomous driving, especially for the pedestrian with ages. The result also shows that the pedestrians perceive this virtual driver concept as an indicator to distinguish whether the vehicle is driving in the automated mode or not. This can help pedestrians to decide their cross behavior based on their self-awareness upon safety conscious. Another result regarding the crossing signals indicates that the relevant traffic light signal can be an effective signal to help making the cross decision, but when there is a settled crossing time defined by the autonomous vehicle, pedestrian preferred to receive explicit time rather than a pedestrian symbol, this reflects more on younger group pedestrian.

A conclusion from this is that pedestrians need additional information in the future vehicle-pedestrian communication in autonomous driving age to compensate for the loss of interaction with human-driver. Particularly, when the driverless car has stopped in front of the pedestrian, a information is needed to be able to provide the vehicle's intention clearly, clarifying if the vehicle itself will let them cross or not, and how long they are allowed to cross. In addition, identifying a car is manually driven or automated vehicle will also be helpful during communication.

The prototype video-based user study shows that the communication between the pedestrian and the autonomous vehicle could be effective with the designed concept. The pedestrians were able to understand the information that was transmitted to them and the prototype video simulated them in the decision-making process.

The methodology developed for designing AV-pedestrian communication and gathering the feedback for the following design iteration towards the problems that might occur when driverless cars are released to the market. The method is simple and easy to use but given the implemented prototype as well the quantitative and qualitative result, there is a lot of room for future work.

On the one hand, the most important point is to iterate the design principle for communication. This can be split into three sub-points: visual signal, auditory signal and communication procedure. For the design iteration of the visual signal, firstly, the placement of the signal can be redesigned to avoid misunderstanding and increase pedestrians' experience. For example, the LED signal around headlight sometimes confused pedestrian. Secondly, considering the strengths and weaknesses of numeric time countdown and pedestrian symbol, the combination of two different signals could be one better solution in next step. And thirdly, the current non-animated virtual driver can be replaced by an interacted one with high resolution. Since the auditory signal was not the core research focus during the user study, the exploration of pedestrians' reaction on different auditory stimulus can also be a direction of further research. When it comes to the design iteration of communication procedure, the interaction point during vehicle-pedestrian communicating could be one consideration in the following design principle.

On the other hand, to get more valid results and find more weakness or strong points in design and usability, upgrading the prototype video to a high-fidelity one and conduct the user study with a real autonomous vehicle instead of laboratory video-based study. For upgrading the prototype video, due to we built our prototype in Unity platform, a VR-based study can be considered as a transition before we conducted with the actual autonomous vehicle. Moreover, we are also interested in more complicated test scenarios, for instance, one autonomous vehicle with single pedestrian or multiple pedestrians, or several autonomous vehicles with single or multiple pedestrians, even mixed vehicle(includes normal vehicle and autonomous vehicle) with single or multiple pedestrians.

Overall, our findings in this research created a basic picture of how autonomous vehicle communicate with the pedestrian in cross-case by relying on provided signals. The iteration of the design concept would be the start point of the further research, and other investigations, explorations either evaluations by different approach or in multiple scenarios could also lead to the challenge regarding the pedestrian-vehicle communication in the age of autonomous driving.

List of Acronyms

2D	Two-dimensional
3D	Three-dimensional
AV	Autonomous Vehicle
AR	Augmented Reality
FG	Focus Group
GPS	Global Positioning System
HCID	Human Computer Interaction and Design
HMI	Human Machine Interaction
Hi-fi	High Fidelity
LED	Light-emitting Diode
PD	Participatory Design
PICTIVE	Plastic Interface for Collaborative Technology Initiative through Video Exploration
QoS	Quality of Service
SAE	Society of Automobile Engineers
SD	Standard Deviation
UE	User Experience
USDOT	U.S. Department of Transportation
USV	User Study Video
USQ	User Study Questionnaire
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
V2P	Vehicle to Pedestrian
VR	Virtual Reality

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