Exploring challenges in developing a smart and effective assistive system for improving the experience of the elderly drivers

JUNG Sebin[1, 2, *], MENG Hongying[1], and QIN Shengfeng[3]

1 *Dept. of Electronic and Computer Engineering, Brunel University London, Uxbridge, UB8 3PH, UK*
2 *Interior Engineering Division, General Motors Korea, Incheon, 403-714, South Korea*
3 *Northumbria School of Design, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK*

Abstract: As the overall population ages, driving-related accidents and injuries, associated with elderly drivers, have risen. Existing research about elderly drivers mainly focuses on factual data collection and analysis, indicating the elderly's growing fatal accident rates and their different behaviours compared to younger drivers. However, few research has focused on design-led practical solutions to mitigate the elderly's growing fatal accidents, by considering their usability and body conditions, afflicting the elderly, such as decreased vision, hearing, and reaction times. In this paper, first, current worldwide situations on growing fatal accident rates for elderly drivers is reviewed and the key impact factors are identified and discussed with regarding to usability and design trend in the automotive technology for elderly. Second, existing smart vehicle technology-based solutions to promote safe driving are explored and their pros and cons are discussed and analysed. Most of solutions are not created by people with driving difficulties, which are caused by health problems most commonly afflicting the elderly. Thirdly, diverse design-led research activities are taken such as a survey, observation, and interviews to gain new understanding of what kinds of driving problems elderly drivers have and demonstrate how new system concepts could be developed for the elderly's benefits. Finally, it is found that the elderly's low vision and late reaction are main factors causing their driving difficulties. Based on this finding, usable vehicle system design ideas have been proposed, by utilising facial expression sensing technology as a solution. The proposed solutions would ensure reducing both the elderly's driving problems and high fatal accident rates and provide a more enjoyable driving environment for the elderly population.

Key words: elderly drivers, aging health conditions, driving behaviours, vision impairment, cognitive impairment, hearing loss, reflexes, fatal collision

1 Introduction

Population aging is rapidly becoming a global phenomenon. According to the United Nations 'World Population Aging' report[1], "The number of elderly aged 60 years or over were about 202 million in 1950, has accelerated to 841 million in 2013, and will triple by 2050." Given the increasing age of the Earth's population, the elderly group has become a socially and economically sector offering us both opportunities and challenges on the various aspects of daily living and health management. In particular, the automotive industry has faced a new challenge to offer vehicle systems for elderly drivers due to the growing number of traffic accidents caused by elderly drivers and their higher fatal injury rates than young drivers in crashes on the road. The National Highway Traffic Safety Administration[2] reported in 2012 that there were 5,560 people 65 and older killed and 214,000 injured in motor vehicle traffic crashes in the U.S. These older people made up 17 percent of all traffic fatalities and 9 percent of all people injured in traffic crashes during the year. Additionally, in 2012, elderly drivers, who are defined as those 65 and up, were involved in 102,997 accidents nationwide — up from 83,058 in 2002[3]. Even in two-vehicle fatal crashes involving elderly driver and a young driver, an older person has an injury rate nearly twice that of a younger driver, i.e. 58% and 35%, respectively.

Due to the growing issue, creating an adequate automotive system for elderly's driving safety has become significant, and many scholars and developers have tried to address the issue and discover a new system to mitigate the elderly's accidents and injuries. However, the current systems are not effective enough to protect the elderly because the elderly's fatal accident rates are still high when looking at their recent fatality data: a total of 4,192 people ages 70 older died in the vehicle crashes in 2014, and deaths of seniors increased 2 percent from 2013 to 2014[4]. Also, the elderly drivers are unsatisfied and feel unsafe with the currently developed systems since the systems have not considered the body conditions afflicting the elderly, such as decreased vision, hearing, and slow reaction times, for system designs and developments. Most of the elderly related studies have just highlighted the elderly's growing fatal accident rates with statistic data and presented how they have different behaviours compared with younger drivers. Although

* Corresponding author. E-mail: sebin.jung@brunel.ac.uk

practical studies about a new system for elderly drivers has been necessary, any studies have not suggested practical solutions paying attention to the elderly's aging health conditions. They just keep highlighting the elderly's growing fatal accidents with statistic data and presenting their different driving behaviours. Furthermore, automotive companies also have been more interested in the promotion about how their vehicles have great designs with high technologies rather than creating a new vehicle system that the elderly group could join the enjoyable driving experience together. Particularly, although a lot of elderly drivers, having less experience with modern technology than others, complain about distractions during driving due to the complex systems, and in 2014, the National Highway Traffic Safety Administration[2] reported a spike in motor vehicle crashes to more than 3,300 deaths on U.S. roadways – which can be attributed to driver distraction issues, vehicle infotainment systems have become more complexed and challenging for them to operate. Given the fact, we could claim that studies related to the elderly's driving issues should be forwards suggesting beneficial solutions with the elderly's high usability by applying their declining health conditions. Otherwise, we might listen to the same issue from the elderly drivers every year via mass media. Therefore, this paper will aim to suggest adequate solutions for the elderly drivers by integrating the elderly users' abilities and needs into system design and development approaches to protect them from fatal accidents and provide a safe driving environment on the road.

For this research aim, this paper first introduces some factual data concerning increasing accident rates for elderly drivers worldwide – Asia, Europe, and North America – to emphasize how fatal accidents have become a serious problem over the world for senior citizens and investigate the elderly's aging body conditions to understand how they could have driving problems from the conditions. Furthermore, a different set of systems developed from current studies for elderly drivers is explored and analysed to investigate the challenges of change in the automotive system. Moreover, this paper clarifies the difficulties and behaviours experienced by elderly people in different driving situations with diverse research activities, such as survey and interviews. Finally, this paper suggests a possible solution to its ideal system task and scenario for creating a smart system design to satisfy both the elderly's needs in the technological and usability aspects and the industry 4.0 in its development steps that would be a new challenge for the future in-vehicle system of the elderly drivers.

2 Problem: Impact of Road Traffic Accidents on Elderly

2.1 Growing fatal accident rates for elderly drivers

When people get older, their body conditions, such as hearing, vision, and reaction have become changed. Although the elderly drivers have a long driving experience than other age groups, they have also become less able to drive and easily damaged from outside of driving impacts than when they are younger. As a result, here shows dramatically increased higher injury rates among elderly drivers from different regions, such as America, Europe, and Asia and these statistical traffic safety facts elicit how the increasing accident rates have become a problem in many countries.

First, U.S and Canada show increased fatal accident rates in involving elderly drivers. In the United States, traffic injuries among the elderly are becoming a severe social problem from diverse data reported. According to the National Highway Traffic Safety Administration[2], 5,671 people age 65 and older were killed in traffic crashes in 2013. This represents 17 percent of all Americans killed on the road. Also, 222,000 older individuals were injured in traffic crashes in 2013. Even in the past, according to data from the NHTSA[5], in 2009, 5,288 people age 65 and older were killed, and 187,000 were injured in traffic crashes. They accounted for 16 percent of all traffic deaths and 8 percent of the wounded, but they accounted for 13 percent of the population. The report said the number of fatalities among drivers age 65 and older grew to 5,750 in 2010. Canada's data for the elderly's accidents are likewise similar. According to Transport Canada[6], seniors aged 65 and older accounted for the second largest proportion of road deaths in Canada, at 16% (or 462 road fatalities) and also accounted for 7.8% (15,545) of injuries in 2006. One finding in the Transport Canada Road Safety Directorate study[6] was the large percentage of fatally injured drivers who were 65 years of age or older (one-quarter of all fatalities): 25.2 percent. This is a considerable over-representation considering that this age group accounts for slightly more than 12 percent of the population and licensed drivers. Even Canadian seniors have a higher vehicle death rate among licensed drivers, with an average of 15.7 deaths per 100,000 licensed drivers, compared to 9.6 deaths for drivers aged 25–64[7].

Also, in Europe, elderly drivers now represent the most rapidly growing segment of traffic accidents. For example, in the United Kingdom in 2008, 190 drivers over the age of 60 were killed in road accidents, 1,148 were seriously injured, and 9,677 were slightly injured[8]. Although the casualty trend is decreasing, it is declining at a slower rate than that of other age groups. Reported statistics indicate that the risk of being involved in accident increases after the age of 70, and drivers over 70 and especially over 80 years are more likely to be at fault when they crash with other cars[8]. Also, in Germany, people 65 years old and older constitute 20 percent of the population but makeup 27 percent of all traffic fatalities[9]. A study by the German Consumer Association showed an injury risk that is 14 percent higher for the age group over 55 years old in comparison to people 18 to 35 years old[9].

South Korea and Japan have the same critical issues. South Korea became an aging society in 2000. Consequently, the high injury rate of the elderly in motor vehicle crashes is a serious concern. According to the Traffic Accident Statistics in 2009, 1,735 people age 65 and older were killed in 2008, and these older individuals made up 29.6 percent of all traffic fatalities[10]. Compared to 2007, all accidents increased by 2.0 percent, but the accidents involving elderly people increased by 8.9 percent. Among people injured in this age group, there was an 8.9 percent increase from 2007[10]. In the case of Japan, while the number of young driving license holders below 24 years of age gradually decreased, the number of elderly license holders aged 65 or older increased[11]. In 2012, elderly drivers, who are defined as those 65 and up, were involved in 102,997 accidents nationwide — up from 83,058 in 2002[3]. Moreover, 70 percent of the 447 accidents were attributed to vision and hearing issues of drivers aged 65 or over[12].

All countries showed a higher injury rate in elderly than younger drivers. Particularly, South Korea showed a high growing rate of 8.9 % in fatal accidents for elderly citizens. In the US and Germany, the fatal collisions rate of elderly drivers is 14~17% higher than young drivers. In Japan, most accidents caused by the elderly are due to impaired vision and hearing. This proves that there is a strong relationship between the higher accident rates and the user segment, elderly - specifically, the elderly's declining health conditions, such as vision and hearing impairment and lower memory and reaction. Thus, it is necessary to understand how the elderly's aging health conditions affect their driving ability, and the elderly group could have such a higher fatal accident with the conditions.

2.2 Health conditions affecting the elderly's driving ability

From the statistical data of the elderly's fatal accident rates over the world, we could recognize that one difference, a health condition between elderly and young drivers could bring different driving accidents rates, and the health status could be the main factor of the elderly's higher fatal accident rates. Main elderly's health conditions, such as limited eyesight, hearing difficulties, late reaction, and cognitive impairment are explained to understand elderly drivers better and how the conditions can impact on their driving.

2.2.1 Lower vision

Some eye conditions can interfere with the elderly's ability to focus their peripheral vision, or can cause them to experience extra sensitivity to light, trouble seeing in the dark, or blurred vision[13]. With imperfect visual acuity, they have difficulties in detecting and judging the location of objects correctly[14]. Elderly people drive more slowly in darker conditions, and may have pathological narrowing of the visual field in addition to a narrowed visual field while driving[14]. Glaucoma is a disease that increases with age, and one symptom is difficulty seeing in one part of the visual field. It is reported that symptoms of open-angle glaucoma are present in about 3.9% of people aged 40 years or older in Japan[11]. Iwase et al. [15] reported that when these glaucoma patients drive, they have an increased likelihood of having an accident.

2.2.2 Hearing

Decreased hearing is a key symptom of aging and hearing and equilibrium functions occur in the ear and are essential for driving. Hearing loss is one of the most common conditions affecting older adults. Nearly 9 million adults in the U.K. suffer from some form of hearing difficulty, from total deafness to being slightly hard of hearing[16]. Thus, sometimes, the elderly don't even realize that they are missing important auditory cues, such as emergency sirens and honking horns when they are driving and the inability to hear honking horns or warning sounds brings about fatal accidents on the roadway[13].

2.2.3 Reflexes

Reflexes are nerve-signal-induced muscular reactions to external stimuli[13]. Although people are born with fast reflexes, their reaction time slows as they age. As reaction times slow with age, the elderly may be slower to spot vehicles emerging from side streets and driveways, or to realize that the vehicle ahead of them has slowed or stopped. Also, it has been found through in-car observations that older drivers have a tough time responding to traffic signals and performing left and right turns due to pain or stiffness in their necks, which prevents movement[13]. So, when a quicker reaction from a sudden situation is needed, such as when a car suddenly changes lanes, it is difficult for an elderly person to react quickly enough to avoid a collision.

2.2.4 Cognitive impairment

Reflexes Cognitive impairment is defined as a decline in at least one of the following domains: short-term memory, attention, orientation, judgment and problem-solving skills, and visuospatial skills. Keeping track of so many road signs, signals, and markings, as well as all the other traffic and pedestrians, can also become more difficult given the fact that the elderly often have decreased memory capabilities and a decreased attention span. The elderly drivers often find themselves missing exits that used to be second nature or find themselves getting frequently lost[17].

Elderly's health conditions show a clear reason of why the elderly drivers could have a higher fatal accident rate than other age-groups with their driving difficulties. We cannot judge what health condition is better or worse than others, although there might be little more dominant health conditions in the specific driving situations. This means that considering one condition for developing an assistant system can be risky and would not be beneficial to many elderly drivers. With the understanding between the elderly's health conditions and their growing fatal accident rates, we need to take a diverse perspective in elderly driving for suggesting more usable and beneficial solutions to effectively protect the elderly drivers on the road.

2.3 The meaning of usability and design trend in the automotive technology for elderly

The meaning of the usability is normally defined as the ease of use and the degree which can be used by specified consumers to achieve quantified objectives with effectiveness, efficiency, and satisfaction in a quantified context of use. This definition is the first and most critical factor in the design process and should be applied to all age-groups. However, steps so far taken to assist the aging population have often been limited although we know that how the elderly's aging body conditions are different from what young group has. According to Hiroko and Hiroyuki[18] in their usability research for the elderly people, current design considerations for elderly group are mostly visual aspects, such as stronger contrasts or larger characters on the displays and printing and their inability to understand the procedures for technological systems has not been excluded to the products or systems. This means that to provide systems that are easy for the elderly to use, it is significant to consider not only the senses, such as vision and hearing and physical characteristics but a comprehensive consideration including cognitive characteristics should also be taken into account.

The case of the automotive industry is not so different for the elderly's usability on the vehicle system development. In the auto industry, older people have become a loyal customer since the aging population has been growing all over the world. Also, individuals who are over 50 years old who purchased higher-end premium vehicles have the majority of new in-vehicle systems[19]. However, while these older consumers are the first buyers of these new technologies, they may be the least likely to rapidly learn and use these systems and have been excluded from such a new technological development.

Although these user needs are related to their health conditions, new devices, interfaces, warnings, navigation, entertainment and related systems are introduced targeting general customers. Even in a study on identifying user needs and requirements for the development of new technological solutions in elderly care, Prazak et al. [20] found that the most critical user requirements for elderly users are safety and security since their body conditions are not as healthy as when they were young, but technologies are used to mitigate the risks posed to the general driving population rather than reduce crashes or injuries for older drivers. When user needs and user abilities are not properly understood by the development team for further vehicle development, resources will be wasted in creating systems that the target user neither needs nor wants. Therefore, to have effective the elderly's usability in the development, various processes, such as surveys, interviews, focus group tests, and observation should be conducted. With the diverse processes, the understanding and analysis of the current vehicle systems should be prioritized to enhance the systems and suggest better solutions for the special user segment, elderly.

Moreover, automotive industry also has followed the design principles of the industry 4.0, which is the current trend of automation and data exchange in manufacturing technologies for better customer services. It suggests four design principles – 1) Interoperability: The ability of machines, devices, sensors, and people to connect and communicate with each other via the internet of things and people, 2) Information Transparency: The ability of information systems to create a virtual copy of the physical world by enriching digital plant models with sensor data, 3) Technical assistance: The ability of assistance systems to support humans by aggregating and visualizing information comprehensible for making informed decisions and solving urgent problems on short notice, 4) Decentralized decisions: The ability of cyber-physical systems to make decisions on their own and to perform their tasks as autonomous as possible - to support companies in identifying and implementing Industry 4.0 scenarios[21]. This trend has become a major topic in many industries as well, and these design principles, specifically interoperability and technical assistance, are expected to help the elderly drivers because they are the persons who need more assistances than another age group due to their declining health conditions. To effectively support the elderly's driving and matching with the industry trend, these principles should be referred to the system proposals.

3 Smart vehicle technology-based solutions

Many studies have been carried out for elderly drivers and have raised the issue that the elderly's fatal accidents rates have been increasing globally. Current studies have proposed some systems for safe driving for this population based on smart technology. In this section, we first describe the exemplary systems as solutions for mitigating the elderly's accidents on the road and then analyse their effectiveness or utility and what should be considered for more beneficial ones.

3.1 A new mobile phone-based safety support system for elderly drivers

This study[22] had been processed to help elderly people who have dementia, and who have many behaviour disorders such as wandering, poor verbal communication and being uncooperative. Their wandering behaviours are a major cause of road deaths. Thus, this study had developed a safety support system for wandering elderly drivers on the road by detecting their location and situation. This system consists of a wearable sensor and a conventional desktop PC with internet access acting as the server computer. When the elderly drivers use the system, they have to install the wearable sensor, attached to the neck of the elderly person's shirt. It has a low transmitting power mobile phone, which is called as W-SIM, a small microphone, and a chip microcontroller. The wandering elderly driver's location is identified within 100m from the mobile phone company's antenna ID through the W-SIM. Other people who are looking for or caring for the elderly drivers could set the elderly's movement by specialized computer software[22]. When the elderly person goes out, the sensor automatically records the environmental sound around the wandering elderly person. Both the wandering elderly person's location and environmental sound are sent to the server computer automatically. The server computer receives the latitude and longitude data of the location from the W-SIM via Internet, and then the data is stored by the server computer and automatically informs other people via email. In this study[22], most elderly drivers are rescued by other people within 20 minutes when they lost their way. Since elderly people forget driving methods easily due to disrupted memory, this system is expected to help those with cognitive impairment.

3.2 Head-up display (HUD)

Charisis et al. [23] developed an interface system, named for Head-Up Display (HUD) in their study. This system mainly provides crucial information to the driver promptly for mitigating elderly's collisions on the road. This interface system comprises a symbolic representation of the lead vehicles and road information acting as a vision enhancement system. Elderly drivers suffer more from slower response times than other groups of drivers, due to their declining sensory functions and reflexes. Also, current complex roadway conditions, adverse weather conditions, and unexpected traffic congestion could be the main factor for slower reactions in elderly drivers causing collisions and resultant fatalities. Thus, this study[23] developed a full windshield Head-Up Display (HUD) interface for offering elderly drivers crucial collision avoidance information by improving the driver's spatial awareness and response times under low visibility conditions. The information was delivered to the users in the following way.

A pathway symbol represents the lane borders and alters the colour depending on the sensing of vehicles on each side, providing a clear warning for blind spots. The lead vehicle's symbols are designed to highlight the first row of leading vehicles. The vehicle in the same lane with the user is additionally noted with an inverted triangle. Also, a traffic symbol appears at the top of the windshield spotting any potential traffic flow bottlenecks[23]. The interface concludes with the turn symbol which acts as an early warning for sharp and potentially unnoticeable roadways, such as curves and rough road[23]. In their research, the system simulation test was conducted with 40 users, age ranged between 20-75 and its main simulation scenario was users under a typical rear-collision accident situation using the HUD interface[23]. This test challenges the reflexes and decision making of the driver on a motorway stretch between Glasgow and Edinburgh. The test weather condition was hazy due to simulated dense fog that creates zero visibility conditions[23]. From the simulation test, the elderly users presented a significant improvement in their response times when using the HUD system which reflected as decreased collisions or low impact collisions in comparison to their performance with the use of the typical dashboard information[23].

3.3 Foot-LITE System

The Foot-LITE system was a research project developed by the UK Engineering and Physical Sciences Research Council, and targets drivers from across the socio-economic spectrum and at all levels of experience, making it an appropriate system for use by elderly drivers[24]. It is composed of an in-vehicle device to provide immediate feedback to the driver on a full-colour screen that indicates the driving error or risky behaviour that has occurred and provides support showing how it may be corrected and avoided in the future[24].

This system works with the following feedback. First, further in-vehicle feedback is provided at the end of a trip, indicating journey length, a cost that is measured by the fuel used, and emissions[24]. Second, it offers support in the form of lessons to be learned[24]. Finally, statements sent out through the Internet at the users' pre-set timing, like weekly or monthly, provide totals of measured driving factors such as fuel consumption or the number of times a driving infringement was committed for that period and also provides a comparison of how the driver is performing in terms of the changes that have been made in driving style and their impact on the cost of driving and vehicle emissions over a longer period which encompasses multiple trips[24]. Lastly, off-vehicle web-based support directs the driver to personalized lessons that will show them how to improve their driving style[24]. With the feedback flow, this system will deliver valuable information to elderly drivers to promote the take-up and retention of appropriate eco-friendly, safe, and efficient driver behaviours.

With the system, elderly drivers can efficiently drive on the road before and during their trip by having diverse information from the road network and selecting alternative routing that avoids traffic congestion and revises trip routes. If elderly drivers use the system, their accidents would be expected to decrease. If they get information from the road network set-up for the Foot-LITE system before their trip, they can avoid congestion and can spend longer time on the road. Thus, they could prevent accidents due to less fatigue from a shorter time driving.

Such systems developed from current studies are in constant development. Introduced systems in the studies are meaningful because the systems were developed to specifically target elderly drivers. Most of the studies have just tried to find beneficial aspects for the elderly drivers from the systems. However, the development and testing of these studies tend to be focused on the driving population as a whole rather than the specific needs of elderly drivers, though many studies have discovered diverse ways to support elderly's safety on the road. Thus, there are still some drawbacks in each system when used by the elderly. For example, a new mobile phone-based safety support system could not be useful to find the elderly drivers' locations when they plan a long drive or new destinations since this system sensor relies on the environmental sound that the elderly is usually in. Also, if the elderly's locations are very quiet, it becomes difficult to presume the locations because a characteristic sound around the locations cannot be recorded by the system sensor. In fact, in the system study, the accuracy of the location around a park area was considerably less than a general GPS system. While the HUD interface system does not guarantee prevention of the elderly driver collisions because some collisions occurred even at very slow response times during the system test. Although the system indicates potential collisions with different visual cues to the elderly drivers, this does not address those with visual problems. Since elderly drivers cannot easily recognize diverse colours, they might not react properly when the visual symbols appear as a warning signal. From the study, researchers mentioned that the sudden induction of a colour-changing pattern to the driver's field of view could cause unexpected reactions. Such colour changes could distract the elderly drivers more rather than help them easily recognize the visual warning cues. As for the Foot-LITE interface system, it focuses on elderly's eco-friendly and efficient driving life more than addressing their declining body conditions for the system. Thus, while the system helps the elderly with more efficient driving time by avoiding roadway congestion, it does not seem to be beneficial for the safer driving actions.

Given the above analysis, it could be concluded that the current studies have shown that usability for the elderly has not been considered. As mentioned above, none of the systems have carefully considered the elderly's aging body conditions to the system development. Some might think that if we apply all the technologies to a new vehicle system for the target, elderly drivers, even including all the driving users could be beneficial enough from the new system. Since most elderly drivers are about to retire or have already retired from their work, they want to save their money for the remainder of their lives. If the system for the elderly is high-priced with all high technologies, they cannot afford to buy the system. If systems are not dominantly effective to the majority of elderly drivers, the systems would not be considered as useful and would disappear from the market sooner. Therefore, it is key to developing a system with competitive prices that every elderly person could take advantage of — one that would improve their safety and take their aging body conditions into consideration.

4 Further Explorations of Utility based Solutions

4.1 Methodology

To find more useful solutions for elderly drivers, the elderly group's survey was utilized since it provided a more direct method for data collection. The first step involved the development of the survey content. The survey was divided into the two sections each addressing a specific area of concern. The first section included background information and medical history of the elderly participants to provide a database of the socioeconomic and health attributes. During the survey section, their background and medical information (Table 1) was requested to determine if any other conditions might be affecting their driving such as any sensory loss. The second section (Table 2) included questions regarding the elderly's specific behaviours in the different driving situations and the relationship with their health conditions. Specifically, the survey questionnaires were created based on the Manchester Driver Behaviour Questionnaire (DBQ), which is a widely used instrument for measuring self-reported driving behaviour. From the two survey sections, six questions were given to the elderly participants and these questions varied between multiple choices and ranking questions on a scale of 1 to 5.

A total of 60 elderly participants joined this survey activity, and survey questionnaire requirements were that participants should over the age of 55, who have a valid driver's license. The reasons to the age variables for the survey, the World Health Organization (WHO) set 55 as the beginning of old age and elderly' person correlate with the chronological ages of over 55 years. Also, it states that most aging symptoms have been easily recognized around that age. The 60 participants were divided into four age groups: 1) 55-60 years old, 2) 60-65 years old, 3) 65-70 years old, and 4) above 70 years. Each group had 20 participants, and an average group of the participants was between ages 66 and 70. The created questionnaires were distributed to elderly people in the different countries via emails, such as South Korea, US, and the UK, where many elderly drivers actively drive around the city areas, to see if they have different difficulties and behaviours in driving. Once the surveys were returned, the data was ready to be analysed. Since the purpose of the activity was to suggest better solutions to elderly drivers based on their specific driving behaviours and difficulties, the database results will be analysed first, and the data comparison with other elderly studies were conducted (presented in the discussion section). The data analysis was conducted with Minitab analysis, which is one of the easy-to-use software to analyse data. The data results are shown in the tables, graphs, and the figure for a better understanding of how the elderly group has a problem with their driving. Also, face-to-face interviews were conducted with interviewees to understand more about the survey result, and the interviewees were randomly selected from the survey participants. The interview results are explained in the result and discussion sections. Moreover, after the survey data analysis, a short focus group observation was conducted to check if the survey result is reliable and correlated with their driving behaviours and other problems identified by the observation. The number of focus groups is four, and they were selected from the survey respondents in each age-group. First, we asked them to drive for 60 minutes during the day and during the night in the same routines. Every 10 minutes, we observed and tracked their common problems.

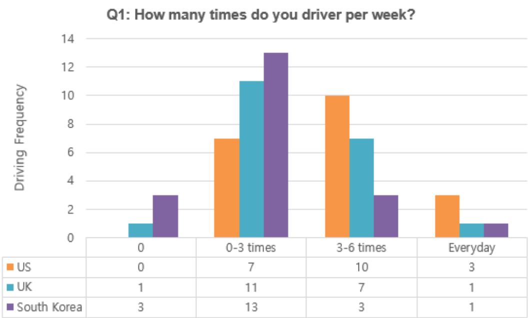
4.2 Results

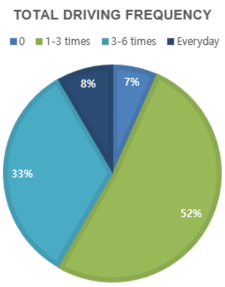
The first section of the survey was used to gain data based on the participants' characteristics. The second section was used to determine an accurate picture of the driving patterns and the relationship of the elderly's health and the driving from the respondents.

The first section of the survey was intended to gain some background information about the elderly drivers. From the data gathered, a majority of the elderly drivers claim to drive 1-3 times a week, with the South Korean elderly group shows the highest rate from the driving time. The frequency of driving per week indicates that 52% of the respondents drive at least 1-3 times, 33% of 3-6 times, and 8% drive daily. Only 7% of respondents reported, "Never drive." The US elderly group tend to drive more on a daily basis than other countries and all the participants from the country drive at least more than once a week due to no response to the answer, "Never driving," while the elderly respondents from South Korea and the UK show 15 and 5 percentages for the same question. Also, the highest rate of the average driving time is 30 minutes to 1 hour. However, while the respondents from the UK (45%) and South Korea (50%) tend to drive for the average time, US respondents (60%) tend to drive 1 and 2 hours. For the medical background from the respondents, of the 60 respondents, 100 % reported having age-related health conditions with most of them stating they have vision impairment.

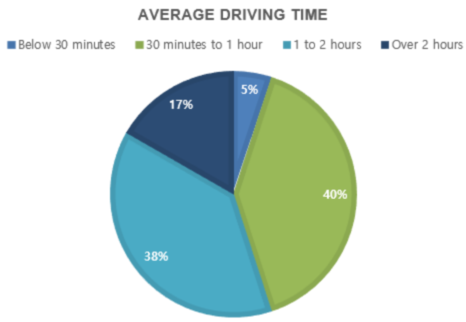
Table 1. Survey Section 1 Result – The elderly's driving information

Survey Section 1				
Q1	How many times do you drive per week?			
	① 0	② 1-3 times	③ 3-6 times	④ Everyday





Q2	What is your average time per driving?			
	① Below 30 minutes	② 30 minutes to 1 hour	③ 1 to 2 hours	④ Over 2 hours

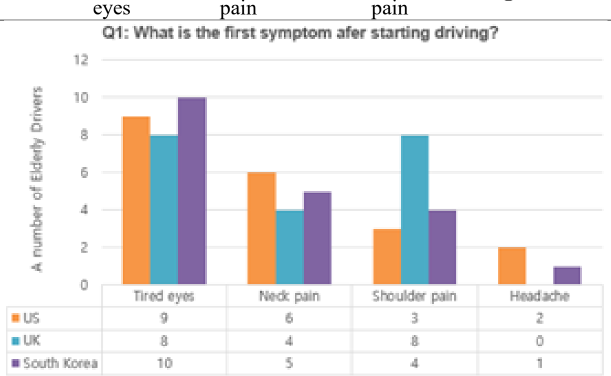


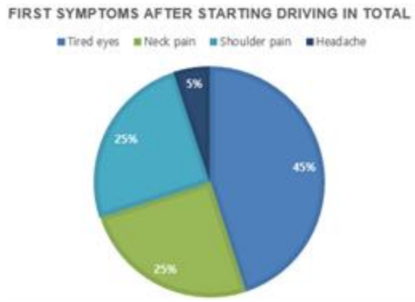
Q3	What kinds of age-related health conditions do you have?			
US	① Vision impairment	② Arthritis, Low reaction	③ Hearing Problem	④ Hearing Problem
UK	① Vision impairment	② Arthritis, Low reaction	③ Low Memory	④ Low Memory
South Korea	① Vision impairment	② Low memory	③ Low reaction	④ Hearing Problem

From the second section, the elderly driving behaviours and difficulties were evaluated. First, 45% reported tired eyes occurred as the first symptom after starting driving and neck and shoulder pain was reported in 25% of responses. Most elderly respondents from all countries reported feeling afraid when they drive. However, more than half of the respondents (55%) from the US do not feel nervous in their driving. The main reason for the nervousness is reduced sight with 57% of all respondents and the second reason is slow body movement, indicated by 24% of them. From the list of the driving patterns and difficulties, difficulty in driving at night was reported most with a mean value = 5 and 267 scores, the second difficulty is entering the wrong lane when approaching a roundabout or a junction, and the third is to misread the signs and exits from a roundabout to the wrong road. These top rankings are listed in Table 3 for a better understanding of the elderly's driving difficulties. The other listed driving patterns do not show a significant difference with the top rated as shown in Table 2. However, while the overall rating results are shown in the figure, ranking varied by different regions. US respondents rated the driving pattern, "Fail to check your rear-mirror before pulling out or changing lanes," higher than misreading signs and Korean respondents ranked higher applying sudden brakes on a slippery road, or steering the wrong way in a skid than misreading signs. The other listed driving patterns do not show a big difference.

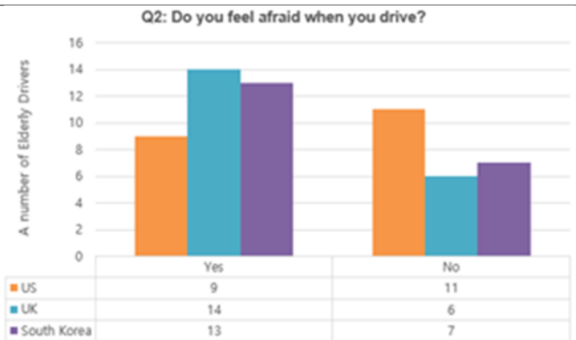
Table 2. Survey Section 2 Result – Elderly's driving difficulties and behaviours

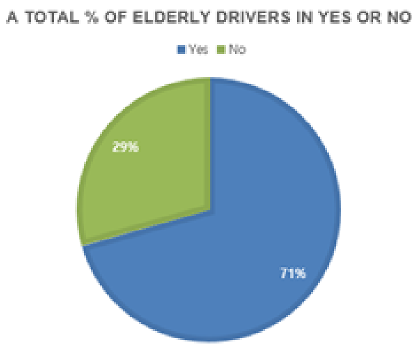
	Survey Section 2			
Q1	**What is the first symptom after starting driving?**			
	① Tired eyes	② Neck pain	③ Shoulder pain	④ Headache



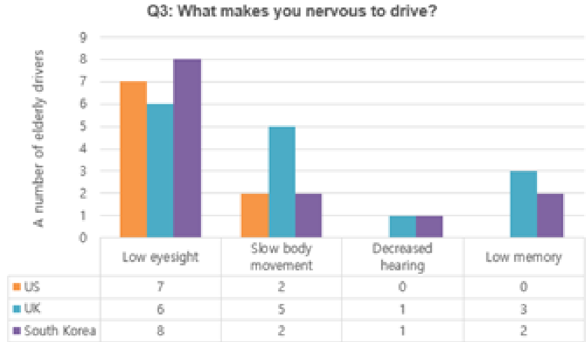


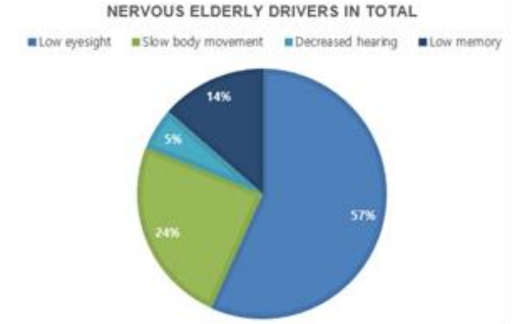
Q2	**Do you feel afraid when you drive?**	
	① Yes	② No





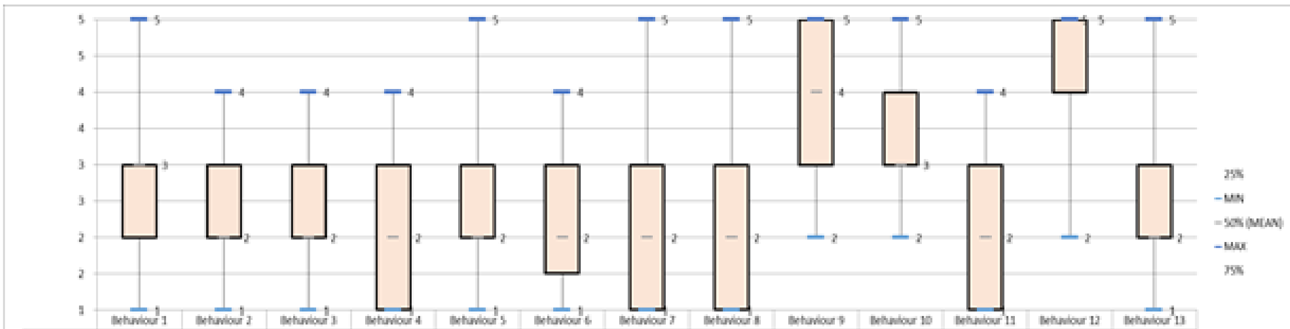
Q3	**If yes, what makes you nervous to drive?**			
	① Low eyesight	② Slow body movement	③ Decreased hearing	④ Low memory





Q4	**What kind of driving patterns and difficulties do you have? Please, rate each list.**	
	Drive especially close to the car in front as a signal to its driver to go faster or get out of the way	1 (Easy) ~ 5 (Difficult)
	Get involved with unofficial 'races' with other drivers	1 (Easy) ~ 5 (Difficult)
	Attempt to overtake someone that you had not noticed to be signaling a left/right turn	1 (Easy) ~ 5 (Difficult)
	Fail to notice that pedestrians are crossing when turning into a side street from a main road	1 (Easy) ~ 5 (Difficult)
	Fail to check your rear-view mirror before pulling out or changing lanes	1 (Easy) ~ 5 (Difficult)
	Fail to control merging into traffic	1 (Easy) ~ 5 (Difficult)
	Take a long time to pass through an intersection	1 (Easy) ~ 5 (Difficult)
	Apply sudden brakes on a slippery road, or steer wrong way in a skid	1 (Easy) ~ 5 (Difficult)
	Get into the wrong lane when approaching a roundabout or a junction	1 (Easy) ~ 5 (Difficult)
	Misread the signs and exit from the roundabout on the wrong road	1 (Easy) ~ 5 (Difficult)
	Forget where you left your car in the car park	1 (Easy) ~ 5 (Difficult)
	Drive away from the traffic lights feel more nervous to drive at night	1 (Easy) ~ 5 (Difficult)
	Switch on another thing, when you intend to switch on something else	1 (Easy) ~ 5 (Difficult)

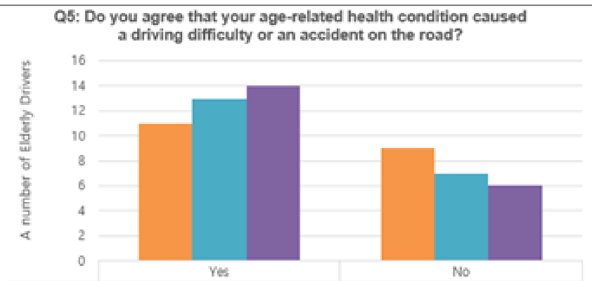
Survey Q4 result: Elderly's driving difficulties and behaviours



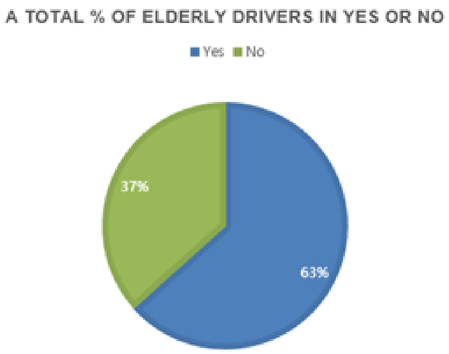
	Behaviour 1	Behaviour 2	Behaviour 3	Behaviour 4	Behaviour 5	Behaviour 6	Behaviour 7	Behaviour 8	Behaviour 9	Behaviour 10	Behaviour 11	Behaviour 12	Behaviour 13
25%	2	2	2	1	2	2	1	1	3	3	1	4	2
MIN	1	1	1	1	1	1	1	1	2	2	1	2	1
50% (MEAN)	3	2	2	2	2	2	2	2	4	3	2	5	2
MAX	5	4	4	4	5	4	5	5	5	5	4	5	5
75%	3	3	3	3	3	3	3	3	5	4	3	5	3

Behaviour 1	Drive especially close to the car in front as a signal to its driver to go faster or get out of the way
Behaviour 2	Get involved with unofficial 'races' with other drivers
Behaviour 3	Attempt to overtake someone that you had not noticed to be signaling a left/right turn
Behaviour 4	Fail to notice that pedestrians are crossing when turning into a side street from a main road
Behaviour 5	Fail to check your rear-view mirror before pulling out or changing lanes
Behaviour 6	Fail to control merging into traffic
Behaviour 7	Take a long time to pass through an intersection
Behaviour 8	Apply sudden brakes on a slippery road, or steer wrong way in a skid
Behaviour 9	Get into the wrong lane when approaching a roundabout or a junction
Behaviour 10	Misread the signs and exit from the roundabout on the wrong road
Behaviour 11	Forget where you left your car in the car park
Behaviour 12	Drive away from the traffic lights feel more nervous to drive at night
Behaviour 13	Switch on another thing, when you intend to switch on something else

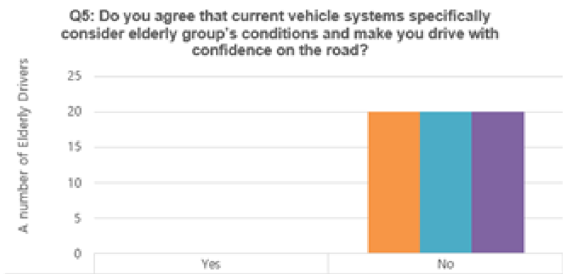
Q5	**Do you agree that your age-related health condition caused a driving difficulty or an accident on the road?**
	① Yes ② No



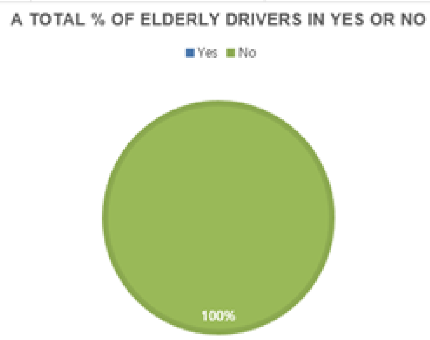
	Yes	No
US	11	9
UK	13	7
South Korea	14	6



Q6	**Do you agree that current vehicle systems specifically consider elderly group's conditions and make you drive with confidence on the road?**
	① Yes ② No



	Yes	No
US	0	20
UK	0	20
South Korea	0	20



4.3 Discussion on the results

From the results, several points can be discussed. First, the survey section 1 showed the elderly's driving frequency and time - Driving 1-3 times a week and an average of 30 minutes to 1 hour per driving session. The respondents stated that their driving frequency and time have been reduced compared with the past and that they have become unconfident due to their aging body conditions. There might be different factors for the reduced driving frequency and time. First, since most of them are retired from their work, they have become inactive in their lives. Also, as they stated in the survey, their declining health conditions affected the result. In contrast, U.S respondents drove more frequently than other respondents and reported driving 3-5 times per week. This different result can be due to their different context. Since the majority of respondents in the other countries live in city metropolitan areas, most of them do not need self-driving for their mobility. However, since the US is a big continent, with less public transport options, self-driving is necessary for their mobility. According to the study of traffic maneuvers of the elderly from Mitchell and Stamatiadis[25], their respondents in the US showed that 89% of the respondents drive daily, and 11 % drive weekly, and even some indicated that they drive monthly. The study was conducted in a Kentucky suburb where driving is a necessity for mobility. Alvarez et al. [17] also stated in their research about fitness to drive assessments that at the age-range group of drivers aged 75 or more, 39 out of 85 drivers (46.4%) who drove less than 3000 km per year had an illness that potentially impairs driving performance and were rated as "fit to drive with restrictions." This study stated that the medical condition of older drivers results in their lower mileage. Koppel et al. [26] also reviewed the issues for and against the mandatory age-based assessment of older drivers, and they found that there is an age-related decline in sensory, physical and cognitive areas related to driving, as well as the underlying medical conditions, with substantial individual differences existing.

Given the study results, we could assume that instances of driving of the elderly respondents could be associated with their health condition because all of them responded "Yes" to the survey questionnaire of whether they have age-related health conditions. However, since we examined with limited respondents who mostly have a vision impairment and lower reaction times in their health conditions, our future studies should perhaps focus on medical impairments related to broader health conditions, such as mental functioning, which are expected to have a greater impact on driving performance of the elderly.

From the second section, we have focused on the findings of the elderly's difficulties and behaviours in driving. First, vision problems can be the main factor as in the first section of the survey; they also responded that they have the highest declining health condition in vision. The majority of the studies related to the elderly drivers stated that when they have vision impairment symptoms, they avoid driving. Also, Lyman et al. [27] reported the relationship between driving difficulty and habits in older drivers via interviews and survey questionnaire that subjects with driving difficulties were significantly more likely to have near vision impairment. Moreover, Middleton and West Wood[28] found in their study for the older driver requirements that it is widely considered that 85-90% of the demand of the driving task is visual in nature, and many older adults have deficits in visual function. Thus, it should be noted that an assistive system should support the elderly's visual modality the most.

From the detailed rating result of the elderly's driving behaviours and difficulties, the elderly's vision problem seems to affect the result because the highest ranked behaviours are night driving and misreading the signs. Some research evidence supports this speculation. One case study from Mitchell and Stamatiadis[25] reviewed traffic maneuvers of elderly and specifically chose typical elderly driving maneuvers, such as merging situations, lane changes, night driving, and left turn maneuvers. The study also said that many of the elderly drivers have problems with their vision, especially at night. The statistical tests of these questions showed that 15% of respondents indicated that they do not drive at night anymore on a regular basis and a significant portion, 68%, also responded that they feel increased apprehension or nervousness while driving at night. Most traffic maneuvers have become problematic when it is dark at night. In fact, from a short focus group observation that we conducted the survey analysis, we also found that their poor eyesight impact on the elderly's driving behaviours and other problems. All four elderly drivers felt tired in their eyes within 30 minutes, and even three out of four drivers have the experience 10 minutes later. Surprisingly, the elderly drivers experienced such an eye fatigue within a shorter time, 7 minutes at night time than at a day time. The participated drivers to the observation said that they feel more tensions while driving at night because most elderly drivers could not easily catch an object or person on the road and see more than when they are driving at a day time. These symptoms often brought their eye fatigues. Based on the observation result and other case studies, it is proved that elderly's low eyesight is dominantly correlated with the elderly's problem in driving and impacts more on their night driving. In addition to the result, back pains and arthritis on the knees were also appeared with the symptoms in the survey questionnaire one while driving for 45 minutes. However, they said that this is not the main factor to impact on their driving problems.

Some researchers tend to show some different results in a certain driving behaviour and difficulty. While our study evaluated the night driving as the most serious problem, Mitchell and Stamatiadis[25] stated a different result from their study research. The results from the lane changing section indicate that the presence of multiple vehicles on the roadway seems to be the most difficult situation for the respondents as they evaluated this difficulty in the related questions. This study also showed left-turn maneuvers as the second most problematic– 49.3 % of respondents reported difficulty in turning left onto a busy street and merging maneuvers, while our survey study showed a lower score. However, although this study shows such a different top-rated behaviour. As a result, lane changing and our third rated list, get into the wrong lane show similar driving behaviours and these behaviours are related to the elderly's late reaction time in their health issues.

Another case study by Parker et al. [29] involving elderly drivers and their accidents, they conducted similar survey activities to find the main types of driving behaviours and used the Manchester Driver Behaviour Questionnaire (DBQ) as we referred to in our study. From the study results, most respondents landed on misread signs and taking the wrong exit from a roundabout, getting into the wrong lane was the second, and disregarding speed limits late at night was the third. Their study results are similar to our study results as the reported top-rated behaviours agree with our results although their rated scores are somewhat different. This case study also confirmed that vision impairment is the leading cause of changing elderly driving behaviours. Interestingly, the behaviour of changing focus to, for example, switch on a device has unexpected results from the survey. We thought that switching on a functional button in the vehicle system could not be difficult for the elderly drivers. However, they said that many functional buttons in the vehicle system are distracting, and they become embarrassed when they are faced with an emergent situation on the road. Moreover, small icons and text on the button can cause errors in their behaviour.

From our study, we could be led to believe that current system design and development have not considered special conditions for the elderly yet. Moreover, all of the elderly respondents disagree that current vehicle systems consider elderly group's health conditions and do make them drive with confidence on the road. Therefore, it is clear that further system designing and developing for elderly drivers should focus on the target users' functionality.

5 New Solutions: Suggesting Usable Ideas for the Elderly Drivers

5.1 Finding solutions based on the sensor technologies

Based on the survey results and current studies for the elderly, we have found that current developments are not yet sufficiently beneficial due to some drawbacks, and there is a need for improvement for safer driving environments for elderly people. With the exploration of the problems in the current systems and diverse activities we have conducted, this section proposes better assistive systems for elderly drivers to address their challenges. The challenges could be that first, currently applied technology and design should be differentiated, second, the needs of the target users should be more carefully considered in the system, and third, many companies and organizations should consider how to make and promote such an assistive system that can be beneficial for the elderly group. According to Fairchild et al. [24], for feedback to be effective, advice given to the driver must be timely and useful, enabling the driver to take action that will improve driving performance in one or more ways. To do so, we started finding a solution based on the elderly's driving problems from the methodology section. In the survey of the section, we could finalize that vision impairment and late reactions have impacted on the elderly's driving difficulties the most. The high ranked results are listed in table 3.

Table 3. Top rankings in elderly's driving difficulties (From the survey section 2 results)

No	Main impacts to the elderly's driving difficulties
1	First symptom after starting driving: Tired eyes
2	Low eyesight, which makes the elderly nervous to drive
3	Main driving patterns and difficulties from elderly: 1) Drive away from the traffic lights feel more nervous to drive at night: Related to the elderly's aging eyesight 2) Get into the wrong lane when approaching a roundabout or a junction: Related to the elderly's late reaction times 3) Misread the signs and exit from the roundabout on the wrong roads: Related to the elderly's aging eyesight and late reaction times

Based on the problems found, solution ideas are researched and brainstormed. The proposed solutions will be considered with the design principles under the industry 4.0, which is introduced in the literature review. As the first step of the solution ideas, applicable technologies are explored. Many systems for elderly drivers have been utilized by different high technologies. However, the fact that road traffic accidents among the elderly are still high proving that we should explore more effective technologies that the elderly users can use more practically with their declining health conditions. When designing biomechanical or physiological parameters, it is important to integrate sensors that are easy to use, comfortable to wear, and minimally obtrusive. Here we suggest utilizing sensing technologies for the elderly drivers as a solution because sensory impairments are the most common symptoms of aging. Since the elderly drivers have delayed reactions from external and internal signals, making them easily recognize the signals could mitigate the problem and more active in driving. Instead of the elderly's overdue recognition from the traffic warning signals, the sensor can catch them faster than the elderly and deliver them to vehicle systems to avoid an accident from many dangerous situations on the road. Three sensing technologies that can be suitable for the elderly drivers are introduced, and more adequate and usable sensing technology for the elderly group is proposed with an ideal scenario in document and user task flows.

5.1.1 Using wearable sensors

Wearable sensors have been widely used in medical sciences, sports and security. Wearable sensors can detect abnormal and unforeseen situations, and monitor physiological parameters and symptoms through these trackers[30]. These days, this technology has transformed healthcare by allowing continuous monitoring of patients without hospitalization. Medical monitoring of patients' body temperature, heart rate, brain activity, muscle motion and other critical data can be delivered through these trackers[30]. With this trend, this wearable sensor can be practically used for the elderly's safe driving. Under the current systems developed, elderly drivers have been passive when using in-vehicle systems by simply following directions of the system. For example, when a system warns a dangerous situation with signals, the users just react according to the system guidelines. So, there is a gap between the warning signal and its reaction. However, allowing physical access to a device can make the users more active and manageable. In particular, the wearable sensors could manage the health conditions of advancing age. When the elderly person is in poor condition, the sensors can detect such a condition and inform the vehicle system. Then, the vehicle system can deliver the information to the elderly person and make them avoid driving or advise them to drive carefully on the road.

5.1.2 A facial expression recognition sensor

A facial expression recognition sensor is capable of identifying or verifying a person from a digital image or a video frame from a video source[31]. One of the ways to do this is by comparing selected facial features from the picture with a facial database. This sensor can also be utilized to the system for safe driving in the elderly population. When a person feels wrong or is sick, this can be evident in facial expressions. If the sensor captures the emotion of the users and informs a vehicle system, the vehicle system can help reduce driver's workload. In fact, the most relevant technological considerations revolve around enhancing user satisfaction and adoption. Recently, it has been found that there was strong correlation between psychophysiological and vehicular data with driver's subjective state in a simulation environment[32].

5.1.3 A brain activity sensor

Electroencephalogram (EEG) refers to the record of the potential which occurred by the spontaneity and rhythmic movement of the brain neurons under the chronological order. Neuroscience, psychology, and cognitive science show that many mental activities and cognitive behaviors can be reflected by EEG. Electroencephalogram (EEG) is an imaging technique used for emotion analysis[33]. EEG measures that electrical activity generated by brain structures via electrodes placed on the scalp[33]. This electrical activity is due to the local current flows produced when neurons are activated[33]. An EEG is used to detect problems in the electrical activity of the brain that may be associated with certain brain disorders. The measurements given by an EEG are used to confirm or rule out various conditions, such as an inflammation of the brain, a brain tumor encephalopathy, memory problems, and sleep disorders, and dementia[34].

Based on the original ideas for sensor development, this can make the system more useful for the elderly drivers since health conditions affected driving performance more than other age groups. This information could then be used automatically by adaptive vehicle systems in various ways to help the driver better manage their conditions.

In one of the introduced sensing technologies, a facial expression recognition sensor was selected as a better utilizing sensing technology because this sensor can help the elderly's main problems from their lower eyesight and late reactions that we have found from the methodology. Also, Lott[31] found in his study of "Face Recognition in the Elderly" that the ability to recognize faces is an important skill for the elderly. He investigated the relationship between contrast sensitivity and face recognition in low-vision patients and faced recognition task performance showed a significant decline with age in the test. Particularly, in the comparison test with a young group, there are sizable differences between the two groups. Furthermore, another study has emphasized vision-related factors with the facial expression recognition. Owsley et al. [35] found that contrast discrimination thresholds for faces were approximately 0.30 log units worse in elderly than in young observers. Moreover, we have asked elderly drivers who had joined survey and interview sessions about how much they would be beneficial from the introduced sensor technologies. They said that if the technologies are applied to current vehicle systems, they would drive more conveniently and could avoid emergent situations on the road. However, they stated that using the EEG sensor on their head for measuring their emotions is not a socially acceptable manner for them, and they would feel uncomfortable when wearing it on their head part. The wearable device is also good enough for the elderly to recognize driving situations on the road. But, it is not beneficial to the elderly who has a vision problem.

5.2 Ideal solution scenario with the facial expression recognition sensor

In order to make a concrete idea for the vehicle system concept, a set of use cases, which describes the interaction between the elderly drivers and systems and makes the users understand how the system is used with the description of what people do and what the system does are created and based on the detailed cases, the system solution scenarios with task flows will be presented at the end.

First, one use cases were specified for an idea presentation, and the duties and functions for one use case, "Driving at night," that most elderly drivers have a driving problem with their deteriorating health condition were produced with detailed parts in the steps (Table 4). The cases in Table 4 specify that the completing of the functionality of the system and the interactions that will occur in user scenarios.

Table 4. The part description of Use cases, "Driving at night"

No	*Part*	*Description*
1	Title	Creating a vehicle application system, using a facial expression recognition sensor for elderly drivers
2	Actors	Elderly drivers who has lower eyesight and late reactions. Their emotions will be the main actors for this new vehicle system.
3	Purpose	Users want to have a safe driving experience without affecting their aging body conditions less.
4	Initial condition	An existing vehicle system in the automotive industry is not beneficial for the users to safety drive, and makes them feel nervous or avoid driving because the existing system does not consider the elderly's aging body conditions.
5	Terminal condition	Users can easily receive their state from the vehicle system with the facial expression recognition sensor constantly assessing the driver's state assessment.

Based on the set of use cases for the elderly drivers, the solution scenario is presented with the task flows in figure 1.

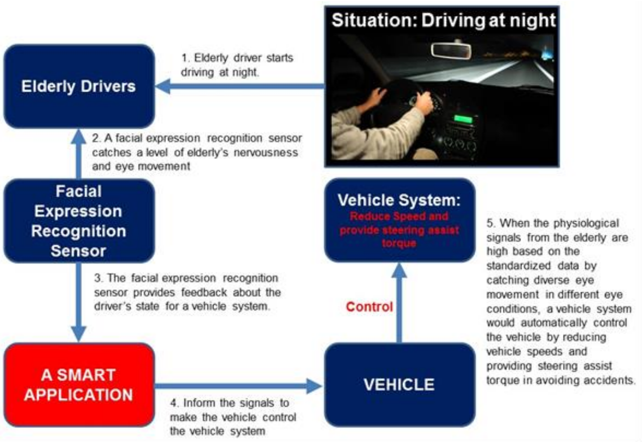


Fig. 1. The solution scenario for the elderly's use case, "Driving at night"

In the solution scenario, the facial expression recognition technology was selected as an adequate assistive technology. In order to set the standardized levels of emotions from the elderly's face, many data gathering would be conducted with some elderly groups. Based on the set level, elderly's state would be confirmed and send its data result to a vehicle system. Also, its scenario would be varied after the actual prototype is made and tested with the elderly focus group and some technical methods might not be available in the market place since automotive technologies have been rapidly changed, and some technologies have strict patent issues. In addition to the original ideas for sensor development, this can make the system more useful for the elderly drivers since health conditions affected driving performance more than other age groups. The information data from the elderly's face could then be used automatically by adaptive vehicle systems in various ways to help the driver better manage their conditions. During high-stress situations, cell phone calls could be diverted to voice mail and navigation systems can be programmed to present the driver with only the most critical information to help reduce driver workload. Also, when the elderly drivers feel angry, the music selection agent in-vehicle system could lower the volume, offer a greater selection of relaxing tunes, and provide the driver with more entertainment options to help cope with their feelings of anger.

This idea presented as a solution for elderly's main problems has to be combined user needs with technologically driven aspect affecting the elderly's aging body conditions. With the aspects emphasized in the elderly's safety system development, market-driven aspect should be considered.

A lot of automotive companies have paid attention to the elderly market as the number of licensed drivers over the age of 65 has been growing with the increasing aging population. Today, that common language is at risk and efforts to identify the ideal strategy to integrate new technologies safely into the elderly driver's vehicle is both business and safety imperative. Successful deployment of active safety strategies, where the car takes a more 'active' role in anticipating and averting an accident, may meet their greatest challenge from the capacity of older drivers to learn, use, value and trust these new systems.

However, the industry has been remarkably successful for decades in introducing innovation, though new safety features have not satisfied elderly customers yet. To establish a strong market for elderly users, both the target user's needs and proper technologies should be carried out. If developers do not interact with their target customer base, they just pour money and effort into developing features that the elderly would not use in the end. This is not just about making a particular system for the elderly. When developers make a vehicle system, they should make it more user-friendly for the predominantly elderly customers. Also, since no policy exists for developing for elderly drivers, particular policies for their target market should be developed. If there are a particular policy and concrete guidelines for developing a vehicle system for elderly drivers, this can help accelerate workflow and make the development of accessible systems an easier process and on that is more marketable for the industry.

5.3 Discussions on Autonomous Car

Very recently, several self-driving car projects, such as the Google self-driving car and Tesla Autopilot, have been introduced in the market. In principle, self-driving cars are designed to navigate safely through city streets, and make driving easy and safe, regardless of their ability to drive. Particularly, the autonomous cars can detect the surroundings using a variety of techniques, such as radar, lidar, GPS, and computer vision. Advanced control systems interpret sensory information to identify appropriate navigation paths, obstacles, and relevant signage[36]. Autonomous cars have control systems, which are capable of analysing sensory data to distinguish between different cars on the road[37]. This is very useful in planning a path to the desired destination. With such innovative self-driving technology, it is expected that elderly drivers could benefit from the car because it could complement the elderly's weak point in driving, such as lower vision, not properly seeing an object on the road, and not reacting as quickly as possible to an emergency situation. For example, when an elderly driver, with vision and reaction problems, drives at night, the sensors in the autonomous car system could catch an object or pedestrian on the road, which the elderly can't easily see and provide a vehicle state for its system to control itself. Thus, elderly drivers keep driving without any nervousness or difficulties. Many people might think that if this vehicle concept has been major in the market, creating an adequate driving system for the elderly would not be necessary. However, since this concept cars have been just launched, it still has more improvements in its design and technology. In fact, serious problems have been exposed with the car.

Tesla, an American automotive company, recently launched a car with an automotive software system, which is named "Auto Pilot" and now has recorded one autopilot fatal crash in 130 million miles of driving in the wake of a May 7 accident in Williston, Florida[38]. The victim of the car driver was in self-driving (autopilot) mode when his car failed to brake when a tractor-trailer turned left in front of the car. Tesla[38] said, "Neither autopilot nor the driver noticed the white side of the tractor-trailer against a brightly lit sky, so the brake was not applied. Autopilot is getting better all the time, but it is not perfect and still requires the driver to remain alert." Furthermore, the industry warned of a security problem, such as car hacking. According to Jianhao Liu, from China's Zhejiang University and the internet security company Qihoo 360[39], "Since the reliability of the sensors directly affects the reliability of autonomous driving, the hack could be executed remotely to the car. So, sensors should be designed with security in mind and always think about intentional attacks, especially when the sensor is going to play a very important role in self-driving cars." Moreover, elderly drivers have less experience with such a modern technology. Knowing how difficult it is for the elderly to use this kind of car is still a subject to study. Therefore, if our proposed solutions apply to the current market, it could be more beneficial to current elderly drivers who feel nervous and have difficulties in their driving and afterwards, the solution could be fused in the self-driving car technologies and contribute to the self-driving concept improvements.

5 Conclusion and Future Research Directions

(1) This research provided different perspectives with which to anticipate safe and usable solutions of elderly drivers in hopes of mitigating accidents. It described the elderly's fatal accident rates in different regions, and elderly's declining health problems, analysed the drawbacks of systems from current studies, and highlighted the significance of system design. Additionally, we addressed diverse aspects of challenges as a feasible solution through interviews and survey with 60 elderly people, and as a result, we gained insight into what type of safe-driving systems would be most beneficial to them.

(2) The research aim is to make the elderly drivers easily accessible to smart vehicle systems and improve their driving conditions via the systems in the vehicle. Some might think that the suggested solutions are not unique but visionary. However, we have experienced that how current system could not help the elderly's safe driving although they used many advanced high technologies. In this point, we would like to emphasize as a conclusion that integral solutions can be the best if they applied to what users want and needed to have. Also, suggested solutions would be more feasible that the elderly users can be satisfied because we approached the system development that can be created easier than other advanced systems in the aspect of usability, cost, and technological productivity. Therefore, customisable safety systems for elderly drivers with age-related health conditions will be an essential concern to mitigate the elderly's accidents and have them enjoyable driving experiences.

(3) This research work is limited by some factors. First, few people participated in the focus groups, aged 55 to 75 years, and they represented only a few countries, i.e., Japan, U.S., and U.K. Bias might occur when applying the established systems to elderly in other regions and to larger numbers of elderly drivers. Due to the safety systems involved with diverse aspects such as HCI, cognitive ergonomics, information systems, human factors, social sciences, and so forth, further research for the system development will consider more elderly drivers in different regions[40].

Secondly, a limitation of our research is that we have only suggested an ideal solution for the elderly's safe driving and usable system development. Thus, since suggested solutions are not tested yet with an actual design system. The suggested solutions could be changed from actual tests with more diverse ideas. In future work, we would develop the concepts based on the suggested solutions and test how the concepts work well for the elderly group, and the concepts will be refined based on the test result.

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Biographical notes

JUNG Sebin, is a HMI Engineer for the BYOM2 Program Management Division of the General Motors Korea. She received her bachelor of Business Administration in Design and Management with honours at Parsons School of Design, New York and a Masters in Integrated Product Design at Brunel University, London. She is currently a PhD candidate in Electrical Engineering and Electronics at Brunel University, London. Her research interests include human need and a design research approach that integrates a human-centred design investigation with the technological or systems dimensions enabled by design thinking.

Tel: +82-010-29095607; E-mail: sebin.jung@brunel.ac.uk or sebin.jung@ gm.com

MENG Hongying, is a Senior Lecturer with the Department of Electronic and Computer Engineering, and Human Centred Design Institute of Brunel University London, U.K. His current research interests include affective computing, machine learning, human computer interaction, digital signal processing, and embedded systems. He has over 90 publications with 1300 citations in these areas.
E-mail: hongying.meng@brunel.ac.uk

QIN Sheng-feng, is currently a Professor in School of Design, Northumbria University. His research interests include digital design and manufacturing, interaction design, design innovation and management.
E-mail: sheng-feng.qin@northumbria.ac.uk