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HUMAN MACHINE INTERFACE DESIGN FOR
NEXT GENERATION OF VEHICLE

BY

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ABSTRACT

As people receive more and more information from the outside world, the vehicle—
as a well-equipped and high technology content traffic carrier, must integrate this
information explosion era efficiently. The vehicle human machine interface is not
only a communication bridge between the driver and the car itself, but is also a
principle connector between the driver and outside world. In the meantime, the
relationships between people and personal mobile information terminals are
increasingly close, the iPhone and iPad play important roles in humans’ daily lives.
The close integration of information systems and personal mobile information
terminals will expand drivers’ entertainment and social networking experiences.
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CHAPTER ONE: INTRODUCTION

In recent years, the vehicle industry has been ripe for a revolution: Integration with the Internet, called vehicle Telematics combination. This revolution actually comes from the increasing number of functions combined with different information within your car. Compared to their driving experience, people’s lives have changed dramatically in the last 20 years. People closely connected with Internet and social-networking community by laptops, mobile phones, tablets and other mobile information devices. Average American people usually spent 4 hours a day on texting, emailing and other online communication in 2013 (Experian Marketing Service, 2014). You may be shocked by the finding that 25% of mobile device use happened in vehicles.

Most car manufactures have noticed this opportunity; they are making great efforts in designing and promoting In-Vehicle Information System (IVIS), which combines traditional car functions with internet radio, social-networking communication and other forms of internet connection. One of the most compelling illustrations of IVIS is the big screen based navigation system. If you compare two same model cars (BMW 325i) from 2000 and 2013 (see Figure 1.1), you will clearly notice that the biggest difference between the interior of these two cars is an 8-inch LCD display screen – not only for basic GPS-based map
navigation, but also to easily access and display driving information (e.g., real-time traffic conditions, weather conditions, and place of interesting). Moreover, this LCD screen can be a flexible display platform for other functions of IVIS. Drivers can deeply access and customize their own car setting by using this platform.

However, using IVIS is a big source of car driving distraction and other safety issues. The one of the biggest problems with current in-vehicle information system is that when the driver needs to operate the system, they are forced to move their eyes away from the road for a few seconds. Based on report of the U.S. National Highway Traffic Safety Administration, 20% of injuries and 16% of fatalities are closely related to driving distraction (NHTSA, 2010). The research on eye movement shows that for more than two seconds moving eyes away from
the road in front will significantly increase the probability of traffic accident occurrence (Seung, J.K., 2009).

To overcome these safety problems with existing IVIS, I propose a concept that combines Head-up Display (HUD) technology and intelligent voice recognition command technology with a 14 inch touch screen operation systems. HUD technology is one of the most popular Human Machine Interface (HMI) solutions, which directly projects driving information onto the windshield. As all information that drivers needed would be directly displayed on the windshield in front of them (See Figure 1.2), this would allow them to always focus on their main mission, and would no longer need to lower their heads. HUD is reducing distractions and increasing driving safety, and is estimated to reduce vehicle crashes by 25 percent.

Figure 1.2 the 2013 BMW X5 with Head-up Display technology
In order to support and control HUD and other advanced Augmented Reality (AR) technology, a new car information display and operating platform is critical and necessary. Tesla, a new US electric car manufacture, released their all electric sports sedan—Model S in 2013. Within this world award-winning car (Figure 1.3), the car manufacturer combines a 17 inch touch screen, a digital instrument cluster, and steering wheel controls, which allows the driver to access and control media, navigation, communications, cabin controls and vehicle data information intuitively and effectively. By using a high-resolution 17 inch touch screen, Model S can show drivers thousands of pieces of information in a well-organized way. Compared to traditional car console and dashboard design, this integrated display and control solution (touch screen, digital instrument cluster, and steering wheel controls) creates a totally new way for designers and engineers to define new Human-Computer Interaction (HCI) in cars.

Figure 1.3 Tesla Model S interior
Not only car manufacturers, but more and more IT companies are entering this most promising market with smart phone and tablet systems. Google announced Open Automotive Alliance to transform the car into an "Android device" by collaborating with GM, Honda, Audi, and Hyundai. Apple also unveiled CarPlay which is aimed to connect iPhones into in-car information and entertainment systems. It is partnering with Ferrari, Mercedes-Benz and Volvo to build CarPlay into their vehicles.

In this environment, it is critical to explore new user experiences of the whole IVIS and test different user scenarios with all of the advanced technologies. By combining these new technologies together, I designed an IVIS which can display different types of driving-related information (speed, gas gauge and navigation), and in the meantime minimize distraction and other safety issues.
CHAPTER TWO: BACKGROUND KNOWLEDGE

2.1 Daily life with mobile devices and the internet

Without doubt, people’s lives have changed a lot within the first ten years of the twenty-first century. Thanks to smartphones and social networking communities, people are closely connected all over the world. If you look into different functions that people engaged in daily, you will find that, instead of calling, texting, navigating and other essential functions, people are now more and more interested in social connections. The survey performed by Experian Marketing Services shows that in the United States,

Source: Experian Marketing Services, May 2013

Figure 2.1 Breakdown of the Average Smartphone Owner’s Daily Time-Spend
smartphone owners spend 58 minutes every day on their phones (Figure 2.1).

Within this one-hour of phone time, 32% of it is focused in social networking and other internet related applications. People are more and more eager for emotional support and company from the Internet. The tricky part of this psychological dependence on the Internet is that people are paying more attention to communication in the virtual world rather than chatting with real people who are sitting around them. Another apt illustration to prove people are concentrate more on online life is the rising of Facebook, Twitter, and other IT companies. Compared to Sony, Nokia and other traditional hardware manufacturers, these new giants are better at selling services and satisfying emotional needs of users.

Figure 2.2 People typing message in the car

But then again, within this one-hour period of average mobile device use, there is a huge overlap with using phones in the car driving scenarios (Figure 2.2). It is illegal to call or text message directly on your phone in most states in the US while
operating a vehicle. In contrast, drivers tend to have favourable attitudes towards Bluetooth earphones or advanced voice recognition functions (like Siri from Apple).

2.2 New trends in automotive industry

2.2.1 In-vehicle entertainment system

“Why put a large touch screen in your dash? Fantastic looks are a great starting point, but there’s so much more you can get from a nine inch LED screen. You can see all the information you need at a single glance, making it easier to keep your eyes on the road. You’ll also have expansion options like downloading different applications which are specially designed for cars from App Store.” This is a
commercial advertisement from a car dealer who wants to sell cars with built-in touch screen entrainment system. In 2014, more and more car manufacturers are entering this promising market with customized in-vehicle entertainment systems. Rather than using different names and definitions for similar functional systems across automotive manufacturers, academics and the involved industries collectively refer to *Automotive Human Machine Interface*.

“As demonstrated with the latest and best in market HMI designs by BMW, Audi, Mercedes Benz (Figure 2.3) as well as Ford, GM, Volvo and Renault, automotive HMI design has become a focal point and battleground for brand differentiation for all automotive segments. It’s not only the arrival of the connected car; it’s perhaps more importantly the arrival of information technology and software that enables next generation multimodal, multi-touch and multi-zone HMI design.” (The Automotive Human Machine Interface Report 2013)

2.2.2 Head-Up Display

“A head-up display or heads-up display is any transparent display that presents data without requiring users to look away from their usual viewpoints.” (The Automotive Human Machine Interface Report 2013)
This advanced technology is used by several German car manufacturers (BMW, Audi, and Mercedes Benz), dating to 2009. From then on, HUD has already become a benchmark for luxury cars. The idea behind using HUD is interacting functionality of cars with simple images and numbers. It has numerous advantages in human ergonomics and cognitive psychology. It already proved by different car research institutes and manufacturers that drivers concentrate on the road in front of them when using HUD.
2.2.3 Adaptive Cruise Control/Self-Driving

“Adaptive Cruise Control (ACC) is an optional cruise control system for road vehicles that automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead.” (Horrey, W. J., 2003) The traditional cruise control function was first applied to cars in 1958 by Chrysler. Today more than 30% of drivers use this function on US’ highways (J.D.Power). On the one hand, it makes the driver’s work much easier and reduced fatigue over long time driving times. On the other hand, it has one drawback—it relies on driver themselves to judge the “closing” distance between their vehicle and the one in front (J.D.Power).

Figure 2.5 Adaptive Cruise Control

In the future, ACC will be one of the most important aspects of the self-driving transportation tool. Even though there are many limitations due to social ethics and traffic laws, traditional car manufacturers and Internet companies are eager
to explore this controversial market. “We’re talking about an effort to force the biggest change in the auto industry since the first Model A drove out of Henry Ford’s factory a century ago.” (cnet.com) Google is the leading company in this area and it announced that their commercial self-driving car will be available by 2017 (Figure 2.6).
CHAPTER THREE: DESIGN PROBLEMS

3.1 Missing functionalities for the vehicle

Vehicles are one of the most phenomenal human achievements of the nineteenth century. For the last one hundred years, car manufacturers kept chasing breakthroughs in the design and mechanical areas: we have elegant aerodynamic car bodies; lower emission engines with more power; and more electronic components to ensure the driving safety. Cars are already becoming indispensable parts of human’s daily life. However, in the twenty-first century, human’s lives are dramatically changed by computer science and technology. In this virtual world, people connect with others and share their resources. Form an Internet-centered perspective, there are still some functions missing in car driving activity.

First of all, we consider multi-dimensional controlling: in addition to using buttons, knobs and other physical controls on car console, there should be more flexibility for using voice and gesture recognition commands. Siri helps Apple attract many users from other smart phone ecosystems. This voice recognition function is more and more popular in different scenarios—you can easily control your phone by voice command when exercising, cooking, or other hands-occupied activities.

In March 2014, Apple unleashed their in-vehicle IOS system (named CarPlay)
combining with Siri (Figure 3.1). More than 60% of the function controls in this system are completed by Siri. It’s now possible for drivers to reply to message or check email when driving. However, driven by their own economic interests of the desire to be the leader of in-vehicle entertainment system, only a few car manufacturers decided to install CarPlay in their future cars. For the rest of the mainstream car brands, physical buttons and knobs controls are still the only option for customers.

![Figure 3.1 Apple Siri and CarPlay system](image)

Secondly, we consider intuitive human-machine interface: related to the topic of Apple CarPlay and other in-vehicle entrainment systems, the question of how to design the interface of this system is a tough mission for both designers and engineers. Before the large and curved touch screen showed up in cars, there was a traditional layout and size standard for car interior design. However, once drivers start to use their smart phones and even tablets in the car for navigation, a new problem emerges: how to make it easy and clear enough for drivers to look and
recognize information form tiny screens of mobile devices? It seems to be a paradox for smartphone designers—on the one hand, everyone prefers to use bigger screens and it is also beneficial for cars that bigger screens can show more information; on the other hand, using bigger and bigger screens will cause ergonomic problems with controlling the screen with one hand. This problem has been found by users of the Samsung Galaxy Note, Nokia Lumia 1020 and other 5-inch touch-screen mobile phones. A better solution by far is designing touch screen especially for cars. The Tesla uses a 14-inch touch screen in their Model S, and it totally replaces all physical control buttons and knobs on the console (see Figure 3.2). The interface of this car is also modified to meet drivers and passengers diverse needs. Like Tesla, increasing number of car manufacturers are willing to build large screen system within their car, but how to design the interface to make it intuitive and easy to use is still a problem.

Figure 3.2 Tesla Model S 14 inch touch screen
Last but not least, we consider multi-media transformation: drivers might feel bored and lonely when they drive alone, which is why most cars have audio system for entertainment. The audio comes from different fountainheads: radio, cassettes, CD, and MP3s. More customers are using their phones as their main source of songs and other streaming media. In this case, there is an apparent gap between phones and car audio systems. Instead of using a cable to physically connect phones, there should be a more simple and convenient way to transfer all media from mobile devices to car audio systems.

3.2 Disconnectivity between driver and internet

People’s daily lives connect with Internet ever more closely: the internet and social networking communities have changed the ways people make friends. The widespread use of email, Twitter, and other Short Message Service (SMS) broke the restriction of territory and time—by using smart phones, tablets, and other mobile devices, people can communicate with friends all over the world. However, this communication pattern is not suitable for the driving environment; because of
safety issues, it is dangerous and illegal to use mobile device when driving (except for navigation). Undoubtedly these mobile devices are one of the biggest distraction sources for drivers. For this reason, people are forbidden to use their phones and other mobile devices in car driving scenarios. However, this Disconnectivity between drivers and the Internet has a huge influence on people's driving behaviors. On the one hand there are more and more electronic accessories try to satisfy driver’s needs for connection. Bluetooth headsets are one of the best examples for merchants to fill this gap. On the other hand, there are still many stubborn drivers who are ignoring the great danger of using mobile devices while operating their vehicles. The ultimate object of this project is to bridge the gap between people’s lives and their car driving activities (Figure 3.3).

Figure 3.3 the relationship between car and driver
3.3 Driving distraction and other safety issues

Over the last one hundred years, cars have become much safer by using more new technologies (seat belts, ABS, air-bags, etc.). Moreover, the popularity of touch screen mobile devices (including GPS, smart phones, and tablets) simplifies the driving experience and leaves more flexibility for automotive designers and engineers to apply more electronic applications into the car. On the other hand, these touch screen devices have the potential to lower driving safety.
4.1 Driving scenario analysis

In order to understand and gain deeper insights into driving activities, it is necessary for designers to categorize different driving scenarios. Because driving activity is one of the most complicated human activities throughout the world, drivers’ behaviors are affected by a wide variety of impact factors. Some come from surroundings (e.g. weather, road conditions, traffic order); and some come from drivers themselves (e.g. age, character, and driving habits). All these impact factors join together to influence driving activity. In this article, the target users of IVIS are 25-35 year old drivers. The driving scenarios (Figure 4.1) that I am talking about below are narrowed down only by external environmental conditions.

4.1.1 Urban

Urbanization and globalization movements are making more and more megacities all over the world. People who lived in New York, Tokyo, or Beijing are encountering the same problem: traffic jams. Because of long distances between residential areas and work area in big cities, many residents need to drive their cars in their daily commutes. It is becoming a time-consuming and annoying part of their life. In the case, driving in urban areas especially in rush hours gives
drivers a unique experience compared to other scenarios. When driving in city urban zones, driver need to be one hundred percent focused on the road—because there will be many pedestrians who are crossing the street and also many other vehicles that are changing and merging lanes. There are also many traffic lights and different signals on the two sides of the road which need to be read carefully by drivers. In this way, the information system must keep all distractions away, and at the same time show useful road information and efficiently guide drivers to the right destination.

4.1.2 Highway

Compared to the urban driving experience, driving on highways can often be a stress-free activity. However, this does not mean that driving on highways is always safe. According to the U.S. National Highway Traffic Safety Administration Survey 2012, 48% of car accidents occur on highways. Moreover, more than 68% of these accidents have serious injuries and deaths. Because of high vehicle speed, it is much easier to cause a serious accident based on one driving misoperation. In highway driving environments, it is critical for car information systems to provide surrounding vehicles with warnings (e.g. lane departure warnings, side blind zone alert, front collision alert, etc.), at the same time that they isolate all distractions form drivers.
Figure 4.1 different driving scenarios
4.1.3 Country

Road trips are one of most unique aspects of driving culture in America. The US has one of the biggest transportation networks in the world. Driving cars through country areas is very different compared to driving in cities and on highways. Weather and road conditions are changeable and unpredictable. Information related to these aspects are becoming more valuable than others information. Moreover, it is necessary for such information systems to provide emergency roadside service in rural settings.

4.2 Functions rearrangement

Over the last twenty years, new technologies have been pushing car design to break old boundaries. On the one hand these technologies have helped to make driving activity safer and more convenient. On the other hand, these progresses in technology give designers and engineers more flexibility in car design and manufacture. For example, by using high capacity rechargeable batteries and great-torque motors, electronic cars can remove the entire engine and transmission systems. Exterior and interior designers can change the traditional proportions of car bodies and seat layouts. In this way, cars will be ever more self-customized by drivers themselves. You will be able to easily change the setting of mechanical components and the design of your car in the future.
However, these new technologies also cause some problems for drivers. One of the biggest problems is that even through drivers have more control of their cars, question about how to arrange all these function buttons is becoming a tough task for designers and engineers. You can see this on the consoles and steering wheels of new cars, there are increasing numbers of buttons. Because the space of these control areas is limited, the size of buttons and the space between them are becoming smaller and smaller. Figure 4.2 is a picture of SAAB 93 interior; there are more than forty buttons on the console and steering wheel in total. Based on ergonomic theory and driver testing, it is relatively easy for drivers to engage in accidental operation. Moreover, finding a specific tiny functional button on the console can significantly distract drivers from the road. This array of behavior is a big hidden danger for driving activities. In
conclusion, it is necessary and valuable to rearrange all different functions which driver will use on the road to safeguard the driving safety and alleviate driver fatigue.

The rearrangement is based on three basic principles; first, functions that will be used frequently during driving activity should be the top priority. Second, functions related to driving behavior and safety should be more important than entrainment functions. Finally, voice recognition control, gesture control and other advanced function control methods should be applied appropriately throughout the whole system. Based on these principles, I reorder all functions in three stages of hierarchy: the most important and frequently use functions are on the steering wheel. In this way, drivers can access these functions at a glance. Secondarily, important functions are placed on console. These functions are closely related to environmental controls and entrainment systems (e.g. air conditioners and stereo systems). The remaining functions will be all integrated into a touch screen Human Machine Interface (HMI). In this way there is no physical button specially designed for them. This will save much space in the console area. Moreover, based on touch screen user interfaces, it will be easier to arrange the information architecture, make it logical and clear for drivers. Figure 4.3 is functionalities rearrangement diagram.
Figure 4.3 car functions rearrangement
4.3 Driver in-depth interviews

In order to deeply understand drivers’ behaviors and the sources of distraction, it is necessary to interview real car drivers and observe their natural behaviors and intuitive responses (Figure 4.4). At the beginning of the research stage, the designer spent significant of time interviewing and observing. During the research period, there were three rounds of interviews: in the first and second rounds, the interviews focused on drivers’ behaviors and observations; the third round of interviews is more about prototype validation.

![Figure 4.4 driver behavior interview](image)

During the first and second round of interviews, the designer used questionnaires to collect demographic data (include time length of driving in daily life, difference
in driving behaviors on weekdays and weekends, using conditions of phones and other mobile device, etc.). The object of these two rounds of interviews was getting a sense of user’s driving attitudes and behaviors, and at the same time exploring potential design concepts based on actual car driving activity.

Based on the first and second round interviews, almost ninety percent of interviewees use their phones to make a call or to answer incoming call. There are only thirty-four of interviewees who use Bluetooth or in-vehicle phone systems. The other sixty-six drivers use mobile phones directly when driving cars (Figure 4.5). This is where most distractions originate.

Figure 4.5 user interview result: 34% (blue part) of interviewees use in-vehicle phone system 66% (orange part ) of drivers user mobile phone directly when driving cars
For the third round of interviews, drivers were asked to test different HMI prototypes. Compared to first and second round interviews, this section is focused on getting feedback about several initial concept ideas. More details about this round interviews will be discussed in the chapter Six.
5.1 Head–up display and augmented reality

As I noted in Chapter Two, the initial Head-Up Display (HUD) comes from aircraft; the first generation of HUD can be traced to 1970s. During early military Head-Up Display (HUD) development, it was found that pilots using HUDs could operate their aircraft with greater precision and accuracy than they could with conventional flight instrument systems. (The Avionics Handbook Chapter 4 : Heads-Up Display)

For the same safety and convenience purposes, car manufacturers started to use HUD in their luxury cars around 2005. From then on HUD was becoming an advanced optional accessory for cars. There are currently two kinds of HUD which had been used in the cars:

![Figure 5.1 jet fighter with HUD technology](image-url)
First, increasing numbers of cars have HUD built into their in-vehicle navigation systems. These cars have full-function HUD integrated with navigation, speedometers, and other parts of car information systems. Figure 5.2 whose the latest HUD system installed in the 2014 Mercedes-Benz C-class. This HUD system does not only display navigation guidance, but also can show real-time traffic conditions and speed limits.

Second, without doubt, build-in HUD systems are still expensive for most car buyers. For these target users, standalone HUD accessories are more attractive and acceptable. Usually this kind of HUD accessory needs to be paired with smartphones, tablets, or other mobile devices via Bluetooth. Using data in phone allows it to can display limited driving information. The leading company in car navigation accessory market, Garmin, has released a $130 car-based HUD (Figure 5.3) that works in conjunction with a smartphone for a projected display on the windshield.
Figure 5.2 2014 Mercedes-Benz C-Class with HUD

Figure 5.3 GARMIN plug-in HUD
HUD is just one of many kinds of Augmented Reality technologies that can be applied in our daily life. Car manufacturers have already started to explore the possibility of integrating more Augmented Reality technology with voice command and gesture control functions in cars.

“Augmented Reality (AR) is a live direct or indirect view of a physical, real-world environment whose elements are augmented (or supplemented) by computer-generated sensory input such as sound, video, graphics or GPS data.” (Liu, Y.C., 2004)

Many people know AR from the movie Minority Report (2002), Tom Cruise used a three-dimensional space as a display screen and controlled it with hand gestures and voice (Figure 5.4). This intuitive interaction between human and machine will be come reality in the near future. The BMW research group has tested a full-sized HUD system for their next generation vehicles. Compared to HUD technology which can only project limited information on the windshield, the new system allows drivers to use the entire windshield as a display screen. Moreover, it can project information in perspective,
specifically for drivers—which means if drivers use navigation functions, he or she can see an arrow directly on the road (see Figure 5.5). This perspective-view technology has been tested by many different car industry suppliers (e.g. Atmel, Visteon, Continental, and Harman/Kardon). The biggest problems blocking progress are safety issues. Unlike what Tom Cruise did in the movie, car-driving environments require drivers to completely focus on road. Any distraction can possibly result in serious accidents. The HUD technology is a double-edged sword: on the one hand it can help drivers receive driving information as quickly as possible; on the other hand, it can be a big distraction source for drivers. In order to solve this problem, many car manufacturers and parts suppliers built driving simulation labs to test different kinds of AR technologies. By tracking the movements of participants’ eyes, researchers can analyze the range of distractions caused by AR.
5.2 Information visualization

When discussing Augmented Reality or other advanced technologies that will be applied to the next generation of vehicles, it is critical to explore the deeper cognitive structure--Information Visualization--for these different display types.

“Information Visualization or information visualization is the study of (interactive) visual representations of abstract data to reinforce human cognition.” (Jamson, A. H., 2005) As with Augmented Reality technology, the newest information visualization exploration always comes from science fiction firm. In Iron Man (2008), Robert Downey Jr. used a helmet that combined different AR technologies all together. At the same time, the different visualizations of large volumes of data show audiences a new way to see and control electrical appliances in the future.
For in-vehicle information system design, research on information visualization is very necessary and phenomenal. By getting more control of the car, the drivers need a safe and effective way to observe and monitor the status of engines and other electronic parts. In the future, it is even possible that drivers will be able to fully customize all functions of car operation based on their own preference. In that case how the information system displays all different kinds of data to drivers is closely related to driving safety issues.

5.3 Information architecture

The standard for evaluating user interface design focuses on the visual aspects. However, when first time users are becoming familiar with the whole system, they will pay more attention to how intuitive and smooth of the total workflow is. A good user–
experience designer can make the whole wireframe natural and intuitive enough for user who have not even used a similar kind of product before. Apple is one of the best examples for such user-centered design. In view of the above-mentioned facts, the structure of the whole system is critical for both designers and users. The structure of applications or other information-based products is called information architecture. During the design process, there is no specific step for designing information architecture. But this is not to say that information architecture has no importance for the system. To the contrary, it very much influences the entire visual component of design. For example, most interface designers will make many of low-fidelity models (see screen shots) to test the initial idea of what the application will looks like. The different interface layouts are fundamentally testing information architecture. Moreover, this is directly affected by the size of the screen (interface): the size of the display area plays an important role in designing layout and content of the interface. Figure 5.7 shows five examples of current in-vehicle HMI information architecture, and each have pros and cons in operation. As is clearly showed, the size of the display interface determines the information architecture of the HMI (e.g. based on its 17 inch touch screen, Tesla has a unique and more information-intensive layout). By analyzing the information architecture of current HMIs, the designer gained a deeper insight into the relationship between layout, content, and hierarchy of various information.
**Figure 5.7** current car HMI information architecture analysis
6.1 Reality simulation

One of the critical factors of designing car-related projects is reality simulation. Because driving experiences and scenarios are really complicated and are affected by multiple factors coming from the outside world and drivers themselves, it is important to simulate the real environment of driving and test initial concepts based on authentic drivers’ behaviors. In order to simulate real visual effects of HUD images, I took photos of real car interiors from the driver’s perspective and used Photoshop CS 6 software to put HUD images on the windshield. By adjusting saturation and color of images, I imitated the real visual effect of images especially with the reflection of sunlight (Figure 6.1). After modifying initial concepts of HUD, it is necessary to make low-fidelity prototype based on the results that can test such HUD images in the real life environments. In order to make the prototype, I bought a current HUD system sold on Amazon.com and installed it on my own car. Figure 6.2 is a real situation photo of the HUD system: using plug-in car power, it can project three digit numbers for vehicle speed on the windshield. In order to enhance the effect the HUD numbers, I designed a physical frame which built by a three dimensional printer to block sunlight reflection from the HUD system. On the one hand this HUD prototype can test the visual effects of projecting images; on the
other hand, it is a critical way to observe and test the drivers’ distractions and other safety issues possibly caused by such HUD systems.

![Reality Simulation of HUD](image)

Figure 6.1 visual simulation of HUD

Figure 6.3 are photos of the HUD prototype during the day and at night. Undoubtedly, drivers can get a real good visual effect of HUD images at night based on higher luminance contrast. Moreover, even in the daytime (photo shot at 2:00 pm), such HUD system can provide clear enough images for drivers. Although such HUD concepts have many advantages (e.g. being more intuitive and driver-oriented), HUD still has problems with the initial idea—by using physical frame and circle images, it blocked a relatively big area of the driver’s view of the road. It is
dangerous to hide such views of the road in front of car considering the importance of road condition observation.

The modified vision of HUD system is meant to strike a balance between information diversity and driving safety. Based on the driving scenario analysis from Chapter Four, the whole HUD display system separates into three different modes: urban, highway, and country. Based on different driving scenarios, the design guidelines for the HUD system changes to satisfy specific requirements.
6.1.1 Urban

This is most common driving scenario for most drivers. Considering complicated traffic patterns and road conditions, drivers need to fully concentrate on the road. Driver in this time-consuming and boring environment need to access key functions directly and in a straightforward way. In this case, the design of HUD images is relatively simple (Figure 6.4) – using blue and green colors can give drivers a refreshing feeling of the natural environment; in the meantime, perspective navigation displays are very useful and necessary for drivers who are unfamiliar with the local roads. Displaying Points Of Interest (POI) is one of the missing functions of current in-vehicle HUD systems. Based on Yelp, Foursquare and other location-based social networking communities, the HUD system I designed can indicate POI on the windshield and explore social networking functions for the driving environment (e.g. drivers can check the location of the nearest restaurant that friends have checked-into or leave good review online).

6.1.2 Highway

Compared to urban driving scenarios, driving on highways is relatively simpler yet more dangerous. Any number of small driving mistakes can lead to serious traffic accidents, perhaps with casualties. In this way driver needs to focus all their attention on the road
and make sure they are ready for any kind of traffic emergency. Moreover, drivers always use navigation functions on highways, and it is critical to make sure car systems can supply accurate road information to drivers in an effective and safe way. By using red color and an analog circle speedometer (Figure 6.5), the HUD display in this mode gives drive a sense of speed and even passion.

Figure 6.3 HUD prototype on daytime and night
Figure 6.4 urban mode of HUD visualization

Figure 6.5 highway mode of HUD visualization
6.1.3 Country

The “road trip” has long been a cultural semiotic symbol for America. Many people love driving their cars though the whole country in one month or for even longer times. Recreational Vehicles (RVs) are one of the products that can satisfy people’s long distance road trip needs. In this case, drivers need different driving information, for example: weather conditions, road conditions, and wildlife warnings. Moreover, in order to prevent running out fuel in deserted area, gas stations are one of the most important POI to display to drivers (see Figure 6.6).
6.2 Wireframe planning

The wireframe structure is the most critical part of interface design that will influence how users interact with the whole system and help first time users become familiar with all functions in a logical way. There are lots of different ways to test wireframes; in this project, the designer used low-fidelity prototype to simulate the workflow of the whole system as well as interactions between different interfaces.

Figure 6.7 wireframe prototype and user test

By drawing the initial interface on paper, designers can easily test different visual layouts and information structures. Moreover, designers can observe users’ behaviors directly by simulating all interface interaction. It is critical for design to test these initial concepts of interface design and develop several rounds of iteration. It is also beneficial for users to do different interaction animations by changing sheets of paper. Figure 6.7 shows a user test for the wireframe.
6.3 Low fidelity model

As mentioned in previous chapter, low fidelity models are very useful for wireframe and interface testing. One of the biggest challenges for such HMI design are real driving environment simulations. Big car manufacturers are willing to build whole simulation laboratories for testing and modifying their initial ideals. Based on the limitation of this independent student project, it is impossible for the designer to test the HUD or wireframe structure using high-end simulation tools. However, by using many different kinds of cheap prototyping methods, the designer can still achieve the ultimate goals of user testing and iteration.

Figure 6.8 shows one of the prototyping methods for this project: in order to design HUD images for different driving scenarios (Urban, Highway, and Country), the designer drew several pictures of driving environments on paper. Then the designer start to draw a few initial concepts of what the HUD will look like on the windshield and test different aesthetic factors of design (color, font, size, layout, and contrast ratio).

After modifying the initial ideals on paper, it is necessary to test this HUD images in real driving environments. In order to make sure the testing results are accurate, the designer needs to simulate the ambient environment as closely as possible. In this case, the designer printed all HUD images in real size and perspective on clear sheets (See Figure 6.9), and then asked people select the best images considering colors, fonts, and different perspectives.
The designer gained deeper insight into information visualization. Afterwards, in order to imitate real driving environments, the designer cut these clear sheets piece by piece, and tape all of them on a real car windshield (Figure 6.10). In this way, the designer developed and modified the HUD images in order to guarantee driving safety and reduce distractions as much as possible.
As with HUD information visualizations, interfaces on consoles are another aspect that needs to be tested several times in order to realize intuitive user experiences for function controls. As I mentioned previously, content mapping, information architecture, and wireframe planning all serve to achieve this object-letting user have smooth and intuitive interaction experiences with HMI systems. In order to reach this target, real user interviews and tests are crucial to the whole design process. Also users’ reactions and feedback help designer to develop and modify the initial concepts.

For this project, the designer made a foam board frame to simulate the 17 inch touch screen on the console (Figure 6.11). By changing sheets of paper to imitate interface workflow, the designer can test real interactions between the system and users.
In conclusion, undoubtedly driving simulation was the toughest part of this project; using different low-end prototypes, the designer tried to imitate real car-driving environments and also drivers’ actual reactions while using HMI. Even though these low-
end prototypes can hardly simulate the real Human Computer Interaction for the system, they still play an important role in user testing and concept modification.

Figure 6.11 touch screen prototype made by foam board
CHAPTER SEVEN: FINAL OUTCOME

7.1 Information display

Figure 7.1 initial sketch shows the combination of touchscreen and physical panel

Based on user interviews and tests, the final design outcome combines physical control with touch screen interfaces (Figure 7.1). The advantage of a 15 in touch screen is information displaying flexibility: compare to traditional car consoles, this touch screen allows designers and engineers to incorporate more functions into the vehicle without space limitations; Moreover, touch screens create a new way to display function
structure (instead of traditional linear structures, touch screen interfaces allow HMI to have progressive lay out)

This combination of hardware and software also is an exploration of User Experience (UX) design. Conventional UX design is usually based on current hardware. Which means the performance of the software is really influenced and even limited by existing product, in other words, the screen. The size and shape of the screen determines the display method of the interface. However, for this project, it is no longer based on the old linear design structure (from hardware to software). The design of the hardware and software come together: the shape and size of the screen will be affected by interface structure; in the meantime, the information structure can change based on the physical control architecture.

As Figure 7.2 shows, the combination of physical control and the touch screen create a new way of function display and operation. Moreover, the HUD display also helps the system to set a hierarchy for the whole IVIS: instead of the dashboard, the most important driving information is projected to the windshield directly; the most commonly used functions are set on the steering wheel; the second mostly used functions are placed on the physical panel; and all other functions are integrated in the touch screen system. Based on this progressive function structure (HUD-steering wheel-physical panel-touch screen), designers can easily set the different layers of functions and help drivers to focus on the road.
For the final design of the touch screen, the designer used a 15.4 inch curved touch screen as the platform for displaying information (Figure 7.3). The curve of touch screen helps drivers to operate the screen in the good ergonomic way. The dig screen has enough space for relatively complicated information display. The whole system has been separated to seven different functions: climate, multi-media, navigation, homepage, phone, setting and HUD (Figure 7.4). All necessary functions are categorized to these seven submenus which will help first-time users to become familiar with the whole system logically and rapidly.
Based on current touch screen mobile device, smart phones and tablets, the visual designs of interfaces try to evoke a similar user experience for these current products. This empathy can help drivers to learn how to operate the whole system in an easier way.

One of the best illustrations of combining conventional car functions with social networking communities is the navigation function. Unlike the traditional navigation systems, which are simply based on location and official information, the designer tried to integrate the social networking function: instead of using official information, the system allows users to transfer personal identifying data and check friend's location histories in social community. Users can find restaurants, hotels, bars and other entertainment places where friends had already checked in before or left a good review for.
This social-based navigation function is one of controversial functions for the users (Figure 7.5): on the one hand, Yelp, Foursquare, and other social entertainment information suppliers participate in our daily life closely. More and more people rely on these information sources to answer questions: such as where are we going to eat? There seems little doubt that in the future, not only customers but also shop owners will value the reputation of such places in social communities—customers are going to use these information sources to find interesting places and shop owners will need higher review rates to attract customers.

On the other hand, such location-based information sources could be a serious privacy disclosure source for users. Many participants in user research have
repeatedly expressed concern that such functions will expose their personal itinerary in front of everyone.

Figure 7.5 social-based navigation function

Another focus of concern are distraction issues. Current in-vehicle touch screen systems do not allow users to operate them without also looking at them. However, as mentioned in previous chapters, it already has been demonstrated that moving drivers’ eyes away from the road will significantly increase the probability of traffic accidents. Moreover, such touch screens cannot give user accurate enough feedback for adequate control. Compared to traditional physical buttons and knobs, touch screens on currently available cars cannot improve users’ experience in safe ways. The combination of physical control and touch screen attempts to resolve this distraction problem: drivers need only to use physical buttons and knobs on the steering wheel and console to access the most frequently and commonly used operating functions of the car. In this case, the touch
screen is more responsible for information display. Figure 7.6 is a comparison between the full access function system and the driving mode system.

Compared to the full access system, drivers are limited to using most functions (navigation, settings, and HUD) when they are driving. This does not mean drivers will have diminished user experiences in the driving mode; many aspects of functions are transferred via other media to the users. For example, in driving mode, users cannot access navigation setting functions. Instead, HUD will project the navigation information directly on the windshield; drivers also can change rote and destination by using voice recognition functions on steering wheel. The fundamental object of limiting some
functions available to drivers while driving is to ensure safety. Beyond limiting functions available to drivers, the screen interface is also modified in driving mode. Figures 7.7 and 7.8 are comparisons between the interfaces in the full access system and in driving mode for the air conditioner and media menus. Prioritizing reduction of driver distractions, the interface in driving mode uses bigger images and fonts. Also the layout of the interface has been simplified to help drivers to receive information as quickly as possible.

Figure 7.7 comparison of Air Conditioner function between full access system and driving mode
Figure 7.8 comparison of Multi-media function between full access system and driving mode

7.2 Function control

Figure 7.9 rendering sketch of whole car dimension
Compared to information visualization, function controls are more closely related to drivers' behaviors and experiences. All controls need to be performed by drivers directly or through mediation. Because of complicated driving scenarios, the way of operation control functions should be categorized into different implementation patterns: as showed in Figure 4.3 car functions rearrangement, the most important control operations should be placed on the steering wheel; secondarily used functions are placed on the console; and the remaining functions are all integrated into the touch screen (see Figure 7.9).

Figure 7.10 sketch of physical panel

For the operation way of functions on steering wheel and console, the physical buttons and knobs are being preserved. The reason of keeping original physical controls is to
help driver to access these most frequently using functions in the most effective and accurate way when driver need to focus on the road in front. Considering of usage efficiency and possibility of misoperation, physical control is the best choice for such key functions compared to other implementation ways (for example voice recognition control, gesture control, touch screen control, etc.). Figure 7.10 is the initial drawing sketch of physical control design: the Air Conditioner and Multi-media related functions are all placed on this physical panel. Depends on different operation methods, they are separated to buttons and knobs.

Figure 7.11 different texture and indicated information of knobs
Moreover, designer integrated two LED screen on the surface of rotation knobs, it can indicate status of Air Conditioner (AC) fan, temperature, and different modes of AC. By covering different texture of the surface of knobs, user can easily distinguish different functions by just holding and feeling of different knobs (Figure 7.11).
Figure 7.12  computer rendered images of whole project
For the size of console and whole car interior dimension, design use the most common four-door sedan as the reference model for the design measurement (see Figure 7.12). Even though there is no specific research for human factor and ergonomics in this project, designer still considered basic principle for human-machine interactions.

The final console design integrated HUD, touch screen, and physical control all together, this combination of different technologies is the future trend of car interior design and also a valuable exploration for human-machine interaction (Figure 7.13)

Figure 7.13  full function displayed console
In this project, the designer integrated different technologies into interior car design. Most new technologies are still new to traditional car design and are also closely related to the IT industry. In the future, without doubt, cars will play a critical role in people's virtual worlds: by connecting with smart phones and other mobile devices, cars are becoming another terminal for the Internet. However, compared to other mobile devices, cars are unique and special considering user experience—the driving safety and distraction issue are the most important factors designers need to think about and resolve in driving scenarios. And also for this project per se, the simulation of real driving environments and user tests is the most difficult component to realize. For car manufacturers and IT companies, the ideal solution for driving tests is to build simulation labs utilizing several screens, hydraulic gears, and computers to imitate real driving experiences. By using cameras to track the movements of drivers’ eye bowls and using medical devices to monitor drivers’ body languages, we can quantize the levels of distraction caused by different designs and concepts.

Even though the designer in this project did not use an expensive simulation lab to test the final design outcome, several low-fidelity prototyping methods used in
this project are practical and valuable for similar car designs and other user experience design projects in the university.
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