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Visualization Tool for Sensor Data Fusion

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ABSTRACT

In recent years researchers has focused on the development of techniques for multi-sensor data fusion systems. Data fusion systems process data from multiple sensors to develop improved estimate of the position, velocity, attributes and identity of entities such as the targets or entities of interest. Visualizing sensor data from fused data to raw data from each sensor help analysts to interpret the data and assess sensor data fusion platform, an evolving situation or threats. Immersive visualization has emerged as an ideal solution for exploration of sensor data and provides opportunities for improvement in multi sensor data fusion.

The thesis aims to investigate possibilities of applying information visualization to sensor data fusion platform in Volvo. A visualization prototype is also developed to enables multiple users to interactively visualize Sensor Data Fusion platform in real-time, mainly in order to demonstrates, evaluate and analyze the platform functionality.

In this industrial study two research methodologies were used; a case study and an experiment for evaluating the results. First a case study was conducted in order to find the best visualization technique for visualizing sensor data fusion platform. Second an experiment was conducted to evaluate the usability of the prototype that has been developed and make sure the user requirement were met.

The visualization tool enabled us to study the effectiveness and efficiency of the visualization techniques used. The results confirm that the visualization method used is effective, efficient for visualizing sensor data fusion platform.

Keywords: Information Visualization, Sensor Fusion, Data Displays, Display Systems, Real-Time Visualization

ABBREVIATIONS

GUI	Graphical User Interface
HCI	Human Computer Interaction
2D	Two dimensional
3D	Three dimensional
HTML	Hypertext Markup Language
InfoVis	Information Visualization
MD	Multivariate Data
UI	User Interface
VA	Visual Analytics
SDF	Sensor Data Fusion
CAN	Controller Area Network
JDL	Joint Directors of Laboratories
OODA	Observe, Orient, Decide and Act
RADAR	Radio Detection And Ranging
LIDAR	Light Detection And Ranging
SDK	Software Development Kit
iOS	Apple's mobile operating system

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1. Introduction

Every year numerous people are being killed or injured in car accidents. Therefore safety features of vehicles are becoming more important than ever and automobile companies are more and more focused on safety features particularly in heavy trucks. Active safeties systems are systems activated in response to safety problems and design in such a way to prevent accident by informing the drivers about potential accident risk and intervene to completely avoid an accident. In order to completely avoid accident these systems need information about the traffic environment surrounding the vehicle which is measured by different sensors. Besides, it is really difficult to deal with massive sets of sensor data to produce the best output of it and make useful decisions for safety and comfort purposes. Hence, one of the essential parts of an active safety system being developed for a vehicle is the sensor data fusion platform which reads in the data from a set of sensors and combines the information using different techniques to describe the environment in the best way possible. Fusing sensor data and further analysis to detect other traffic participants is expected to help driver assistance systems increase driver safety.

The specialists who interpret the data usually need an easy tool to use for manage the collection of data. Besides Information usually contains multiple kinds of uncertainty and it is essential to understand the uncertainty involved in the data. Exploration and analysis of sensor data relies strongly on the visualization tool to assist the user in discovering and interpreting hidden patterns within a large dataset. Hence for development of sensor data fusion platforms it is required to visualize representation of all levels of such data, starting with raw sensor data from each single sensor up to fused data which is combined information, gathered from multiple sensors. Such visualization is necessary for debugging and analyzing purposes during the development process of the systems. Moreover, the visualization will be used as an interface for demonstrating the sensor data fusion platform functionality. Researchers confirm that advances in information visualization and human computer interaction open new possibilities for the access, analysis, navigation and retrieval of sensor information [1].

Visualization of sensor data can also fill the gap between researchers in sensor fusion and in HMI presentation concepts.

In this thesis we are focused on applying an appropriate visualization technique to sensor data fusion.

Figure 1: Volvo Truck demonstrator

1.1. About Volvo Group Truck Technology

Volvo Technology Corp (VTEC) is part of the Volvo Group and employs about 400 people. VTEC is an innovation company that develops new technologies, new products and new business concepts within the transport and vehicle industry, and they are an integral part of the research and development in the Volvo Group. The master thesis was conducted at their office located at Regnbågsgatan, Gothenburg. It is part of a larger research project, namely Non-hit Car and Truck, which aims to improve automotive safety and support Volvo safety visions by developing technologies to reduce accident risks.

1.2. Thesis Outline

After this introductory chapter, the remaining chapters of the thesis are organized as follows:

Chapter 2 (Purpose and Motivation) defines the research approach for carrying out the study. Starting with problem domain background, this chapter presents the research questions, research methods being used to answer these questions, aims and objectives of the study.

Chapter 3 (Research Methodology) describe the research methodology adopted to carry out this research.

Chapter 4 (Information fusion) presents the concepts of data fusion and the role of information visualization in data fusion.

Chapter 5 (Information Visualization) provides an overview of the existing literature regarding the graphical representation of data. Multivariate data and Information Visualization (InfoVis) techniques that will be used in this study are discussed here.

Chapter 6 (Mobile Applications) gives a brief introduction to mobile applications and different mobile platforms that are available and the challenges in developing mobile applications.

Chapter 7 (Implementation) provides details about the implementation details of visualization tool.

Chapter 8 (Usability Evaluation) illustrates the evaluation phase of the thesis.

Chapter 9 (Conclusion and Future Works) presents the findings from the study and the future works.

2. Purpose and Motivation

2.1. Problem Statement

The scope of the thesis is divided in two parts, development and evaluation.

Development: The increasing complexity of sensors in the automotive industry calls for more efficient testing and verification process early in development phase of the data fusion platform. To further improve the testing and validation there is a need for an application which is capable of visualizing a multitude of data in real time. Furthermore, it can be used both as a debugger tool and the experimental platform for the design of the future upcoming driver assistance systems. Hence, the system is not intended to be used as a real driver assistance system. It aims to bridge the gap between Human Computer Interface designers and the sensing engineers during the development phase.

Evaluation: The application will be evaluated both regarding usability and its advantages for the company. Suitable human computer interaction (HCI) models will be used for the usability part and the second part will be evaluated through questionnaire.

2.2. Aims and Objectives

The main aim is to find the most suitable visualization technique for visualizing sensor data fusion platform. This thesis project has the following in detailed objectives:

- Select the suitable Information Visualization technique to visualize receiving sensor data.
- Bring the users to focus in the visualization process
- Develop a prototype which uses these techniques.
- Evaluate the Information Visualization techniques used.

2.3. Research Questions

The main research question formulated as follows:

RQ1**.** How can the visualization technique be applied to sensor data fusion platform**?**

RQ1.1 what is the requirement of users who want to view the Sensor data fusion platform in a visual representation?

RQ1.2 what is the appropriate visualization technique for visualizing sensor data fusion platform?

RQ1.3 how can the uncertainty involved in sensor measurements be visualized?

RQ1.4 has the visualization tool developed effective in analyzing and demonstrating the platform functionality?

RQ2 what are the limitations of visualizing sensor data on the mobile device?

2.5. Initial Constraints

From the start, a number of initial constraints have been set for this project. The application was to be developed for a current-generation mobile device. The device was to receive sensor data through wireless communication from a Matlab/Simulink platform. The application was to be able to visualize data in real time for in-car use on the road.

The final prototype was required to be a fully functional interface that could receive data in real time. The implementation was limited to plot the data in 2D.

2.6. Expected Outcomes

This Master thesis provides aimed to investigate the possibilities of visualizing sensor data fusion platform. Moreover, by the end of the project a working visualization tool is expected to be developed that fulfills the requirements of the industry. The visualization tool would be evaluated regarding usability and its advantages for the company.

3. Research Methodology

The research methodology used in this thesis is thoroughly described in this chapter. This chapter consists of five sub sections. The first section gives a general overview of the research methodology. A brief description about the literature study that has been carried out is described in second section. In the next part, the possible data collection methods are introduced. In forth section interview analysis and requirements are described and in the final section the design ideas for prototype has been discussed.

3.1. Overview

This research is an industry based thesis intends to find solution for a specific problem defined earlier. Different research approaches used in this industrial thesis for applying the proper visualization technique for visualizing sensor data fusion platform. Author used qualitative and quantitative research approaches [2] in order to provide answers to the research questions.

Qualitative research belongs to data such as words or non-numerical data that is collected from observations of participants during performing tasks, interview and making a meaningful data that users bring to them. Quantitative research belongs to any numeric data, measures of data and analysis of statistical techniques [3].

A literature study is conducted in order to get insight to the problem which is finding the proper visualization techniques that could be applied to sensor data fusion platform and related work in this context.

According to the Yin.R [4] there are three conditions for choosing the appropriate research method: (1) the type of research question (2) if the researchers have control over behavioral events (3) focus on contemporary events. Due to our main research question "how visualization can be applied to data fusion" and two other factors the best research method for this thesis is case study.

In order to have a better understanding of the product that was to be designed and gathering the requirements, interviews with potential users of the application is conducted prior to the beginning of the design work. One of the main reasons for the interviews was precisely to allow a better analysis of the initial assumptions of the designer. This has clearly resulted in a better insight of the problem. Ethnographic interviewing is a qualitative method that is useful for data-gathering and can be used early in the project to help understand the user needs [4].

In the final step a usability study has been carried out to evaluate the visualization tool according to the user needs and satisfaction. So, the visualization tool has been qualitatively evaluated. A questionnaire has been used to collect comments and feedbacks of the users for further improvements of the tool and assessing the effectiveness of it.

3.2. Literature Review

A literature review is carried out to answer research question 1.2 and get insight into problem which is finding the proper visualization techniques that could be applied to sensor data fusion platform. This literature review regarding the visualization concepts is described in chapter 4 thoroughly. Moreover in order to get insight into sensor data fusion and the importance of visualization in this context a literature review has been carried out which described in chapter 5. For answering to research question 2 a literature study carries out on mobile platform available and the visualization challenges in a mobile device.

3.3. Data Collection Techniques

To get full understanding of users' requirements and design new interfaces that fit their needs and benefits neatly, it is important to gather and analyze their requirements carefully in advance before moving to the designing phase. User requirement gathered using an interview method with the target users of the visualization tool.

3.3.1. Interview

Ethnographic interviewing is a qualitative method that is useful for data-gathering and can be used early in the project to help understand the user needs. In this section we will discuss an ethnographic interview method developed by Hugh Beyer and Karen Holtzblatt called *contextual inquiry* [5].This method is the underlying basis for the goal-oriented technique devised by Cooper [6] that was used in this project, which will be described later. Beyer and Holtzblatt describe their method as follows: "The core premise of Contextual Inquiry is very simple: go where the customer works, observe the costumer as he or she works, and talk to the customer about the work. In this work, Beyer [6] Enumerate four principles that adapt the master-apprentice technique to their proposed method: context, partnership, interpretation and focus. The context refers to the importance of performing the interview in the customer's normal work environment. In his work on an improvement to this process, Cooper [6] notes:

"*Observing users as they perform activities and questioning them in their own environments, filled with the artifacts they use each day, can bring the all-important details of their behaviors to light*.

The second principle simply states that the interview should take a tone of collaboration. The third principle, interpretation, means that the designer has to interpret everything that they see and hear from the interviewee and be able to put it all together for analysis. Finally, focus refers to the responsibility of the designer to drive the interview to achieve important and relevant points.

In his book, Cooper [6] proposes an improvement of this method. According to him, results in a better research phase increases the chances of success of the design. These improvements include shorter interview times, smaller design teams that interact with all interviewed users, and most importantly to give priority to identifying goals before determining the tasks involved.

I received a list of potential users from which I managed to get four of them for interviews. Although such a small number is not ideal but the users of the visualization tool ware limited only to sensor researchers that use sensor data fusion regularly. The interviews were performed in a semi-structured fashion where lists of questions were used merely as a guide to ensure that all important topics were covered. The interview questionnaire is enclosed to this report as Appendix A.

3.4. Interview analysis and requirements

The interview method proved to be fundamental as it rendered important insights to the needs of these users and define the requirements for the visualization tool according to their needs. The semi-structure aspect of the method allowed the author to have relevant follow-up questions covering the topics with a greater degree of depth. This setting also allowed to cover the key topics with ease and made plenty new information available for author. Since the project started with the set of requirements already mentioned in the previous chapters, the interviews allowed author to complement this initial list with important notes or additions. In the next step the requirements were analyzed and grouped into three categories: strongly requested, optional, or not requested.

Visualizing SDF platform in 2D was an initial constraint from the beginning of the thesis and the interview confirmed that the users are persistent with 2D visualizations. Users indicated that the SDF platform is under development and there is not any information available for 3D visualizations such as the exact position of a 3D object. Furthermore, the users stated that graphical quality of the visualization is less important comparing to the accuracy of each task that needs to be visualized.

A bird's-eye view, where the scene is viewed from directly above, seems to be the standard for these kinds of visualizations. It is an efficient method for displaying a certain amount of data in a somewhat wide region. Additionally, users seemed to be used to this view and to feel comfortable using it. Therefore, although this view was already included in the initial plans, the interview confirmed it to be the most appropriate view.

In addition, it became clear that there is a need for the ability of zooming in/out in order to have a better view over the data being visualized. This is especially true for this project considering the reduced screen size of mobile devices. Together with zooming ability, it is clear that panning can be very useful as well since the zoom severely restricts the visualized area.

After identifying important features that are necessary the necessary information was available to start designing the product.

3.5. Designing the Prototype

The process started with sensor observations taken from the 'World'. The information required is collected and mapped to the existing Ontology, using standard methods of knowledge-gathering. This information may be generated by the Fusion process or gathered directly as "raw" data. The Fusion process in turn may be influenced by the data being prepared for visualization. Next, absolute and abstract data values are identified. Absolute values may include information such as uncertainty. Once this stage is complete, known visualization or representation schemes represent the identified information, and display techniques are applied to visualize it.

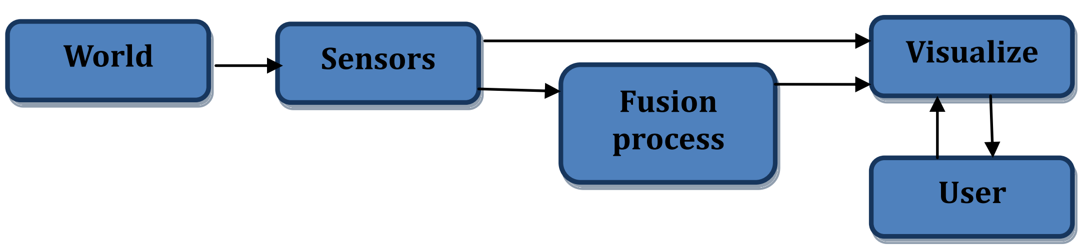

Figure 2: prototype design

The nature of this work is based on user needs and satisfaction. The users should be involved throughout the entire visualization design process [7]. Hence, a user centered design approach adopted. According to Kulyk [8] in order to develop a successful visualization, there is a need to analyze who the users are and what tasks they want to perform using the visualizations. The users are researchers and engineers developing sensor data fusion platform in Volvo Technology. The tasks were defined by the users of the visualization tool in an interview.

Finally, a number of deliverables was established as follows:

- Application will be written Java using Android SDK and should run on all Android-powered devices with appropriate system version.
- A protocol for feeding the sensor data to the mobile device.
- Ability to receive a live stream of data.
- Ability to visualize different objects.
- Ability to visualize the prediction of all objects.
- Ability to visualize velocity of objects.
- Ability to visualize the covariance contour of the objects.
- Ability to visualize the road line.
- All objects should be visualized in a bird’s-eye view.
- The user shall be able to zoom into the view.
- The user shall be able to pan without changing the position
- Every object shall be labeled with its number.
- Objects that belong to different sources shall be separated.

4. Sensor Fusion

This chapter gives a brief introduction about the sensor information fusion and its concepts and the importance of visualization in sensor information fusion.

4.1. Introduction

In literature, there are three different levels of fusion: information fusion, sensor fusion and data fusion. Several attempts have been made to define the fusion terms and techniques. The term data Fusion first appeared in the literature around 1960 as mathematical models for data manipulation[9].Data fusion is the process of combining data from different sources to achieve better state estimate and predictions that might not be possible to deduce from a single source [10].

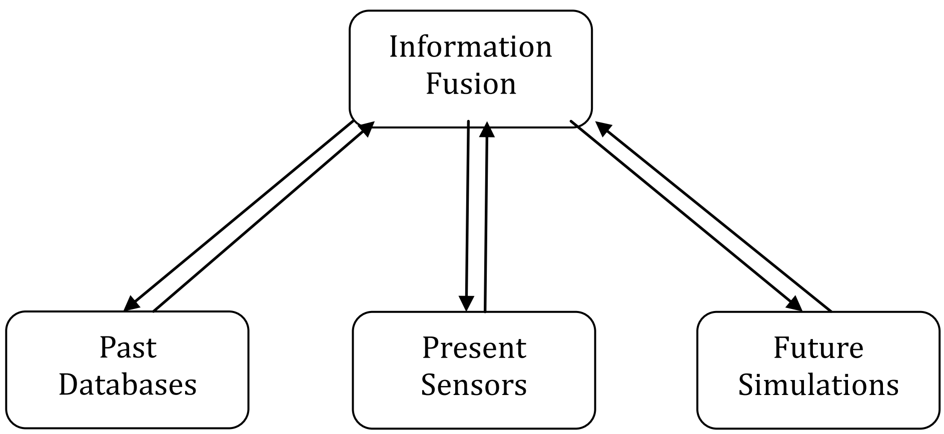

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Figure 3: Information fusion from databases, sensors and simulations.

Information fusion is used for fusing information that cannot always be represented with real numbers however sensor fusion and data fusion combine numerical data from several sources.

Sensor fusion includes techniques and tools for fusing the information gathered from multiple sensors and combine them into an accurate result. The resulting estimation is better than result of the individual sensors [11]. The term better in this case means more accurate and reliable and the goal is to get as accurate and reliable information as possible.

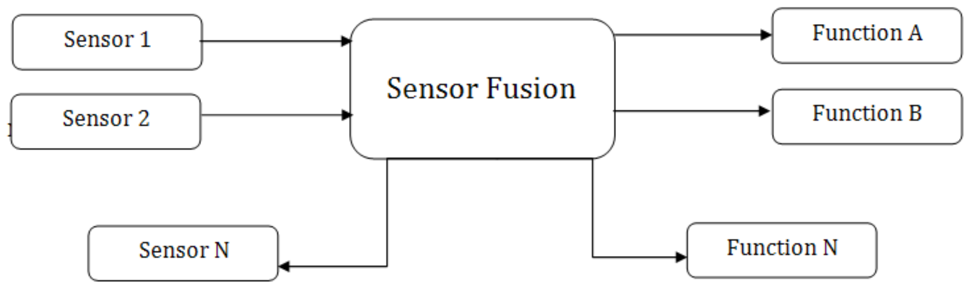

Figure 4: The main components of the sensor fusion framework

Figure 4 illustrates the basic concepts of sensor fusion framework. The framework receives information from multiple sensors, fuses the information and produces an estimation which will be used by several applications.

4.2. Automotive Sensor fusion

Currently there is a huge attention in active safety systems within the automotive industry. Sensor fusion is the key element in active safety systems. It is the element that sorts all of the events, and supplies the driver and various subsystems in the vehicle with right information. As an example when several warnings are received simultaneously, the system must prioritize them so that the most urgent problems are dealt with first.

4.3. Sensors

Sensors have played a vital role for enhancement of vehicle safety. A sensor is an electronic device that converts the measures of a physical quantity into signals and enables an observer or an instrument to understand the surrounding objects of a vehicle including pedestrians. There are different sensors in modern vehicle. Internal sensors such as accelerometers measure the motion of the truck while external sensors measure the objects around the truck. There are also sensors for communication with other vehicles and with the infrastructure using controller area network (CAN).CAN is a serial bus communication protocol developed by Bosch in the early 1980s. It designed to allow communications of microcontrollers and other devices with each other within a vehicle without a host computer.

External sensors in a truck are as follows:

- Radar (radio detection and ranging) is an object-detection system which uses pulses of radio waves in way to measure the location of close objects or relative speed of moving or fixed objects.
- Lidar (light detection and ranging) is a technique for remote sensing which measures the distance to objects by using laser pulses. A Lidar emits a laser pulse and detects the reflected signal. It measures the time delay between transmission and reception of laser pulse and computes the distances or ranges to objects.
- Cameras: they are an increasingly important part of active safety systems [12] and have many usages.

Apart from these three sensors there are other sensors that may be used in a vehicle depending on the goal of the projects. These sensors are laser scanner, ultrasonic sensors, thermal sensors, rain and light sensor, etc.

Different sensors have different resolution and behave differently in various temperatures, weather conditions and etc. Sensors may even stop working in certain conditions. False detection is also one of the issues of sensors. Figure 5 illustrates automotive imaging applications for machine vision.

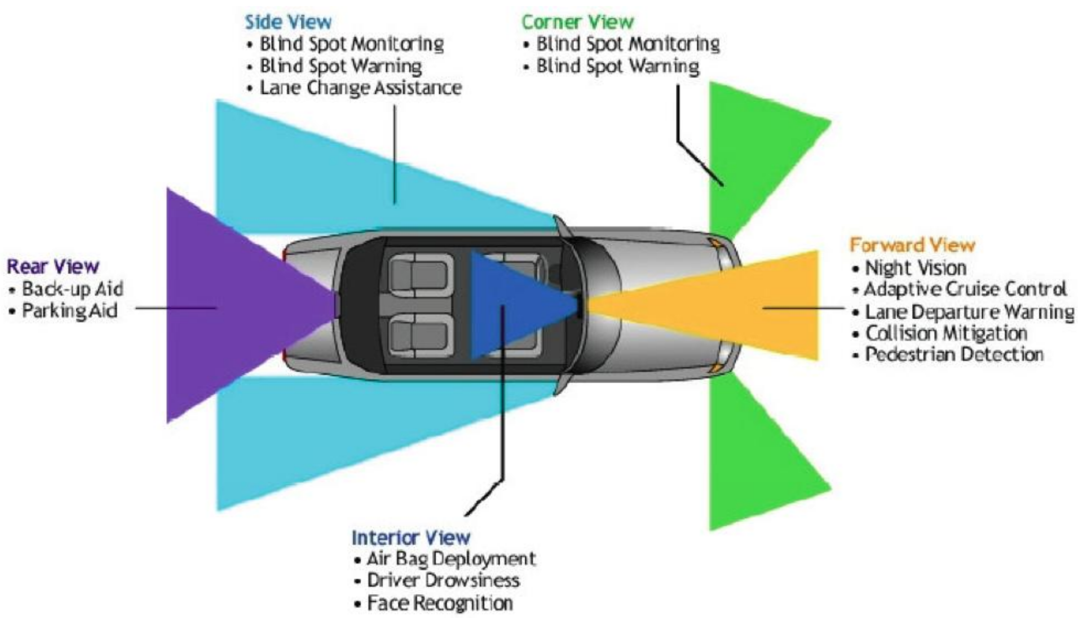

Figure 5: applications of machine vision in driver assistance [13]

4.4. Uncertainty

An important aspect of sensor data is that it is often contains a degree of uncertainty and incompleteness even with perfect measurement. Pang [14] described uncertainty as statistical variations or spread, errors and differences, minimum-maximum range values and noisy or missing data.

Foody and Atkinson [15] defined uncertainty as a quantitative statement about the probability of error, where inaccurate measurements or predictions are associated with large uncertainty.

It is essential to visualize uncertainty involved in data received from sensors. As for analyzing and interpreting sensor data and develop future driver assistance system it is essential to be aware of the uncertainty involved in data. Many researchers confirmed the need for visualizing uncertainty involved in sensor data ([16], [17] [18]). However most of the researchers in this area ignored the issue or separated the presentation of the uncertainty from the data [19].

4.5. Sensor fusion architecture

Sensor fusion architecture describes how information from different sensors are combined using mathematical techniques and processing in order to perform a fusion operation. Sensor fusion models are greatly depends on the applications. Therefore there is no model of sensor fusion accepted generally as a unique model for all domains [20]. This thesis is focused on models which have been known for a long period of time.

4.5.1. The JDL Fusion Architecture

The most widely used models for categorizing data fusion related functions are Joint Directors of Laboratories (JDL) model.It was proposed in 1985 under the guidance of the Department of Defence [21].

The description of all levels of JDL is as follows [22]:

• Level 0: Signal Assessment:

This level preprocesses the data in the sensors and estimates and predicts signals. It includes functions like signal processing [9].

• Level 1: Object Assessment

Level 1 is the process of extracting and combining data from multiple sources to obtain the most accurate and reliable estimation or prediction of entity’s speed, velocity, direction [9].

• Level 2: Situation Assessment

Level 2 “*In order to refine our estimate of a situation, automated reasoning needs to be done*” [9].

• Level 3: Impact Assessment

Level 3 is the process of estimating and predicting the threats. Esteban [9] explain this level as follows: *“projection of the current situation into the future or define alternative hypotheses regarding possible threats or future conditions*”.

• Level 4: Process Refinement

Level 4 is the process of monitoring and optimizing the overall process of data fusion. According to [9] it is “*a meta process that monitors the ongoing data fusion process to improve the processing results (namely improved accuracy of estimated kinematics/identity of entities and improved assessment of the current situation and hypothesized threats*”

Level 5: Cognitive Refinement

Level 5 presents the fused information to the user through interface. It focuses on “*interaction between the data fusion system and a human decision maker to improve the interpretation of results and decision making process*” [9]. The need for a level 5 was first proposed by Hall [1] and labeled as Cognitive Refinement.

Level 5 deals with “*monitoring the ongoing interaction between the data fusion computer system and a human decision maker; optimization of displays, interaction commands, focus of attention to improve the human/computer effectiveness*” [9].

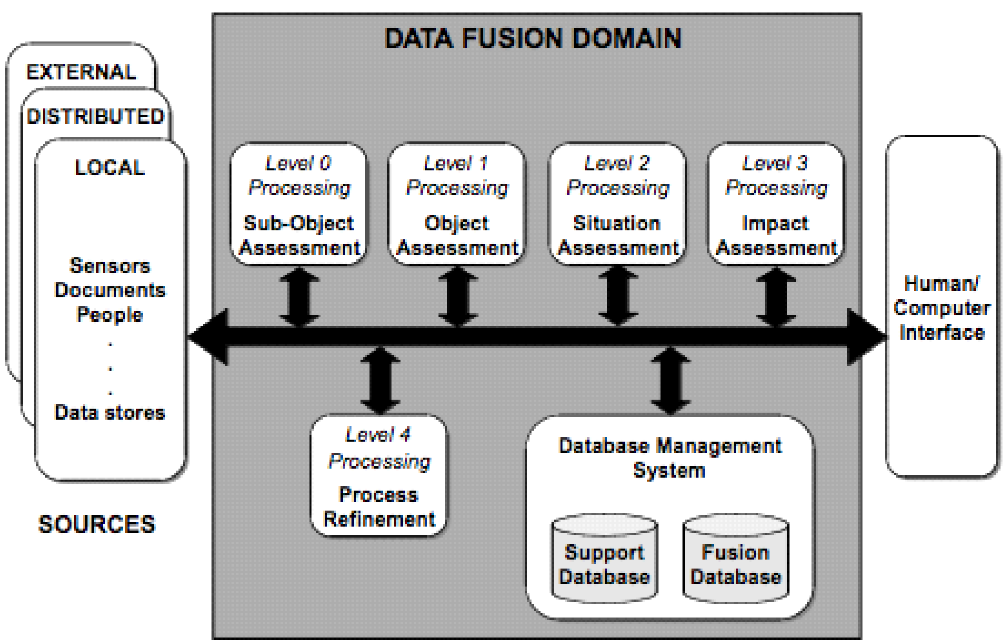

Figure 6: Revised JDL data fusion model [21].

Hall [23] stated that the model is useful for common understanding, but does not guide a developer in identifying the methods that should be used and could not be helpful on developing architecture for a real system.

4.5.2. Boyd's decision loop (OODA)

Observe, orient, decide and act (OODA) loop is one of the models to describe the decision making process in information fusion. Boyd has described four levels of the OODA loop model that are as follows [24].

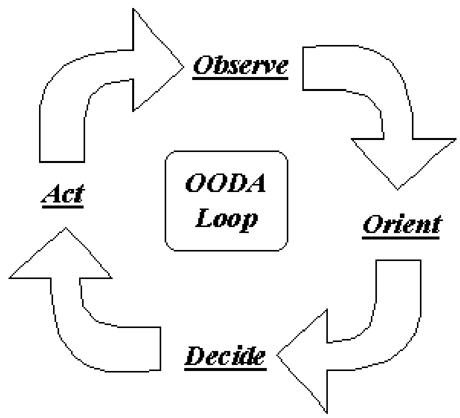

Figure 7: Boyd's OODA loop

Observe: the First activity involves gathering of observations and facts of the environment. According to Ware [25]"*more information is acquired through the vision than through all of the other senses combined*".

Orient: the next level includes perform a situation assessment related to the gathered data. Boyd describes, this phase is affected by factors like generic heritage, cultural traditions and previous experience as well as the mental process of analysis. So, the visual system should act as a cognitive tool to ease the mental processes of analysis

Decide: make the decision considering the likelihood of alternative hypotheses and the consequences of each hypothesis. Thus, the visualization system should be designed as an important part of the decision making support software. It is the bridge between data and seeing the picture which will allow the commanders to envision tactical alternatives [26].

Act: the decision maker act based on the decision. Thus, the visual display should be designed in such a way that supports decision making process.

This model lacks the appropriate structure for identifying and separating different sensor fusion tasks.

4.5.3. Other Models

There are other models such as the waterfall model and the omnibus model. The waterfall model emphasizes on the processing functions on the lower levels [27]**.** At level 1, the raw data is properly transformed to provide the required information about the environment. Level 2 is composed of feature extraction and fusion of these features.

Thus, the water fall model is very similar to the JDL model and it suffers from the same drawbacks. Water fall model is more accurate on analyzing the fusion process than other models. However it suffers from the lack of any feedback data flow.

Bedworth and O'Brien presented the Omnibus model in 1999 based on the strengths and weaknesses of existing models [28]. The cyclic structure in Omnibus model can be compared with the Boyd loop, but provides a much more fine-grained structuring of the processing levels.

4.6. Visualization Importance in Sensor Fusion

A lot of sensor fusion applications process large number of data in order to produce better estimation of data. Though, entirely automatic sensor fusion is often impossible because of noise, inconsistency and uncertainty involved in data. Hence Visual displays are the core of the fusion process in order to assist analyst assessing fused data and increase the data understanding. Information visualization is a solution for exploration of sensor data and offers opportunities for improvement in multi sensor data fusion.

5. Information Visualization

This chapter gives a general introduction to information visualization and provides a brief literature background of related work and techniques in this area. In this chapter, the visualization technique that is appropriate for this thesis is presented. To limit the scope more, I focused on techniques that would help with the visualization of the sensor data in real time on mobile screen.

5.1. Visualization

Nowadays there are almost no limitations for storing information however analyzing large amount of data and deriving valuable information hidden within it, is a great challenge. One way to manage this challenge is Information Visualization (InfoVis). Researchers focus on how visual data representations can assist people to better understand and gain insights into these large and complex datasets. The major objective of Visual Analytics [VA] is amplifying cognition and not just drawing nice graphics. Williams [29] stated that information visualization is "*a cognitive process performed by humans in forming a mental image of a domain space*".

Since then, several different definitions and various descriptions of the field appeared. One of the widely cited definitions of information visualization is by Card [30]: "*Information visualization is the use of computer-supported, interactive, visual representations of abstract data to amplify cognition*."

According to the above definition, three main characteristics of information visualization are defined by Viola as follows [31]:

1. Interactive systems: information visualization is about interactive tool.

2. Abstract data: According to Chen [32], abstract data typically describes non-spatial, high-dimensional information that is often hierarchical or network-structured and contains multivariate parameters.

3. Amplify cognition: The major goal of information visualization is "*amplify cognitive performance, not just to create pretty pictures"*. This main objective can be found in almost all definitions of [VA], for instance "*Gaining insight into the data*" [33] "*, making new discoveries*" [34] or getting an "*Ah-ha*" effect when exploring the data [35].

Scientific visualization which is focused on the visual representation of the physical data as opposed to information visualization which is visualization applied to abstract data. The data transformations which typically convert the raw information to a well-organized data format are a central component in the visualization reference model.

Tufte [36] defined the characteristics of a good visualization by two graphical principles: graphical excellence and graphical integrity as follows:

- Graphical excellence: It is the well-designed presentation of data communicated with graphical clarity, precision and efficiency [36].

- Graphical integrity: Clear and detailed labeling should be used to defeat the graphical distortion and ambiguity; the representation of numbers should be directly proportional to the numerical quantities represented; show data variations and not design variations; the number of information carrying dimensions should not exceed the data dimensions; show deflated and standardized units in time-series displays of money; graphics must not present data out of contest; convincing graphics should demonstrate cause and effect[36].

- Maximize the data-ink ratio: The quantity of elements present in visualization should not overload the reader with too much elements [36].

- Design aesthetics: the complexity of the data should match the simplicity of design[36].

5.2. Information visualization challenges

One of the aspects of visualization technology is to support the exploration and analysis of very large amounts of data. There are several techniques for explore and analyzing various kinds of data. Although information visualization techniques are used broadly these days but still there are some problems that need to be taking care of. One of them is visualizing large amount of data without overcrowding the displays. Another problem is the flexibility of the visualization tools. There are different users with different interests and expectations. A visualization tool should fulfills all the user needs so it should be flexible in a way that users be able to adjust it due to his own needs. One of the goals of this master thesis is to bring the users to the focus and choose the visualization techniques and methods to fit their exact needs.

5.3. Visualization Reference Model

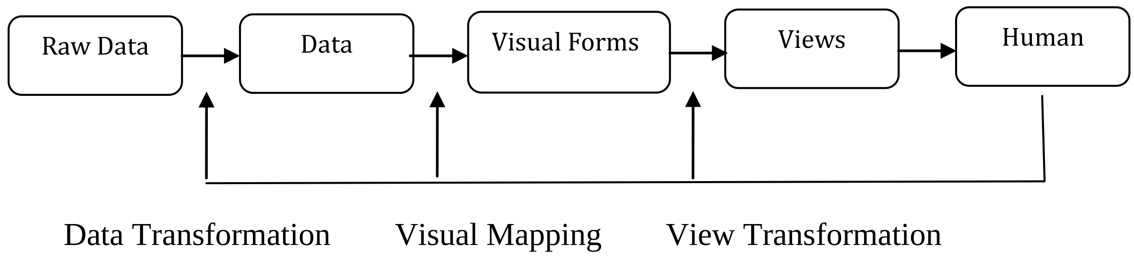

Figure 8: The visualization pipeline showing the path from raw data to visual representation (Adopted from [30]).

A model called the visualization reference model was suggested by Card [30] to convert raw data into a visual representation. Figure 8 demonstrates the model and show the major steps which is as follows:

1. Data Transformation: The first step is to convert the raw information to a well-organized data format. In this step, missing values can be interpolated, the data can be filtered, or invalid information can be corrected. Additionally, data mining and clustering techniques can be applied at this stage in order to compose meaningful formats of the data (Fayyad, Grinstein, and Wierse [37] - Keim [33]).
2. Visual Mapping: The second step is mapping the dataset to a visual form and is the heart of the visualization process. The data items specified in the previous step are mapped to geometric primitives such as points or lines, and to their visual attributes such as color, position, etc.
3. View Transformation: In the third step the visual forms are integrated into views which are shown on the screen and which can provide view transformations such as user navigation.

After the raw data has been transformed into visual views, the user can interpret and reconstruct information by looking at the views.

5.4. Visualizing Spatio-temporal Data

In this master thesis, we are dealing with spatio-temporal data from multiple sources (Camera, Radar, etc.). Spatio-temporal data is the data that contains both space and time information. For achieving effective visualization it is vital to consider the characteristic of the data which needs to be presented. According to Ormeling [38] representation of spatio-temporal data consists of three important components: time, space and objects.

Peuquet [39] defines how spatio-temporal data are categorized into three components:

- Objects: Indicate the objects that are present at a given location at a given time.
- Space: Indicate the location occupied by a given object at a given time.
- Time: Indicate the times that a given object occupied a given location.

It is challenging to visualize spatio-temporal data since there are three dimensions to consider (one dimensional time and two dimensional spaces).The most commonly used spatio-temporal visualization techniques are static maps and animation. Static maps are the first technique used for geo-visualization. In static maps, for indicating changes in time or representing an event at a certain time graphic attributes such as position , orientation , color are used. Animation is a sequence of image used to convey illusion of movement [40]. It is inherently a change of some visual representation over time. Thus, it is naturally used to facilitate perception of changes in some model over time [41]. According to Kaheo [42] animation help improve motivation and make a difficult topic more approachable. Ware's [43] observe that the brain has a strong tendency to group moving objects in a hierarchical fashion. Zongker and Salesin [44] describe a number of design principles that make animation presentations effective. Griffin [45] compares animated maps to static small multiples displays, finding significant advantages in both speed and accuracy for animated maps.

Static maps are insufficient for the task of representing time while animation offers significant advantage by consistently represent changes over time [46]. In this research animation is better suited because it can explicitly present information over time. In other words static maps are restrictive in this context due to the fact that only one variable can be represented with static maps and users should switch between maps to compare different variables.

Animation is created by rendering the data for each time step to a frame of an animation. Usually, color coding is used to represent the data in each frame. As such, animations are useful for comprehending the evolution of time dependent data within a spatial context.

For achieving comparison of different time steps users would be compelled to browse through the animation over and over again, especially if the amount of data to be visualized is very large. In recent years this issue has been addressed by several researchers. Their efforts have resulted in the development of the following concepts:

- Overview plus detail.
- Focus context, and Information hiding.

Overview plus detail and focus context are widely used concepts for visualizations that are dealing with heavily loaded graphics. Overview plus detail techniques represent the data as an overview and allow zooming in for a detailed data analysis [30]. Since detailed views are represented separately from the overview, further efforts are required for understanding the data. Therefore, the focus context techniques try to combine overview and detailed view within a common display [35].

Applying overview plus detail or focus context could solve the problem of overloaded and cluttered displays due to the limitation of the display.

5.5. Uncertainty Visualization Techniques

Sensor data measurements always have some level of uncertainty due to the noise, errors, imprecision, etc. and analyst should be aware of the uncertainty included in data. Hence there is not only a need to visualize the sensor data but also to visualize the uncertainty associated with data.

Most of the previous work in uncertainty visualization has been developed in the area of Geographic Information systems, GIS [47]. Pang [48] present several categories for representing uncertainty: add glyphs, add geometry, modify geometry, modify attributes and animation. These methods were tested and proved to be useful for visualizing uncertainty and help the analyst analyze the data.

Griethe [49] also describe a list of techniques for displaying uncertainty:

- Utilization of free graphical variables such as color, size and position.
- Additional objects such as labels, different images or glyphs.
- Use of Animation and parameters such as speed and duration.
- Interactive representation such as mouse interaction.

Furthermore according to [49] uncertainty information should not conceal or obscure the underlying data. Hence some the mentioned techniques are not applicable for visualizing uncertainty in this thesis.

5.6. Choosing the Visualization Technique

Scatter plots is one of the most popular methods for exploring relationship between variables. It is a widespread data mining visualization technique which helps in finding clusters and trends in data. Scatter plots visualize multidimensional data by mapping two dimensions to the X and Y coordinates. Visualizing the data with individual scatter plots would not show the development of the two variables over time and animation is the best way for showing the changes in variables over time. Furthermore, as mentioned above it is also one of the common methods for visualizing uncertainty which is part of our visualization.

Rosling [50] applied animation to scatter plots in 2007. Overall, there is no clear view on the usage of animation in visualizing spatio-temporal data. Researchers presented Opposing views in prior research. As an example, Griffin [51] suggest that animation is suitable for identifying moving clusters whereas other researchers argue that animation is not a suitable technique for analysis tasks since it lacks comparable contents [52]. Hence, there is a need for further research to investigate animation in visualizing sensor data fusion platform.

Focus context, and Information hiding is used to eliminate the problem of overcrowded and cluttered screen. Due to the resolution of the data, many data points lies at the same coordinates. In order to eliminate this problem zooming and panning added.

6. Mobile Applications

One of the initial constraints for this industrial thesis was to visualize the sensor data fusion platform in mobile devices.

This chapter gives a brief introduction on different mobile platforms that are available. The challenges in developing mobile applications will also be reviewed and finally the choice of mobile platform for this thesis will be discussed.

6.1. Mobile Device

The world is facing a new mobile era and for the first time in history, more smart phones were shipped than client PCs. This has had a great influence on mobile application development, as it clearly shows the shift from personal computers to mobile devices, where mobility and handling have won over the users.

Mobile applications are considered to be one of the fastest growing trends in Information Systems industry [53].

Software companies attempts to cover the mobile market as much as possible with their applications. Table 1 shows the most important mobile operating systems and the programming languages for developing mobile applications in related operating system.

Operation Systems	**Google Android**	**Apple iPhone**	**Microsoft Windows Phone**
Programming Languages	**Java**	**Objective-C**	**C#**

Table 1: mobile operating systems

According to Charland [54] several major features of mobile devices include screen size, high quality resolution, changing portrait/landscape view, input devices and HTML5 support have an influence on the final user interfaces of mobile application.

Google Android

Android is produced by Google and its first release was launched in 2007 [55]. According to the official Android website, "*Android is a software stack for mobile devices that includes an operating system, middleware and key applications*" [56]. Android provides the "*core set of applications*" [56], and also it is possible to download further applications through Google Play service [57]. Android can be found in millions of mobile device which makes it a major platform for application developers. Android applications are written in Java programming language and are based on Linux [55]. Android is an open development platform which gives the developers opportunity to build innovative applications. It let developers to have access to the same framework APIs and application programming interfaces which are used by the core applications [55]. Android uses a DALVIK virtual machine to run its applications. The Android SDK offers a group of tools required for developing Android applications including Android SDK Manager, the AVD Manager, the emulator and the Dalvik Debug Monitor Server [55]. Furthermore, Android SDK runs on almost all available operating systems which make it an easy and affordable choice.

iPhone OS

iOS known as iPhone OS is a UNIX-based mobile operating system developed by Apple. It is the default operating system in iPhone, iPod Touch, and iPad mobile device. All iPhone development is done in XCode and by Objective-C language. Important features like support for animation, 2D and 3D rendering, video and still image manipulation are part of graphics technologies. The fact that for developing iOS application developers need a Mac computer makes it quite expensive choice.

6.2. Challenges of Smartphone programming

In order to answer the research question 2 we need to analyze the limitation of mobile design and the possible problems that may occur.

Generally developing programs for a phone is a different experience than developing desktop applications or web sites. The reason is that there are many limitations in developing mobile applications [58].

According to Chittaro [59] challenges in developing mobile applications are as follows:

- Small Screen: One of the main challenges in mobile device is their displays which are very limited (small size, low resolution, less colors, etc) [59].
- The other problem is the on-board hardware (CPU, memory, buses, graphic hardware) is limited compared with what are available on desktops and servers [59].
- The input is often inadequate for complex tasks [59].
- Keyboards are small. On some smart phones physical keyboards do not exists.
- Devices are limited to the OS the manufactures have selected [58].

As a result of the limitations, it is impossible to scale visualization applications developed for desktop computers to mobile devices. Thus, it is essential to approach mobile visualization differently. Moreover, the knowledge available on developing visualizations for the mobility context is limited.

According to Murphy [58], Traditional desktop visualization has limited applicability to mobile visualization. Chittaro [59] proposed new approaches that specifically target mobile devices. These approaches are described as follows:

- Visual references to off-screen area: In this approach, the detail view is augmented with interactive visual references to the context. Therefore, although the context view is not shown, users are aware of parts of the view that are relevant to the current task [60].
- Navigation techniques: This approach keeps the traditional idea of navigating visualization by scrolling and zooming while reducing the cognitive complexity by taking also into account the input techniques used in mobile devices [60].

6.3. Choose the platform

Google android has been chosen as the platform for developing the visualization tool mainly since it is a truly open and free development platform based on Linux. So it does not need any additional tools and has the lowest cost. Furthermore, in android all programs are written in Java and the author is more familiar with developing android applications.

7. Implementation

The implementation part of the research consisted of two distinct applications, a client and a server application. This chapter will describe the practical aspects of the implementation such as environments, software architecture and the communication protocol between both parts.

7.1. Environment

Windows was used as the operating system for the development environment. The mobile platform was android and Eclipse was the chosen integrated development environment (IDE) as recommended by Google Inc. The code was written in Java and used Java 2D API for the 2-dimensional image rendering.

7.2. System Architecture

7.2.1 Client

The client application was implemented on an Android environment. Two different versions of this platform were used throughout the development, starting with an Android 2.3 based device which was then replaced by an Android 4.0 device, the latter being the target platform.

The network thread establishes a connection with the server and starts to receive data. This data is parsed and passed on to the Java 2D thread. The Java 2D thread holds a list of objects that is updated to hold the current objects that needs to be displayed. The list of objects is included in appendix B.

7.2.2. Server

In order to develop a functional client, a server was developed in Matlab to provide the client with the data stream to be visualized. The server communicates with the client with a specific protocol. This protocol is described in the next section.

The server program was developed to be a proof-of-concept of a device that would be used in a truck to supply the visualization device with live sensor data. It complies with the protocol defined for live visualization and, therefore, makes use of UDP communication to transfer the data.

7.2.3. Prototyping and Development

The visualization framework allows continuous navigation through the scene without any delay or freezing when new data is loading in order to render the current scene. The visualization framework renders the objects in bird's-eye view. The framework renders the main truck, surrounding objects, the prediction of the truck, the prediction of the object around the truck, the velocity of each objects and the covariance contour (uncertainty) which is thoroughly describe in the next sections. The main truck is visualized in the center of the screen and all other objects are rendered relative to the main truck position. In sensor data fusion platform objects are classifying based on their type which could be car, a truck, a pedestrian and etc. Hence, the objects are rendered base on their type. The objects are rendered with a specific color in order to easily distinguish the data that are received from each sensor.
One unit of the coordinate system is equal to one pixel on the screen. Android coordinate system is standard Cartesian coordinate system with the origin point (0, 0) on the top left of the screen. Therefore, the coordinate system needs to be adjusted to have the layout in the center of the screen.

7.2.4. Prediction of objects and truck

In order to assess the risk of an accident it is essential to interpret complex traffic situations. Hence it is necessary to predict the position of the vehicle and other vehicles around it over time intervals as long as several seconds.

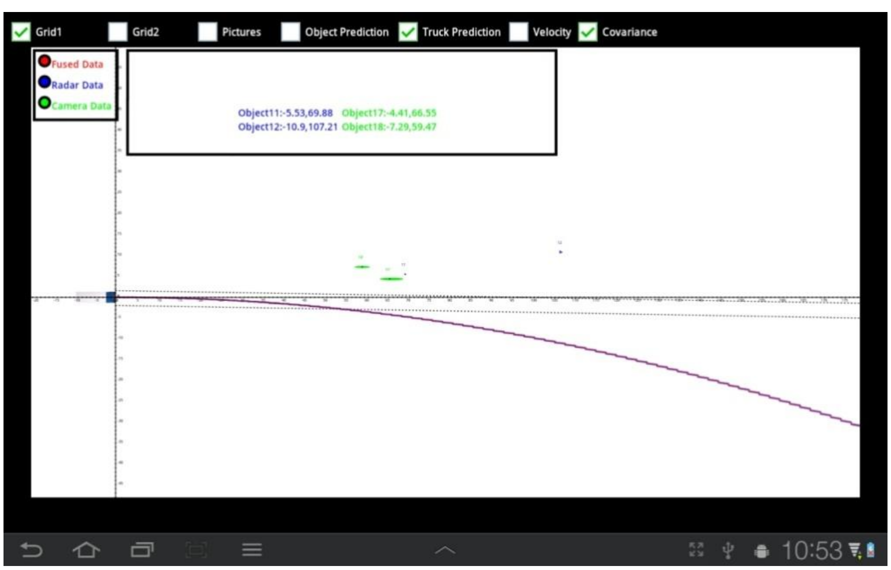

Figure 9: Truck prediction

The predicting of the position of objects visualized in next 10 seconds. The position states for the main truck and objects around the truck was Predicted using a constant acceleration assumption as follows:

$$\text{longPosition} = \text{longPosition} + \text{longVelocity} * \text{predictionLength} + \text{longAcceleration} * (\text{predictionLength}^2)/2;$$

$$\text{latPosition} = \text{latPosition} + \text{latVelocity} * \text{predictionLength} + \text{latAcceleration} * (\text{predictionLength}^2)/2;$$

Figure 10: Object prediction

7.2.5. Velocity

Velocity is the rate of change of the position of an object which is equivalent to the speed and direction of motion. Speed describes how fast an object is moving; whereas velocity gives both how fast and in what direction the object is moving.

Figure 11: Velocity

7.2.6. Covariance

Measurements are not perfect. Measurement error is the differences between true value and result value. Uncertainty is a measure of the correctness of a measurement result. Though the exact measurement error is never known but a range of possible values can be estimated. The information related to uncertainty estimation can be described in covariance matrix. Covariance matrix is a measure of estimation uncertainty. An uncertainty statement for a complex quantity represents a region of the complex plane. This region is often an ellipse. The size of the covariance ellipse (ellipsoid) indicates the localization uncertainty of the position estimate.

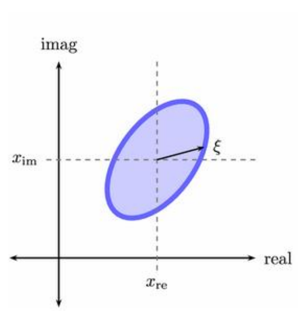

Figure 12: Covariance ellipse

For drawing the covariance we calculate the width and height and angle of covariance ellipse in Matlab and sent that to the device to visualize the covariance ellipse.

Figure 13: covariance contour

7.2.7. Calculate the Road Lane

Accurate estimation of the geometry of the road is essential for a variety of automotive applications, since it empowers prediction of the future path of the vehicle and detection and response to other vehicles or threats on this path.

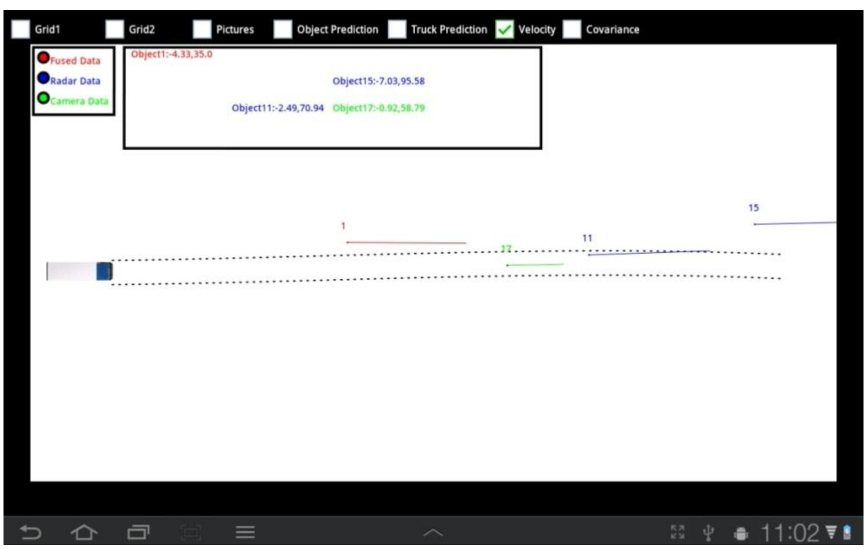

Figure 14: Road prediction

The road lane calculated according to the following formula:

$$R = \begin{bmatrix} \cos(-\mathrm{psi}_{\mathrm{rel}}) - \sin(-\mathrm{psi}_{\mathrm{rel}}) \\ \sin(-\mathrm{psi}_{\mathrm{rel}}) - \cos(-\mathrm{psi}_{\mathrm{rel}}) \end{bmatrix}$$

$$\mathrm{Cart} = \mathrm{R} * \begin{bmatrix} \eta_{\mathrm{x}} - (\mathrm{C}_0 * \eta_{\mathrm{x}} + \mathrm{C}_1 * \eta_{\mathrm{x}}{}^{2.2}) * \eta_{\mathrm{y}} \\ \eta_{\mathrm{y}} - \mathrm{y}_{\mathrm{off}} + \mathrm{C}_0 * \eta_{\mathrm{x}}{}^{2.2} + \mathrm{C}_1 * \eta_{\mathrm{x}}{}^{3.6} \end{bmatrix}$$

η_{x} : The longitudinal position of an object.

η_{y} : The lateral position of an object.

$\mathrm{y}_{\mathrm{off}}$: Describes the ego vehicle offset to the ego lane.

$\mathrm{psi}_{\mathrm{rel}}$: The estimated heading angle.

C_0 : The curvature state of the road.

C_1: The curvature rate state of the road.

The data sent from the sensor data fusion platform in Matlab using Simulink to the tablet. The road lane calculated according to the above formula in the device.

8. Usability Evaluation

8.1 Introduction

Empirical evaluation use experiments that make use of functioning prototypes of systems and involve the final users of the product. Based on the collected data, experiments are divided into qualitative studies and quantitative studies. Common evaluation methods in the context of information visualization are categorized into four groups [61].

- Controlled experiments comparing design elements
- Usability evaluation of a tool
- Controlled experiment comparing two or more tools
- Case studies of tools in realistic settings

Usability evaluation methods can be categorized into three groups.

- Expert based methods: A usability expert examines an application and estimate it's usability for certain users. There are no users in this method and given results are entirely based on the experts judgment.
- Model based methods: in this method an expert uses formal methods to predict user performance when carrying out a given test in an application. Again, no user is involved during this usability evaluation.
- Usability testing (user based methods): in this method a sample of users tries to use application. The users perform a set of pre-defined tasks. This method gives more accurate and reliable estimation of an application's usability because users are involved in testing. Usability test is an experimental method that can provide both subjective and objective feedback. The method lets the users test a concept or prototype in a laboratory environment or in reality. The participants should be as alike the expected target group as possible depending on what kind of results that are aimed at. The expected time durance for usability test should not be more that 30 minutes. Totally one hour including introduction and final discussion. It is important that the participants are informed that it is not their performance but the products usability that is tested and evaluated [62].

Usability testing is based on how the feedback from the users is collected. Since our focus is on the user and our design was user centered design we have chosen usability testing for evaluating the visualization tool.

There are different methods for usability testing. These methods are as follows:

- Interviews and videos: The testers ask users question about their experiences in using the application. The users point out their views about the system and likes and dislikes in carrying out specific tasks on the application. A video may be also used which can help in analysis of the data during the users interaction with the application.
- Unstructured user based tests: the user and the tester together interacting with the system to agree on what works, what does not work, what is good with the design and what might be problematic with the design. This method can be effective especially in earlier stages of the design.
- Questionnaires: This technique gives the user ideas about an application by asking the users fill in questionnaires as they use the application or immediately after using the application. How to design the questionnaires is an important issue if questionnaires are to be used. The purpose of the usability testing should be clearly brought out in the questionnaires by designing the questions to fit the intended areas to be tested. The use of questionnaires guarantees less time to be spent in testing, wider user group can be targeted and the results of the questionnaires can be easily and effectively analyzed. The questionnaires must however be reliable and valid to ensure testing for efficiency and effectiveness of the application
- Observation: Observation method is regularly used to test for effectiveness of the system and user satisfaction. During the usability testing session, the tester observes users as they use the system to complete tasks. They observe the user's attitude, reactions, emotions, facial expressions, verbal comments, sitting adjustments and so on to establish the user's attitude towards the system.
- Think-aloud protocol: The general principle of the technique is to encourage the users to think aloud while performing the tasks.

There are different ways of measuring the usability. International organization for standardization (ISO) [63] identified three usability measures which include satisfaction, effectiveness and efficiency. The usability process which is conducted in this research, measured against user's satisfaction effectiveness and efficiency.

8.2 Test Goals

Usability test measures the suitability of the product for users as well as the satisfaction users have with the product. According to Dumas and Redish [64] "*Testing usability means making sure that people can* *find and work with the product's functions to meet their needs*". Hence, the goal is analyzing how well various functions of the prototype work in order to represent sensor data fusion platform and to satisfy users by providing relevant functionality.

The test goals break downs leads to following sub-goals:

- Assess the effectiveness and efficiency and satisfaction on the tool by using current functions.
- Getting user feedback on the missing function for future improvement and recommendations.

8.3 Test Design

According to Dumas and Redish [64] "*One of the essential requirements of every usability test is that the test participants attempt tasks that users of the product will want to do with it*" This indicates a very careful design of the tasks to be performed, especially since the time available for testing was very limited. Dix [65] suggests that:

"*In addition to evaluating the system design in terms of its functional capabilities it is important to be able to measure the impact of the design on the user. This includes considering aspects such as how easy the user learned to work with the system, its usability and the user's attitude towards it. In addition, it is important to identify areas of the design which overload the user in some way, perhaps by requiring an excessive amount of information to be remembered.*"

A simple method was used to gather usability data on a smaller scale as an informal test. It was an informal usability testing on considerably smaller scale than in the real usability tests. A user was asked to try out a specific feature of the prototype. The feedback from this informal method was used in the design and implementation work in order to find the major problems with the system and fix them before the main test study

8.4 Gather Usability Data

An informal usability test has been conducted on smaller scale before the real usability test with the real data. This informal test helped in detecting the problems of the Visualization tool and eliminating them before the main usability test. The test was formulated aiming to test the tool on two different size datasets and compare user performance over these datasets. In order to obtain how fast the task has been done the start point and end point of each task was recorded by user. The test data sent to the Visualization tool using Simulink.There were two feedbacks about the issues that discussed. The first was that the Visualization tool required a better grid to help users analyse the data more accurately. So, the users suggested adding a new grid to the current grid and an option to enable/disable it. The second feedback was the road lane which had some issues according to the users. The solution for solving the issues with the road lane was also discussed.

8.5. Test Session

The main usability test was carried out in Volvo Group test center in Hällered. The issues detected in informal test were eliminated before the main study. Eight domain experts have chosen to participate in the study. They were all aged between twenty seven and forty-five. The main factor that was considered in selecting the participants was being familiar with sensor data fusion platform and being representative users for the Visualization tool**.** Considering these goals, we did not have access to more than eight users. However, according to [66] approximately 80 percent of the usability problems in a product can be detected with 6 users per test grouping. As the number of test users rises beyond 6, there is a diminishing returns factor as most of the major usability problems have already been revealed. The equipment for the test session included a test truck equipped with internal and external sensors, an automotive PC hosting the data fusion platform and an android tablet. The scenario consisted of the main truck with users inside that and a second truck a head of the main truck and other cars each driving with different speed in other lines. So the users were able to analyze each feature (Positions, Velocity, Road lane and etc.) of the visualization tool in real time such as the velocity of main truck with the velocity that the tool is showing. In this study the Visualization tool is tested against the three ISO usability measures efficiency, effectiveness and satisfaction [67].

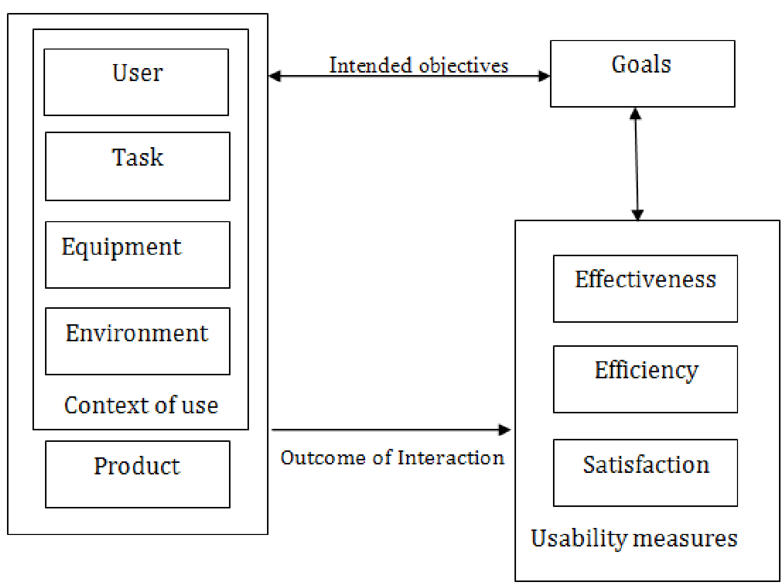

Figure 15: ISO Usability Framework

The efficiency and effectiveness of the system evaluated by looking at how the Visualization tool assists the user to accurately complete the tasks and observe time and effort required to accomplish particular task. The user satisfactions evaluated by investigating to what extend the users expectations are met.

This test session divided to three parts: the introduction, the actual test and the sessions. In the introduction part users were given a brief introduction which aimed to demonstrate the system's functionality and to let users learn and get comfortable with the functionality that was going to be tested. The actual test session and questionnaire session aimed at collecting test data for usability evaluation. In this study a think-aloud protocol was used. The users conducted a short task and asked to evaluate different aspect of the Visualization by giving both positive and critical feedback. The introduction took approximately 10 minutes, each user was told about the objective of the tests and what they need to do during the test.The tasks consisted of a set of 7 tasks in order to have more time to freely discuss about the Visualization with users. The tasks are described in appendix C and included exercises in using the tool. The users were asked to record the start time and end time for each task. Afterwards a questionnaire was given to users in order to gather subjective ratings.

8.6. Results & Analysis

In the previous section the test goals, design and test session described. This section concentrates on the analysis of results.

The assessment data was collected by asking the users to do a series of. In the first part of the tasks the users were doing the defined tasks and answered to the questions. In the second part the users gave rating scores to each usability measures. This was the source for quantitative assessment. The score rating was of seven types: 0(Strongly Disagree), 1, 2, 3, and 4(Strongly Agree).

For measuring the efficiency and effectiveness of the tool, correctness and completeness and the time spent on each task was taken into account. If the user's answered the entire question in each section, it considered as a complete answer. For correctness, the user's answer to each question was analysed in order to see if the user provide the correct answer to the question. For calculating the average time users spent on each tasks, the duration of the time the user spent to finish the tasks with the system was calculated. This time will be needed to compute the efficiency of the system, which is about the number of the tasks that can be done by the user in a time interval.

All users needed a short time to get familiar with the tool.90% of the users gave correct answers to first task which confirms that the graphical variables was fitted to the objects and types and help users perceive the environment.

The users were asked regarding the road lane in task 2 and asked to compare the road line visualized with the actual road line including road line element in Matlab.

Task 3 and 4 the questions are about the prediction of the position of the truck and objects around it in the next 10 seconds and users were asked to analyse the visualization regarding the predictions.

Task 5 is regarding the velocity (speed) of the objects and users were able to easily compare the speed of the truck with the velocity that the visualization tool visualized.

By these 5 tasks we were interested to analyse if the representation method clearly illustrates different scenarios and if users can easily conceive these scenarios. We were also interested to see how much time and effort does each user need to conceive each scenarios. Scene understanding tasks were solved by 80% in average.

We were also interested to know if the users can thoroughly understand distance measurements by task 6. Task 7 is regarding the uncertainty involved in the data received from sensors. In this task users were asked to analyse with objects has the higher level of uncertainty.

More than 80 percent of the users indicate that they either used animated map before or they are familiar with it.

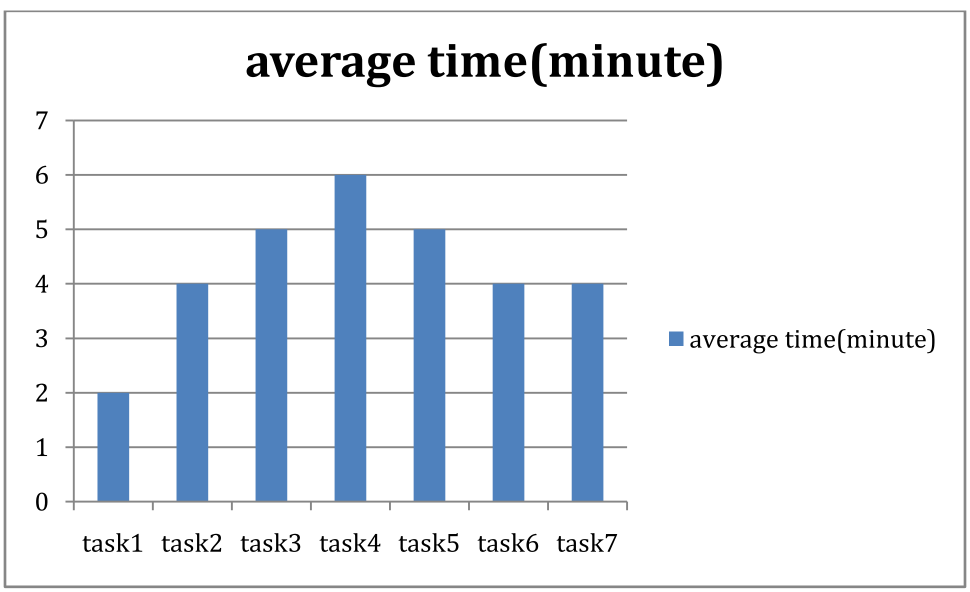

Figure 16: average time spent on each tasks

The usability test cleared that the level of details and complexity effects on the understanding of the users from the visualization tool. The possibility of filtering the information allowed users to study and analyze a specific feature of the data at a time and avoid complexity that is usually involve in visualizing large data.

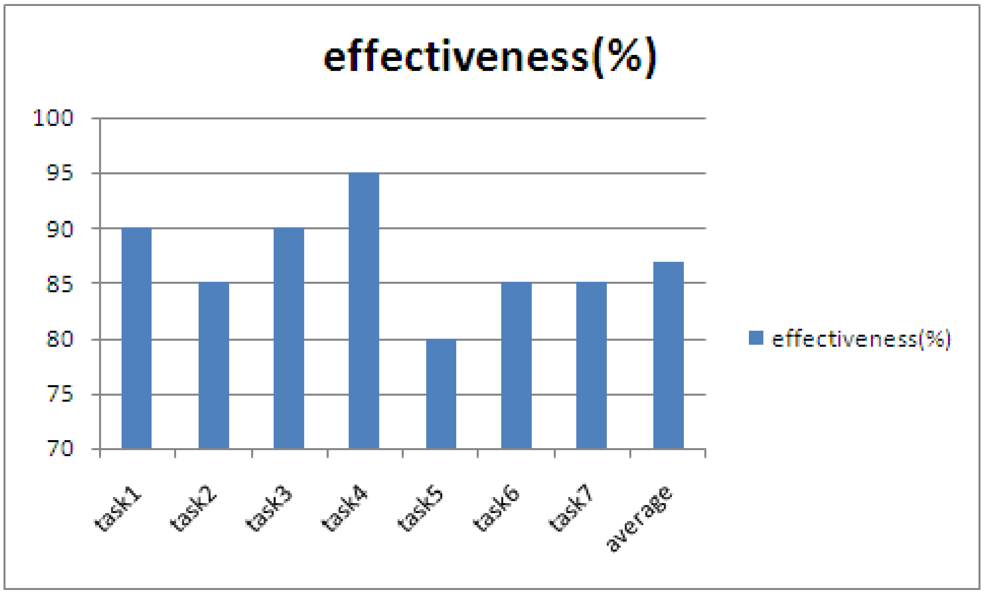

Figure 17: correctness of each task

Effectiveness in this study is measured by how many answers are correct. Figure 17 indicates the effectiveness scores for each task. As you can see in the figure 17, task 4 has the highest level of correctness and also needs more time to complete. This cleared that experienced users were able to analyse the situation with high uncertainty perfectly. The reason could be that experienced user has a good understanding of the situations including radar and camera accuracy which results in noise and uncertainty in data.One of the important features of the visualization was receiving and visualizing the data in real time and the test reveals that the visualization is in real time without any delays.

The tests also reveal that when the time of observation increase it is harder to keep track of the objects. While with the bigger observing time users were able to give more correct answers to the tasks.

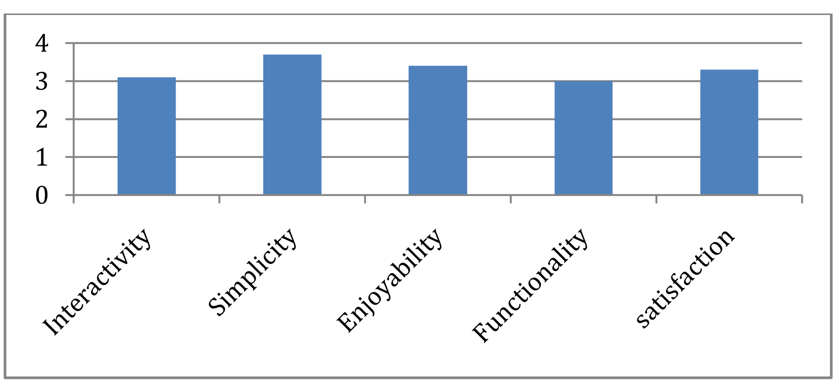

Figure 18

One of the essential aspects defined as an initial constraint was simplicity. The design of an interface should be simple enough to make the user interaction reasonably simple. The test reveals that the Visualization tool was simple and easily understandable. More specifically users were able to find the required information with only a few clicks.

Regarding the functionality of the tool most of the users rated the functionality very satisfying though they mentioned that with the development of the sensor data fusion platform more functionality could be added to the tool.

Learnability is also one of the fundamental attribute in usability. The system should be easy to learn so that new user can quickly start working with the system. Learnability is to examine learning effort of using the system and to measure how easy users get the overview of what the system offers. Learnability is also examined by how many questions subjects can answer correctly and how much time it takes on the system.

Tasks	Correctness	Speed
Task1	90%	2min.
Task2	85%	4min.
Task3	90%	5min.
Task4	95%	6min.
Task5	80%	5min.
Task6	85%	4min.
Task7	85%	4min.

Table2: Learnability of the visualization Tool

As indicated by Table 2 users were easily able to answer task 1 in short time due to the lower complexity level of this task while task 4 which is related to the prediction of objects needs more time and effort.

One the usability problems identified was the lack of feedback which caused some confusion in the first task. Users indicate that it would be beneficial to show the system current state.

Another cause of confusion was the fact that all the functions was turned off by default. Hence the users were not able to receive any feedback while activating different functions.

Despite the positive feedback regarding the functionality of the tool, users presented their feedback about the functionality that could be added in future in post-test discussion. Their comments point towards functionality and features that assists in the investigation of sensor data.

All in all, the usability test show that the users are able to draw accurate conclusions about the data and scenarios used in the usability tests by using the visualization tool.

9. Conclusion and Future Work

In this thesis project we aimed to investigate the possibilities of applying visualization techniques on sensor data fusion in a real case and to specify user's requirements, develop a visualization tool that meets the requirements of users and finally evaluate the visualization tool. It has been defined to visualize the sensor data in 2 dimensional as an initial constraint since most of the data can be easily read and layered in 2D. The Application will contribute to close the gap between researchers in sensor fusion and in HMI presentation concepts. To specify the requirement of the users an interview with potential users has been conducted and a set of requirements were defined. The visualization tool was developed according to the Software Engineering techniques and Computer-Human Interaction guidelines to implement a well-designed object oriented application that is easy to maintain and extend. A literature study has been conducted on the possible evaluation methods that exist for evaluating information visualization tools that has been discussed in chapter 8. Moreover, one of the common issues in developing visualization is the evaluation of their usefulness which in this thesis was evaluated to ensure it fits to user needs.

By studying the tool with automotive experts, we have learned that the InfoVis techniques used can lead to better understanding of sensor data including uncertainty and noise involved in data which provides opportunity for improving in the SDF platform.

The uncertainty involved in sensor measurement visualized as a covariance ellipse (ellipsoid) which has been describe thoroughly in earlier chapters. The size of the covariance ellipse specified the level of the uncertainty of the position estimates.

One of the main limitations in a mobile device is the screen space that can lead to quickly end up with too much to visualize in a too little display area. In order to solve this problem we categorized the main important features that need to be visualized and filter the less important ones. Users are also able to activate different features using checkboxes. Navigation functions such as scroll and zoom that allow the user to move among different parts of the visualization is also helps in solving this problem.

One of the challenges during this thesis was the fact that sensor data platform was under development and depending on the updates available the requirement of the users were also changed. Hence, with improvements of the sensor data fusion platform the visualization tool needs to be updated as well.

There are some limitations in visualizing 2D representation of data. As an example it is hard to visualize and identify a pedestrian or a tree in 2D representation. 3D representation allows the user to model objects and produces many views of the design by simply rotating the model. So, one of the future works could be visualizing the data fusion platform in 3D representation.

Though the filters allow the user to visualize different aspects of data separately but it would be beneficial to add filters according to the user's role in the company. While a researcher needs all aspects of information to analyze the platform, there is no need to visualize all levels of data for demonstrating purposes to a group of people that do not need to know all the details.

Meanwhile as developing sensor data fusion platform is complex and time consuming the offered solutions for visualizing sensor data should be as simple as possible.

Furthermore, the thesis reveals that close integration of the industrial applications with existing tools and methods already available is essential. The reason is that engineers are usually not comfortable with new methods and tools they are not familiar. Hence they would not able to use these tools in their daily work. This was one of the reasons for choosing to write the server in Matlab and send the data via Simulink. It is one the important aspects that researchers in industry should take into consideration.

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Appendices

Appendix A: Interview Questionnaires

General information:

Name:
Email:
Experience:
Date:

1. What are the tasks you are interested to do using the visualization?

2. Please give priority to each task:

Tasks	1	2	3

2. What are the important factors in visualizing sensor data fusion platform?

3. Are you interested to see the sensor data fusion platform in 2D representation or 3D?

4. What additional functionality you are interested to have on the visualization?

5. Additional Comments

Appendix B

Here is the list of the information that is send to client:

Type		Size
id	1 int32	4 bytes
Object type	1 int32	4 bytes
Truck status	1 int32	4 bytes
Longitude position	3 int32	12 bytes
Latitude position	3 int32	12 bytes
Velocity	1 int32	4 bytes
Covariance contour	1 int32	4 bytes

Table 3: Object Information

Besides the objects, the following road properties are also transmitted to the client:

Lane info

Type		Size
Angle of road	1 int32	4 bytes
Road width	1 int32	4 bytes
Lane width	1 int32	4 bytes
Road curvature	1 int32	4 bytes

Table 4: Road Information

Appendix C

General information:

Name:
Email:
Experience:
Date:

Part 1

1.You can see objects are moving around the track, (could you see the object in the visualization tool in real time?)
If yes:
a. Please indicate which objects are visualizing in the screen?

b. Please indicate if the object is detected by Camera, Radar or is fused data?

c. Please indicate the type of objects (truck, car, pedestrian, etc).

2. Select the option to visualize the road lane. Choose the grid options.
a. Look at the road lane and compare it with the road lane the Visualization tool is drawing. Does it give you a correct visualization of the road lane in real time?

3. Select the prediction of the truck. Choose the grids options
a. What is the current position of the main truck?

b. What is the prediction of the position of the main truck in next 5 seconds?

c. Does it give you a correct estimation of the prediction of the position of the main truck?

4. Select the prediction for the objects around the truck. Choose the grids options
a. What is the current position of the objects that are moving in the screen?

b. What is the prediction of the position of the objects in next 5 seconds?

c. Does it give you a correct estimation of the prediction of the position of the objects around the truck?

5. Select the velocity checkbox to draw the velocity of the objects around the truck. Choose the grids options.
a. What is the velocity of the main truck?

b. What is the average velocity of object 1?

c. Does it give you a correct estimation of the velocity of the objects?

d. Is the average velocity of objects 1 significantly differs from the velocity of the main truck?

6. Enable drawing the picture of the objects

.

a. Estimate the destination of the main truck from the object 1?

b. What is the type of object 1? Truck Car Pedestrian

c. Object 1 is detected by: 1: Radar Camera Fused data

d. Is there significant changes in the destination of the main truck from object 1?

7. Select the covariance contour checkbox.

a. which objects has the higher level of uncertainty? Why?

Part 2

Please fill in the following questions according to the below scale:
0(Strongly Disagree), 1, 2, 3, 4 (Strongly Agree).

1. All in all it is easy to use the tool : 0, 1, 2, 3, 4
   Comment:

2. I was able to understand the scenarios :0, 1, 2, 3, 4
   Comment:

3. I found the system unnecessarily complex:0, 1, 2, 3, 4
   Comment:

4. I think that I would need the support of a technical person to be able to use this system:0, 1, 2, 3, 4
   Comment:

5. I was comfortable with the tool: 0, 1, 2, 3, 4
   Comment:

6. I liked the Visualization tool: 0, 1, 2, 3, 4
   Comment:

7. The visualization Tool helped me in accomplishing the tasks:0, 1, 2, 3, 4
   Comment:

8. I feel lost going through the system and performing the assigned tasks: 0, 1, 2, 3, 4
   Comment:

9. Overall, the system was effective in helping me complete the tasks:0, 1, 2, 3, 4
   Comment:

10. I completed the tasks quickly:0, 1, 2, 3, 4
    Comment:

11. Visual Quality of the Tool was satisfying: 0, 1, 2, 3, 4
    Comment:

12. Visual Comfort of the tool was satisfying: 0, 1, 2, 3, 4
    Comment:

13. This system has all the required features I would need:0, 1, 2, 3, 4
    Comment:

14. I found different functions of the tool well integrated: 0, 1, 2, 3, 4
    Comment:

15. Please rate the accuracy of the result. 0, 1, 2, 3, 4
    Comment:

16. The interface of the tool was pleasant and transparent to use. 0, 1, 2, 3, 4
    Comment:

17. Please rate the user interaction: 0, 1, 2, 3, 4
    Comment:

18. How satisfied were you with the system, including the features and the resulting display:0, 1, 2, 3, 4
    Comment:

19. I will use this system more in the future:0, 1, 2, 3, 4
    Comment:

20. What features of the visualization tool were the most useful features?