Impact of using mixed reality visualization to augment the exploration and analysis of water contamination events in a simulated car engine

TERESE NOTHNAGEL
Impact of using mixed reality visualization to augment the exploration and analysis of water contamination events in a simulated car engine

Inverkan av att använda “mixed reality”-visualisering för att förbättra utforskning och analys av vattenföröreningshändelser i en simulerad bilmotor

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ABSTRACT
The aim of this thesis is to understand the impact of virtual reality (VR) on user’s performance and experience in practical industrial applications. In particular, I collaborated with Volvo Cars supporting their current engineering design practices. VR has the potential to augment and thereby improve a person’s observational analysis. Current VR publications are focused on VR applications and their potential benefits and improvements, mainly towards science, industry, medicine, and education. Yet, no research on the impact of augmenting the exploration and analysis of water contamination events in a simulated car engine has been done. In this thesis, this issue has been explored by performing a task-based controlled user study with two conditions: the Workstation and the Wall. The Workstation is the current system examining contamination events in a video with keyboard and mouse on a normal desktop screen. The Wall is the developed system examining contamination events through interaction with an Xbox-controller and Kinect head-tracking motion control on a 4K screen (400 x 240 cm projection surface) with stereoscopy using passive 3D glasses. This thesis is a pilot to discover meaningful differences and trade-offs for future studies. The result of the study shows significant differences between the two conditions. Where the Workstation is faster, but less precise, the Wall is more precise and gives more options for analysis. Nevertheless, the current version of the Wall has some weaknesses, in particular, lag and discrete steps in the rotation following the head-tracking, which meant increased duration performing the task. Overall, the high level of interaction using the Wall, the details from the 4K screen, and the stereoscopic rendering were seen as helpful in solving the task. However, the participants were not unanimous on which features were most important or whether or not every feature was essential. Therefore, research, beyond the scope of this thesis, needs to be done to examine how these individual factors affect task performance.

Author Keywords
Quality control in engineering design; simulated car engine; user experience

ACM Classification Keywords
Virtual Reality, Mixed Reality, Visualization

SAMMANFATTNING
Syftet med detta examensarbete är att studera vilken effekt virtual reality (VR) har på användares prestation och upplevelse när de använder industriella applikationer avsedda för att utföra uppgiften i den verkliga världen. Jag samarbetade med Volvo Cars i att stödja deras nuvarande tekniska designmetod. VR har möjligheten att förstärka och därigenom förbättra analysen av en persons observationer. Nuvarande forskning rörande VR fokuserar på potentiella fördelar och möjliga förbättringar i VR applikationer, riktad mot vetenskap, industri, medicin, utbildning m.m. Emellertid har inte någon forskning gjorts över effekterna av att förstärka sättet att utforska och analysera vattenföröreningshändelser i en simulerad bilmotor. I detta examensarbete har denna fråga studerats genom en uppgiftsbaserad användarstudie med två olika metoder, nämligen Workstation och Wall. Workstation är det system som idag används för att leta efter vattenföröreningshändelser, vilket sker genom en video med tangentbord och mus på en vanlig datorskärm. Wall är ett mer utvecklat system där förekomsten av vattenföröreningshändelser kontrolleras med hjälp av en Xbox-spelkontroll och Kinect “head-tracking” rörelsekontroller på en 4K skärm (400 x 240 cm projektyrning) med stereoskopiskt med 3D-glasögon. Examensarbetet är ett pilotstudie för att upptäcka skillnader mellan dessa metoder i syfte att hitta infallsvinklar inför framtida studier. Resultatet av studien visar en signifikant skillnad mellan de två metoderna. Workstation är snabbare men mindre exakt medan Wall är mer noggrann och ger fler analysmöjligheter. Den nuvarande versionen av Wall har dock problem med bl.a. fördröjningar som gör att
Volvo engineers then analyse the data further by analysing how water got on the engine and what design alteration the splash shield need in order to prevent the contamination event. We were provided the data from Volvo to explore how VR can support their current design practices.

The research question of this thesis is:
For the human task of detecting and collaboratively analyzing simulated contamination events, what is the impact on task performance of augmenting the analysis of the simulation with a first-person embodied 3D visualization when compared to the current method using video on a 2D screen?

In this thesis, the task performance is measured by time-to-task completion, observation accuracy (frame number displayed on the screen), and user experience. The thesis has also focused on looking at how well engineers can collaborate during the task. The task could be partially automated using collision detection. Nevertheless, collision detection algorithms generate false positives and negatives, thus the results still need to be confirmed. Furthermore, engineers at Volvo analyze not only the contamination event itself, but how the water got there. The task is only the first step in analysing the design of the splash shield and how well it protects the engine. To that end, the task cannot be fully automated. Ultimately, we selected this task as a measurement of the differences between the first-person embodied 3D visualization compared to the current method using video on a 2D screen.

2. RELATED WORK
Despite decades of scientific research into VR and Virtual Environments, there is no universal definition of it [5, 6]. For the sake of clarification in this thesis, I use Sherman and Craig’s definition of VR: “Virtual reality [is] a medium composed of interactive computer simulation that sense[s] the ...[user’s] position and actions and replace[s] or augment[s] the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world)” [5].

For Immersive Virtual Reality (IVR), there is an added condition to the definition of VR; that the user is surrounded by the virtual environment [7, 8]. Commonly used systems, for IVR, are CAVE [9]; a recursive acronym that stands for Cave Automatic Virtual Environment, and head-mounted displays (HMDs). CAVE is a VR environment that is projected on the walls of the room. HMDs are systems where the display is worn on the head. For VR, there is also “Fish tank” [10] or virtual holographic display, looking at desktop/wall with, for example, 3D glasses, to produce stereoscopic and head-tracking interaction, allowing users to not be completely cut off from the real world.

Andries Van Dam et al. [7, 8] write that VR gives the participants a sensation of immersion, that the

Figure 1. Image of a visualization in Paraview of a simulation of water entering the inside of a car (XC90) from Volvo. Parts of the vehicle are not rendered and appear transparent.
simulation and the virtual environment have a feeling of “realness” to them. This broader sensation of immersion helps the observational analysis when looking in the VR environment.

2.1 Interaction in VR
Interactivity is an essential part of IVR and VR in order to facilitate immersion and exploration of the data that is being simulated in VR. When working with VR, real-time interaction is critical to not break immersion. For 3D environments, there are four basic interaction tasks, namely:
1) Navigation (includes Travel: physical movement in space, and “Wayfinding”: cognitive task of “knowing where you are and how to get to a desired location”),
2) Selection,
3) Manipulation,
4) and System Control (system and user interaction outside of the VR environment) [11, 12].

Selection and Manipulation are sometimes counted as the same task, as they are often used together. VR immerses the user into a 3D environment. It is important that these interaction tasks have an equivalent interface in VR. Outside these basic tasks, there is no unified definition of VR interaction. Instead, it is almost entirely defined by the needs for the developed VR application. Non-visual methods of interaction as sound and haptic can also be used [11, 12].

There are different tools that can be used as a method of interaction, either physical interfaces or tracking of the user. Physical interfaces can, for example, be standard game controllers, such as the Nintendo Wiimotes. Physical interfaces can also be tailored made to mimic the physical appearance of a practical tool in an industry. Tracking of the user can be head-tracking or gesture based tracking where the participant’s hand is the tool [11, 12].

2.2 Evaluation methods in VR
Since there is an increased focus on the uses and needs of different VR applications, usability focused evaluation of VR and task performance have become more important [13]. The next question is how to compare and evaluate the diversifying range of VR application and research. For example, there are usability studies [13] and research into VR technology, for instance, comparing different head-tracking systems [14]. The process of integrating existing fields such as Computational Fluid Dynamics into the use and analysis in VR can also be mentioned [15]. These areas of research all have important factors that can support the analysis of the impact on task performance in VR. This makes analysis and evaluation of the impact of immersion, interaction, usability and more on VR complicated. Therefore, it is often difficult to extract what factors impact the result and if the result can be reproduced for another task or application [13, 16].

Bowman and McMahan [16] observe that the VR community runs control studies looking at the impact on task performance for single-factors. However, these single-factor studies can miss important impacts on immersion because of the interaction between all the factors. So they propose a two-step approach, to first perform a study on an immersive VR system with a non-immersive system for the same task. If this study produces significant results for the VR system, further studies can be performed that vary the factors while preserving control over the experiments.

2.3 First-person perspective of projection environments (embodied perspective)
An important aspect of this thesis is the user’s first-person perspective in wall-displayed VR, called Embodied perspective or Embodied interaction in [17]. This previous work looked into bringing visualizations “out from the screen” and creating an immersive VR that does not block the participants view. A natural continuation of this project was looking into adding real data and analysing task performance on the created VR system compared to existing practices for a target population of professional engineers. The tasks to evaluate the system quantitatively are inspired by Forsberg, Chen and Laidlaw [18]. The next chapter, Methods, will describe the VR interaction system developed for the task of finding contamination events in and around the engine belt.

3. METHODS
This thesis explores a mixed-reality, first-person perspective tool for analysing three-dimensional data provided by design engineers at Volvo. For that purpose, I developed a system, named the Wall, which allowed the user’s to view the data in 3D and interacting with it using a Microsoft Xbox controller and head-tracking enabled by a Microsoft Kinect. The developed system was then evaluated by comparing it to the existing system, named the Workstation, in a task-based, controlled user study. ANOVA was used to measure statistically significant difference between the conditions with significance level 5%. ANOVA is comparable to a two-tailed t-test where approximately equal variance is assumed. ANOVA is often used over t-test when the number of groups compared is greater than two as the t-test is less robust. The likelihood of a Type I error, i.e. false positive, increases the more groups that are compared with the t-test.

3.1 Development
I used Paraview [4], a scientific visualization program to visualize the data provided by Volvo. I aimed to mirror the current practices of Volvo engineers who routinely use Paraview. A stereo option in Paraview called “SplitViewportHorizontal” was chosen to work with the 4K screen at the VIC studio [19] at KTH to achieve stereo with 3D glasses. The studio screen (henceforth the Wall) is a 400 x 240 cm projection surface rendering 4096 x 2400 pixels. It provides a stereoscopic projection of 4K rendering per eye at 60HZ. Animations on the screen have no visible lag and the pixels are not perceptible beyond 60 cm from the Wall.
The interaction for the Wall was developed in Python [20] to work within the Paraview program. Rotation, removing parts of the model, playing time forward and backward was mapped to the Xbox-controller [see Appendix Control Scheme] using pygame [21]. Head-tracking with Kinect was implemented using pykinect [22], allowing the closest person to the Kinect to move around to rotate the model and to stand still and move their head to change the perspective of the model.

3.2 Evaluation
To compare and evaluate the developed system with the existing system that Volvo uses, a task-based user study was performed. The study was performed in the VIC studio [19] at KTH. After the user study, user experience was first collected with a survey [see Appendix Survey], and after that through an open-ended interview using the survey questions as a starting point. The survey was conducted after the user study as I wanted the participants’ individual thoughts on the difference between the systems before the interview. I also wanted them to experience both systems before giving their thoughts on each system. The data from the user study and the interview was collected using video recording and written notes. Time to task completion was recorded using a timer. The survey was collected using computers and Google forms.

Three participants took part in a tech pilot before the user study. One participant took part in a test setup and answered the survey. There was only one participant in the test setup as the other participants who had scheduled for that session had to cancel because of sickness. The participants worked in groups of two to test how well they could collaborate during the task. If the task was not collaborative, I could have done a study with one participant and use HMD. A total of 22 participants took part in the user study, with two participants in each session; the total number of sessions was 11. In each session of the user study, the two participants formed a group and took the role of Volvo engineers looking for water contamination events. Water contamination events occur when mud and water from the road splash from the tire passing over it and pass through the mudguards and into the engine and engine belt.

The participants of the tech pilot, the test setup and the user study were students at KTH, between 22-39 years old, with a varying background in computer science, media technology, human computer interaction, industrial engineering and management, information technology, machine learning and professional computer graphics. All participants took part in the course Advanced Graphics and Interaction at KTH and as a motivational reward received 2% credit in the course for taking part in the study. The group of participants were chosen to get more participants and as a test group to discover interesting differences and trade-offs between the systems. Three of the 26 participants were women and were put into different groups. I did not control the proficiency in using the Xbox-controller of the participants, however, in which session a participant took part in was randomized. Despite that the pre-experience in using the Xbox-controller might have varied between the participants, the mappings between the model and the controller were novel to them and had to be learned for all participants.

3.2.1 Pilot Study
A tech pilot and a test setup pilot were performed before the study. The tech pilot tested the developed method for bugs, missing features or other features that could be improved before the study. The test setup, tested the study setup and if the allocated time frame for each part was enough. During the tech pilot, I discovered that a method to point in 3D was needed in order for the participants to understand what others were looking at. Therefore, I implemented a visual element, a yellow ball, for pointing which could be moved with the right joystick. I chose a yellow ball as a point of reference as it is easy to distinguish from the car components and water. The participants of the study were then instructed to use the yellow ball as a reference point. The implementation of the yellow ball was made in last minute and could have, with more time for improvement, been used to record location in coordinate space.

3.2.2 The User Study
The study was divided into a control case, called the Workstation (see Figure 2) and the experimental case, called the Wall (see Figure 3). The Workstation is the system that Volvo uses; where Volvo engineers observe video on a normal desktop screen and interacts with mouse and keyboard. To save time, instead of letting the participants watch different videos, one video was created with three different views of the model (see Figure 4). The three views were taken from views provided by Volvo. The Wall is the system of looking at the 4K screen with 3D-glasses and interaction with an Xbox-controller and head-tracking with Kinect.

Figure 2. Image of a user working with the Workstation. The user controls the model through standard keyboard and mouse interactions. The controls only play, pause and rewind time.
Figure 3. Image of a user working with the Wall. The participant sees the image in stereo with glasses. Also, she controls the camera position by moving her head, tracked by the Kinect on top of the screen. She controls the model with an Xbox game controller that she holds in her hands. The controls include rotation, translation, translucency and time animation.

Figure 4. Image shows the three views of the Workstation.

The study setup was to introduce the task; to point approximately in place to a contamination event and say when the water hit the engine or the engine belt. Participants reported time by referencing the frame number on the screen. The participants always started with the Workstation, where the important parts were highlighted before starting the task. After the task had been completed on the Workstation, the participants performed the same task on the Wall. The participants of each group took turns being the operator and observer on both the Workstation and the Wall to let both participants experience the interaction for both cases. Because of this and to avoid learning and fatigue effects, the data were split into four different sequences in time and the participants were split into two groups (A and B). Out of the total eleven sessions, five of the session were in group A, six of the session were in group B. Participants in group A and group B saw the data at different times in the two cases (see Table 1). Participants saw the control condition first as this was the existing method at Volvo. The model mimics the experience Volvo engineers would have in encountering the Wall for the first time.

4. RESULTS

In this section, I present the results of the user study, for the conditions: the Workstation and the Wall. As described above, the Workstation is the existing system of looking for contamination event in a video with keyboard and mouse on a normal desktop screen. The Wall is the developed system of looking for contamination event with interaction with an Xbox controller and Kinect motion controls on a 4K screen (400 x 240 cm projection surface) with stereoscopy with 3D glasses.

Due to technical recording problems, one group was excluded from the analysis of time and accuracy of finding contamination events, but gave user feedback in the survey and interview. This group was in a session belonging to group B. Excluding the group with technical recording problems, there was a total of ten sessions with five sessions in group A and five sessions in group B. Below, first I present the results starting with time to task completion, moving on to observation and accuracy of the identified contamination events, and ending with user experience.

<table>
<thead>
<tr>
<th>Group/Period (Time step)</th>
<th>Period 1 (15-50)</th>
<th>Period 2 (51-85)</th>
<th>Period 3 (86-121)</th>
<th>Period 4 (122-157)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Workstation</td>
<td>Workstation</td>
<td>Wall</td>
<td>Wall</td>
</tr>
<tr>
<td>B</td>
<td>Wall</td>
<td>Wall</td>
<td>Workstation</td>
<td>Workstation</td>
</tr>
</tbody>
</table>

Table 1. Order of the groups observing the data at the different periods (with corresponding time steps). The first 14 time steps (or 0,14 seconds) were omitted because that is the time for the water to hit the wheel and pass the splash shield.
4.1 Time to task completion
Recall that the task is to detect all contamination events on the sequence of analysis. In total there were 20 data entries for the Workstation and 20 data entries for the Wall. The average time to task completion for the ten groups over the four time periods on the Workstation was 4.08 min, which was significantly faster (p-value: $3 \times 10^{-8}$, significance level 5%) than the Wall, which had an average time to task completion of 9.08 min. The average duration of the different time periods can be seen in Figures 5 - 8.

4.2 Identifying contamination events (accuracy and observations)
As the engine belt was instructed to be the most critical part to avoid contamination, all participants spent the majority of time analysing events involving the belt. Using the Workstation, participants found it difficult to judge the spatial location of the water and whether there was water coming from beneath and hitting under the engine or below the belt.

4.2.1 Finding water contamination on the engine belt
There are no contamination events on the engine belt and surrounding area for periods 1-3. The first instance of water contamination around the belt is at time step 132 and thereafter there is water contamination on the belt and surrounding engine for the rest of period 4 (see Table 2). The contamination event occurs when a droplet of water first hits the engine, if the water stays or moves on the affected area it is considered the same contamination event until the area is free from water. If a separate water droplet hits the already affected area it is regarded as a new contamination event. However, the events need to be visually distinguishable, therefore if two separate droplets of water merge into one entity of water it is regarded as one event. Vice versa, if one droplet distinguishable splits into two separate entities of water it is counted as separate events. The participants were instructed to look for the time of the events themselves, if there were several events or just one contamination event (for example one droplet of water).
### Table 2. The number of distinguishable contamination events, in period 4, on the engine belt and surrounding area. The third column explains which events the participants were able to detect.

<table>
<thead>
<tr>
<th>Time steps</th>
<th>Number of distinguishable contamination events</th>
<th>Event description</th>
</tr>
</thead>
<tbody>
<tr>
<td>122-131</td>
<td>0</td>
<td>No contamination events on the engine belt.</td>
</tr>
<tr>
<td>132</td>
<td>1</td>
<td>The first impact of water on the engine belt.</td>
</tr>
<tr>
<td>133</td>
<td>2</td>
<td>The first drop of water splits in two. Drop 1 stays visible for both conditions. Drop 2 is not visible on the Workstation as it continues inwards into the engine.</td>
</tr>
<tr>
<td>134</td>
<td>2</td>
<td>The events above affect the area</td>
</tr>
<tr>
<td>135</td>
<td>3</td>
<td>Drop 1 splits in two; Drop 1.1 and Drop 1.2. Drop 1.2 continues downward faster than Drop 1.1.</td>
</tr>
<tr>
<td>136-138</td>
<td>3</td>
<td>Drop 1.1, Drop 1.2 and Drop 2 affect the area.</td>
</tr>
<tr>
<td>139</td>
<td>3</td>
<td>A droplet, Droplet 1, causes another contamination event, hits on top of Drop 1.2, thereby merging into one entity of water. However, Drop 2 is no longer affecting the area, i.e. the total number of event remains the same.</td>
</tr>
<tr>
<td>140</td>
<td>2</td>
<td>Drop 1.1 and Drop 1.2 has merged into Drop 3 and are therefore counted as one event</td>
</tr>
<tr>
<td>141</td>
<td>3</td>
<td>A new contamination event, Drop 4.</td>
</tr>
<tr>
<td>142</td>
<td>3</td>
<td>Drop 1.1, Drop 3 and Drop 4 affect the area.</td>
</tr>
<tr>
<td>143</td>
<td>4</td>
<td>A new contamination event, Drop 5.</td>
</tr>
<tr>
<td>144-157</td>
<td>4</td>
<td>Contamination events (Drop 1.1, 3, 4 and 5) affect the area until the end of the simulation.</td>
</tr>
</tbody>
</table>

All groups for the Wall and the Workstation correctly determined that there were no contamination events on engine belt for period 1-3. For the Workstation, in period 1, two groups thought that it might be a risk for a contamination event on the belt from underneath. The first group said it was around time steps 40-41. Similarly, the second group found a possible event around time step 45. Both groups determined correctly that it was not a contamination event at those times, but were unsure since the three views of the Workstation did not provide a good perspective from below. Detecting contamination event where such event did not exist is a false positive classification. For period 1, four groups using the Wall also saw the water closing on the engine belt. These groups identified different time intervals that might come close to being a contamination event. Two groups thought there might be a contamination event at time steps 39-40, the third group at time steps 26-38, and the fourth group at time steps 47-48. For these time steps on the Wall, the participants took care to analyse these possible contamination events from different angles. After their initial impression, they could determine that the water was close, but did not hit the engine belt. One group working with the Workstation, for period 3, thought that there might be water hitting the engine belt from underneath around time step 70, but determined that it was not striking the engine belt. At time step 84, one group using the Wall saw a tiny speck of water, but concluded that it did not hit.

For period 4, there were contamination events on the engine belt and surrounding engine area. All groups on the Wall and the Workstation correctly identified the events hitting and staying on the engine belt to the end. However, the exact time of the impact of the first contamination event (time step 132) differed slightly (see Table 3 for the time on the Workstation and Table 4 for the time on the Wall).
Table 3. The time step where the different groups expressed detecting the first instance of contamination on the engine belt for the Workstation.

<table>
<thead>
<tr>
<th>Group</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time step (Workstation)</td>
<td>137</td>
<td>135</td>
<td>137</td>
<td>133</td>
<td>135</td>
</tr>
</tbody>
</table>

Table 4. The time step where the different groups expressed detecting the first instance of contamination on the engine belt for the Wall.

<table>
<thead>
<tr>
<th>Group</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time steps (Wall)</td>
<td>133</td>
<td>133</td>
<td>134</td>
<td>132-134</td>
<td>131-132</td>
</tr>
</tbody>
</table>

4.2.2 Finding water contamination on other parts of the engine

The area that rendered most analysis after the engine belt was the region around the shaft. The shaft drew attention from the participants since half of the shaft is not covered by the splash shield and it is almost always somewhat covered with water. Also, water splashes in and upwards from the shaft area drew attention to it. With the Workstation, it could be difficult to see small details, as it has a smaller display and less resolution than the Wall. However, period 3 provides an example where small water drops can, with the right view, be seen on the Workstation. During the entire period 3, small drops of water were lying on the shaft (Figure 9). These drops were mentioned as correctly identified contamination events by four out of five groups for both the Workstation and the Wall.

For the Workstation, there are certain parts of the engine that could not be seen with the selected views, mainly the inside and bottom left parts of the engine. Therefore, for all time periods, the participants could not certify water contamination in certain areas of the engine. While performing the task on the Workstation, participants also expressed a difficulty in seeing and knowing what was going on between different engine parts. This lack of depth perception made the participants unsure of the water ever hitting the engine or just passing by the engine for the entirety of the simulation.

For the Wall, several groups did not try to get a good view of the inside of the engine, as most inner parts can be hard to navigate to and may require cuts or translucency into the engine and the water. Working with the Workstation first could have unintentionally trained the participants to only look at the immediate outside of the engine and replicate the views from the Workstation when performing the task on the Wall. However, groups working with the Wall, did at different time periods, analyse and observe contamination events on areas of the engine, for example the aforementioned bottom left side of the engine, which cannot be seen on the Workstation.

Figure 9. Small water drops located on the shaft marked in red circle at time step 100 (during period 3). On the left is the Wall (here without stereoscopy) and on the right, the Workstation.
4.3 User experience

In this section, I present an overview of the user experiences extracted from written text in the survey or expressed in the interview. An overview of the participants’ response to the survey Likert scale questions can be seen in Figure 10 for the intuitiveness of the condition, Figure 11 for the participants perceived task performance on the different conditions, and Figure 12 for expressing if different features help the task performance.

4.3.1 Synthesis of the participants’ perspectives on the conditions

Overall, the participants thought they performed better on the Wall (see Table 5 for the number of individual responses and Figure 13 for overall distribution on task performance), this with a significant result (p-value: $2.27 \times 10^{-8}$, significance level 5%). However, both the Workstation and the Wall have their strengths and weaknesses as described by the participants.
From the participants’ perspective, the Workstation is faster, provides a good first overview and has easier controls. The three different views were seen as helpful as it allowed the participants to see from different angles at the same time. The Workstation is intuitive because the participants are used to it and it is “trivial/easy to use” because of pre-existing knowledge in how to use it. A plus is also that the Workstation is equipment-independent. It is straightforward to distribute a video to someone across the world that can be watched on several devices without any setup.

However, the Workstation is not as precise because of lower resolution/screen size and lack of options to rotate, zoom and to filter out data in order to look at details. Also, the participants expressed that the Workstation was not as precise because it lacked a feeling of depth (due to the 2D view). Because of these limitations, the participants felt that they could not really see if the water hit a critical part or not. As the participants could not be sure of water contamination no matter how much they looked at the video, the participants felt more uncertain and felt that they were guessing and some thought it was harder to perform the task. But some participants still felt that the Workstation was enough to say with high certainty that the engine is safe from water contamination.

From the participants’ perspective, the Wall performed better as it is more precise, detailed, has more interactive options and is a more comprehensive oversight compared to the Workstation. With the controls, the participants felt that they could go into more detail and focus on different parts to better perform the task. Also, on the Wall, the participants thought that it was easier to see the result more clearly, find contamination events and really guarantee that it is safe and requires less guesswork.

The controls of the Wall were perceived as advanced. While the Xbox-controller was not new to the participants, the mappings between the model and the controller were novel to them. Because of this unfamiliarity, participants expressed having to go through a learning curve. Due to the learning curve, the participants expressed that it was hard to remember what all controls did at first and that it takes some time to understand the controls. Therefore, the Wall can be difficult, overwhelming and intimidating for novices, but the participants felt that they could become experts given more time.

The task on the Wall took longer due to lag, delay of interaction and slowness of rendering. The lag was often seen as the biggest negative for the participants. While these artefacts of the rendering technology had an effect on the study, we consider that with the expected exponential development of hardware capacity the problem will cease to exist. The delay of the controls made it sometimes hard to navigate to the right position, understand what was going on and took away a portion of the overall experience. The longer time to task completion for the Wall can also be explained by the fact that the controller afforded more options for interacting with the model and, therefore, for exploration. A negative aspect of the Wall was that participants could not jump in time and see how far the problem will cease to exist. The delay of the controls and, therefore, for exploration. A negative aspect of the Wall was that participants could not jump in time and see how far the model had run or how much time was left. Another negative aspect to the Wall is its complexity and expense. The Wall employs two high-end projectors, large high-quality glass walls and is difficult to install. While it is not prohibitively expensive for a large engineering firm like Volvo, it is also true that it is not for the everyday user.

### 4.3.2 Synthesis of the participants’ perspectives on intuitiveness

There was not really any consensus (see Table 6) between the participants on which of the systems was more intuitive and there was no statistically significant difference (p-value: $5.102\times10^{-2}$, significance level 5%). The intuitiveness of the systems depends on what type of control method the participants preferred, were comfortable with and what previous experience the participants had with the Xbox-controller and Kinect.

<table>
<thead>
<tr>
<th>Choose</th>
<th>Higher for the Wall</th>
<th>The same</th>
<th>Lower for the Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of participants</td>
<td>13</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 6. Number of participants that choose higher/the same/lower number score for the Wall compared to the Workstation on the question on how intuitive interaction was.
In general, the Workstation was seen as trivial to use and intuitive because of previous experience working with videos and limited interaction methods that are easy to use. Similarly, the Wall had more advanced controls and was new, making the Wall overall less intuitive, especially for beginners. Also, on the Wall, some participants felt that the camera controls were inverted. Participants believed the camera moved the wrong way, which is unintuitive and also made participants take more time as they try to correct their camera movements with their body. As one participant said: “...[with the controls] don’t know if you should do left or right so you try and realize you are going the wrong way then you go back”. Despite this, some participants wrote in the survey or said during the interview that the Wall was (more) intuitive or had a more intuitive analysis, but at the same time, others said that the Wall did not have intuitive controls (see Figure 14).

4.3.3 Synthesis of the participants’ perspectives on the interaction

The limited options and lack of interaction mean that the Workstation only can do so much, is a less comprehensive oversight and some participants even said that it is not enough to finish the task accurately.

4.3.3.1 Rotation
The participants expressed that missing the ability to explore different angles on the Workstation is restricting; the locked angles on the Workstation provide limited observation and made it difficult to detect contamination events. As one participant said; “The three aspects provide less information (Workstation) than interaction can provide (Wall)”. This restriction makes the Workstation dependent on chosen camera angles, but could be enough depending on what the user is looking for. On the Wall, the participants could rotate freely which they thought was helpful (see Figure 15), as they can spend more time looking for interesting angles to visualize what happens. As another participant said: “The perspective might in some cases make it a bit harder (Workstation)...

4.3.3.2 Zoom
The participants expressed that zooming was helpful (see Figure 16), but that it could cause disorientation if zoomed in too close to the model, as some participant felt like they did not know what was up or down when they did.

4.3.3.3 Removing parts
One other factor that was expressed by the participants was the option to be able to remove parts, that is, make them invisible in the rendering of the model. Removing parts was seen as helpful, as it allowed for filtration of the data, removal of blocking parts and observation of certain elements for a better view. However, as some participants pointed out, it could cause them to miss some contamination event on parts that are hidden from the view.

4.3.4 Synthesis of the participants’ perspectives on 3D and the 4K screen
Overall the participants thought that the interaction and 3D were helpful in solving the task, but had different views on what was more important, and ultimately,
what features was absolutely needed, between interaction, details from the 4K screen and the 3D.

The participants thought that the 4K screen was helpful (see Figure 17), but since the whole screen was not used, a normal sized TV screen would have been sufficient. The resolution of the Workstation video was too low and the three views made the model very small, but the participants’ thought that the 4K resolution is maybe not needed even though it is helpful when the model is very detailed. Another factor in screen size is also that the Kinect might not work if the user is too close to the screen. The size of the screen could be chosen depending on model size and what information the user wants on the screen and how many views are on the screen.

Participants also thought that the 3D gives depth perception and immersion to the scene which they thought was helpful (see Figure 18), as it provides clarity to the water to the screen/scene. Also, the participants expressed that 3D made it easier to see past obstructing particles and helps to locate contamination events. However, 3D has a downside to it as well, as a three participants experienced discomfort (headache, dizziness or disorientation), one to the point that they felt like they needed a break. This discomfort made the participants feel like they would not want to use the Wall “all day” or for a longer period of time. Others expressed that the 3D was not enough and that they still had to interact with the data. Also, the 3D might have more advantage to it, when working alone as it gives participants different perspectives of the data. As another participant said; “makes it harder to understand what the other person meant and to communicate where you want to look and rotate to in 3D”.

Participants also expressed that there was repeated mapping between the controller and Kinect which made the overall interaction difficult to remember. Since the game controller worked better (one participant: “was more powerful”), had lower delay than the Kinect, and performed all the tasks that the Kinect performed, some participants felt that the Kinect was redundant. As one participant put it; “Don’t know how (much) to move with Kinect and know exactly how much the controller moved”. This may be due to the artefact of latency and discrete, not continuous movements. In a previous experiment using the same setup but without the latency, participants expressed feeling significantly empowered by the first person perspective [17].

As the Kinect can pick up on unintended movements of the operator or the movement of the observer (if the observer is too close to the operator), it can change the view (“bug out”) when the operator did not mean to. This could cause dizziness, disorientation or confusion as the view changes unintentionally. Overall, the participants wanted the option to pause the Kinect to take a break or to allow groups of people to be able to move around and point at the screen.

Despite this, the Kinect could be good for looking in and around quickly as it can be difficult to do so with
the controller. A few participants thought that the Kinect controls were more intuitive. Yet, given the current state of the Kinect control, participants expressed that the interface needed to be optimized with more accurate and efficient tracking to remove perceptible delay, to produce a smoother and real-time animation and not to move in discrete steps, as movement is perceived continuously in the real world. Head-tracking might not have been the right motion tracking for the task. As one participant said; “You want to be in front of the screen and not look away from it, so hand gestures may be better (head also does a lot of unintended movements)”.

4.3.6 Synthesis of the participants’ perspectives on collaboration

The majority of the participants felt like that there was not that many or any collaborative elements, that it was more of a solo person task, but that it was good to have a second pair of eyes. Therefore some participants felt that collaboration was not better or worse on either system. However, other participants thought that it was easier to collaborate on the Workstation because they saw the same view and it was easier to point and show others which made it easier to discuss materials. These participants expressed that collaboration was harder for them on the Wall because the different perspectives in 3D meant that the observer and operator did not have the same view of the model (when standing in different parts of the room).

A feature that the participants expressed was missing for collaboration on the Wall was to allow the observer to point to with some device at the screen and/or to pause the Kinect to allow the observer to be close to the operator without disturbing the Kinect. The participants expressed as the observer they did not know how close they could be to the operator without disturbing the Kinect. Another negative factor for collaboration on the Wall was that it was harder to understand what the other person meant and communicate on the Wall, which was partly because of the 3D environment, controls, and 3D glasses.

5. DISCUSSION

In this section, I discuss the results of augmenting the exploration and analysis of contamination events, followed by a critical view on possible improvements of the developed system and chosen methods, ending with potential future research.

5.1 Summary of results

As expected, the time to task completion was significantly faster for the Workstation. The longer time spent on the Wall can be explained by three factors: 1) The slow update of the rendering of the scene when interacting, 2) That there were more possibilities to analyse the data, 3) and the non-trivial controls. Despite that the time to task completion was longer on the Wall, the participants thought they performed the task significantly better on the Wall compared to the Workstation. Table 7 shows a summary of the advantages and disadvantages of the Workstation and the Wall.

Extracted from these results, in the next section, follows a summary and discussion of factors that might have impacted the task performance.

5.1.1 Observational accuracy in time

On the Workstation despite its three given views, the participants were not able to see all the contamination events on the engine. This aside, the participants’ ability to observe contamination events in time was roughly the same for the Workstation and the Wall, but the difference in accuracy is difficult to evaluate as spatial accuracy was not measured.

<table>
<thead>
<tr>
<th>The Workstation</th>
<th>The Wall</th>
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<tbody>
<tr>
<td><strong>Advantages:</strong></td>
<td><strong>Advantages:</strong></td>
</tr>
<tr>
<td>• Faster</td>
<td>• Option to interactively analyse the data</td>
</tr>
<tr>
<td>• Provides a good overview</td>
<td>• Clearly easier to see where objects are in space and in relation to each other in-depth</td>
</tr>
<tr>
<td>• Trivial</td>
<td>• More precise and detailed</td>
</tr>
<tr>
<td>• More views possible at the same time</td>
<td>• A more comprehensive overview</td>
</tr>
<tr>
<td>• Equipment independent</td>
<td></td>
</tr>
<tr>
<td><strong>Disadvantages:</strong></td>
<td><strong>Disadvantages:</strong></td>
</tr>
<tr>
<td>• Not as comprehensive</td>
<td>• Lag</td>
</tr>
<tr>
<td>• Lacks options to interact with the data</td>
<td>• Takes longer time</td>
</tr>
<tr>
<td>• Lacks spatial information on where objects are in-depth</td>
<td>• Advanced controls</td>
</tr>
<tr>
<td>• Involves “guesswork”</td>
<td>• May cause motion sickness, dizziness or discomfort</td>
</tr>
<tr>
<td>• Less detailed</td>
<td>• Equipment dependent</td>
</tr>
<tr>
<td></td>
<td>• Lack natural way to point</td>
</tr>
</tbody>
</table>

Table 7. A summary of advantages and disadvantages of the Workstation and the Wall.
5.1.2 Intuitiveness
The Workstation is easy to access since an average person is familiar working with a video and interacting with keyboard and mouse controls. The Wall, on the other hand, has two methods of interaction that are non-trivial, which meant that the participants had to learn two new and different controls at once. The participants had a varying degree of pre-experience using the Xbox-controller. The previous experience working in VR environments overall were limited or completely nonexistent among many participants, and probably is the same for the target users of the application, Volvo engineers. An average person is a novice in VR systems similar to the Wall and, therefore, has a learning curve to overcome. This can of course impact overall task performance in an introduction phase of a system as the Wall.

5.1.3 Interaction
The ability to freely explore the data by interactively rotating, zooming and removing parts was, overall, seen as helpful performing the task since it enabled more in-depth analysis. Also, this interaction gave the participants a possibility to really guarantee that there were no contamination events anywhere on the engine. This thesis does not embrace the question of which interaction method is best to use. However, using both an Xbox-controller and Kinect motion controls for interaction made the overall interaction harder to remember as there was repeated mapping between the two control methods.

5.1.4 The screen/display (size and resolution)
Since a model of a car engine is large and detailed it seems natural that a larger and higher resolution display/screen will be preferable. The three views on the Workstation clearly made the visualisation smaller and, as described by the participants, were worsened by the low resolution of the video. However, such a large screen as the 4K Wall is probably not necessary. Instead a normal-sized TV screen, depending on the amount of information displayed, probably will work just as well.

5.1.5 Stereoscopy
Stereoscopy gives depth perception and immersion to the scene, which the participants expressed, made it easier to see past obstructing particles and helped them to locate contamination event. Though, the participants also expressed that 3D alone was not enough and that they still had to interact with the data. Stereoscopy may also cause motion sickness. In the survey and interview, three participants expressed that they had experienced some discomfort during their session working with the Wall. However, it is unclear if these participants experienced it because of general motion sickness or because of the lag and unintended movements caused by the controls. I conclude that it likely was a combination of the two.

5.1.6 Collaboration
In general, participants expressed that there were few collaborative elements in the task and that their experience as to collaboration therefore was almost equivalent between the Workstation and the Wall. However, participants also thought it was harder to collaborate when using the Wall because it lacked a natural way to point and because participants standing at separate parts of the room had different views/perspectives of the visualisation. Another factor to consider is the equipment independency of the Workstation, which makes it easy to collaborate on all kinds of devices across the world. In contrast, a prerequisite for a system as the Wall is that specific equipment has to be purchased and set up before use.

5.2 Choice of method and implementation critique
As previously stated for VR, it is often difficult to extract what factors impact the result [13, 16]. I have made the same conclusion in this thesis; all factors summarised above in section 5.1 impact the task performance to some extent, but the method used does not make it possible to study their individual impact.

5.2.1 Method critique
The chosen method was designed to examine and reveal the general differences between the Workstation and the Wall and these two conditions are too diverse for a detailed comparative analysis. This study was designed as a pilot to discover interesting differences and trade-offs for future studies. The method used shows similarities with the first step in Bowman and McMahan [16] two-step approach. The results of the user study shows that there is a significant difference between the immersive and non-immersive system, therefore, the result can be analysed further in “step-two” with studies focusing on a single factor.

The fact that the method for pointing was implemented in last minute can also be criticised, but the change did not impact the study since it was not a focus point of the thesis. The reference point, the yellow ball mentioned in the methods chapter, was sufficient for this study. Ideally, pointing needs to be looked into more specifically before the Wall can be implemented for everyday use. Another factor to be considered with the chosen method is that I did not measure spatial accuracy, nor did I analyse precision and recall.

For the survey, as mentioned in the result, it became apparent during the interviews that some participants were somewhat puzzled over the questions about intuitiveness and collaboration. From the interviews, it became apparent that there may have been a confusion about the question on intuitiveness as some might have rated the Workstation lower because of the lack of interaction. However, others might have rated it high for the same reasons because limited controls are easy to remember and difficult to use erroneously compared to the many detailed controls of the Wall. Also, as one participant put it, “the order of the interaction method played a part ... because of the new task was less intuitive (Workstation), I knew what to do [on the Wall]“. As the task was new, it might have felt less intuitive on the Workstation because it was the first
time the participants performed the task. Since the Workstation is trivial to use, questions about intuitiveness for the Workstation could have been omitted. For the Wall, separate and more detailed questions could have been asked about the Xbox-controls, the Kinect controls and if seeing the data in stereoscopic 3D with 3D glasses was intuitive. Also, a separate question on how the participants experienced the first-person perspective controls was missing as well as a Likert question on whether or not removing parts was helpful for the task. Regarding collaboration, some participants might have misunderstood the question as they answered with how they felt working together instead of how they collaborated on the different systems. Therefore, the question preferably would have been clarified so the participants understood that I asked about the difference between the systems. A criticism of the survey is that it was only performed after the two conditions, because of that I might have missed some of the participants’ initial thoughts and impression on the Workstation. Some questions regarding the Workstation might, therefore, have been asked in-between the two conditions. However, I wanted the participants to experience both systems before they gave their feedback.

In order to make the task more collaborative, the observer could have been assigned to take notes over the detected contamination events. In this respect, the participants would have had a checklist of what to look at and the operators’ notes could be compared against each other. Another aspect that can be discussed is that only three out of the 26 participants were women, because the recruitment to the study was made within a course at KTH with a vast majority of male students. Better effort could have been made to recruit participant outside this course to get a better gender balance. I did not observe any gender difference in the study, but I cannot make general assumptions because I only had three participants that were women. A study that has more participants and a better gender balance might observe differences that I could not observe. However, differences between the participants could also depend on other factors, for instance, the proficiency in using the Xbox-controller, and not in the gender. As I did not control the Xbox-controller proficiency is problematic for statistical analysis but mirrors the real world. Another study that controls this by only recruit proficient users or put users with different pre-experience into different groups could remove or measure the impact of the pre-existing experience of the participants.

On the Workstation, the choice to show the video with three views was made to save time during the user study. However, this meant that the details on the Workstation became even smaller than if it had been shown on a video with a single view. Another study that uses three (or more) videos with a different single view, letting the participants switch between them freely instead of three views in one video may result in a different outcome. Also, in this thesis, the user study was performed with the Workstation first, showing off current practices to better understand the task. This factor may of course have impacted the result. If the participants would have been given a reasonable period to learn the task and performing it naturally on the Workstation, this would have reduce the impact of the learning effect on the task and would have mirrored the work of Volvo engineers better.

The fact that the participants were not experts means that the result does not completely mirror the result of expert Volvo engineers performing the same task. A professional would know what to analyse and get more out of the analysis on both systems. However, because the participants were novices I could test the systems with more participants. Also, the participants identified improvements and current implementation problems with the Wall. Ideally, before handing it over to experts, another iteration of the development of the Wall could be done. The experts could then give feedback on the crucial parts for their practices and not get distracted by the current implementation problems.

5.2.2 Implementation critique and improvements
The main implementation error for the Wall was the lag. The lag made the participants unsure of what was happening and made them think they were not managing the interaction with the Xbox-controller and the Kinect controls correctly. Every head-tracking system “in a VR environment has to be accurate, of low latency, provide sufficiently high update rates, and be robust” [14], also lag in VR “may make the user much more sensitive to jitter than for a regular workstation” [10]. The participants also expressed they expected more responsiveness from the Kinect controls and not less. Because of this, many participants probably did not feel the first-person perspective controls of the Kinect, were confused by or did not understand the controls or felt the Xbox-controller performed the same functions with the same performance or even better. Thereby, the participants used the Xbox-controller to a higher extent than the Kinect. Since the participants had to learn and memorize new controls, some participants might also simply have forgotten the Kinect. Some of these performance problems can be attributed to the position of the Kinect; namely that the Kinect is looking down at the user from the top of the screen, which may cause some problems with the Kinect's tracking [17]. Although, this does not explain the overall performance problems of the Wall, which needs to be optimized.

Interestingly, head-tracking might not be the ultimate choice for motion controls. As pointed out by one participant, a user wants to be in front of the screen and not looking away from it. Also, moving the head around may lead to uncomfortable body positions where the Kinect needs to be paused in order for the operator to straighten themselves up without changing the view. Currently, for the Wall, the Kinect head-tracking needs to be paused in order for the observer to move close to
the operator, allowing them to see the same perspective. With the head-tracking, the operator has a limited area in which he or she can move, therefore the Xbox-controller is needed in order to rotate the model all the way around (360°).

Improvements I identify for the Wall:
- Optimise to remove lag and improve overall responsiveness of interaction.
- Explore ways to point and thereby record spatial accuracy. Also, develop means of letting additional persons, not only the operator, to point at the Wall.
- Add an option to pause or take a break from Kinect and 3D
- Time playing backward and forward in real-time and time looping back to start at the end of the time period.
- Look into graphical changes; colour choices and information on the screen. Also, for wayfinding, make the background into a “3D space”, with different checkers like floor and ceiling to make navigation easier.
- Zoom not only to enlarge the image, but also to move past blocking parts.
- Enable the user to choose to use the right or the left joystick for left-handed people, and change the camera controls as the participants often felt that they were inverted.

5.3 Future Work
As previously stated, this thesis is comparable to the first step in Bowman and McMahan’s [16] two-step approach. As for the task of finding contamination events in a simulated car engine, the second step of the approach is yet to be explored. In order to fully understand the causes and effects of different factors, future work needs to be performed on single factors that might impact the overall task performance. Future work can, for example, examine if the control method makes a difference by removing the effect of the stereoscopic and first-person perspective. Such study would thereby focus only on the impact of different interaction methods. Also, as VR technology is constantly evolving, new technology like Oculus Rift and HTC VIVE can be used and evaluated to see what added benefits or limitations these technologies can provide.

6. CONCLUSION
In this thesis, the impact of augmenting the exploration and analysis of contamination events has been explored by performing a task-based user study with two conditions, namely the Workstation and the Wall. The Workstation is the existing system of looking for contamination event in a video with keyboard and mouse on a normal desktop screen. The Wall is the developed system of looking for contamination event with interaction with an Xbox-controller and Kinect motion controls on a 4K screen (400 x 240 cm projection surface) with stereoscopy with 3D glasses.

Overall advantages and disadvantages of each system have been discussed:
- The Workstation could be used for a quick overview since it is faster, familiar and equipment independent, but gives a more uncertain and less comprehensive result. The Workstation is restrained by its limited interaction and is, therefore, dependent on chosen camera angles, but could be sufficient depending on what a user specifically requires.
- The Wall takes longer time, has a learning curve and is equipment dependent, but has additional in-depth analysis options. The Wall needs optimisation to work “in an everyday environment”, especially eliminating lag and better pointing method is needed. Also, other interaction methods need to be analysed.

This thesis is meant as a pilot to discover interesting differences and trade-offs for future studies. Overall the participants of the user study thought that the interaction and stereoscopic 3D were helpful solving the task, but had different views on what interaction, details from the 4K screen or the 3D were more important and if every feature on the Wall was necessary. Therefore, research, beyond the scope of this thesis, needs to be done to examine how these individual factors affect task performance.

ACKNOWLEDGMENT
We want to thank our contacts at Volvo for their time, and for providing the data.

REFERENCES


[22] Pykinect 1.0; package in Python that provides access to the Kinect device. Retrieved May 3, 2017 from https://pypi.python.org/pypi/pykinect/1.0
APPENDIX
Control Scheme

Image. Modified image of an Xbox-controller to show the control scheme, original image taken from https://en.wikipedia.org/wiki/File:360_controller.svg

**Left trigger:** Tilt the model clockwise.

**Left bumper:** Click to move time backwards one time step, hold-in to keep time playing backwards.

**Right trigger:** Tilt the model counterclockwise.

**Right bumper:** Click to move time forward one time step, hold-in to keep time playing forwards.

**Left stick:** Horizontal and Vertical movement around the model. Press down to change the left and right triggers to move the yellow ball for pointing in-depth, press again to revert back the triggers to tilt the model.

**Right stick:** Moves yellow ball for pointing vertically and horizontally. Press down to show/hide the yellow ball.

**Directional pad:** Up button to zoom in, Down button to zoom out, Right button to move the model to the right, Left button to move the model to the left.

**Back:** Resets the view and the yellow ball for pointing to the starting position.

**Guide:** Used to turn on Xbox-controller.

**Start:** Stops the interaction and code/program running on computer.

**X button:** Press to show/hide the gray engine part.

**Y button:** Press to show/hide wheel axis and parts that connects wheel with engine.

**B button:** Press to show/hide orange mud guard parts.

**A button:** Press to hide the red wheel, press again to hide the red-orange wheel cover, press a third time to show both wheel and wheel cover again.
Survey

Group (test number)
Your answer

Please answer these questions about yourself

What is your age?
Your answer

What is your gender?
□ Male
□ Female

How do you rate your previous own experience working with and developing for 3D?

[ ] 1
[ ] 2
[ ] 3
[ ] 4
[ ] 5

Inexperienced

[ ] Experienced

What is your academic background (program, school)?
Your answer

Are you an exchange student?
□ Yes
□ No
Questions on the two different platforms

Answer with your own experience and thoughts on the different platforms

How intuitive was the interaction on the workstation?

1  2  3  4  5
not at all intuitive fully intuitive

How intuitive was the interaction on the wall?

1  2  3  4  5
not at all intuitive fully intuitive

Please add comments here about how intuitive the interaction felt to you if you have them.

Your answer

How well did you think you were able to perform the task on the workstation?

1  2  3  4  5
Poorly Expertly

How well did you think you were able to perform the task on the wall?

1  2  3  4  5
Poorly Expertly
Please, if you have comments about your performance add them here.

Your answer

What is the advantages of The Workstation?

Your answer

What is the disadvantages of The Workstation?

Your answer

What is the advantages of The Wall?

Your answer

What is the disadvantages of The Wall?

Your answer

Compare both the Wall and the Workstation. Are there any features from the Workstation that you wished where on the Wall? Are there any features from the Wall that you wished where on the Workstation?

Your answer

How was it to co-operate on the Wall and the Workstation?

Your answer
General questions on the task

Rotating the camera improves the task performance

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<th>3</th>
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<th>5</th>
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<tr>
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Zooming improves the task performance

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<td></td>
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Working on the 4k screen helps the task performance

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Seeing the data in stereo (with 3D glasses) helps the task performance

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</thead>
<tbody>
<tr>
<td>disagree</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Thank you for your participation

SUBMIT
**STATISTICAL ANALYSIS**

ANOVA with significance level 5%

**Time to task completion**

*For all groups and time periods*

**ANOVA**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
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<td>249.30049</td>
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</table>

*For the different time periods*

**Period 1**

**ANOVA**

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<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
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<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>100,67929</td>
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### Period 2

**Anova: Single Factor**

#### SUMMARY

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<tr>
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<th>Variance</th>
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<tbody>
<tr>
<td>Workstation 51.85</td>
<td>5</td>
<td>15.58</td>
<td>3.116</td>
<td>1.47966</td>
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<tr>
<td>Wall 51.85</td>
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<td>44.37</td>
<td>8.874</td>
<td>1.47688</td>
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#### ANOVA

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<th>P-value</th>
<th>F crit</th>
</tr>
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<tbody>
<tr>
<td>Between Groups</td>
<td>82,88641</td>
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<td>56,06949292</td>
<td>7,00725E-05</td>
<td>5,317655063</td>
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<tr>
<td>Within Groups</td>
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<td>8</td>
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### Period 3

**Anova: Single Factor**

#### SUMMARY

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<th>Variance</th>
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</thead>
<tbody>
<tr>
<td>Workstation 86-121</td>
<td>5</td>
<td>21.68</td>
<td>4.336</td>
<td>4.80103</td>
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<tr>
<td>Wall 86-121</td>
<td>5</td>
<td>42.59</td>
<td>8.518</td>
<td>6.78922</td>
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</table>

#### ANOVA

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<tr>
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<th>F</th>
<th>P-value</th>
<th>F crit</th>
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</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>43,72281</td>
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<td>43,72281</td>
<td>7,544757016</td>
<td>0.025184234</td>
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<td>Within Groups</td>
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<td>5,795125</td>
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### Period 4

**Anova: Single Factor**

#### SUMMARY

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<th>Average</th>
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</thead>
<tbody>
<tr>
<td>Workstation 122-157</td>
<td>5</td>
<td>25.35</td>
<td>5.07</td>
<td>14,3799</td>
</tr>
<tr>
<td>Wall 122-157</td>
<td>5</td>
<td>43.78</td>
<td>8.756</td>
<td>4.68263</td>
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#### ANOVA

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<th>Source of Variation</th>
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<th>F</th>
<th>P-value</th>
<th>F crit</th>
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</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>33,96649</td>
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<td>33,96649</td>
<td>3,563691703</td>
<td>0.095753358</td>
<td>5,317655063</td>
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<tr>
<td>Within Groups</td>
<td>76,25012</td>
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### Survey Likert scale questions

#### Intuitiveness

**ANOVA: Single Factor**

<table>
<thead>
<tr>
<th>Groups</th>
<th>Count</th>
<th>Sum</th>
<th>Average</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>How intuitive was the interaction on the workstation?</td>
<td>23</td>
<td>67</td>
<td>2.91304348</td>
<td>1.719367589</td>
</tr>
<tr>
<td>How intuitive was the interaction on the wall?</td>
<td>23</td>
<td>82</td>
<td>3.565217391</td>
<td>0.711462451</td>
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</tbody>
</table>

**ANOVA**

<table>
<thead>
<tr>
<th>Source of Variation</th>
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<th>df</th>
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<th>F</th>
<th>P-value</th>
<th>F crit</th>
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</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>48913</td>
<td>1</td>
<td>4891304348</td>
<td>4.024390244</td>
<td>0.051018573</td>
<td>4.061706349</td>
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<tr>
<td>Within Groups</td>
<td>53478</td>
<td>44</td>
<td>121541502</td>
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<tr>
<td>Total</td>
<td>58377</td>
<td>45</td>
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</tbody>
</table>

#### Perceived task performance

**ANOVA: Single Factor**

<table>
<thead>
<tr>
<th>Groups</th>
<th>Count</th>
<th>Sum</th>
<th>Average</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>How well did you think you were able to perform the task on the workstation?</td>
<td>23</td>
<td>58</td>
<td>2.52173913</td>
<td>0.624505629</td>
</tr>
<tr>
<td>How well did you think you were able to perform the task on the wall?</td>
<td>23</td>
<td>95</td>
<td>4.130434783</td>
<td>0.694031621</td>
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</tbody>
</table>

**ANOVA**

<table>
<thead>
<tr>
<th>Source of Variation</th>
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<th>F crit</th>
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<tbody>
<tr>
<td>Between Groups</td>
<td>29701</td>
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<td>46.19325153</td>
<td>2.27293E-08</td>
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<tr>
<td>Within Groups</td>
<td>28348</td>
<td>44</td>
<td>644268775</td>
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</tr>
<tr>
<td>Total</td>
<td>58109</td>
<td>45</td>
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