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The effect of composite vs. first person perspective view in real world telerobotic operations

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The effect of composite vs. first person perspective view in real world tele-robotic operations

by

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DEDICATION

This research is dedicated to my parents Byung un Chon, Sun young Kim and my wife Yun chong Kim. Also it is dedicated to my lovely daughter Sharon Jun and one or two upcoming babies. Thanks you for endless support. Without their support, I would not have been able to complete this work.

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ABSTRACT

Tele-robotics is an area of robotics concerned with the control of robots from a distance, chiefly using wireless connections like Wi-Fi, Bluetooth, the Deep Space Network, 'tethered' connections, or the Internet. Most tele-robotic systems are teleoperated which means that it relies on the human operator's capabilities. Many aspects like limited perception, cognitive workload, mental capacity, and stress of human operator can restrict human's level 3 SA in operating tele-robotic systems. This study investigated the impact of tele-robotics system operation on operator SA and driving performance. Also it identified specific cognitive factors that affect operator performance and SA in operating a tele-robotic system. Finally, this study was to understand the impact of human workload on performance.

CHAPTER 1. INTRODUCTION

1.1. What is a tele-robot?

Tele-robotics is an area of robotics concerned with the control of robots from a distance, chiefly using wireless connections like Wi-Fi, Bluetooth, the Deep Space Network, 'tethered' connections, or the Internet. According to Ferre et al (2007), tele-robotic systems allow human operators to properly interact with a tele-robot to telemanipulate objects in a remote environment. This means that human actions are extended to remote locations allowing the execution of complex tasks and avoiding risky situations for the human operator (Sheridan, 1989). It is a combination of two major subfields, teleoperation and telepresence. A teleoperator is a machine enabling a human operator to move about, sense, and mechanically manipulate objects at a distance. It usually has artificial sensors and effectors for manipulation and/or mobility, plus a means for the human to communicate with both. Most generally, any tool which extends a person's mechanical action beyond his reach is a teleoperator (Sheridan, 1995). A telepresence is the feeling that the operator exists somewhere else. Equipment like head-mounted displays (HMDs) is an example of telepresence. If the operator can control a device at a distance or remotely, the device is called a tele-robot. The tele-robot requires an operator's manipulation or control to perform its functions. Some examples of tele-robots are radio controlled model aircrafts, tethered deep submarine vehicles, remote control vehicles to eliminate explosive, etc. There are lots of application areas in tele-robotics. The tele-robot has been used and will be used under the environment where human cannot access, such as a space exploration, a deep water working and micro-surgical systems. According to Ferre et al. (2007), the human operator plays an important role in a tele-robotic system. The human operator perceives information from the remote environment through the human system interface and acts accordingly by sending commands to the remote devices. The tele-robotic system has two major functions. First, by allowing the operator to see the remote environment on a computer monitor or screen, the tele-robotic system stimulates the operator's senses. Second, it handles the operator commands in order to properly control remote devices such as robots. There are many kinds of human system interface using motion, force, voice or symbolic inputs (Ferre et al, 2007). These multi-modal commands are conveyed to the tele-robot to perform the remote task properly.

1.2. Situation awareness

An important element of performance in dynamic situations like flying an aircraft, directing traffic at an airport, driving a vehicle, and operating large-systems, is to diagnose and investigate the changing environment and make effective decision in a rapid time. In Endsley's theory (1995a) of situation awareness (SA), there are three stages of construction in a situation awareness; perception, comprehension, and projection. Several researchers have proposed definitions of SA. Sarter and Woods (1991) proposed a definition of SA which states 'accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of recurrent situation assessments' (p.52). Fracker (1988) defines SA as 'the knowledge that results when attention is allocated to a zone of interest at a level of abstraction' (p. 102). Haines and Flateau (1992) states SA as 'One's ability to remain aware of everything that is happening at the same time and to integrate that sense of awareness into what one is doing at the moment' (p.43). Adam (1993) states SA as ‘knowing what is going on so you can figure out what to do’ (p. 319). Among many definitions of SA, the most common reference was Endsley’s (1988) ‘Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future’ (p.97). According to Endsley(1995a), SA consists of three stages. The first level of SA (Level 1) is perception of the elements in environment. In case of aircraft pilot, the pilot would perceive elements such as aircraft, mountains, or warning lights along with their relevant characteristics such as color, size, speed and location. The second level of SA (Level 2) is comprehension of the current situation. This level of SA is based on a synthesis of disjointed Level 1 elements. The final stage of SA is Level 3 which is projection of future status along with both Level 1 and 2. For example, if an operator is controlling a tele-robotic system, he or she can make decision that which direction is preferable to avoid obstacle from previously known information about the environment around the tele-robot. This projection of future status is deduced from both Level 1 and Level 2 of SA (see Figure 1). According to Endsley (1995a), SA is based on these three stages which can help to advance decisions and actions towards accomplishing goals and objectives. This perspective on controlling a tele-robotic system shows the operator’s task of controlling a tele-robotic system which is continually developing a new SA along with feedback from action performance to state of the environment.

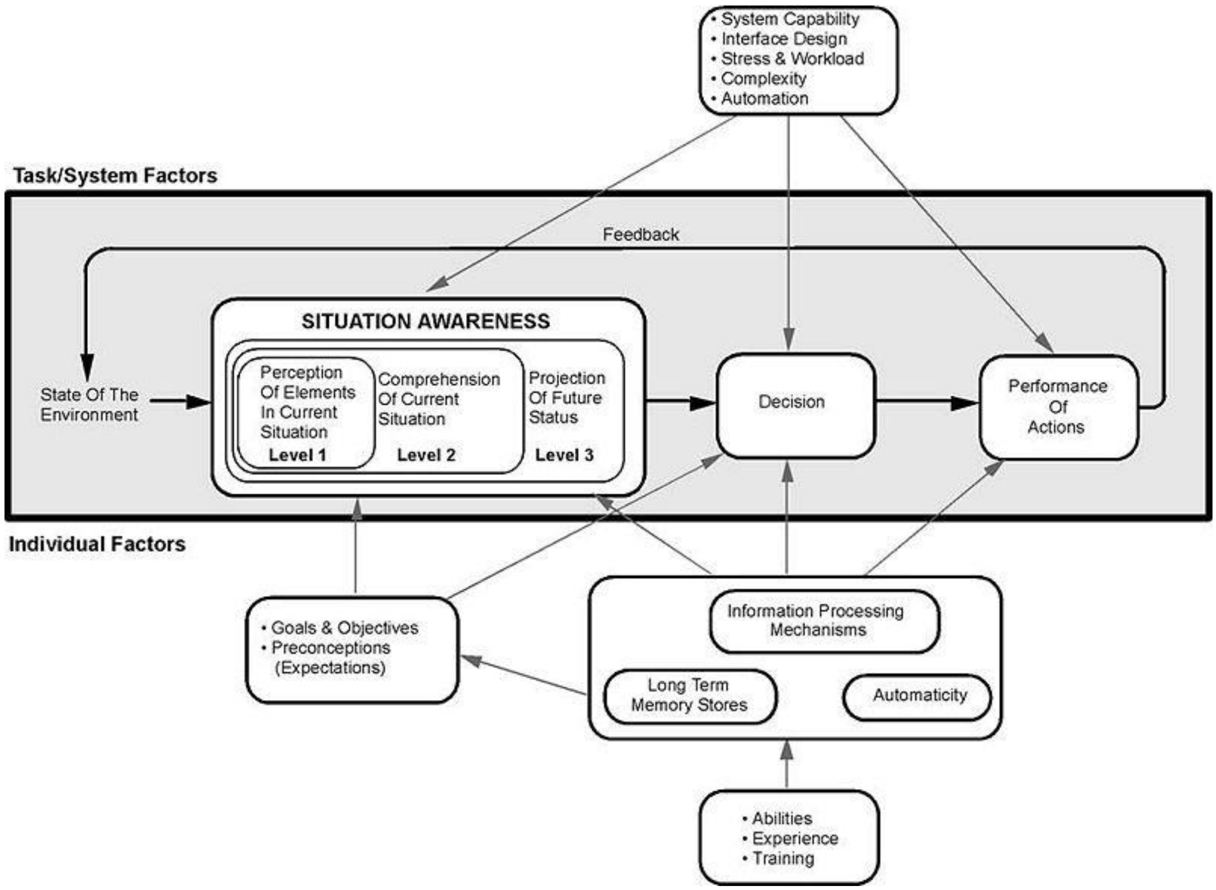

Figure 1. Model of situation awareness (Endsley, 1995a)

1.2.1. Situation awareness in tele-robotic system

Most tele-robotic systems are teleoperated which means that it relies on the human operator's capabilities. Consequently, a mission success requires the human to be a tightly integrated system component. Humans are able to understand highly dynamic and complex environments via their cognitive capabilities. One component of these cognitive capabilities is situation awareness (SA) (Endsley 1988; Endsley 1995a) namely, the human's ability to perceive the environment, comprehend the situation, project that comprehension into the near future, and determine the best action to execute. Thus SA research has focused solely on the human's ability to attain and maintain SA. In a tele-robotic system, the data transmitted from the view of a tele-robot to the operator is very limited. Due to the limited visibility, the human operator needs to be cautious of the environmental conditions which can impair the human operator's SA to perform a task. In the tele-robotic system SA, the perception (Level 1 SA) is only limited by visual or auditory in most cases. Since the human operator can get the limited visual or auditory information from the remote system in most current tele-robotic system, the comprehension (Level 2 SA) is restricted within only integrated information of limited visual or auditory environmental perception. The human operators can predict what will occur in the near future based upon their perception and comprehension of the situation in a tele-robotic system. Thus good projection (Level 3 SA) is directly dependent upon attaining good level 1 and 2 SA. Projection needs a superb understanding of the mission domain (e.g. mental model) and is often a highly demanding cognitive activity. Many aspects like limited perception, cognitive workload, mental capacity, and stress of human operator can restrict human's level 3 SA in operating tele-robotic systems.

1.3 Visual attention

Attention is the cognitive process of selectively concentrating on one aspect of the environment while ignoring other things. According to Anderson (2004), attention has also been referred to as the allocation of processing resources. Basically, humans have limited amount of resources available for an allocation to different tasks, thus humans cannot attend to everything at once. For example, when reading a book, a person easily ignores most sounds around his or her surroundings. Listening carefully to what someone is saying while ignoring other conversation in a room (the cocktail party effect) or listening to a cell phone conversation while driving a car (Strayer et al 2003). Attention is a mechanism of human cognitive function. It includes only perceptions which relate to the objects of interest. For example, as stated before, when a person is reading a book, he or she can easily ignore the surrounding sounds but easily catch a sound that someone calls their name. The visual attention can be considered from the perspective of distributed brain activity engendered by visual input.

1.3.1 Visual attention in tele-robotic system

The tele-robotic system is based on performing its mission by remote control system. Unlike human vision which has 120 degrees perception in the horizontal dimension (Robert 2005, p.3), a tele-robot's visual perception has a shorter span. It only depends on a webcam or several webcams attached on a tele-robot itself, and the human operator only can see the view which is provided by this webcam or webcams. Due to its poorer quality, the image processing in current webcams is not comparable to the visual system of the human organism. In addition, the video motion (frame rate) degradation is a lower quality compared to the human eye. Keskinpala and Adams (2004) research shows expert operators of bomb disposal devices complained that the monochrome and monoscopic video that they had to use made their telemanipulation tasks very difficult, especially when dealing with small objects in outdoor, or in bright sunshine and shadow conditions. Also, according to Darken et al. (2001), people's spatial orientation and object identification in the remote environment also tends to be degraded.

CHAPTER 2. HYPOTHESES

All hypotheses presented in this section represent the effect of the tele-robot operating ability on SA, performance and human workload.

2.1 Impact of information related to operator SA

Situation Awareness is defined by three stages; perception, comprehension, and projection. According to Regal et al. (1988), the broader the knowledge is, the greater the degree of situation awareness. Managing the attention and conceptual process that permit cogent SA requires a significant amount of cognitive resources (Adam et al. 1995). Ultimately the greater the amount of environmental information perceived by the human the greater the likely hood of achieving task comprehension and with that comes a great ability for the human to project on future events. Therefore greater levels of situational awareness are often linked to superior task understanding and performance. On this basis, it is expected that more information can increase human SA. Thus it is hypothesized that the CP group will have a higher SA score than the FPP group (H1).

2.2 Relation of performance and different point of view in tele-robot operating

According to Jennifer (2001), a telepresence is a psychological experience of the human that is postulated to enhance a sensorimotor, as well as cognitive, performance in a teleoperation. As a concept, telepresence has been defined in many ways. Telepresence has been described in terms of teleoperations – meaning present at a distance or control at a distance. Prior research has suggested a relation between task performance and telepresence.

Sheridan (1992a) states that a telepresence is the sense of being physical present with virtual objects at the teleoperator site and the feeling like you are actually 'there' at the remote site of operation. Hine et al., (1995) asserts that a telepresence has been hypothesized to have an influence on human performance with virtual control interfaces for real system operations. Also, they expected that they will experience more effective performance at the control interface. According to Draper et al. (1998), it will be difficult to derive a direct relationship between presence and performance due to a lack of 'appropriate studies' conducted to specifically elucidate the relationship. Accordingly, Welch (1999) has proposed several types of studies to be conducted in order to determine the relationship between presence and performance. Welch suggests manipulating some factors speculated to influence presence and carefully measuring an aspect of task performance that is not directly relevant to the manipulated factor. Kaber and Riley (2000) and Kaber et al. (2000), involving experiments on simulated tele-robot control operations, revealed significant positive relationships between subjective measures of telepresence and performance. Also, Sheridan (1992a) proposed three principal determinants of the sense of presence in an integrated model, including the extent of sensory information, the control of sensors and the ability to modify the computer-generated or remote environment. He asserted that the sensory information dimension of this model includes visual and auditory channels, viewpoint and other factors, such as tactile feedback, which may be important to providing a sense of telepresence in tele-robot operations. Based on those reviews, it is expected that a different point of view and its effects on visual attention in operating a tele-robot system would be of particular interest in further defining the role of telepresense in remote operations. Multiple viewpoints can provide a greater amount of information to the operator. This could result in increased SA (depending on the task difficulty) and a decreased overall task time due to superior vantage point. Thus it is hypothesized that participants in the CP group demonstrate superior task performance when compared to participants in the FPP group (H2).

2.3 Relation between human workload and different point of view in tele-robot operating

According to Posner et al. (1976), the phenomenon of visual dominance, a bias towards information that is presented in the visual modality, acts to further limit human attention capacities. Additionally, a narrow of attention to only specific information of greater importance and centrality will occur under high mental workload, in a manner which Sheridan (1981) calls 'cognitive tunnel vision'. Thus lower visual attention cam result in higher mental workload. Draper and Blair (1996) used two subjective questions in order to measure telepresence in a teleoperation task and demonstrated significant correlations with mental workload in teleoperation tasks. Thus it is hypothesized that the FPP group will have a higher mental workload than the CP group (H3).

CHAPTER 3. EXPERIMENTAL METHODOLOGY

3.1. Experimental group

There were two groups in this experiment. One group was allowed to see both the tele-robot and the computer monitor. This view was a mixture of first and third person perspective of view and was called the composite perspective view group (CP group). The other group was only allowed to see the computer monitor and this was called first person perspective view group (FPP group).

3.2. Experimental track

This was an indoor experiment where the track was in an experimental environment which was surrounded by natural obstacles like a big machine and tables. The length of the path line was 125 ft. Even though the CP group could see the experimental track directly from the participants' view, only a partial view of the whole track was allowed. The CP group could see 63 ft of track (50.4 % of whole track) with the tele-robot in motion. Figure 2 shows an aerial view of the experimental track. Figure 3 represents the partial visible site where the CP group can see the experimental track.

3.3. Task

Participants were asked to operate a tele-robotic system. The goal of the task was to arrive at a destination (the starting point) after finding five objects within a limit of 15 minutes. Participants didn't have to follow the exact path line. The path line served as a guide for the participants while they were running the experiment (see Figure 2). This experimental environment was surrounded by natural obstacles such as a big machine and tables. Thus even though the CP group could use the third person perspective view which is technically a wider point of view than what the FPP group could see, there still existed a blind spot for the CP group. Eventually, the CP group had to rely on viewing the computer monitor on some points of location where the third person perspective view was impaired. Since the webcam on the tele-robot has very limited sight, both groups might have easily gotten lost during the experiment.

There were five objects, which were green cups, and every object was numbered 1 through 5. This provided discrimination to distinguish from whether or not the participants already had found the specific object. The objects featured upside-down figures and those sizes were 5 cm * 20 cm. There were two obstacles on the path and these were white boxes (60cm * 40cm). The participants could choose any direction according to their convenience to pass obstacles when they encountered them.

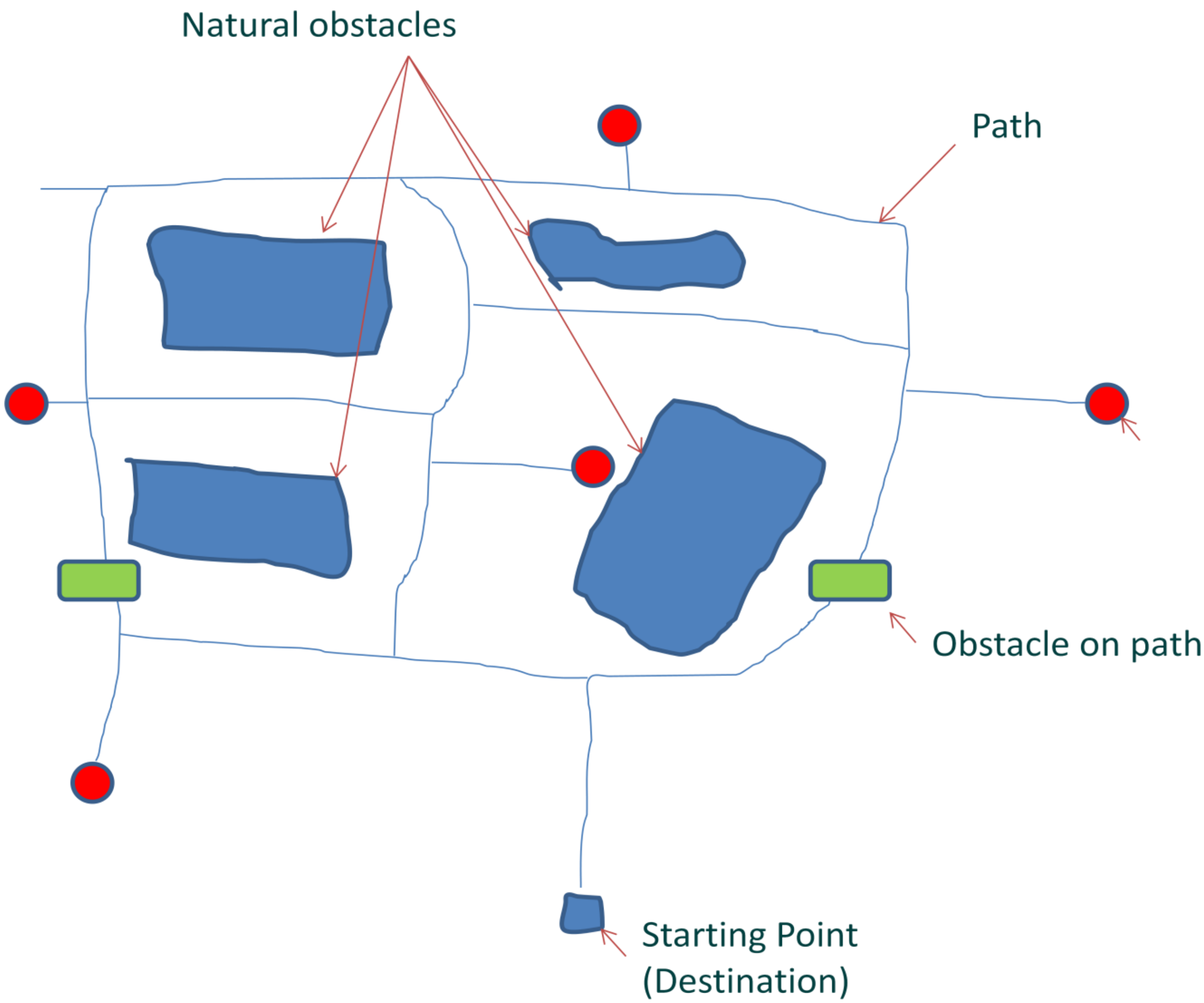

Figure 2. The aerial view of experimental track

Figure 3. The view which CP group can see (63ft, 50.4% of total experiment track)

3.4. Apparatus

The Corobot tele-robotic system, developed by Coroware Inc., was used to perform this experiment (Figure 4). This tele-robot is equipped with a PC-class CPU (via 1.5 GHz) and the operating system of the Corobot is Windows XP edition. The Corobot has a 4 wheel drive skid steer base. Also, the Corobot has the Logitech webcam device on the front. Thus during a remote controlling the Corobot, the operator could see what is on front of the Corobot. Table 1 provides a detail of the Corobot specifications.

Table 1. Specifications of Corobot tele-robot

SPECS			
Dimensions	12"L x 13"W x 10"H (16"T w/ arm)	Bumper Sensors	Front (standard) Rear (optional)
CPU	1.5 GHz	Voltage Sensor	Yes
RAM	1 GB	Arm Size	14"L
Disk Space	80 GB	Arm DOF	4
Wi-Fi	802.11 b/g/n	Gripper Span	1.3"
Battery	10 AH	Gripper Sensor	Yes
Battery Life	2.5 Hours	Arm Payload Capacity	8 oz.
Base Type/Steering	Choice of 4WD skid steer or 2WD diff-drive	Base Payload Capacity	5 lbs.
Camera	High Quality 2 Megapixel Color Camera	Windows®	XP, Supporting C-language API
Wheel Encoders	Yes	Linux®	Ubuntu, Player
Inputs/Outputs	4 digital inputs, 8 digital outputs, 6 analog inputs	Optional Pan/tilt Camera	Yes
Optional Laser Range Finder	URG-04LX-UG01	Max Speed	1.5 ft. per second

Figure 4. Picture of Corobot

On the remote side, the Corobot requires a PC or a laptop computer equipped with a Windows operating system. Figure 5 shows a laptop with a joystick. As shown in Figure 5, the remote side has very limited sight through the webcam on the Corobot. Also, this system has 0.1 to 0.5 second time delay when manipulating the Corobot tele-robot. There is no time delay between the Corobot movement and controlling robot using a joystick. However, the display data from the webcam on the tele-robot to the laptop computer can have a delay up to 0.5 second due to the low frame rate of the webcam. The reason for the time delay is a low frame rate, which is required for smooth communication between the tele-robot and the remote side computer to occupy the data within 2.4 GHz wireless data stream limitation. A low performance CPU is equipped due to keeping low power consumption on the tele-robot in order to operate the Corobot as long as possible.

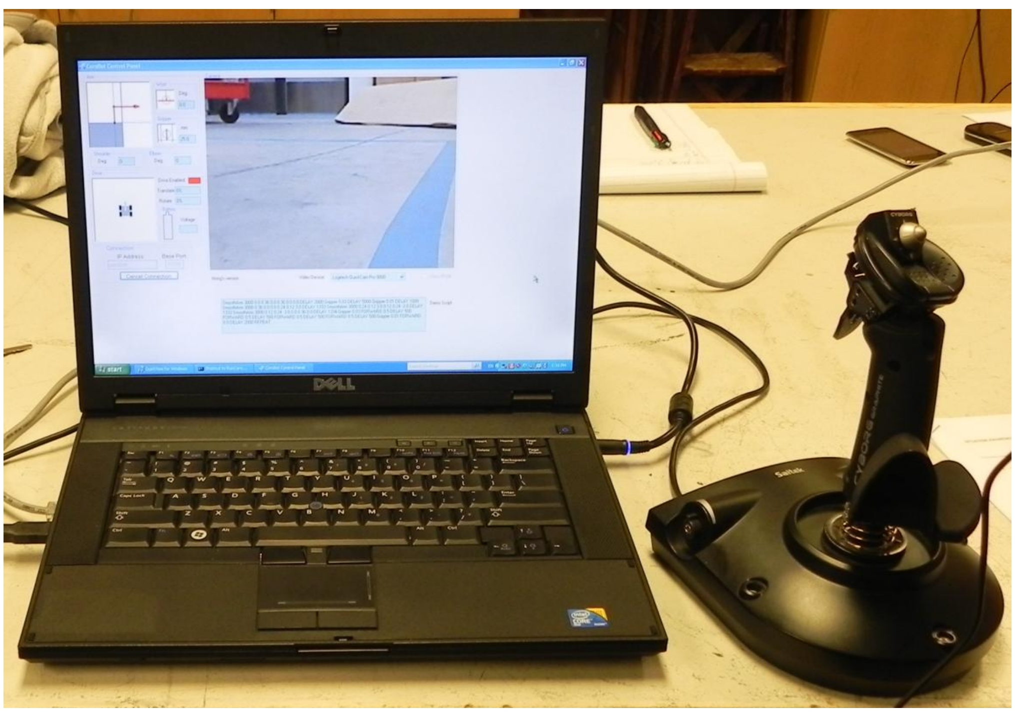

Figure 5. Remote controller system of the Corobot

The remote controller system (user interface) runs its operating system as Windows XP 32 bit version, the size of laptop monitor is 15” (1280 X 800 display resolution) and the joystick is the ‘Saitek Cyborg graphite USB’ product. The laptop is Dell latitude E5500 product. It has 2.8 GHz Intel CPU, 4GB of RAM, and 320GB HDD drive. The communication between the Corobot and the remote controller system is performed via 2.4 GHz wireless signal with transmitter (‘Avalan’ wireless transmitter product) on both sides.

The eye tracker system was used for estimating how many times the participant glanced at the Corobot and the duration of each glance. The eye tracker system was developed by Dongheng Li, a previous Human Computer Interaction (HCI) department student at Iowa State University (Donghen. 2006). He invented the low cost eye tracker system and the starburst algorithm that enable to chase human's corneal movement. The purpose of using the eye tracker system in this experiment was to simply estimate where the participants were looking. The eye tracker system measured how many times the participants glanced at the Corobot and the duration of each glance.

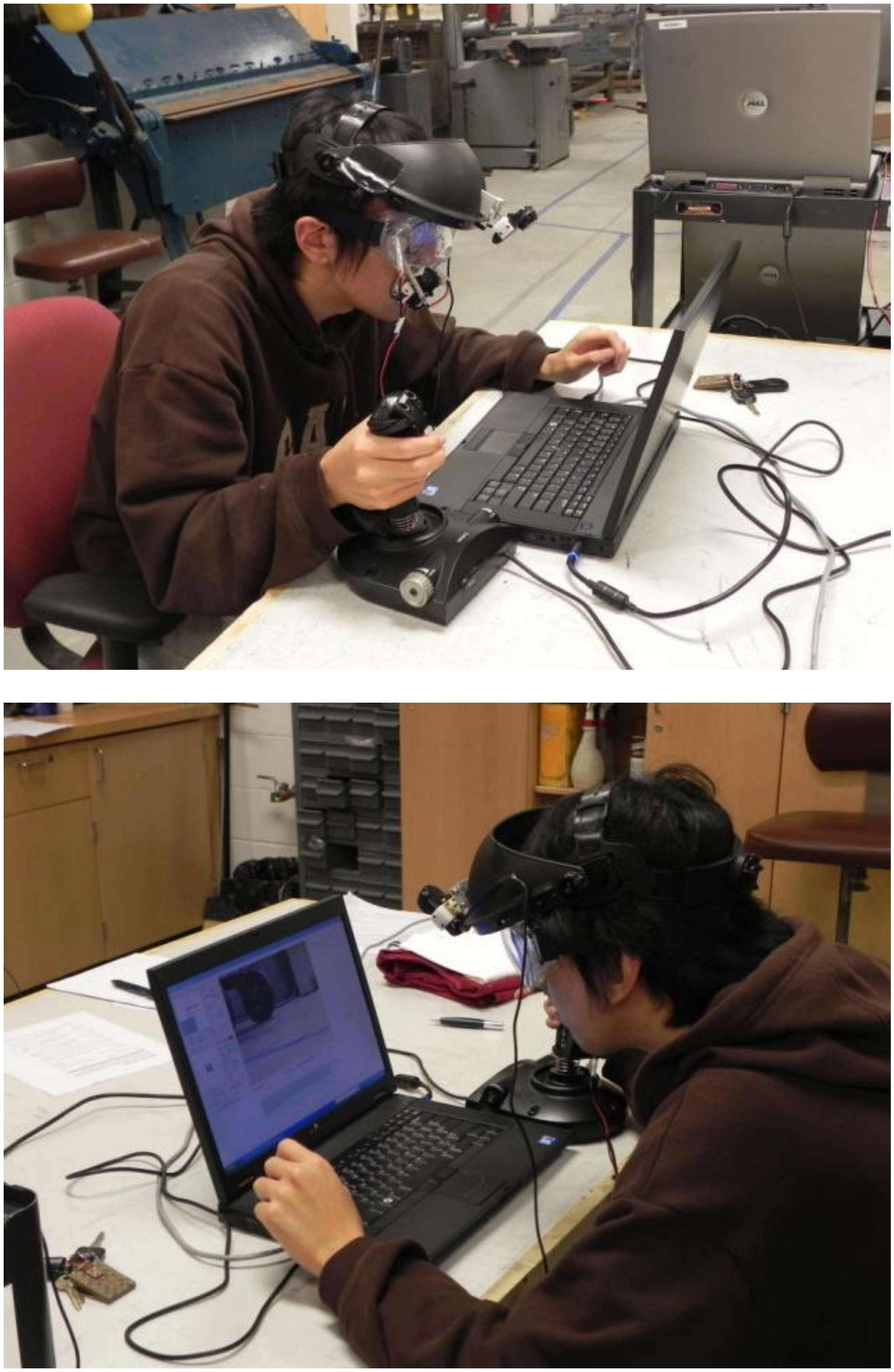

Figure 6. Pictures of wearing the eye tracker equipment.

3.5. Participants

Twenty six subjects (26) were recruited for this experiment with flyer and online postings. All subjects were required to have 20/20 vision or wear corrective glasses or lenses. The participants' age was over 18 years old because industrial tele-robotic systems are typically operated by an adult person(s).

3.6. Experimental design

3.6.1. Independent variable

The experiment design included one independent factor with available point of view. The independent variable in this experiment was point of view at two levels (CP vs. FPP). First, the CP group could see the tele-robot itself and the computer monitor screen during the experiment. Second, FPP group could not see the tele-robot directly during the experiment. The FPP group only could see the video data which transmitted from the webcam on the Corobot through the computer monitor screen. Since an unbalanced sample of males and females was achieved in recruiting (18 males and 8 females), gender was not considerable factor in this study. With these 26 participants, it was randomly divided by two groups (CP group which means Composite Perspective of view and FPP which means First Person Perspective of view group). Each group consisted of 9 males and 4 females.

3.6.2. Dependent variables

Three categories of dependent variables were observed in this study. (1) Operator SA. SA questions were asked at randomly selected times after the participant had passed obstacle, using the SAGAT (Situation Awareness Global Assessment Technique) methodology

(Endsley, 1995b). The SAGAT was developed to assess all SA levels, perception, comprehension, and projection (Appendix D). The SA questions were asked by observer during the experiment. Whenever a question was asked, the experiment would suspend (stop timer) and then resume the task after the SA questions had been answered. The SAGAT question was developed to determine which aspects of the environment were most critical to an operators understanding and performance of their assigned task. The specific SAGAT questionnaire developed for this study was based on goal-directed task analysis (GDTA), a form of cognitive task analysis methodology (Endsley, 2000). This GDTA shows various cognitive aspects while operating a tele-robot. (2) Human workload. At the end of experiment, participants were asked to complete the NASA-TLX (Task Load Index) rating form (Hart and Staveland, 1988). The NASA-TLX is a subjective workload assessment tool for measuring operator workload (stress) with various human-machine systems. There are six types of operator workload measurement in NASA-TLX rating form: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. These six workload factors are integrated to produce a rank-weighted sum of rating after experiment. The observer handed in the NASA-TLX form to the participants when the participants had completed the experiment. An example of NASA-TLX questionnaires is shown in Appendix E. (3) Task performance. This represented task time, the number of objects found and glance activity. Task time was the elapsed time a participant took to perform a mission and returned to finished area. The number of objects found, was a count of how many object were found at the end of a mission. Glance activity was recorded for the CP group participants, this represented the number of glances (time the participant looked away from the control system to the robot) at the robot and the total duration of time spent glancing in the direction of the robot.

3.7. Procedures

Each participant was given basic tele-robotic navigation training and given a practice session prior to beginning the experimental task. The participants were then fitted with an eye tracker. The eye tracker system is composed of two parts; an eye chasing goggle and a frontal view head mount. None of the participants had any experience wearing an eye tracker system. The goggle did not disturb the participants' ability to see clearly. All participants had to perform a calibration trial so as to ensure that the of the eye tracker system would respond accurately to their eye type.

During the experiment, the participants were stopped randomly and asked to answer the SA questions. After participants answered the question(s), they resumed the experiment and the experimenter resumed the timer. The NASA-TLX rating form was administrated after the experiment. Table 2 presents a list of the experimental procedures along with the estimated times for each step.

Table 2. Overview of experimental procedure and approximate time estimates

	Steps in procedure	Time (min.)
1	Introduction and sign informed consent form (see Appendix B)	15
2	Pre-experimental questionnaire (see Appendix C)	5
3	Freely operating the Corobot along with wearing the eye tracker system	5
4	Calibrating the eye tracker system and start experiment to find out 5 objects and avoid 2 obstacles on the path	20
5	During performing step 4, freeze experiment and answer the SA questionnaires (see Appendix D)	5
6	Answer the NASA-TLX rating form after experiment	5
	TOTAL	**55 min.**

CHAPTER 4. DATA HANDLING AND ANALYSIS

4.1 Situation awareness

Scores for level of SA were graded by comparison of subject answers to SA questions during the experiment to that of the actual states of action. The true state of events was verified using video captured by the eye tracker system. The scene camera on the eye tracker system was used to verifying whether the participants had answered questions accurately given the information available to them prior to questioning. For example, one of the questions of Level 1 SA is 'what direction was your last turn?'. If the participant chose 'left turn' and the scene video showed the participant has made a left turn, it was marked as correct. Questions that were wrong, not answered or skipped by subjects were considered incorrect.

The percentage of correct responses to SA verification for each level of SA (Level 1- perception, Level 2- comprehension, and Level 3- projection) were computed for statistical analysis. According to Endsley (1998), SAGAT provides an objective measure of SA based on queries during freezes in a simulation. Endsley also states, 'the main advantage of SAGAT is that it allows an objective, unbiased index of SA that assesses operator SA across a wide range of elements that are important for SA in a particular system' (p.2). In this study, since the workload was also one factor of data analyses, SAGAT was used to estimate the SA queries.

The SAGAT questions used in this study were marked as 'correct' or 'incorrect', which violates the normality assumption of parametric statistical tests. But Endsley (1995b) validated an arcsine function as an effective transformation to solve for this problem in the use of SAGAT. Thus in this study, the arcsine function was used to get parametric statistical analysis from the percentage of correct SA responses. Every SA response was compared to recorded video data from the eye tracking system and graded for each subject.

4.2 NASA-TLX

A paper version of NASA-TLX was used in this study to get overall TLX score, based on the value for each of six workload factors: Mental demand, Physical demand, Temporal demand, Performance, Effort, and Frustration. Also, each factor has weight correlations. The total scale of TLX score was estimated by manually and converted to 0 – 100 scores.

4.3 Operating performance

The overall time to complete a task (task time) was recorded (in seconds) for each subject. Additionally, for members of the CP group, the number of glances at the robot and the duration of those glances (seconds) were recorded. Like SA data, the number of glances at the robot and duration of glances data were determined via review of the video from the eye tracking system.

4.4 Statistical analysis

All the statistical analyses in this study were conducted using Minitab 15. Prior to model analysis, raw data was arranged using Microsoft Excel. The SA data were discrete, and as such this data did not conform to normal distributions. Thus, Kruskal-Wallis test was conducted on all response measures among the SA scores and the different point of view conditions. Since the probability of elapsed time did not satisfy normal distribution, the natural log transformation was used for elapsed time data. For the analysis of operation performance, the Pearson correlation coefficients were used to compare SA, the number of glances at the robot, and the time interval for looking the robot. Univariate analyses of variance (ANOVA) were conducted to determine if any significant main effect or interaction effects existed between the different levels of point of view and performance. Also ANOVA and post hoc tests were conducted to investigate interactive effects between different point of view and NASA-TLX scores.

CHAPTER 5. RESULTS

5.1 Participant characteristics

The twenty six (18 males and 8 females) were recruited for this study. All participants were undergraduate or graduate students at Iowa State University. All subjects had uncorrected or corrected 20/20 vision ability. The average age of the participants was 26.9 years with a standard deviation of 5.4 years. Only two of the 26 participants had experience operating a tele-robot.

5.2 Situation awareness

Prior to performing inferential statistical analysis to investigate the relationship between SA and point of view, normality test for each of the three SA levels and total SA scores was reviewed (see appendix F). The results of normality of each SA and total SA were discrete, so a Kruskal-Wallis test was performed. The results show that the different point of view does not significantly affect SA scores (p =0.457 on SA 1, p =0.898 on SA 2, p =0.626 on SA 3, and p = 0.427 on total SA). The difference of total SA average between CP group and FPP group is only 0.044. The difference between the medians is 0.089. Therefore there is no significant difference between groups (CP group and FPP group) (see Table 3). This table shows that it is not easy to define the difference SA between two groups in this experiment.

Table 3. Median and p values for SA for independent variables on Kruskal-Wallis test

Independent Variables		Dependent Variables			
		SA Level 1	SA Level 2	SA Level 3	Total SA
CP group	Median	1.0297	0.6435	0.5236	0.6751
FPP group	Median	0.9851	0.5236	0.3398	0.7647
p-value		0.457	0.898	0.626	0.427

5.3 Performance (elapsed time)

Prior to analyzing the correlation between different points of view and performance, the elapsed time was normalized. Since the result of *p*-value of elapsed time is 0.070, the requirement of normal distribution was not obtained. So, natural log transformation was adopted to satisfy a normal distribution. The results of *p*-value of elapsed time after adopting natural log transformation was 0.542 which satisfies a normal distribution (see appendix F). The ANOVA test was conducted to investigate a relation between different points of view and performance in terms of overall task time (elapsed time). Figure 7 presents the interval plot of elapsed time given a 95% CI. The mean value of CP group was 483 sec and the mean value of FPP group was 604 sec. The results show there is a significant difference between two groups on their performance (p = 0.021). In this study, the performance in a CP group increases around 25% than FPP group (25.051% increased).

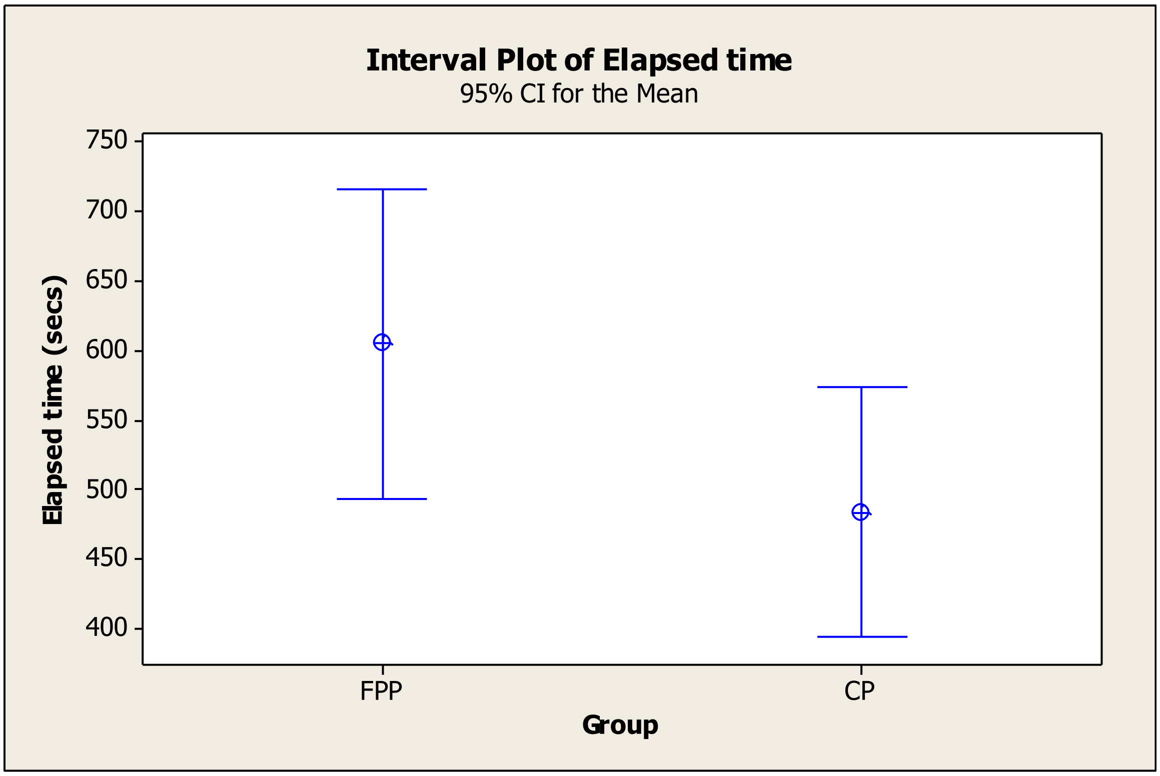

Figure 7. Interval plot of elapsed time

5.4 Correlation analysis

5.4.1 SA vs. visual attention factors

Pearsons correlation coefficient was used to test the correlation between SA score and the visual attention factors (the number of glances at a tele-robot and the duration of glance a tele-robot). This analysis is only for the CP group. The results show there is not a significant relation between SA scores and the number of glances at a tele-robot and the duration of glance a tele-robot except the relation between the Level 3 SA score and the duration of glance a tele-robot. Table 4 presents that Pearson correlation and p-value along with each

SA level score and total SA scores. Only the duration of glance at the tele-robot has a correlation with Level 3 SA.

Table 4. Correlation analysis between each level of SA and total SA scores and the number of glances at a tele-robot and the glance duration

Visual attention factors		Level 1 SA	Level 2 SA	Level 3 SA	Total SA
Number of glances at a tele-robot	Pearson correlation	-0.079	0.168	0.281	0.195
	p-value	0.797	0.583	0.353	0.522
Duration of glance	Pearson correlation	-0.014	0.174	0.618	0.428
	p-value	0.964	0.570	0.025	0.145

5.4.2 SA vs. performance

Pearson correlation coefficients were used to test a correlation between SA score and the performance (the elapsed time). The results show there is not a significant correlation between each SA scores and the performance. Only total SA score has a correlation with performance (p = 0.027). Table 5 presents the correlations between SA level scores and performance.

Table 5. Correlation analysis between each level of SA and total SA scores and the performance.

		Level 1 SA	Level 2 SA	Level 3 SA	Total SA
Level 2 SA	Pearson correlation	0.107			
	p-value	0.602			
Level 3 SA	Pearson correlation	0.147	0.073		
	p-value	0.475	0.724		
Total SA	Pearson correlation	0.589	0.597	0.680	
	p-value	0.002	0.001	0.000	
Elapsed time (Performance)	Pearson correlation	-0.112	-0.347	-0.251	-0.432
	p-value	0.585	0.085	0.217	0.027

5.4.3 NASA-TLX score vs. different point of view

Regarding the relation between NASA-TLX scores and different point of view, ANOVA test has been performed to investigate a correlation between those factors. The physical demand on NASA-TLX score had little relation with different point of view (p = 0.064). But other NASA-TLX scores do not have significant relations with different point of view. It reveals there is no significant relation between each NASA-TLX score and different point of view (see Table 6). Figure 8 to 14 are the interval plot graphs between different point of view and each factor of NASA-TLX.

Table 6. ANOVA results for NASA-TLX with a different point of view

		ANOVA results						
		NASA-TLX						
		Overall	Mental demand	physical demand	temporal demand	performance	effort	frustration
Different point of view	F	0.02	1.45	3.76	0.02	0.53	0.00	0.04
	p-value	0.883	0.241	0.064	0.886	0.474	0.968	0.853

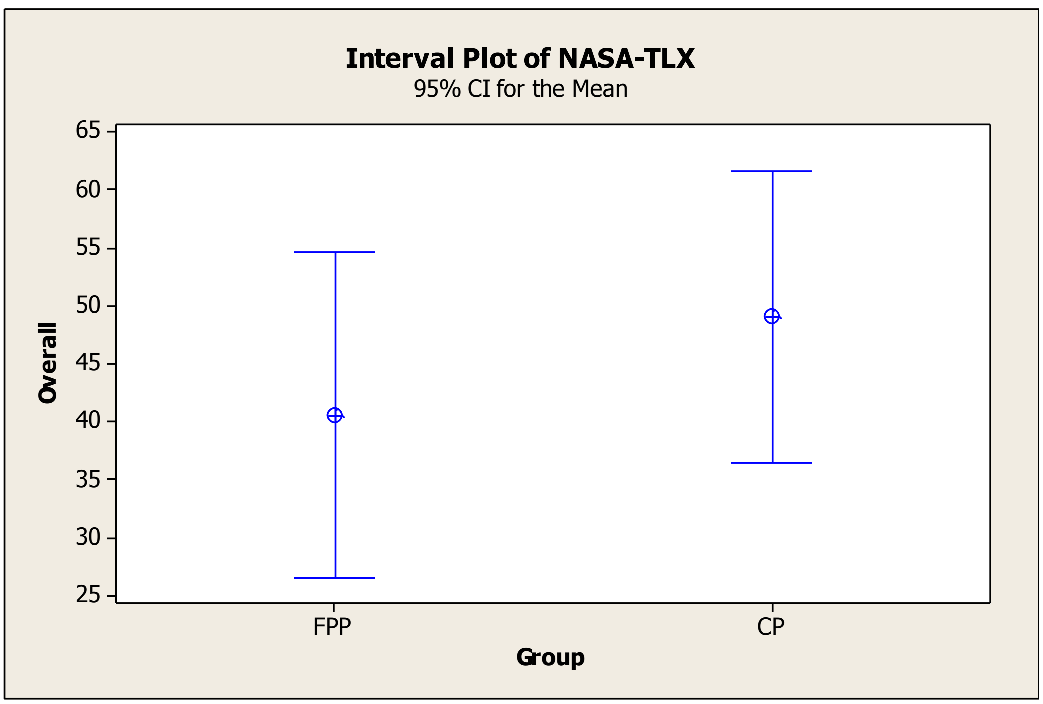

Figure 8. Interval plot of total NASA-TLX with different point of view condition

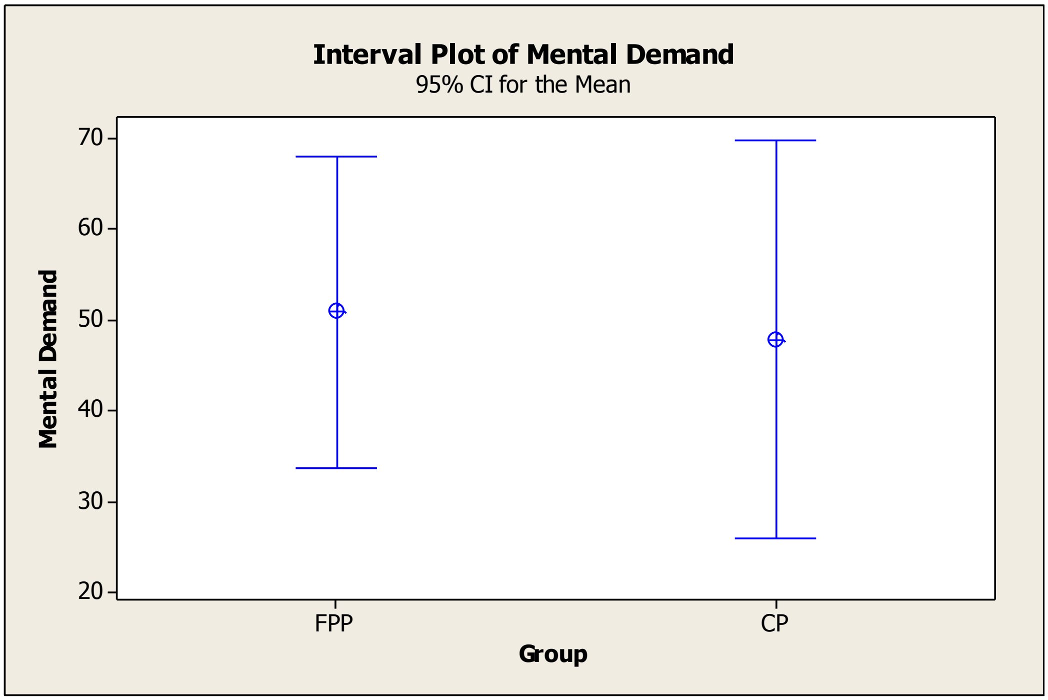

Figure 9. Interval plot of mental demand with a different point of view condition

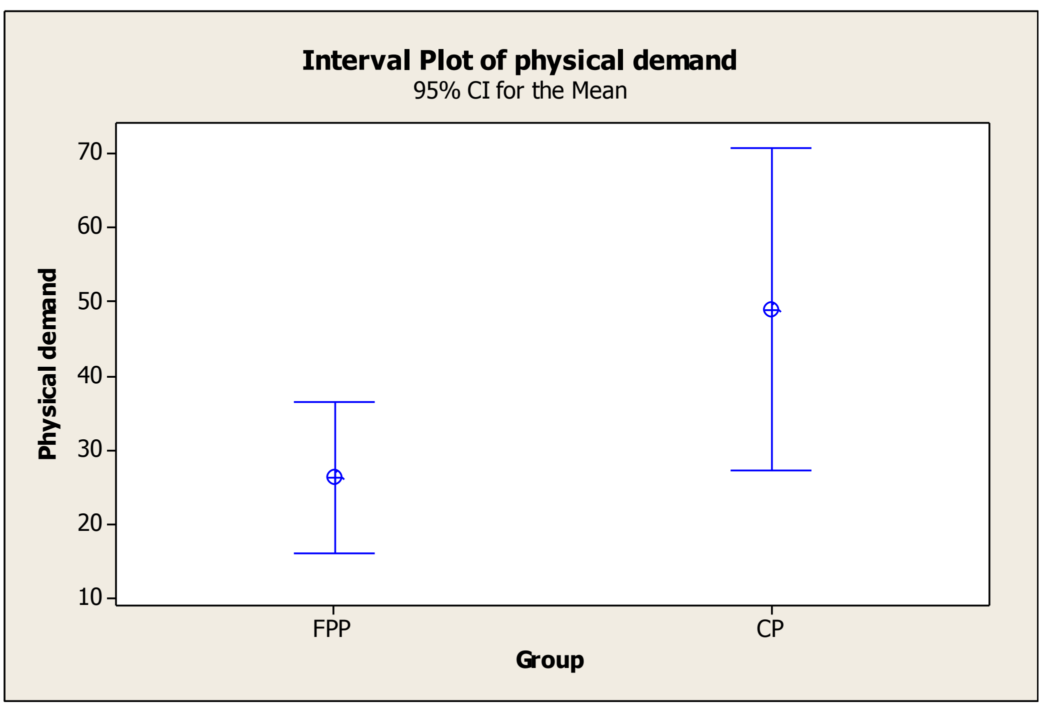

Figure 10. Interval plot of physical demand with a different point of view condition

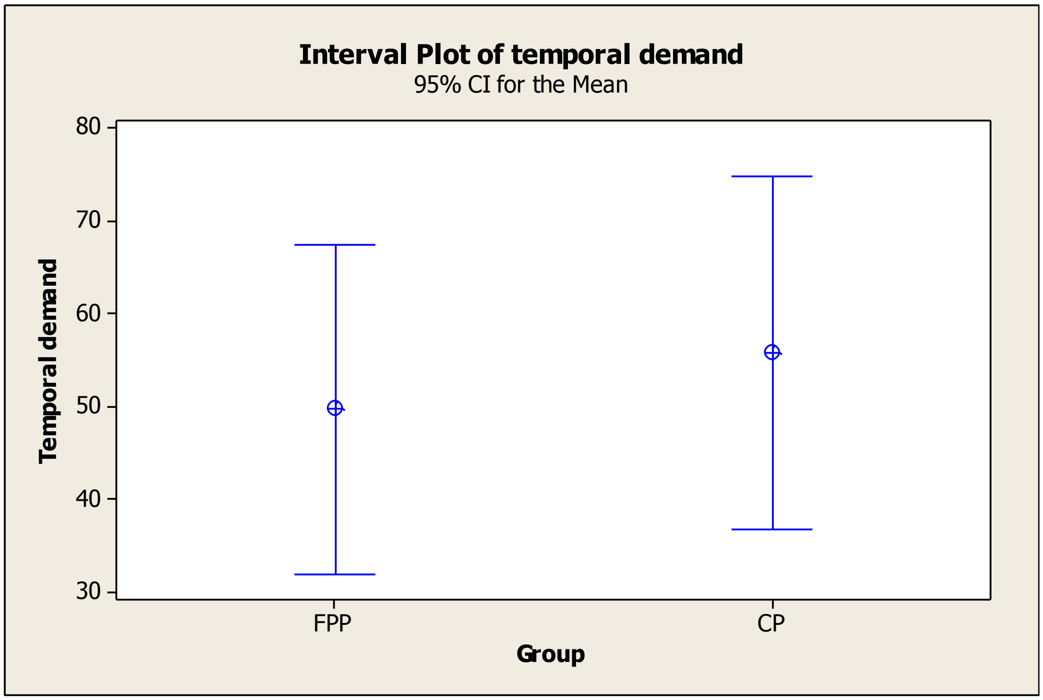

Figure 11. Interval plot of temporal demand with a different point of view condition

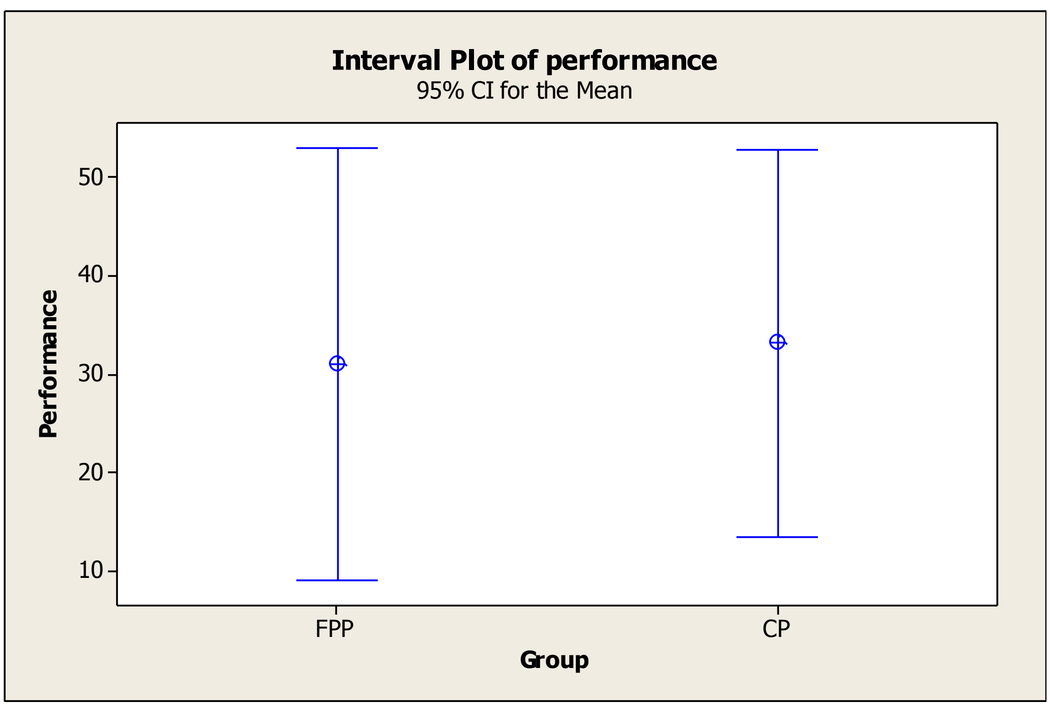

Figure 12. Interval plot of performance with a different point of view condition

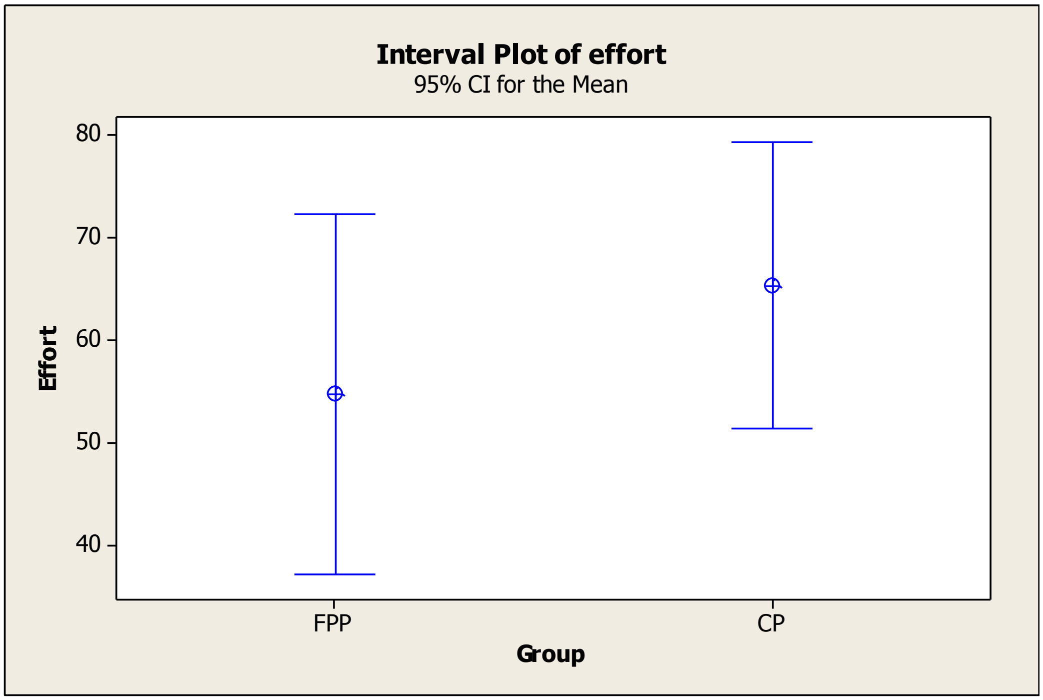

Figure 13. Interval plot of effect with a different point of view condition

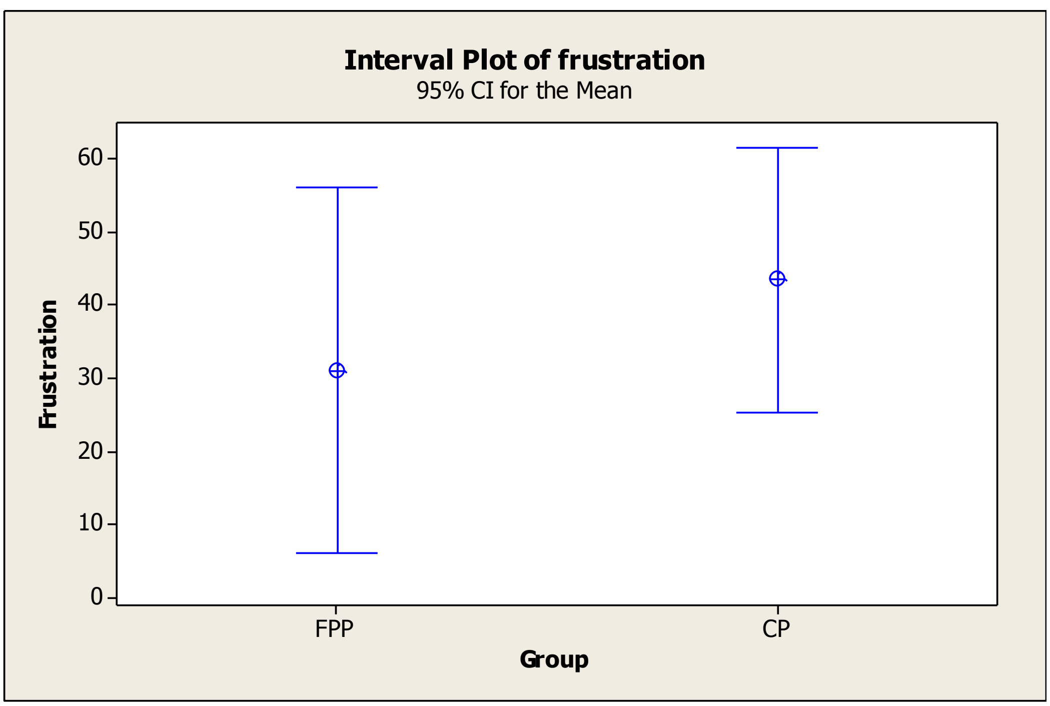

Figure 14. Interval plot of frustration with a different point of view condition

CHAPTER 6. DISCUSSION

6.1 SA and tele-robot operation

6.1.1 The effect of different points of view on SA

Prior researchers have found that visual attention will degrade SA and will increase the operator's mental workload (Posner et al., 1976; Sheridan et al., 1981; Keskinpala and Adams, 2004; Darken et al. 2001). It was expected that if the operator receives more visual data while operating a tele-robotic system, the operator could process more information and improve perception. Descriptive information supports the H1 hypothesis; more information (in the CP group) can increase the operator SA. However, contrary to hypothesis H1, there was no significant difference on SA level 1 between the CP group and the FPP group in this study (p = 0.457). Even at SA level 2, the result is worse than at SA level 1 (p = 0.457) or SA level 3 (p = 0.626). The result of p-value at SA level 2 scores shows that both groups' SA is almost comparable (p = 0.898). The median of total SA in the CP group (0.6751) is slightly lower than in the FPP group (0.7647). The p-value of two groups is 0.427 which shows there is no significant difference also.

Human SA is a very complex notion that is influenced by a number of internal and external factors (Endsley 1995a; Salmon et al. 2006; Wickens 2002). Most of the previous research has focused on complicated testbeds like airplane or driving vehicle simulations. The relative simplicity of the testbed in this study makes comparison with previous work problematic. There are two possible explanations of the results in this study. First, it is possible that the experiment in this study might be too simple to show significant differences in SA. However it should be noted that most low level operations (police and military use of exploratory robots) represent direct analogue to the operation performed in this study. Hence the number of divisions required by the visual system is likely a significant factor for any tele-robotic operation. Second, it is possible that the different point of view does not affect the human operator's SA in the tele-robotic system. This is highly unlikely given our findings that time was a significant factor. It is more likely that the SA development simply occurred more quickly for members in the CP group. In future work time given to participant in this same experiment should be used as an independent factor, so as to determine the nature of the time SA development relationship.

6.1.2 The effect of visual attention factors on SA

The correlation between visual attention factors and SA has been investigated in the CP group. The visual attention factors include the following: (1) the number of times a participant looked away from the screen and glanced at the robot, and (2) the duration of the glance. Consistent with H1, it was expected that the information gain would be greater in the CP group. Hence, the Level 1 SA score was anticipated to increase if a participant looked away from the screen and stared at the tele-robot more frequently. However, the results show that there is no relation between the frequency of the glances and the score at SA level 1 and 3 SA. However, there is a significant correlation between the score and the duration of the glance (Pearson correlation = 0.618, p = 0.025). This study confirms that only the duration of the glance impacts SA.

6.2 Operator performance

In this study, the elapsed time is used to measure performance. Prior research suggests a relationship between performance and telepresence. Operating a tele-robot has been hypothesized to improve human performance with virtual control (Sheridan, 1992b; Hine et al., 1995). However, the evidence for improvement is mixed. One study emphasizes the difficulty of establishing a direct relationship between telepresence and performance (Draper et al., 1998). Other studies have demonstrated that time delay in the control loop between the operator and the robot can negatively affect operator performance (Conklin, 1957; Sheridan and Ferrell, 1963; Sheridan, 1992b). Black (1971) showed similar results illustrating the increase in task time with higher levels of delay for a 6 DOF manipulator task. In this study, the tele-robot operating performance worsened showing a significantly increase in task time for the FPP group. The performance of the FPP group was 25% worse than the performance of the CP group ($F = 6.14$, $p = 0.021$). The average difference in the time elapsed was 121 seconds. Clearly, an additional point of view improves task performance. This result supports the hypothesis (H2) that a mixture of first and third person perspective of view (the CP group) can improve performance. The most significant factor contributing to an increase in elapsed time in the FPP group was ‘over actuation’. Over actuation involves redundant control actions performed by the operator. Delay between the command input via joystick and the display output on the monitor creates the illusion that the operator’s commands are ineffectual. The operator compensates by issuing more commands that complicate error correction. This distracts the operator and increases task time.

6.3 Operator workload

According to Bosse et al. (2006), concentration is one of the factors affecting visual attention. Distractions while operating a tele-robot interfere with the operator's concentration. A narrow of attention to only specific information of greater importance and centrality expected to occur under high mental workload. Thus the operator's workload (stress) may increase when the operator is exposed under low visible capability circumstance. The lower visual attention in the FPP group expected to get higher human workload than the CP group. It is only demonstrated that the physical demand ($F = 3.76$, $p = 0.064$) is significantly different between the CP and the FPP groups. However, the overall results indicate that there is no significant relationship between operator workload and point of view. Also, there is no significant relationship between operator mental workload and point of view ($F = 1.45$, $p = 0.241$). Thus H3, the FPP group has higher mental workload than the CP group, is not true.

CHAPTER 7. CONCLUSION

This study had the following objectives: (1) to investigate the impact of tele-robotic system operation on operator SA and operating performance; (2) to identify specific cognitive factors that affect operating performance and SA; (3) to gain a better understanding of the relationship between point of view and SA; (4) to compare the FPP environment to the CP environment in order to measure operator performance; and (5) to understand the correlation between human workload and the different point of view on operating a tele-robotic system.

7.1 Operator SA, human workload, and point of view

Two points of view were utilized in this study. One group of operators was allowed to see both the tele-robot and the monitor. This mix of first and third person perspective is called the Composite perspective (CP) group. The other group was only allowed to see the computer monitor. This group had first person perspective view and was called the FPP group. This study revealed no significant correlation between operator SA and point of view in the tele-robotic system. It has been shown that all levels of SA; including perception, comprehension, and projection are not affected by point of view. Also, this study revealed that there is no significant correlation between human workload and point of view.

7.2 Operator performance

The difference in performance between the two groups was significant. This study showed that operators perform 25% worse when they cannot see the tele-robot directly. This led to redundant command input in the FPP group that complicated error correction when operating the tele-robot.

7.3 Caveats

There was limitation in this study. It was in analysing human operator SA. There is no previous work with which to validate our measurements of SA in operating tele-robotic system. According to Endsley (1998), the SA questionnaires should be completed in 3 to 5 minutes to prevent operator's working memory decaying. Thus the SA questionnaires should be short enough to complete in 5 minutes. In this study, only 13 SA questions were included to satisfy Endsley's theory. If more questions were included it is possible that the SA results might have been different.

7.4 Future research

Directions for future research include examining the performance of different genders. To analyzing the relationship among SA, performance, and working memory is also of interest. As SA is based on initial information perception and comprehension, it is important to understand the relationship between working memory and SA at level 1 and 2. Also, this would provide a point of comparison for the same participants repeatedly. Finally, comparing the results of the correlations among human operator SA, workload, and performance in existing real world tele-robot to the results of a tele-robotic system simulation program could provide insight into tele-robotic system design.

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Appendix A: GDTA FOR OPERATING TELE-ROBOT

<u>Basic Goal Statement</u>: Arrive at destination within a limited time after find out all 5 objects

1) Plan to follow the path line & strategy
    a. Perceive current state of vehicle (position, speed) (see Sub-goal 3)
    b. Perceive remained object found out
    c. Object size
    d. Perceive elapsed time
    e. Perceive the number of times to look outside of monitor screen
    f. Analyzing the difference between monitor screen and look at the tele-robot itself

2) Conform to roadway conditions and/ or environment
    a. Perceive current state of vehicle (position, speed) (see sub-goal 3)
    b. Perceive path, obstacles on path, natural obstacles
        i. Type of path figure
        ii. What was last turn
        iii. Status of path incline
    c. Perceive obstacles on path
        i. The shape of obstacles on path
        ii. The size of obstacles on path
        iii. Which direction is easy to avoid the obstacle on path
    d. Intersection on path

i. How many intersection met

ii. How many branch on first intersection

iii. How long have you been passed last intersection

3) Perceive the status of tele-robot

a. Current location

b. Current direction

c. Current speed

Appendix B: INFORMED CONSENT DOCUMENT

Title of Study:

Approaching Situation Awareness research under interfering visual attention on Telerobot with time delay with time delay circumstance

Investigators:

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This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION

The aim of this study is to explore the relationships between visual attention and situation awareness on time delay status. Visual attention in this study is defined as the degree to which a participant can concentrate on key display elements apposed. Situation awareness referees to how humans react with limited information and how human make a decision with this information.

In this study a participant will be asked to navigate a tele-robotic system while looking for lost items in an open field. During this task the experimenters will evaluate visual attention and situational awareness by utilizing to common techniques (eye-tracking and verbal Questions). eye tracking is a common and risk free technique which requires the participant to wear a goggles with attached cameras.

The Eye-tracker tracks human eye movement by record video of the eye and the object the human is looking at. The experimenters will verbally ask situational relevant question while the participant is performing their task. Using these methods we intend to define the relationships between visual attention and situation awareness in the context of common tele-robotic tasks. The data collects from our testing can be used to guide and to improve the design of human-robot regarding to safety and efficiency.

DESCRIPTION OF PROCEDURES

If you agree to participate in this study, your participation will last for 1 hour and 30 minutes**.** During the study you may expect the following study procedures to be followed:

Pre-Experiment (10-15 minutes)
Participants will be greeted by the experimenters and asked to review and sign the informed consent document. After participants make an agreement to participant the experiment, they will be asked to fill out a pre-experimental questionnaire which involves the questions about their automation control experience. Then participants wear the Eye-tracker system on their head. Then the participants are randomly and equally divided into two groups, one is exposing visual attention group, the other is No exposing visual attention group.

Calibration eye-tracker and Exercise Section (10-15 minutes)

All participants will be calibrated eye-tracker system. Due to the difference of human's head and face appearance, we need to set to calibrate eye-tracker for every participant. Then they will be given 5 to 10 minutes to control the tele-robot system freely to become familiar with controlling tele-robot system with joystick.

Experiment Section (30-45 minutes)
Participants will see the movements of tele-robot system with video screen. The exposing visual attention group can see what happens and the movement of tele-robot in two ways, one is seeing with computer monitor screen and the other is watching tele-robot itself with participant's own eyes. The No exposing visual attention group can see only with computer monitor screen and they cannot see the tele-robot itself.
The object of this control tele-robot is control the tele-robot with following the line. And if there is obstacles during driving tele-robot, avoid obstacles and keep following the line to arrive to final point.
While participants are following the line, they need to find object which is explained before experiment beginning by observer.
After driving 5 minutes, the participants stop to control the tele-robot, and answer the questionnaire by supervisor.
It will last for 10 to 20 minutes to answering questionnaire expected.
After finishing answering the questionnaire, participants continue to drive tele-robot to arrive the finish point.

RISKS

In the unlikely event that participants experience discomfort while wearing the Eye-tracker, experimenters will adjust the placement of eye-tracker to fit comfortably and not to block experimenter's vision. The eye-tracker in this experiment construct with goggles and face shields along with webcam is positioned near beneath of experimenter's left eye. Experimenter can adjust the position and angle of web-cam to fit comfort during experiment. It should be noted that no study using eye trackers has ever reported an injury due to it's use. In additional the only discomfort every reported was related to the goggle unit being fitted to tightly

BENEFITS

The interactions between humans and automation robot are becoming increasingly important and intimate. Our study result can help and improve human performance in human-robot system because issues related to use, misuse, and judge (decision making by human) these automation robots. The outcomes of this study will be used to create a detailing report complete with design recommendations for controlling attention issues for on small scale tele-robotic operations.

The participants in this study will benefit by learning how to perform a tele-robotic search task. Beyond compensation there are no other direct benefits to the participant in this study.

COSTS AND COMPENSATION

You will not have any costs from participating in this study. You will be given a T-shirt as compensation.

PARTICIPANT RIGHTS

Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled.

RESEARCH INJURY

Emergency treatment of any injuries that may occur as a direct result of participation in this research is available at the Iowa State University Thomas B. Thielen Student Health Center, and/or referred to Mary Greeley Medical Center or another physician or medical facility at the location of the research activity. Compensation for any injuries will be paid if it is determined under the Iowa Tort Claims Act, Chapter 669 Iowa Code. Claims for compensation should be submitted on approved forms to the State Appeals Board and are available from the Iowa State University Office of Risk Management and Insurance.

CONFIDENTIALITY

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies, auditing departments of Iowa State University, and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, the following measures will be taken Individual privacy will be maintained in all published and written data resulting from the study. Participants will be given a Unique Person Number(UPN). This number will be used instead of names to identify information collected during the study. Data in electronic or paper form (with no associated identifying information) will be stored, indefinitely, on computers or data storage devices belonging to the PI and/or the Iowa State University. Association of participant names with data will not be possible from the stored files. If the results are published, your identity will remain confidential.

QUESTIONS OR PROBLEMS

You are encouraged to ask questions at any time during this study.

- For further information about the study contact

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- If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.

****

PARTICIPANT SIGNATURE

Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the written informed consent prior to your participation in the study.

Participant's Name (printed) ____

____   _________________________

(Participant's Signature)   (Date)

INVESTIGATOR STATEMENT

I certify that the participant has been given adequate time to read and learn about the study and all of their questions have been answered. It is my opinion that the participant understands the purpose, risks, benefits and the procedures that will be followed in this study and has voluntarily agreed to participate.

____   _________________________

(Signature of Person Obtaining   (Date)

Informed Consent)

Appendix C: PRE-EXPERIMENT QUESTIONNARE

Name:

Age:

Sex (circle one) Male Female

Current corrected vision(e.g., 20/20, 20/30): Left: Right:

1. Do you play video games often? Yes / No
   If yes, how often?(e.g., 10hours per week)

2. Do you play with remote control cars often? Yes / No

3. Do you have a remote control car at home? Yes / No

4. Do you use a joystick controller often? Yes / No

5. Do you drive a vehicle every day? Yes / No

6. Have you ever manipulated a Tele-operational experiment? Yes / No

7. Have you ever worn an I-tracker system? Yes / No

8. Are you interested in the experiment? Yes / No

DO NOT WRITE BELOW THIS LINE

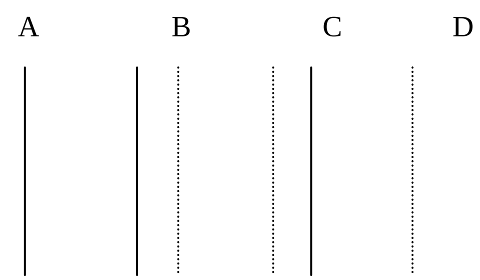
Subject #

Appendix D: SA QUESTIONAIRE

SITUATION AWARENESS QUESTIONAIRE (TYPE A) – For FPP Group

SUBJECT # :

1. What is the current Driving Line on the path? (LEVEL 1 SA)
    a. Solid single line
    b. A solid line on the left and a broken or dashed line on the right
    c. A solid line on the right and a broken or dashed line on the right
    d. Single dashed line



2. What is your last turn? (LEVEL 1 SA)
    a. Left turn
    b. Right turn
    c. Never made turn

3. Is there any incline on the path? (LEVEL 1 SA)
    a. YES
    b. NO

4. Have you ever experienced an obstacle on your path? (LEVEL 1 SA)
    a. YES
    b. NO

5. Have you found any object to find out? (LEVEL 1 SA)
    a. YES
    b. NO

6. How many object have you found? (LEVEL 1 SA)
    a. None
    b. 1
    c. 2
    d. 3
    e. 4

7. How big is obstacle? (LEVEL 2 SA)
    a. Never met any obstacle
    b. 20cm * 15cm
    c. 40cm * 30cm
    d. 60cm * 40cm
    e. Over 60cm * 40cm

8. How long has it been since you passed the last intersection or curve? (LEVEL 2 SA)
    a. Less than 15sec.
    b. 15-30 sec.
    c. 31-60sec.
    d. Over 60sec.

9. Which direction was easier to avoid an obstacle while you are driving? (LEVEL 2 SA)
    a. Left direction
    b. Right direction
    c. Does not matter

10. How big is object? (LEVEL 2 SA)
    a. 5 cm * 20cm
    b. 10 cm * 30cm
    c. 20cm * 40cm
    d. More bigger than 20cm * 40cm
11. How long will you take to arrive in next intersection or curve? (LEVEL 3 SA)
    a. Less than 10 sec.
    b. 11-30 sec.
    c. 31-40 sec.
    d. 41-50 sec.
    e. More than 51 sec.

12. How many object can you find out finally? (LEVEL 3 SA)
    a. None.
    b. 1
    c. 2
    d. 3
    e. 4
    f. 5

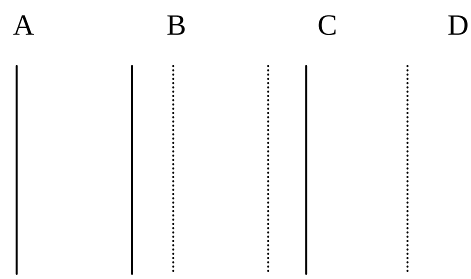
13. How long will you take to finish this experiment? (LEVEL 3 SA)
    a. Less than 5 min.
    b. 5- 10 min.
    c. 11-15 min.
    d. 16-20 min.
    e. 21-25 min.
    f. More than 25 min.

SITUATION AWARENESS QUESTIONAIRE (TYPE B) – For CP Group

SUBJECT # :

What is the current Driving Line on the path? (LEVEL 1 SA)

a. Solid single line
b. A solid line on the left and a broken or dashed line on the right
c. A solid line on the right and a broken or dashed line on the right
d. Single dashed line



2. What direction was your last turn? (LEVEL 1 SA)
   a. Left turn
   b. Right turn
   c. Never made turn

3. Is there any incline on the path? (LEVEL 1 SA)
   a. YES
   b. NO

4. Have you ever experienced an obstacle on your path? (LEVEL 1 SA)
   a. YES
   b. NO

5. Have you found any object? (LEVEL 1 SA)
   a. YES
   b. NO

6. How many object have you found? (LEVEL 1 SA)

a. None
b. 1
c. 2
d. 3
e. 4

7. How many times did you see outside of monitor screen? (LEVEL 1 SA)
   a. None
   b. 1-5 times
   c. 6-10 times
   d. 11-15 times
   e. More than 15 times

8. How big is obstacle? (LEVEL 2 SA)
   a. Never met any obstacle
   b. 20cm * 15cm
   c. 40cm * 30cm
   d. 60cm * 40cm
   e. Over 60cm * 40cm

9. How long has it been since you passed the last intersection or curve? (LEVEL 2 SA)
   a. Less than 15sec.
   b. 15-30 sec.
   c. 31-60sec.
   d. Over 60sec.

10. Which direction was easier to avoid an obstacle while you are driving? (LEVEL 2 SA)
    a. Left direction
    b. Right direction
    c. Does not matter

11. How big is object? (LEVEL 2 SA)
    a. 5 cm * 20cm
    b. 10 cm * 30cm
    c. 20cm * 40cm
    d. More bigger than 20cm * 40cm

12. Did you feel there is no difference between watching monitor screen and using your own sight to look around or to find object or to avoid obstacles? (LEVEL 2 SA)
    a. There is no difference among them

b. Watching monitor screen is more easier to figure out
c. Using my own sight is more is more easier to figure out
d. Both of them are hard to figure out

13. How long will you take to arrive in next intersection or curve? (LEVEL 3 SA)
    a. Less than 10 sec.
    b. 11-30 sec.
    c. 31-40 sec.
    d. 41-50 sec.
    e. More than 51 sec.

14. How many object can you find out finally? (LEVEL 3 SA)
    a. None.
    b. 1
    c. 2
    d. 3
    e. 4
    f. 5

15. How long will you take to finish this experiment? (LEVEL 3 SA)
    a. Less than 5 min.
    b. 5- 10 min.
    c. 11-15 min.
    d. 16-20 min.
    e. 21-25 min.
    f. More than 25 min.

16. How many times will you look around with your own sight to finish this experiment?
    a. None
    b. 1-10 times
    c. 11-20 times
    d. 21-30 times
    e. 31-40 times
    f. More than 40 times

Appendix E: NASA-TLX

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

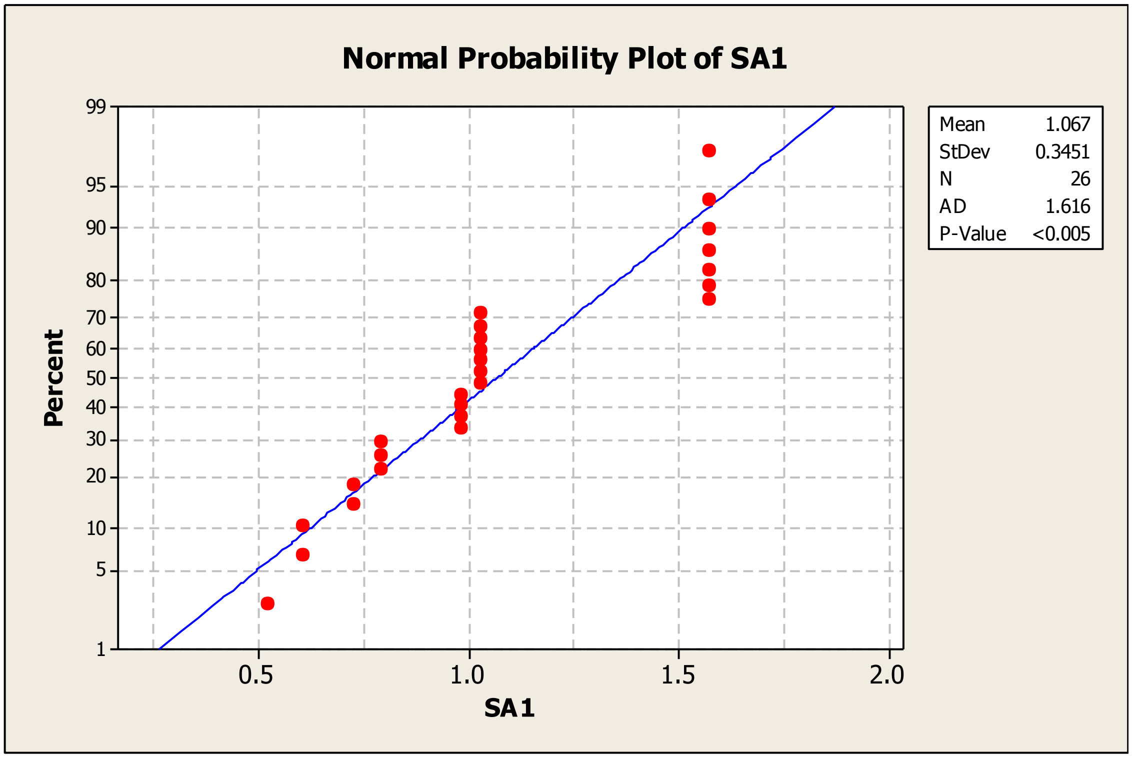
Effort — How hard did you have to work to accomplish your level of performance?

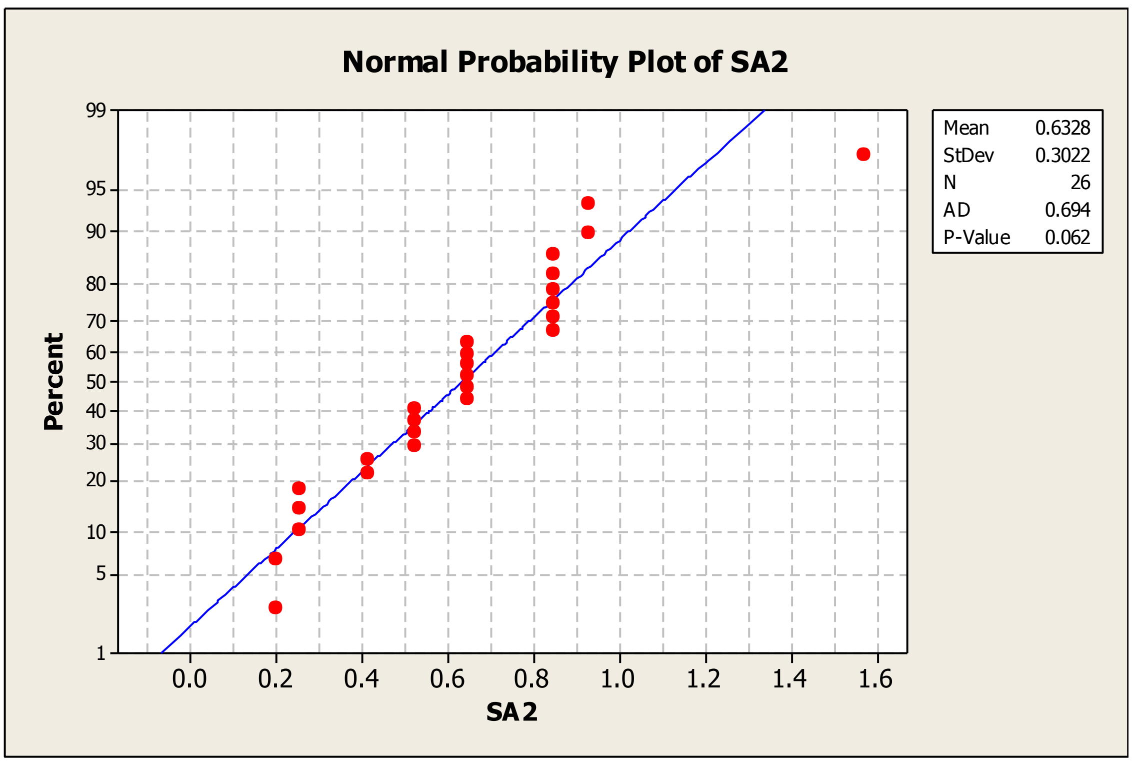
Very Low — Very High

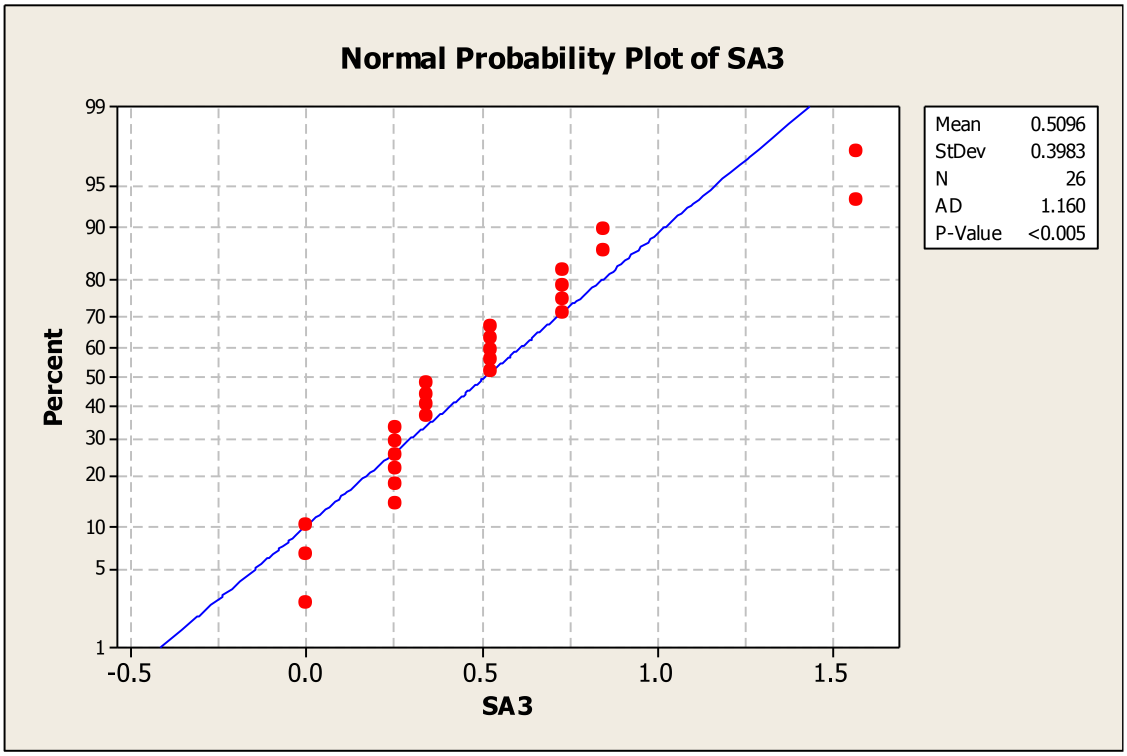
Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

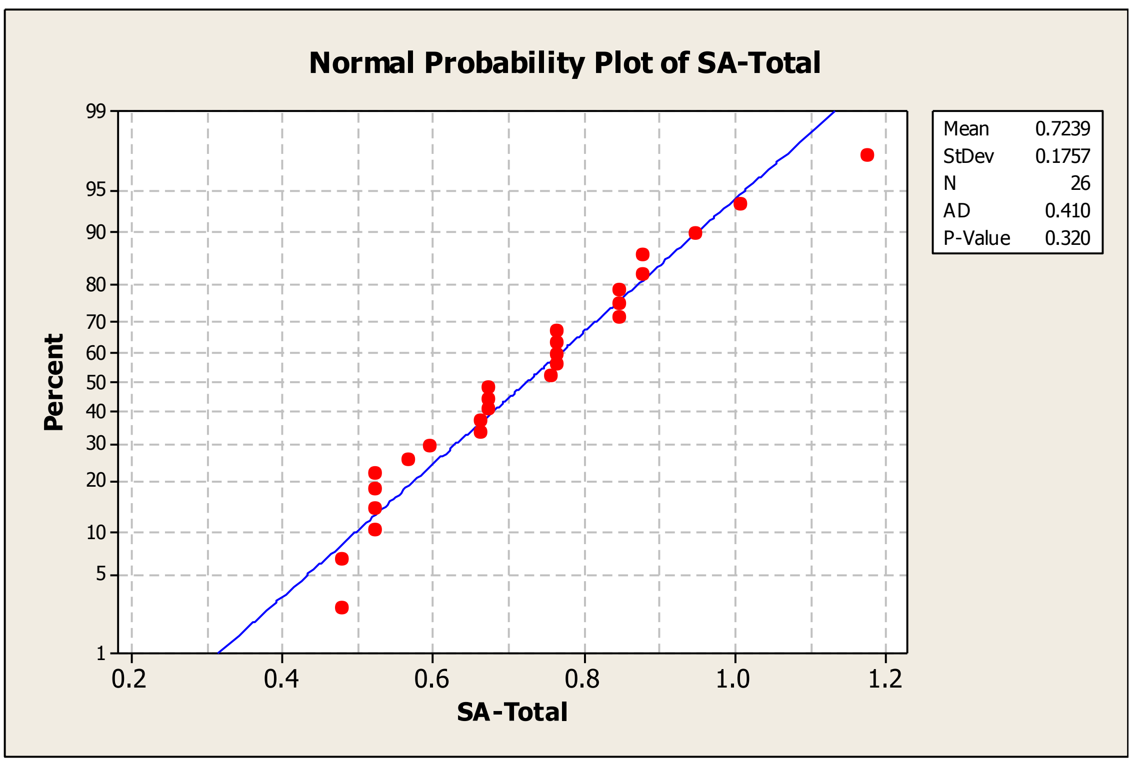
Very Low — Very High

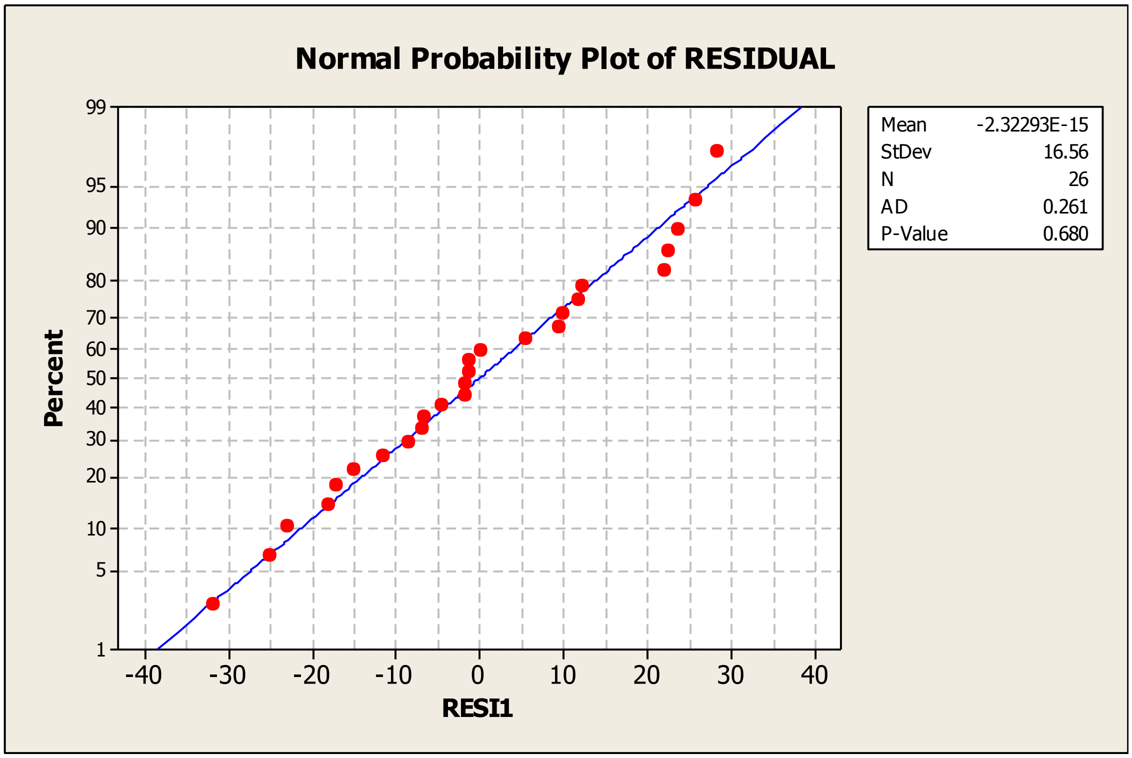
Appendix F: STATISTICAL MODEL ADEQUACY CHECKING






Normal Probability Plot of SA3
Percent
SA3
Mean 0.5096
StDev 0.3983
N 26
AD 1.160
P-Value <0.005
99
95
90
80
70
60
50
40
30
20
10
5
1
-0.5
0.0
0.5
1.0
1.5


Normal Probability Plot of SA-Total
Percent
SA-Total
Mean 0.7239
StDev 0.1757
N 26
AD 0.410
P-Value 0.320
99
95
90
80
70
60
50
40
30
20
10
5
1
0.2
0.4
0.6
0.8
1.0
1.2



Normal Probability Plot of RESIDUAL
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
-40
-30
-20
-10
0
10
20
30
40
RESI1
Mean -2.32293E-15
StDev 16.56
N 26
AD 0.261
P-Value 0.680