Design Methodology Evaluation: An Investigation into the "Right" Data for Situational Awareness of RTS-based Tele-Robotic Systems in Limited Network Environments

A dissertation submitted by:

Fraser Border

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Abstract

Robotic navigation has been a prominent area of development within many industries over a significant period of time. Due to such high complexity, the employment of human within tele-operation systems remain to be the most effective method to address these applications. It is a widely accepted notion that the enablement of human intuition within these systems is primarily linked to the user's situational awareness, yet upon investigation it was identified that the conventional design methodology employed was quite inadequate. Through further investigation it was identified that this methodology focuses only on one of the three elements widely accepted to determine situational awareness, which is the primary reason for its inadequacy to assist designers to develop systems for limited network environments. In order to investigate an improved design methodology for these particular environments experimentation was conducted into exploring the relationship between users' situational awareness and the amount of data provided to further analyse the determination of the "Right" data for the system - an element disregarded within the conventional methodology.

Experimentation was conducted by assessing the awareness of the user with varying degrees of data, considering image and LiDAR hardware. This research identified that a logarithmic relationship existed between these parameters for both the image and LiDAR hardware considered. With the additional support of a qualitative analysis, these findings indicated that a particularly significant reduction in the data requirements of a system may be attained with negligible reduction in situational awareness. Through these analyses various other conclusions could be drawn for this relationship considering other influential factors which may assist to create a more effective system within a limited network environment.

In consideration of the situational awareness definition initially consulted, these findings were applied to suggest a more effective design methodology. This methodology encourages the designer to first determine the "right" data for the

system considering design objectives and network limitations before applying an iterative approach. As such, the optimal compromise between the situational awareness and data transfer requirements may be considered to better address the design objective of the tele-robotic system in a limited network environment.

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I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Fraser Border

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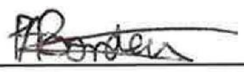

Signature

13th of October, 2016

Date

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I'd like to thank both my parents for all the support they've shown -especially my father for showing such support throughout the assembly of this report. You've essentially kept me alive – and to that I appreciate. Thanks for the support Mad and Mitch – it must be hard dealing with such a nerdy brother!

Lastly, I'd like to acknowledge the efforts of the markers reading this dissertation: if reading this document is even a millionth as much effort as writing it you'll be in for quite a ride!

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The following figures are referred to within the dissertation.

List of Appendices

The following appendices are included within this dissertation.

1 Introduction

1.1 Chapter Overview

This section will provide a clear perspective of the research to be conducted within this paper. It will initially outline the applications of this research before exploring the background information required to appreciate the contextual applications of this investigation. Finally the direction that this paper will take will be stated through specific research aims and objectives.

1.2 Application of Research

By nature, tele-operation systems rely upon wireless networks to transmit the robotic hardware data to be presented within the user-interface. The rate at which this data may be transmitted at is predominantly determined by the network bandwidth, which is itself significantly dependent on the operation environment of the system. In many instances this environment can impose limitations upon network bandwidth, which is typical in the environments of, for example:

- The control of drones within both military and civilian search and rescue missions
- Interplanetary operation of navigation robots in space
- Precise control of medical instruments in telemedicine applications
- Navigation and surveillance of radioactive environments in concrete structures

In such conditions the effects of network latency can significantly reduce the effectiveness of tele-robotic systems or, in some cases, render the system completely unusable. Through the investigation of the relationship between situational awareness and hardware data an alternative design methodology may be proposed to address the inadequacy of the conventional methodology identified. In doing so, a more effective design approach may be applied to improve latency robustness, and therefore, the effectiveness of tele-robotics within limited network environments.

1.3 Research Background

In today's world robotic mechanisms have been employed within a plethora of environments to conduct particular tasks. In many applications there is a need to operate within an environment which is either inaccessible or uninhabitable for humans, and thus, tele-operation or autonomous robotic systems are employed. Despite such a dominant presence of machine automation in today's market there still remains many limitations with the utilisation of this technology. It is a widely accepted notion that robots are not yet able to understand the environment as humans do in order to quickly apply high-level decision making behaviour within complex or unknown environments based on intuition. Thus, due to this necessity, tele-robotic systems are frequently employed in such circumstances.

A tele-robotic system operates by providing bi-lateral communication through a wireless network where the user may apply intuition based upon the robotic hardware data presented within a user-interface (see Figure 1-1). The effectiveness of the system is determined by the ease of which the user may apply intuition within the system, which is significantly dependent on the user's situational awareness of the robot. A widely-accepted definition of situational awareness within the design science tele-robotic systems identifies that an effective system 'has the capability to present only the required information to the right users at the right time' (Jenkins et al. (2012)).

In spite of this substantially established definition, an investigation of the commercial tele-robotic designs highlight a consistent design flaw among the significant majority of texts reviewed. It evident that system designers fail to apply consideration in retaining the real-time communication characteristics of the tele-operation system. Not only does this contradict quite a prominent and widely accepted definition, but it also suggests that the systems within these papers were created under the assumption that an ideal wireless network will be permanently available. In many real-life applications this type of network does not exist and hence many systems, including those seen within literature, are considerably effected by network latency and are likely to fail at the instance where the operating environment network is not ideal.

This conventional design approach, which is commonly employed within industry, is seen to be inadequate in its ability to guide designers to design tele-operation systems within limited network environments. As such, it is highlighted that a re-evaluation of this design methodology is required with respect to how, by definition, it may address situational awareness. From this review it may be suggested where research should be conducted to investigate the development of an improved design methodology.

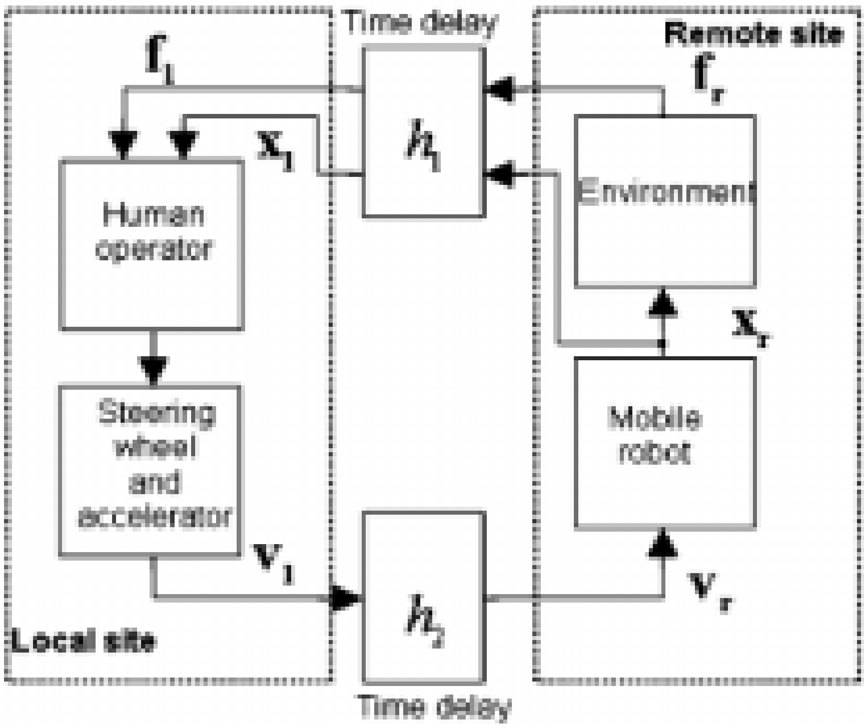

Figure 1-1: An illustrative example of the general operation of a tele-robotic system (Slawsinski & Mut, 2016)

1.4 Project Aim

The aim of this paper was to improve the effectiveness of tele-robotic systems operating within limited network environments through the suggestion of an alternative design methodology. The scope of this project, illustrated below within Figure 1-2, is quite specific to the investigation into the ability for the applied design methodology to enable the incorporation of situational awareness to occur within tele-robotic systems.

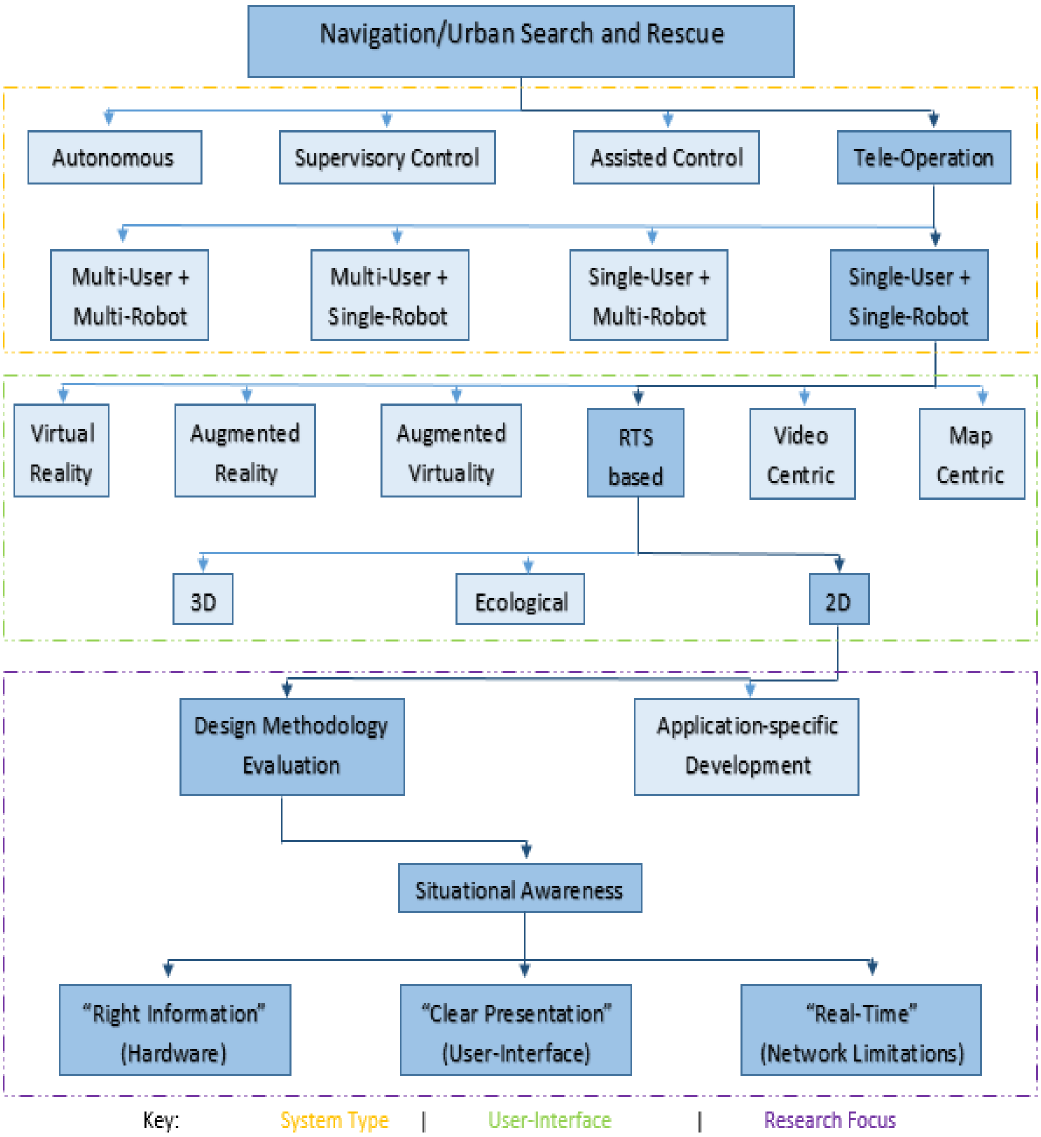

Figure 1-2: An illustrative indication of the direction that this project will take

1.5 Project Objectives

This dissertation seeks to address the aforementioned aim by addressing the following objectives. These objectives closely reflect those outlined within the project specification presented within Appendix A.

I. Identify the deficiencies of the conventional design methodology to address all elements of situational awareness through an evaluative comparison applying the widely-accepted definition of situational awareness to the systems designed within literature

II. Conduct experimentation to assess the attainable situational awareness of a user provided with varying degrees of hardware information typical to RTS-based tele-operation (e.g. image and LiDAR data)

III. Examine the key relationships found within experimentation between situational awareness and the presentation of hardware data in consideration with various system parameters (e.g. environment complexity, participant demographic, etc.)

IV. Explore the potential applications of these relationships in regards to the improvement in the design of a tele-robotic system operating within limited network environments

V. Further evaluate the findings identified within the experiments conducted through a qualitative analysis of the combined system (comparison of conventional and prototype systems).

VI. Draw final conclusions from these findings in regards to the suggestion of an alternative design methodology that may assist designers to consider a better approach of incorporating situational awareness within these systems

1.6 Chapter Summary

It has been highlighted that there is a significant gap within literature for the design methodology of tele-operation systems that operate within telecommunication constraints. It is found that the typical methodology applied for tele-operated robots, regardless of the system's environmental conditions, implicitly assumes that there is an idealised network present. This is an unrealistic expectation and, consequently, the disregard of the applied design methodology causes many systems to be created that cannot cope in limited network environments. As such this paper will address this issue by evaluating this methodology further to identify the particular elements of situational awareness that requires further investigation. The conclusions drawn from this investigation will be used to further evaluate the conventional design methodology and also suggest a more effective alternative methodology. As such, this research will assist designers to create more effective tele-operation systems through the identification of valuable design science relationships and an improved design methodology within limited network environments.

1.7 Report Outline

The paper will present the research obtained in the following structure:

I. **Chapter 1: Introduction**

This section will introduce the rationale of the conducted research through an exploration of the relevant applications and context of this research, as well as the identification of project aims and objectives.

II. **Chapter 2: Investigation of Literature**

This section will review the relevant literature required to evaluate the effectiveness of the conventional design methodology. The deficiencies identified within the evaluative comparison of the conventional design methodology and the situational awareness definition will be identified as the key knowledge gap of consideration.

III. Chapter 3: Research Methodology

This section will explore the research focus that was considered to enable the experimental investigation to identify results valuable in addressing the identified knowledge gap. The development of research questions were employed to ensure this purpose may be addressed with specific purpose.

IV. Chapter 4: Experimental Outline

This section will outline the particular processes applied in both designing and conducting the experiments of this dissertation. Furthermore, the interpretation and the approach employed within the analysis to identify conclusive trends within the obtained results is outlined.

V. Chapter 5: Analysis of Results

This section will provide in-depth analyses of the experimental results obtained and identify key relationships between the elements of situational awareness considered in regards to various other influential factors. These relationships are then applied in order to propose an improved design methodology that may better assist designers of limited network tele-operation systems.

VI. Chapter 6: Conclusion

This section will summarise the key findings identified within the research conducted and highlight the significance of such conclusions to the real-life applications of this research. Further will also be identified to suggest the particular areas of the conclusions identified which require further investigation.

VII. Chapter 7: Reference List

This section will acknowledge the various resources referenced within this dissertation.

VIII. Chapter 8: Appendices

This section will include all additional documents that are of supplementary importance to the research presented within this dissertation.

2 Investigation of Literature

2.1 Chapter Overview

As previously indicated, in order to conduct a comprehensive evaluation of the conventional design methodology typically applied within literature the definition situational awareness must first be investigated. This definition will then be applied to evaluate the observations identified within literature to identify the deficiencies within the approach applied. This will conclude whether situational awareness is being addressed effectively and therefore whether this approach may be improved to better address this design objective.

2.2 Situational Awareness

The enablement of human-intuition is an essential design principle within all tele-operated robotic devices, and is widely recognised to be most significant factor attributed to the system's effectiveness. Both studies by Mortimer & Horan (2015) and Gomez (2016) strongly support this notion, identifying that the ability to utilise the unique capabilities of the human operator within tele-operation is of extreme importance. The direct connection between the enablement of incorporating human intuition within the system and user situational awareness strongly reflected within literature (Riley & Endsley, 2005; Murphy and Burke, 2005). Upon the review of one hundred and fifty sources a text by Chen, Haas & Barnes highlights this same conclusion and further, identifies that the evaluation of a system's situational awareness is a clear indication of the system's effectiveness. The link between a system's effectiveness and the user's situational awareness, through the enablement of human intuition, is a premise that constituted the further exploration into the applications of situational awareness within tele-operation for the remainder of this chapter.

2.2.1 Application of Definition

Many robotic systems have applied the definition established within Jenkins et al. (2012), a publication exploring the analysis of situational awareness within complex, collaborative military operations. Through the findings of numerous studies identified that three elements were recognised to contribute to the determination of situational awareness for the design of tele-operation systems. As identified by Jenkins et al. (2012), a system effective in the enablement of situational awareness is one that 'has the capability to present only the required information to the right users at the right time.' In order to evaluate the tele-operation systems investigated within literature with this definition, the key terms stated above were associated with the various subsystems identified within tele-operation systems.

I. The term of 'present' can be quite clearly associated with the presentation of data within the system's user-interface.
II. The phrase 'only the required data' can be directly related to the information of which the user requires in order to apply human intuition within the tele-operation system. As the user of this type of system applies intuition based upon the provided hardware data, this phrase can be associated with the hardware data required by the user
III. 'Right time' within tele-operation is quite commonly considered synonymous with 'real-time'. As such, this term will be discussed in regards to this system parameter.

In the application of this prominent definition to tele-operation it may be identified that the aforementioned system characteristics all contribute to the overall situational awareness of the system. As such, these will be further investigated in the following subsections to enable the evaluation of the effectiveness of the conventional design methodology in regards to the situational awareness instilled within the systems developed within literature.

2.2.1.1 Element 1: User-Interface

In regards to the presentation of information, Jenkins et al. (2012) further suggests that the clarity of which this information is presented should be considered of crucial importance. Since the inception of this notion numerous papers, including Zhao, Mei & Pan (2015), have sought to contribute research towards the widely-debated investigation of developing presentation clarity. In many instances the improvement of the clarity of which this information is presented is the predominant focus regardless of the user-interface of the system (Hainsworth, 2005; Chen, Haas & Barnes, 2007; Chen et al., 2006). For example, the below figure (Figure 2-1) illustrates a user-interface of an RTS-based system which was iteratively developed to improve the clarity of information presented to the user.

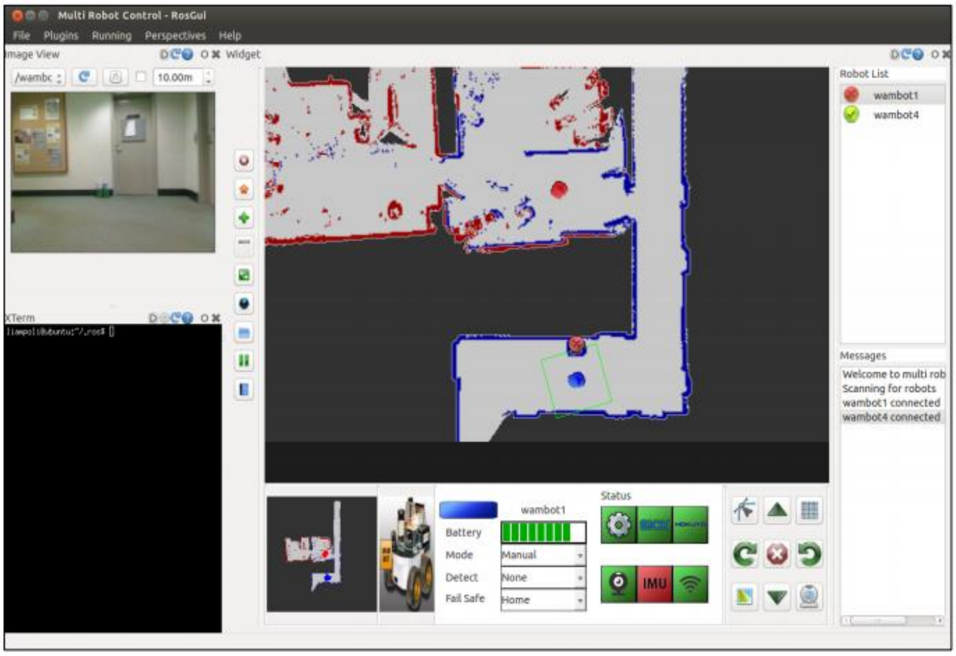

Figure 2-1: An example of a typical RTS-based User-Interface (Poli, 2013)

2.2.1.2 Element 2: 'Right' Hardware Data

According to Jenkins et al. (2012), in order to distinguish the type of required information the specific application must be considered. For the navigational application considered within this paper, various types of hardware information could be used within the system. This is typically seen to be camera, LiDAR and ultrasonic technologies (further examined within Appendix B). Whilst this hardware may provide the required ***type*** of information this, by definition, is not the ***right*** information. This observation is particularly highlighted within this text when it was expressed that an effective system should '… communicate the right information (and no more that this)'. Toner R (2009) presents yet another paper further supporting this notion.

2.2.1.3 Element 3: Real-Time Performance

According to an investigation into navigational systems conducted by Básaca-Preciado et al. (2014) it was identified that these systems should be designed "with the main goal of obtaining (data) in real-time". The design mentality proposed within this text aligns and further contextualises the definition of this situational awareness element stated by Jenkins et al. (2012) in regards to acquiring data at the "right time". This is yet further reflected in numerous other prominent, tele-operation-related publications such as Hyaejin et al. (2016), Matveev et al. (2015) and Tang et al. (2015). Furthermore, in such a situation where real-time characteristics cannot be sustained there can be a significant reduction in the user's situational awareness and therefore ability to effectively maintain control of the robot. Although imperceptible, this phenomena will begin to degrade system performance at as little as thirteen milliseconds. Furthermore, various studies of latency have identified that the significance of these effects become increasingly prevalent as this delay lengthens (Rosenberg (1993); Avgousti et al. (2016)). These findings are further supported by Michaud et al. (2012) which, upon testing navigation control, finds a time delay of 1300ms 'impossible to control' even for expert users.

2.2.2 Assessment Framework

Founded from the general definition of situational awareness by Jenkins (2012), the assessment framework developed by Yanco, Drury, & Scholtz (2004a) may be specifically applied for single robot, RTS-based tele-operated navigation system. This paper proposes an effective explicit performance assessment technique, termed 'LASSO', to evaluate situational awareness by considering the system's performance rating in the following categories:

I. **L**ocation awareness
II. **A**ctivity awareness
III. **S**urrounding awareness
IV. **S**tatus awareness
V. **O**verall mission awareness

Further detail in regards to the further identification and application of these elements is considered in detail within Appendix C.

2.3 Analysis of Tele-Operation Systems

From a plethora of papers consulted, fifteen of the most applicable papers outlining the development of a tele-operation system, in regards to the incorporation of situational awareness, were analysed. In reference to the investigated definition of situational awareness within this application a reflective evaluation could be made of the conventional design methodology observed in the development of these systems. This evaluation was conducted in terms of the three elements identified in the application of the situational awareness to tele-operation as identified within Section 2.2.1.

2.3.1 User-Interface

Although many types of user-interfaces exist, from the collection of literature it can be identified that there are common trends between systems. With the exclusion of the video-centric system (Saakes et al., 2014)**,** the user-interfaces of the reviewed literature provided information to the user with a variety of presentation techniques. In a majority of systems this included local map and a live-feed video, whilst often the operational feedback of the robot was also provided. As previously identified, the conventional user-interface illustrated within these designs incorporated colour image and the complete dataset measured by proximity hardware. The detailed design of the user-interface was typically documented by all designers regardless of the design's interface. The evaluation conducted highlighted the quite considerable debate between designers in regards to the most effective user-interface to incorporate within tele-operation. Despite this, the considerable developments made for the improvement of this subsection of tele-operation design was quite substantial. Furthermore, although many designers made reference to Jenkin's (2012) definition of situational awareness, the general consensus of these designers was that the user-interface was the most, if not the only, influential factor in enablement of situational awareness within tele-operation.

2.3.2 'Right' Hardware Data

With the exception of the video-centric system presented by Saakes (2014), all navigation systems considered within the consulted literature utilised the combination of proximity and image data. The proximity sensors utilised within these systems were predominantly some form of LiDAR technology (73.3%), followed by; ultrasonic (26.7%), infrared (20 %) and Xbox Kinect (6.7%) sensors. Although many infrared sensors were used in place of LiDAR hardware in the system developed by Sanguino et al. (2013), difficulty was reported in attaining a useful field of view of the environment. In regards to imaging data, the use of colour images captured by a standard webcam was employed consistently yet the justification for doing so was not stated.

From this evaluation it was identified that the technology employed within navigational tele-operated robotics was quite consistent. In reference to the applied definition of situational awareness the conclusion that the type of data required for these systems. The absence of any such investigation into the determination of the 'right' data required by the system was observed in the significant majority of designs considered. In these cases, the use of all hardware data (for both types considered) was identified to be the convention despite the significant lack of justification. The system presented within Winkvist, Rushforth, & Young (2013) remains to be the only design that has considered the succinctness of data for use within the system. Due to the limited network available, alterations were made by designers to reduce the effectiveness of the user-interface improve the real-time capabilities of the system. Although no further investigation was conducted to identify the link between these elements the mentality applied does suggest that in considering the relationship of situational awareness and system data is particular important within low network circumstance. The significant technical design applications implemented from this mentality include:

I. Environmental Geometry Assumption

The assumption that the geometry of these indoor environments could be considered straight and orthogonal. Thus, the SLAM algorithm is simplified as it is less computational effort to compare line geometries rather than a collection of data points.

II. Point Cloud Reduction

Flight tests were conducted that for an environment approximately twenty metres wide a good balance between reliability, accuracy and speed may be found using every 5th point.

III. Reduction of Map Update Frequency

It was considered that the world map update frequency should be dependent on how far the robot has travelled.

2.3.3 Real-Time Performance

Within the reviewed literature the commonality of designers' presumption that a network with adequate bandwidth will be available is prevalent. The disregard for the consideration of wireless data transfer implicitly suggests that the network is assumed to be completely "ideal". The ideology is highlighted when considering that only two sources had considered the data transfer rate of their system, whilst a third of designers did not even consider the identification of the type of network used by the system noteworthy (Nielsen, Goodrich & Ricks, 2007; Manavalan & Wagner, 2001). As such, in many cases the real-time performance of the designed system is significantly reduced in instances of limited network environments. This occurrence is emphasised in the considerable time delay imposed to quite a number of the systems observed within literature (Nielsen, Goodrich & Ricks, 2007; Kam et al., 2015; Cossell, Whitty & Guivant, 2011). In a particular instance the reduction of the real-time capabilities of the system were of such significance that the entire system could not be operated by the user (Poli, 2013). Despite being a key characteristic of situational awareness this factor evidently remains of little consideration within the conventional design methodology applied by the majority of texts.

2.4 Conventional Design Methodology Evaluation

A holistic evaluation of Section 2.3 indicates that the significant majority of observed designers held an overly-dominant focus upon the improvement of the user-interface to better incorporate situational awareness within design. In quite a number of instances, the designers of these systems had only considered the situational awareness could only be improved through the further development of the system's user-interface. This focus has substantially diverted the attention of designers to consider the remaining two elements that contribute to the overall situational awareness of tele-operation systems. As such the real-time capabilities and, essentially, the effectiveness of these systems have been significantly reduced through the employment of this design methodology. Despite the commonality for designers to reference Jenkin's (2012) definition of situational awareness this conventional design methodology has restricted designers' focus upon only one of the three elements of situational awareness. Therefore by definition, the current design methodology applied was identified to be ineffective in assisting designers to incorporate situational awareness within tele-operation systems. By nature of this methodology, this inadequacy is particularly prevalent within the design of tele-robotic systems operating within a limited network environment.

Through evaluating the system outcomes of the paper presented by Winkvist, Rushforth & Young (2013) it has been identified that these elements of situational awareness may, in actuality, be closely linked. Interestingly, this design has also highlighted the potential benefit that may be attained by compromising situational awareness for real-time performance capabilities for tele-operation within limited networks. Thus, in an investigation to improve the effectiveness of these systems the relationship between the user's situational awareness and the provided data was identified to be of interest. The evaluation of this relationship will a further analysis into the determination of the "Right" data of the system by considering the succinctness of the data provided. Furthermore, the findings of such an investigation may also be applied to suggest an improved design methodology adequate to assist designers for limited network systems.

2.5 – Chapter Summary

In the evaluation of current literature it was identified that there is a need to further explore the design methodology applied in the effective creation of these tele-operation systems. The evaluation conducted upon the conventional methodology in terms of the definition of situational awareness has indicated that further investigation of the relationship between situational awareness should be conducted. As such, this chapter was identified that through further investigation of this relationship the determination of "Right" data for these systems may be further analysed. These findings will enable conclusions to be drawn that assist designers to make the effective compromise of situational awareness with data as well as indicate an alternative design methodology to be applied in these instances.

3 Research Methodology

3.1 Chapter Overview

This section will explore the method applied to conduct a deeper investigation within this field of tele-robotic design science. The below subsections will outline the focus of this research before applying this to identify the experimental objectives that will therefore be considered to obtain valuable results for this investigation.

3.2 Research Focus

The research focus of this paper will be defined through; the identification of research aims, the outline of the scope considered and the questions that may be considered paramount to providing a conclusive analysis for this research.

3.2.1 Research Aim

Within the analysis of literature (Chapter 2) the conventional design methodology was determined to be ineffective in guiding designers to achieve the design objective (the facilitation of situational awareness). From this evaluation it was seen that the designers utilising this approach held an overly-dominant focus upon the development of the system's user-interface to incorporate situational awareness. Evidently, it was seen that the other contributory elements of situational awareness were neglected which suggested, by definition, that this methodology was inadequate. Further supporting this viewpoint, various systems designed using this methodology were seen to be particularly ineffective within limited environment networks.

As such, the aim of this research is to further explore the relationships between these elements to investigate an effective compromise between situational awareness to design a more effective tele-robotic system holistically. Particularly, this dissertation will focus upon exploring the relationship between situational awareness and the provision of data to the user to investigate the determination of the "Right" data further. As an element of situational awareness this is typically over-simplified through the conventional design methodology and, as such, many systems are unable to operate effectively in limited network environments. This research will therefore aim to illuminate various relationships that may assist in the design of limited network systems. Furthermore, these findings will be applied to evaluate the conventional methodology and, in consideration to the situational awareness definition, suggest an alternative methodology that may better guide designers in these particular environments.

3.2.2 Research Scope

Due to the brevity of this dissertation the scope of this research will be quite limited to ensure an in-depth analysis may be conducted. The research scope is expressed within the title of this dissertation, and therefore key terms of this phrase will be expanded upon to provide further clarity.

3.2.2.1 Design Methodology Evaluation

As identified within literature the conventional methodology is evidently quite ineffective in particular environments of which tele-robotic systems may operate. From the research presented within this paper an evaluation of this design methodology will be conducted to identify the reason for this inadequacy.

3.2.2.2 "Right" Data

Of all elements identified to contribute to situational awareness the particular focus of this dissertation is the investigation of "Right" data. As this element would directly affect the other elements of situational awareness it was determined to be of primary consideration within investigation and therefore suggested that the relationship between situational awareness and data be evaluated.

3.2.2.3 RTS-Based Tele-Robotic Systems

The conventional, RTS-based tele-robotic systems are of primary interest as they are one of the most commonly utilised robotic systems for indoor navigation at the time this paper was written. Although appreciation is given that various user-interfaces may be used (e.g. three-dimensional, virtual reality, ecological perspective, etc.) and even more elaborate types of systems exist (e.g. neuro-transmission, haptic feedback, body position recognition, etc.), these will not be considered within the scope of this research. The general majority of tele-operated robots investigated within literature were controlled through a two-dimensional, computer-based user-interface using camera or LiDAR data. Therefore, the research conducted within this paper will most applicably apply to these type of systems (commonly referred to as "RTS-based" tele-robotic systems). It must be recognised that through the selection of this particular system the data to be investigated, and the associated relationships, is confined to this system's hardware technology (camera and LiDAR).

3.2.2.4 Limited Network Environments

This research obtained within this investigation particularly addresses the environments that are of particular concern for the effective operation of tele-robotic systems. This was identified to be a focus of this research as literature suggested that the conventional design methodology did not adequately assist designers to develop systems to be robust to the implications of this type of environment. It should be noted that a "limited" network does not strictly apply to an environment where the availability of high network bandwidth is unattainable. Instead, this is considered to be any environment where a system may suffer considerable latency due to the inability of a network bandwidth to meet the system's data transfer rate requirement.

3.2.3 Research Questions

In order to retain focus throughout experimentation on the research aim identified the following research questions were developed.

3.2.3.1 Research Question 1

What is the relationship that exists between the situational awareness of the user and the amount of hardware data utilised within a tele-robotic system?

3.2.3.2 Research Question 2

How did the data reducing formats perform in comparison to the conventional formats typically used in tele-operation systems? What trends were identified in the performance of these formats in consideration to various environmental factors?

3.2.3.3 Research Question 3

How does this relationship relate to the current design methodology that is typically applied within literature? If this evaluation concludes that this methodology is ineffective, what does it otherwise suggest?

3.3 Experimental Objectives

In order to address this research focus two experiments were designed to evaluate the degree of situational awareness that a user could obtain with varying degrees of hardware data. These particular experiments focused upon investigating the factors that may be considered in determining “Right” data for the typical hardware of a RTS-based system.

3.3.1 Experiment 1 – Image Formats

The objective of this particular experiment was to assess the user’s situational awareness of the robotic environment through varying degrees of image data. In doing so the relationship between situational awareness and data could be determined in detail in regards to imaging hardware technology within RTS-based systems.

3.3.2 Experiment 2 – LiDAR Formats

The objective of this particular experiment was to assess the user’s situational awareness of the robotic environment through varying degrees of LiDAR data. In doing so the relationship between situational awareness and data could be determined in detail in regards to LiDAR hardware technology within RTS-based systems.

3.4 Chapter Summary

This chapter has identified the particular methodology that will be used to address the previously identified gap within literature. The research aim highlighted the particular focus of this investigation into the relationship of situational awareness and data to further analyse the definition of "Right" data in tele-robotic systems. This focus was reflected within the experimental objectives which will be referred to within the development of the applied experimental process outlined in the preceding chapter.

4 Experiment Outline

4.1 Chapter Overview

This section will summarise the experimental process applied to obtain results that may enable valuable conclusions to be drawn in response to the research focus previously defined. In order to do so, the experimental development and the applied process will be thoroughly discussed and justified within the subsections of this chapter for both experiments. Furthermore, the method of analysis will be presented to provide an indication of how the obtained results were observed to draw conclusions upon in respect to the research focus outlined within the aforementioned research methodology (Section 3).

4.2 Experimental Development

The development of each experiment was conducted in adherence to the experimental objectives outlined in Section 3.3. These two experiments are discussed separately in the following sub-sections.

4.2.1 Experiment 1 – Image Data

To ensure that the conclusions drawn from this experiment may be as least subject as possible, the well-established, explicit performance LASSO assessment framework was applied within the experiment. By applying this framework in reference to the typical use imaging hardware within these systems it was identified that the participants' "Surrounding" awareness could be assessed through observing object recognition ability. Additionally, a selection of common image formats were identified to provide varying degrees of data to be observed within the experiment. By considering the ability of participants to identify a number of objects within a given image format the experimental objectives could be achieved in respect to the data provided by the imaging hardware examined. Importantly, the particular sequence of the formats presented was from least to most data-intensive to ensure that the most effectively method of evaluating the "Right" data (which considers succinctness) was conducted. Although both black and white and edge images are of equivalent size (both are binary formats), edge was weighted minutely larger due to time required for the computation required before the transmission of this data. It was considered that as the conclusions made from this data are consistently referring to real-time performance that this classification could be made. Furthermore, various environment complexities and participant demographics were considered to provide a more in-depth analysis of these results to be conducted. The following subsections outline the justifications of the various key elements of this experiment.

4.2.1.1 - Development of Image Formats

Four image formats were selected to be used within the experiment to provide varying degrees of data to the user. To ensure that the experimental findings may related to the conventional system, colour was selected as one of these image formats. A selection of less data-intensive image formats were then investigated to be compared to this conventional format. Various common image filters were chosen to be applied as image formats within the experiment due to the familiarity of these formats and thus relevance of use by participants (Brauni, 2016). These formats were greyscale, edge detection (using the 'Sobel' algorithm with an automatically varying threshold setting) and black and white (with an automatic constant threshold value of 0.5). The various Matlab scripts used to apply the filters of these formats are presented within Appendix D.

A comparative, graphic illustration of each of these formats is exemplified in Figure 4-1.

Figure 4-1: A visual comparison of the various image formats considered within Experiment 1 (from top-left clockwise these formats are Colour, Edge, Greyscale and Black and White respectively).

Furthermore, due to the importance of considering data within this analysis, Figure 4-2 illustrates the various data requirements of each format. The 'Total' data calculation presented within this figure is outlined within Appendix E, yet this should be considered for illustrative purposes only.

Data Requirements of Image Formats					
Analysis	**Data**	**Black and White**	**Edge**	**Greyscale**	**Colour**
Absolute	Data (Bits per Pixel)	1	1	8	24
	Total (kilobytes)	64	64	512	1536
Cumulative	Data (Bits per Pixel)	1	2	10	34
	Total (kilobytes)	64	128	640	2176
Percentage of Conventional Format		**2.9%**	**5.9%**	**29.4%**	**100.0%**

Figure 4-2: A comparative consideration of image formats in regards to their respective data requirements.

It should be noted that the data requirements present within the above figure (Figure 4-2) are considered both individually and cumulatively. Whilst these individual values are useful to exemplify the difference between formats' data requirements, the method of analysis to be applied will consider the cumulative data requirements of each format (as discussed in Section 4.4).

4.2.1.2 - Development of Test System

A Logitech webcam was utilised to capture and store colour images in various, typical indoor environments from the perspective alike to that expected of a first-person, tele-robot (refer to Appendix F for hardware datasheets). This hardware and the images captured aimed to enable the results obtained to be most relevant to a typical tele-robotic system. The test system was essentially the collation of these captured images, in all formats considered, within a PowerPoint presentation. This particular aspect of the experiment was carefully considered to enable a vast number of participants to be examined within a short timeframe. In this regard the validity and resolution of responses acquired from this experiment was significantly increased to enable the conducted analysis to be better performed.

4.2.1.3 - Development of Image Environment

A total of fifteen indoor, image environments of varying degrees of difficult (low, moderate and high) were utilised within this experiment (five for each environment complexity). Although the classification of complexity is subjective, this was determined by the number of obstacles within the frame and the degree of the objects' immersion within the environment. The environmental complexity classification of the image environments used within testing may be evaluated using the illustrations presented in Appendix G.1.1.

The objects of interest were placed within these environments at randomly offset distances from the camera between 0.75 and 2.4 metres. In order to remove as much bias as possible from the participants' ability to recognise the objects within the image environment the following considerations were made:

I. All objects chosen to be identified were common, indoor objects

II. All participants confirmed the recognition of these objects prior to experimentation
III. All image environments were unknown by participants

As such, the nine objects used within the experiment were chosen to be those pictured in the below figure (Figure 4-3).

Figure 4-3: A list of objects to be identified within Experiment 1

4.2.2 Experiment 2 – LiDAR Data

Considering the justification expressed within Section 4.2.1, it was identified that the application of the LASSO assessment framework to examine participants' situational awareness was most beneficial. Additionally, it was considered that the predominant use of LiDAR data was to present the surrounding environment outlay to the user within the user-interface. In this regard, it was identified that by applying the LASSO framework the elements of "Activity" and "Surroundings" may be assessed through the use of questions assessing participants' explicit performance. Due to both the absence of SLAM and/or image data within this experiment the possibility of a person identifying the robot's location is not worth considering, whilst an attempt to ask the user to define the overall mission in a recording would be trivial. It should be noted that these observations were made in reference to the illustrated application of this framework exemplified within Appendix C.2. Furthermore, a selection of LiDAR formats were justified for use within this experiment to enable varying degrees of data to be observed within the experiment. By considering participants' awareness of the test system's "Activity" and "Surroundings" using a given LiDAR format the experimental objectives could be achieved in respect to the data provided by the LiDAR hardware examined. Alike to the previous experiment, the particular sequence of the formats presented was from least to most data-intensive to best evaluate the "Right" data (in terms of succinctness). Again, various environment complexities and participant demographics were considered to provide a more in-depth analysis of these results to be conducted. The following subsections outline the justifications of the various key elements of this experiment.

4.2.2.1 - Development of LiDAR Data Configuration Formats

Five LiDAR formats were created to be used within the experiment to provide varying degrees of data to the user. These formats were created through the use of Matlab scripts which would; collect the complete LiDAR scan data, apply a particular data reducing algorithm and present this reduced data to the participant. The types of algorithms used to create these formats were carefully considered to ensure that these reflected a high level of relevance and reliability to tele-robotic systems. To ensure that the experimental findings may related to the conventional system, a format without data reduction was used within the experiment (Format A).

Due to the success seen in the paper of Nielsen, Goodrich & Ricks (2007), a similar algorithm was applied within this experiment due to the proven reliability and applicability to this type of system. The algorithm used within this paper incorporated both a straight line approximation as well as a simple data division factor (e.g. every 'nth' data point is presented) to reduce the amount of data presented from each LiDAR scan. In accordance to these techniques, this experiment applied a similar approach to create LiDAR formats which presented every 8th (Format "C") and 32nd data point

(Format “E”) within the user-interface using a straight line approximation between these points.

Another algorithm applied was to survey successive groups of data points throughout the scan and display only the nearest point of this group. It was the experimenter’s opinion that this technique seemed alike enough to the aforementioned algorithm to be considered relevant yet, intuitively, may improve the format by providing a selection of data points based on proximity rather than a simple numerical pattern. As such a LiDAR format was created based on this algorithm for a survey group of four (Format “B”) and sixteen (Format “D”) data points. Again, a straight line approximation was applied to these data points.

Although five were developed, one of these formats (Format “D”) was not interpretable due to programming and time constraints and thus, the four configurations used were reordered (Format “E” became Format “D”). The scripts developed to apply these algorithms, and thus create these various LiDAR formats, are presented within Appendix D. To illustrate the difference between these formats a simplified illustration of how these algorithms will affect the presented information within the below figure (Figure 4-4). Within this figure Format A, represented as the continuous black line, is seen to present all data points and thus portray the surrounding environment accurately. In comparison, Formats C and D, represented by the green and red colours respectively, use an algorithm which select an even spacing with accordance with a step size 8 and 32 data points. Format B’s algorithm surveys a group of four data points throughout the scan to then present the closest point of each group to present. In order to illustrate the difference between this “minimum point” algorithm to the “even spacing” algorithm these are illustrated within the figure as purple and blue colours respectively. This highlights the more cautious approach that the minimum point algorithm applies due to the higher weighting considered for closer points. Generally, as the number of points considered in each group or step size increases, the angular resolution of this algorithm (and formats) will decrease.

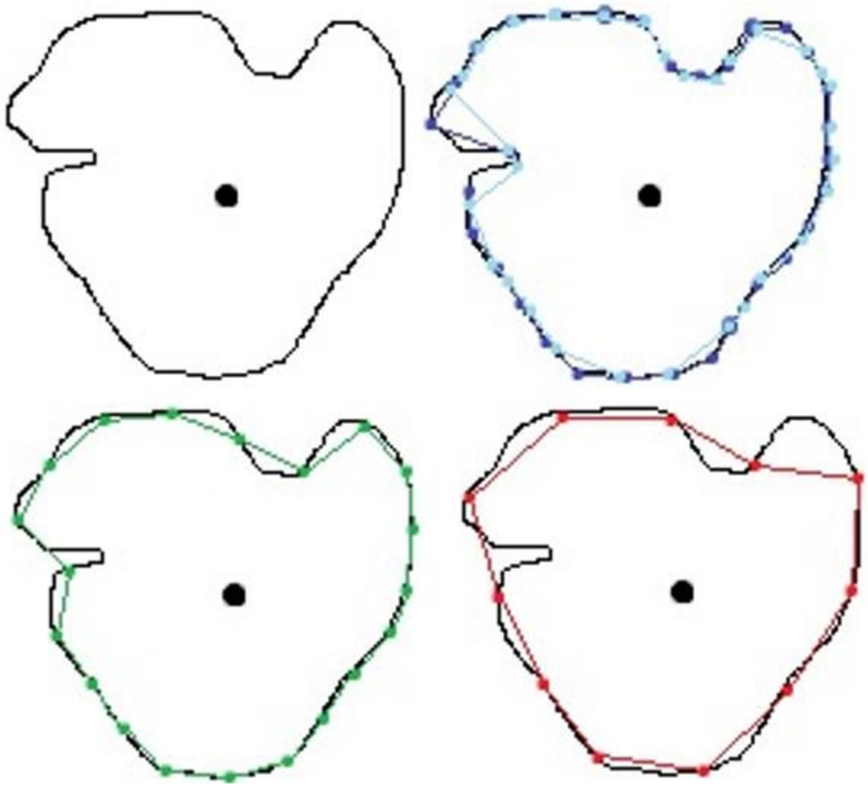

Figure 4-4: A visual comparison of the various LiDAR formats considered within Experiment 2 (from top-left clockwise these formats are Format A, Format B, Format D and Format C respectively).

The data requirements of each format are presented in Figure 4-5 in reference to the calculations made in Appendix E.2. Again, both individual and cumulative data requirements are considered due to the illustrative and evaluative worth of these respectively.

Data Requirements of LiDAR Formats					
Analysis	**Data**	**Format D**	**Format C**	**Format B**	**Format A**
Absolute	Data (Datapoints per Scan)	22	86	170	682
	Total (bits per Scan)	528	2064	4080	16368
Cumulative	Data (Datapoints per Scan)	22	108	192	704
	Total (kilobytes)	528	2592	6672	23040
Percentage of Conventional Format		**2.3%**	**11.3%**	**29.0%**	**100.0%**

Figure 4-5: A comparative consideration of image formats in regards to their respective data requirements.

4.2.2.2 - Development of Test System

For simplicity the LiDAR formats considered were examined within the experiment without the employment of a tele-operated robot. Whilst this did not compromise the experimental ability to assess the situational awareness of the user it did enable the applied process to be much more efficient as it enabled multiple participants to be examined simultaneously (within the same session as the previous experiment). Thus, a simple test-system was created to simulate the navigation of a tele-operated robot within an environment. This system was essentially created by mounting a typical URG 04LX laser scanner (see Appendix F.2 for hardware specifications) and a laptop to a sturdy, cardboard box. This system, pictured in Figure 4-6, was then manoeuvred at a constant speed within a particularly designed indoor environment to simulate the navigation of a robot.

Figure 4-6: A picture of the test system used to assess LiDAR formats within Experiment 2

In order to assess participants' awareness in detail the maximum range presented to the user was limited to two metres. The presentation method of each format was kept consistent and were recorded with CamStudio to be later viewed by the experiment's participants. It should be noted that although the hardware data is transmitted serially, this does not inhibit the experiment from addressing the experiment objective.

4.2.2.3 - Development of Operation Environment

Three indoor scenarios were created for the test system to be maneuvered within using the various LiDAR formats identified. These scenarios were created of varying degrees of complexity (low, moderate and high) which was determined by the number of obstacles and manoeuvres conducted by the test system. Of course, it should be considered that a degree of subjectivity does exist as there was no particular framework that could be applied to create environments at these degrees of complexity. Each of these scenario was referred to as Scenario 1, Scenario 2 and Scenario 3, whilst all were created to be unknown by participants to remove bias that could result from environmental familiarity. The environmental complexity may be determined within the scenario sketches provided within Appendix G.1.2, whilst these sketches also identify the instant at which the experiment assessment questions were posed to the participants.

4.2.2.4 - Development of Assessment Questions

In close reference to the exemplified application of LASSO previously highlighted, the particular questions posed within the experiment were created to assess both elements of LASSO considered (“Activity” and “Surroundings”). Though subjectivity is unavoidable and is likely to be small due to the consistency of the created experimental question’s similarity to the examples previously referred to.

4.3 Experimental Process

The following subsection outlines the process implemented to acquire the results of these experiments, as well as the interpretation of results and associated limitations of this approach.

4.3.1 Procedure Implemented

To enable as many users to be tested as possible within a tight timeframe both of these experiments were conducted within a single session with the use of a large classroom and projector. Over three, one hour sessions thirty-two participants were assessed in both of the experiments conducted. To enable an additional dimension to be considered within the analysis the demographic background and experience of the sample population was identified through the use of an initial survey (Appendix G.2.1). Furthermore, an informed consent form was used to ensure the ethical publication of these results within this paper could be confirmed (Appendix G.2.2).

4.3.1.1 Experiment 1 – Image Format

The procedure followed for obtaining results for this experiment was as follows:

1. **Assemble Participants**

The participants of each session were gathered within a large classroom and given the necessary documents to conduct the experiment. It was ensured that where possible the spacing between participants was sufficient to prevent the collusion of results.

2. **Explain the experiment**

It was explained that the participants must attempt to identify three of the nine possible objects (presented on the desk at the front of the room) that will be present within each image. The importance of indicating what objects where identified using which format was emphasised to the participants.

3. **Outline the response process**

The way in which participants may indicate their responses using the provided experiment response sheet, presented in Appendix G.3, was then outlined. This was essentially explaining how participants were expected to express what objects they could recognise in the various formats of the fifteen image environments.

4. **Exemplify this process**

This process was exemplified to further illustrate the process for the participants to follow using various examples similar to those within the experiment.

5. **Outline experiment rules**

Before beginning the experiment it was clearly expressed that participants were not to share answers or at any stage make verbal comments that may affect others' responses. However, it was not stated that talking was not permitted as the general observations of the participants within this test environment were recorded to be considered within the analysis.

6. **Conduct the experiment.**

The fifteen image environments were presented in the order of least to most data-intensive (black and white, edge, greyscale and colour) on a projector screen. Ten seconds were given to enable participants enough time to view the image for a sufficient amount of time and also record their response.

7. **Qualitative Evaluation**

At the conclusion of this experiment a questionnaire was presented to obtain participants' evaluative opinions of the formats used. These questions are presented at the conclusion of the response sheet (refer to Appendix G.3).

4.3.1.2 Experiment 2 – LiDAR Format

The procedure followed for obtaining results for this experiment was as follows:

1. **Assemble Participants**

As this experiment was conducted after previous experiment the participants were already assembled.

2. **Explain the experiment**

It was explained that the participants must attempt to answer the questions posed using the provided LiDAR format. It was expressed that limited time would be given to answer each question and therefore at times it may be appropriate to response with a "best guess" approach.

3. **Outline the response process**

Again, the process of providing responses using the experimental response sheet identified in Appendix G.4 was outlined to ensure that these results could be obtained correctly.

4. **Exemplify this process**

This process was exemplified to further illustrate the process for the participants to follow. Also, as many participants were quite unfamiliar to LiDAR technology various examples indicating how to interpret information from this hardware was illustrated. This was illustrated for questions similar to those used within the experiment.

5. **Outline experiment rules**

Refer to Experiment 1.

6. **Conduct the experiment.**

The three recorded scenarios were presented on a projector screen in the order of least to most data-intensive (Format D, Format C, Format B and Format A). At particular instances of each scenario the recording was stopped to ask participants particular questions within the experimental response sheet. This process was repeated for all scenarios for all formats.

7. **Qualitative Evaluation**

Again, a questionnaire was presented at the conclusion of the experiment to obtain participants' evaluative opinions of the formats used. These are outlined at the conclusion of the response sheet (refer to Appendix G.4).

4.3.2 Experimental Limitations

The following limitations were identified to accompany the experimental procedure implemented. These should be considered in the validity of applying the findings of this research. From this list, '1' and '2' refer to the limitations' imposition on Experiment 1 and Experiment 2 respectively.

4.3.2.1 Test Subject Sample Size (1, 2)

The experimentation was conducted with quite a small sample size. As such the results obtained may not be completely representative of the general user population that the experimentation results assumes.

4.3.2.2 User-Interface Development Platform (1)

The user-interface for this system was to be developed on the multi-purpose platform of Matlab. This software platform did offer many benefits in computational and Graphical User Interface (GUI) tools and was quite an effective, intuitive program to use.

Although this will likely have little effect upon the applicability of these results to another development platform this has not been confirmed.

4.3.2.3 Insignificant Computational Time Delay (1, 2)

The various formats considered in these experiments vary, to some small degree, in the time taken to be applied through computation. As only formats' data requirements have been considered, the conclusions drawn are limited to the assumption that this computational time delay is insignificant in regards to the delay associated with the network latency. Although this is a very realistic assumption to make it is important to state and gives an indication of the context of these findings.

4.3.2.4 Situational Assessment (1, 2)

To enable the measurement of situational awareness the assumption that the LASSO framework may be applied, in part, similar to its application to an entire system. Furthermore, it was also assumed that partial systems may be evaluated with this framework also. Due to the clear disparity in identification of each LASSO element and considering situational awareness as the sum of these elements these assumptions are intuitively valid yet worth mention.

4.3.2.5 Lack of User Input (1, 2)

The experimentation was conducted through the provision of images and user-interface videos that were pre-recorded. As such, due to the limited user input (such as control of the robot) there may be some affect upon the user's situational awareness. Although this may likely affect all formats equally and therefore have no effect upon this comparison study this is an assumption that is inherent to the experimental procedure employed.

4.4 Experimental Analysis

As previously stated, the procedure used within experimentation was based upon the LASSO assessment framework to determine participants' situational awareness. Both the interpretation of these results and the evaluative approach to be applied will illustrate the method used for the analyses presented in Section 5.1 and 5.2.

4.4.1 Interpretation of Experimental Results

The following subsection will demonstrate how the raw data obtained within these experiments may be interpreted to identify participants' situational awareness.

4.4.1.1 Experiment 1 – Image Study

Through considering the purpose of imaging hardware within these systems it was understood that users were required to identify objects within various, indoor environments. The application of experimental process enabled the determination of which objects were identified using each format for a total of fifteen images (within low, moderate and high complexity environments). From the results obtained in this experiment it was supposed that a participant had complete (100%) situational awareness in the instance that all three objects within a given image were identified. Alternatively, participants' situational awareness percentage was also approximated by the fractional percentage of objects identified using a particular format.

4.4.1.2 Experiment 2 – LiDAR Study

The use of LiDAR data was considered primarily for the user to acquire awareness of system "Activity" and "Surroundings". The application of experimental process enabled the determination of participants' awareness of these elements with the use of various formats within low, moderate and high complexity environments. From these results it was supposed that a user had complete (100%) situational awareness in the instance the responses to all posed questions were correct. Alternatively, participants' situational awareness percentage was also approximated by the fractional percentage of correct responses identified for scenario using a particular format.

4.4.2 Evaluation of Experimental Results

Using the interpretation identified above, this subsection will demonstrate how the relationship between situational awareness and format data requirements will be evaluated in both experiments. It is important to note that the evaluations conducted quite restrictedly relate to the cumulative relationships of these formats. Therefore, the cumulative amounts of situational awareness and provided data will generally be considered. Furthermore, in order to address the research focus of this dissertation, the conclusions of these analyses will be applied to evaluate the conventional design methodology.

4.4.2.1 - Format Effectiveness

The effectiveness of a format was considered to be determined by its ability to provide the user with full situational awareness. Thus, the effectiveness of the formats considered will be evaluated as the percentage of participants that could acquire complete (100%) situational awareness. This analysis will identify which of the formats examined is most considered most effective in regards to a various number of factors influential to format performance. Such conclusions may not only assist to identify the relationship between situational awareness and data, but also identify conclusive experimental relationships that may aid designers to select or even develop more effective data reducing formats in various applications.

4.4.2.2 – Format Efficacy

The efficacy of a format was considered to be determined by the ability of the additional data it provides to further improve the situational awareness of the user. In such an instance full situational awareness becomes less important and, instead, the ratio between the data provided to the user and the user's degree of situational awareness is of paramount consideration. Therefore, as previously outlined, the percentage of situational awareness for each format was considered within this evaluation. This analysis will highlight the relationship between situational awareness and data most clearly, which will enable reflection to be made upon the determination of the "Right" data for a tele-robotic system. This conclusion will assist designers of tele-operated systems operating with limited network bandwidth by exploring the essentiality of various types and amounts of image or LiDAR data within the facilitation of situational awareness. Further, such experimental findings will enable the evaluation of the current design methodology typically utilised in the development of tele-operated systems.

5. Analysis of Results

5.1 Chapter Overview

The following section will explore the analyses of the attained results and highlight the trends between situational awareness and the amount of data supplied to the user. Furthermore these relationships, in conjunction with indications observed within a qualitative analysis, will be applied to suggest the possibility of an alternative design methodology that may better address the incorporation of situational awareness within limited network systems. It should be noted that these experimental results are summarised within Appendix H and the method applied to conduct the analyses presented below is outlined in Section 4.4.

5.2 Experiment 1 – Image Format Analysis

The first section (5.2.1) will explore the general trends of factors that are identified to influence the effectiveness of the various image formats considered to facilitate full situational awareness. The second section (5.2.2) will evaluate these formats in terms of their respective efficacy to provide the user with situational awareness with the amount of data required to do so.

5.2.1 Format Effectiveness

This analysis was conducted based upon Section 4.4.1 to investigate the effectiveness of the various image formats considered within Experiment 1. The key findings of this experiment are presented to then be further evaluated to draw conclusions of these relationships to provide valuable suggestions to system designers. It should be noted that "full" situational awareness referred to in the following text is defined as the instance where the user was able to identify all three objects (100%) correctly within an image environment using a particular image format.

5.2.1.1 Overall

In an overall reflection of results it can be seen that the predominant format used by participants throughout all considered environments was greyscale in 59% of all cases. Black and white, Edge and Colour formats were employed in 25%, 15% and 1% of cases respectively (see Figure 5-1). Although quite simplistic, these findings may assist a designer to predict the approximate effectiveness of the system to have in facilitating situational awareness if such formats were employed.

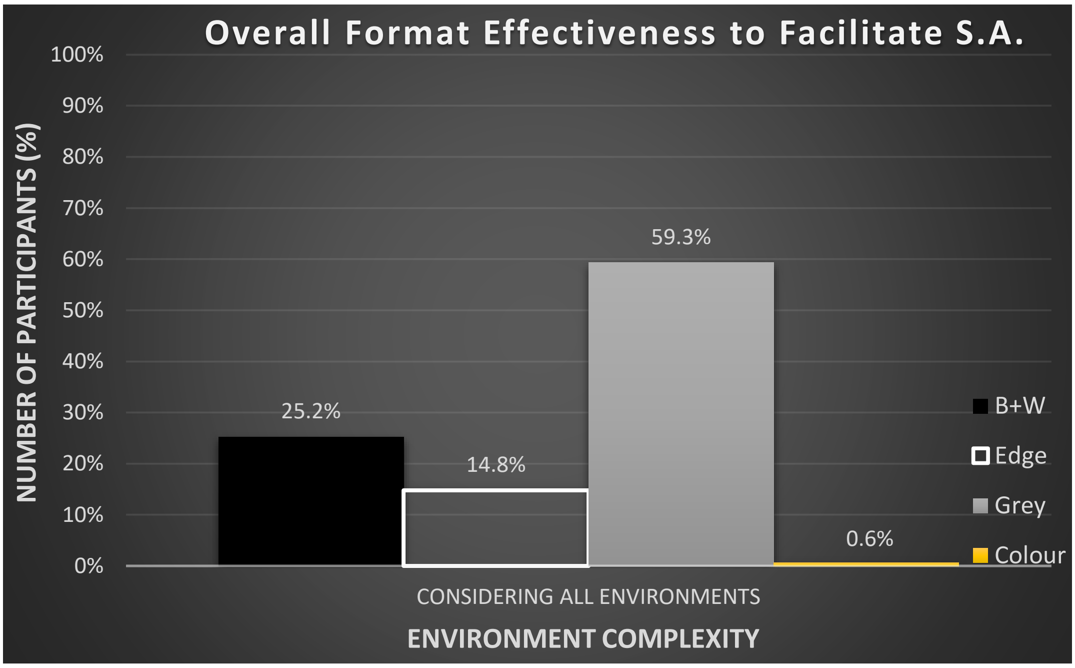

Figure 5-1: Overall Image Format Effectiveness to Facilitate Full S.A.

5.2.1.2 Various Environments

The results displayed within Figure 5-2 highlight the relationship between the use of image formats within environments of low, moderate and high complexity. A cumulative column graph was used in the presentation of these results to underline the distribution of use for each format within different environments.

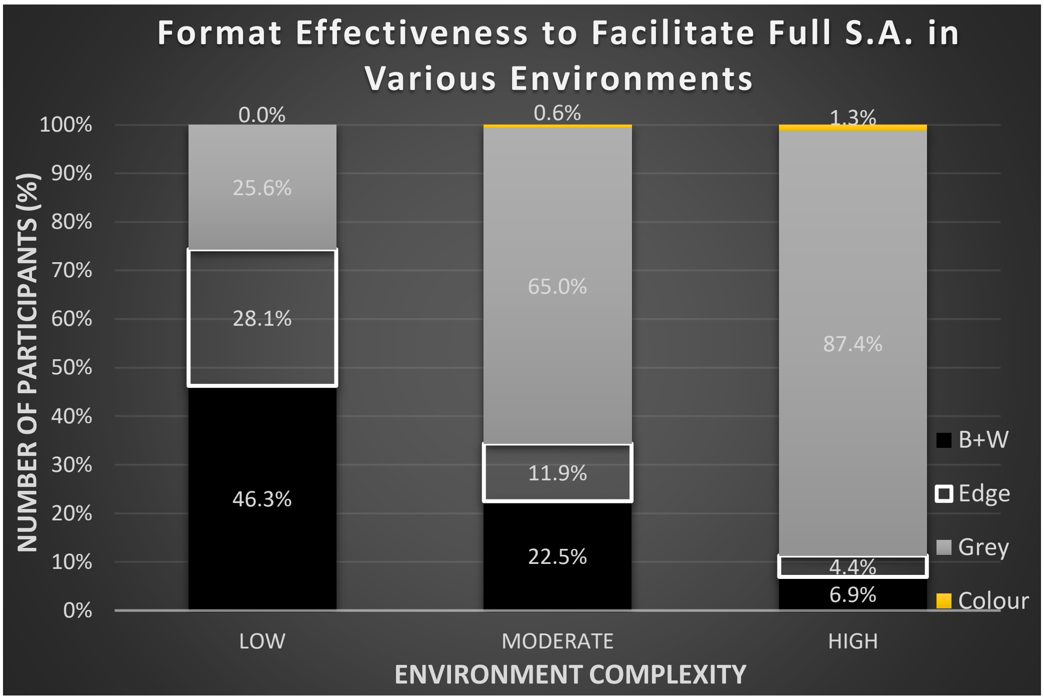

Figure 5-2: Image format effectiveness to facilitate full situational awareness in various complexity environments

From these results the link between the effectiveness of particular image formats and environmental complexity was quite prevalent. For low complexity environments it can be seen that three quarters of participants were able to acquire full situational awareness using only Black and White and Edge formats. Yet, the ability of these formats was seen to diminish significantly as the complexity of the image environment heightened. Furthermore, the rate of which the effectiveness of these formats reduced was seen to increase quite dramatically. Whilst the participants' use of these formats halved between low and moderate environments, a further reduction of two thirds of this group occurred between moderate and high complexity environment. Similar conclusions were strongly reflected within the opinions expressed by the participants. In the written responses provided at the conclusion of the experiment it was evident that the significant majority of participants felt that both Black and White and Edge formats where only effective in particularly simple environments. This behaviour identifies the effectiveness of both the Black and White and Edge formats, yet only for the restricted domain of low complexity environments. As such a designer may, in particularly simplistic environments, find either of these formats to be an adequate data combination to incorporate within the system.

In comparison, Edge was used in at least 60% less instances by participants to gain full situational awareness consistently across all environments. In support of this, 34% of participants articulated that Edge was considerably more difficult format to use than Black and White to identify objects within the images presented. This may suggest to some extent that Black and White may be a more effective image format to utilise for the same amount of data (1 bit per pixel).

The participants' use of the greyscale format was quite low within the low complexity environment due to the sufficient adequacy of the previous formats. Yet, in all other environments the employment of this format was more than all other formats combined. This significance was most noteworthy within the high complexity environment in which greyscale was used for 87 % of the population considered to acquire full situational awareness. These results highlight the robustness of this format to perform well regardless of the environment it is applied within. Despite such significant use in a high complexity environment only in very few cases this format could not meet the demands of the participants. This was reiterated within participant responses in which no cases remarked that greyscale was more difficult to use in high complexity environments. Furthermore, 100% of participants expressed that in the absence of the conventional image format (colour) this format would be preferred. Both the quantitative and quantitative results obtained indicate this format is, in general, much more superior than the alternative reduced data formats in facilitating situational awareness.

In all experimental testing the colour format was only utilised in a total of three occasions, two of which were for high complexity image environments. Although limited results were obtained, due to the respective increase in data of this image it may be expected that the robustness of the colour format would be similar to that reflected in the results of the greyscale format. Similar qualitative responses were obtained for colour as the greyscale format. These results emphasise the apparent redundancy of this format in the instance where the user has been provided the previous image formats.

A qualitative evaluation of these formats was obtained through the results of the participants' opinions of the most effective format to use within the experiment. It was found that the significant majority (63%) of people elected the greyscale, whilst 34% elected the colour format of all considered (see Figure 5-3). The various reasons expressed by the participants who had selected colour include:

a) Greyscale had enough "clarity" or "detail"
b) Greyscale could guarantee all objects would be seen
c) Greyscale was easier on the eyes and therefore "provided a clearer image" or "defined the shapes easier"
d) Colour was "unnecessary", "pointless" or "not needed"

Many interesting points are highlighted within these responses yet the primary theme is the appreciation that the information provided by the greyscale format is sufficient for the participant's objective.

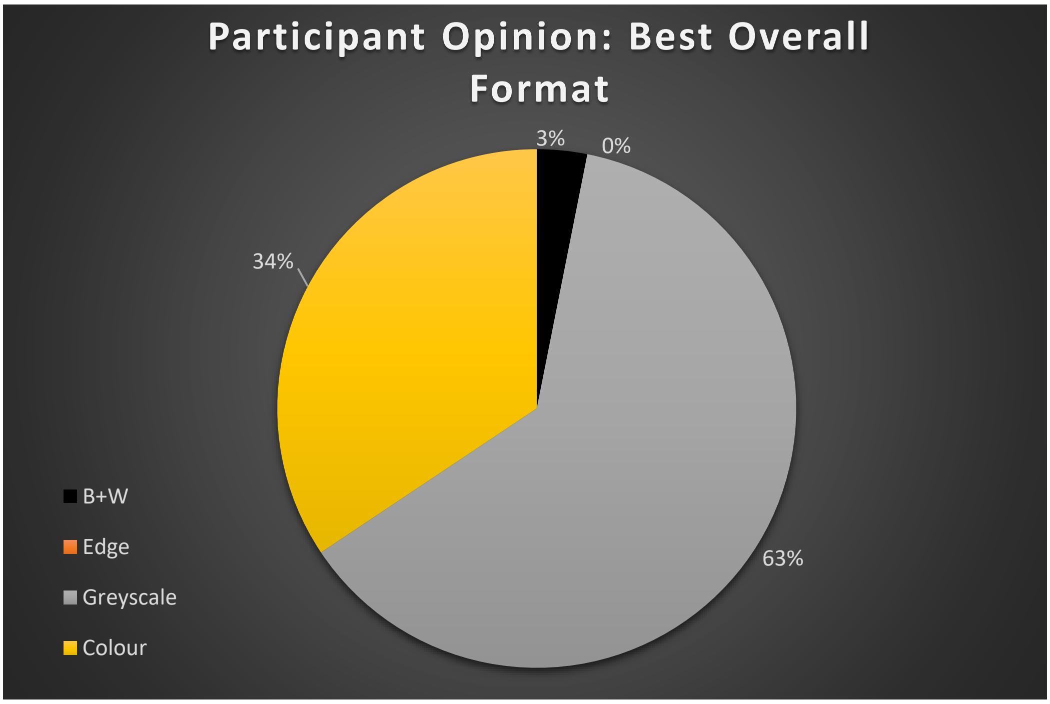

Figure 5-3: Participant's opinion of the best overall image format

Interestingly, unlike participants who chose greyscale, those who selected colour (34%) seemed to lack a reflective reason for doing so. Of this group, less than one fifth actually used colour at any instance within the experiment, and those who did only used this format once in the fifteen assessed environments. This finding is quite remarkable in the regard that such a preference towards the colour format was present within participants despite the extreme lack of use of this format by the participants. Furthermore, as these results were obtained at the conclusion of the experiment it may be quite a reasonable expectation that after personally experiencing the lack of dependence on colour that the participants would less likely believe colour was the most effective format. Although this may seem peculiar, the reasons for selecting colour highlight the underlying reason for these results. It was expressed by some participants that colour was selected simply because it was considered "what humans are used to seeing" or "what our eyes are familiar to seeing". Although this viewpoint is likely to be held by 34% of the sample population considered it is quite contradictory in regards to the quantitative results identified.

Thus, with the lack of reasoning to support this viewpoint it is quite likely that this consensus is a common misconception amidst the general population. This is a very strong supposition to form the indications of these results are quite conclusive. This conclusion may not only suggest that designers should reconsider the use colour images for these applications but also proposes a re-evaluation of the conventional formats utilised within these systems.

5.2.1.3 Various Environments (Format Relativity)

Within a detailed investigation of results it was identified that in low complexity environments participants were able to attain information using the Edge format preceding the use of Black and White. In order to examine this relationship more thoroughly the percentage of instances where participants were able to identify more objects within the frame were identified for each environment complexity (presented in Figure 5-4).

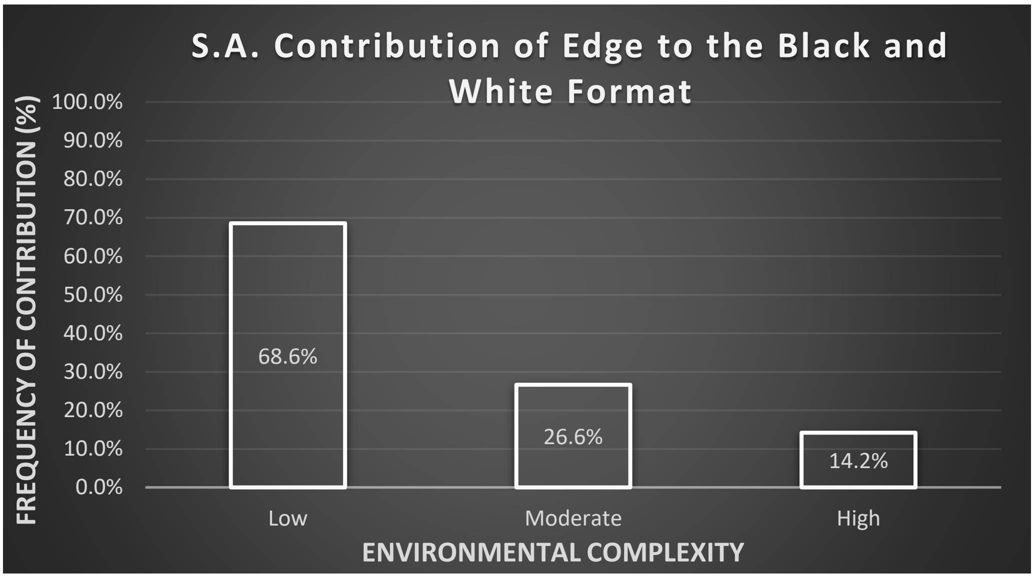

Figure 5-4: Situational Awareness Contribution acquired using Edge to that obtained from the Black and White format

From the above figure it was subsequently confirmed that the Edge format quite significantly contributed in increasing participants' situational awareness in low complexity environments (69%). Although this trend continued throughout environments of higher complexity the reduction in its contributory significance was quite extensive. This relationship was also highlighted by a comment made by a participant who joked, "at least the furniture showed up well!". This remark implied that although the Edge format was effective at highlighting obstacles edges within images the format could rarely apply this to objects of interest in the presence of background obstacles (apparent in moderate and high complexity environments). Although this complementary relationship between these formats was only consistent for low complexity environments it does indicate that this format combination may be useful in situations of very low network bandwidth for simple environments. It may also be concluded that the effectiveness of the Edge format was primarily reduced due to the algorithm's inability to target the desired objects of interest.

Due to the experimental process employed to some extent it must be considered that the full situational awareness of a participant was achieved through all presented image formats (not only the final format). Although this cumulative approach has been applied for the analysis presented in this subsection, a particular examination into the independent performance of these formats may be conducted. This may be determined by identifying the both the instances and number of opportunities that participants had to acquire full situational awareness using only a single image format (see Figure 5-5). It should be noted that this approach will be applied to assess the independence of each format's effectiveness from the previous format/s presented and does not singularly indicate format effectiveness. Due to the absence of opportunity for participants to use greyscale to identify all objects in a low complexity environment this could not be assessed. For similar reasons the independence of colour was also unable to be examined within any of the environments considered.

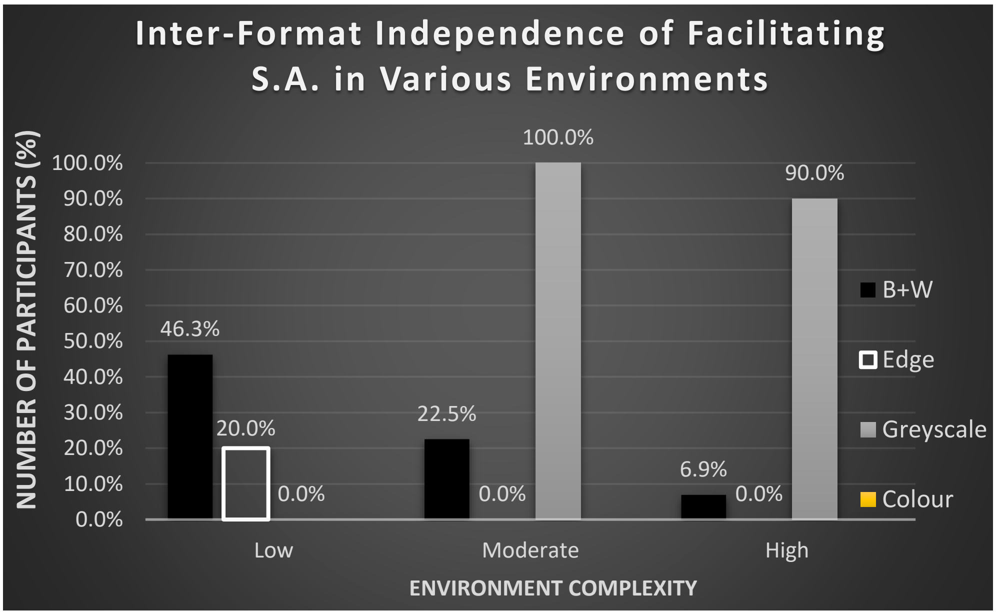

Figure 5-5: Inter-format independence of facilitating situational awareness in various environments

As expected, due to the Black and White format being presented first the percentage of cases where this format could provide full situational awareness remains unchanged. The independence of the Edge format is seen to quickly disappear with the increase in environmental complexity increase. This yet supports the previously suggested notion that Edge becomes very ineffective in all environments that are not simplistic. On average, it is seen that given the opportunity the greyscale format provided all required data to the participant regardless of the environment's complexity in 95% of cases. The outstanding independence of this format indicates that the cumulative effectiveness previously identified is likely to be a realistic reflection of its individual performance to provide situational awareness. This is supported by many participant comments such as, for example, “greyscale could guarantee all objects to be seen”. Thus, in cumulative effectiveness of this image format identified within this subsection is likely to be indicative of its individual performance. Such a conclusion could be valuable for a tele-robotic designer to consider to further justify the use of greyscale instead of a colour image format within the system.

5.2.1.4 Various Environments (Depth Perception)

In evaluating the participants’ ability to perceive depth from the image formats in environments of various complexity no conclusive relationship could be identified. This may be due to the randomness of object spacing within these environments so therefore this effect of this factor may not be accurately determined.

5.2.1.5 Various Environments (Participant Demographic)

The performance of each demographic of participants were investigated to identify whether any relationship could be identified. This considered the participant’s experience in image filters and depth perception ability as well as their gender. No conclusive link could be found between these factors and the resulting situational awareness acquired. From this conclusion it may be likely that the ability of a user is not dependent upon these particular factors. Therefore, in the selection of a user these factors may likely be omitted from consideration.

5.2.2 Format Efficacy

This analysis was conducted based upon Section 4.4.2 to investigate the efficacy of the various image formats considered within Experiment 1. The key findings of this analysis are presented and then further investigated within this sub-section to enable a valuable evaluation to be discussed. It should be noted that the participants’ average situational awareness was determined as a percentage of correct answers attained using each format.

5.2.2.1 Overall

Regardless of the most effective format in enabling users to attain situational awareness, limited network bandwidth may have a significant influence on the choice of image format within the robotic system. Therefore, the format's ability to facilitate both the situational awareness of the system and the data requirements of this format may need to be considered. In order to evaluate this relationship the situational awareness attained by participants using various image formats and the data requirements of these format were plotted. In this regards as the experimental approach employed both the cumulative situational awareness and data requirements for each image format are considered. Therefore, the data requirement percentage in terms of the conventional format will be used which, for these cumulative formats are 3, 6, 30 and 100 % respectively (as identified within Section 4.2.1.1). The relationship found within this study considering all environments is shown in the below figure (Figure 5-6).

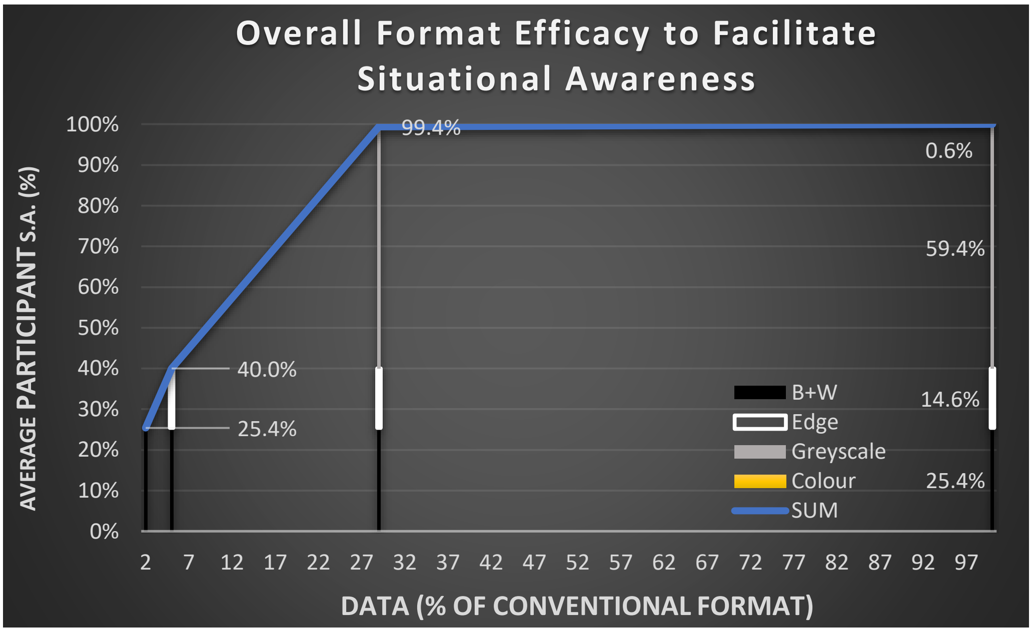

Figure 5-6: Overall format efficacy to facilitate situational awareness

As expected, these results illustrated that the participants were able to acquire more situational awareness with the provision of more data (through sequential formats). Furthermore, the influence of this data towards improving the situational awareness of the participant rapidly decreased as additional data was provided. For example, by additionally providing the participant with the Edge format, and essentially doubling the amount of data presented, an awareness increase of 15% was attained. Whilst an increase in 60% was observed with a five-fold increase in data (greyscale format), a three-and-a-half fold increase of data (colour format) only increased the participants' situational awareness by a mere 0.6%. In respect to the rapidly decreasing gradient, this relationship quite distinctly resembles that of a logarithmic function. This approximation is quite evident by the summation line fitted to the collected data which highlights the significant decrease in the data's efficacy to increase the user's situational awareness as more data is supplied. With this conclusion a designer of a system in a limited network environment may wish to consider the benefits available in compromising what data will be transmitted.

5.2.2.2 Various Environments

A similar relationship as that outlined above clearly extends into the various environment complexities considered. Figures 5-7, 5-8 and 5-9 illustrate this in further detail in regards to the cumulative situational awareness and provided data for these environments.

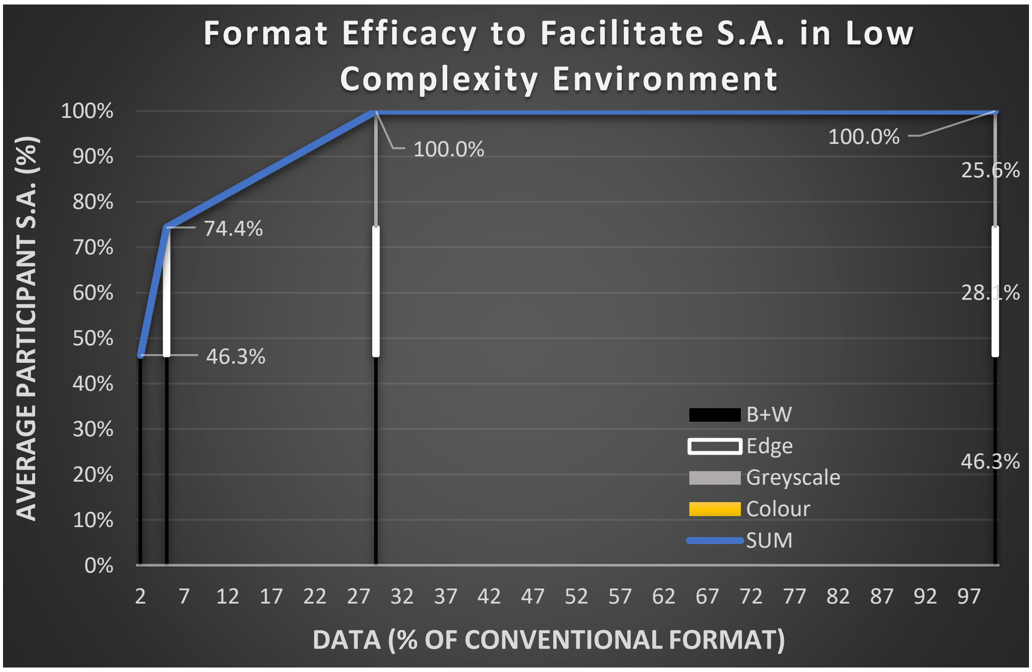

Figure 5-7: Format efficacy to facilitate situational awareness in low complexity environments

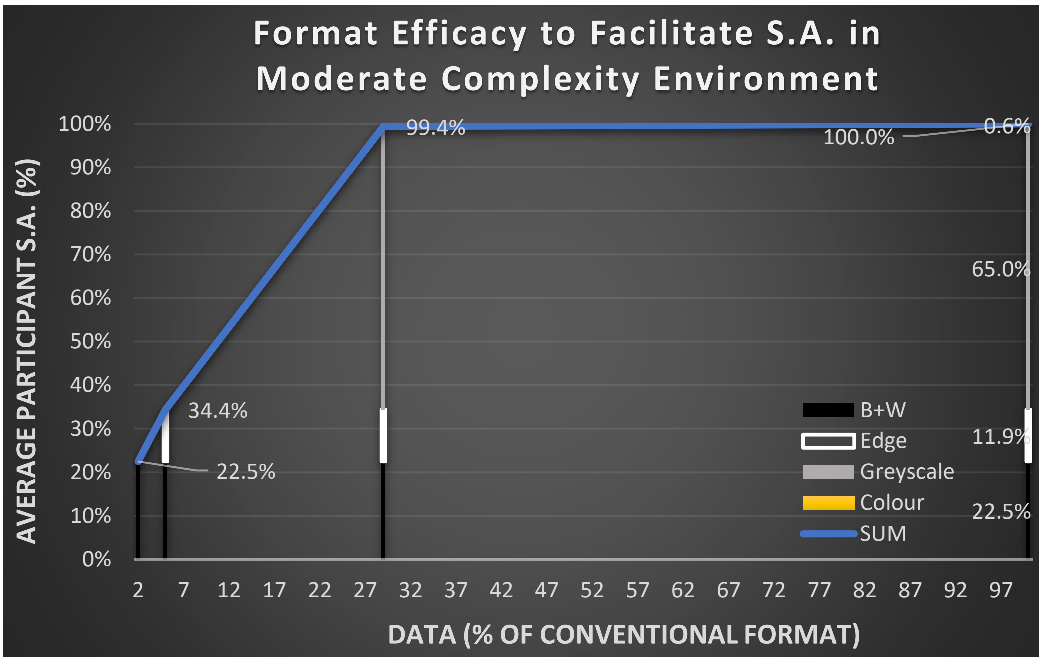

Figure 5-8: Format efficacy to facilitate situational awareness in moderate complexity environments

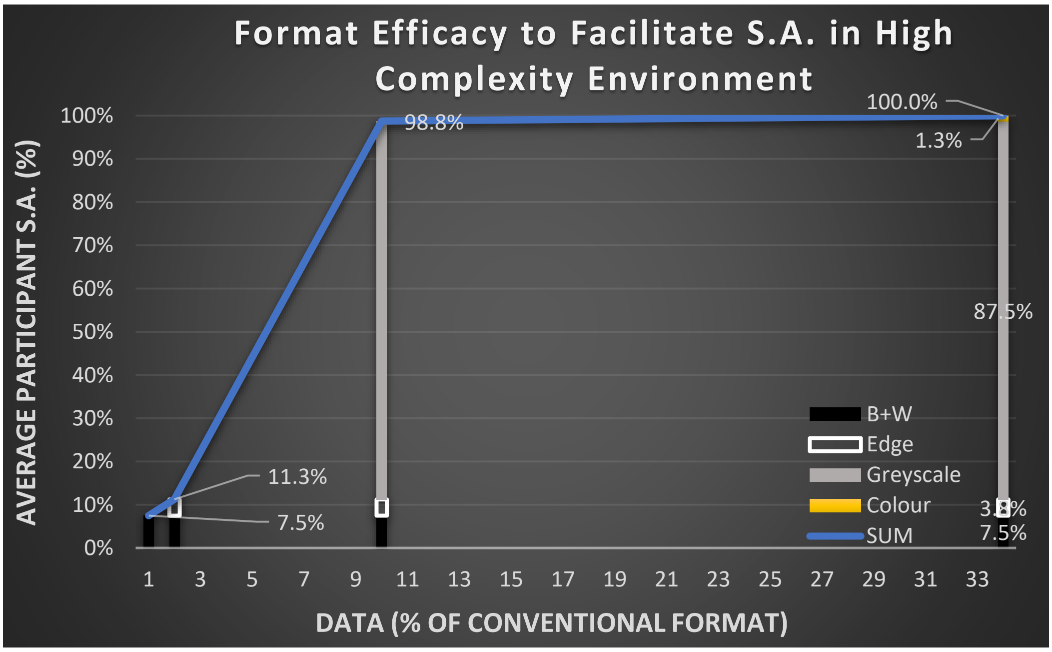

Figure 5-9: Format efficacy to facilitate situational awareness in high complexity environments

These figures highlight the quite drastic reduction in the format effectiveness of Black and White and the sequential combination of Black and White and Edge formats. Interestingly, the gradient between these format combinations reduces significantly with the environmental complexity indicating a reduction in the addition benefit of the

Edge format in terms of data efficacy. This may be considered within the design of a system to justify the addition or removal of the Edge format based upon the operation environment complexity.

5.2.3 Bias of Results

The conclusions drawn within this subsection are based upon the results obtained that may have inherent bias associated with the experimental process employed to record this data. The list below will explore the potential influence of the various bias that may have affected these results.

5.2.3.1 Sequence of Format Presentation

Due to the presentation order of least to most data-intensive formats to the participant the results obtained are in fact somewhat bias to the least data-intensive formats. Due to the opportunity for these formats to be used before others, and therefore, it is likely that the number of participants that attain situational awareness using these formats will be increased. As such, in general the effectiveness of each format considered cannot be accurately identified as the singular performance of these formats. Despite this, it should be noted that this experimental approach was particularly chosen in order to enable the experimental aims to be achieved. Thus, the results obtained will be considered cumulatively unless otherwise justified, such as that of the greyscale format.

5.2.3.2 Repetition of Environment Presentation

Throughout experimentation the user was presented with the varying representations of the same environment. As such it could be stated that bias due to familiarity may increase the performance results of participants using formats presented later in the series (more data-intensive formats). This bias was considered to hold considerably less significance on results as opposed to the substantial subjectivity inherent with justifying different, similar environments to use for each format. Due to the sequence of formats presented the reasonable assumption was made that if a participant could provide a correct answer with limited data he/she would very likely provide this same correct response when given even more data to consider.

5.2.3.3 Subjectivity of Environmental Complexity

The scenarios created to obtain results within environments of various complexity were based upon the experimenter's interpretation. Therefore, although justification of the applied classification method was outlined in Section 4.2.1, subjectivity of this definition does exist. Although the environments create were typical to those that a small, indoor robotic system would encounter it is unlikely that the classification of low, moderate and high complexity environments will not be equivalent between the experimenter and other designers. Thus, the conclusions drawn inferring relationships between various parameters amongst the change in environmental complexity should therefore also be considered to entail a degree of subjectivity.

5.2.3.4 Identification of Object within an Environment

Due to the focus of this experiment to identify objects the results obtained may be influenced by object familiarisation bias. Due to the participant knowing the object's general size, shape and colour it may be easier for to identify this object within an environment. This was expected to assist the user within all formats considered quite evenly and therefore not affect the comparison between image formats. Furthermore, navigation within an indoor environment would most likely encompass objects that are well familiarised to the user and therefore this bias may actually assist in the real-life environment.

5.2.3.5 Resolution of Formats Considered

It should be noted that the results used to evaluate the design methodology of tele-operation systems is limited to some extend by the number of formats considered. The experiments conducted to evaluate the relationship between the user's situational awareness and the data provided for both camera and LiDAR hardware considered only four formats. Although this was considered to be quite sufficient for an initial investigation the conclusions drawn remain somewhat bias to the formats considered due to the limited resolution of this analysis.

5.2.4 Summary

The following subsections summarise the findings previously identified within the conducted analysis. In exploring the relationship between the user's situational awareness and the provision of data (e.g. formats) many findings were highlighted that would be of use to consider for effective use of imaging hardware data within a tele-robotic system. To further demonstrate the application of these findings, examples of how the consideration of such a conclusion may assist a designer to develop a more effective system. It should be considered that an effective use of image data would be to provide situational awareness whilst efficacy relates to the effective balance of situational awareness and data required by the system.

5.2.4.1 Effectiveness

In evaluating the effectiveness of various formats to acquire situational awareness the following relationships were identified:

a) *Overall the Greyscale format was most commonly employed to acquire full situational awareness whilst Colour was very rarely required.*

These findings suggest that there remains no foreseeable benefit in utilising a colour image format to provide situational awareness if alternative, less data-intensive formats are instead provided. As such a designer may justify the use of greyscale instead of a colour format within the imaging of the system.

b) *Black and White and Edge quite adequate within low complexity, whilst Greyscale was consistently effective in all other environments*

This particular conclusion may suggest to the tele-robotic designer what data may be required for various environment complexities. This could serve as a "base-line" or recommended data requirement that may then be further investigated through an iterative design approach to improve the system.

c) *The misconception that in order to acquire adequate information from an image the colour image format is required was identified within the population considered.*

Although this mentality is typically associated with the approach of the conventional design methodology, designers should consider this whilst creating the tele-robotic system. In doing so the designer may be able to avoid particularly incorrect assumptions that inhibit the effectiveness of the system.

d) *Within low complexity environments Edge may provide a quite effective supplement to Black and White formats, whilst the effectiveness of the Greyscale format was seen to be independent to all other formats.*

This may suggest that users of a tele-robotic system, within a simplistic environment, may find considerable benefit in acquiring both Black and White formats to attain situational awareness. Therefore if the system only requires very basic information, or the responsiveness of a system using a limited network is of paramount consideration, the designer may use such a conclusion to identify that limiting the data transmitted may best address the design objectives. Alternatively, for more complex environments this conclusion suggests that a system should utilise at least a Greyscale image format (or a format of similar data) to ensure adequate information can be provided to the user. Both of these statements may guide the designer towards the identification of what image formats may be either adequate or most effective in particular environments.

e) *No conclusive links could be made in regards to user performance to participant demographic background.*

With this in consideration it may be suggested that the user selected to operate this system should be judged upon factors other than those investigated within this experiment.

5.2.4.2 Efficacy

The relationship between the parameters considered within this analysis indicates that the effectiveness of data to further improve situational awareness significantly reduces as additional data is provided. This is clearly exemplified in the change of gradient between the data configurations (formats) considered. Due the observed logarithmic relationship, a minute reduction in situational awareness will likely enable a significant reduction in the required amount of data to be used, which highlights the potential benefit of its consideration within tele-operation design. Furthermore, as this trend is more prominent in high complexity environments such a relationship may be even more important to consider in real-life applications. Through the application of this relationship, a designer may be able to optimise tele-operation to best address the design objectives in respect to the user situational awareness and the real-time characteristics required (predominantly associated to the data transmitted through the system's network). For example, a designer incorporating the use of the greyscale instead of the colour format may be able to reduce the system data required to be transmitted by two thirds whilst retaining 99% of the user's situational awareness. Although this exemplifies only one case of the benefits attainable through considering these findings, it does indicate the importance of the determination of succinct "Right" data for effective tele-robotic system design (further investigated within **Section** 5.5).

5.3 Experiment 2 – LiDAR Format Analysis

The first section (5.2.1) will explore the general trends and comparative effectiveness of the LiDAR formats considered in regards to enabling the user to attain full situational awareness. The second section (5.2.2) will evaluate these formats in terms of their respective efficacy to provide situational awareness with the data presented.

5.3.1 Format Effectiveness

This analysis was conducted based upon Section 4.4.1 to investigate the effectiveness of the various LiDAR formats considered within Experiment 2. The key findings of this analysis are presented and then further investigated within this sub-section to enable a valuable evaluation to be discussed. Again, it should be noted that "full" situational awareness is defined as the instance where the user was able to answer all questions (100%) correctly in the given scenario using a particular LiDAR format.

5.3.1.1 Overall

In examining the results obtained within the experiment it can be seen that on average the majority (55%) of participants were able to acquire full situational awareness using Format C. Formats D and B where used 31% and 14% respectively, whilst Format A was not required at any instance by participants (Figure 5-10). Although quite simplistic, these findings may assist a designer to predict the approximate effectiveness of the system to have in facilitating situational awareness if such formats were employed.

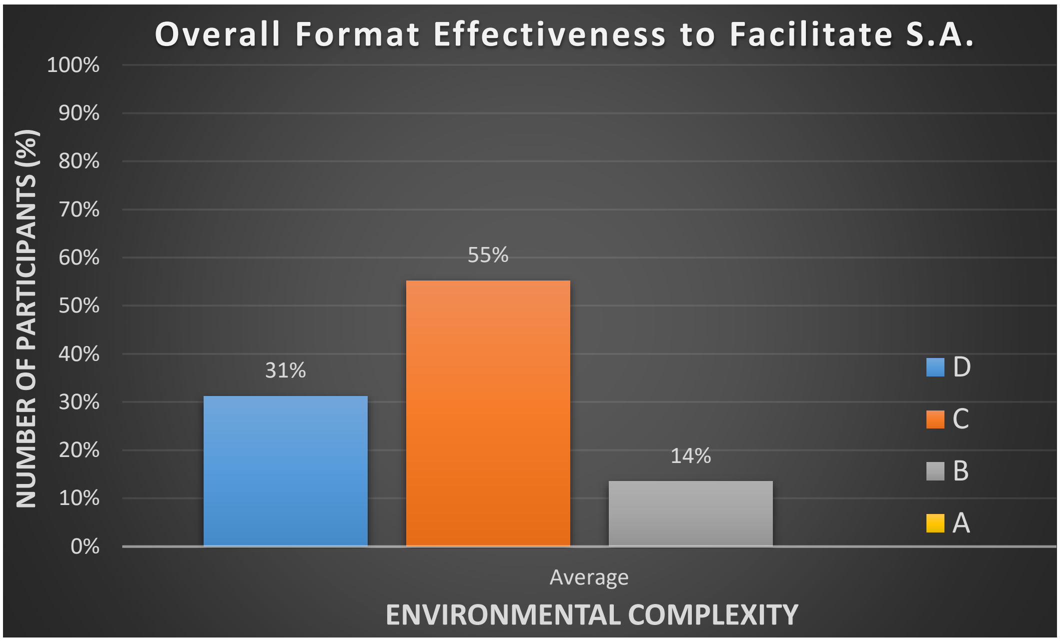

Figure 5-10: Overall LiDAR Format Effectiveness to Facilitate Full S.A.

5.3.1.2 Various Environments

A more detailed insight into participants' use of these formats can be identified by considering their use within environments of varying degrees of complexity. These results are presented within Figure 5-11 as a cumulative column graph to enable the comparison between the frequencies of use (as a percentage) of each of the formats to attain full situational awareness in different environments.

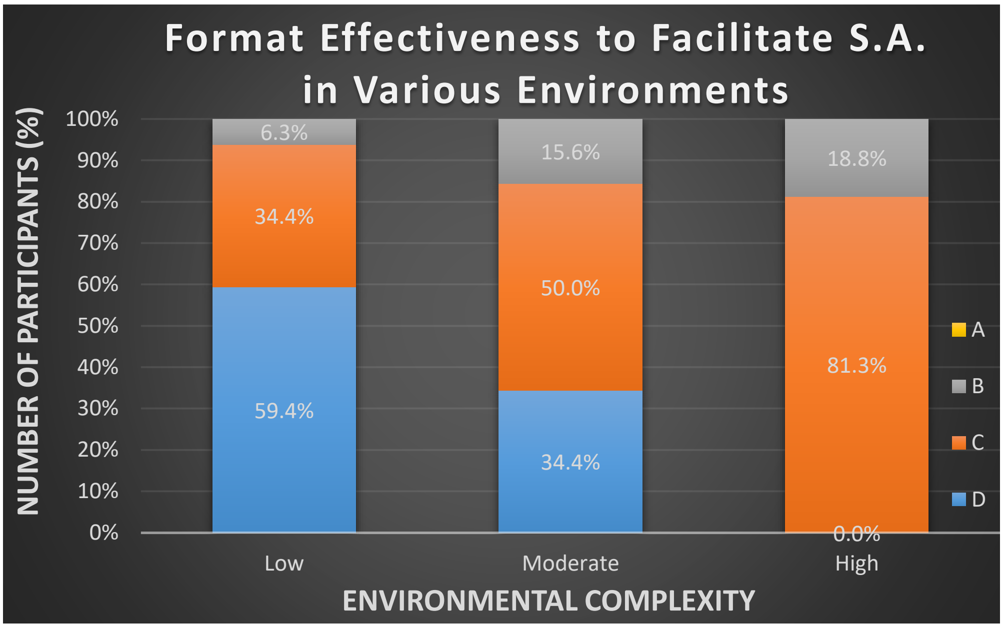

Figure 5-11: LiDAR Format Effectiveness to Facilitate Full S.A. in Various Environments

Within the above figure it can be seen that for low complexity environments Format D somewhat adequate, of which 59% of participants were able to acquire full awareness using. This was supported by the many comments obtained indicating that participants found Format D quite "adequate" for the assessment applied within Scenario 1. Evidently, it can be seen that as the environment complexity increased participants were required to rely upon more data-intensive formats to consistently attain complete situational awareness. Such an observation is emphasised by the considerable reduction participant usage of Format D from 59%, 34% to 0% in low, moderate and high complexity environments respectively. Furthermore, it can be seen that as the use of Format D declined the significant majority of participants were able to instead use the next least data-intensive format (Format C). This can be identified in considering the allocation of the reduced percentage usage of Format D from low to moderate and moderate to high complexity environments. Within the moderately complex environment the percentage increase of Format C and B were 15.6% and 9.3% respectively whilst this ratio was considerably different, 31.3% and 3.2%, within the high complexity environment. This particular correlation was further examined by investigating the factors which contributed to Format D's inability to address the assessed elements of situational awareness ("Activity" and "Surroundings" of the LASSO framework).

5.3.1.3 Various Environments ("Activity" Assessment)

In order to evaluate this particular element the cumulative percentage of participants able to answer all questions in each scenario assessing "Activity" was calculated for each LiDAR format (refer to Figure 5-12).

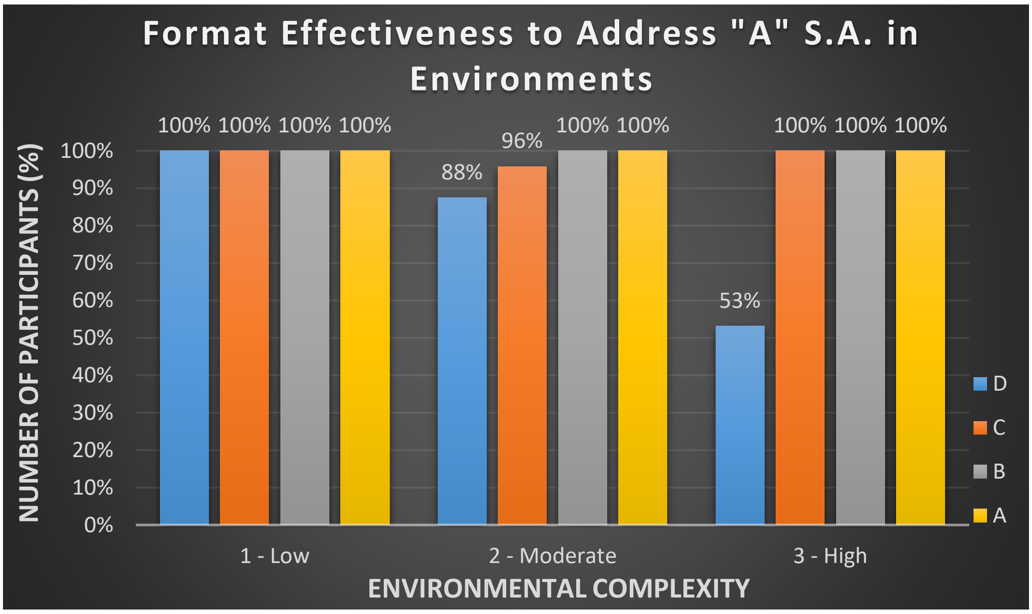

Figure 5-12: LiDAR Format Effectiveness to Facilitate Full Activity" Situational Awareness within Various Environments

It is evident within the above figure that the effectiveness of Format D to provide information to the user regarding the robot's activity is reduced as the environmental complexity increases. It can be seen in both the moderate and high complexity environments that Format C was able to effectively provide this missing information required by participants. This is particularly prevalent in the high complexity category where this format was able to restore the cumulative total awareness within this category to 100% of participants from 53%. Through further analysis of Format D's inadequacy the specific questions found to be of particular difficulty were Q6 and Q8 in Scenario 2 and 3 respectively. In observing the recordings of Format D, C and B of Scenario 2 at the instant Q6 was posed (Figures 5-13, 5-14 and 5-15 respectively) various conclusions can be drawn to suggest the factors that inhibit a format's ability to provide "Activity" awareness.

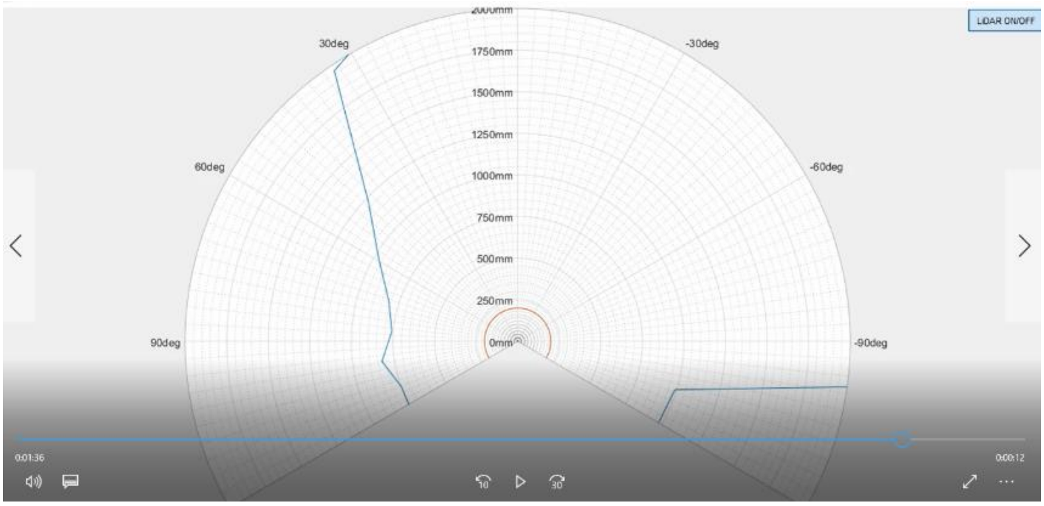

Figure 5-13: LiDAR Format D at the instant which Q6 in Scenario 2 was posed.

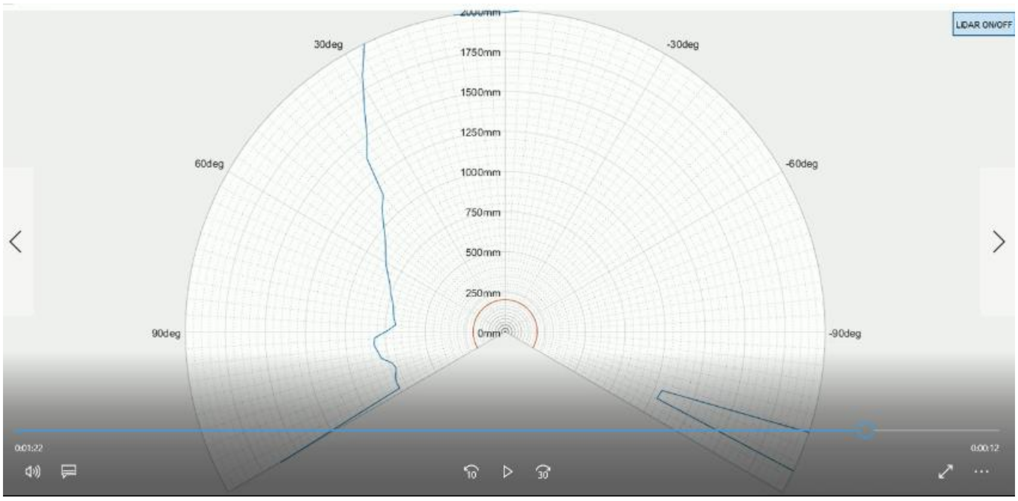

Figure 5-14: LiDAR Format C at the instant which Q6 in Scenario 2 was posed.

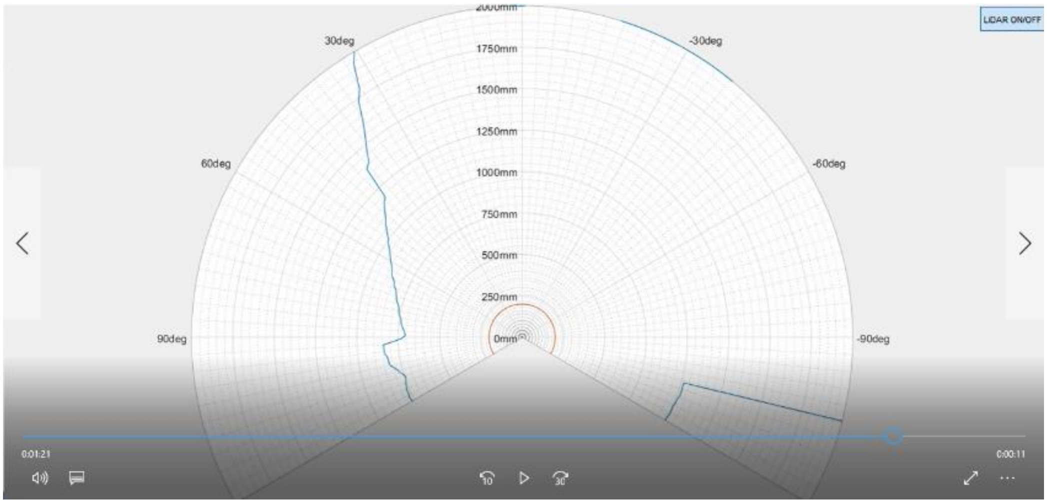

Figure 5-15: LiDAR Format B at the instant which Q6 in Scenario 2 was posed.

From these figures it was identified that the most significant difference between the data presented in these formats was the number of distinguishing features that could be identified. From Figure 5-13 it can it can be seen that the lines created by Format D appear much more smooth due to the larger approximations employed by this format's algorithm. The only distinguishing feature within the data presented is a "bump" along the left wall (at an approximate 100 degree orientation). Comparatively, quite a number of distinguishing features can be identified within both Format B and C, both of which were much more consistent in providing the participant which awareness regarding the test system's activity. This same trend is reflected in the case of the results of participant responses in regards to Q8 of Scenario 2. As such, it may be suggested that a connection "Activity" awareness and the presentation of distinguishing features within the environments may exist. Due to the effectiveness of Format B and C to address this issue in both occasions the appearance of distinguishing features within the user-interface may be attributed to the use of more data-intense formats. This conclusion may be considered by a tele-robotic designer to justify the use of Format C or B (or an equivalent data configuration) to improve a user's "Activity" awareness within a system. Alternatively, this finding may suggest how an algorithm, used within a LiDAR format, may be optimised to best address this issue.

5.3.1.4 Various Environments (“Surroundings” Assessment)

Figure 5-16 illustrates the cumulative percentage of participants able to acquire complete situational awareness for element “S” of the LASSO framework using the LiDAR formats considered. It can be seen that the effectiveness of Format D to enable the participants to become aware of the test system’s surroundings steadily declines with the increase in environmental complexity. Yet again, the employment of Format C significantly increased participants’ “Surrounding” awareness for all environments considered.

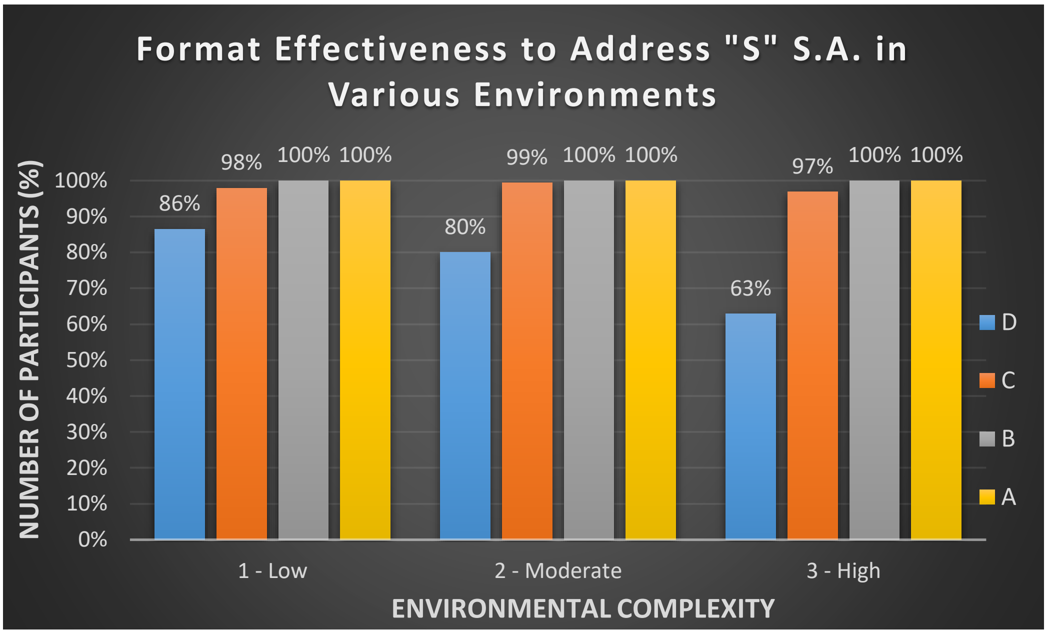

Figure 5-16: LiDAR Format Effectiveness to Facilitate Full “Surroundings” Situational Awareness within Various Environments

Yet again a detailed investigation into the results for each question employed to assess this element to identify what characteristics may be attributed to the effectiveness of Format C. In doing so it was identified that the additional data associated with Format C would only offer benefit to the participants’ detailed “Surrounding” awareness. This relationship was highlighted by separately considering the improvement of this awareness element in regards to general and specific details. The classification of general and specific details of this element was made in considering that specific details of the test system’s surroundings will be that which indicate the object’s respective proximity and orientation. In accordance to this definition the questions assessing participants' "Surrounding" awareness were classified (see Figure 5-17) and the additional awareness benefit of Format C was presented between these classifications (see Figure 5-18).

"Surrounding" Situational Awareness	
General	Specifc
Q1/Scenario 1	Q5/Scenario 2
Q2/Scenario 1	Q7/Scenario 2
Q4/Scenario 1	Q8/Scenario 2
Q1/Scenario 2	Q3/Scenario 3
Q4/Scenario 2	Q4/Scenario 3
Q1/Scenario 3	Q5/Scenario 3
Q9/Scenario 3	Q6/Scenario 3
	Q7/Scenario 3

Figure 5-17: Classification of "Surrounding" assessment questions for situational awareness

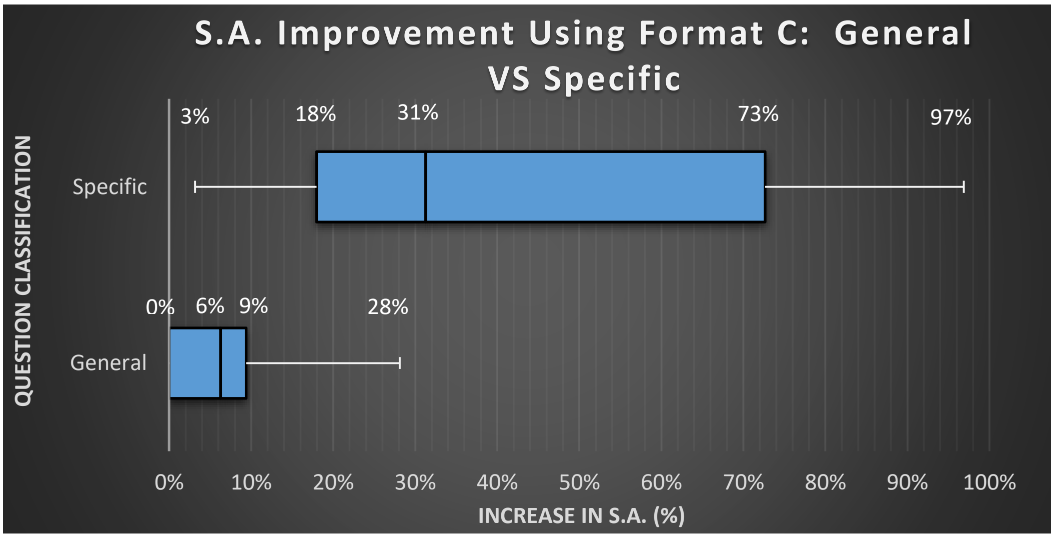

Figure 5-18: A comparison of the situational awareness improvement attained in general and specific "Surrounding" information

The statistical evaluation provided within Figure 5-18 strongly highlights the contribution that the data within Format C has in participants' general and specific

“Surrounding” awareness. It can be seen that, on average, Format C could only offer participants’ an additional 6 % in general spatial awareness compared to Format D. In cases where specific information was required the benefit of the employment of Format C was significantly more evident. In a quarter of such cases an increase of 75% was obtained whilst, on average, a 31% benefit was identified. Such a dramatic improvement attained upon the employment from Format D highlights the substantial inadequacy of Format D within this particular subset of “Surrounding” awareness. Specifically, this performance deficiency is most observable within the results of Q7 of Scenario 3 where participants’ detailed “Surrounding” awareness drastically improved from 0% to 97% with the use of Format C. The user-interface of Format C and D at the instance that this question was posed in shown in the below figures (Figures 5-19 and 5-20…).

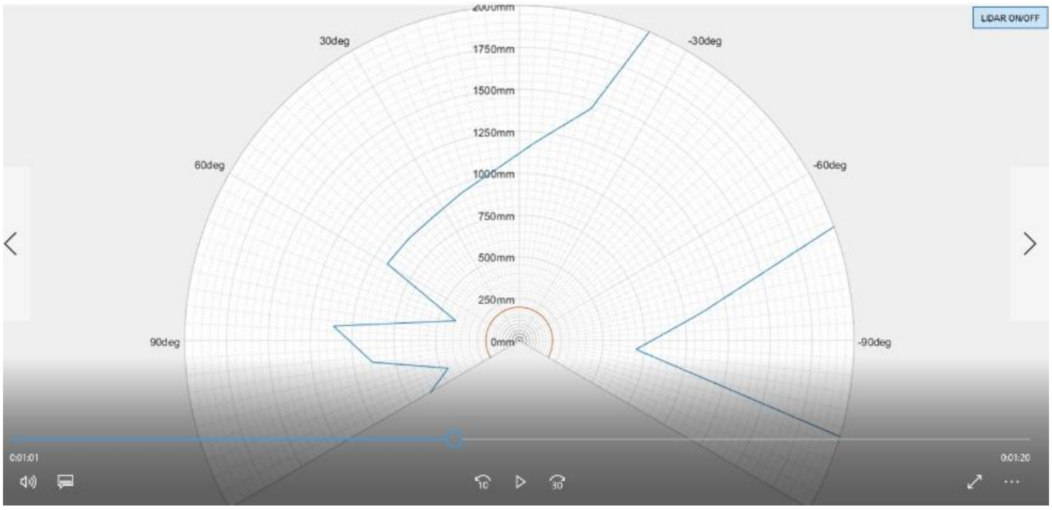

Figure 5-19: LiDAR Format D at the instant which Q7 in Scenario 3 was posed.

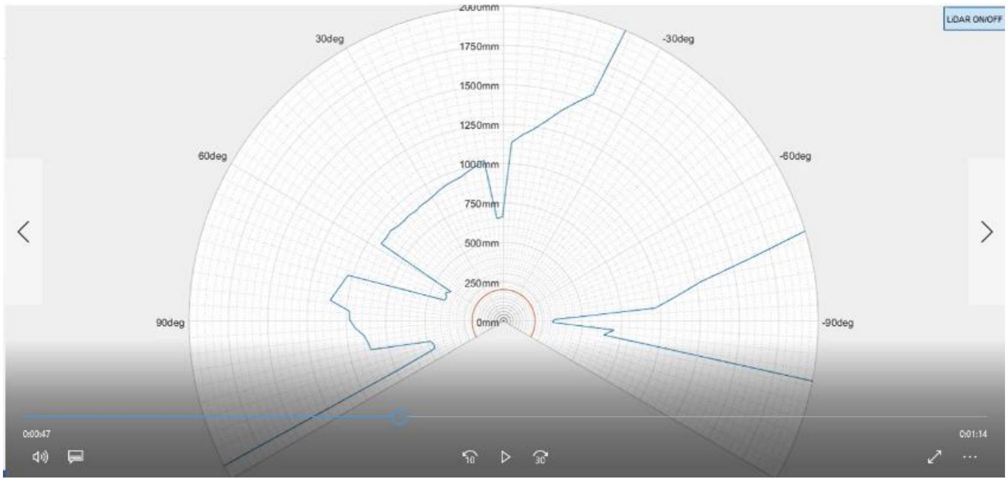

Figure 5-20: LiDAR Format C at the instant which Q7 in Scenario 3 was posed.

Upon viewing the above figures it becomes clear as to the reason for this format's inability to facilitate the information for participants to acquire the detailed information required for "Surrounding" awareness. Question 7 of Scenario 3, which asked for the orientation of the nearest object, had no correct responses from participants using Format D. Evidently, it can be seen that the crucial detail of the object at -90 degrees presented in Format C was not presented to the user within Format D. Furthermore, it can be seen that Format D only presented three of the four objects to participants which therefore inhibited almost all participants to acquire detailed awareness of the test system's surroundings. Both of these examples illustrate the significant limitation of Format D to provide the information for participants to acquire detailed "Surrounding" awareness. This deficiency was most likely caused by the large distance spacing between the displayed data points of Format D (illustrated in Figure 5-21).

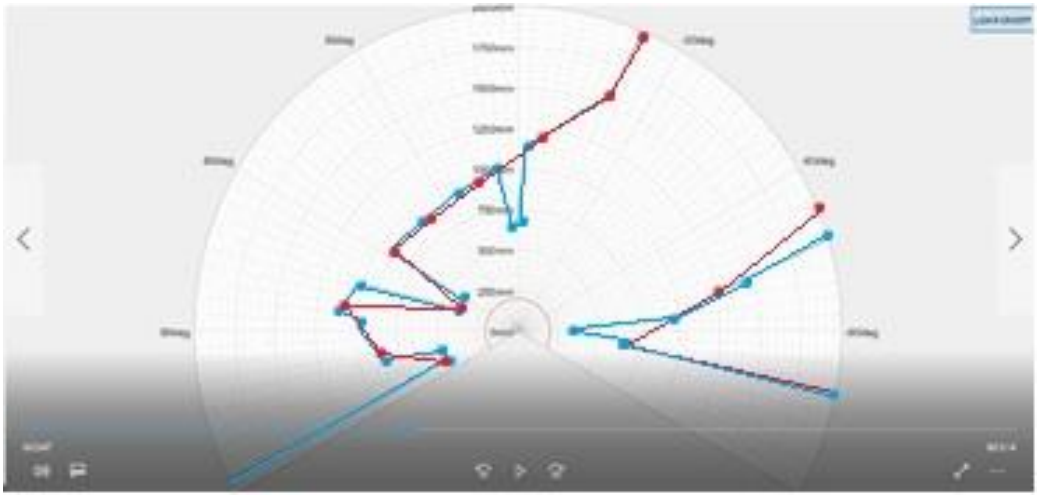

Figure 5-21: An illustration of the ineffectiveness of Format D to recognise the nearby objects (where Format D and C are illustrated respectively by red and blue colour).

This conclusion suggests that the effectiveness of a LiDAR format to provide the user with detailed surrounding awareness is quite dependent upon the resolution of data utilised. As this resolution is in terms of angular spacing, as such the range of the environment surveyed would also contribute to the influence of this phenomena. A designer may consider this information to select identify a maximum angular resolution that a system may use without the significant loss of detailed information.

5.3.1.5 Various Environments ("Location" Assessment)

Although this element of the LASSO framework was not quantitatively considered it was identified to be of significance within the qualitative comments of the participants. The significant majority of participants expressed their opinion that Format D did not enable adequate information from the environment to be acquired. Approximately half of these comments were in relation to the limited data it presented, yet 82% of these comments expressed that the formats' "jumpiness" was of considerable concern. Various, similar terms were used to describe this phenomena, such as; "jumpy", "slow to react", "sensitive to movement", "not sharp", "jittery", "jaggity" and "having jumpiness". In a number of instances verbal comments and reactions were made throughout experiment which clearly highlighted the disorientation that some participants encountered in particular instances of the viewed recording. These comments were particularly prevalent when participants were observing either Format C or D. This observation was further demonstrated when considering that the only formats to receive complaints for "jumpiness" were these particular formats (with Format D receiving the most complaints). From those who had complained of unwanted jitter only 11% did not select Format B as the preferred format, whilst others explicitly commented that in comparison to all considered formats "B was less jittery". Therefore, due to its prevalence within these findings further investigation was conducted into the cause of jitter.

The user-interface recording of the formats were investigated in order to attempt to define this phenomena and the factors that cause it to occur. The description of jitter, albeit quite subjective, seemed to fit the inconsistent manner in which Format C and D would display the position of nearby obstacles. Whilst Format A and B would consistently present the obstacle within each successive frame (whilst in view) these formats would seem to unexpectedly "lose sight" of the object. This would generally create quite a disorientating effect on the user due to the disassociation created between the successive frames of the user interface. Thus it was considered that jitter is, at least somewhat, due to the disappearance and reappearance of nearby objects. To illustrate this behaviour an analysis was conducted to somewhat quantify the jitter of Format C and D. This jitter analysis presented in Figure 5-22 records the detected distances of particular objects (in millimetres) in successive frames of the user-interface for both formats considered. The jitter of each system is exemplified by the absence of object detection, indicated by "---", which would generally create a sudden significant change in the LiDAR data presented within the user-interface.

Frames	Obstacle: Q2/Scenario 1		Obstacle: Q4/Scenario 1	
	Format D	Format C	Format D	Format C
1	1250	1950	1500	1850
2	1150	---	---	1450
3	---	1700	1300	---
4	---	---	---	1150
5	---	1500	---	---
6	800	---	---	850
7	750			
8	---	1250	650	
9	650			

Figure 5-22: A quantified analysis of jitter within Formats C and D

From this the analysis applied it may be suggested that the following factors may reduce the impact of jitter upon these systems:

a) Increasing the amount of data points presented to increase the resolution of the LiDAR scan to decrease the likelihood of "missing" a data point which had detected a nearby object. The behaviour investigated and the reduced number of complaints within comments for Format C are in support of this belief.
b) Employing a "minimum point" algorithm rather than an "even spacing" data reduction algorithm. Although this may not be supported by the results obtained within the experiment it may contribute to the robust performance of Format B due to the algorithm's filtering bias towards the closest data points (generally these data points would measuring object distances).

Although this phenomena could not be exhaustively evaluated within this experiment the above suggestions can be drawn from the analysis applied based on the qualitative responses acquired. In order to avoid jitter within a system these suggestions may be considered within the design stages of a tele-robotic system.

5.3.1.6 Various Environments (Participant Demographic)

Although the participants' performance was also analysed in terms of gender and experience demographic (LiDAR hardware and RTS-based gaming experience) as there was no more than a few percent difference it was concluded that no particularly conclusive relationship existed.

5.3.2 – Format Efficacy

This analysis was conducted based upon Section 4.4.2 to investigate the efficacy of the various LiDAR formats considered within Experiment 2. The key findings of this analysis are presented and then further investigated within this sub-section to enable a valuable evaluation to be discussed. Again, it should be noted that the participants' average situational awareness was determined as a percentage of correct answers attained using each format.

5.3.2.1 Overall

In order to assess this relationship the situational awareness obtained by participants was compared to the data provided per scan of the hardware. This general relationship, averaged for all environments considered, was plotted in Figure 5-23. It should be noted that for each format a cumulative percentage of the both the data requirements illustrated in Section 4.2.2.1 and participants' situational awareness was considered. Furthermore, the percentage of contribution for each of these formats is indicated by the various colours, whilst the total situational awareness is summed cumulatively as the thick blue line.

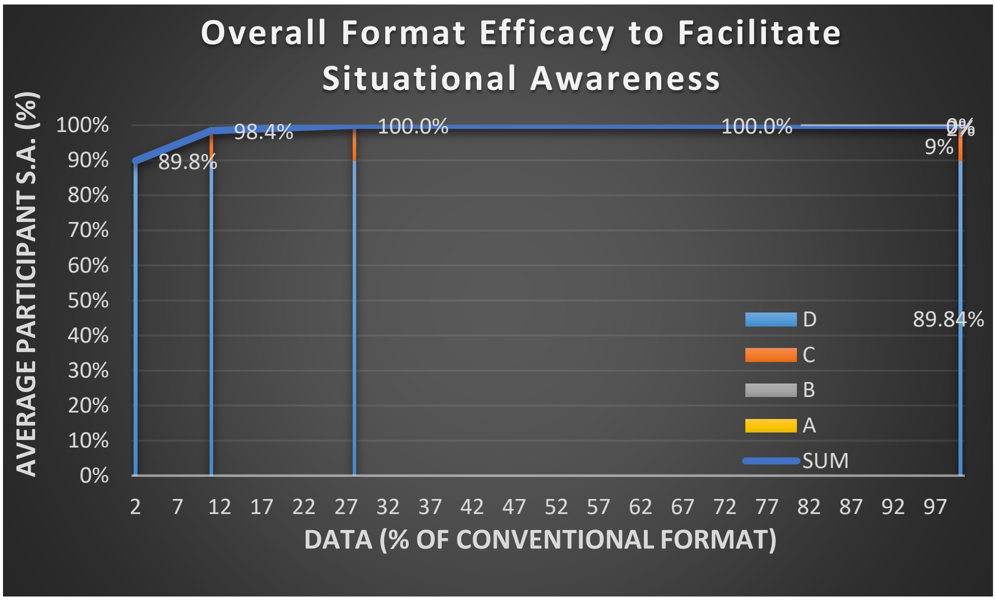

Figure 5-23: Overall LiDAR format efficacy to facilitate situational awareness

These results clearly reflect the widely accepted notion that the situational awareness of the user will increase as they are provided more data. Yet it can be seen that the rate of which the user may gain situational awareness dramatically decreases as larger amounts of data are provided. Although this behaviour may not be modelled with great accuracy using the overlayed logarithmic function, it does seemingly indicate this relationship despite a lack of considered resolution. For example, a 23% increase in situational awareness can be attained with the addition of the 9% of data (258 bytes / scan) provided using Format C also. Additionally, the use of Format B provides an increase of 1.9% in situational awareness for another 18% of data (510 bytes per scan). Results identify that the addition of Format A, and thus also 70% of data (2046 bytes / scan), no beneficial increase in situational awareness is found. From the formats considered it can be seen that the efficacy of data to provide situational awareness decreases as the amount provided increases. On average Format B is seen to enable participants to acquire approximately 98% of situational awareness whilst using Format C all awareness could be guaranteed. Although Format A is the conventional format of these systems it was found not to be required in any situation if the participant was provided the previous formats. The investigation of such a relationship may assist the designer of a tele-robotic system to explore the benefits that may accompany various degrees of compromise between these parameters.

5.3.2.2 Various Environments

Although this general trend can be seen in all considered environments various differences can be observed in Figures 5-24, 5-25 and 5-26.

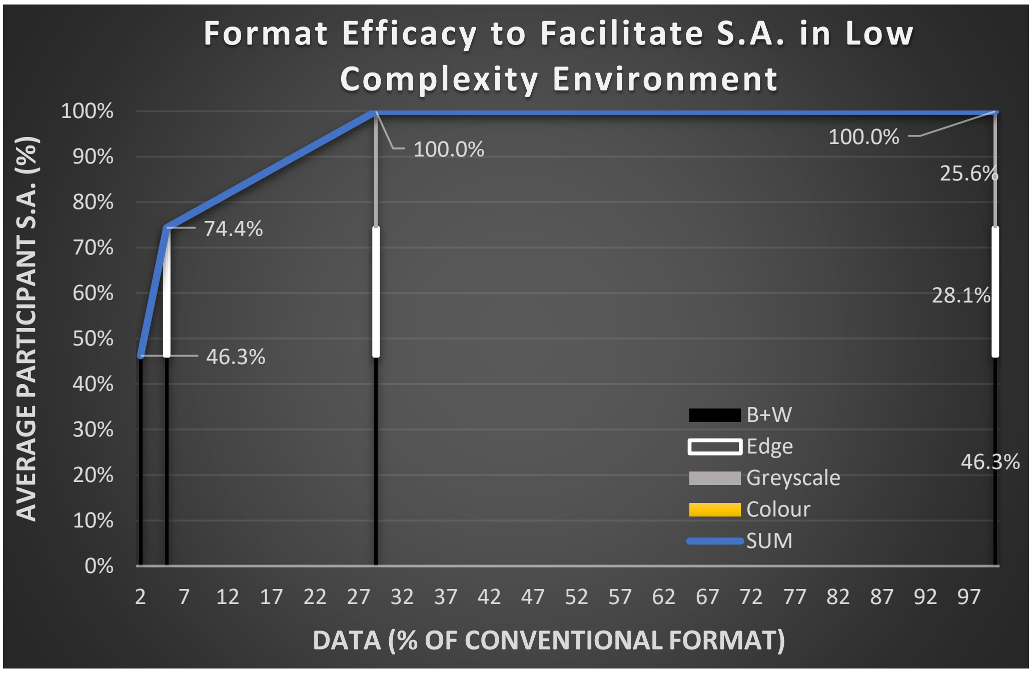

Figure 5-24: Format efficacy to facilitate situational awareness in low complexity environments

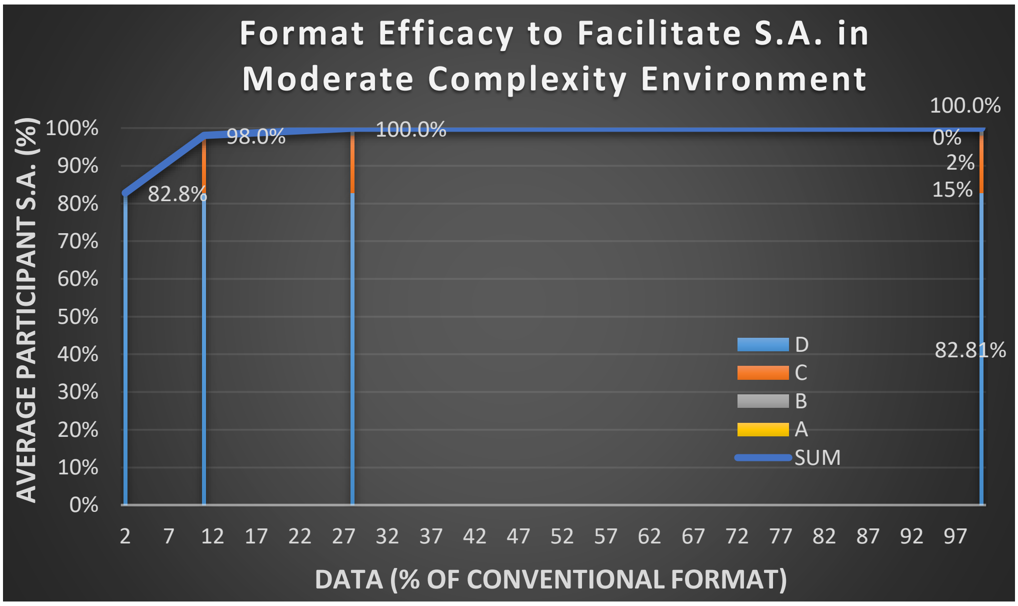

Figure 5-25: Format efficacy to facilitate situational awareness in moderate complexity environments

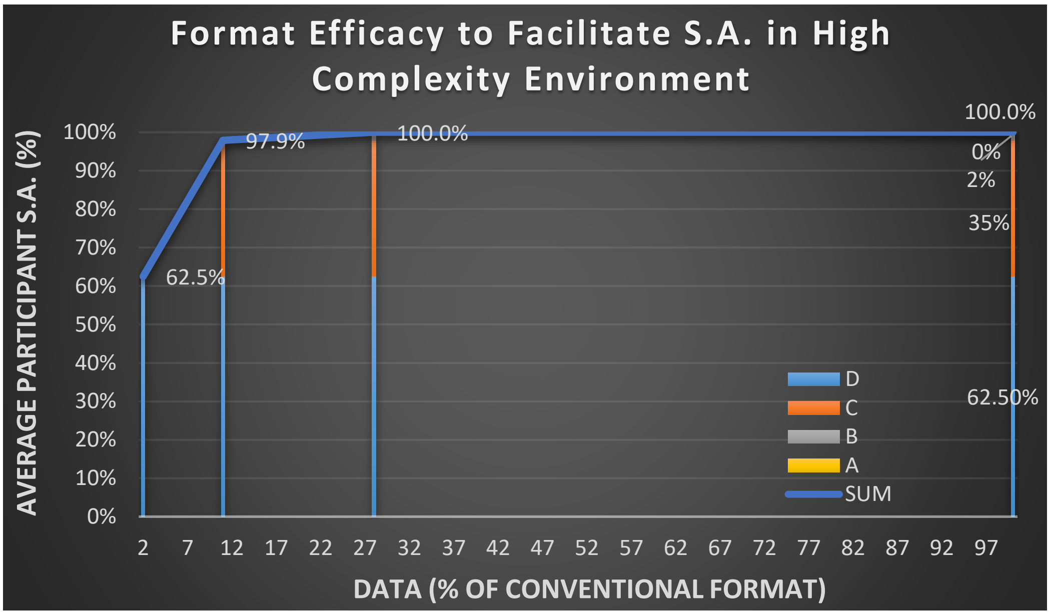

Figure 5-26: Format efficacy to facilitate situational awareness in high complexity environments

It can be seen that the general effectiveness of using only Format D is quite effective for low complexity environments, yet this is significantly reduced as the environment complexity is increased. This trend seems to become more prominent as the complexity of the environment increases for the first two format combinations considered. This is highlighted by the increasing significance the addition of Format B has in enabling participants to score more highly. This is identified when considering that the additional benefit of this format is 8.6%, 15.2% and 35.4% for low, moderate and high complexity environments respectively. Although the performance of participants was seen to reduce slightly with the use of Format C in more complex environments, Format B consistently enabled all situational awareness to be acquired regardless of the environment. The conclusion of these findings may assist the designer to more specifically apply the evaluation of this relationship yet more specifically to environments of varying degrees of complexity.

5.3.3 – Bias of Results

The figures that have been attained within this subsection are based upon the results obtained and the inherent bias associated with the process employed to record this data. The list below will explore the potential influence of the various bias that may have affected these results.

5.3.3.1 Sequence of Format Presentation

Refer to Section 5.1.3.1.

5.3.3.2 Repetition of Environment Presentation

Refer to Section 5.1.3.2.

5.3.3.3 Subjectivity of Environmental Complexity

Refer to Section 5.1.3.3.

5.3.3.4 Qualitative Analysis of Format Jitter

Due to the focus of this experiment to investigate only particular elements of situational awareness using the LASSO framework ("A" and "S") the analysis of jitter was out of scope. Despite this, much qualitative evidence was obtained that to some extend conclusions could be drawn in regards to the formats' ability to counteract the negative impacts of jitter. It should be considered that although these conclusions were based upon results obtained these were not based upon quantitatively examined data.

5.3.3.5 Resolution of Formats Considered

Refer to Section 5.1.3.5.

5.3.4 – Summary

The following subsections summarise the findings previously identified within the conducted analysis. For each of these findings an illustrative example is outlined to exemplify how such a conclusion may assist in identifying an effective use of LiDAR data within a tele-robotic system. It should be considered that an effective use of LiDAR data would be to provide situational awareness whilst efficacy relates to the effective balance of situational awareness and data required by the system.

5.3.4.1 Effectiveness

From the analysis conducted the following findings were indicated:

a) *Overall Format C was the most commonly employed to acquire full situational awareness whilst in no circumstance Format A was required.*

These findings suggest that there remains no foreseeable benefit in transmitting the entire data set of LiDAR readings to the user-interface in terms of the enablement of situational awareness. Alternatively, a designer may wish use Format B (or a format of equivalent data transmission requirements) to identify a general "base-line" for which they may expect to create a system that still consistently provides full situational awareness to users.

b) *Format D was only effective within low complexity environments whilst many more participants had to use more data-intense formats (eg. Format C and B) as the complexity increased.*

These findings may be used to tailer the amount of LiDAR data a system may use to address a specific environment complexity. Although the definition of environmental complexity is quite subjective the designer may still apply these findings to guide what amount of data will and will not be sufficient for the environment considered.

c) *"Activity" situational awareness was noticeably increased with the increased display of data points due to the user's ability to reference distinct shapes/points to assist in distinguishing movement.*

This observation may be used to identify the improvement of a tele-operated system where users are, at some instances, unable to identify the behaviour of the robot. Otherwise this finding may simply be considered within the design optimisation of an algorithm that may seek to reduce the amount of data whilst retaining distinguishing elements of the data set.

d) "Surrounding" situational awareness was noticeably increased with the increased display of data points, yet this trend was found to be quite restricted to circumstances where the user required detailed information (e.g. obstacle direction and orientation).

This finding may assist a designer to approximate the amount of data necessary to transmit according to the degree of detailed information the user requires.

e) Participants consistently considered "jumpiness" to predominantly determine system effectiveness. Potential solutions of this phenomena were considered to be increasing the data point display (alike to that of Format B) and applying a "minimum point" algorithm to reduce data point.

This information may be used to optimise an algorithm that could be applied to filter jitter from LiDAR data to be transmitted. In doing so the designer may be able to improve the usability of the system.

5.3.4.2 Efficacy

In regards to efficiency that the relationship between the user's situational awareness and the amount of LiDAR data provided is not constant. The gradient of this relationship, which is illustrative of the data efficacy in improving situational awareness, reduces quite significantly as the amount of data is increased. Again, by evaluating the gradient relating these parameters it can be identified that this relationship becomes even more prominent as the environmental complexity increases. A designer may be able to optimise a tele-robotic system by identifying the "balance point" within the relationship between situational awareness and data. Essentially by doing so the "Right" data may be determined more succinctly which may enable a system to increase real-time performance without considerably affecting the provision of situational awareness.

5.4 Qualitative Evaluation – Combined System Comparison

The following analysis was conducted to compare the performance of two RTS-Based systems which present the combination of image and LiDAR data to the user. It should be noted that this qualitative evaluation was not conducted in order to acquire more quantitative results to analyse in detail. Instead it serves to provide an additional dimension of investigation through applying the findings identified within previous subsections (Sections 5.2 and 5.3) and evaluating this system through the perspective of a tele-robotic designer.

5.4.1 – Design Outline

The design of these systems are quite briefly outlined in the below sub-sections. Due to the inherent subjectivity of this analysis the need to document this process in detail seemed quite unnecessary.

5.4.1.1 Key Design Concepts

The conventional system, which presented the user (i.e. the experimenter) with colour imaging and complete LiDAR scan data, was compared to a prototype system, which instead displayed both the greyscale (image format) and Format B (LiDAR format) data arrangements within a user-interface. These formats were chosen particularly to:

a) Simulate a quite typical scenario where the designer may wish to reduce the system's data transfer rate requirement without noticeably affecting the user's situational awareness.
b) Enable a simple, comparative examination technique to be employed to reflect upon the performance of these systems

5.4.1.2 Design Data Comparison

It is likely that this 'reductionist' design approach would only be considered in the instance where the network capability of the operation environment is somewhat inadequate. The reduction of the amount of data transmitted would enable the improvement of the system's real-time characteristics. Although this was not examined within the analysis, an approximation of the network latency for each system was calculated for illustrative purposes. The following figure (Figure 5-27) illustrates the difference of data required for each of the considered systems whilst a typical bandwidth of 240 kilobits/second was considered to simply illustrate the difference in network latency between these systems (ItNews, 2015).

	Prototype System		Conventional System	
	Image	LiDAR	Image	LiDAR
Component Data (Bits)	4.2106x10^6	16.32x10^3	12.583x10^6	65.47x10^3
System Data (Bits)	4.2106x10^6		12.648x10^6	
Data Comparison (% of Conventional System)	33%		100%	
Associated Latency (seconds)	17.5		52.7	

Figure 5-27: Real-Time System Capability Comparison between the conventional and prototype systems of consideration

5.4.2 – Analysis Outline

The user-interface of each system was recorded as the test-system maneuvered within a typical, indoor environment. This user-interface was later analysed qualitatively by the designer was assessed qualitatively in terms of the perceived situational awareness that the system provided. The primary objectives of this analysis were quite simply to:

c) Investigate whether the prototype system could enable the user to simultaneously interpret the data presented by the selected image and LiDAR formats

d) Compare the user-interfaces of each system and identify if a considerable difference in situational awareness seemed present.

5.4.3 – Potential Bias

Although quite a thorough evaluation may be made as a system designer there is of course the possibility that bias may be present within the inferences expressed. Furthermore, as previously highlighted, a degree of subjectivity is associated with the opinions stated within this analysis.

5.4.4 – Qualitative Observations

The following observations were made in regards to the objectives considered within this analysis.

5.4.4.1 Simultaneous Use of Format Combinations

In order to further evaluate the validity of the findings identified within the previous sections (5.2 and 5.3) reducing formats were incorporated within a system to be used simultaneously. As predicted, it was found that the combination of these formats did indeed increase the awareness that could be provided by the system. This prototype system was very successful in enabling the designer to combine the data of each hardware to attain a better understanding of the system environment. Within the following figure (Figure 5-28) it is illustrated that whilst LiDAR data could be used to determine the proximity and orientation of the object, the image data could be used simultaneously to assist in the identification of this object. This was observed in many instances by the designer which indicates, at least qualitatively, that the previously identified findings may apply consistently to a complete system.

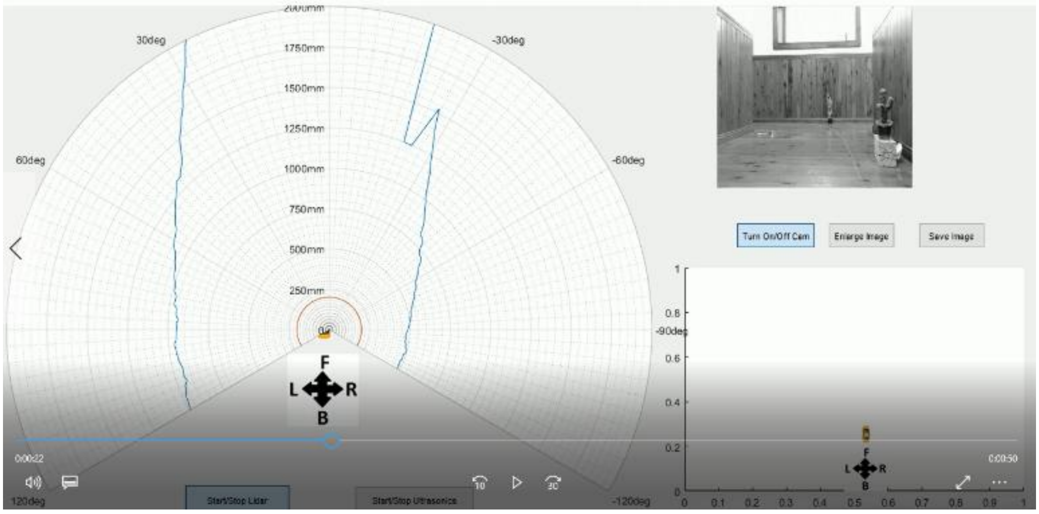

Figure 5-28: Illustration of the prototype system considered

5.4.4.2 Comparison of Systems

Although an obvious visual difference was observed between the systems' imaging window these systems appeared to present essentially the same information. For the application considered, there was no appreciable benefit in using the more data-intensive system. Various key findings identified with previous experiments were reflected upon and it was found that:

- Greyscale and colour images were similarly effective in identifying objects in view without either holding a perceivable advantage in depth perception
- There was no additional advantage of presenting all LiDAR data in determining the activity or the surroundings of the test system.
- There was no jitter observed within either system

5.4.5 Summary

This analysis was able to further support the findings previously identified using a qualitative approach. It was observed that through the combined incorporation of the reduced data formats considered the awareness of the environment could be improved. The cooperation of this data supports that these findings may be applied to complete systems with the expectation that similar conclusions will be deduced.

This qualitative analysis is not, in itself, adequate to comprehensively confirm the success of applying experimental findings. Yet it does further illustrate how these findings may be applied within tele-operation and does suggest that these findings may be quite relevant to entire systems. Although quite subjectively, this further emphasises the potential benefits that can be attained by reconsidering the amount of data that is essential (e.g. the succinct “Right” data) within the design of a tele-robotic system.

5.5 Design Methodology Evaluation

This subsection will apply the findings presented within the previous subsections to evaluate the validity of the conventional design methodology typically employed within industry. Subsequently, the findings of this section will then be considered in regards to the definition of situational awareness to suggest the design methodology indicative of this research.

5.5.1 Indications from Findings

Within all conducted experiments, both quantitative and qualitative, the relationship between the user's situational awareness and the amount of data provided has been consistently identified. The typical relationship over various environmental complexity is presented within Figures 5.29 and 5.30.

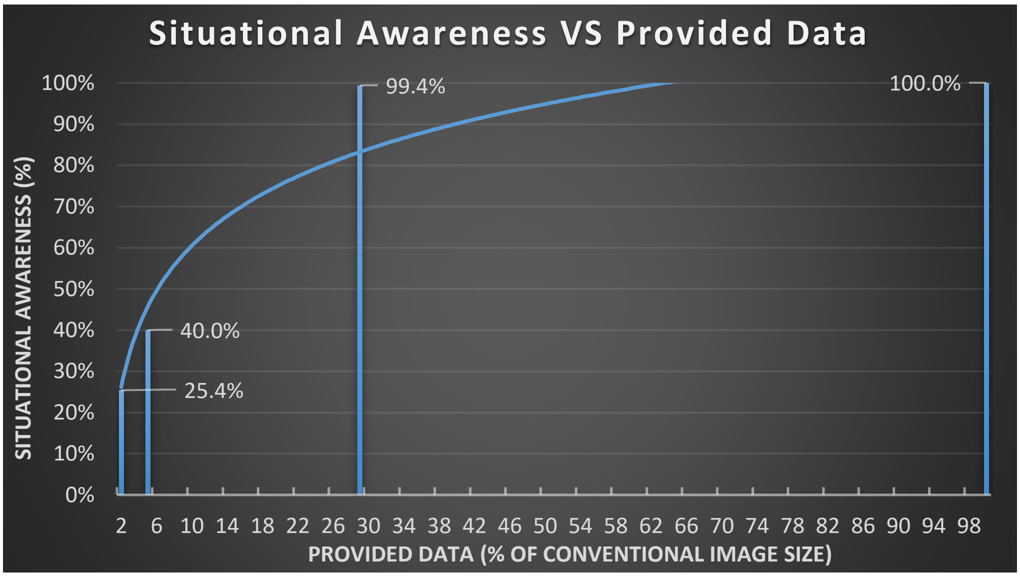

Figure 5-29: General relationship between users' situational awareness and provided data in regards to image hardware.

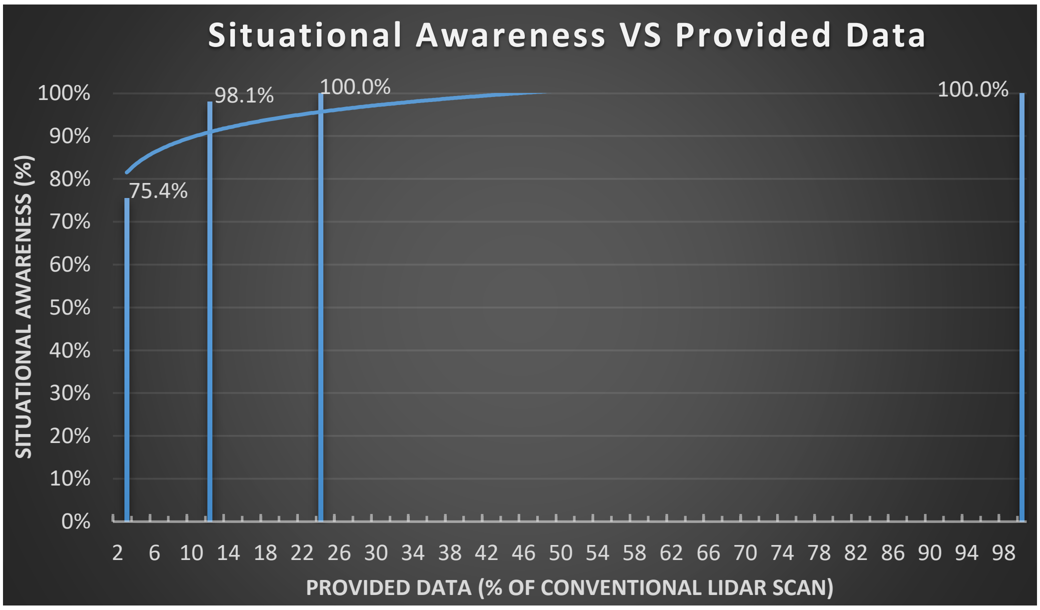

Figure 5-30: General relationship between users' situational awareness and provided data in regards to LiDAR hardware.

Current Methodology

Most simply, the situational awareness of the user is seen to increase as the system utilises more hardware data to present within its user-interface. In this regard the relationship observed reflects the viewpoint of the current design methodology typically applied by designers observed within literature. As highlighted within Section 2, this methodology suggests that designers should focus upon the development of a user-interface to present the robotic hardware data to the user with as much clarity as possible (illustrated in Figure 5-31). The employment of this approach inherently supports the mentality that all hard data should be transmitted to the user-interface to be used to most clearly present information to the user. As such, through this design methodology the “Right” data for the system, by definition, is considered to be all hardware data. Although such a focus will not inhibit the system’s functionality in instances where an ideal network is available, in other such circumstances this approach becomes inadequate. The inability of the network bandwidth to support the data transfer requirements of the system is most significantly the cause of system latency, and thus, the depletion of the real-time element of situational awareness. For instances particularly requiring the address of this element, such as low network environments, this conventional design methodology is seen to be ineffective for designers to use.

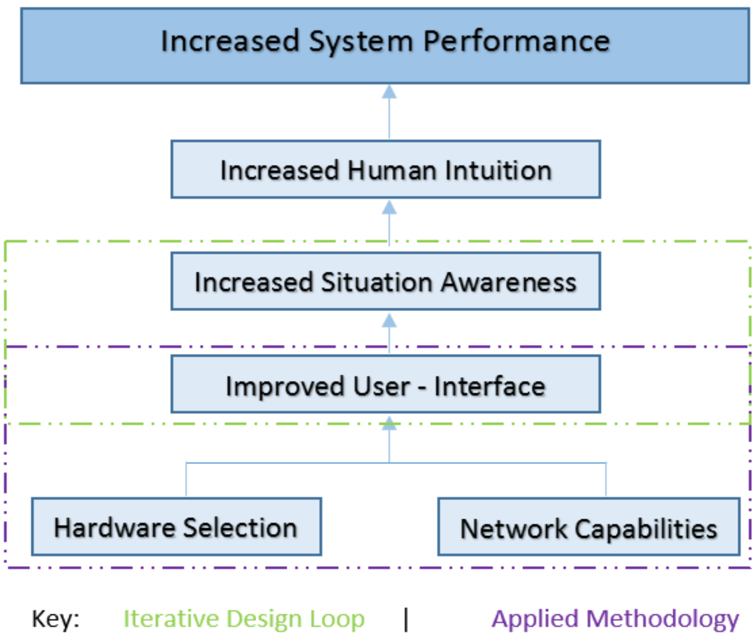

Figure 5-31: A pictorial representation of the convention methodology highlighting the focus that hardware data and network capabilities are assumed to support the user-interface

5.5.1.2 Proposed Methodology

In considering these findings in more detail it can be seen that the investigated relationship is quite a logarithmic. Such a function indicates that quite a considerable reduction in the required data transfer rate of the system (directly linked to the amount of data required within the user-interface) could be made without the loss of considerable situational awareness to the user. This highlights the potential benefit of compromising a degree of situational awareness to significantly improve the real-time capabilities of a system restricted by network bandwidth.

Applying the definition of situational awareness to tele-operation identified that all three system elements (identified below) contribute to the overall mutational awareness facilitated by the system.

- Element 1: User-Interface
- Element 2: 'Right' Hardware data
- Element 3: Real-Time Performance

Whilst the current methodology focuses predominantly on Element 1, the notion supposed by this analysis indicates that a compromise of these elements would be a more effective approach for designers of limited network systems. The relationships identified, such as those shown in Figures 5-29 and 5-30, strongly suggest that the definition of the system's "Right" data is not considered succinctly within the conventional design methodology as outlined within its definition. The misconception that the definition of "right" data is all obtained hardware data is significantly highlighted in both literature and the conducted experiments. The findings of this research suggest that by reconsidering the succinctness of the system's "right" data (element 1) a system may be designed to be significantly robust against system latency (element 3) at a small compromise of the effectiveness of the user-interface (element 2). Consequently, the proposed design methodology suggests that designers should instead aim to balance the various elements of situational awareness in order to best address the design objectives of tele-robotic systems in limited network environments (illustrated pictorially in Figure 5-32).

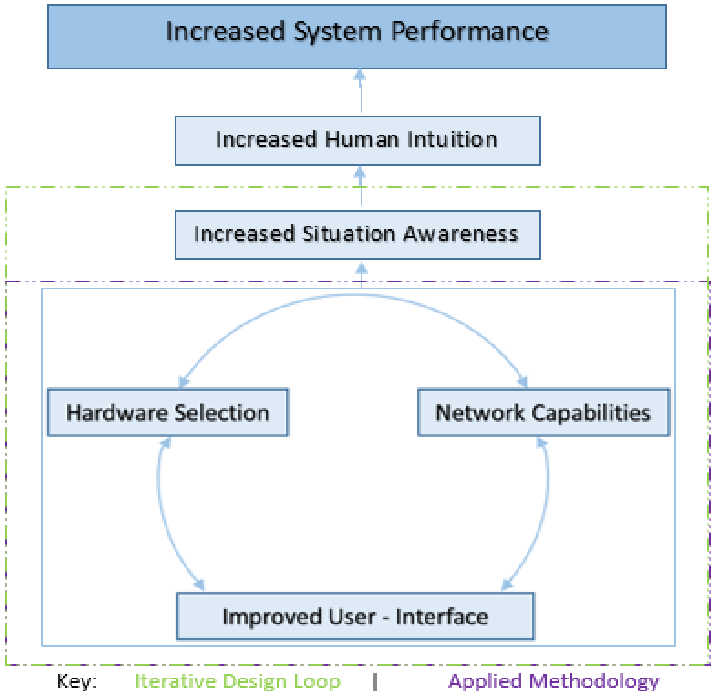

Figure 5-32: A pictorial representation of the proposed methodology highlighting the focus that all elements of situational awareness must be considered in relation to each other to determine the best compromise for the system.

As tele-operation is used in so many diverse applications, with various design objectives and network capabilities, each system will likely be unique in its definition of the "right" data. Therefore, a designer applying this methodology should first investigate this definition by considering the compromise of data presented to the user and the real time characteristics of the system that best suits the design objectives of the system. After doing so, an iterative approach should be employed to further refine the system to best achieve the design objective.

5.5.3 – Summary

In evaluating the conventional methodology typically applied within literature it is seen that the relationships identified between situational awareness and data are in fact consistent. Despite this, within limited network environments this methodology is unable to guide designers in creating a system robust to the implications of network latency associated with this environment. Evaluating the experimental findings in consideration to the definition of situational awareness it was evident that significant benefit could be attained by carefully considering the “Right” data of the system in regards to its design objectives. For a limited network environment this was of particular importance and resembled the optimal compromise for this system. It is suggested, and only suggested, that the proposed methodology would serve to better guide designers to create more effective tele-robotic systems for use within limited network environments.

6. Conclusion

6.1 Chapter Overview

The following chapter will identify how key findings of the conducted research and how these findings address the initially posed research questions of the dissertation. Furthermore the significance of discovering such conclusions will be highlighted before outlining the future work to be conducted within this field of design science within tele-operation systems.

6.2 Key Findings

The research conducted within this dissertation was successful in retaining focus on providing an in-depth investigation to the research questions initially posed. In order to holistically express the key findings of this research these will be presented as concise responses to the following research questions initially developed.

6.2.1 Research Response 1

What is the relationship that exists between the situational awareness of the user and the amount of hardware data utilised within a tele-robotic system?

From the various quantitative and qualitative analyses it was identified that as a larger amount of data was displayed the situational awareness of the user increased. Furthermore, this relationship was evidently quite logarithmic for both image and LiDAR hardware data within environments of various complexity.

6.2.2 Research Response 2

How did the data reducing formats perform in comparison to the conventional formats typically used in tele-operation systems? What trends were identified in the performance of these formats in consideration to various environmental factors?

In general, for all cases considered the amount of data required by the user to acquire situational awareness increased with environmental complexity. It was strongly evident within results that the most data-intensive format, considered to be the data configuration of typical tele-robotic systems, was very rarely required to attain full situational awareness within any environmental complexity. This notion was evident within a qualitative analysis which further supported these conclusions and their validity to be related to tele-robotic systems.

6.2.3 Research Response 3

How does this relationship relate to the current design methodology that is typically applied within literature? If this evaluation concludes that this methodology is ineffective, what does it otherwise suggest?

These various analyses conducted have identified a relationship between situational awareness and data that is, to some quite simplistic extent, consistent with the conventional design methodology. Yet through further analysis of this relationship and in considering the definition of situational awareness an alternative design methodology is suggested. This methodology aims to identify the most beneficial compromise between situational awareness elements (referred to as succinct “right” data) to optimise the system’s ability to facilitate situational awareness. Through applying such a methodology tele-robotic designers are able to design the most effective system to address design objectives whilst accounting for constraints associated with limited network environments.

6.3 Significance of Findings

The research conducted within this dissertation has substantially addressed the design issues associated with typical tele-operation systems within limited network environments. The evaluation of this design methodology has clearly highlighted its inadequacy to assist designers to develop effective tele-robotic systems in environments absent of an idea network. Subsequently an alternative design methodology was suggested, based upon the definition of situational awareness and the relationships identified, which may likely assist designers to address the design complications previously unresolved (see "Summary" of Section 5.5).

Furthermore, the investigation conducted has comprehensively highlighted both the relationship between situational awareness and data and the performance characteristics of various data reducing formats for image and LiDAR hardware. In doing so numerous factors have been determined to contribute to the effectiveness of particular formats considered or, in general, to a particular degree of data. Designers may use this information to either select these formats or develop unique formats to improve system functionality (see "Summary" of Section 5.2, 5.3 and 5.4).

6.4 Further Work

Although the evaluative approach applied was founded upon a well-established definition within the design science of tele-operation this approach employed seems to be quite unprecedented. As such there remains additional work to be conducted to further investigate the validity of the relationships identified within this research and apply these findings to various applications and designs of tele-robotic systems.

6.4.1 Further Validation of Relationships Identified

The following investigations may be conducted to further validate the relationships identified within this dissertation.

6.4.1.1 Consideration of Additional Formats

By considering a larger number of formats during experimentation the resolution of the relationship between parameters may be increased. By doing so this relationship may be identified with more accuracy by removing format performance bias and thereby further validate the relationships identified in previous chapters.

Additionally an investigation into various other image and LiDAR formats and the algorithms applied within these may assist to identify relationships between formats. This may assist designers in selecting the most effective format to employ in various applications. Within the findings of Section 5.3 it was suggested that the "minimum point survey" algorithm used within Format B may be more effective than the "even spacing" data reduction algorithms applied in Formats C and D. This is an example of how the effectiveness of format algorithms should be further investigated. Alternatively, the image formats considered may be applying an algorithm which may select the saturation value of the black and white format based upon the surveyed environment. This may impact the performance associated with this type of format to facilitate situational awareness.

6.4.1.2 Consideration of Other Hardware

In order to further identify the breadth of systems that this research applies to various other hardware should be investigated similarly to that presented within this dissertation. For example by conducting a similar investigation into the relationship between situational awareness and data with an Xbox Kinect sensor may assist in designing more effective 3D user-interface navigation systems in low network environments.

6.4.1.3 More Comprehensive Assessment of Situational Awareness

Although the jitter of the LiDAR formats was identified to effect user performance this could only be subjectively analysed through a qualitative examination. By conducting a similar evaluation yet with a complete tele-robotic system additional elements of LASSO may be applied to provide a more in-depth analysis of the relationships identified. This would likely include the assessment of jitter as a factor that effects the "Location" element of the LASSO framework.

6.4.2 Application of Format Findings and Design Methodology

To evaluate the conclusions drawn for the both the hardware considered and the design methodology suggested these findings should be applied in the design of a tele-robotic system operating with limited network capabilities. The effectiveness of these systems could then be evaluated to suggest the effectiveness of the various formats and the design methodology employed.

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8. Appendices

Appendix A: Project Specification

ENG4111/4112 Research Project
Project Specification

For: Fraser Border

Title: Design Methodology Evaluation: An Investigation into the "Right" Data for Situational Awareness of RTS-based Tele-Robotic Systems in Limited Network Environments

Major: Mechanical Engineering

Supervisors: Dr. Tobias Low, University of Southern Queensland

Enrolment: ENG4111 – ONC S1, 2016 ENG4112 – ONC S2, 2016

Project Aim: The aim of this paper is to improve the effectiveness of tele-robotic systems operating within limited network environments through the suggestion of an alternative design methodology

Programme: Issue B, 11th October 2016

1. Identify the deficiencies of the conventional design methodology to address all elements of situational awareness through an evaluative comparison applying the widely-accepted definition of situational awareness to the systems designed within literature

2. Conduct experimentation to assess the attainable situational awareness of a user provided with varying degrees of hardware information typical to RTS-based tele-operation (e.g. image and LiDAR data)

3. Examine the key relationships found within experimentation between situational awareness and the presentation of hardware data in consideration with various system parameters (e.g. environment complexity, participant demographic, etc.)

4. Explore the potential applications of these relationships in regards to the improvement in the design of a tele-robotic system operating within limited network environments

5. Draw final conclusions from these findings in regards to the suggestion of an alternative design methodology that may assist designers to consider a better approach of incorporating situational awareness within these systems

If time and resources permit, in order of significance:

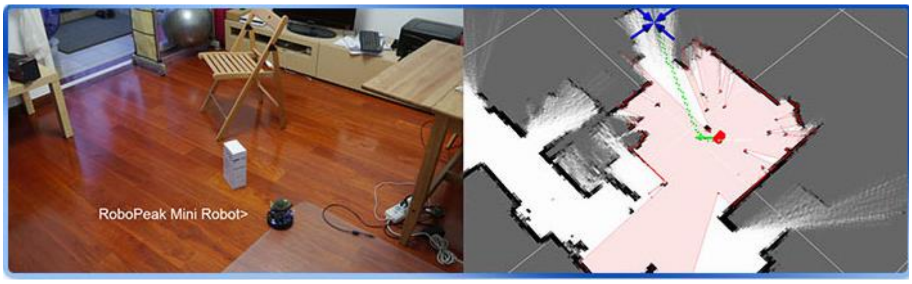
6. Further evaluate the findings identified within the experiments conducted through a qualitative analysis of the combined system (conventional VS prototype system).

Appendix B: Typical Tele-Operation Hardware Technology

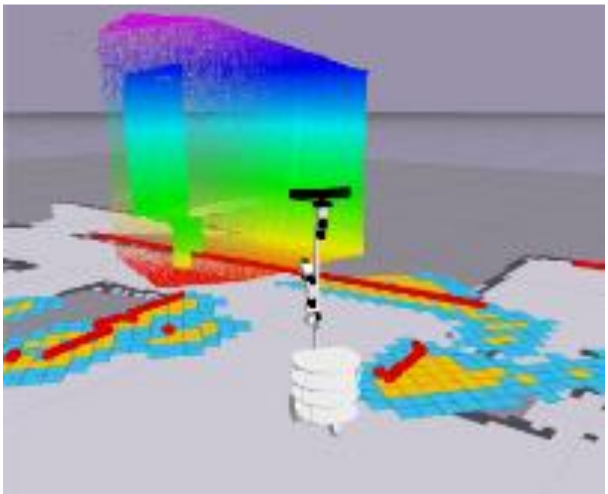
The following text provides a further examination into the use of typical hardware technologies within tele-robotic systems.

Appendix B.1 – LiDAR Hardware

Data obtained by LiDAR (Light Detection And Ranging) sensors is commonly used within these designs for visualisation applications. A LiDAR system will generate a local point cloud which can be used to precisely identify the relative distance to the nearest surface of objects within a particular range. This technology works by emitting infra-red light from a rapidly spinning platform and measuring the phase difference between the emitted and reflected light waves in a 2D or 3D plane. By considering the speed of light and the time associated with the measured phase difference, the relative distances of detected obstacles may be quantified. Due to the functional capability of precise object detection, regardless of the environmental lighting conditions, LiDAR technology is quite an effective hardware for robotic localisation systems. The use of two and three-dimensional LiDAR data point clouds is illustrated in figures below.



A 2D LiDAR Scan of Environment (Poli, 2013)



An application of 3D LiDAR Scan Data within RVIZ (Google Images 2016)

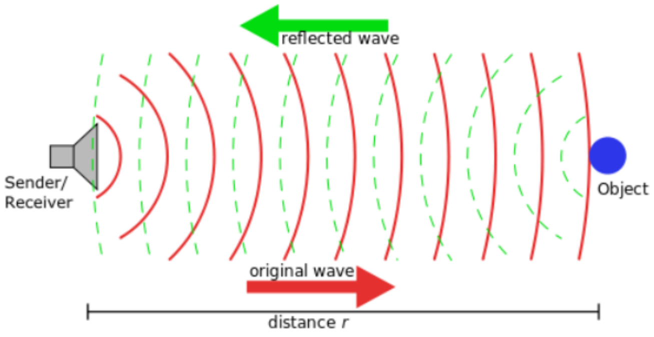
Appendix B.2 - Vision Camera

Vision cameras are typically used to provide the user with image data of the environment or the objects thereof in. Cameras may have different characteristics such as; its field of view, primary magnification, image and colour resolution and shutter rate, all of which are determined by the sensor used within the camera data. In particular applications the image data obtained may be filtered as illustrated. Other uses of cameras include the combination of multiple cameras to construct a three-dimensional image to attain depth perception of an environment.

Comparison of Various Image Filter. From right to left: colour, grayscale and black and white (Cookson, 2016)

Appendix B.3 - Ultrasonics

Ultrasonic sensors, also known as sonar transducers, may be interfaced to detect the proximity of objects using soundwaves. The transmitter of this sensor emits a high frequency, inaudible sound wave by applying a varying voltage signal to vibrate its diaphragm. A nearby object will reflect this wave and, upon vibrating the receiver diaphragm, may be detected as a voltage signal. By considering the speed of sound and the time taken for the transmitted wave to return the distance of this object may be quantified.



An Illustration of the use of soundwaves for ultrasonic distance measurements (Intro Robotics, 2016)

Appendix C: LASSO Assessment Framework

The particular terms within this assessment framework are defined and exemplified below.

Appendix C.1 – Element Identification

The terms of the LASSO assessment are defined below in particular detail.

Appendix C.1.1 Location Awareness

Defined as the user's awareness of the robot orientation in respect to environmental landmarks. It could be noted that the system would be rated a positive value in the event where the user was able to recall seeing a landmark whilst a negative value was assigned when the user was unsure of their location.

Appendix C.1.2 Activity Awareness

Defined as the ability for the user to perceive what the robot was doing to ensure that they have the ability to recognise whether the robot was performing an activity to achieve its goal. This was assessed as a positive value when the user was able to identify the actions currently being undertaken by the robot (i.e. not moving, moving, etc.).

Appendix C.1.3 Surrounding Awareness

Defined as the ability for the user to perceive the location of obstacles relative to the robot being controlled. This was assigned a positive value in the case where the user was able to predict whether, for a defined movement path, the robot would collide with an obstacle.

Appendix C.1.4– Status Awareness

Defined as the user's ability to understand the status of the robot (i.e. battery level, knocked camera, loss of a robotic part, etc.) as well as the robot's capabilities at any moment in time. Any lack of understanding between the human and the robotic action was regarded as a negative value.

Appendix C.1.5 – Overall Mission Awareness

Defined as the user's awareness of the other robotic systems current progress within the mission goals. Generally, this was hardly considered a negative value due to the single human-robot system being used.

Appendix C.2 – Element Application

The elements the LASSO framework were considered to be intuitively applied to explicitly assess participants' situational awareness (taken from referenced text).

Appendix C.2.1 Location Awareness

Location awareness was defined as a map-based concept: orientation with respect to landmarks. If an operator was unsure of his or her location, this constituted negative location awareness. Positive location awareness was recorded when the operator noted correctly that he or she had seen a particular landmark before. An example of when an operator lacked awareness of the robot's location can be inferred by his statement of, "OK, the problem with going down a dead end is you're not sure where the heck you are." When operators stated, "I've been here before. I'm sure" (and we know they are correct), we coded that statement as a positive awareness of the robot's location.

Appendix C.2.2 Activity Awareness

Activity awareness pertained to an understanding of the progress the robot was making towards completing its mission, and was especially pertinent in cases where the robot was working autonomously. The human needed to know what the robot was doing at least so that he or she understood whether the robot was doing what it needed to do to complete its part of the mission. Whenever the operator said something about the robot not moving, for example, this was interpreted as awareness of the robot's activity and thus was positive. Negative activity awareness was recorded when the operator did not understand how the robot was moving, particularly during autonomous operations. Another operator drove up a pole attached to a platform and the experimenters stopped the robot. The operator asked, "What did I do? Crash him?" While this statement could be construed as a lack of awareness of the robot's surroundings, it also indicated a lack of awareness of the robot's activities.

Appendix C.2.3 Surroundings Awareness

Surroundings awareness pertained to obstacle avoidance: someone could be quite aware of where the robot was on a map but still run into obstacles. An operator was credited with having positive surroundings awareness if he or she knew that they would hit an obstacle if they continued along their current path. When operators indicated that they were unable to move for some reason but didn't indicate why, there was no way to determine whether they had adequate or inadequate understanding of their surroundings (hence we rated this "neutral"). If the operator noted that the robot was not moving (and thus had positive activity awareness) but didn't know why and something was blocking them, we coded this as negative awareness of surroundings. An operator in “Safe” mode (a mode designed to slow and stop before bumping into obstacles) couldn’t turn right because an obstacle was in the way. While that operator knew that Safe would keep him from running into obstacles, he said, “I don’t see where I’m in contact with anything, so it’s not clear why I’m having a problem.” In other words, he was not aware that his immediate surroundings contained an obstacle. Thus, we coded this statement as indicative of a lack of awareness of the robot’s surroundings.

Appendix C.2.4 Status Awareness

Status awareness pertained to understanding the health (e.g., battery level, a camera that was knocked askew, a part that had fallen from the robot) and mode of the robot, plus what the robot was capable of doing in that mode, at any given moment. If the operator noted that the robot was not moving (positive activity awareness) and knew that there was something blocking them but didn't know why the robot wasn't moving, we coded this as negative awareness of status (in other words, the operator was unaware the robot's current mode, designed to prevent the robot to stop before bumping into obstacles, was keeping the robot from moving). In a few cases, experiment participants made statements that indicated a lack of awareness of the robot’s status. Participant 3 said, “C’mon, I know I can fit through that hole,” while being unaware that the robot was in Safe mode and it was hindering him from going through the opening. Positive understanding of robot status was coded when the operator noted that they were in a particular mode that was causing the robot to work the way it was.

Appendix C.2.5 Overall Mission Awareness

Overall mission awareness was defined as the understanding that the humans had of the progress all of the robots and other humans, as a coordinating group rather than individuals, were making towards completing the tasks involved in the mission. Since only one human and one robot performed the tasks at any given time, and since the tasks were straightforward, there were few incidents of negative mission awareness. Finally, there were a few instances in which an experiment participant stated they had lost sight of overall mission awareness. For example, one operator’s statement illustrated the cognitive toll that navigation was taking on keeping mission goals in mind: “…now that I've been sitting here driving, I've sort of lost focus on what I'm supposed to be doing, and that is find the victims. I'm just trying to navigate."

Appendix D: Matlab Scripts

The following Matlab scripts were incorporated within testing to enable the assessment of the considered formats.

Appendix D.1 - Image Formats

The image formats were applied using separate scripts to first capture and then apply the desired filters to the image. Initially a single script was used, yet this process was quite time-intensive due to awaiting the computation associated with applying these filters. Instead, an individual colour image saved and presented to later be filtered within the total group of images.

Appendix D.1.1 Image Capture Script

This script was used to capture and save the colour image format using a standard webcam. The applied naming convention enabled these images to be saved the particular viewing order of the experiment.

```
%% Image Capture Script

clear all
close all
clc

%% Single Image Capture

% Ensure that the Webcam is connected to right-most USB Port (winvideo
2)

vid=videoinput('winvideo',1);
img=getsnapshot(vid);
imshow(img);
FileName=strcat(num2str(18),'_Colour','.jpg');
imwrite(img,FileName);
pause(0.8);
```

Appendix D.1.2 Image Processing Script

This script was used to apply the filters of various formats to all saved colour images instantaneously. Furthermore, the applied naming convention enabled these formats to be saved the particular viewing order of the experiment for each image.

```
%% Image Processing Script

clear all
close all
```

```
clc
warning('off')

%% Filter Loop of Colour Images

for k = 1:20 % Number of Images to Process

    % This file name was used to identify the images of which to apply
    % the various filters to.

    ColourFileName = strcat(num2str(k),'_Colour','.jpg');

    if exist(ColourFileName, 'file')


% Colour
    Image_Colour = imread(ColourFileName);
    figure
    imshow(Image_Colour);


% Grayscale
    GreyFileName=strcat(num2str(k),'_3Grey','.jpg');
    Image_Grey = rgb2gray(Image_Colour);
    imwrite(Image_Grey, GreyFileName);
    figure
    imshow(Image_Grey);


% Black and White (default saturation of 0.5)
    BWFileName=strcat(num2str(k),'_1BW','.jpg');
    Image_BW = imbinarize(Image_Grey);
    imwrite(Image_BW,BWFileName);
    figure
    imshow(Image_BW);


% Edge Detection (automatic saturation)
    EdgeFileName=strcat(num2str(k),'_2Edge','.jpg');
    Image_Edge = edge(Image_Grey);
    imwrite(Image_Edge,EdgeFileName);
    figure
    imshow(Image_Edge);

    else
        fprintf('File %s does not exist.\n', ColourFileName);
    end

end
```

Appendix D.2 - LiDAR Formats

The various LiDAR formats were applied using separate scripts to apply the individual algorithms of these formats.

Appendix D.2.1 Format A

The full Matlab script to present all LiDAR data within a designed user-interface is included below.

```
function varargout = A_ALL(varargin)


% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @A_ALL_OpeningFcn, ...
                   'gui_OutputFcn',  @A_ALL_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT


% --- Executes just before A_ALL is made visible.
function A_ALL_OpeningFcn(hObject, eventdata, handles, varargin)


% Choose default command line output for A_ALL
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = A_ALL_OutputFcn(hObject, eventdata, handles)

% Get default command line output from handles structure
varargout{1} = handles.output;


% --- Executes on button press in LiDAR_Button.
function LiDAR_Button_Callback(hObject, eventdata, handles)

%% The following code will be run whilst the GUI's togglebuttton is ON
```

```matlab
% Reset the connection between the LiDAR and the computer
delete(instrfind({'Port'},{'COM3'}));
warning('off', 'all');

% Run the initialisation script to connect LiDAR hardware
SetupLidar;

% Create various preset variables to be plotted within
% the user-interface

theta=deg2rad(linspace(-30,239.77,682));
Robot_dist=200*ones(1,682);

i=1;
while i==1;
                % Collect LiDAR data from scan
                R=LidarScan(lidar);

                % Simple filtering of data
                for q = 1:length(R)
                    if R(q) < 50
                        R(q)=4000;
                    end
                end

                %%
                %% APPLY DATA REDUCTION ALGORITHM
                %%

                % The plot of this data to a pre-designed
                % interface.
                h = polarplot(theta,R,theta,Robot_dist);
                ax=gca;
                ax.ThetaLim = [-30 210];
                ax.ThetaTick=[-30 0 30 60 90 120 150 180 210];
                ax.ThetaTickLabel={'-120deg' '-90deg' '-60deg' '-30deg'
'0deg' '30deg' '60deg' '90deg' '120deg'};
                ax.RAxisLocation =90;
                ax.RLim=[0 2000];
                ax.RTick=[0 250 500 750 1000 1250 1500 1750 2000];
                ax.RTickLabel={'0mm' '250mm' '500mm' '750mm' '1000mm'
'1250mm' '1500mm' '1750mm' '2000mm'};
                ax.RMinorGrid = 'on';
                ax.ThetaMinorGrid = 'on';
                ax.Layer='bottom';
                pause(0.001);
                i=get(hObject,'Value');
                disp('scanning..');


end

% Disconnect LiDAR
delete(instrfind({'Port'},{'COM3'}));
DisconnectLidar;
set(handles.Start_Stop_Lidar,'Value',0);
disp('Exit LiDar Scan')
```

Appendix D.2.2 Format B

The following script was employed within the script above (within the "APPLY DATA REDUCTION ALGORITHM" section). Although simple and most likely not optimised, with the limited amount of time available it enabled results to be attained.

```
% Using 'n' as the number of points within the
% surveyed group.
n = 4;
k=1;

for i = n:n:682
    % This filter loop was quickly applied to
    % fix unexpected readings.
    if R(i-3)<40
        R(i-3)=4000;
    end
    if R(i-2)<40
        R(i-2)=4000;
    end
    if R(i-1)<40
        R(i-1)=4000;
    end
    if R(i)<40
        R(i)=4000;
    end

    % After filtering the datapoint, based upon
    % the most proximal value, was stored to later
    % be presented within the user-interface.
    [size,index] = min([R(i-3);R(i-2);...
                        R(i-1);R(i)]);

    if R(i-3)==4000 && R(i-2)==4000 && ...
            R(i-1)==4000 && R(i)==4000
        size=2000; index=n;
    end

    % Again, another filter was requried.
    SIZE(k)=size;    INDEX(k)=index + (i-n);
    k=k+1;
end

    % Recreation of the various preset variables
    % to be plotted within the user-interface
    % according to the new dimensions of the data

    for z = 1:length(INDEX)
        theta2(z)=theta(INDEX(z));
    end

    Robot_dist2=200*ones(1,170);
```

Appendix D.2.3 Format C

The following script was employed within the script above (within the "APPLY DATA REDUCTION ALGORITHM" section). Again, although simple, it enabled results to be attained.

```
% Considering 'n' to be the interval considered.
n=8;
R_all=LidarScan(lidar);
R=R_all(1:n:length(R_all));
```

Appendix D.2.4 Format D

The following script was employed within the script above (within the "APPLY DATA REDUCTION ALGORITHM" section).

```
% Considering 'n' to be the interval considered.
n=32;
R_all=LidarScan(lidar);
R=R_all(1:n:length(R_all));
```

Appendix E: Format Data Calculations

This appendix will outline the calculations and the simplifications used in their justification.

Appendix E.1 – Image Format Calculations

These calculations were made by considering that the image frame size presented within the user-interface of RTS-based systems were approximately A8. This approximation was made by measuring the system developed for the qualitative analysis conducted within this dissertation (60 x 60 mm) and assuming that this was approximately equivalent to the size of A8 (52 x 74 mm). Although Matlab was initially used and, with more time, this may have been used to provide a more accurate figure this was not feasible for such a simplified illustrative calculation. Using the generalisation outlined by Shutha (2016) the data requirement of this colour was approximated as 1.5 megabytes. This was converted to kilobytes (1536) and the simplification of calculating other formats' size according to their respective bits / pixel approximations was used.

Thus, in absolute terms:

$$Black\ and\ White = 1536 * \frac{1}{24} = 64kB.$$

$$Edge = 1536 * \frac{1}{24} = 64kB.$$

$$Greyscale = 1536 * \frac{1}{3} = 512kB.$$

In cumulative terms:

$$Black\ and\ White = 64kB.$$

$$Edge = 64 + 64 = 128kB.$$

$$Greyscale = 64 + 64 + 512 = 640kB.$$

$$Colour = 64 + 64 + 512 + 1536 = 2176kB.$$

Appendix E.2 – LiDAR Format Calculations

These calculations were made in consideration to the SCIP2.0 datasheet of the LiDAR hardware (33). Within the communication protocol (SCIP2.0) it was identified that, at most, a four-character encoding technique would be applied to convert the characters into ASCII format to then by transferred to the host. Thus, this protocol would therefore require 6 bits for each character of each LiDAR reading. In considering this, and that the each LiDAR scan would attain 682 readings, the amount of data required for each scan of the conventional format (Format A) could be approximated.

$$Format\ A = 6\frac{bits}{character} * 4\frac{characters}{reading} * 682\frac{readings}{scan} = 16368\frac{bits}{scan}.$$

By considering the fractional comparison between these other formats to Format A their respective data requirements could also be approximated. It should be noted that this data comparison was considered for each scan of these formats.

Thus, in absolute terms:

$$Format\ A = 16368\ bits.$$

$$Format\ B = 16368 * \frac{170}{682} = 4080bits.$$

$$Format\ C = 16368 * \frac{86}{682} = 2064bits.$$

$$Format\ D = 16368 * \frac{22}{682} = 528bits.$$

In cumulative terms:

$$Format\ D = 528bits.$$

$$Format\ C = 528 + 2064 = 2592bits.$$

$$Format\ B = 528 + 2064 + 4080 = 6672bits.$$

$$Format\ A = 528 + 2064 + 4080 + 16368 = 23040bits.$$

Appendix F: Hardware Datasheets

This appendix will provide the data sheets of the hardware used within these experiments.

Appendix F.1 – Imaging Hardware

The datasheet for the Logitech webcam used is provided below.

Face-to-face communication for ultimate

Cisco Jabber™ collaboration

The Logitech C920-C Webcam

The Logitech C920-C Webcam, designed exclusively for Cisco®, is the professional webcam that seamlessly integrates with Cisco solutions to deliver true-to-life HD 1080p[1] quality video. With a 78-degree field of view, UVC H.264 encoding and omnidirectional mics, the C920-C brings high-quality desktop face-to-face collaboration to UC.

Features:

- HD 1080p[1] video at up to 30 frames per second
- UVC H.264 encoding technology
- 78-degree field of view with true widescreen
- Logitech RightLight™ 2 technology and autofocus
- Omnidirectional dual stereo microphones
- Convenient privacy shutter
- Multiple mounting options
- USB plug-and-play set up
- Cisco® Compatible[2]

CISCO Compatible

Logitech

UC for Real People

Appendix F.2 – LiDAR Hardware

The datasheet for the URG-04LX Hokuyo laser scanner used is provided below.

Date :2009.8.20

Scanning Laser Range Finder URG-04LX-UG01 (Simple-URG)

Specifications

Svmbol	Amended Reason	Pages	Date	Corrector	Amendment No

Approved by	Checked by	Drawn by	Designed by	Title	Scanning Laser Range Finder URG-04LX-UG01 Specifications	
MORI	MAEDA	YAMAMOTO	MORI	Drawing No.	C-42-3635	1/4

1. General

URG-04LX-UG01 is a laser sensor for area scanning. The light source of the sensor is infrared laser of wavelength 785nm with laser class 1 safety. Scan area is 240° semicircle with maximum radius 4000mm. Pitch angle is 0.36° and sensor outputs the distance measured at every point (683 steps). Laser beam diameter is less than 20mm at 2000mm with maximum divergence

3. Specifications

Product Name	Scanning Laser Range Finder
Model	URG-04LX-UG01
Light source	Semiconductor laser diode (λ=785nm), Laser safety Class 1 (IEC60825-1)
Power source	5V DC ±5% (USB buspower)
Current consumption	500mA or less (Rush current 800mA)
Detection distance	20mm ~ 4000mm
Accuracy	Distance 20mm ~ 1000mm : ±30mm* Distance 20mm ~ 4000mm : ±3% of measurement*
Resolution	1 mm
Scan Angle	240°
Angular Resolution	0.36°
Scan Time	100msec/scan
Interface	USB Version 2.0 FS mode (12Mbps)
Ambient (Temperature/Humidity)	-10 ~ 50°C / 85% or less (without dew and frost)
Preservation temperature	-25 ~ 75°C
Ambient Light Resistance	10000Lx or less
Vibration Resistance	Double amplitude 1.5mm 10 ~ 55Hz, 2 hours each in X, Y and Z direction, and 98m/s² 55Hz ~ 150Hz in 2 minutes sweep, 1 hours each in X, Y and Z direction
Impact Resistance	196 m/s², 10 times each in X, Y and Z direction
Protective Structure	Optics : IP64 Case : IP40
Insulation Resistance	10MΩ for DC 500Vmegger
Weight	Approx. 160 g
Case	Polycarbonate
External dimension (W×D×H)	50×50×70mm (Reference design sheet No.3502)

*Under standard test conditions with white Kent sheet 70mm×70mm

4. Quality reference value

Operating Vibration resistance	19.6m/s², 10Hz ~ 150Hz with 2 minutes sweep, 0.5 hours each in X, Y and Z direction
Operating Impact resistance	49 m/s², 10 times each in X, Y and Z direction
Angular Speed	360 deg/s
Angular Acceleration	π/2 rad/s²
Life	5 years (Varies depending upon the operating conditions)
Sound level	25db or less (at 300mm)
FDA	This product complies with 21 CFR parts 1040.10 and 1040.11. (Accession Number 0521258-002)

Title	URG-04LX-UG01 Specification	Drawing No	C-42-3635	3/4

5. Interface

CN USB-mini (5 Pin)
Cable is not included. Use commercially available compatible unit.

Note:
Refer specifications number C-42-3320B for communication protocol (SCIP2.0).

6. Notice:
Supply voltage is DC 5Volts. Sensor will damage if high voltage is supplied.

USB buspower may not be sufficient during the start up of URG-04LX-UG01 in some PCs.
Use the auxiliary cable supplied with the sensor to avoid the problem.

The maximum data step is 683 points. Sensor's angular resolution is 0.3515625º (360º /1024 steps) and angular range is 239.765625º ((683-1)× 360/1024)

Angular resolution can be specified form the host. Read communication protocol specification (No C-42-3320B) for details.

USB driver is communication device class (CDC) supported by standard operating system. The device is connected as a COM port with the same utility.

Plug and play function is not supported.

Title	URG-04LX-UG01 Specification	Drawing No	C-42-3635	4/4

Appendix G: Experiment Materials

The following appendix will outline the various materials or documents created for use within the conducted experiments.

Appendix G.1 – Experiment Environments/Scenarios

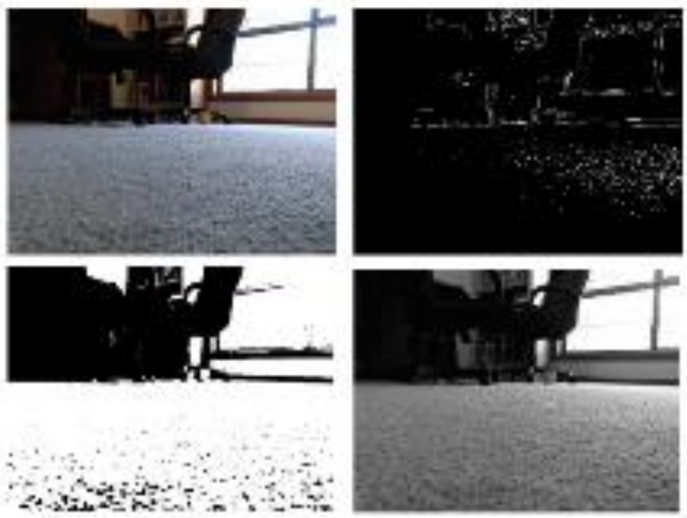
The following environments/scenarios were created to test the various formats within Experiment 1 and 2.

Appendix G.1.1 – Image Environments

The following images were used within Experiment 1 to assess the situational awareness of participants. It should be noted that due to size restrictions one image from each of the categories of environmental complexity considered is presented.

Low Complexity Environment

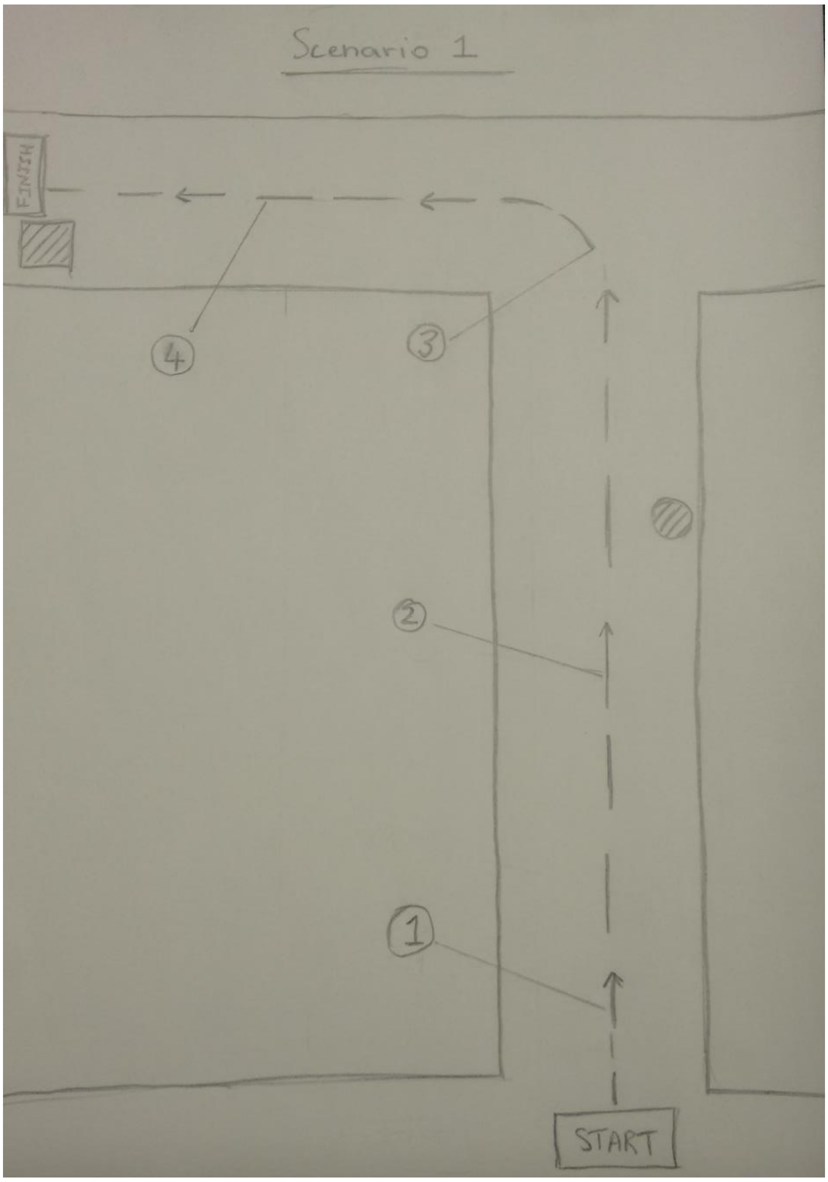
Moderate Complexity Environment



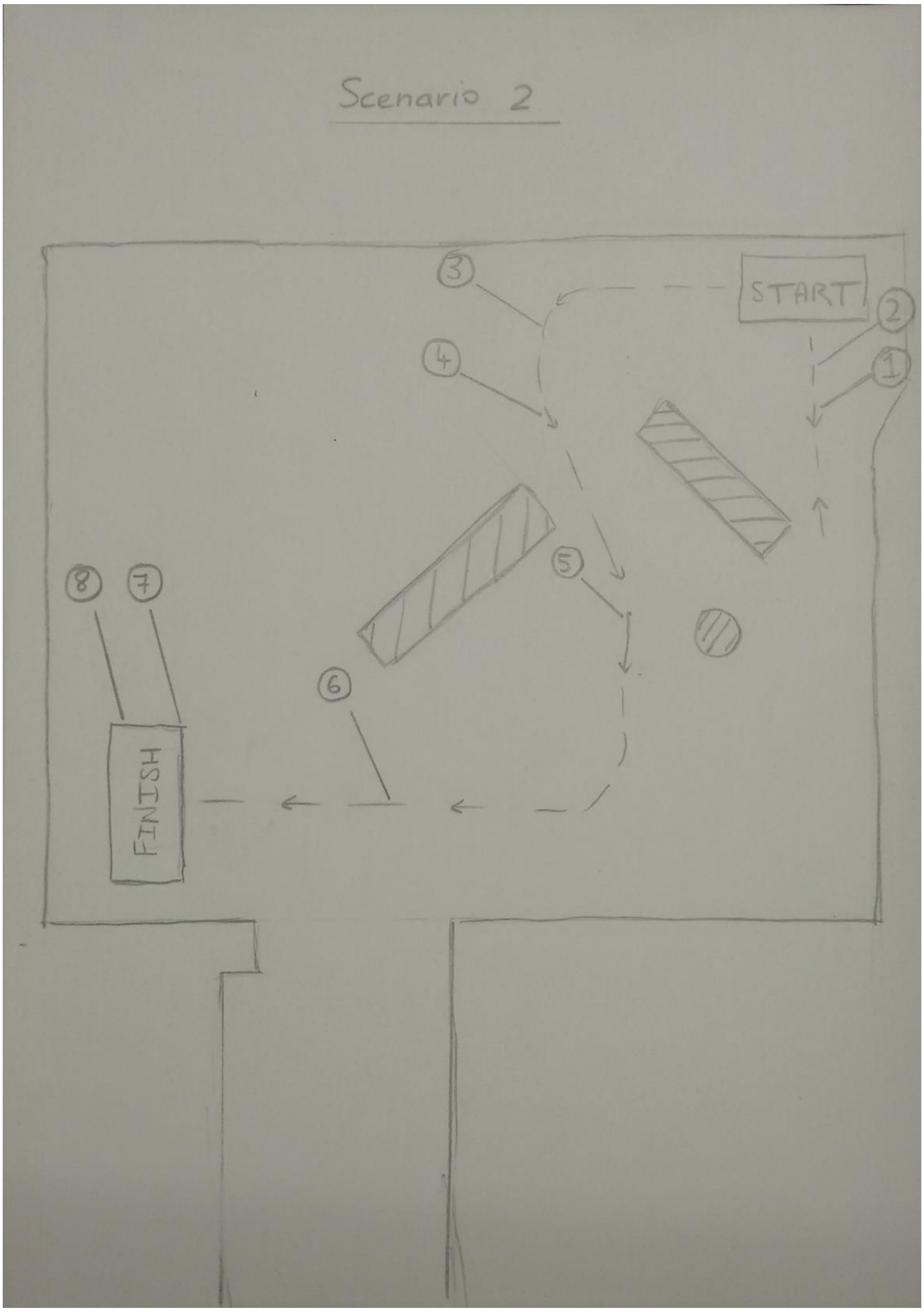
High Complexity Environment

Appendix G.1.2 – Experiment LiDAR Environments

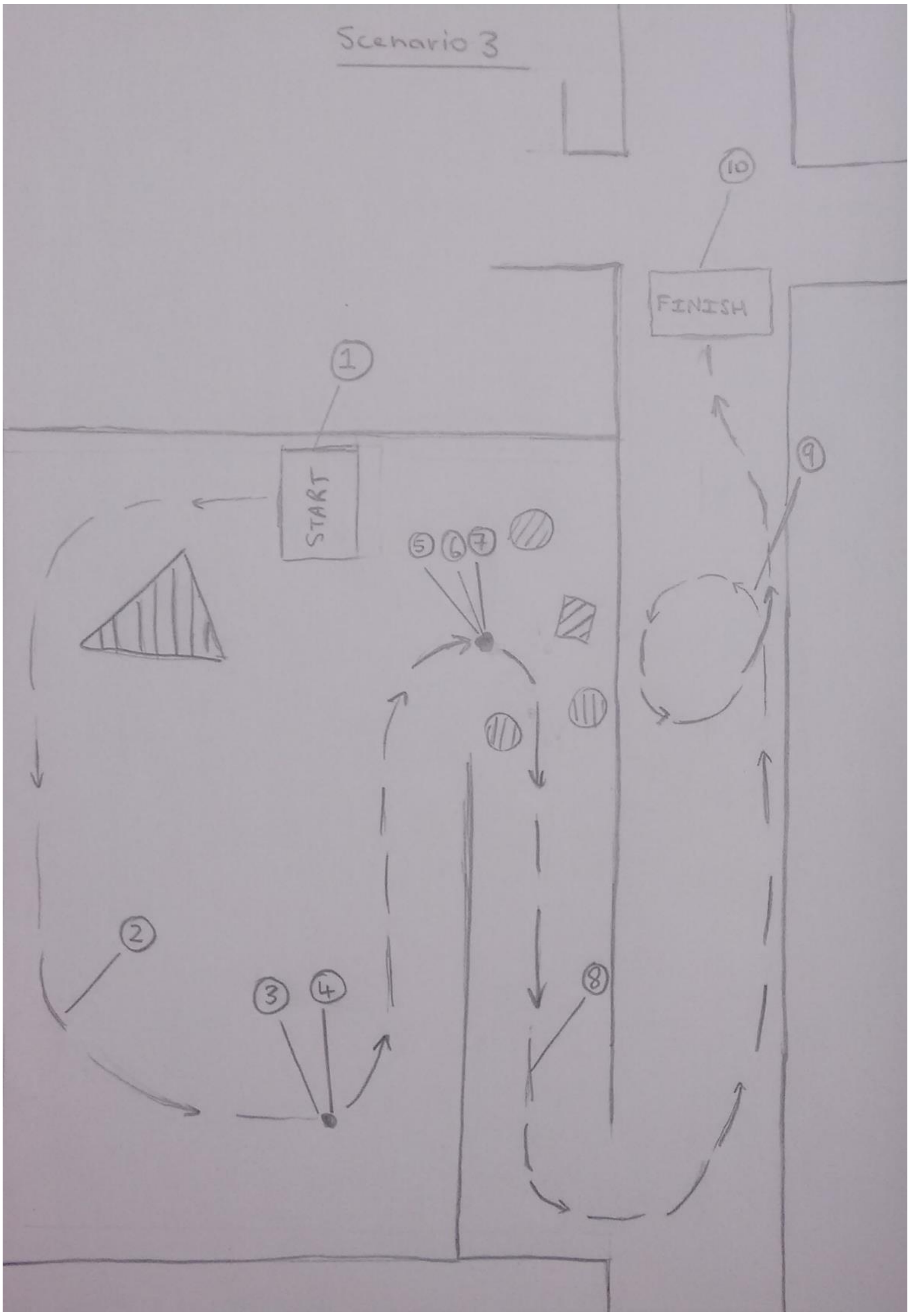
The general outline of the LiDAR experiment for each scenario considered is provided with the use of the following sketches. The numbers identified within each sketch indicate at which instance of the scenario this particular question was posed to participants. These questions were identified within the LiDAR response sheet presented in Appendix G.4.



Low Complexity Environment



Moderate Complexity Environment



High Complexity Environment

Appendix G.2 – General Experiment Documents

The following experimental documents were used generally within all conducted experimentation.

Appendix G.2.1 Dissertation Informed Consent Form

This form was signed by participants to enable the publication of the results obtained within experimentation within this dissertation.

INFORMED CONSENT PROFORMA

Informed Consent Form [Bachelor of Engineering (Hons)] Dissertation Research

Please complete this form after you have read the Information Sheet and listened to an explanation about the research.

Project Title: Design Methodology Evaluation: Tele-Operated Robots in Limited Network Environments

Researcher: Fraser Border

Thank you for your interest in taking part in this research. Before you agree to take part, please await further explanation.

If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you to decide whether to join in. If you would like to be given a copy of this Consent Form to keep please ask the researcher prior to the commencement of the experiment.

Participant's Statement

I agree that:

- I have read the notes written above and the Information Sheet, and understand what the study involves.
- I understand that the information I will submit will be published as results within a dissertation. Confidentiality and anonymity will be maintained and it will not be possible to identify me from any publications.
- I understand that if I decide at any time that I no longer wish to take part in this project, I can notify the researcher involved and withdraw immediately.
- I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

Signature: Date:

Appendix G.2.2 Participant Initial Survey

Participants' demographic details obtained through this initial survey were considered within the analysis of both Experiment 1 and 2.

Initial Survey

General Details:

Name: Gender: M / F

D.O.B.: Occupation:

Experimental Details:

1. Have you ever used LiDAR equipment? Y/N
If yes please indicate how often:

2. Do you generally use image filters such as grayscale, black and white, edge detection, etc? Y/N
If yes please indicate how often:

3. Do you partake in computer games monthly? Y/N
If yes please indicate how often:

4. Do you recognise all objects that are being used in this experiment? Y/N
If no please indicate which object:

5. How would you rate yourself on your ability to judge distances on a scale of 1 to 5 (1 being terrible and 5 being extremely well)?

1 2 3 4 5

Appendix G.3 - Image Study Response Sheet

This sheet was used by participants for the recording of results for Experiment 1.

1. Image Study

Purpose of Study:

Evaluation:

How did you find using each of the formats (edge detection, black and white, greyscale and colour)?

Which was the best and why?

If colour could not be given, which of the other formats would be next preferred?

Any extra comments you wish to make leave here.

Appendix G.4 - LiDAR Study Response Sheet

This sheet was used by participants for the recording of results for Experiment 2.

2. LiDAR Study

Purpose of Study:

The purpose of this study is to assess your ability to attain situational awareness of the environment using various amounts of LiDAR images.

Study Instructions:

The participant will watch a robot follow a particular path using the LiDAR images collected by the robot. Four videos will be watched, each with successively more LiDAR data, and various questions will be asked throughout the viewing. These questions will be about the robot's location, activity and surroundings.

Possible Activity Answers:

The robot may be:

- driving forward
- driving backward
- stationary
- turning left
- turning right
- driving back and forward repeatedly

Results:

Scenario 1:

1. Is the robot entering a room or a hallway?

2. Is there an obstacle? Which side did this obstacle pass the robot?

3. What is the robot doing now?

4. Will the robot hit the upcoming obstacle?

Scenario 2:

1. Will the robot fit through this passage?

2. What is the robot doing now?

3. What is the robot doing now?

4. Will the robot fit through this passage?

5. If there was an obstacle near the robot, where would it be (degrees)? Also, how close is the robot to it (roughly)?

6. What is the robot doing now?

7. How close is the wall in front of the robot (0 degrees)

8. How close is the robot to the wall to the left of it (90 degrees)?

<u>Scenario 3:</u>

1. Will it fit through this passage?

2. What is the robot doing right now?

3. How close to the wall on the right?

4. How close to wall in front?

5. How many objects are in view?

6. How close is the closest object?

7. What orientation is this object (degrees)?
8. What does this entity look like?
9. What is the robot doing now?
10. What type of intersection is this?

Evaluation:

How did you find using each of the different formats (A, B, C and D)?

____

____

____

Which was the best and why? Or were they similar?

____

____

____

Which was preferred? If A was preferred, what would be the next preferred?

____

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____

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Any extra comments you wish to make leave here.

____

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Appendix H: Experimental Results

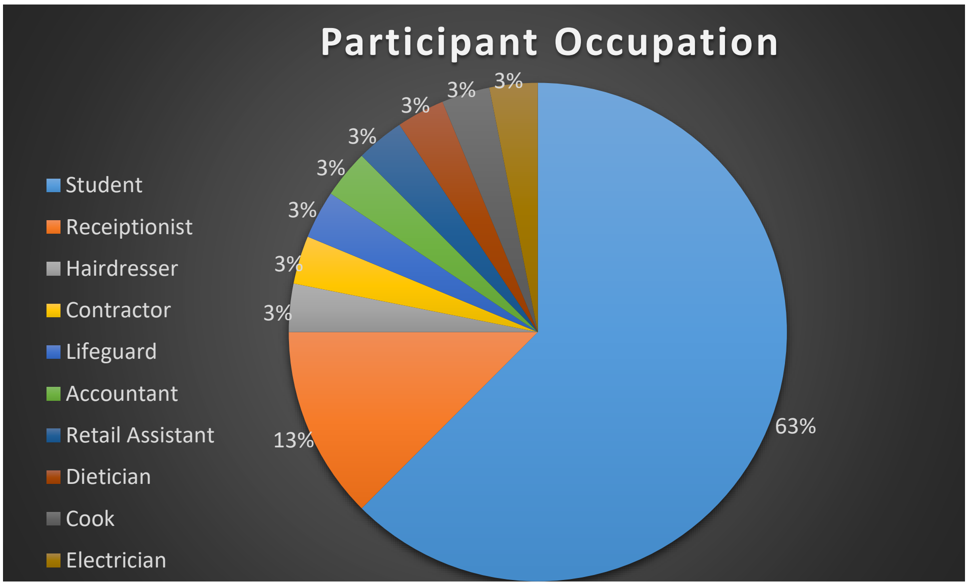
This appendix presents a conclusive summarised of the results obtained from the conducted experiments.

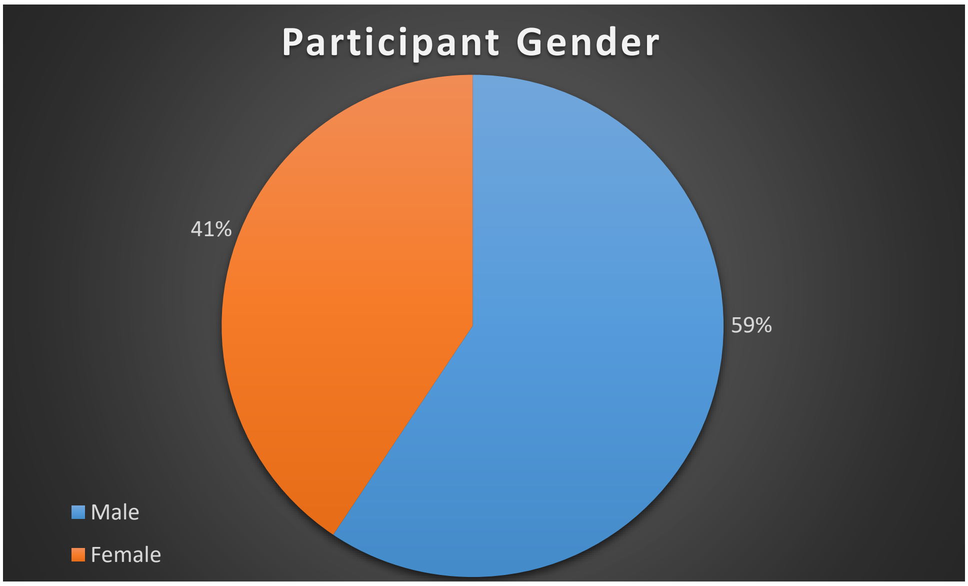
Appendix H.1 – General Results

The following graphs were creating using the data obtained within the initial survey questionnaire.

Appendix H.1.1 Demographic of Participants

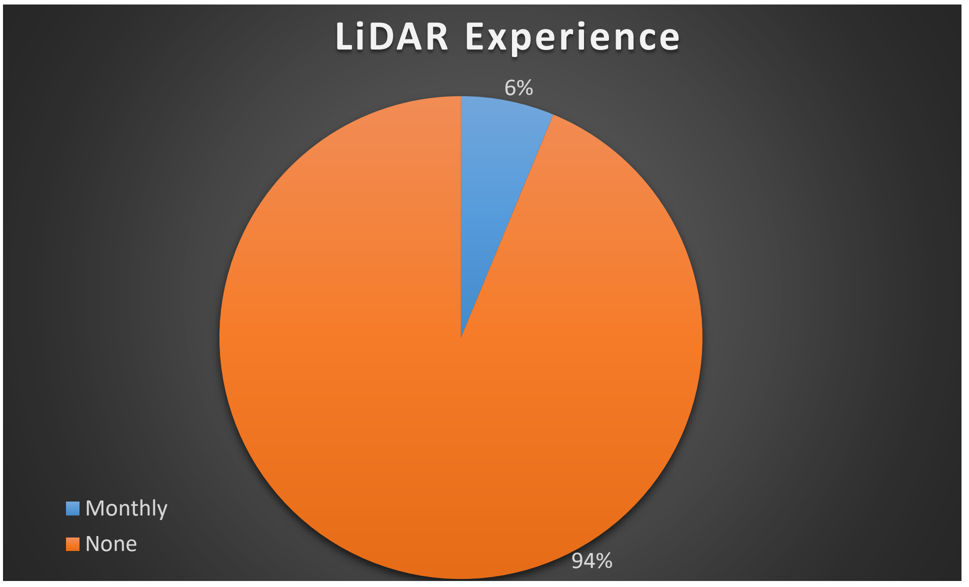
These graphs represent the demographic of participants that were assessed within experimentation in regards to occupation and gender.

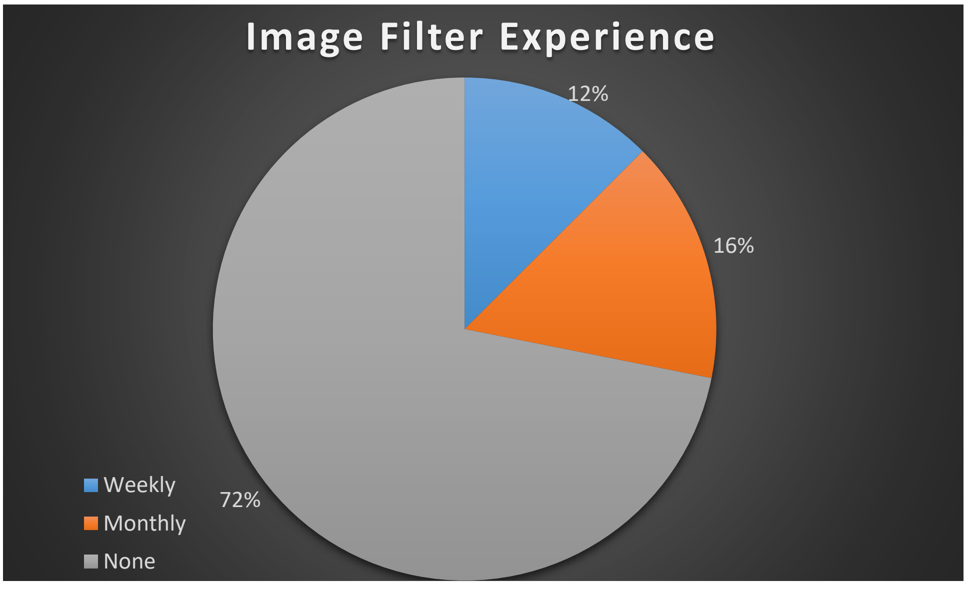


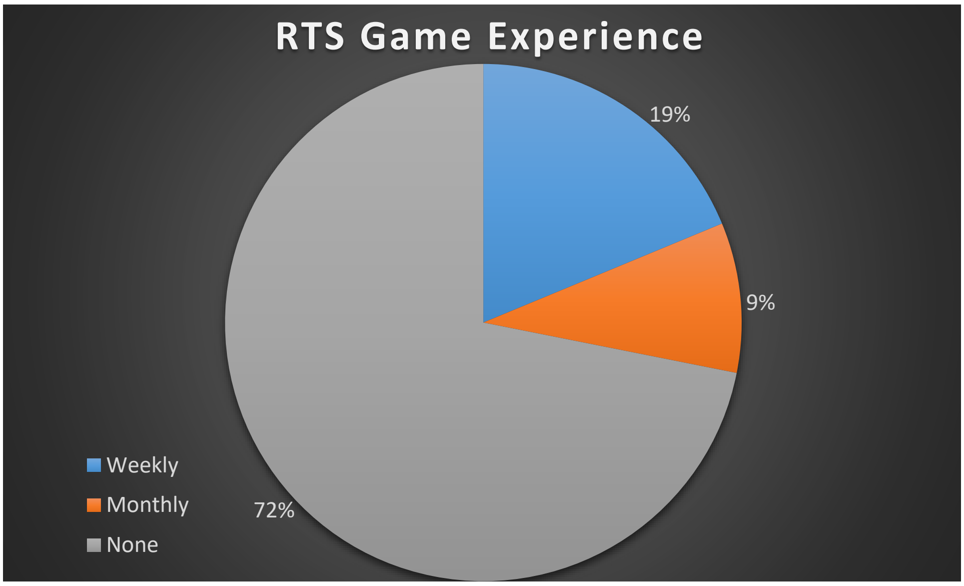


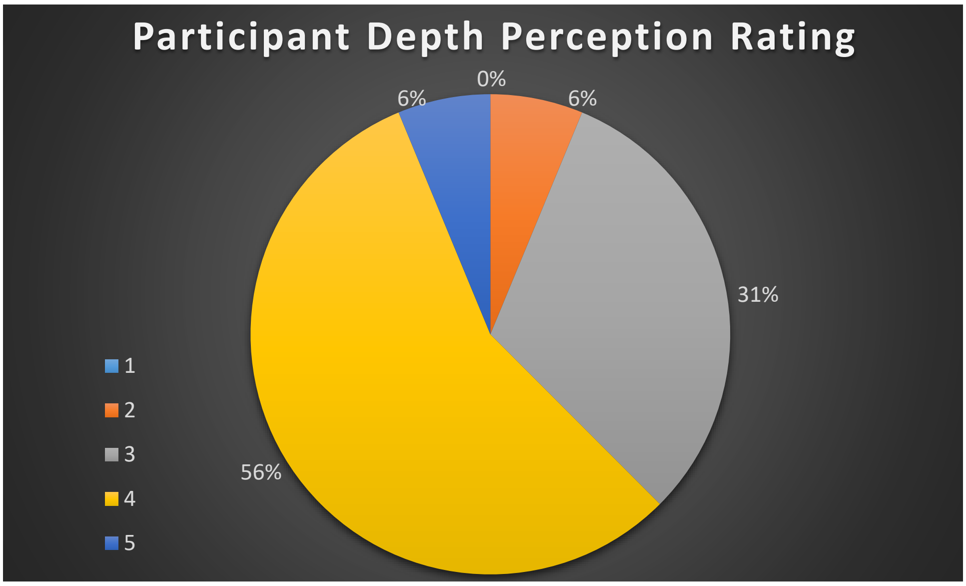
Appendix H.1.2 Experience of Participants

These graphs represent the demographic of participants that were assessed within experimentation in regards to experience to LiDAR technology, image filters, RTS-based gaming and self-determined depth perception rating using a Likert Scale (1 to 5).






RTS Game Experience
19%
9%
72%
Weekly
Monthly
None


Participant Depth Perception Rating
6%
0%
6%
31%
56%
1
2
3
4
5

Appendix H.2 - Experiment 1 Results

Due to the results these are summarised below. The file used within this analysis is included with the softcopy submission.

Experiment 1 - Image Study										
Part No	LOW		MODERATE		HIGH		OVERALL		OVERALL	
	Points	%	Points	%	Points	%	Points	%	Points	%
1	54	90%	52	87%	48	80%	302	84%	11	73%
2	54	90%	50	83%	42	70%	280	78%	12	80%
3	55	92%	54	90%	48	80%	307	85%	11	73%
4	58	97%	54	90%	57	95%	337	94%	11	73%
5	55	92%	46	77%	46	77%	285	79%	11	73%
6	55	92%	43	72%	44	73%	273	76%	7	47%
7	57	95%	55	92%	43	72%	296	82%	9	60%
8	55	92%	45	75%	44	73%	277	77%	15	100%
9	51	85%	42	70%	41	68%	258	72%	11	73%
10	53	88%	47	78%	45	75%	282	78%	10	67%
11	55	92%	51	85%	50	83%	307	85%	14	93%
12	50	83%	39	65%	38	63%	242	67%	10	67%
13	54	90%	46	77%	41	68%	269	75%	12	80%
14	54	90%	40	67%	36	60%	242	67%	5	33%
15	53	88%	52	87%	47	78%	298	83%	13	87%
16	55	92%	51	85%	46	77%	295	82%	12	80%
17	54	90%	52	87%	43	72%	287	80%	12	80%
18	53	88%	41	68%	39	65%	252	70%	14	93%
19	56	93%	53	88%	47	78%	303	84%	14	93%
20	57	95%	46	77%	44	73%	281	78%	13	87%
21	54	90%	52	87%	40	67%	278	77%	13	87%
22	54	90%	49	82%	43	72%	281	78%	13	87%
23	54	90%	50	83%	48	80%	298	83%	14	93%
24	52	87%	46	77%	38	63%	258	72%	11	73%
25	58	97%	48	80%	48	80%	298	83%	11	73%
26	53	88%	44	73%	44	73%	273	76%	14	93%
27	57	95%	46	77%	48	80%	293	81%	13	87%
28	54	90%	48	80%	39	65%	267	74%	12	80%
29	57	95%	53	88%	48	80%	307	85%	12	80%
30	60	100%	57	95%	43	72%	303	84%	14	93%
31	59	98%	55	92%	48	80%	313	87%	15	100%
32	58	97%	52	87%	52	87%	318	88%	15	100%

Appendix H.3 - Experiment 2 Results

Due to the results these are summarised below. The file used within this analysis is included with the softcopy submission.

Experiment 2 - LiDAR Study												
Part. No.	Scenario 1				Scenario 2				Scenario 3			
	D	C	B	A	D	C	B	A	D	C	B	A
1	100%	100%	100%	100%	88%	100%	100%	100%	56%	100%	100%	100%
2	100%	100%	100%	100%	75%	88%	100%	100%	56%	100%	100%	100%
3	100%	100%	100%	100%	100%	100%	100%	100%	67%	100%	100%	100%
4	75%	100%	100%	100%	100%	100%	100%	100%	78%	100%	100%	100%
5	100%	100%	100%	100%	100%	100%	100%	100%	56%	100%	100%	100%
6	100%	100%	100%	100%	50%	88%	100%	100%	78%	100%	100%	100%
7	100%	100%	100%	100%	88%	100%	100%	100%	56%	100%	100%	100%
8	100%	100%	100%	100%	88%	100%	100%	100%	78%	100%	100%	100%
9	100%	100%	100%	100%	100%	100%	100%	100%	56%	100%	100%	100%
10	100%	100%	100%	100%	100%	100%	100%	100%	67%	89%	100%	100%
11	100%	100%	100%	100%	63%	100%	100%	100%	67%	100%	100%	100%
12	100%	100%	100%	100%	63%	88%	100%	100%	44%	100%	100%	100%
13	100%	100%	100%	100%	88%	100%	100%	100%	67%	100%	100%	100%
14	100%	100%	100%	100%	50%	100%	100%	100%	67%	100%	100%	100%
15	100%	100%	100%	100%	88%	100%	100%	100%	67%	100%	100%	100%
16	100%	100%	100%	100%	100%	100%	100%	100%	67%	100%	100%	100%
17	100%	100%	100%	100%	75%	88%	100%	100%	78%	100%	100%	100%
18	100%	100%	100%	100%	100%	100%	100%	100%	67%	89%	100%	100%
19	100%	100%	100%	100%	88%	100%	100%	100%	56%	100%	100%	100%
20	75%	100%	100%	100%	75%	100%	100%	100%	56%	100%	100%	100%
21	75%	75%	100%	100%	88%	100%	100%	100%	67%	100%	100%	100%
22	100%	100%	100%	100%	100%	100%	100%	100%	67%	67%	100%	100%
23	75%	100%	100%	100%	75%	100%	100%	100%	56%	100%	100%	100%
24	75%	100%	100%	100%	88%	100%	100%	100%	67%	100%	100%	100%
25	75%	100%	100%	100%	50%	88%	100%	100%	56%	100%	100%	100%
26	75%	100%	100%	100%	100%	100%	100%	100%	67%	100%	100%	100%
27	75%	75%	100%	100%	63%	100%	100%	100%	44%	100%	100%	100%
28	75%	100%	100%	100%	100%	100%	100%	100%	56%	100%	100%	100%
29	75%	100%	100%	100%	63%	100%	100%	100%	56%	89%	100%	100%
30	75%	100%	100%	100%	100%	100%	100%	100%	67%	100%	100%	100%
31	75%	100%	100%	100%	63%	100%	100%	100%	67%	100%	100%	100%
32	75%	100%	100%	100%	88%	100%	100%	100%	56%	100%	100%	100%