Modeling Human Workload in Unmanned Aerial Systems

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ABSTRACT

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Unmanned aerial systems (UASs) often require multiple human operators fulfilling diverse roles for safe correct operation [4, 5, 10]. Although some dispute the utility of minimizing the number of humans needed to administer a UAS [11], minimization remains a long-standing objective for many designers. Reliably designing the human interaction, autonomy, and decision making aspects of these systems requires the use of modeling. We propose a conceptual model which models human machine interaction systems as a group of actors connected by a network of communication channels. We also propose a workload taxonomy derived from a review of the relevant literature which we then apply to the conceptual model. We present a simulation framework implemented in Java, with an optional XML model parser, which can be analyzed using the Java Pathfinder (JPF) model checker. The simulator produces a workload profile over time for each human actor in the system. We conducted case studies by modeling two different UAS. Wilderness search and rescue using a UAV (WiSAR) and UAS integration into the national air space (NAS). The results of these case studies, while inconclusive, are consistent with known workload events and the simple workload metric presented by Wickens [12].

Keywords: human workload, unmanned aerial system, uas, national air space, unmanned aerial vehicle, modeling human machine interaction

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Chapter 1

Introduction and Overview

Most existing Unmanned Aerial Systems (UASs) require two or more human operators[5, 10]. Standard UAS practice is to have one human to control the aerial vehicle and another to control the camera or other payloads. In addition to this a third human is often responsible for overseeing task completion and interfacing with the command structure. Although some argue persuasively that this is a desirable organization [11], there is considerable interest in reducing the required number of humans and reducing human workload using improved autonomy and enhanced user interfaces [4, 8, 9].

Our initial proposal was to move directly into software development. Given our prior experience with UAS-enabled Wilderness Search and Rescue (WiSAR) [8] we proposed to construct a UAS for that domain. During the requirement gathering and design steps of this project it became clear just how complex the system was. While we had prototypes of almost all the functionality we had no way of measuring if the system itself would meet the requirements. On top of that the limited time and resources meant that we would only get one shot at creating this system. Because of this we decided to take a more conservative approach. Instead of blindly pressing forward with the software development we decided that it would be more beneficial to validate our designs through modeling.

System modeling is not a new approach. There are many different modeling languages each of which is designed to perform specific types of validation [1]. While it was possible to extend an existing modeling language to support our goals much like Bolton and Bass have done with EOFM []. We chose to create our own modeling language from scratch. We chose this direction for a few reasons not the least of which being our lack of experience with other modeling languages. Instead of learning a new language we desired to use a language and model checker we were already familiar with, Java and Java Pathfinder. Also, a common denominator among system modeling languages is the focus on tasks. This is ideal for modeling an existing system, however, for new systems these detailed tasks are vague or undefined [**?**]. We needed to be able to model and validate these tasks without needing to understand their details. We also desired to measure human workload as a consequence of the system design, something which is relatively new to human machine interface validation [1].

Our modeling language allows models to be implemented in Java simply by implementing a core set of Java interfaces which comply with our conceptual model. These models are then processed in a simulation framework which is run inside JPF for the model checking and metric gathering. The conceptual model underneath the modeling framework consists of Directed Role Graphs (DiRGs) and Directed Team Graphs (DiTGs) which focus on the key Actors within the system and the communication channels which they use to perform their work. The model itself is defined as a state machine. This common approach to modeling allows us a flexible approach to abstraction while still allowing us to gather workload data and lends itself well to model checking.

We chose to base our workload measurements off of multiple resource theory [**?**] with ties to queing theory [**?**] and operator fan-out theory []. By relating these theories to the different operational components of the model we can obtain a quantitative measure of an Actors workload for each time-step in the system.

We performed two case studies, one for WiSAR and another representing the introduction of a UAS into the National Air Space (NAS). We chose WiSAR because of the host of modeling information available to us [2]. We chose to model a UAS operating within the NAS because of the current interest in the subject [**?**] and the decided lack of modeling information available to us which required us to use high levels of abstraction. The results of the case studies show that the modeling language we developed is capable of accurately modeling UASs. They also demonstrate the ability to model systems using varying degrees of abstraction. While the workload metrics are still unverified initial results appear very promising and trend well with known high workload areas.

1.1 Overview and Papers

Chapters 2 and 3 of this thesis consist of two published papers. Chapter 2 introduces some of the

Chapter 2

Modeling UASs for Role Fusion and Human Machine Interface Optimization

Chapter 3

Modeling Human Workload in Unmanned Aerial Systems

Chapter 4

Refactoring the Modeling Framework

Chapter 5

Case Study: UAS operating in the NAS

Chapter 6

Conclusions and Future Work

Appendix A

UAS-enabled WiSAR Proposal

A.1 INTRODUCTION

Advances in Micro Unmanned Aerial Vehicle (mUAV) technology has pushed mUAVs into new frontiers. UAV Enabled Wilderness Search and Rescue (UE-WiSAR), one of these frontiers, has been a focus of the Human Centered Machine Intelligence (HCMI), Multiple Agent Intelligent Coordination and Control (MAGICC) and Computer Vision (CV) labs at Brigham Young University since 2005. In that time research has been conducted on human interaction with mUAVs, improving target detection by enhancing video taken from a mUAV, integrating mUAVs into a SAR environment, and improving the mUAVs chance of getting video footage of the target. Over the course of this research many of the ideas for improving UE-WiSAR results have been validated through simple experiments and user studies. Live Field Demo's with actual Search and Rescue personnel have also shown favourable results. These results represent important progress in Human Robot Interaction.

Although the research has proven successful, many of the tools developed for UE-WiSAR are unfit to share with a broader community. This proposal outlines the challenges faced by UE-WiSAR, the solutions discovered for overcoming these challenges and a plan for creating UE-WiSAR software that incorporates said solutions into a stable software package as part of an industrial thesis. As an industrial thesis the emphasis is not on new research but on delivering high quality software

A.2 PREVIOUS WORK

One goal of this project is to take past research and present it in a software application that encourages future researchers to use the software as a framework for continued research. Essentially what this means is that the entire purpose of developing the UE-WiSAR software is to make it available to future researchers and, more importantly, practicing searchers. The majority of the referenced work comes from a combined effort from the HCMI, MAGICC, and CV labs at BYU and focuses on solving the specific problems that arise when bringing a small UAV into the WiSAR arena. This proposal represents the realization of this goal [**?**].

A.3 WiSAR

A.3.1 The Problem

Wilderness Search and Rescue (WiSAR) is more prevalent today then in any other time in history. While Search and Rescue has been around since the beginning of mankind [**?** , p. 13], the improved communications and increased accessibility to wilderness areas have caused an increase need for WiSAR operations. Often times these operations have limited resources due to limited funds, remote locations, and dangerous conditions.

A.3.2 Concepts

To help understand how UE-WiSAR will be effective, some WiSAR concepts, defined by T.J. Setnicka [**?** , p. 35], will be used. The first concept is the four core elements of a WiSAR operation.

$$\mathit{Locate} \Rightarrow \mathit{Reach} \Rightarrow \mathit{Stabilize} \Rightarrow \mathit{Evacuate}$$

Figure A.1: Core SAR Elements

The second concept is the WiSAR plan and its components, specifically Strategy and Tactics. Strategy is the process of gathering information and making an accurate assessment of the situation. Tactics are outlined solutions for specific situations that can be used as part of a Strategy.

A.3.3 Searching

Locating an individual in the wilderness can be a daunting task and typically represents the majority of time spent on an operation if the person is missing. SAR commanders develop Strategies for locating the person and use the Tactics available to them as part of those Strategies. Each Tactic applied to a search is based on availability, effectiveness, and cost. One Tactic that has proven it's effectiveness is aerial surveillance. One large drawback to this Tactic is the cost and availability. Until recently most aerial surveillance has been done with piloted aircraft. Advances in Unmanned Aerial Vehicles (UAV) have created new options for providing aerial surveillance, but high-end commercial UAVs are still incredibly expensive. This has prompted a deeper look into using mUAVs that are low-cost but by their very nature have a long list of obstacles that need to be overcome before they can be effective.

A.4 WHY DEVELOP UE-WiSAR

A.4.1 New Search Tactic

As mentioned earlier, most WiSAR operations are limited in the search Tactics they can use. Using mUAVs offers a new aerial surveillance Tactic. The mUAVs are small and relatively inexpensive; cost estimates are between $1,000 and $10,000 per mUAV [6**?** **?**]. These platforms represent a small fraction of the possible mUAVs that are capable of performing UE-WiSAR tasks. One model that is currently receiving attention is the multi-rotor mUAVs which can move at slow speeds and remain stationary if needed [**?**]. The relatively low cost of these mUAVs makes them attractive for aerial surveillance. mUAVs also reduce the risk to search personnel in the event of critical user/equipment failure. Also, future work will allow for multiple simultaneous mUAV surveillance [**?**].

While very capable, mUAVs are not fit for every situation. Few battery-powered mUAVs can stay aloft with the required camera-equipment for more than 90 min, many for less than half that time. This means that mUAVs are limited in their search range and effective search time. Also, the mUAV is extremely suseptible to high winds, rain, and snow which further limits its use.

While future advances may improve mUAV performance these limitations are important to understand about this search Tactic.

A.4.2 mUAV Surveillance Works

While far from perfect, mUAV surveillance has proven capable of successfully finding search targets in staged settings. User studies using NTSC video showed a probability of detection improvement of 43% over standard footage by using mosaicing on live video feeds [**?**]. A simplied field trial, close proximit with bright colors, conducted in May 2008 using prototype software was able to locate the simulated missing person in 40 minutes using a lawnmower search pattern [7]. After the field trial a qualitative analysis was performed. Field ready aspects from the analysis were the ability to quickly launch and fly the mUAV and the usefullness of mosaicing for detecting objects from the mUAV. The analysis also identified the need for improved user interfaces and communication. This need for improved user interfaces is an essential component of the UE-WiSAR proposal.

A.4.3 Community Outreach

Although the WiSAR project at BYU is winding down the potential research opportunities in this area have only increased. Improvements can be made in mUAV control, video enhancement, object detection, and more. The problem for those wishing to continue this research or to use the tools in practice is the lack of stable software containing the solutions that have been found. UE-WiSAR is that missing piece. One question that naturally follows deciding to build software is has it been done before. UE-WiSAR fits into four roles that typically remain independent. The roles are Ground Control Station (GCS), Video Enhancer (VE), Search and Rescue (SAR), and Command and Control (CC). There are many open source software packages for performing tasks related to these roles, but there is no open source software that combines all of these roles into a single framework. UE-WiSAR will do just that making it ideal for continued research in the UE-WiSAR domain.

A.4.4 Thesis Statement

The WiSAR research and prototype software can be refactored into a cohesive and stable software package, UAV Enabled Wilderness Search and Rescue (UE-WiSAR). When finished UE-WiSAR will function as a new Search Tactic capable of performing aerial searches and integrating with real SAR operations. UE-WiSAR will also follow industry design standards with clear documentation making it an idea platform for future research and development in the SAR, UAV, and academic communities.

A.5 PROJECT GOALS

Overcoming the obstacles of using mUAV for WiSAR (Wilderness Search and Resue) operations has been a primary research focus at BYU since 2005. In that time many solutions have been found to overcome these obstacles. These solutions will be outlined in greater detail later in the proposal. In the process of discovering these solutions a plethera of software was created. This software was then used in user tests to determine it's effectiveness. Also, many studies where conducted in understanding SAR, human mUAV interaction, and mUAV-WiSAR integration. These software pieces along with the knowledge of how to use them for WiSAR is incredibly valuable. Unfortunately the software that has been created is disjointed and unstable, as is often the case with research software. Much of the software was written as prototypes for user studies and is not fit for distribution individually or as a whole. **The UE-WiSAR project will combine these prototypes into a cohesive**

and stable software package, designed as a new Tactic, for distribution to the SAR, mUAV, and research communities.

A.5.1 Everyone a Pilot

One goal of the UE-WiSAR project is to simplify mUAV piloting through the use of strategic automation and an intuitive user interface. Manual piloting of mUAVs is a highly cognitive task that takes years to master. Automation in the mUAV for auto take-off and landing, flight stabalization, and user-directed automation such as flight-path generation removes major hurdles for inexperienced pilots making mUAVs more accesible to SAR personnel [**?**].

A.5.2 Independent Search Operation

Wilderness Search and Rescue can potentially involve hundreds of personnel, many of which are volunteers. This can cause chaos and, unless organized properly, can have harmful effects on the search. To avoid this UE-WiSAR will focus on working as an independent technical search team. This implies an internal organization comprised of a Mission Manager, UAV Pilot, and Video Analysts. This structure is designed to minimize the personnel needed to operate the mUAV search tactic while maximizing its effectiveness. The goal is that this command structure will be able to fold into the main command heirarchy with minimum supervision and maximum effect, communicating the location of the missing person [**?**].

A.5.3 Improve UAV Video Quality

UE-WiSAR is not useful if human users cannot detect signs of the target. This fact stresses the importance of detecting targets that appear in captured footage. While UAV piloting has a great impact on the content and quality it is not enough. Low resolution, constant movement, and a small detection window make human target detection unacceptably low. To counteract these issues UE-WiSAR will use mosaicing and anomaly detection to improve detection rates with the goal of generating high object detection rates with mUAV video [? ?].

A.5.4 SAR Contribution

One of the most important phases of the WiSAR plan is the Critique [?]. The ability to recognize what went wrong and what went well is important for improving future operations. Analysis of multiple past WiSAR operations is also an effective way of gleening insights that can improve future operations. UE-WiSAR is organized to provide spatio-temporal information gathered during the search. This data can then be accessed for review or shared for further analysis. The goal is that the accessibility and organization of the UE-WiSAR data will improve the sharing of search data with SAR repositories such as the International Search & Rescue Incident Database.

A.5.5 Stable R&D Platform

UE-WiSAR has a great deal of untapped potential. The research that has been conducted at BYU represents the initial merging of exciting new technologies. This potential however is difficult to realize without a foundation to build upon. The UE-WiSAR software is that foundation. Without the need to create custom GCS, CC, SAR and VE interfaces, future researchers and developers can pursue new ideas that add-to or improve UE-WiSAR.

A.6 OBSTACLES

UE-WiSAR presents many problems to overcome. This project will deal specifically with those problems that occur in the Human-Robot Interaction, SAR, and Computer Vision domains. In analyzing these problems it is important to realize that these obstacles are built on the assumption that other problems have already been solved. mUAV automation, for example, will prevent undesired crashes during normal flight. To better describe these obstacles and their relationship to UE-WiSAR each obstacle has been assigned to a solution category. Please see Figure A.2 on page 23.

A.6.1 UAV Piloting

High Cognitive Load. mUAVs operate under multiple degrees of freedom which can be disorienting for pilots. A high level of concentration is required to avoid becoming confused while piloting. This is somewhat mitigated by the low-level autonomy that this project builds upon [**?**]. However, a fair amount of cognitive load is still required. Path-planning, status monitoring and team communication are tasks that must still be addressed.

Hardware Variety. The variety of hardware that can be used for mUAVs is constantly increasing. For any system to be viable as a perpetual framework for UAV research it must have mechanisms in place to allow for the piloting of any number of unique mUAVs.

Limited Flight Time. Most battery-powered mUAVs are limited to a flight time of under 120 minutes, many are much less. This limitation makes flight planning much more difficult and introduces the potential for critical failure during a flight.

A.6.2 Object Detection

Human Perception Limitations. To be successful human users must be able to detect objects on screen. This implies that video presented to users will only be effective if it accounts for the limitations of the human eye [**?**]. The eye is only able to discern high detail with the cones located in the center. This means that to detect an object the user must be looking almost directly at the object while it moves across the screen. Another limitation is that the eye has difficulty detecting small changes in intensity, an effect that gets worse as brightness goes down [**?**].

Low Resolution. The video resolution is a result of current hardware. The mUAVs at this time broadcast NTSC 640x480 resolution. This resolution makes it extremely difficult to locate small objects which may be represented by only a few pixels [7].

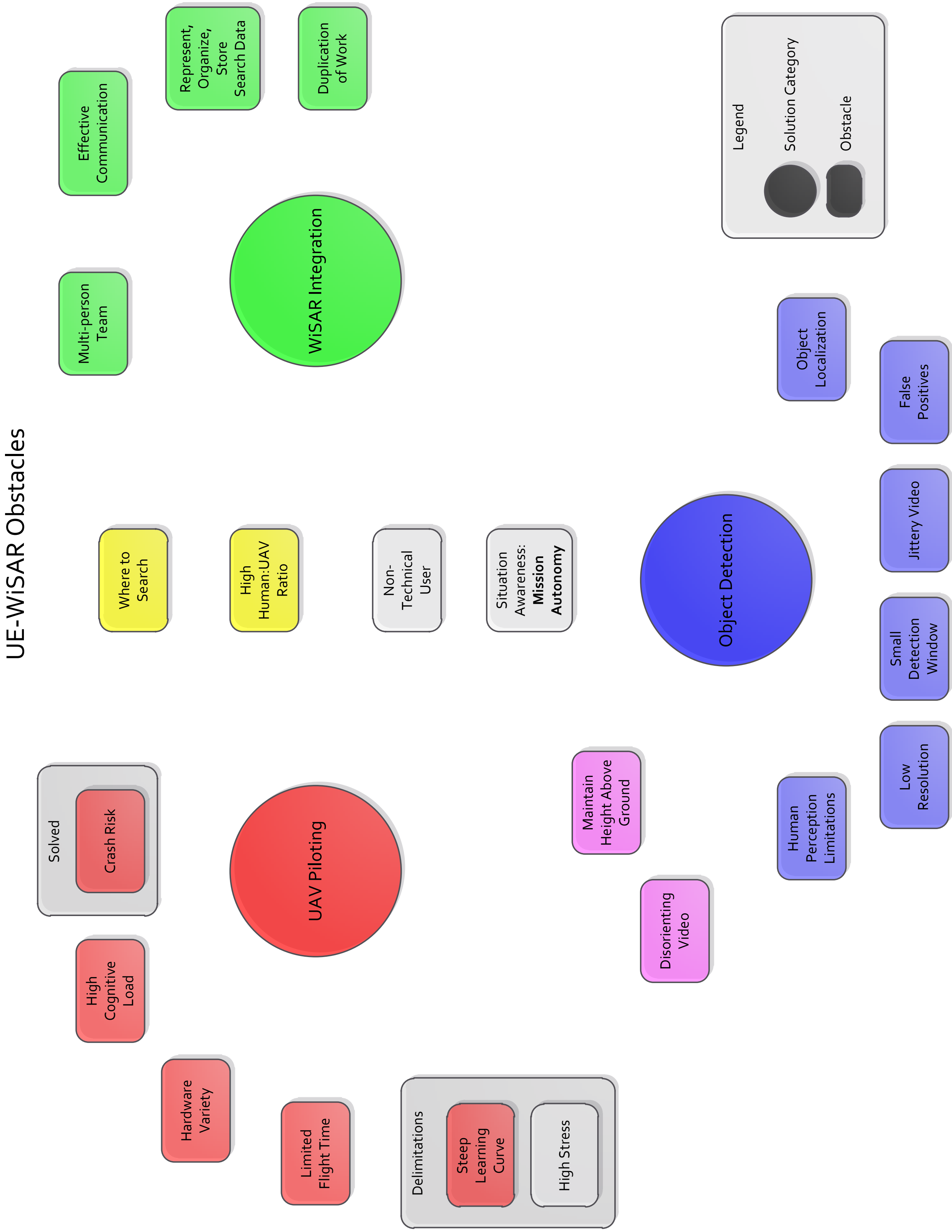

Figure A.2: UE-WiSAR Obstacles

Small Detection Window. When using a fixed wing mUAV the video captured is in constant motion. This motion means that a potential target will only remain visible for a short time. Minimum mUAV flight speeds only slightly improve the detection window and cannot fully correct this problem [7].

Jittery Video. For stable flight, the mUAV is constantly correcting course through small adjustments. These adjustments occasionally have the undesired effect of making video appear jittery. This problem is magnified in adverse weather conditions [7].

Object Localization. Assuming an object has been detected in surveillance video the next step in a WiSAR operation is to send ground searchers to the object. In a May 2008 field trial, video analysts where unable to accurately communicate the location of an object and had to observe the searchers from the mUAV to give them directions relative to the object [7]. This example illustrates a different challenge which is determining the exact location of a detected object.

False Positive Detections. Due to the cost associated with missed detection, a human life, a high false alarm rate is considered tolerable. If the false alarm rate is too high, however, it degrades the practicality of the tactic. On top of that each false alarm requires effort that may bog down the search or leach resources from other tactics [**?**].

A.6.3 WiSAR Integration

The next group of obstacles fall under the WiSAR Integration category and represent the challenges from introducing mUAVs into a WiSAR operation. A cognitive task analysis was performed to provide insights for such an integration [**?**]. The goal directed task analysis and work domain analysis from this effort communicate how complex a WiSAR operation is. To integrate with such a complex endeavor a few obstacles must be overcome.

Multi-Person Team. WiSAR operations are made up of potentially hundreds of people. Additionally, the mUAV requires its own team. Not only must the mUAV team operate as a team but it must also interact with the overall operation. These multi-person, multi-team environments often generate role confusion, conflict, and inefficiency [?].

Effective Communication. No search can be effective without the relevant data. A typical WiSAR operation uses a hierarchical command structure. The mUAV team must be able to fold into the hierarchy such that it receives relevant search data. The mUAV team must then communicate internally as individual roles are performed. Important information must then be communicated back into the parent command structure.

Representing, Organizing, and Saving Search Data. The data provided to the mUAV team must be interpreted so that it can be understood by the mUAV. Additionally the data provided by the mUAV must then be interpreted so it can be understood by users and commands further up the chain. This implies an internal data organization associated with the mUAV. This organization must facilitate the storing and sharing of said data.

Duplication of Work. This mostly applies to search area coverage. The mUAV team must be able to track what it has searched and how well it was searched. Without this information search planning will be inaccurate which could have fatal consequences.

A.6.4 UAV Piloting & WiSAR Integration

Where to Search. During a WiSAR operation the probability of area (POA) [?] is constantly changing as new information is acquired. For a UAV to integrate into a WiSAR operation it must have the ability to interpret this information, act on information, and contribute information. If information is lacking then it must be able to generate information to act upon. A target can only be spotted by the mUAV if it shows up on the video.

High Human to UAV Ratios. This obstacle is based on practicality. It is not practical to require a large team for a single mUAV. With the variety of tasks that emerge when introducing a mUAV to WiSAR it becomes quite challenging to keep this ratio down. A study by Cooper [3, 7] speculates that it may be possible for a single human to simultaneously navigate an area while localizing objects. His conclusion outlines several requirements he feels must be met before this can become reality. This becomes even more challenging when considering the Mision Manager role as well.

A.6.5 UAV Piloting & Object Detection

Maintaining Height Above Ground (HAG) [?]. This represents one of the major crash risks associated with user error. In an early test flight the pilot placed two way points of similar HAG a fair distance apart. As the mUAV flew between the way points it crashed into a tall ridge that separated the waypoints. The pilot wasn't aware that his flight path went through the ridge. This example illustrates one reason for maintaining HAG; another reason is related to Object Detection. Goodrich et al. state that the minimal resolution of an image for detecting a human form is 5cm per pixel [?]. This means that an image can cover an area no wider than 32m and 24m tall. They go on to suggest that the maximum HAG be between 60m to 100m.

Disorienting Video. Disorienting video is produced when the mUAV is performing manuevers which change the camera field of view and cause the user to feel disoriented [?]. Even small manuevers can be disorienting when occurring in succession. This is a challenge because the UAV cannot obtain the needed surveillance without turning. Also, the light weight of the mUAV causes it to be susceptible to wind which can cause excess manuevering.

A.6.6 Universal Obstacles

Non-Technical Users. For UE-WiSAR to be practical it must strive to be accessible to the greatest number of users. With this said UE-WiSAR is a technical operation and cannot be divorced completely from its technical aspects. UE-WiSAR requires some knowledge of mUAVs, networking, and radio transmission. The real obstacle is segregating and limiting the technical experience required for UE-WiSAR into as few roles as possible.

Situation Awareness. This represents the user's ability to maintain awareness of the bigger picture while performing tasks. This is broken into two categories. The first category relates to the mission. The main goal of any UE-WiSAR operation is to find the missing person. If the tasks performed by mUAV team members require a cognitive load that is too high team members will be unable to meet their respective responsibilities which may have tragic consequences to the search. The second category relates to autonomy. Autonomy is a central concept to UE-WiSAR. As autonomy increases certain negative attributes can emerge [**?**], including:

- Reduced situational awareness
- Difficulty in supervising autonomy
- Increased interaction time
- Increased demands on the human and autonomy

As autonomy decreases the following negative attributes can emerge [**?**]:

- High cognitive load on operator
- Steep learning curve
- Increase pilot:UAV ratio

The balancing of this dynamic relationship between the autonomous and operator-controlled elements of UE-WiSAR is important because it is directly linked to the usability of the solution.

A.7 SOLUTIONS

The solutions to the above mentioned obstacles are organized into three categories. See Figure A.2 on page 23. This organization is preferred because many of the solutions discussed here solve problems associated with multiple obstacles.

As mentioned earlier, these solutions already exist in different states. The subsequent paragraphs will expand on the work required to add the solution to UE-WiSAR.

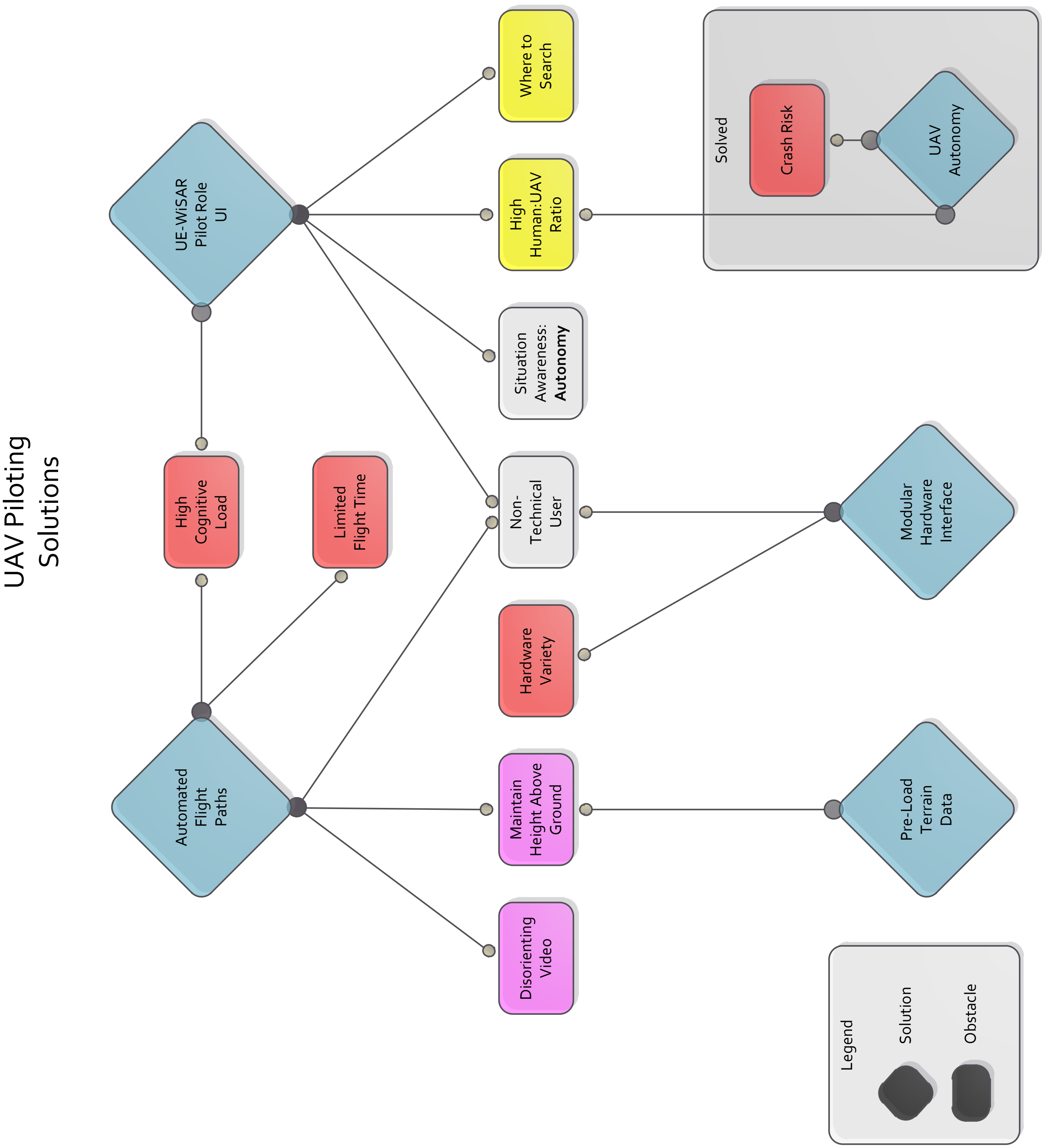

Figure A.3: UAV Piloting Solutions

A.7.1 UAV Piloting

This solution category focuses on overcoming obstacles associated with piloting the mUAV. See Figure A.3 on page 28.

Automated Flight Paths (AFP). The first obstacle this addresses is the high cognitive load on the pilot. Detailed flight paths can be generated in a matter of moments with minimal user input. These flight paths can also be adjusted based on the limited flight time. Lin has created an algorithm that when given a probability distribution map, start point, end point and flight time will generate a flight path that maximizes the mUAV cameras coverage of the probability distribution [**?**]. Another type of flight path is the Generalized Contour Search [**?**]. This flight path requires a gimbaled camera but also generates optimal search patterns for certain conditions. Automatically generated flight paths can also attempt to limit the number of turns made by the UAV to minimize the amount of disorienting video captured during a flight. Lastly, these flight paths can use HAG information to maintain the optimal HAG for object detection while also avoiding obstacles such as ridges or cliffs.

Pre-Load Terrain Data. Terrain data provided by a number of sources can be downloaded over the internet prior to the search. This data is critical for implementing effective AFPs and POA distributions.

Modular Hardware Interface. To overcome the hardware variety obstacle UE-WiSAR will use piloting interfaces that must be implemented for specific technologies. While the initial UE-WiSAR release will have limited hardware support, namely Procerus and Mikrocopter, more support can be added through implementing a single interface for the specific technology. This approach minimizes the work and knowledge required to adapt the software to new hardware.

UE-WiSAR Pilot UI. This user interface has two main requirements [**?**]. First is assigning tasks to the mUAV. This implies an ability to make the mUAV an effective part of the search by having the mUAV capture high quality video footage of regions specified by the incident commander. It does not imply deep understanding of mUAV piloting, flight path automation, or other technical details associated with piloting a mUAV [**?**].

The second requirement is the ability to monitor the health of the mUAV. This means the UI must communicate the exact position and status of the mUAV at all times and alert the pilot when user input is required. Because this UI is the main focus point for the pilot, it is a primary concern for loss of situation awareness. To avoid this the UI must be able to dynamically adjust the amount of automation needed as dictated by the situation.

A.7.2 Object Detection

This section focuses on detecting objects in video captured by the mUAV. See Figure A.4 on page 31.

Temporally Localized Mosaic [**? ?**]. This process allows the user to view the current frame in relation to a history of previous frames. An object that appeared in a single frame may now remain visible for multiple frames. Morse et al. conducted user studies to analyze the effectiveness of this approach. Those studies found a 43% improvement in hit probability when using mosaiced views versus non-mosaiced views. While there was an increase in false positive detections this increase is considered inconsequential along side the improvement to hit probability.

Spectral Anomaly Detection [**? ?**]. In typical WiSAR video the majority of colors are varying shades of grey, brown, and green. This process looks for objects that are "out-of-place". This autonomous detection will not replace user detection, instead it aids user detection by suggesting objects to the user for closer inspection.

GPS Frame Referencing [**?**]. This process uses geometry to map pixels to gps coordinates. The algorithm uses the GPS coordinates of the mUAV, mUAV position, terrain data, and camera specifications to determine the relation of the point to the UAV. While the process is simple, it suffers from the limited precision of mUAV sensors and may provide highly inaccurate locations.

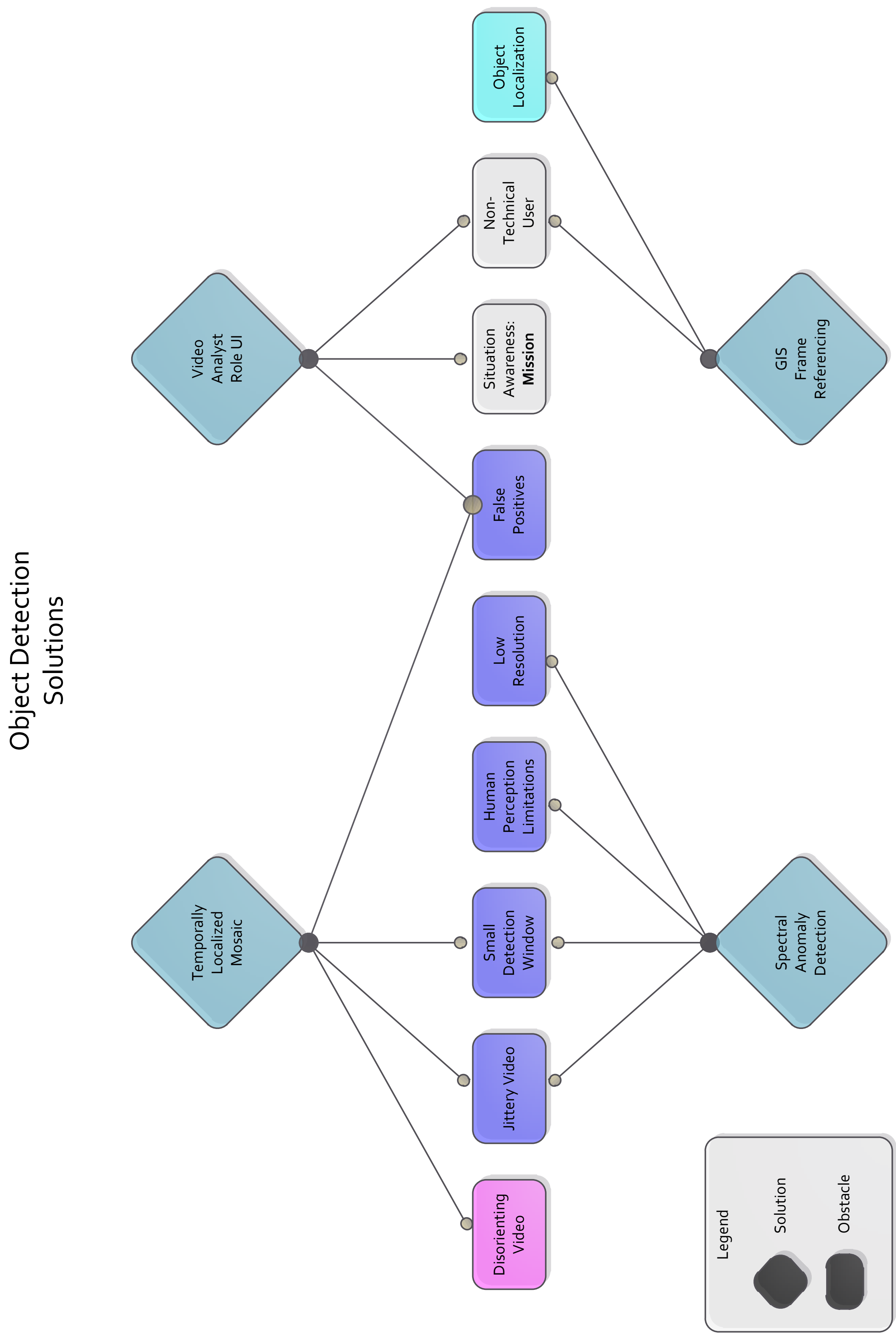

Figure A.4: UAV Piloting Solutions

Video Analyst UI [?]. This UI is meant for users operating under the Video Analyst Role. Its purpose is to help Video Analysts detect objects seen by the mUAV. There are three main requirements associated with accomplishing this purpose. The first is to provide video to the user. As a search progresses Video Analysts may need to analyze live video, video of specific areas, or video from certain times. The UI must make it easy for analysts to find the video that needs to be analyzed. The second requirement is to aid in object detection. The UI must be able to enhance the video as directed by the user. This includes the above mentioned solutions along with other simple enhancements such as brightness, contrast, and rate of playback. The last requirement is that the UI allow the analyst to communicate with the mUAV team. As an analyst works they must be able to communicate findings to the mUAV team.

A.7.3 WiSAR Integration

WiSAR Integration focuses on introducing a mUAV to a WiSAR operation. See Figure A.5 on page 33.

Team Roles [6? ?]. UE-WiSAR will use a hierarchical command structure. The top level role is the *Mission Manager* (MM). The MM is responsible for defining the search in UE-WiSAR. The MM is also responsible for directing the other roles associated with a mUAV search.

The next role is *UAV Pilot*. The Pilot is responsible for capturing video with the mUAV as directed by the MM and communicating important information about the status of the mUAV to the MM.

The last role is *Video Analyst*. The Analyst is responsible for detecting objects in the captured video. The Analyst communicates any findings to the MM.

This role breakdown enables a mUAV team of two or more people to operate effectively through a clean breakdown of work and established communication channels.

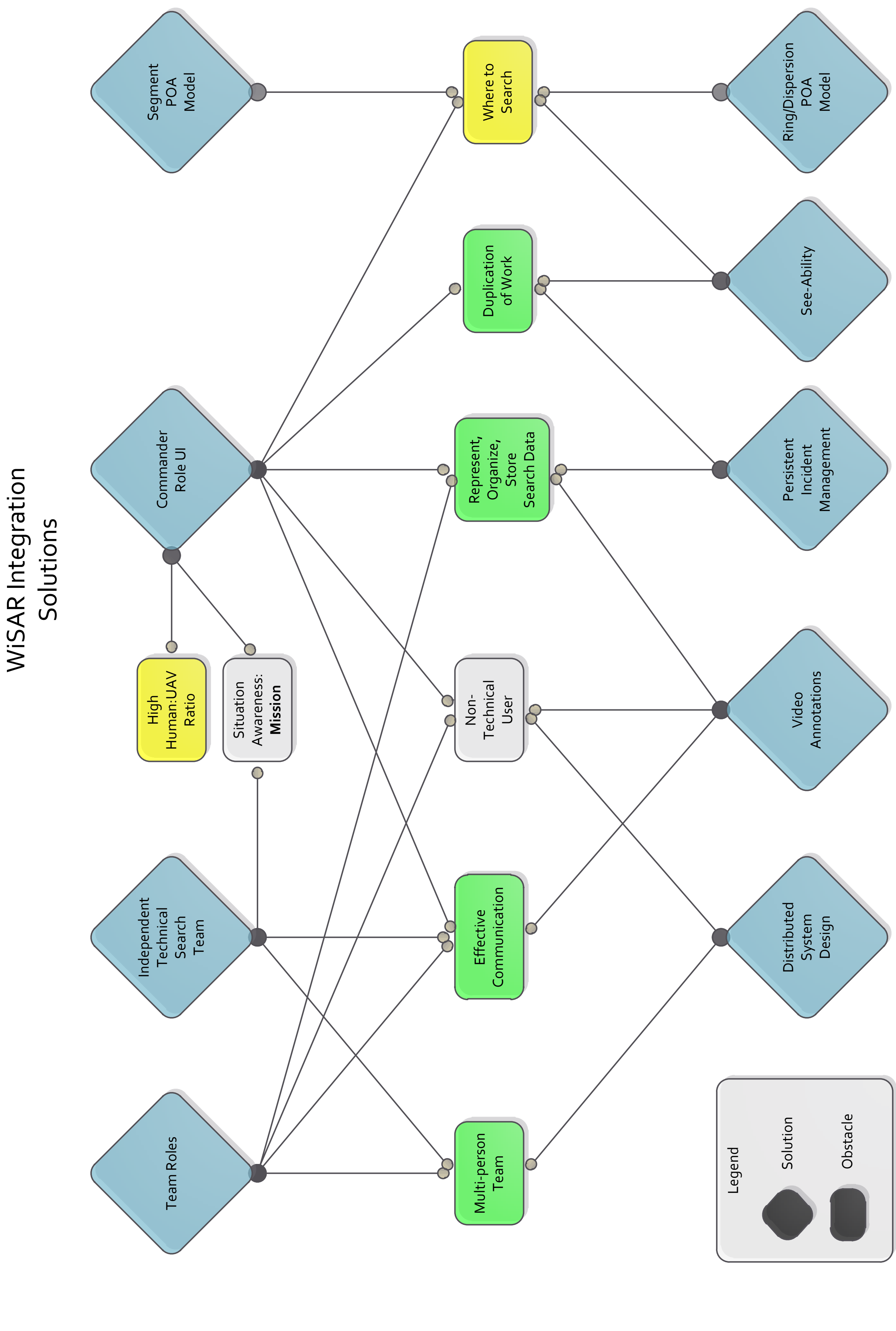

Figure A.5: WiSAR Integration

Independent Technical Search Team [?]. UE-WiSAR represents a single search tactic for locating missing persons. This implies that UE-WiSAR will be used as part of a larger WiSAR operation. This is facilitated through the MM role. The MM is responsible for obtaining the missing person data and entering the data into UE-WiSAR. The MM is then responsible for constructing a mUAV search plan as directed from the chain of command. As the mUAV team follows the search plan, everything is reported back to the MM who then relays relevant information back to the main chain of command.

Command & Control UI This UI is meant for users operating under the Mission Manager Role. Its purpose is to facilitate the MM responsibilities. There are three main requirements for accomplishing this purpose. The first is the ability to build a missing person profile. Information such as the last known location, clothing color, destination, starting point, etc. is essential for the automation and the mUAV team. The UI must allow the MM to enter this data but not overload the MM with tedious data entry. The next requirement is the ability to define a search plan. The UI must show relevant search data to the MM and allow the MM to define a search plan which can then be carried out by the Pilot. The last requirement is the ability to receive communications from mUAV team members. The UI must alert the IC of detected objects, mUAV status, search progress. The UI must also communicate this information in a way that it can be presented to the main chain of command. Additionally the UI must be intuitive, clean, and simple.

Distributed System Design A client-server architecture has been chosen for UE-WiSAR for several reasons. The first reason is the computational load required to enhance video received by the mUAV. The resources needed are much greater than those of a typical desktop computer and require a powerful server. Once the video has been enhanced, however, it can be distributed to clients at little cost. Another reason for this architecture is the unknown team size. Collected video must be analyzed by the human-eye. This architecture allows for any number of video analysts to work symultaneously, assuming there is enough bandwidth. Another reason for this architecture is to simplify the software. Instead of building an all-in-one software solution, a server and multiple independent client applications can be written. Clients can then choose which application to run according to their roles which in turn makes the client roles less confusing.

Video Annotations These are the primary means of communication for the Analysts. When an Analyst detects an object they can click on the object and create an annotation. The annotation will then carry information about that object such as location, time of discovery, place in video, analyst comments, priority, etc. Once an annotation is created it instantly becomes available to other team members, in the case of the IC, alerting them of the annotation. The annotation can then be modified as needed depending if it was a false alarm or a real sign. If an annotation is a real sign it can be converted to a format acceptable to the external chain of command.

Persistent Incident Management Essentially this refers to a relational data model specifically designed for UE-WiSAR. The root node of this data model will be an incident, all other data will be linked to an incident. The model will hold missing person data, search plans, flight plans, videos, annotations, etc. Storing data in the model will reduce work duplication and make data more accessible. The model will also simplify persistent storage as xml files or a sql database. In concert with the project goals this data model can be shared with other search groups and search databases to help improve WiSAR.

See-Ability [**?**] This is a method of determining how well an area has been searched by the mUAV. The algorithm uses the position of the camera in relation to the ground to determine the quality of the view. This can later be used to find how many times a location has been viewed, how many unique angles has it been viewed from, and what is the overall quality of the viewings. This can be a great help to the MM and Pilot in avoiding over-viewed areas, narrowing search parameters, and maintaining situation awareness.

POA Models [**?**] Because UE-WiSAR must be able to act independently, two probability of area models will be added to the CC interface. The first is the Segment Model. This model allows the IC to strategically breakdown a large search region into smaller search regions. Efforts can then be focused on high priority regions as directed by the IC. The second model is the Ring/Dispersion Model. This model uses the last known location along with the intended destination to create an ever expanding search corridor with eminating rings that occur at specific distances. The highest POA occurs inside the corridor and inside the first ring, then second ring, etc.

A.8 DELIVERABLES

As an industrial thesis a major goal is to produce high quality software that is on par with industry standards. Quality as it relates to the project goals is the users ability to perform tasks within their roles and to allow future developers to understand UE-WiSAR well enough to modify/enhance the software as needed. To following descriptions of work will be used to validate that the project goals have been met and that the project is a success.

Therefore, the first deliverable will be a detailed list of requirements organized into groups and prioritized. Glass's law [**?** , p. 16] states that "Requirement deficiencies are the prime source of project failures." The list of requirements is meant to be an ideal goal. Not every requirment will be acheived, and some may change, instead it is meant to be a road map. By clarifying the project requirements early the student and committee members can make informed decisions, avoid mistakes, and measure progress. It is also expected that design specifications will improve the design and make prototyping more effective.

The second deliverable will be detailed design documents specifying the architecture, data model, workflows, dataflows, protocols, user manuals and language/framework considerations. These documents will make up a collection of text, UML, and other documents. Their purpose is to clarify how the system works and how it accomplishes project goals. Boehm's first law [**?** , p. 17] states "Errors are most frequent during the requirements and design activities and are the more expensive the later they are removed." This step of the project will help to reduce bugs and development time by allowing for peer review and prototyping before major work is done. Many of these documents are living documents and will change as the project progresses, some may not exist until after coding has been completed. It is expected that requirements and design will take up to one third of the total project time.

The third deliverable will be the actual UAV Enabled Wilderness Search and Rescue code. The code will be well documented, follow consistent coding practices, and compile on designated operating systems. This represents the majority of work done on the project.

The fourth deliverable will be a demonstration of the software in a live environment with a real mUAV and controlled targets. This demostration will show that core features exist, the software is stable, and users are able to perform tasks by following written instructions. Core features are the set of features decided on by the student and committee that the software must have to be considered functional. The users will be individuals, preferably familiar with WiSAR, unfamiliar with operating the UE-WiSAR software. At least one user per role will be involved. An experienced mUAV pilot will also be involved to reduce risk to equipment. Basic tasks will be assigned that require use of the core features. This will not be an exercise in validating prior research.

A.9 DELIMITATIONS

Due to the nature of software development and the size of this project there will be a large list of things to do that can be done in a reasonable amount of time. The goal of this project is not to implement the maximum amount of features, instead the goal is to create a stable foundation for others to implement the features they choose. This is particularly relevent in regards to user interfaces.

This project will not create the ideal user interfaces as described in the solution section as those are subjective and become much too time consuming. Instead the project will focus on functionality and creating basic user interfaces that can be easily replaced by future developers.

The project also doesn't account for the High Stress that is associated with SAR operations. It is known that High Stress has a negative impact on an individuals cognitive load capacity, however, it is too complicated to include in this proposal.

There are several learning curves that are associated with different aspects of this project. Because learning curves are unavoidable and vary with the individual it is enough for this proposal that the software is targeted at as large a user group as possible.

There are too many unknowns to accurately predict the amount of time a project this size will take to complete. The focus will be on the deliverables and working closely with advisors during the development process to adjust the requirements to fit with time constraints.

A.10 CONCLUSION

UE-WiSAR represents an opportunity for the research done at BYU to serve a greater community. As Thomas Edison once said "The value of an idea lies in the using of it." UE-WiSAR will not only provide a new search Tactic for SAR operations, it also provides a framework for mUAV enthusiasts and researchers to build upon for continued research in the field. What now exists as a collection of interesting ideas will become the do-it-yourself manual for performing aerial surveillance using mUAVs.

Unlike many open source solutions, the focus of creating software at current industry standards makes UE-WiSAR even more valuable. With good design and documentation the project is much more likely to take hold in the open source community further increasing its ability to serve those communities it is meant to serve.

References

[1] *Using Foirmal Verification to Evaluate Human-Automation Interaction: A Review*, 2013.

[2] Julie A Adams, Curtis M Humphrey, Michael A Goodrich, Joseph L Cooper, Bryan S Morse, Cameron Engh, and Nathan Rasmussen. Cognitive task analysis for developing unmanned aerial vehicle wilderness search support. *Journal of cognitive engineering and decision making*, 3(1):1–26, 2009.

[3] J. Cooper and M.A. Goodrich. Towards combining UAV and sensor operator roles in UAV-enabled visual search. In *Proceedings of the 3rd ACM/IEEE international conference on Human robot interaction*, pages 351–358. ACM, 2008.

[4] M. L. Cummings, C. E. Nehme, J. Crandall, and P. Mitchell. *Developing Operator Capacity Estimates for Supervisory Control of Autonomous Vehicles*, volume 70 of *Studies in Computational Intelligence*, pages 11–37. Springer, 2007.

[5] M. A. Goodrich, B. S. Morse, D. Gerhardt, J. L. Cooper, M. Quigley, J. A. Adams, and C. Humphrey. Supporting wilderness search and rescue using a camera-equipped mini UAV. *Journal of Field Robotics*, 25(1-2):89–110, 2008.

[6] M.A. Goodrich, J.L. Cooper, J.A. Adams, C. Humphrey, R. Zeeman, and B.G. Buss. Using a mini-UAV to support wilderness search and rescue: Practices for human-robot teaming. In *Safety, Security and Rescue Robotics, 2007. SSRR 2007. IEEE International Workshop on*, pages 1–6. IEEE, 2007.

[7] M.A. Goodrich, B.S. Morse, C. Engh, J.L. Cooper, and J.A. Adams. Towards using unmanned aerial vehicles (UAVs) in wilderness search and rescue: Lessons from field trials. *Interaction Studies*, 10(3):453–478, 2009.

[8] Michael A. Goodrich. On maximizing fan-out: Towards controlling multiple unmanned vehicles. In M. Barnes and F. Jentsch, editors, *Human-Robot Interactions in Future Military Operations*. Ashgate Publishing, Surrey, England, 2010.

[9] P. M. Mitchell and M. L. Cummings. Management of multiple dynamic human supervisory control tasks. In *10th International Command and Control Research And Technology Symposium*, 2005.

[10] R. Murphy, S. Stover, K. Pratt, and C. Griffin. Cooperative damage inspection with unmanned surface vehicle and micro unmanned aerial vehicle at hurrican Wilma. IROS 2006 Video Session, October 2006.

[11] R. R. Murphy and J. L. Burke. The safe human-robot ratio. In M. Barnes and F. Jentsch, editors, *Human-Robot Interaction in Future Military Operations*, chapter 3, pages 31–49. Ashgate Publishing, 2010.

[12] Christopher D Wickens. Multiple resources and performance prediction. *Theoretical issues in ergonomics science*, 3(2):159–177, 2002.