The Inherent Components of Unmanned Vehicle Situation Awareness

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***Abstract*—The purpose of this paper is to present an initial delineation of the inherent components required for unmanned vehicles to possess situation awareness. A broadly adapted human situation awareness definition is directly applied to the notion of unmanned vehicle situation awareness. This work focuses on identifying the inherent components of unmanned vehicle situation based upon the components of human situation awareness. The presented work is foundational for developing a holistic unmanned vehicle situation awareness architecture. It is hypothesized that unmanned vehicles that possess situation awareness will better accommodate dynamic situations while improving human-robotic interaction.**

I. Introduction

Many of today's deployed unmanned vehicle (UV) systems are teleoperated, semi-autonomous or rely on very fragile autonomous capabilities. Consequently, mission success is dependent upon the human operator's ability to manage and direct the UV system. Future UV systems will deploy individual or teams of fully autonomous UVs that will incorporate humans in roles such as supervisors, operators, mechanics, peers, or bystanders [18]. Such UV systems will require the UV to be capable of accurately perceiving the environment, understanding the situation, locating and interacting with environmental elements, and communicating mission assessments to team members or superiors (either human or machine).

Humans understand highly dynamic and complex environments via their cognitive capabilities. One component of these cognitive capabilities is situation awareness (SA) [7, 8] namely, the human's ability to perceive the environment, comprehend the situation, project that comprehension into the near future, and determine the best action to execute. Thus far SA research, including UV SA research, has focused solely on the human's ability to attain and maintain SA. Our hypothesis is that a UV with human-like SA will improve mission success rates while supporting the human's SA and interaction with the UV; resulting in a single human being able to simultaneously supervise a larger number of vehicles.

The focus on developing the UV SA architecture was motivated by a number of factors. First, the development of fully autonomous UVs with SA is necessary for the future deployment of large numbers of UVs that can successfully complete missions in highly dynamic environments. Such systems require a holistic development approach to attaining UV SA, rather than stove pipe technology development. Thus far, stove pipe development of artificial intelligence and autonomy has not provided the integration required to attain UVs that are reliable in highly dynamic task environments. Second, the development of fully autonomous UVs with human like reactive capabilities requires UVs to possess SA. Third, in order to improve human SA when working with remote systems, UV SA is required as user interaction capabilities and intelligent autonomous behaviors will not wholly resolve current issues associated with humans' SA issues. Fourth, in order to reduce the human-to-UV ratio, the number of UVs a single human can supervise simultaneously, UV SA is required. Current approaches that attempt to improve user interaction, intelligence, and/or autonomous behaviors will not solely lead to improved human SA or a reduced human-to-UV ratio.

This paper presents an initial delineation of the inherent components necessary for UV SA. These components are based upon existing research in human factors that has focused on understanding situation awareness and the effect of increased system autonomy. These SA components are also based on current and future UV capabilities.

II. Human Situation Awareness

Many human SA definitions exist [3, 7, 8, 11, 16]. Endsley's commonly accepted definition is adopted in this work: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" [7]. This definition incorporates three levels of SA: level one - the perception of information from the environment; level two - the comprehension of the perceived information; and level three - the projection of the information into the near future for the purpose of guiding actions.

Traditional SA research has focused solely on the human's ability to obtain SA when working with a system. Recently there has been a focus on the human's SA for UV systems [4, 5, 6, 12, 22]. Most current UV systems require high-levels of human interaction and control. Often the UV resides at a remote location, thus limiting the human's understanding of the UV and the environment.

Human SA is a very complex notion that is influenced by a number of internal and external factors [9, 15, 20] and UV SA is just as complex. There exist many parallels between human SA and UV SA; however a one-to-one mapping does not

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exist. The existing human SA literature is being employed in the development of the UV SA architecture. It is well known that SA has a significant effect on humans' abilities to successfully complete missions; thus future UV systems must provide similar capabilities. Known limitations with human SA may not be limitations with UV SA; however, there are newly identified limitations for UV SA that must be resolved.

III. Unmanned Vehicle Situation Awareness

We apply Endsley's SA definition to UV SA as it is a commonly accepted definition that can be directly employed for either human or UV SA (e.g. it is not human specific). This SA definition also provides an excellent basis for defining human-like SA and supporting the human components of the UV system. The differences between human and UV SA appear when one develops the formal UV SA architecture.

A. Human Situation Awareness and Unmanned Vehicle Situation Awareness

Human SA focuses on the human's ability to perceive the environment, comprehend the information that has been perceived, and project that information into the near future in order to select an appropriate response. While the SA specific information requirements vary across domains, SA drives the humans' decision-making and performance.

Level One SA - Perception: Level one SA represents the perception of the environment relative to the assigned mission. Humans rely on their five sensing modalities and various combinations of these modalities in order to perceive relevant environmental aspects across application domains. Today's UVs are not necessarily capable of perceiving all environmental percepts. Many UVs ignore relevant percepts because they are programmed to sense particular percepts.

Level Two SA – Comprehension: Humans achieve level two SA by integrating their environmental perceptions (level one SA) with their goals and associated information from memory. Similar capabilities are required in order to achieve UV SA. Level two SA requires the integration of large amounts of perceived data and the prioritization of the importance and meaning of the integrated information with regard to mission goals. Current UVs either rely on the human to understand the situation or blindly carryout the assigned mission.

Level Three SA – Projection: Humans are able to predict what will occur in the near future based upon their perception and comprehension of the situation, thus level three SA is directly dependent upon attaining good level one and two SA. Projection requires an excellent understanding of the mission domain and is frequently a highly demanding cognitive activity. Various aspects such as cognitive workload, mental capacity, and environmental stressors can limit humans' level three SA. Current UV technologies have limited, if any, ability to emulate human level three SA.

The entire UV SA architecture must provide connections between the levels as perceptions (level one) are required for comprehension (level two) and both of these lower levels feed into projecting the actions to perform (level three). A holistic, system-of-systems approach is required to integrate existing capabilities with novel elements into an UV SA architecture.

B. Automation and Situation Awareness

Human SA is highly sensitive to a number of external (e.g. environmental stressors, salience, automation) or internal (e.g. cognitive workload, vigilance, fatigue, stress) factors. Automation was originally touted as a mechanism to reduce the cognitive demands placed on humans; however, SA can fall as the level of automation increases [13, 17, 20].

A current assumption is that the level of required UV SA correlates to the UV's level of autonomy. Parasuraman et al. [13] revised Sheridan and Verplank's [19] ten levels of autonomy. Similarly, Endsley and Kaber [10] and the Army scale for the Future Combat System [2] each provide ten slightly different levels of autonomy. Irrespective of the definitional differences, at the lowest autonomy level the human has full control of the UV and the UV has no autonomy, thus the UV may have little, if any SA. A fully autonomous UV will require SA capabilities to ensure safe and successful mission completion. The intermediary levels of automation will result in varying relationships between the human and the UV, thus resulting in varying the levels of SA for each entity. The UV SA architecture will delineate the characteristics required for varying levels of autonomy in addition to how the level of UV SA influences human SA.

C. Unmanned Vehicle Situation Awareness Formalization

Existing knowledge of human SA can be employed to develop a preliminary representation of UV SA. Improvements to human SA focus on providing better interfaces between the human and machine. Human SA does not represent the machine's ability to possess SA; therefore, a new formalization that represents each entity's contribution to SA has been developed [1]. This new formalization delineates system SA and system team SA. System SA simply represents a single human interacting with a single vehicle and the combination of the two entities represents the system SA. The individual entities contribute to the system SA based upon the UV's level of automation and SA.

The vehicle's SA is influenced by the UV's level of automation. There are also a number of characteristics, other than the autonomy level, that will determine the UV SA level, including characteristics specific to the environment and characteristics unrelated to the level of autonomy or the environment. Examples of characteristics associated with the level of autonomy include workload, stress, attention, perception, memory, and vigilance. Weather, terrain, location, and operational requirements represent items included in the environmental characteristic set, while the set of other characteristics may include items such as training, capabilities, task complexity, and communication errors.

The preliminary UV SA representation provides an understanding of the relationships between humans and UVs based on the existing definitions of human SA. Full details of the current formalization are provided in Adams [1].

IV. Inherent Unmanned Vehicle Situation Awareness Components

A portion of our work thus far has focused on identifying SA components specific to UVs. There are a number of human SA components and factors that apply to UV SA. Two groups of components have been defined: inherent and non-inherent. Inherent UV SA components are defined by the features and limitations of the UV hardware and software. The non-inherent UV SA components are introduced by the UV designer as a result of the humans' natural biases. This paper specifically focuses on the presentation of the inherent UV SA components due to space limitations.

The inherent components of UV SA are defined by the hardware and software capabilities of the UVs and represent elements of human SA that are often difficult to measure. Table 1 provides a list of the inherent SA components that are analyzed for inclusion in the UV SA architecture. Each component will be discussed in turn.

TABLE 1
A List of the Inherent SA Components for UVs.

Attention
Explicit Focus
Working Memory
Long-Term Memory
Stress
Workload
Failures
Uncertainty/Confidence
Ideal/Achievable/Actual SA
Vigilance

A. Attention

Attention management affects a human's ability to sense and understand the surrounding environment. While attending to a particular sensory channel does not guarantee perception, generally speaking attention is required to attain perception [21], which is critical for level one SA. Humans are able to divide, direct, and select their attentional capabilities. However, human perception is limited and finite. UVs may be able to surpass such human limitations. Human attentional resources are limited by the demands of the sensory channels and complex, dynamic environments can quickly overload the human's attentive abilities, as a result humans selectively sample their sensory channels. UVs are able perceive the environment based upon their sensors and the associated sensor processing; however these capabilities are also limited. Humans typically manage their attentional focus based upon the frequency that percepts must be updated or the information update rate. Future UVs will suffer similar limitations; however, the saturation point for information collection may higher for UVs than for humans. Human perception is also limited by the human's ability to parallel process sensor percepts due to sensor modalities and working memory constraints. UVs may encounter similar situations and must be able to manage attention or the processing of percepts; the UV SA architecture will need to direct attention and percept processing appropriately. Current UV technology does not necessarily consider these aspects of attention, in particular how they affect awareness.

B. Explicit Focus

Humans are able to direct their attention, and potentially the sensory channels that they are relying on, based upon the surrounding environment and the dynamics of the associated tasks. The ability to rapidly redirect human attention is critical for level one SA and as a result has an effect on level two and three SA. UVs currently do not possess the ability to rapidly adapt or redirect their attention, via their sensory capabilities, to developing situations. In fact, the UV will frequently "ignore" information that would cause a human to redirect their attention. This limitation is due to the currently available hardware and software that are designed to gather particular data and process the data in a predefined manner. UV SA will require the development of adaptable sensory capabilities along with the associated attentional capabilities that redirect attention appropriately.

C. Working and Long-Term Memory

Humans possess working (short-term) memory and long-term memory that are directly relevant to developing SA. Short-term memory suffers from limited capacity and humans have unreliable long-term memory recall. Random access memory is an inherent UV component that can be potentially employed to simulate or replicate human working memory while a hard drive can be employed as a representation of long-term memory. The result may be that the UV can possess a larger working memory that may facilitate SA. Additionally, the accuracy of UV long term memory recall may also improve all levels of SA.

Due to the limitations associated with human memory, humans tend to rely upon mental models, schemas, scripts, and heuristics. Specifically, heuristics allow humans to react with a fairly good probability of success based upon their prior experience. Humans tend to generalize existing mental models, schemas, scripts, and heuristics to unknown or similar situations often resulting in less than optimal performance [21]. UV memory may contain structures such that it is composed of mental models, schemas. and scripts as the underlying memory constructs. These constructs can be integration with the UV and facilitate longer-term memory recall, which in turn can influence overall SA. UVs may also have the capacity to rely less on heuristics than their human counterparts, thus increasing the likelihood that the UV will provide a high probability of mission success. Memory constructs of this nature will be necessarily for UV SA.

D. Stress

Human SA tends to suffer as the human's stress level increases. Often the discussion of human stress focuses on internal, cognitive stressors. UVs do not encounter stress in this same manner. Humans can also encounter stress due to physical (e.g. fatigue) and environmental (e.g. bright light, intense heat) demands. A similar parallel exists for UVs that can inherently suffer from stressors that arise due to system and algorithmic limitations. Mechanical stress may occur when the device is stressed due to heat, wear, or inferior design and construction. Algorithmic stress may occur when the computation complexity reduces the ability to process information in a timely manner or results in a fragmentation of the UV's memory. Both types of stress can result in reduced perceptual capabilities (level one SA) and reduced ability to comprehend the situation (level two SA).

E. *Workload*

Human SA is affected by both cognitive and physical workload. Similarly, workload will affect UV SA. UVs, like humans, have limited physical abilities that vary dramatically across UVs. UVs that are unable to obtain a particular physical configuration in order to obtain particular sensory percepts will encounter SA limitations. UVs may also suffer from cognitive tunneling when the UV focuses attention on a particular percept set or on a demanding physical task. UVs may also suffer from a notion similar to cognitive workload due to limited processing capabilities and algorithmic limitations that hinder the UVs' ability to properly understand the perceived information. These limitations will arise as a result of UV's sensors, actuators, and software capabilities.

F. *Failures*

Humans are prone to a number of physical and cognitive errors, mistakes, and failures; similarly UVs will suffer from physical and computational errors, mistakes, and failures. Currently, UVs frequently suffer from any number of failures. Often failures are physical in nature and include situations where a sensor or actuator fails, the UVs power source expires, the UVs capabilities do not provide the physical capabilities to complete the assigned task, etc. UV algorithmic failures may be considered similar in concept to human cognitive failures. UV algorithms currently are very fragile and sensor data oscillation can result in an algorithm incorrectly classifying and processing the data. Human failures can result in reduced SA and often are a result of inaccurate or insufficient SA; UV failures will have similar implications for UV SA.

G. *Uncertainty/Confidence*

Uncertainty and confidence play a pivotal role in the relationship between human SA and performance. Human uncertainty often manifests itself in the human's hesitation or failure to act. Frequently humans will continue to gather additional information in order to improve their awareness and confidence in their selected action to achieve the desired objective. UVs must rely on their sensors, actuators, and software capabilities in order to modify their SA, hence the UVs confidence and certainty levels. However, sensors and actuators introduce uncertainty into the perception (level one SA), that is then integrated into the level two and three SA. UV sensor capabilities have considerably narrower field of views than human sensory capabilities thus further increasing the uncertainty associated with the UV's SA. Finally, the software and algorithms may also introduce additional uncertainty. For example, algorithms may abstract the percept data prior to processing and then employ heuristics to generate further data abstractions. This process may introduce noise or lost data may result in higher uncertainty and lower confidence in the results.

H. *Ideal/Achievable/Actual Situation Awareness*

Pew [14] classifies human SA into three categories; ideal, achievable, and actual SA. Ideal SA is often unachievable as it represents an awareness of the entire situation. Achievable SA, a subset of ideal SA, captures the best level of SA for a given situation that is possible with the human's cognitive and perceptual capabilities. Actual SA represents the human's current SA, which is often a subset of the achievable SA category. This classification can be applied to UV SA. Achievable SA may be defined and limited based upon the UVs existing configuration and the UV's ability to modify its own configuration. UV achievable SA may also refer to all the potential information the robot could attain to develop SA, whether or not that information is necessary given the current situation. A UV with limited sensory, actuator, and software capabilities will have a narrower actual SA. A narrow achievable SA may or may not result in a narrower actual SA. However, the ability to improve the achievable and ideal SA spaces by adding additional UV capabilities may, but not necessarily, result in improved overall SA. There are, however, tradeoffs. Simply increasing the UVs sensory and actuator capabilities may result in software/algorithmic stressors that result in limited to no improvement in the overall SA. The opposite effect is that the new capabilities may result in additional information that is ignored due to limitations of the UV's software capabilities. For example, the UV is unable to process and interpret the newly available information, thus resulting in no improvement to overall SA.

I. *Vigilance*

It is well known that human vigilance levels drop dramatically over time and have an affect on overall SA. Human vigilance levels often drop due to boredom or fatigue, fortunately, UVs do not suffer from such limitations. UVs possess the capabilities to provide persistent vigilance levels, levels that are necessary for tasks such as persistent surveillance.

Similarities in the concepts of the inherent components of SA between human and UVs exist; however, the underlying considerations tend to be dramatically different. As a result, the UV SA architecture must accommodate these differences based upon the UV's inherent capabilities and the components necessary to achieve UV SA.

V. CONCLUSION

We have begun the process of developing a situation awareness architecture for unmanned vehicles. This UV SA architecture will permit UVs to obtain an awareness of the surrounding environment and mission, thus resulting in a higher overall mission success while reducing the demands placed on the human operator. Current UV systems rely heavily on the human operator to integrate information, make decisions, and provide commands for the UVs to carryout. Increased UV autonomy has not lead to improving the overall number of UVs that a single human operator can supervise. This limitation exists because the UV does not possess an awareness of the situation that can lead to the UV making better decisions and providing the human with more accurate, relevant, and human parse-able information.

This work has adopted Endsley's [7, 8] commonly accepted situation awareness definition that has been applied to human operators. There are a number of SA definitions; however, Endsley's definition is not human specific and can be applied directly to the UV SA architecture. As with human SA, there are a number of factors that will affect UV SA. We have defined a preliminary relationship between human SA, UV SA, and levels of automation and have hypothesized how the level of UV automation and SA will influence human SA. We have also developed a preliminary formalization of the UV SA concept and the resulting relationships. The UV SA architecture will include components that are inherent to the UVs and components that are non-inherent. The purpose of this paper has been to focus on delineating the inherent UV SA components. Each of the inherent components has parallels to human SA; however the influence of these components on the entities' SA differs between the UVs and the humans.

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