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Representation of Search and Target Acquisition Protocol in Models and Simulation

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Abstract: This research evaluates the representation of individual Soldier Search and Target Acquisition (STA) protocols in models and simulation and identifies gaps in the current methodology and implementation. The primary contributions of this research include a synthesis of related literature, an algorithmic exploration of the current STA algorithms implemented in military simulation models, a functional analysis of three systems with a significant relationship to STA, and a determination of gaps and proposed solutions to improve the representation of human STA in military simulation models. The analysis highlighted gaps in three important STA representations: (1) field of view search, (2) identification in a field of view, and (3) information acquisition and situational awareness. Implications and recommendations to resolve these gaps are discussed.

Keywords: Search and Target Acquisition, Models and Simulation, IWARS

1. Introduction

Search and Target Acquisition (STA) is the process a human undergoes to acquire a given target in time and space. Understanding a combatant's ability to search a battlespace and acquire a target is a crucial aspect of building an accurate representation of effectiveness on the battlefield. Accredited military defense simulation tools incorporate STA protocols in order to model how a human would perform STA in a given scenario. In order to understand how STA is represented in these simulation tools, this research includes a literature review, an algorithmic exploration, a functional analysis of three systems with a significant relationship to STA, and a determination of gaps and proposed solutions to improve the representation of human STA in simulation tools.

1.1 Background

Soldier STA is used widely in defense simulation models to support decisions related to material acquisition, force structure, and doctrine. This research team strived to better understand the current STA protocol implemented in simulation tools and determine the gaps in that representation. A better understanding will help to inform the development of a soldier lethality rating or score. This research was conducted using the simulation tool Infantry Warrior Simulation (IWARS). IWARS is a combat simulation tool that encompasses individual, team, and small-unit operations in complex environments (IWARS User Guide, 2014). IWARS utilizes the ACQUIRE-Target Task Performance Metric (ACQUIRE-TTPM) STA methodology, which is very similar to the protocol found in other accredited defense simulation tools, such as One Semi-Automated Forces (OneSAF), expanding the applicability of this work (Target Acquisition and Misidentification ACQUIRE-TTPM-TAS PKAD, 2012 and IWARS Methodology Guide, 2010).

1.2 Related Work

With an end goal to best inform the development of a soldier lethality rating and create a tool that more accurately represents the human STA behavior, research began with the investigation of two relevant topic areas. The first area was STA conceptually focusing on how the human eye works. The second was the evolution of search and target acquisition in simulation. Focus in these areas provided familiarization and the necessary background knowledge to further the research in the STA field.

Numerous military missions rely on the human eye to some extent. Humans are adaptive to constantly changing variables in STA, making them an effective sensor and data analyzer (Jones, 1974). Visual scenes are complex, and many variables affect the detection and identification of targets like clutter, camouflage, and atmospheric conditions (Alaways & Watkins, 1999). Najemnik and Geisler (2010) explain that visual search can be better understood by a probabilistic framework, where beliefs are represented as prior and posterior probabilities. Prior probabilities consist of the searcher's beliefs of the target being located at each possible position. The searcher then develops visual data and uses the data to update their beliefs, which become posterior probabilities. When the posterior probability of a specific location becomes significantly large, the search is stopped, and that location is picked as the target location. The search can also be stopped if no posterior probability gets large enough; likely meaning the target is nonexistent (Najemnik & Geisler, 2010). Human instinctive search behavior is complex and highly effective. Representing this behavior in combat models remains an open area of research (Darken, Evangelista, & Jungkunz, 2011). It is often second nature for soldiers to identify one area as safe and another as threatening, but predicting human visual behavior becomes less clear when complex stimuli are introduced. Visual information processing analyzes and breaks down human search, it can occur at two levels: automatically or with focused attention. In the first, aspects occur simultaneously and automatically. In focused attention, it can be thought of as moving a mental spotlight to various locations intentionally and one at a time, which cannot be done simultaneously (Treisman,1986).

The representation of STA in models has evolved continuously over time. Work on STA within models began in the 1950s with the Johnson Criteria, which determined the resolution required of a system to perform certain target interpretation processes (direction, shape orientation, shape recognition, detail recognition, and target identification) (Donohue, 1991). Johnson ultimately found that as the number of cycles, or scans, across a target increased, that the probability of the observer successfully locating the target also increased (Sjaardema, Smith, & Birch). One of the big shortcomings of this model was that it did not take into account several other factors regarding the target, observer, and overall scene/environment such as clutter, or anything in a scene that was not of interest to the observer (Donohue, 1991). To close this gap, the Targeting Task Performance Metric (TTPM) was developed, which aimed to represent the entire frequency spectrum of the image, as opposed to the Johnson Criteria, which could only determine the performance of the imager solely by the highest spatial frequency visible at the average target-to-background contrast. This TTPM model was able to be applied directly to sampled imagers and to imagers that exhibit colored (spectrally weighted) noise due to frequency boost; which was not possible with the previous Johnson Criteria (Vollmerhausen, Jacobs, & Driggers, 2004). Although this TTPM model was more accurate and versatile than the Johnson Criteria, it was very computationally complex and therefore not ideal for combat simulations. Around the same time, the ACQUIRE-LC model was developed to predict detection probability for vehicle sensors against camouflaged targets but has been recently modified to work for human STA against conventional targets. This model is a signal-to-clutter detection model, where the performance of a human-sensor pair can be characterized as a function of "complexity," or clutter (Driggers et al., 2006). Finally, the model that is currently used in simulation tools like IWARS and OneSAF, is a combination of the TTPM and ACQUIRE-LC models - called ACQUIRE-TTPM. This model first uses the Target Acquisition Draw Methodology (TADM) to later compare to the TTPM output (P-infinity) to determine if detection is possible. The model then uses the TTPM calculations to determine the P-infinity values, the time to detect, and ultimately the level of acquisition is achieved (detection, force call, or correct force) (Target Acquisition and Misidentification ACQUIRE-TTPM-TAS PKAD, 2012 and IWARS Methodology Guide, 2010).

2. Methodology

In order to gain an understanding of the STA protocol within IWARS, an Excel model that replicated the IWARS ACQUIRE-TTPM algorithms was created. Next, the model was validated by running a simple scenario in IWARS where one Blue and one Red Force agent faced one another, at a distance of 300 meters. The output of this scenario was gathered through the IWARS application Batch Run Analysis and Simulation Studio (BRASS) and was compared to the output of the model created with the same environmental and scenario parameters. IWARS is a compiled computer program. Therefore, without analyzing source code, which was not available, it was not possible to verify the exact logic of the implementation of STA algorithms in IWARS. However, using the IWARS Methodology Guide and Target Acquisition PKAD, it was possible to duplicate the algorithm. Table 1 shows the results of an Excel based duplication and the IWARS BRASS output. It is evident from the table that the two models compare well. Without examining source code, it can only be assumed that the slight differences result from round-off error or subtle source data differences.

Table 1. Model Verification

BRASS Output from IWARS				Output from Excel Model			
Acquisition Level	V/V50 Ratio	Pinfinity	TTPM	Acquisition Level	V/V50 Ratio	Pinfinity	TTPM
Detection	2.8348	.9074	6.2055	Detection	2.8358	.9075	6.2555
Force Call	1.5749	.7021	6.2055	Force Call	1.5755	.7023	6.2555
Correct Force	1.0903	.5382	6.2055	Correct Force	1.0907	.5384	6.2555

Following this exploration and development of the teams understanding of the ACQUIRE-TTPM methodology, an assessment was conducted on how well IWARS represents the human process of search and target acquisition. In order to complete this assessment three functional hierarchy diagrams were created. Figure 1 shows the hierarchy for how a soldier performs specific tasks, focusing on the acquisition of a target. Two more functional hierarchy diagrams were created, breaking down how a target is acquired by a human and how a target is acquired in IWARS. Figure 2 shows the functional breakdown of human STA, while Figure 3 shows the breakdown of IWARS STA. These two hierarchy diagrams were compared to identify gaps where human STA is not appropriately represented in the IWARS methodology.

The Soldier as a System
Fundamental Objective: Perform Soldier Tasks
1. Acquire Target
  1.1 Search FOV
  1.2 Identify Object in FOV
  1.3 Gather Information About the Object
  1.4 Determine Threat Level of Object
2. Shoot
3. Move
4. Protect
5. Sustain

Human STA System
Fundamental Objective: Acquire Target
1. Search FOV
  1.1 Quickly Scan Entire FOV
  1.2 Scan FOV in order of potential threat
2. ID Object in FOV
  2.1 Identify Threat in a FOV or Move to Next Threat
3. Gather Info About the Object
  3.1 Fixate on Object
  3.2 Identify Characteristics of Object
4. Determine Level of Acquisition Achieved
  4.1 Process Gathered Information
  4.2 Determine How Much Info is Known About the Object (Acquisition Level)

IWARS STA System
Fundamental Objective: Acquire Target
1. Search FOV
  1.1 Search all FOVs in FOR for equal time
  1.2 Determine T(FOV)
2. IF Object in FOV
  2.1 Use scenario information to determine probability of detection
  2.2 Determine if an object is detected in FOV
  2.3 Determine T(DET)
3. Gather Info About the Object
  3.1 Use random numbers to identify characteristics of object
4. Determine Level of Acquisition Achieved
  4.1 Determine how much info is known about the object (acquisition level)
  4.2 Repeat IOT attempt to achieve higher acquisition level

Figure 1. Functional Decomposition of Relevant Systems

3. Results

Once functional decomposition was conducted and functional hierarchies were created for each of the three systems, the functions of the human and IWARS STA systems were compared in order to determine gaps in IWARS' representation of the human STA behavior. Through this analysis, three gaps were identified with: (1) field of view search, (2) identification in a field of view, and (3) information acquisition and situational awareness. For each of the identified gaps there is a brief explanation of the problem, followed by a recommended solution.

3.1 Field of View Search

Humans search a given area by quickly scanning their entire Field of Regard (FOR), then scanning their smaller Field of Views (FOVs) by order of potential threat. Additionally, if there is a distinct target within an observer's FOR, it immediately appears during search due to preattentive processing and automatically become the focus of the observer's attention (Treisman, 1986). The time the observer spends searching each FOV is subconsciously determined by how likely they believe a threat to be within an area (Evangelista, Darken, and Jungkunz, 2011). In IWARS, the searching behavior is represented by the agent searching each FOV in their FOR for an equal amount of time in a "windshield wiper pattern", determined by 6.8 divided by the ratio of V/V50 values for detection (IWARS Methodology Guide, 2010). This windshield wiper pattern method is not representative of how a human searches an area. This method does not take into account the unequal likelihood of a threat among all FOVs. Instead, humans search by spending more time searching locations they deem more likely to have threats and making their way through their FOR by continuously looking through these areas (not just a sweep from left to right or vice versa). This gap can be supported through the eye tracking data collected in "Modeling and integration of situational awareness and soldier target search" (Evangelista, Darken, and Jungkunz, 2011). This data showed that in general the agent's focus is towards the center of the FOV, then they search by spreading out from the center to more obvious targets and threatening areas. It showed that the agent continuously looks over the areas they have deemed to be most threatening as they broaden their search. This data supports the claim that the way IWARS represents STA by having the agent search each FOV in their FOR for an equal amount of time, in a windshield wiper pattern, is not representative of how humans search and acquire targets.

In order to incorporate the results of this study and others like it, one could modify the search behavior in IWARS by having the agent default to the center of their FOR, then broaden their fixations to areas with more clutter and therefore a higher chance of having a threat. The time spent in each FOV could be determined by using a random number to determine the average time, then add or subtract a proportion of that time for each FOV based on the level of clutter/probability of a threat.

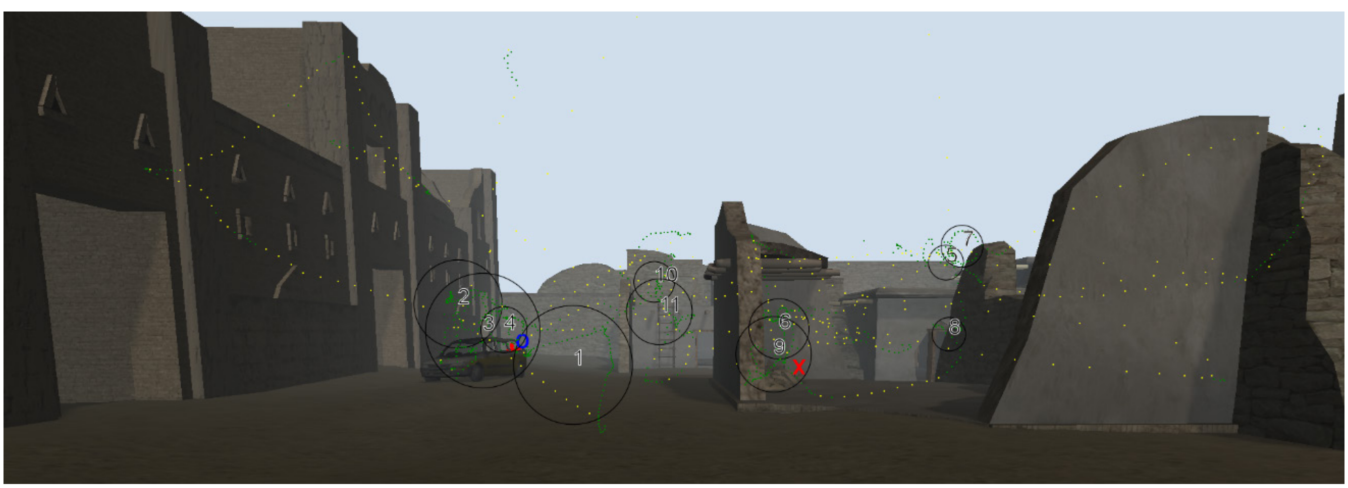

Figure 4. Sample Image from STA Eye Tracking Data (Darken, Evangelista, and Jungkunz, 2011)

3.2 Identification of an Object in a Field of View

When dealing with the identification of an object in a field of view, humans are rather straightforward. They either identify an object in their FOV or move on to the next FOV. In IWARS, however, scenario information and random numbers are used to determine the probability of detection, whether or not detection occurs, and the time it takes to detect the object. IWARS' use of scenario information to determine the probability of detection or ability of the agent to detect the object in the given scenario is appropriate. However, IWARS' use of random numbers to determine whether or not the agent will identify the object and how long it will take, is not appropriate. Human observers do not have a random probability regarding whether or not they will detect an object. Instead, humans utilize battlefield cues, to increase their ability or likelihood to detect an object (Sutherland, 2010). The presence of these battlefield cues causes an observer to identify an object much easier and quicker than when they are not present. Therefore, the presence of these battlefield cues makes detection more likely, and therefore inherently not random. By using random numbers to determine the probability of detecting an object in an observer's FOV, IWARS does not accurately represent how a human naturally conducts STA through the use of battlefield cues.

In order to better represent human STA, battlefield cues and how human agents react to them should be implemented in the IWARS database appropriately. For instance, the observer's search behavior should be programmed to direct their attention toward perceived battlefield cues such as a muzzle flash, sound of gunfire, target marking, etc. in order to increase their probability of detection.

3.3 Information Acquisition and Situational Awareness

After a human observer has searched an area and detected an object, they gather information about the object by fixating on it and identifying its important characteristics. Identifying important characteristics allows humans to determine how much information is known about the object (the acquisition level). Unlike a human, IWARS uses random numbers to identify characteristics of the object in order to determine the acquisition level. This process is then continuously repeated while there is a perceived threat in an attempt to achieve a higher acquisition level. Human observers do not have a random probability regarding what level of acquisition they reach. Rather, humans continuously gather more information about an object. As the amount of knowledge increases, so does the probability of reaching a higher level of acquisition (Sutherland, 2010). The use of random numbers to identify characteristics of an object is not the most appropriate way to represent the chance of a human observer reaching each level of acquisition.

IWARS should implement evolving gained knowledge of a target. In doing so, the probability of reaching a higher level of acquisition would increase as the observer gains more information about the target. Instead of using random numbers to determine the level of acquisition achieved, the information the observer knows about the object should be stored and built upon as well as programmed to equate to higher levels of acquisition based on the known object characteristics. For instance, the simulation tool should automatically equate knowledge such as a human sized figure that is showing hostile activity with force call (the second level of acquisition). Once this information is gathered, it should be stored so that when the observer identifies additional characteristics it can build upon this prior knowledge and therefore achieve a higher acquisition level quicker.

4. Conclusion

The presented research provides four main contributions: (1) synthesis of literature, (2) an algorithmic exploration of STA protocol within current simulation tools, (3) a functional analysis of the Soldier, human STA, and IWARS STA behaviors, and (4) identification of gaps and proposed solutions for the representation of human STA behaviors in simulation. Gaps were identified in the processes of FOV search, identification of an object in a FOV, and information acquisition and situational awareness. In order to resolve these gaps, the current algorithms need to be enhanced to incorporate modified searching behaviors, battlefield cues, and evolving knowledge of a target. Through analysis, portions of the STA protocol that need to be improved to be more representative of human behavior based on accepted research were identified. Additionally, one component, the method of FOV search, clearly violates principles of accepted research. Therefore, it Is recommended that efforts to improve STA protocol in accredited simulation tools focus on the modification and improvement of the FOV search behavior as previously discussed. The improvement of the FOV search behavior, as well as the other identified gaps, is instrumental to the creation of a more accurate representation of human STA within simulation tools.

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6. Citations and References

Alaways, LeRoy & Watkins, Wendell R. (1999). *Depth Perception Applied to Search and Target Acquisition*. Utrcht, The Netherlands: RTO MP-45.

Darken, Christian J., Evangelista, Paul F., & Jungkunz, Patrick. (2011). *Modeling and Integration of Situational Awareness and Soldier Target Search*. Monterey, California: Institutional Archive of the Naval Postgraduate School.

D. E. Schmieder and M. R. Weathersby, "Detection Performance in Clutter with Variable Resolution," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-19, no. 4, pp. 622-630, July (1983).

Donohue, J. (1991). *Introductory review of target discrimination criteria* (No. E-19290U). Dynamics Research Corp Wilmington, Ma.

Driggers, R. G., Jacobs, E. L., Vollmerhausen, R. H., O'Kane, B., Self, M., Moyer, S., ... & Kistner, R. (2006, May). Current infrared target acquisition approach for military sensor design and wargaming. In *Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XVII* (Vol. 6207, p. 620709). International Society for Optics and Photonics.

"Introduction," *IWARS 5.1 User Guide.* April (2014).

IWARS Methodology Guide. Version 2.0.6. (2010)

Jones, Daniel B. (1974). *Air-to-Ground Target Acquisition Source Book: A Review of Literature*. Alexandria, Virginia: US Department of Commerce.

Najemnik, Jiri & Geisler, Wilson S. (2010). *Eye Movement Statistics in Humans are Consistent with an Optimal Search Strategy*. Bethesda, Maryland: National Institutes of Health.

Sjaardema, Tracy A., Smith, Collin S., & Birch, Gabriel Carisle. History and Evolution of the Johnson Criteria. (n.d). United States.

Sutherland, D. M. (2010). *Identification of Soldier Behaviors Associated with Search and Target Acquisition (STA)* (No. Natick/Tr-10/010). Army Natick Soldier Research Development and Engineering Center Ma.

Target Acquisition and Misidentification ACQUIRE-TTPM-TAS. Physical Model Acquisition Document (PKAD). (2012). (U.S. Army Material Systems Analysis Activity, Aberdeen Proving Ground, Maryland).

Treisman, Anne. (1986). *Features and Objects in Visual Processing*. New York: Scientific American, Inc.

Vollmerhausen, R. H., Jacobs, E. L., & Driggers, R. G. (2004). New metric for predicting target acquisition performance. *Optical Engineering*, *43*(11), 2806-2819.