Transparency of Military Threat Evaluation through Visualizing Uncertainty and System Rationale

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Abstract. Threat evaluation (TE) is concerned with determining the intent, capability and opportunity of detected targets. To their aid, military operators use support systems that analyse incoming data and make inferences based on the active evaluation framework. Several interface and interaction guidelines have been proposed for the implementation of TE systems; however there is a lack of research regarding how to make these systems transparent to their operators. This paper presents the results from interviews conducted with TE operators focusing on the need for and possibilities of improving the transparency of TE systems through the visualization of uncertainty and the presentation of the system rationale.

Keywords: Automation transparency, threat evaluation, trust, uncertainty visualization, system rationale.

1 Introduction

In military settings, it is crucial that the decision makers, such as fighter pilots and command and control operators, have a good view of the current and evolving situation to be able to defend important assets, civilians and military personnel. As such, TE is an ongoing process that involves the determination of the intent, capability and opportunity of detected targets, i.e. what the targets intend to do, if they have sufficient resources to inflict harm and whether the context makes it possible for the targets to carry out their tasks [1-3]. Further, the TE process includes a classification of potential threats into categories (such as high/medium/low threat) along with a prioritization of these according to how much threat they pose to the defended asset(s) [2, 4]. However, in data-intensive and time-critical situations, military operators might find it difficult to perform these threat evaluation activities fast and with high quality, and incidents have occurred. For example, in 1988 the US Navy Cruiser USS Vincennes launched two missiles against what they believed was a hostile Iranian Air Force military aircraft in attack mode, when it was in fact an Iranian passenger airliner [5]. Another incident took place in 2003 where one British Royal Air Force Tornado GR4A was misclassified as hostile and shoot down by a US Army Patriot Surface-to-Air-Missile [6]. Several causes have been listed as contributing to these incidents – inexperienced crew, lack of time, insufficient data quality, failure of the

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battle management system, classification criteria, rules of engagement and malfunction of the identification system [6, 7]. To avoid additional incidents, further development of computerized support has been recognized as crucial for aiding military operators perform their tasks (see for instance [2], [8, 9]). However, reports from various domains indicate that there are positive and negative effects of implementing computerized support systems, such as improved situation awareness and decreased workload on the one hand, but skill degradation and complacent behaviour on the other (see for instance [10-12]). As such, it is important to develop systems that provide appropriate support for the operator, that are easy to use and that the operator can trust. As discussed by [13], the possible severe consequences of making a wrong decision related to threat evaluation can result in that the operator becomes overly concerned with the risks associated with a course of action and, as such, will unlikely accept a system recommendation if he/she does not fully understand it or if the recommendation is different from the ones already considered by the operator. Thus, it is of utmost importance that the system generates and visualizes high quality recommendations along with a rationale for the recommendations generated [13]. This characteristic is termed *system transparency*, which implies that the system operators are able to easily use and understand how a system works (see [14, 15]). Important to note is that system transparency can take many forms – it can for example be associated with the underlying reasoning models used by the system, the input/output data, how to use the system as well as the system performance. To achieve improved system transparency, several researchers have investigated the effects of presenting additional meta-information regarding the inferences performed by the support systems on operator performance, such as the uncertainty associated with any system generated recommendation or by providing explanations to the behaviour of the system (see for instance [16-18]). For example, in the study presented in [18], it was revealed that the presentation of system confidence information aided the operators to more appropriately calibrate their trust in the system used. In the TE domain, where military operators have to rapidly analyse large amounts of possibly uncertain and contradictory data from multiple sources, we believe that the visualization of uncertainty and the system rationale can be of great importance for improved operator trust in the system used and better operator performance.

As a first step towards improving the transparency of TE systems, we argue that TE systems must include visualizations of the uncertainty associated with relevant pieces of threat information, as well as provide a rationale for the threat values suggested by the system. We believe that this is a challenging domain for such visualizations due to the massive amounts of information available and the fast-paced decision situation for the operator, making it imperative to investigate suitable information visualization representations. Further, it is believed that the importance of uncertainty visualization within this domain will become crucial due to improvements in sensor capabilities, making it possible to detect objects at farther distances, however with varying degrees of information quality, which must be conveyed to the operator. We anticipate that the visualizations of uncertainty and recommendation rationale will positively affect the performance of operators of TE systems, as well as lay a foundation for better trust in the TE systems used. To investigate this, the current paper presents interviews conducted with operators of TE systems where their perceived needs for system transparency were collected and analysed. The paper is organized as follows: section 2 provides background material related to threat evaluation and support system transparency. Section 3 presents the study setup and results, whereas section 4 summarizes and discusses the results obtained. Finally, section 5 outlines the conclusions drawn from the study as well as our ideas for future work.

2 Background

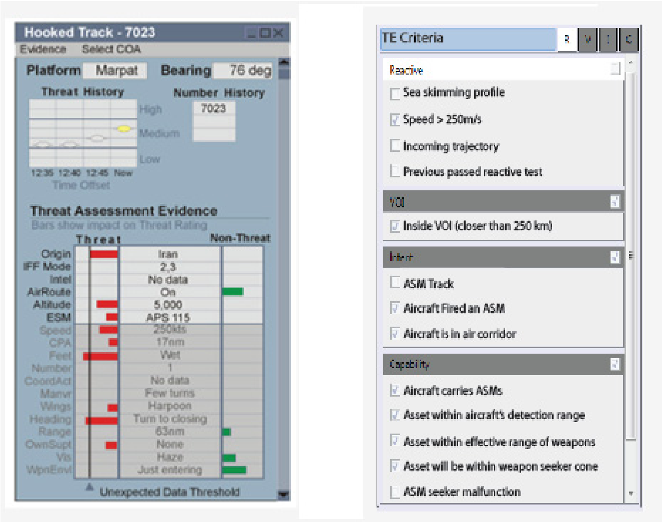
To evaluate threats, military operators have to analyze large amounts of data from multiple sources, which might be uncertain and contradictory as well as valid for only a short period of time. Uncertainty is prevalent due to, for example, the unpredictability of the behavior of the threats as well as due to imperfection of the information sources available. Time is also an important factor in the TE process due to the fast-paced tempo of the decision and action activities that must be performed. As stated by [8], the process of TE is cognitively challenging under usual conditions, and possibly worse under extreme conditions due to factors such as time, stress, short-term memory requirements and multi-tasking demands. In [8], the results from a task analysis performed together with military operators working in the maritime domain regarding how they perform their threat evaluation tasks is presented. Their results indicate that during a threat evaluation process, the operators formulate a hypothesis regarding the observed object by activating a threat profile that corresponds to the type of object that has been observed. Depending on the type of object and its behaviour, the operators can draw conclusions regarding the object's intent, capability and opportunity to harm the defended asset(s). During this evaluation process, it was found that the operator searches for evidence that confirms to the activated threat profile, but often fails to accommodate evidence that contradict the hypothesis. This is in line with research regarding naturalistic decision making (see [19]), where studies of human decision making in stressful, dynamic and uncertain environments have been conducted and where it has been found that decision makers perform poorly when it comes to recognizing contradictory information. Furthermore, due to the challenging decision situation where military operators must make decisions fast, the operators are prone to make errors and are often susceptive to biases [2]. As such, it is believed that transparency of TE support systems in terms of the reliability of the recommendations generated will have a positive effect on operator performance [2].

A feeling of system transparency can be achieved during operator training with the system, but also during system usage through explaining the inferences made and the recommendations generated. Such explanatory capacity of a system has been highlighted as crucial for appropriate confidence in and usage of a system (see for example [20, 21]). However, explanatory functions are seldom incorporated into automated systems. In [18], it is argued that support systems often present the operator with a diagnosis or solution to a problem with little or no explanation or qualification, which places the operator in a position where he/she must fully accept the system's advice or perform the entire decision making process on his/her own, often under time pressure and in critical situations. Yet, there are exceptions. For example, in the study presented in [22], it was revealed that the presentation of information regarding the performance of the system used to aid novice and expert command and control operators respond to battlefield threats through resource allocation indeed positively influenced the operators' trust and usage of the system. When indicated that the system was not performing reliably, the operators in the study appropriately adjusted their trust in the system through discarding the system recommendations. However, just like trust, there is a balancing act between too much and too little system transparency. A fully transparent system can result in operator information overload, causing high workload and reduced situation awareness [23]. However, at the other extreme, a system that does not provide information or adequate feedback regarding the system behaviour may lead to reduced workload, but at the cost of transparency which in turn can result in diminished situation awareness [23]. Hence, the result of not analysing appropriate ways of achieving system transparency might have severe effects on operator performance and trust.

Two studies were found during a literature search where interface and interaction guidelines for TE systems are discussed (see [2, 8] for more information). Amongst these guidelines, the importance of providing the TE operators with the cues used in the automatic reasoning of the system together with an explanation of the system generated recommendations is highlighted. For example, in the prototype presented in [8], evidence and counter-evidence with regard to the estimated threat level of an object is graphically represented and in [2], the TE criteria fulfilled by a detected object is presented to the operators (see Fig. 1). However, neither of these studies investigated ways of visualizing uncertainty or how to improve the transparency of the TE system used through providing a more detailed system rationale in terms of the degree to which a detected object fulfills the TE criteria. We argue that such visualizations could further improve the transparency of TE support systems. The next section presents results from interviews conducted together with operators of TE systems, focusing on the needs for improving the transparency of TE systems as well as possible ways of achieving such transparency.

3 Study

To investigate possible ways of making TE support systems transparent, semi-structured individual interviews were conducted with four active operators of air defense TE systems. The participants were between 25–35 years old and were all well accustomed to using TE systems. In this paper, we report on the findings regarding the necessity and willingness of the participating TE operators to recognize and interact with the uncertainty associated with the data presented and the rationale behind the system recommendations.



a) b)

Fig. 1. Parts of TE screenshots displaying a) evidence and counter-evidence of a threat rating of an object and b) the criteria fulfilled in the threat evaluation (from [8] and [2])

3.1 Dealing with Uncertainty

The participants in the study argued that they constantly perform actions to decrease the uncertainty associated with the current and evolving situation, such as uncertainties regarding the type of object detected and its altitude. However, such uncertainty is not displayed to the operators. Instead, the operators have to constantly analyze incoming data, redirect the sensors used and communicate within the military teams to create a good situational picture with little/no uncertainty. Yet, uncertainty is often prevalent due to countermeasures used by the adversary, making the reliability of the sensor data non-sufficient for performing evaluations with adequate quality. To more easily identify the sources of uncertainty, the participants in the study were positive towards being presented with the uncertain parameters, especially those that have a large impact on the calculated threat value, in close proximity to the target symbol on the map view of the TE system. In the same spirit, the participants argued that being presented with a summary of the variables that fulfill/do not fulfill the evaluation criteria would aid them to make better estimations of the evaluations performed. This is in line with the research presented in [8] where the importance of highlighting evidence and counter- evidence associated with the threat level of an object was reported. However, to not overwhelm the operators with too many variables presented simultaneously, the participants argued that the visualization of uncertain parameters with non-crucial impact on the generated threat value should not be default, but be easily extracted through navigating the menus of the TE system. As such, the participants argued for the default presentation of both an overview of the uncertainty associated with a calculated threat value on the map view of the TE system, including the uncertain parameters that have a large impact on the calculated threat value, as well as an optional, easily accessible detailed presentation of the uncertainty associated with the participating variables in the threat evaluations.

During the interviews, it became evident that it is not only large uncertainties that are of importance when making decisions in the TE domain, but also smaller ones. If the uncertainty regarding an important parameter used in the threat evaluation is too large, the operators will most often be forced to perform time-consuming data collections and analyses before making a decision due to the risk of fratricides. However, in the case of small uncertainties, the operators will have the opportunity to rely on their own experience and analytical expertise in order to deduce the most appropriate decision and action. As such, the visualization of small uncertainties must be further examined in the TE domain.

3.2 Transparency of TE Model

There are various models that can be used for TE (see [24] for more information). A common technique is the one based on rules where threats are prioritized according to their level of rule and parameter threshold fulfillment, for example "if SPEED=X and ALTITUDE=Y then THREAT=Z". Further, these rules and parameters can be weighted differently according to their presumed importance for the threat level of an object in different situations. In [2], the fulfillment of TE criteria used as a base for the evaluations performed is indicated by marking the corresponding "criteria fulfillment box". However, to which degree these criteria influence the threat evaluation is not presented – for instance, are the criteria met by far or just by passing the threshold value and how much does a single parameter influence the resulting threat value? During the interviews performed, the participants argued that such indication would aid them to more appropriately calibrate their trust in the system used as well as improve their understanding of the inner workings of the system. Furthermore, the participants in the study argued that the indication of rule/criteria threshold fulfillment and knowledge of different parameter weights in the evaluation process would also be useful when testing the sensitivity/insensitivity of different TE rule and parameter setups, which would further improve their understanding and usage of the TE system. As argued by one of the participants, knowledge of this kind could, for example, aid TE operators to understand quick fluctuations in threat values as well as identify where uncertainties exist in order for the operators to make their own estimation of the evaluations performed.

4 Discussion

The TE operators interviewed were positive towards having interactive representations of the uncertainty associated with the data as well as being presented with more detailed information regarding the system rationale behind the threat values automatically assigned to the targets. As such, the interviews have provided initial results regarding how the transparency of TE systems can be improved based on the systems

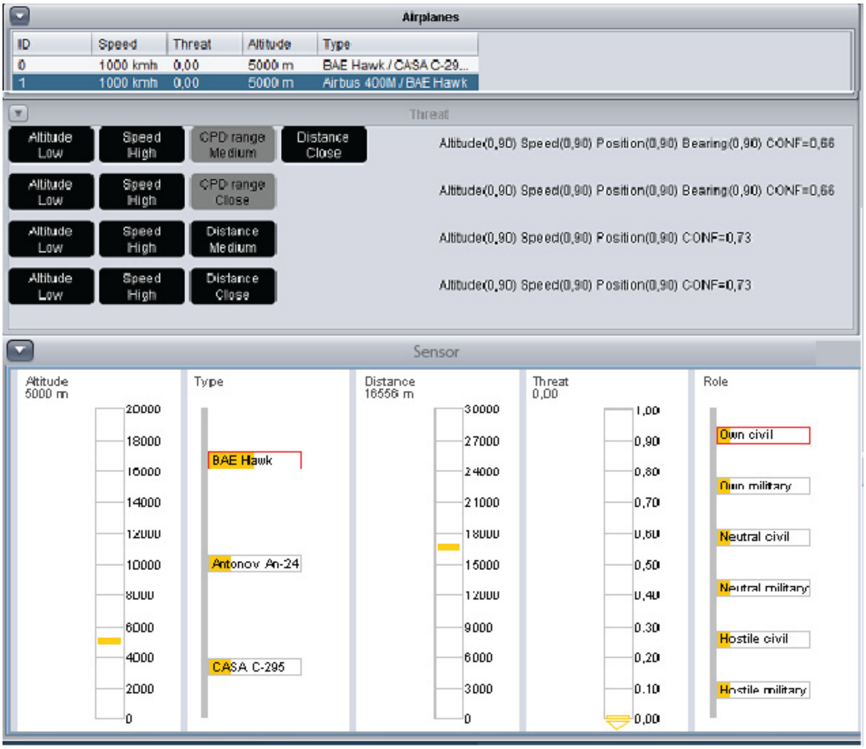


Fig. 2. A first version of the TE prototype, depicting possible in-depth visualizations of uncertainty through using intervals as well as TE criteria fulfillment with associated confidence measures

described in [8] and [2]. However, more research is needed regarding suitable ways of representing the uncertainty associated with the automatic evaluations performed. Several approaches toward visualizing uncertainty have been proposed in various domains. In [25], different techniques are listed, such as to use colors, edge crispness and transparency of graphical variables. However, as argued by [26], these techniques have not been empirically evaluated and it is not obvious how to select between them or how to integrate them. As such, it is imperative to investigate different representations in the domain of interest to be able to choose a visualization that appropriately reflects the uncertainty associated with the data used and that aids the operators make sense of the data. One representation of uncertainty that seems promising in the TE domain is the one based on intervals. Intervals were used to convey uncertainty within the engineering domain in a study performed by [17], with good results. We believe that this representation can be suitable in the military domain as well due to the importance of making it possible for the operators to receive a quick overview of the data collected, as well as to be able to quickly understand (on a more detailed level) where the uncertainty stems from, due to the importance of having a good awareness of the situation.

Further investigations are also needed in relation to finding suitable interaction formats between the TE operators and the models used for TE. Several TE models have been proposed, such as rule-based, fuzzy logic and graphical models (see [27]), which all have different possibilities and delimitations in their interactive capabilities. As such, empirical investigations together with TE operators are needed in order to establish appropriate interactions with and visualizations of the TE models. For example, should threshold values for incorporated TE criteria be determined by establishing fixed values that must be met, or by having gradually overlapping values, such as in the case with fuzzy logic? Or is it the cause-and-effect relations between the variables that provide the most valuable information about the TE process to the operators, as possibly represented through graphical models? It may also be the case that the suitable interaction and visualization formats depend on the planned usage of the TE system, for example during training sessions, system setups and as well as during battles.

As a first step towards investigating suitable visualization and interaction formats requested by TE operators, a TE prototype has been implemented. Fig. 2 depicts the first version of this prototype where the suggested interval representation for conveying the uncertainty associated with the individual parameters used in the TE process is illustrated. Furthermore, the figure shows one possible way of indicating which TE criteria that have been fulfilled as well as the confidence associated with these criteria.

5 Conclusions and Future Work

The results from the interviews carried out together with TE operators indicate that the transparency of TE systems can be improved in several ways. This paper has focused on increasing the TE system transparency through the visualization of uncertainty and through proving the operators with additional details regarding the rules and parameters used in the evaluations. Future work will include a series of evaluations of different ways of visualizing the uncertainty associated with the results generated by the TE support system. These evaluations will focus on which types of uncertainties should be presented to the operators, at which level of abstraction and in which situations. Future work will also include an evaluation of different recognized TE models in terms of their interactive and transparent capabilities and delimitations. Further developments of the TE prototype will be carried out and used in simulator settings together with TE operators in order to evaluate the effects of different visualizations and interactions on operator performance, decision making and trust in the TE system. A similar study will also be conducted in the fighter aircraft domain, where the impact of different visualizations of uncertainties and system rationale on the fighter pilots' trust in the system and performance will be evaluated.

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