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The need for separate operational and engineering user interfaces for command and control of airborne synthetic aperture radar systems

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ABSTRACT

In this paper, we address the needed components to create usable engineering and operational user interfaces (UIs) for airborne Synthetic Aperture Radar (SAR) systems. As airborne SAR technology gains wider acceptance in the remote sensing and Intelligence, Surveillance, and Reconnaissance (ISR) communities, the need for effective and appropriate UIs to command and control these sensors has also increased. However, despite the growing demand for SAR in operational environments, the technology still faces an adoption roadblock, in large part due to the lack of effective UIs. It is common to find operational interfaces that have barely grown beyond the disparate tools engineers and technologists developed to demonstrate an initial concept or system. While sensor usability and utility are common requirements to engineers and operators, their objectives for interacting with the sensor are different. As such, the amount and type of information presented ought to be tailored to the specific application.

Keywords: Synthetic Aperture Radar (SAR), Intelligence, Surveillance, and Reconnaissance (ISR), Usability, Human-System Integration (HSI)

1. INTRODUCTION

SAR is powerful sensor that has the potential to revolutionize airborne ISR missions. Multi-mode SAR's ability to operate irrespective of weather and daylight cover a crucial capability gap in airborne ISR missions. This theoretical utility is acknowledged across the ISR community, and SAR sensors are increasingly joining the standard suite of sensors on ISR platforms. Operationally, however, SAR is often overlooked in comparison to other tools, even when the situation is ideally suited for SAR operations. A significant contributor to this under-utilization is the lack of an effective user interface. SAR is a complex technology, and often the interaction model presented by its interface is rooted in an engineer's need to interact with the SAR system as it is being developed to verify and validate technical performance. SAR Operators also need to interact with the system, but in a way that enables them to accomplish their mission, not in a way that requires they learn the physics and signal processing behind the technology. A UI that fails to appropriately abstract away those details is a UI that will limit or prevent a user from adopting that sensor. As this case study presents, the blending of engineering and operational UIs are a major cause of error and misuse of SAR in operational ISR missions. When these functions are separated, the utility and usability of the SAR sensor significantly increases.

1.1 Overview

In this paper, we discuss the results of an ongoing, iterative, design-implement-and-evaluate software engineering project that is establishing principles for usable and useful interfaces for deployed radar systems. Our team includes software engineers, human-computer interaction designers, and SAR radar engineers from Sandia National Laboratories and General Atomics Aeronautical Systems, Inc. One of the key discoveries of this project was the awareness of a wide range of users who interact with radar systems. These unique classes of users have different reasons for interacting with radar, and consequently develop different mental models of the system. To illustrate this finding we focus on one key operation, Moving Target Indicator (MTI) mode, to describe the different interactions and mental models associated with radar operators and radar engineers. Using straightforward usability heuristics, we explain how the blending of operational and engineering mental models impacts usability of the Lynx radar, and provide guidance for redesign of the mode to separate the needed functionality for effective radar operation. We close with advice for engineers who are developing systems for non-domain expert users to ensure that systems are learnable.

2. PROJECT CONTEXT

Sandia National Laboratories and General Atomics have engaged in a multi-decade partnership to advance the performance of airborne SAR systems. This partnership has been primarily focused with enhancing the Lynx family of radar systems, but has recently expanded to include the evaluation and design of the human-machine interface associated with these sensors. In 2015, GA and Sandia partnered to investigate and evaluate complaints raised by the ISR community against the usability of operational radar interfaces. Over the ensuing 18 months, GA and Sandia collaborated on this project, culminating in a usability evaluation of two radar operator interfaces, and concluded with providing redesign guidelines to ameliorate the issues that were uncovered during this effort. The two interfaces will be referred to as Interface A: an existing operational radar interface; and Interface B: an operational radar interface designed using established software usability guidelines, and findings from the user community. A key finding of this work was the discovery that unique mental models pertain to different user communities, and that experience bias prevents engineers from realizing how their constructs may not apply to operators.

3. UNIQUE MENTAL MODELS FOR OPERATORS AND ENGINEERS

Radar engineers and operators develop unique mental models interacting with SAR. As such, the interface with which they interact with the system should be tailored to present the necessary and sufficient information to build and enhance that model, and enable them to accomplish their objectives. When this construct is not followed, the consequence results in high error rates and unsuccessful use of the sensor by the operator.

SAR radar operators generally approach SAR from the perspective of using the technology in the context of accomplishing their mission. They are generally tasked with executing against a set of collection requirements, and conducting a cursory inspection of the resulting products. Presenting the modes and capabilities of the SAR system with terminology and language common to the user the community helps build the mental model the user will develop when planning and executing a mission. An example to demonstrate this concept is the Moving Target Indicator (MTI) mode. This radar mode detects moving objects and overlays those detections on a map or SAR image. This mode offers great utility to reconnaissance missions, where the objective is to obtain situation awareness in a dynamic ground environment. An operator's mental model of MTI is built around answering questions such as: "what type of activity am I looking for?" and "where do I think this activity is located?"

SAR radar engineers are generally concerned with verifying and validating the radar's operational performance against the system's theoretical design envelope. Their mental model is built by interacting with foundational parameters of the radar, and observing the change in its performance or capability as a result. This interaction will occur anywhere from initial system development, to testing of new features, to initializing the range of a given parameter that an operational user may select. Continuing with the MTI example, an engineer's mental model of this mode is built around technical concepts such as scene and target reflectivity, antenna gain, and pulse repetition frequency. Observing how a change to one or more of these variables influence the radar's ability to discriminate between the returns of a moving target from the returns of ground clutter enhances the engineer's understanding of how this mode functions.

4. MOVING TARGET INDICATOR EXAMPLE

This section of the paper illustrates how assuming an engineering/physics mental model makes it difficult for operators to learn and remember how to use an interface. We describe how one implementation of the MTI functionality was problematic and then use basic principles from software usability to explain *why* that implementation was problematic. Then we discuss how these principles were used to inform the re-implementation of the mode, before discussing findings from an experimental usability evaluation of the system in Section 5.

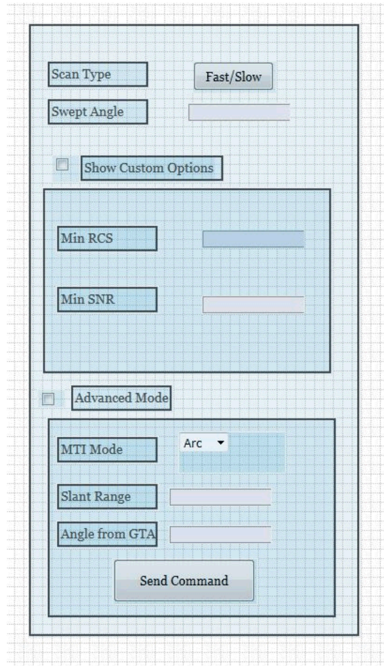

Figure1. Wireframe of MTI command panel in Interface A.

Figure 1 is a wireframe of the MTI mode command panel in Interface A. The interaction model of this interface required the operator to engage with the following elements:

1. Scan Type. This pushbutton provided two options: 'Fast' and 'Slow.' A more appropriate label for this element would be Scan Speed, and indirectly, is dependent on the size of the object the operator desires to detect. The expectation was that the user would select 'Slow' for the smallest detectable objects, such as human foot traffic. The 'Fast' option was for detecting all other objects.
2. Swept Angle. This user editable field afforded the operator to change the effective area on the ground over which the radar transmitted energy. This parameter, along with scan speed, influences the ability of the radar to repeatedly detect an object as it moves through the area being interrogated. This field offered no constraints on the entered values; in fact, operators were able to enter values such as 360 degrees, values that were beyond the physical limits of the radar.
3. Show Custom Options. This check box expands a sub panel of items: Min RCS and Min SNR.
4. Min RCS. Radar Cross Section (RCS) is an engineering variable that quantifies the amount of radar energy that a given target reflects back to the radar.
5. Min SNR. Signal to Noise Ratio (SNR) is an engineering variable that quantifies the threshold between the energy from thermal noise in the radar and the return energy that indicates a target has been detected.
6. Advanced Mode. This check box expands to present a sub-panel of items that a user must interact with to effectively command the MTI collect: MTI Mode and Send Command.
7. MTI Mode. This dropdown selection box enables the user to select one of two sub-modes the MTI mode supports: 'Spot' and 'Arc.' Spot commands the mode against a fixed location on the ground. Arc commands the mode against a fixed location with respect to the aircraft's nose.
8. MTI-Arc. When in 'Arc' sub-mode, the command panel presents two parameters to define the sub-mode: Slant Range and Angle from GTA. Slant Range is the range from the antenna phase center to the initial collect location on the ground. Angle from GTA is the angle from the aircraft's Ground Track Angle that the collect will hold as the MTI collect executes.
9. MTI-Spot. When in 'Spot' sub-mode, the command panel presents the field Geo-Location. This field does not follow any specific user interaction models, and the user can enter in a geo-coordinate in several different formats (e.g. Latitude and Longitude in degrees, minutes, seconds; Latitude and Longitude in decimal degrees;

Military Grid Reference System) or from a saved location. To access these different fields the user must click within the text box and use either the keyboard arrow keys or the mouse scroll wheel.

10. Send Command. This pushbutton sends the MTI collect information for the radar to execute.

The MTI command panel as implemented above was designed without considering the complexity of the workflow caused by its structure (or lack thereof). We examine this complexity using the Nielsen Heuristics. As discussed in a previous paper[1], the Nielsen Heuristics are ten empirically established software interaction design principles that, when followed, enable a sound foundation of interface usability.

The illogical order and intermingling of engineering terminology with which the MTI command options are presented violates the Nielsen Heuristic: Congruence between system and the real world. The ability of users to enter unrealistic values in swept angle and slant range fields, along with inappropriate default values violates the Nielsen Heuristic: Error prevention. The necessity to enter absolute values for Min RCS and Min SNR violate the Nielsen Heuristic: Recognition rather than recall. Requiring interaction with at least nine items to setup and execute the collect violates the Nielsen Heuristic: Aesthetic and minimalist design.

The MTI command panel also highlights the need for both an operator and engineering interface. The parameters 'Min RCS' and 'Min SNR' are distinct concepts that are necessary to define the MTI mode, and their values necessarily must be tailored to a specific application or objective. However, the format of these concepts as presented is not appropriate for operational control of the radar. An engineer may think about radar and MTI using those terms, but an operator thinks about MTI in the context of accomplishing representative task of monitoring for types of activity in a given location.

A target's physical cross-sectional area, the reflectivity of its material composition and surface structure, and the directivity of the radar antenna all influence the RCS of an object. To an engineer, it makes sense to conduct MTI collects while manipulating the absolute value of this variable. This is a necessary task to assess and validate the performance of the radar. However, without an exhaustive knowledge of the RCS properties for the objects of interest, or a detailed lookup table that maps absolute values to representative targets, asking an operator to supply these values is unreasonable. An operator is concerned with what is causing the activity, such as motorcycles or trucks. To support this mental model, this parameter would be best presented as target size.

Similarly, SNR is an underlying parameter in setting probability of detection and false alarm rates within the processing of the MTI detections. Engineering measurements and analysis are required to appropriately set these thresholds. Operators do not perform these measurements and do not relate the task of searching for objects with a relative brightness compared to the noise floor of the radar. An operator thinks about where activity might occur, such as inside a city or along a dirt road. Using the concept of "scene content" better correlates the technical specification of the "background" level of energy the radar should consider noise to an operational mental model.

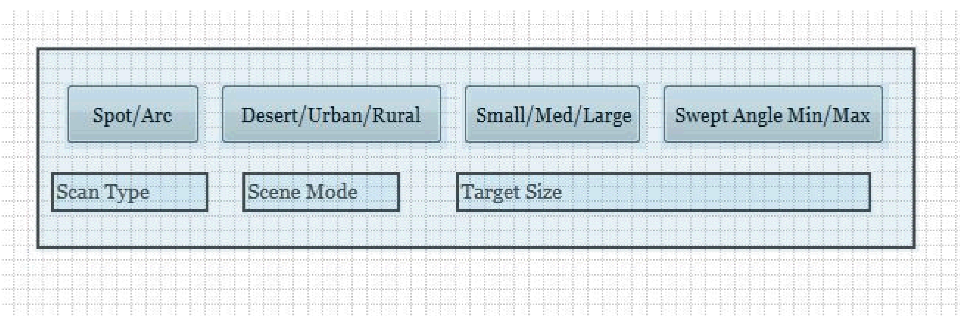

Figure 2. Wireframe of MTI command panel in Interface B.

Using the Nielsen Heuristics and the awareness of a unique operator mental model, the MTI command panel was redesigned as part of Interface B. Figure 2 shows a wireframe of the redesign for this mode.

The interaction model of this redesigned interface relies on the following elements:

1. Scan Type. This pushbutton toggles between the two sub-modes defined earlier: Spot and Arc.

2. Scene Mode. This pushbutton toggles between three scene reflectivity options: Desert, Urban, and Rural. Additionally there is a drop down option to change the sensitivity of the scene mode.
3. Target Size. This pushbutton toggles between four target size options: Small, Medium, Large, and Extra-Large.
4. Swept Angle. This pushbutton toggles between five allowable sweep angles/ revisit rates for a given target size. If the target size button value is changed, the range of values available from the swept angle button also change, keeping the allowable options of this parameter consistent with the parameter that drives the selection.

In this new interface, the number of elements has been reduced to the minimum number required to properly define the collect. The order in which a user selects the MTI options better supports the operator's mental model of thinking about the collect from the perspective of what activity they hope to monitor and the mission location. Users no longer need to recall absolute values, and instead rely on recognition of icons to make decisions. Opportunities for error have been mitigated through a discrete range of allowable options for both target size and swept angle. The engineering concepts of RCS and SNR have been transmogrified into the appropriate operational concepts of target size and scene mode. Scan speed has also been abstracted from the operator's awareness and is automatically and appropriately set based on the selected combination of target size and swept angle.

5. EXPERIMENTAL EVALUATION

In the summer of 2016, our team ran a longitudinal evaluation study to assess the operational usability of Interface A compared to Interface B. Due to the drastic differences in the interaction models between the two interfaces, we measured the overall usability of the systems using the following measures: Task completion rate, time on task, errors per task, external assistance events, NASA Task Load Index (TLX), and System Usability Scale. As part of this comparative evaluation, participants were tasked with commanding MTI collections from the command panel in. Of the users tasked with commanding an MTI Spot from the command panel, 50% correctly completed the in Interface A. 100% completed the task correctly in Interface B. Additionally, users of Interface B were on average five seconds faster at completing the task.

6. RECOMMENDATIONS

This paper presented a simple example of how differences in experience render an interface easily comprehensible or profoundly unusable. When implementing an interface for a complex sensor, it is helpful to employ basic usability guidelines such as the Nielsen Heuristics while developing the interaction model for the system. Additionally, different classes of users approach the sensor with a unique perspective, and that perspective is foundational to the perceived usability of the system. As such, the interface must be flexible to support the mental model of the user to affect a greater usability of the sensor.

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