A Virtual Assistant for Space Situational Awareness

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ABSTRACT

Virtual assistants such as Alexa/Siri are now routinely used for everyday tasks. The objective of our work is to design and develop a virtual assistant for space situational awareness (VIRSA) to support command and control decision-making during space operations. VIRSA is a domain-specific assistant that leverages existing artificial intelligence techniques to perform tasks that are time-sensitive, data-intensive, recurring, or otherwise challenging. The contributions of this paper include: identifying the highest impact initial features to develop, evaluating these features within the context of Phase I of the DARPA Hallmark program, and identifying additional assistant functionality to be developed during Phase II of the program.

1. INTRODUCTION

The complexity of space operations has increased dramatically in the past decade. Space has become an increasingly congested and contested environment as nations and commercial entities have become more and more reliant on space-based capabilities. Enhanced space-domain awareness will be necessary to manage these challenges, but the tools and processes available today will be insufficient for the future. For example, there is an abundance of information available to space operators, but it can be underutilized given the operational tempo and the complexity of decisions being made at vast distances and orbital speeds.

The objective of this project was to develop a virtual assistant to enhance decision making in space operations by (1) filtering, searching, and synthesizing heterogeneous data (2) operating both proactively in the background and on demand (3) providing tailored assistance to operators for tasks that are time-sensitive, data-intensive, recurring, or otherwise challenging, and (4) reducing operator workload with an intuitive user interface. Our requirements necessitated that the virtual assistant be tailored to real-world operational tasks, complementary to existing capabilities, intuitive, unobtrusive, quick, reliable, and convenient.

2. BACKGROUND

"DARPA's Hallmark program seeks to develop revolutionary tools and technologies to plan, assess, and execute U.S. military operations in space." [1]

One of the focus areas of the Phase I DARPA Hallmark program is the development and evaluation of testbeds and tools for space operations concepts. The participants include two testbeds, an ontology team, a number of tool teams, and two cognitive evaluation teams. It should be noted that this paper presents a narrow slice of the overall program; there are other participants in the Hallmark program and additional focus areas that are outside the scope of this paper.

Two testbeds form the technological foundation of Phase I. Each of the testbeds use a distinct cloud-based technology stack to deploy tools, support inter-tool communication, and provide access to shared data. Each testbed is also responsible for running scenarios, where realistic data is used to simulate future space situational awareness and command and control challenges.

A variety of teams developed a number of tools (including VIRSA) that visualize and analyze data to support decision-making during space operations. The tools work together in a complementary fashion to provide the full range of functionality needed on a space operations floor. All of the tools are deployed on both testbeds, requiring a flexible implementation to support the distinct technology stacks, communication methods, and data access methods.

A series of evaluation events allowed space operations personnel to test the Hallmark environment, using the testbeds, tools, and data to make real-time decisions during situational awareness and command and control scenarios. The evaluation events are significant undertakings, where scenarios were presented in the context of a simulated operations floor and staffed with personnel with real-world experience. Each of the testbeds was paired with a cognitive evaluation team responsible for carrying out these week-long evaluation events. This included providing training, supporting scenarios, measuring performance, compiling feedback and guidance for future work, and then sharing the overall results with the greater Hallmark team.

3. RELATED WORK

Virtual assistant technology for everyday life is nearly ubiquitous in modern smartphones and computers. Two of the most well-known assistants are Apple's Siri and Amazon's Alexa, both of which answer questions or performs actions as directed by the user via voice commands and audio responses. For example, a user can ask for 'brunch places nearby'. Google search is another example of a commonly used assistant, leveraging typed commands and responses displayed on a computer screen. In this case, a search for 'brunch' yields a summary of nearby restaurants, a collection of images, and a list of questions other people asked about brunch and their answers. Domain-specific virtual assistants generally perform a constrained set of complex tasks that require a deep understanding of a particular domain (e.g. [2]). When they work correctly, virtual assistants help users get their tasks done without digging through a variety of websites and applications or a cumbersome user interface. This is exactly the kind of utility that VIRSA should provide; however, VIRSA answers questions about resident space objects rather than brunch.

All of these assistants follow from a massive investment by these companies and builds on the Personal Assistant that Learns (PAL) research program led by DARPA [3]. The Cognitive Assistant that Learns and Organizes (CALO), a precursor to Siri, was one of the projects funded under this program to assist users with a variety of high-level functions, including organizing and prioritizing information, task management, scheduling, and reasoning in time. Especially relevant to the virtual assistant described in this paper, there are numerous platforms (e.g., wit.ai; api.ai) and open source projects (e.g. [4]–[6]) where developers can take advantage of implemented natural language understanding, conversation management, and search to connect natural language interactions with devices, applications, and services.

Finally, there is existing research in a domain similar to Virsa, though utilizing much older technology. The TAPTalk system [7] assisted operators in air operations centers with creating air plans as part of the Theater Air Planning (TAP) module of the Theatre Battle Management Core Systems (TBMCS) software. The primary assistance that TAPTalk provided was using voice commands to bypass a cumbersome graphical user interface (e.g. replacing clicking on six menu items in two windows with a single voice command).

From a technical perspective, VIRSA leverages existing open-source projects such as the ones listed above. The primary contribution of this paper is the results of our investigation into the role a virtual assistant might fill in a space operations center and what features it should support. The results include identifying the highest impact initial features to develop, evaluating these features within the context of Phase I of the DARPA Hallmark program, and identifying additional assistant functionality to be developed during Phase II of the program.

4. INITIAL FEATURE SELECTION

To identify candidate features, we began by reviewing stakeholder documents such as the DARPA Hallmark Phase Zero Demonstration reports [8, 9, 10, 11], and considering ideas discussed during the kickoff meeting. After generating a list of candidate features culled from these documents and discussions, we conducted a series of interdisciplinary sessions to narrow the list to a small set of features judged to have the potential to positively impact decision making and efficiency, and to be feasible within the time and resource constraints of the Hallmark program. Two decision science researchers, one former space operator, and two software developers independently identified 5 features from the list that they believed were feasible and would have a positive impact. The team met to discuss each participant's top choices. Using a consensus-based approach, we discussed until the group reached consensus on a small set of top choices. The team then met a second time to refine the list further, identifying two options that would provide a realistic demonstration of the potential value of VIRSA, and would also provide a foundation for future, more sophisticated features. These two features became the focus of development and demonstration efforts:

RSO Summary: at-a-glance summary of key information about a resident space object. Operators can use this information to quickly assess a situation, solve problems in the face of unexpected events, dynamically re-plan, and anticipate implications of potential courses of action.

Keyword Search: addresses the need to perform efficient searches across many tools and data sources (currently a pain point for operators).

Fig. 1 depicts Virsa with the RSO Summary at the top and the Keyword Search at the bottom. Operators type the name of a space object into the search bar to quickly retrieve the information.

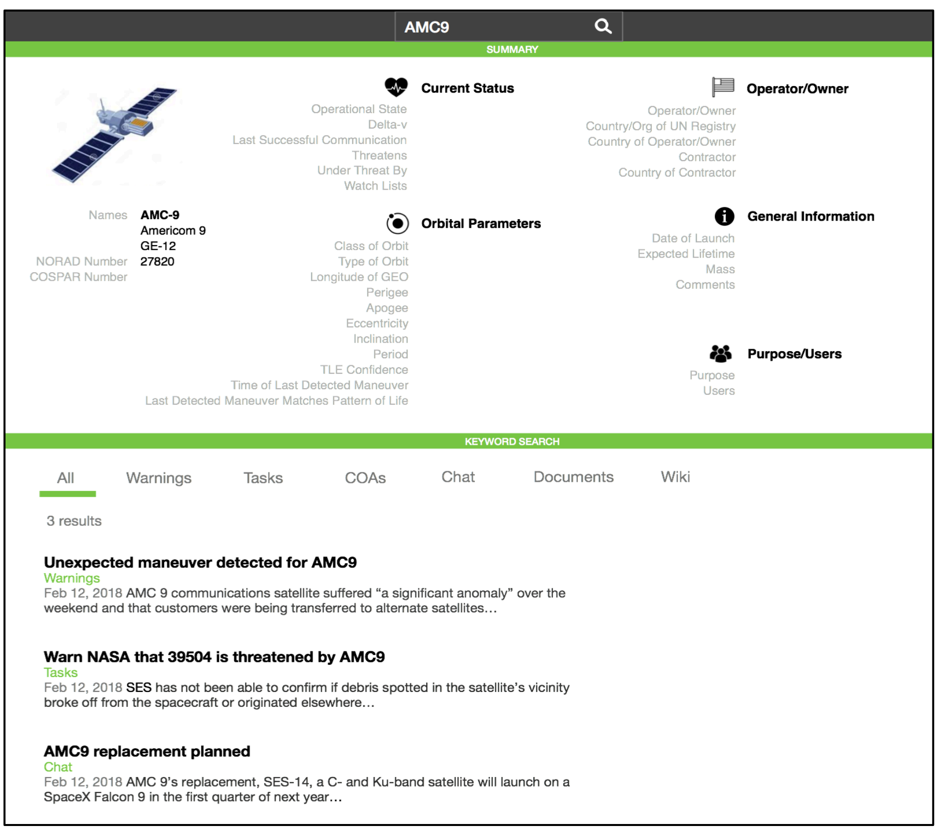

Fig. 1 Virsa with RSO Summary at the top and Keyword Search at the bottom.

5. EVALUATION EVENTS

One issue with developing a virtual assistant for space operations is that the functionality requested by operators is limited only by the imagination. It is also difficult to know ahead of time what tasks are going to be time-sensitive, data-intensive, recurring, or otherwise challenging in the Hallmark environment until after the tools and scenarios are developed. The evaluation events carried out by the cognitive evaluation teams address this issue by evaluating the performance of the Hallmark environment every three months and generating very specific recommendations. This paper covers the first four evaluation events.

The first evaluation event at the three-month mark utilized the tool developers as the operations personnel, led by subject matter experts. This event was a shake-down cruise of the tools, the testbeds, and their ability to work together. VIRSA functionality leverages the user interface of existing visualization tools to support seamless integration into the overall workflow. First an operator interacts with the search bar in a visualization tool, which sends a message to VIRSA requesting a search. Second, VIRSA uses the data sources supplied by the testbed and information from other tools to generate search results. Third, VIRSA sends the search results back to the operator's visualization tool for display. The primary takeaway for VIRSA was that the information provided by Summary and Keyword search would be essential, supported by the amount of time operators spent searching the internet for information.

The second, third, and fourth evaluation events featured operators with real-world expertise and experience. Their expertise was matched against increasingly complex scenarios and an increasingly capable Hallmark environment. The feedback from VIRSA from the events were confirmation of the utility of the Summary and Keyword search results provided by VIRSA – along with a list of requests to make these features even more useful. Implementing these requests consumed much of the VIRSA Phase I development cycle. The cognitive evaluation teams also identified specific tasks that an assistant should be able to perform within the Hallmark environment beyond 'simple' search. These features are described in the Future Work section.

6. FUTURE WORK

The cognitive evaluation team identified three specific areas where a virtual assistant would have a significant impact in the Hallmark environment. These specific items are the expected focus for VIRSA in Phase II of the Hallmark program.

Answer questions and perform tasks:
- What RSOs could support tasks assigned to AMC-9?
- Add 42063 to the HVA watchlist.
- Show the checklist for a missed maneuver warning.
- Find existing COAs relevant to the most recent warning.
- How do I perform a reachability analysis?

Perform dynamic filtering:
- Show all USAF missile defense sats in GEO.
- What ground assets can view TDRS-12 right now?
- What RSOs can the Guam ground station see?
- What asset is scheduled to view TDRS-12 next?
- What RSOs were in the vicinity of TDRS-12 since the last successful communication?
-

Automatically respond to anomalies:
- Perform diagnostic investigation based on the anomaly information and summarize results.
- Search for replacement assets when an RSO is found to be non-mission capable.
- Prompt user to investigate pre-identified workflow questions when warnings are received.

7. CONCLUSION

VIRSA illustrates concrete features that a virtual assistant could use to improve decision-making on the space operations floor. Within the context of the Hallmark environment, we have identified the highest impact initial features, evaluated these features in a series of week-long evaluation events, and identified additional assistant functionality to be developed during Phase II of the program.

Based on the realism and complexity of the evaluation events, we believe that these same features will be useful in other space operations environments as well. Currently, the most significant challenge to implementing an assistant like VIRSA in a real-world operations center will likely end up being data classification issues – not the technology behind the virtual assistant.

8. ACKNOWLEDGEMENTS

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