RESEARCH SUMMARY

Artificial Intelligence and Machine Learning for Space Domain Awareness

The Development of Two Artificial Intelligence Case Studies

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ISSUE

To address the growing demands of operating in the space domain, space domain awareness (SDA) operators must determine how to prioritize sensor observations more effectively, scale up to meet the sheer volume of resident space objects, and develop analytic capabilities that reflect the complexity of orbital mechanics and space operations, all while maintaining the responsiveness necessitated by operations in a warfighting domain. These factors present significant challenges to those tasked with the SDA mission and point to this mission as a prime candidate for support from artificial intelligence (AI) and machine learning (ML) tools, as such tools have the potential to increase the analysis tempo, expand the amount of usable data for this analysis, and free up operator time for more-complex tasks. AI/ML tools may help SDA operators meet these increasing challenges.

Although AI/ML tools have the potential to help meet these SDA challenges, the impact of these tools on the overall success of the SDA mission is not well understood, and this lack of understanding is a barrier to plan for and optimize the integration of these tools. The research documented in this report seeks to develop insight into the following questions through the development of AI/ML case studies:

- How can existing AI/ML and automation technologies benefit the SDA mission?
- Which processes within the SDA mission area can be improved from increased automation and AI/ML?
- What are the prerequisites and enabling technologies that are necessary for AI/ML implementation?
- What limitations (inherent or built in) should be considered when employing these technologies?



APPROACH

Our approach outlined in this report focuses on the development of two AI/ML case studies that explore the value of AI/ML for SDA mission processes. These two case studies offer a way to investigate in detail how AI/ML could be leveraged and to emphasize potential challenges to implementing an operational AI/ML tool. Accomplishing this first requires an understanding of the processes that make up this mission, the requirements and metrics for these processes, where there are opportunities for impact through leveraging AI/ML tools, and the nature of what these tools would change in the process and the outcomes. We then document the AI/ML

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tool development process and methodology, characterizing the algorithm design space, and discuss algorithm performance and the downstream implications for SDA operators and practitioners. Lastly, we provide recommendations and opportunities for further research and analysis to improve our AI/ML tools.

The work presented here focuses on the highly resource-intensive conjunction assessment mission under the broader SDA mission set. The case studies focus on prediction and classification capabilities of neural networks and use of the capabilities to improve the conjunction assessment. We also address the need for uncertainty quantification in AI/ML tools for both improving the prediction and classification performance and mitigating some of the potential AI/ML policy barriers, including facilitating operator-machine teaming and operator trust.



KEY FINDINGS

- Neural networks are capable approximators for complex nonlinear functions. We demonstrate that prediction and classification capabilities can be applied to SDA mission processes with standard and Bayesian neural networks.
- AI/ML tool developers should focus on tools that are compatible with the operational SDA architecture, data infrastructure, and processes.
- Quantification of risk and uncertainty tolerance provides an operator or analyst with the capability to provide feedback to an AI/ML model by setting thresholds based on acceptable risk.
- Quantification of risk and uncertainty tolerance can support improved performance of AI/ML tools focused on prediction and classification when compared with standard neural network approaches.
- Active learning may be an attractive AI/ML feature when paired with SDA mission processes.



RECOMMENDATIONS

- The development of AI/ML tools requires significant investment in ensuring high-quality training data. The Office of the Chief Scientist of the U.S. Air Force, with input from SDA operators, should consider the availability of such data for AI/ML investment.
- AI/ML tool developers should consider SDA processes and limitations that have implications for tool design, including the selection of algorithms, metrics of performance, and benchmark requirements.
- The U.S. Department of Defense should continue to consider the value of uncertainty quantification methodologies when developing and deploying operational AI/ML tools. SDA operators should be trained to use the uncertainty quantification provided by these methodologies.

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