Implementing Artificial Thinking Autonomy with Model-Based Systems Engineering

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Developing complex systems capable of operating independently under unknown and harsh conditions requires innovation in modern development strategies for paradigms in autonomous systems. Developing a system-of-systems, or a constellation system, which can ostensibly think for itself remains a matter of ongoing research in the field of autonomy. Maturing the systems architecting, modeling, and simulation methodologies for developing these Thinking Autonomous Constellation System can usher in the next generation of intelligent systems for space exploration through digital mission planning and high-fidelity computer simulations.

This work delves into the usage of Model-Based Systems Engineering and digital mission simulation techniques to create SysML models extended by real-time expert system development software Gensym G2 for a novel biomimetic thinking autonomy paradigm. We compare this approach to conventional document-based development strategies and contemporary software development methodologies. Our novel paradigm expands upon historical metacognitive philosophy, which has much to offer for architects seeking to develop system autonomy. Anachronistic concepts like classical philosophy can inspire solutions and design, leading to the development of functional systems which have the potential to revolutionize the field of thinking autonomy for complex constellation systems. This is particularly true for our target autonomy strategy we develop and simulate through Model-Based Systems Engineering. Experienced NASA software engineers have published literature with a generalized implementation plan for a Thinking Autonomous System by drawing inspiration from the work of classical philosophers including Immanuel Kant, Georg Hegel, and Arthur Schopenhauer.

By conducting digital transformation on this NASA-based literature, we create descriptive and executable SysML models that communicate through digital thread with Gensym G2's real-time expert system operating capabilities on NASA Autonomous System Laboratory's Platform for Autonomous Systems. This platform provides a direct solution to the shortfalls of SysML in modeling thinking autonomy by inherently covering all capabilities espoused by SysML, with the addition of real-time operations, autonomous strategy implementation methodologies, and integrated system health management. Our integrated SysML-G2 models foundational architectures behind true thinking autonomy and intelligent systems, enabling further research into novel strategies for cyber-mechanical systems to act without crew reliance, resilient to operating conditions and lack of ground communication.

We describe future steps for developing the proposed Thinking Autonomous Constellation System software architecture, including the thinking system's utilization as a controller for task prioritization aboard future space habitats like NASA Gateway. Ensuring that an autonomous system framework is trustworthy and adaptable to specific implementations even beyond the space sector requires careful consideration of ethics for system behavior and accountability, human factors for teaming with a thinking autonomous system, and comparison to other modern approaches to true autonomy. NASA Autonomous System Laboratory's approach to Thinking Autonomous Systems enables modeling and simulation of

ethical behaviors, with the ability to support ethical design best practices within its development lifecycle. While we do discuss modeling human-autonomous teaming, this remains a topic requiring additional research and development through Model-Based Systems Engineering.