MIRAGE
the future of autonomous operations in space.
A meteoric rise in the number of applications that leverage access to Earth’s orbits is propelling the Space Economy through a period of incredible growth. As new players enter the market and competition increases, technological and commercial differentiation are becoming pivotal for competitiveness. Moreover, the traditional, human-controlled mission operations are proving unscalable and inefficient, and the ballooning number of satellites now threatens the sustainability of space activities itself.

AIKO envisions spacecraft automation as the key to tackling these problems. AIKO’s solution, MiRAGE, is an artificial intelligence (AI)-based software that supports and augments space missions by making satellites independent from ground control. Composed of interlinked submodules built on state-of-the-art algorithms, MiRAGE is the most advanced system on the market for complete mission autonomy. It enables significant savings in spacecraft operations costs, bypassing humans in the loop for faster response to unexpected events and optimized deployment of resources. Scheduled to reach TRL 7 by 2021, MiRAGE will fly its first mission in orbit in 2022.
Space is a hostile environment that demands onerous system requirements for tolerance to extreme conditions. Flight-grade hardware is thus being continuously improved upon to sustain such a burden for extended periods of time. However, spacecraft software has not undergone the same level of evolution, and most satellites to date remain rudimentary systems that are limited to executing commands from human operators on the ground.

As a consequence, missions in the Earth orbits are plagued with inefficiencies throughout the value chain, induced by factors ranging from latency and limited communication windows to an inability to respond and adapt to unforeseen events. This impacts the bottom line of space companies, resulting in higher costs and lower revenues.

Moreover, technological improvements and inflows of capital are furthering the growth of the space ecosystem and enabling new, complex mission design architectures. Constellations of satellites are congesting the orbital regimes and threatening the sustainability of space activities. In such a context, any single accident may have catastrophic consequences.

The need for autonomous spacecraft that rapidly act upon unexpected events has never been greater.
Such a reality has become evident for commercial and institutional space-sector players alike: “Missions that cannot receive commands from Earth quickly and reliably will need the autonomous capability to explore with reduced or no human intervention. Autonomy can increase spacecraft productivity and, when the spacecraft cannot wait for ground commands, enable rapid reactions.” Jet Propulsion Laboratory, 2019.

We can conclude that the traditional spacecraft management systems with multiple decision-making layers are today technologically obsolete and inadequate for the rapidly growing market. The satellite cannot remain a non-intelligent platform that executes pre-defined commands only. Instead, it must become an intelligent system that structures its tasks independently from the intervention of ground control to maximize the mission outcome.
Our Solution.

MiRAGE, a software library for onboard autonomy.
MiRAGE (Mission Replanning through Autonomous Goal gEneration) is a software package that enables complete mission autonomy for satellites. It represents the brain of next-generation satellites in which the onboard computer (OBC) allows the platform to operate in the mission environment autonomously. MiRAGE is built upon a vast ecosystem of technologies that collectively enable autonomous sensing, mission planning, satellite control, and cooperative systems. The software supports many types of space missions, from small satellites to flagship, in low Earth orbit and deep space, within single satellites and constellations.

MiRAGE consists of three pillars: (i) onboard data processing, (ii) operations planning, and (iii) autonomous control. The software abstracts a simple cognitive architecture from complex space systems, providing satellites with the ability to:

- Sense the environment and its status (through onboard data processing).
- Plan tasks according to acquired or inferred knowledge (operations planning).
- Self-maneuver in the orbital environment (autonomous control).
- Operate in coordination with other constellation nodes to accomplish complex and distributed tasks.

Specifically, MiRAGE boasts event detection and pattern recognition.
capabilities deriving from payload and telemetry data processing. With MiRAGE, the satellite can predict or prevent detrimental behaviors during the mission, react to unexpected events, and exploit unforeseen mission opportunities. MiRAGE also optimizes resources onboard through goal reasoning and planning capabilities. Tasks can be dynamically planned and executed in an uncertain environment by maintaining a high level of flexibility, simultaneously guaranteeing adaptability to faults and events.

Furthermore, MiRAGE enables autonomous control capabilities, combining accurate sensing and specific adaptive planning features. MiRAGE-equipped spacecraft can carry out complex endeavors such as proximity operations, docking, and in-orbit servicing. In the context of constellations, the scalable nature of MiRAGE enables features including autonomous constellation management, cooperative operations, goal negotiation, intent prediction, and collective knowledge.

Internal tests by AIKO suggest MiRAGE can produce a reduction in mission operations costs of up to 60%, introduced by the lower dependence on human operators and optimized deployment of spacecraft resources. Considering that operations are the second or third largest cost item in a mission, it is evident that MiRAGE will be the technological enabler for further growth in the space sector.
MiRAGE is based on a microservices architecture that permits extreme flexibility in deployment. Controlled and managed by a central core, the microservices are responsible for the payload and platform data processing. Each microservice constitutes a MiRAGE module that works independently from the others, and that is interfaced with core libraries only. Thus, the modules conform to a specific mission scenario, guaranteeing maximum computational efficiency.

Thanks to standardized interfaces, the MiRAGE modules can run independently once the mission scenario is defined.
The MiRAGE core libraries have been successfully tested for x86-64 and ARM computing architectures.

Processing modules are compatible with a wide range of state-of-the-art hardware accelerators, resulting in several key advantages:

- Reduced inference time on the deep learning (DL) model.
- Reduced workload on the CPU.
- Optimized power consumption.

Sample hardware accelerators include Intel Myriad, Google Coral, Nvidia Jetson.
The increased complexity in space mission operations requires adopting innovative, high-performing solutions for feature extraction. Recent advancements in AI and DL have enabled outstanding progress in computer vision and time-series analysis. MiRAGE leverages these technologies for its advanced functionalities.

A reversed data-centric approach allows MiRAGE to define an implicit model. This model is trained using supervision to autonomously extract relevant features from the data by backpropagating the neural network’s parameters. A Deep Learning-based system then enables MiRAGE to handle complex pipelines for sensors-based satellite data.

The concept applies to a range of payloads, for instance spacecraft cameras. In this scenario, a Deep Convolutional Neural Network is used to firstly extract relevant features from the images acquired, which are then passed to the Reasoning Manager for event generation - from cloud detection and object tracking to super-resolution.
MiRAGE provides E4 autonomy through a combination of several autonomous reasoning and onboard real-time planning modules. The software infers augmented information, starting with the state of the external environment and of the platform. It subsequently applies reasoning processes over ontologies and logic expressions representing its world knowledge. Thus, MiRAGE develops explanations underlying discrepancies between the expected and the real environment state.

Concurrently, MiRAGE evaluates the optimal mission goals to be pursued. Such an optimization process considers the actual platform state, level of resources, science and commercial objectives, collaboration opportunities, and self-maintenance needs. MiRAGE maintains the autonomously defined mission goal queue according to the Mission Planning and Scheduling CCSDS standards.

MiRAGE also embeds an advanced onboard real-time planning module to identify the optimal sequence of tasks and subtasks over the
planning & goal reasoning

Provide E4 Autonomy

planning horizon. It evaluates optimality conditions by reaching primary goals. Then, it assesses the agent's status after reaching those goals, pursuing the minimization of resources before initiating the discovery of new goals. Last but not least, during the definition of a dynamic plan MiRAGE accounts for causal and temporal constraints, along with several state variables. In particular, the ability to obtain a non-static plan solves the problem of dealing with variable duration of tasks and/or with uncontrollable events.
AIKO started MiRAGE development in 2017. In 2018, AIKO received the H2020 SME Instrument Phase 1 funds that brought the product at TRL 6. In 2019, a beta version of MiRAGE's payload data-processing technology was tested in orbit during an Earth Observation mission on a Satellogic satellite. Then, in 2020, AIKO released V1, MiRAGE's first stabilized application, which is now under testing before integration in the 2022 GOMX-5 mission by ESA/GomSpace. We expect to validate in orbit the complete MiRAGE package and to reach TRL 9 by late 2021 or early 2022.

AIKO is already improving upon MiRAGE V1, complementing it with new features including:
• Optimized algorithms, targeted at execution performance in low computational environments.
• Standardized and simplified installation and integration process through improvement of the MiRAGE APIs and procedures.
• Explainability suite and improved validation process.
• Advanced constellation functionalities.

Furthermore, AIKO is currently gathering feedback from potential customers and users through an ongoing Early Adopters Program. This iterative activity ensures MiRAGE accurately addresses the technical requirements and commercial needs of space sector players.
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