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An Intelligent Machine-to-Machine Framework for Services Based on Satellite Planetary and Earth Observation, and Exploration Data

Executive Summary Report

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Machine-to-Machine (M2M) transfer of information and services, as well as decision making through the processing of cloud-based big-data structures that are compiled from input from all kinds of static or mobile devices and instruments (i.e., satellites, drones and UAVs, sensors, analytical instruments, cameras, robots) is a powerful concept that can be used to automate large missions and field work campaigns, especially in natural sciences. Such missions often take place in remote areas, and the requirement to minimize human intervention and presence is of importance. In astrobiological research, as well as planetology, there is also the need to characterise extreme environments as planetary analogues in high detail and create a virtual framework of this for the study of others, or for direct comparisons with investigations during missions. At the same time, methods have to be identified and protocols defined on how interdisciplinary work must be perform for efficiency purposes and for the preservation of possibly important evidence.

To perform such long and detailed tasks, Machine-to-Machine (M2M) automation is considered as a powerful concept for many scientific and technological applications, which can also find many commercial activities on Earth (i.e., medical, environmental protection, financial, etc.). This concept is in the framework of the well-known and well-advertised “internet-of-things”, however, advanced features will be requested to enhance communications by reducing the number of protocols and interfaces. To achieve this, a smart communication network and clever protocols are required for every hardware or software entity that is part of the system. When focusing on autonomous Earth and Space exploration, it is required to define protocols and standards to dynamically handle scientific data output formats and methods during analysis and characterisation.

To fulfil the above requirements, we envisage the development off a new architecture which is based on a new meta-language that merges data, protocols, and methods under a single structure. This prototype event-based “meta-language” will handle communications as well as monitoring of all adaptive data formats and interfaces through Intelligent Agent software units that act on every form of memory or data storage (i.e., big cloud databases, local memory on devices) but also on any device. This “meta-language” will be capable of controlling the integrity of the data that is produced by each device, instrument, or human, structurally and in content (the informational content), and will decide for the merging of related information into consolidated knowledge while improving processing. All data will of course be location-aware, and secure using blockchain encrypting technologies. All these properties are necessary in order to reach correct conclusions about a physical system through automated interpretation and decision-making, which also leads to proper generalization and theory formation (physical laws should be supported instead of only fuzzy generalisations coming from machine learning techniques, the later supporting the former in order to understand natural systems and the parameters involved). In shorter words, all acquired information should be converted into dense knowledge structures.

Although the integrity of the data is an absolute necessity, one more parameter is often forgotten and this has to do with the intellectual property rights. These should be automatically protected when any kind of data or text is published. As already mentioned, the aim is to produce compressed knowledge, avoiding human intervention in data production and reduce problems from mistreated data or fraud science. We also intent to affect the way we review science, handle intellectual rights, and publish data.

This is compulsory today because redundancy of information that come from a plurality of opinions and publishing means is a need. These dense knowledge structures should be used equally by instruments and systems of instruments, as well as by humans, and in a secure way.

The objective is, therefore, to develop a new framework that is based on the concept of Machine-to-Machine communications and automation, and of a new meta-language, with which data, methods, and standards are integrated in the form of dynamic ontologies and intelligent agents. The meta-language should handle all operations and processing of the data, wherever these are stored, leading to automated interpretations which can be used both by humans and machines. This information should be communicated between them, also guiding each other during research and exploration activities.

Our practical objective was to design and test in the field a scenario that involves a set of instruments, appropriate for geological and astrobiological field work. It was decided that an appropriate scenario to be used as a working example is the integration of a few analytical instruments used to perform geological and geochemical work under an M2M concept. This will be done especially when field work is performed, during which information is difficult to retrieve and register, optimising in this way the exploration through in-situ and on-demand data acquisition and interpretation. This concept expands to the level where the new knowledge is published, for which novel ways are also required to secure IPRs and integrity of proper scientific results. The demonstration of the concept is based on a variety of analytical instruments (i.e., portable XRF and a hyperspectral imager operating online during field work and integrated with instruments in the lab that will be operated later). This work will be supported by drones to make instruments mobile, and a sampling device for sample acquisition. The field work will be performed on two Greek islands that can be easily considered planetary analogues due to their rough topography, volcanic origin, and variety of alterations, mineralogy, petrology, and of other geological and geochemical features.

The planned framework has also numerous commercial applications, since it is designed to be a superset of the 'Internet-of-Things' concept. Especially through this project, the way instruments output their data should be affected, as well as how these results are used to publish scientific knowledge. So, commercial instrument vendors are the first to adopt such an open standard for interconnecting their devices and storing fully formatted and compatible instrument measurements.

During the project, we have reviewed the major technologies on the machine-to-machine concept and have selected existing language platforms that can be integrated into a new meta-language. This metalanguage is based on a combination of existing languages, such as the LISP and the Julia computer languages. These can effectively merge all types of data and formats, methods, standards, communications, and decision-making algorithms under a universal informational structure. We have provided some examples on how these can be integrated and be used. We will use this metalanguage with the above-mentioned setup of representative set of instruments to perform automated field work. This plan involves humans as well. We have already selected commercial instruments and devices that can be easily adapted by us and have identified all the parts that require modification. We gave also examples on how current meta-data and data-structures can be translated into the new meta-language, and how instrument output can be re-written and standardized with this, as well as be secure.

Integrating data and methods into intelligent software pieces that can talk the same language is a powerful way to automate missions. Instruments can then work unattended with a swarm intelligence. This has also huge potential for space missions and for commercial applications because many activities can be automated. ESA and any space agency can benefit from this because it will be able to describe existing data into this new format as well as to provide direct access of these data to instruments in order to automate many processes. The same can be applied in all aspects where machines need to take decisions, where information must be continuously re-evaluated, and where credits should be properly handled, as well as where data must be secured.

We now plan to develop a running subset of the meta-language and apply this to describe analytical instruments and their output. We will then upload this language on some instruments, which will work together in an autonomous way in the field for realistic geological and astrobiological investigations. This is a follow-on technology activity targeted to GSTP to achieve TRL3.