ANALYSIS IN ROBOTIC AUTONOMY FOR FUTURE PLANETARY MISSIONS

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Abstract

Future planetary surface exploration missions as envisioned by international agencies would require of human and robot cooperation. Past, ongoing and upcoming surface robotics missions will pave the way for technology infusion and to demonstrate its readiness for critical-safety missions. Rovers with major autonomous capabilities are a must and are under investigation and development; however, there are some aspects highlighted in this article that cannot be operationally demonstrated with precursor missions by its nature. First, rovers that would require of manifold control modes from fully manual teleoperation to autonomous, where we propose to approach this flexible system architecture by defining different autonomy control levels. Second, rovers might be differently operated depending on the mission's phase, where we address robotic taxonomies as a driver for designing operational needs. To initiate this topic, we summarise the state-of-the-art of autonomous capabilities of Mars Exploration Rovers gathered from NASA literature.

1 WHAT IS COMING NEXT?

The human exploration of planets is on the roadmap of future missions as well as the fostering of international cooperation among agencies [1] and its proper coordination at European level [2]. The European Space Agency (ESA) has envisioned to explore the surface of Mars with humans by the year 2033 within the Aurora Programme, and the National Aeronautics and Space Administration (NASA) has targeted to explore the surface of Moon with humans by the year of 2020 within The Vision for Space Exploration.

NASA plans to build bases on the lunar surface, where astronauts will live in pressurized habitats for a certain period of time to achieve the mission's scientific goals. The scenario of such a mission shall include many elements, including Earth-Moon communication relay satellites, ground communication antennas, lunar bases, astronauts performing Extra-vehicular Activity (EVA) or Intra-vehicular Activity (IVA), astronauts travelling in pressurised vehicles from remote bases, robots to perform repetitive and hazardous tasks, instruments deployed on the lunar surface, and so forth.

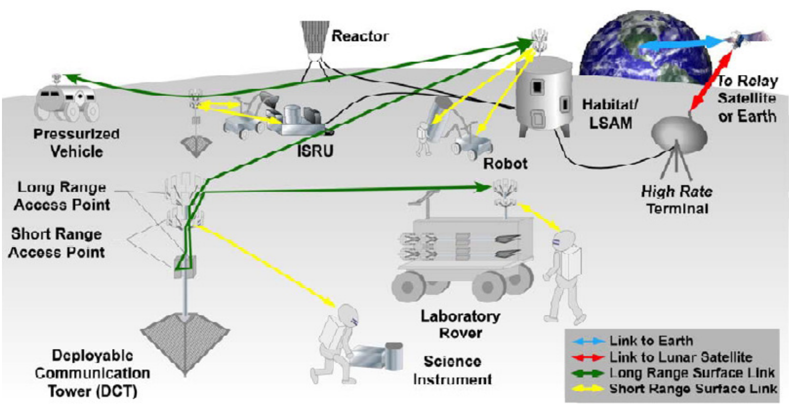

Figure 1 – Operational infrastructure for lunar exploration [3]

Figure 1 illustrates the use of robotics within such a complex mission: ranging from autonomous rovers for transportation and logistics support capable of long traverses, dexterous manipulators in support of construction and assembly, robots to help astronauts in performing activities or performing surveillance, and for deployment and maintenance of surface assets, *etc.*

There is a long journey before human and robots can explore with permanent bases on the Moon. First, all related infrastructure to support such mission must be developed: redundant launcher technologies, Earth Moon Lagrange (EML) communications relay points, Low Earth Orbit (LEO) or Low Lunar Orbit (LLO) stations, Lunar Descent Module (LDM) and so on [4,5,6,7]. All these technologies and infrastructures that would provide and ensure a sustainable Lunar or Martian surface exploration by humans, with the support of robots, will need an iterative development of key technologies and precursor missions to demonstrate and prepare the environment, as proposed by Christie *et al.* [8]:

1. Reconnaissance Rovers
2. Site Preparation and Simple Instalments
3. Permanent Moon Base Construction
4. Sustaining Lunar Infrastructure and Exploration

Reconnaissance rovers are necessary before returning to the lunar surface to enhance the knowledge of the landing site (assumed to be polar, based on the current mission roadmaps) and its actual surface environmental conditions; to perform topology and general mapping of the lunar surface providing complementary data of precursor orbital missions, as the Japanese SELENE. The technology basis of these rovers would be the current state of the art, *i.e.* those deployed on Mars: the Mars Exploration Rovers (MERs), Mars Science Laboratory (MSL), ExoMars or the Phoenix Lander. The objective of these rovers would involve conducting surveying activities, geological analysis and deployment of initial navigation beacons and communication infrastructures. They would need to be capable of operating in a minimum of two modes: fully autonomous and remotely operated, initially from Earth-based control centres and eventually from Lunar-based stations. They would need direct-to-Earth communication capabilities yet also be capable of interfacing with both the beacons as well as any precursor lunar landers. Technologically, the rover would need surface feature recognition capabilities or some other means for relative localisation. Navigation solutions can be divided into relative localisation (*e.g.* LIDAR as primary and normal optics as secondary due to lighting lunar conditions), absolute heading (*e.g.* star tracker) and global localisation (*e.g.* radio localisation/descent imagery). Scientific and exploration tools and payloads would be controlled by pre-determined procedures or, as on the MERs, be controlled via remote control by scientists and operators on Earth. These rovers may also be equipped with secondary purpose assets in order to perform auxiliary experiments. The rovers might be also controlled by astronauts once humans arrive in manned missions, and need to be designed with enough endurance.

Site preparation and simple instalments would include manned missions that shall benefit from more comprehensive survey datasets of the local lunar surface, with the aid of navigation and communication assets deployed on the surface. It is probable this phase involves the establishment of a lunar-based communications and robotics control centre, integrated with, or independent from, a habitat for astronauts. This centre might be equipped with all of the functionality of the terrestrial control centre with respect to robotic control, providing to the astronauts the capability to operate and coordinate missions on-site. This centre would interface with the terrestrial control centre such that critical mission data (asset location, telemetry data and video) could be shared. It may be possible that all such lunar assets would be supported by a lunar space station, located at LLO or EML points [7]. The LLO option would provide safe haven capabilities, lunar outpost logistics preparation and handling, support of cargo staging packages prior to shipment to lunar surface, communications enhancements and redundancy, as well as navigation support to lunar-based rovers. It shall be also capable of controlling any robotic assets on the surface freeing up of tasks to astronauts on the surface. The design basis for this LLO station would be the approach of the International Space Station (ISS) and its associated robotic elements, *i.e.* a set of highly specialised modules with standardised interfaces for docking, electrical and fluid connections, *etc.*

This phase would also include delivery, set-up and test of heavy duty construction equipment using an autonomously-controlled robotic platform, upon which a variety of mission-specific modules could be mounted. This robot would be supervised by Moon-based astronauts. To complete the phase, a lunar personnel manned roving vehicle might be used to provide astronauts with a means of transportation, having the same operational characteristics as precursor rovers, with similar mobility capacities (terrain assessment, path planning, localisation and navigation) and communications interfaces.

Permanent moon base construction shall build a series of interconnected standalone modules shipped sequentially; and implicate the crewmembers in various tasks, *e.g.* construction tasks like unpacking, checkout, transport, anchoring and connection to power grid and data lines, all with the help of surface rovers.

Sustaining lunar infrastructure and exploration shall include the tasks of maintaining the outpost, although a more comprehensive study of the actual effects on long-term exposure to the lunar environment would be needed. Activities might include the installation of newer equipment once their useful lifetime is expired, routine tasks of supervising the equipment via remote-controlled or autonomous robots in order to reduce the astronauts' exposure and safety of EVA.

2 OVERVIEW OF AUTONOMOUS CAPABILITIES

MERs, MSL and ExoMars shall provide the technological heritage to future *reconnaissance rovers* as introduced previously. At the moment, in order to overview the state-of-the-art in autonomous capabilities from an operational perspective, we need to focus on the excellent performance that MERs have offered during their lifetime. The following table aims at giving an overall picture of onboard autonomous capabilities of the rovers, mostly focusing on mobility and autonomous science aspects [9], dated from 2007. We have also mapped the autonomy capability to an Autonomy Maturity Level (AML) recalling the operational experience and confidence during operations:

AML	*Description*	*Corresponding TRL*
1	Technology under development for its use in space	3 - 5
2	Technology developed, tested, verified and validated in rover prototypes for its use in space	5-7
3	Technology experimentally tested during the mission in highly controlled conditions	7-8
4	Technology used during nominal operations over the mission	9
5	Technology extensively used during nominal operations and/or in contingency procedures	9

Table 1 – Definition of Autonomy Maturity Levels and comparison with Technology Readiness Level

Capability	*Requirement Source*	*Approach*	*Sensors/SW*	*AML*
Absolute Orientation Sensing (OBS)	Onboard position estimate can accumulate several degrees of drift after integrating the gyros for thousands of seconds.	Sun vector recalibration (and position) by pointing the camera where the Sun is supposed to be, and processing the image to reallocate its centre (or conventional sun sensor for lunar applications).	PANCAM, Local Solar Time, Inertial Measurement Units (IMUs)	5 (used in Sojourner mission and extensively in MERs)
Stereo Imaging Processing (SIP)	Need for depth, geometry and shape information of surrounding terrain.	Generate 3D measurements (disparity) of points in stereo images, performing a windowed 1D search using the sum-of-absolute-differences metric. Software relies on the camera's geometric lens calibration.	PANCAM (2 stereo-pairs) and NAVCAMs with different FOV	5 (used in Sojourner mission and extensively in MERs)
Local Path Selection (LPS)	Detect drift conditions when traversing, *e.g.* in sandy slopes.	Add attitude drift information processed from IMUs *[algorithm Ali et al., 2005, 9]*	Wheel encoders and gyros (IMUs)	4
Visual Odometry (VO)	LPS does not detect slippage conditions when traversing, *e.g.* in steep hillsides, mixed sand/rock terrains inside craters or sandy ripples in flat plains of Meridiani.	Software compares pairs of NAVCAM images of nearby terrain to autonomously detect and track features between them. 2D and 3D motion of those features is used to update the onboard position estimate. *[algorithm Maimone et al., 2007, 9]*	NAVCAM	4
Terrain Assessment (TA)	Detect geometric hazards around the area to assist drive modes, *e.g.* rocks, ditches or cliffs.	Clouds of 3D points are fitted in rover-sized patches of data to a plane. Software searches for 1) steep obstacles - large deltas in elevation of best fit plane, 2) tilt hazards - large angle between surface normal and the Up vector, 3) Roughness hazards - residual of the planar fit. Software performs traversability analysis with up to 10 separate points of clouds; normally performed with a single stereo pair.	SIP imagery Software tool: Grid-Based Estimation of Surface Traversability Applied to Local Terrain (GESTALT)	4
Instrument Placement (IP)	Guarantee knowledge of terrain geometry relative to the rover; enable human-in-the-loop to safely deploy the Instrument	High-resolution images are acquired to find the closest point on the terrain to the commanded target, and to ensure that it meets workspace, surface orientation, and roughness requirements. It is	SIP imagery Software tool: AutoPlace	3 (software upgrade onboard over the

Capability	Requirement Source	Approach	Sensors/SW	AML
	Deployment Device (IDD) into target.	performed by a workspace safety analysis: free of self-collisions and collisions with terrain as well as modelling volumes due to occlusions and stereo dropouts (unsafe regions). Trajectory generation is based on manual build of IDD command sequences considering multiple kinematic configurations.		mission lifetime)
Visual Target Tracking (VTT)	Difficulty in driving precisely to a pre-specified target when falls off the square of the target's distance from cameras, due to position estimation uncertainty (higher if VO is not enabled) and target specification precision.	Specify the target (feature) by its appearance rather than its predicted location. Feature's location extracted from SIP is maintained at each step using a correlation function. *[algorithm Kim et al., 2005, 9]*	SIP imagery	3 (software upgrade onboard over the mission lifetime)
Autonomous Science (AS)	Interesting science observations occur in an opportunistic manner, as image dust devils and clouds. The approach of collecting and observing during a long period is not optimum due to need for high bandwidth requirements of useless observed data.	Detect the presence of these features autonomously onboard, and transmit only interesting images. *[algorithm detected the absence of dust devils and the presence of clouds, Castano et al., 2006, 9]*	SIP imagery	3 (software upgrade onboard over the mission lifetime)
Global Path Selection (GPS)	TA + LPS is enough to navigate around occasional small obstacles but not in larger, *e.g.* rocks > 1m, multiple parallel ripples, fractures or craters. In such situation the rover stops cause of is unable to backtrack far enough to continue towards its goal.	A new planner that maintains larger world maps (*e.g.* 50x50m2 and 0.4m cells) based on the Field D* planner of CMU, together with the ability to plan arbitrary paths through its map. *[algorithm Ferguson and Stentz, 2005, 9]*	SIP imagery	3 (software upgrade onboard over the mission lifetime)
Onboard Planning and Scheduling (OPS)	Adaptation of uplinked plans according to real-time state and resources information. This would allow modifying the plan to increase rover usage and optimise onboard resources to increase lifetime and science return.	Continuous evaluation of time-tagged activities that represent rover actions and behaviours. This evaluation is performed with plan timelines that contains both, states and resources. Timelines are calculated by reasoning about activity effects and represent past, current and expected state of the rover over time.	Status information. Software tool: Continuous Activity Scheduling, Planning, Execution and Replanning (CASPER)	5

Table 2 – Overview of MERs' autonomous capabilities

NASA is enhancing most of these described autonomous capabilities for the upcoming MSL mission to be launched during 2009. At the time of writing, we have identified these improvements from the available literature:

- Improvements on the VO algorithm: it is four times computationally more efficient while tracking more features; and it can be operated when no motion estimate is available. It is being tested on standard NASA platforms: Rocky 8, FIDO and ATHLETE [10].
- Improvements on the AS capabilities: better support to the exploration and characterisation of geological features, by identifying scientific criteria of selecting observations that would improve the quality of the area covered by samples. It will allow to scientists to mark sub-regions of interest (spatial coverage) with relative priorities for exploration, which will be directly linked to the onboard continuous (re)planning and optimization framework, CASPER [11,12].
- Improvements on the AS capabilities: to close the loop between sensor data collection, science goal selection, and activity planning and scheduling. Current approach requires human analysis to determine science goals and to convert them in low-level rover command sequences. The Onboard Autonomous Science Investigation Systems (OASIS) will generate science alerts for the CASPER framework that has the responsibility to replan and reschedule resources dynamically when possible, in order to undertake opportunistic science activities [13].
- Improvement on the overall integration of autonomy capabilities: MERs robotic capabilities are the product of previous NASA funding in research programmes, transferred to the mission through an inconsistent process of software infusion that became the de facto standard for future mission comparison. The Couple Layer Architecture for Robotic Autonomy (CLARAty) aims at providing a common software environment for

heterogeneous rover research platforms to test, verify and validate the functional and decisional layers, with contemporary approaches (modular and reusable software, UML design, *etc.*) [14,15].

3 THE ROLE OF AUTONOMY CONTROL LEVELS

The capabilities of a robotic system significantly impact human-robot performance during operations as demonstrated in applications in the non-space sector, in addition to the quality of the design and implementation of the Human Machine Interface (HMI). These capabilities, including autonomy, depend on sensory systems, mobility capacities and control algorithms. Human Robotic Interaction (HRI) studies *how* and *when* human involvement in robot control maximises the operational effectiveness. *How* a human operator is involved in the robot control is a function of the Level Of Autonomy (LOA) that measures the static function assignments of the human and the robot, in contrast to Adaptive Automation (AA) that occurs when the LOA changes dynamically [16].

The following table inspired by the hierarchy of LOAs [17], proposes ten autonomy levels describing dynamic and multitask autonomy scenarios for robotic systems [16]. The roles are represented by four functions:
1) *monitoring* is perceiving the system's state of health; 2) *analysing* is creating and generating the options or strategies of the given task; 3) *deciding* is selecting (acceptance or refusal) of the option; and 4) *executing* is implementing the accepted option. The studies by Sheridan et al. have also been a reference for defining ACL in robotic applications for the aeronautical sector, especially for Unmanned Aerial Vehicles (UAVs) [18], or NASA's human spaceflight vehicles [19].

Level of autonomy (LOA)	***Roles***			
	Monitoring	***Analysing***	***Deciding***	***Executing***
(1) Manual control	Human	Human	Human	Human
(2) Action support	Human Computer	Human	Human	Human Computer
(3) Batch processing	Human Computer	Human	Human	Computer
(4) Shared control	Human Computer	Human Computer	Human	Human Computer
(5) Decision support	Human Computer	Human Computer	Human	Computer
(6) Blended decision making	Human Computer	Human Computer	Human Computer	Computer
(7) Rigid system	Human Computer	Computer	Human	Computer
(8) Automated decision making	Human Computer	Human Computer	Computer	Computer
(9) Supervisory control	Human Computer	Computer	Computer	Computer
(10) Full automation	Computer	Computer	Computer	Computer

Table 3 – Levels of autonomy for space robotic operations

Absolute orientation sensing and stereo image processing capabilities are fully automated procedures (LOA 10), and both considered with the highest AML. With regards to mobility capabilities: local path selection, visual odometry and terrain assessment, classified with AML 4; are fully automated procedures executed onboard, but supervised by ground segment operators (LOA 9). If any conflict or malfunctioning is detected, or there is simply the need to drive the rover to another location, mobility capabilities may change to batch processing (LOA 3). Instrument placement requires human-in-the-loop for validating and deciding the best approach (LOA 5). Visual target tracking is driven by the selection, made by operators or scientists, of the feature to be tracked during traverse, *e.g.* a rock. This onboard algorithm processes the rock's characteristics to automatically correct the drive towards the rock using visual information (LOA 8). Autonomous science detects the presence of features autonomously, and scientists and engineers supervise the quality of selected and downloaded images (LOA 9).

The LOA defined in the system is very important during the operational lifecycle. A high LOA may cause degradation in manual or mental skill of the operator, loss of overall Situational Awareness (SA), decision bias to the operator controlling an automated system, vigilance decrement due to an excessive confidence on the system, and bad response to unexpected situations due to lack of attention and training of the operator, as well as operator's involvement during nominal situations. Conversely, under full manual control, issues like high mental demand on the operator, human decision bias in time-critical tasks to be executed with a short response time, operator's complacency and boredom, and inconsistent control behaviour will degrade the performance. The conclusion is that in unknown, unstructured, uncertain and dynamic environments as presented in this paper, a uniform LOA would not be efficient. The 'best' LOA at any time is based on complexity, difficulty, dynamism and quality requirements of the task [16]. A contradictory observation is that operator's preference ranges from shared control (LOA 4) to teleoperation (LOA 1) with increasing experience, as it has been experimented in robotic-assisted Search and Rescue (SAR). Furthermore, in this SAR experiment, the selected LOA with same robotic application might not be appropriate depending on the number of robots under the operator's responsibility [20].

An adjustable system, *i.e.* AA, to switch from teleoperation to an autonomous system, may be an appropriate solution. This dynamic transition among LOA could be a combination of autonomy suggestions to the operator on the monitoring and controlling working station [16]. AA provides four approaches to changing the autonomy level [21] still applicable to space operations: 1) driven by criticality of the event; 2) driven by the human monitoring performance measurement, *e.g.* a set of thresholds; 3) driven by the psychophysiological assessment approach, *i.e.* physiological measures; and 4) driven by behaviour model approach according to operator's model and permissions to interact with the model.

4 ROBOTIC TELEOPERATION TAXONOMIES

Chong *et al.* [22] proposed a useful taxonomy for teleoperation systems based on the number of operators and robots: 1) Single Operator Single Robot (SOSR); 2) Multiple Operator Single Robot (MOSR); 3) Single Operator Multiple Robot (SOMR); and 4) Multiple Operator Multiple Robot (MOMR). Later works have also identified a variant of the SOMR taxonomy for collaborative/cooperative robotics called Non-Operator Multiple Robot (NOMR). Most networked robots are SOSR, in which the control is limited to one human operator at a time. To the knowledge of the authors, all of space robotics for On-Orbit Servicing (OSS) and for exploration fit into SOSR architectures, with examples including ROTEX (DLR, 1993), ETS-VII (JAXA, 1998), GETEX (DLR experiment on ETS-VII, 1999), ROKVISS (DLR, 2005), SRMS-Canadarm1 (MDA, 1981), SSRMS-Canadarm2 (MDA, 2001), Sojourner (NASA, 1997), MERs (NASA, 2003), and in the future MSL (NASA, 2009) and ExoMars (ESA, 2013). Some of these robots are designed with shared-control, some with autonomous capabilities, some are operated with a delay of about 5 seconds and some with delays up to 40 minutes. Some are operated from Earth and some from the ISS - but all of them are designed and operated with SOSR taxonomy.

The operation of rovers in the envisioned scenario would require flexible system architecture, to adjust ground and flight segment services and functions to the diverse tasks to be performed across the different phases with the same robotic platform. For instance, *reconnaissance rovers* could be manually teleoperated with a delay minimum of about 3 seconds (1.3 seconds one-way-light-time) fitting into SOSR taxonomy. However, the same rovers could also be (semi)autonomously operated or cooperate amongst themselves in a NOMR scenario, where the operator would only supervise (LOA 9). These rovers during *site preparation and simple instalment* might be directly operated by astronauts with a negligible time delay, but with significant delays for supervisory control back on Earth. In this scenario, MOSR taxonomy is possible and in addition, each operator may have a different role and interact with a different LOA when interfacing with the robot. The robot therefore concurrently supports multiple LOAs depending upon the number, and nature, of the operators in the scenario.

A robotic architecture based on the MOSR classification might be of special interest when the robot can be teleoperated by astronauts (on site, from a lunar robotic centre or from an LLO station), and by an Earth-based control centre. The latter could remotely assist astronauts either in a supervisory role or even with low-level and detailed control tasks. This approach might bring a more effective and optimised manipulation with a reduction of task's completion time.

An example of MOSR architecture is shown in Figure 2, and an illustrative collaborative task would be the pick-and-place of lunar assets performed by a robotic arm during construction and assembly activities.

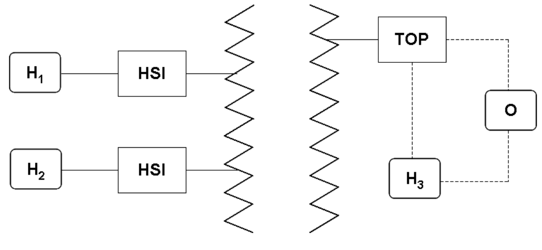

Figure 2 – Architecture for collaborative teleoperation

H_1: Operator on Earth-based centre
H_2: Operator on LLO station / lunar-based centre
H_3: Astronaut
HSI: Human-System Interface
TOP: Teleoperator (robot), O: Object

Real-time crew health and status monitoring systems are not represented.

This could be implemented by an augmented or virtualised reality system, in which the main task of the Earth-based control is to select virtual fixturing zones based on detailed mission information. Such control centres would require displays of predictive state information to compensate signal delay. The LLO station or lunar-based centre could be the main master, due to minor signal delay, mastering the robot control. Conflict resolution should be addressed throughout this distributed control system, using a delay-tolerant method. An astronaut could collaborate with the robot to help in executing the tasks, *e.g.* guiding the movement. In Figure 2 we designate the operators by functions H1 and H2 who interact with the remote system via Human-System Interfaces (HSI) from different locations.

5 CONCLUSIONS ON THE SYSTEM ARCHITECTURE PARADIGM

The topic we address in this paper is the analysis of robotic autonomy for planetary surface robotics. We reviewed the state-of-the-art of autonomous capabilities of Mars rovers, mapping each capability to an autonomy maturity level based on the operational level of confidence. The standardisation of this confidence level would restrict the operational procedures and in turn, increase mission safety.

Current rover technology shall be the basis for implementing new autonomy requirements for future planetary surface missions. In addition, they should be implemented with flexibility, modularity and adaptability within this complex system architecture, considering operational autonomy requirements from design [24]. We propose to classify each of these autonomous functions with a level of autonomy (LOA), which maps the four relevant functions of a system (monitoring, analysing, deciding, executing) with the responsible of controlling them (human, computer or both). This would provide a framework for redefining an operational standard of autonomous functions for the European Cooperation on Space Standardisation (ECSS). This has been a limiting factor to formulate widely-applicable requirements specifically for routine operations and fault management [25], where the authors also approached this operational need recommending a classification for autonomous functions based on: mission execution, mission data management and fault management.

This classification would provide a modular framework for autonomous components in an hierarchical system architecture, which should include and incorporate flight *autonomy* with ground segment *automation*. One approach to tackle this architectural need from a system and software perspective is to define LOA managers and services with a publisher/subscriber model, *e.g.* similar to the distributed CORBA architecture [26]. For instance, the LOA for a specific operational task could be adjusted by the user at ground mission control centre, by simply selecting fully manual teleoperation mode (LOA1). The subscriber would notify to the publisher, which would be the responsible in notifying next subscribers, *e.g.* lunar-based mission control centre and rover, which will at same time disable specific onboard subsystems for autonomous functions. Other criteria could be selected to adjust the LOA, *i.e.* historical trend analysis of successful experience on similar tasks, user operational experience, task criticality classification, number of distributed operators, and so forth.

Considering the future operational needs, these robots might be operated locally at lunar surface or from distributed remote sites, *etc.* so there is the need to use multiple-operator single-robot (MOSR) robotic control architectures either for teleoperation or (semi)autonomous mode. This architecture requirement should be further analysed within the context of established ECSS guidelines, and in particular the Packet Utilisation Services (PUS) [27] that specifies the data protocol, format, time synchronisation and onboard services at software level. Particular concepts familiar to spacecraft operators today such as events/actions (EVAC) implementation, onboard control procedures (OBCPs), and management of the mission timeline with schedules and subschedules are all implicated in the future autonomy requirements onboard the robotic system, and therefore the models used on ground to represent the prediction of current state (recognising that MOSR may make state changes to a robot from another facility) require serious attention. One early approach could be to recognise that useful levels of autonomy do not fit comfortably into established practices for operations, and therefore are difficult to ‘retro-fit’ into the standards, guidelines, software, and models used. There are nevertheless features within the standards that could be leveraged by a new concept for an autonomy management service, *e.g.* telecommands may already contain a *Source ID* in the data field header that recognises the fact that commands may come from multiple different sources. Coupling local (to the robot) knowledge of per-operator LOA with *Source ID* already provides for a mechanism of establishing command authority within a given state.

The clear conclusion from this survey of autonomy and examination of future requirements is that much work is needed in harmonising the different efforts – and terminology – even within the space sector.

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