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Autonomy Architectures for Vision Based Exploration Robotics

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1. Introduction

International space exploration plans currently call for multiple, robotic and human missions to the Moon, Mars and other destinations (e.g. Phobos). These exploration programmes will rely heavily on vision based robotic systems to achieve their high-level science goals. With this in mind, ESA have commissioned a study called Exploration robotics or X-ROB (led by Thales Alenia Space-Italia) to establish user requirements, concepts and partial bread-board validation of generic and cost efficient modular robotic systems. The concepts developed in this work should form a reference baseline for robotic systems which will service the needs of missions to Mars, the Moon, In-orbit and across four exploration phases:

1. Remote Exploration
2. Human Arrival Imminent
3. Human Arrival
4. Long-term Human Presence

i.e. across 12 (Mars,Moon,In-Orbit = 3 x 4) general mission scenarios. There are numerous aspects to consider and study in such a wide-ranging activity and one of the most critical is the area of robotic autonomy. As part of X-ROB the authors led a small industrial/academic team to look at the autonomy requirements for the 12 mission scenarios. This work looked at various aspects such as the need for discrete vision based autonomy components like navigation, localization, robotic arm control, autonomous science and wider issues such as robot-robot or human-robot interaction. This paper focuses mainly on the need for high-level supervisory autonomy components identified in the X-ROB initial assessment and its impact for vision based autonomy where relevant.

2. Motivation & Objectives

Following the ESA A&R approach the initial X-ROB activity analysis identified discrete tasks and actions which would be required to meet the defined mission objectives across the 12 scenarios. Whilst discrete tasks such as navigation, arm placement, science target detection are ideal candidates for an autonomous implementation and would provide the basic building blocks for many missions, we also identified the need for higher-level supervisory tasks and an associated architecture in order to:

- Manage resources such as time and power to ensure that the discrete tasks are able achieve their objectives whilst balancing the different priorities within the overall mission
- To decide which tasks should be run and when in order to achieve mission goals
- To manage interaction with other agents particularly with respect to robot-robot or robot-human cooperation, collaboration and coordination

This aspect of the study therefore sought to address two key questions:

1. Which supervisory functions are required for the 12 X-ROB scenarios ?
2. Who should carry out the task in each case – humans or robots given that X-ROB includes long-term missions with

human and robot presence – and how should this be decided?
3. What are the implications for individual autonomy component design – the majority of which require some vision based capability?

The most difficult and we think novel aspect of this work is its scale i.e. trying to identify a common set of supervisory functions and a human/robot trade-off methodology across the range of all possible exploration and robotic missions identified by ESA. Clearly this is a huge challenge but we believe that the approach outlined below provides a first step in this regard. Also the issue of human-robot interaction for Lunar/Mars missions is in its early days from a European perspective. This work seeks to progress some of the key issues in this area such as adjustable autonomy.

3. Approach and Results

To address question 1 we first of all looked at the supervisory requirements for a single agent in the various mission scenarios. Given the eventual multi-agent nature of these scenarios we then looked at how a multi-agent configuration would effect the supervisory requirements and this included looking at the complex but important issue of adjustable autonomy. Both a bottom-up and top-down approach were used to derive the baseline list of functions for the single agent case looking at requirements on a case-by-case basis and also surveying the many existing robotic control architectures [e.g. Bossano et al 97, Firby 87, Volpe et al 2001]. Finally, a consolidated list of nine key functions and a generic architecture were produced with the list being further augmented as multi-agent and adjustable autonomy issues were explored in detail. The analysis also included recommending a scheme for adjustable autonomy which would be suitable for long term X-ROB deployment.

To decide who was best placed to execute a function for any given 12 X-ROB scenarios, we evaluated the suitability of a human versus robot scenario for each of the functions identified in the previous phase of the work against criteria such as: Complexity; Technology Readiness; Responsiveness; Risk; Efficiency; Reusability; Cost; Ease of Interaction. In addition we then developed a methodology, captured in flow-chart based decision trees to permit an initial trade-off and assignment of human versus robot operation. This allowed us to provide an assignment for each function to either humans or robots in each of the twelve X-ROB scenarios.

4. Expected Impact

The second phase of X-ROB calls for the bread-boarding of some critical concepts and components identified in the first phase. Given the central role of autonomy in the activity a number of the supervisory components identified in our analysis have been proposed for bread-boarding. This will include basic human robot interaction to explore the issues associated with having astronauts use robots in the field (or in-orbit). This activity is due to commence imminently with results being available in summer 2010. The bread-board schemes are focused on rapidly testing applications on existing robotic infrastructure such as ESA's Eurobot. A number of autonomy applications have been developed by the SciSys team which will be used where suitable to accelerate evaluation of the analytical conclusions. This includes a PDA (iPhone) driven AI planning system integrated with a mission control system which would allow astronauts to use an exploration platform to assist in the field in a number of different scenarios

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This work could potentially have broad reach across the ESA domain as it seeks to recommend strategies for autonomy across a wide range of robotic missions. The authors believe that it is important to disseminate these conclusions to the wider space community to ensure wider participation from the relevant experts. Given the predominance of vision as an enabling element for autonomy components and remote science we believe that it is essential to present these ideas to the space robotics and vision researchers in particular. The inclusion of the bread-board phase to test this wide ranging, component based approach will also assist in evaluating the soundness of the approach and therefore provide a more informed commentary to the space robotics community.