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THE EVA ROBOTIC ASSISTANT EXPERIMENT ON THE HAUGHTON-MARS 99 EXPEDITION

Nicolas Vandapel (1), Pascal Lee (2), Dimitrios Apostolopoulos (1),
Geoffrey Briggs (2), Bill Clancey (2), Brian Glass (2),
Steve Hoffman (3), Kimberly Shillcutt (1), Maarten Sierhuis (2),
Mike Sims (2), H. Thomas (2) and W. "Red" Whittaker (1)*

ABSTRACT

Humans and robots will both be needed to explore and settle Mars, as the two present specific capabilities and performances that may in many instances be regarded as complementary rather than redundant. But what role should and can humans and robots play given the current status of robotic technology and optimistic timeframes for human exploration (human missions to Mars beginning within the next 2 decades)?

In response to the growing interest in understanding how humans and robots might work together on Mars, we plan to carry out baseline observations and field simulations in human-robot integration on the 1999 Haughton-Mars Project expedition to Devon Island, Arctic Canada. A variety of tasks will be performed, including an inventory of all activities that support field work to assess the range of possible robotic needs in field exploration, a systematic recording of the metrics of extravehicular (i.e., outdoor) activity (EVA) in those areas likely to require field robotic support, and a definition of the information technology architectures likely to be needed to achieve a well-integrated human-robot exploration system. Among the planned simulations, we will have a roboticist on an all-terrain vehicle (ATV) accompany field scientists on traverses across the Mars-like terrains of Devon Island acting as if he/she were a robotic assistant. Tasks to be performed by this EVA Robotic Assistant may range from navigation and supplies caching to sample curation and geologic interpretation. The exercise should help identify specific robotic needs of astronaut explorers on Mars and help guide future robotic research in this area.

An integrated, synergistic human-robot exploration system is envisioned as a possible outcome of this research. Preliminary results from the 1999 field season will be presented. This work is supported by the Haughton-Mars Project and its sponsors, including The Robotics Institute of Carnegie Mellon University and the Mars Society.

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*(1) Carnegie Mellon University
(2) NASA Ames Research Center
(3) NASA Johnson Space Center
Contact information: vandapel@cs.cmu.edu, pclee@mail.arc.nasa.gov, da1v@cs.cmu.edu

I. INTRODUCTION

I.1. Robotics to support EVA

Robotic probes proved their usefulness in planetary exploration in the past decades and more recently mobile robot as remote science platform too [Mishkin-98]. The next step will consist in the design of robots for surface operations in the context of the human exploration of Mars. The roles planned [Duke-98] include: site reconnaissance, power system deployment, base maintenance, construction material production and science activities in geology, geophysics, meteorology and exobiology. Some of them will have to be done by autonomous precursor robots, other could be done by teleopered or autonomous rovers landed with the crew.

But one of the most challenging aspects is in supporting directly astronauts in their extra vehicular activities (EVA). The robot can be designed to reduce astronaut payload in carrying part of the life support system as the semi-autonomous cart, voice activated, described in [Hodgson-98]. The robot can have also an extended autonomy and can be used along different scenarios – scout, video coverage assistant, science field assistant, technical field assistant – as in the ASRO experiment conducted last February by a NASA team lead by Ames roboticists with the Marsokhod rover [Cabrol-99]. A design study from the University of Maryland [Weisman-99] describes a rover to support EVA as life support, tools carrier, etc….

I.2. Expedition motivation

Our approach differs from the work presented above because we will justify and evaluate the use of a robot with metrics, and we will work, not at the scale of a full robot, but at the level of robotic functionality. To lead our work we first tried to reply to basic questions like “why, for which purpose, for which kind of environment and for how long designing a robotic support?”. The answers to those questions will have a direct influence on the level of autonomy, on the level of mobility and science capability required. For example, as we will see later, you may have just to instrument the scientist with a display and to put a sensor on his vehicle to solve his problem.

So during the Haughton-Mars 99 expedition a series of experiments were conducted to understand field science and to evaluate, with metrics, robotic needs and/or requirements to support activities of biologists and geologists. Field activities studied included: impact crater geological mapping, site characterization (determining the formation process of a depression), site reconnaissance to settle a base camp and repeaters for communication, lake biology and oases survey.

This paper deals mainly with the first one – impact crater geological mapping – and it is organized as followed: the next part presents the methodology used during the expedition to collect data, the third part gives an overview of the field work and the kind of data gathered, the fourth one contains results based on the data processed and the final one presents our conclusion and recommendations.

II. METHODOLOGY

II.1. Approach

Field study of geologists has been conducted previously by [McGreevy-92] in order to design virtual reality tools to help geologist during virtual exploration, in that case with an ethnographic centered approach, work pursued in [McGreevy-94]. In our case we choose to base our approach on **action characterization** where **metrics** play the major role in order to have quantitative results to analyze fieldwork and to justify the technical solutions proposed.

Each mission performed by the geologist is segmented into different levels. From the broader to the more specific we have sub-missions, tasks, functionalities and tools. For example by using a level (*tool*) you can measure the structure orientation of some feature (*functionality*) in order to document a site (*task*) during a study of a local (*sub-mission*) as part of a geological exploration process (*mission*). For a more detailed example see the paragraph IV.1. Each task is then characterized by quantitative and qualitative metrics described in Table 1.

Trip/movement	**Science**	**Human factors**
Time Distance Pattern described Communication	Kind/amount of data gathered Visual range acuity Level of report Amount of post-analysis	Interest for the geologist Physical difficulty Level of skill Level of attention required Level of planning

Table 1: Metrics used

II.2. Observation/Simulation

Field study was conducted in two ways: by observing the geologist at work and by making "robotic simulation". By observing the geologist you can understand, describe and characterize his tasks. By making "robotic simulation" you can discovery unplanned or hidden needs and see the major challenge to design robotic solutions to support EVA. By following this method we tried to avoid bias and *a priori* ideas from both sides (roboticist and geologist). The robotic simulation experiment was centered on four main scenarios – or missions - inspired by [1]:

- *Pathfinder*: the robot will be a remote controlled or autonomous scout
- *Caretaker*: the robot will monitor geologist activity during EVA
- *Co-worker*: the robot will work in a closely way with the scientist. It can be a "scientist" as a mean to deploy a specific sensor, it can be a "secretary" taking notes and registering data, or an "explorer" by covering an area and looking for something specific and finally in the cleverest case an "assistant" by helping directly.
- *Tools/Energy carrier*

In both cases (observation/simulation) we used the approach described in section II.1.

III. FIELD WORK

III.1. Mission studied

The results presented in this paper are based on the study of one specific mission performed by one geologist: impact crater geological mapping. It consisted in gathering rock samples, making sketches of geological formation, taking pictures and drawing frontiers between different kinds of geological terrain on a topographic map. Modified tools or powered tools were not used nor was any scientific instrument like a spectrometer. Rock samples were identified on the field; best samples will be analyzed more extensively after the trip in a laboratory.

III.2. Environment description

The terrain explored were outcrop, breccia and a canyon

Outcrops are apparent bedrock usually on steep slope of hills surrounding by gravel and small rocks. They are only accessible by feet sometimes with difficulty, see Figure 1.

Figure 1: Outcrop

Breccia explored were small hills with a plateau on the top and with small slopes. They were accessible by ATV with no obstacle on the plateau, see Figure 2.

Figure 2: Breccia

One canyon was explored (“*the lost valley”*). A river – the *Malvina* River - runs inside and steep slopes surround it. One end was not accessible by ATV and a foot exploration was performed, see Figure 3.

Figure 3: Canyon

III.3. Experiments

Experiments were conducted during 8 field trips, see Table 2, on all terrain vehicles (ATV) with time and distance constraints, respectively less than 8 hours and less than 10 km far from the camp.

Date (July-99)	4	5	6	7	9	11	14	15
Length (hh:mn)	6:00	7:20	6:10	4:40	6:30	3:45	6:00	7:45
Notes	Outcrop			Spacesuit simulation	Breccia		Canyon	

Table 2: Field activities

Different kinds of traverses were performed: long range and short range, in unknown or partially known environment. *A priori* information available included a topographic map of the crater (1/50,000) and aerial pictures.

During one day, the 7th, the geologist wearied a firesuit to reduce his mobility, visibility and dexterity. That day one of us assisted him and followed his orders as a “robot” could do it. During the other days a partial and time limited support was provided in some cases in carrying tools and rocks for examples.

III.4. Data recorded

For each field trip a set of common data, related to the ATV and the geologist, were logged as describe in Table 3. Each time one of the entries changed a new line was generated, so a minute per minute description of field activities is available.

Time	ATV		Geologist			Data
	Location	Status	Location	Task	Tool	

Table 3: database

The column “Data” deals with additional data collected in order to document work practice or the site explored. This includes video, pictures and sketches. Sketches represent the area explored with drawn on it geologic features (boulder, outcrop), location where the geologist collected some material (pictures, sketches, samples) and the path he followed to reach that location. GPS coordinates of the geologist’s ATV are available for some traverses.

Data recorded by the geologist were also available after the field trip. For each location studied by him we have the coordinates of it, the number of pictures taken, the number of sketches made, as well as the number of samples collected.

IV. RESULTS

IV.1. Action decomposition

Here we present an overview of the action decomposition scheme applied to the “impact crater geological mapping” mission based on the data gathered. This mission was divided into 7 sub-missions, 21 tasks and 25 different functionalities. The following table contains a partial view of this decomposition. You have in it all the sub-mission (**in bold face**), for one sub-mission (**Studying local area**) all the tasks (underline) and for one task (Site documentation) all the functionalities (*in italic*) and tools.

Each of the tasks identified was then quantified with the metrics described in Table 1, page 3.

Planning trips to cover the crater
Trip set-up
Navigation
Studying local area
    Exploring area
    Taking samples
    Document site
        Measure structure orientation compass/level
        Make sketches notebook
        Take pictures camera, tripod, scale
        Draw limitation of geological features topographic map
    Studying large scale feature
Data post-processing
    Vital functions support

Table 4: Partial action decomposition for the "Impact crater geological mapping" mission

IV.2. Robotic simulation

Table 5 provides an overview of the tasks performed or not during the simulations and what was the key point or justification in case or success or failure respectively was.

Scenario	Task performed	Task non performed	Key point/Justification
Pathfinder		Scout	Environment known
Caretaker	Warning if out of sight		
Carrier	Put in bag and store safely		Dexterity
		Grabbing rocks on the ground	Target recognition
		Selecting rocks	Geological knowledge
		Tools carrier	No heavy tool
Co-worker		Exploring area	Geological knowledge
	Taking video		Understanding order
		Making sketches	Geological knowledge
		Scientist	No instrument
		Assistant	Understanding order/task

Table 5: Simulation overview

The first key point, common to all the scenarios tested, was *understanding orders*. That aspect involved the size of the vocabulary required, the number of orders, the context of the situation and the *a priori* knowledge needed to understand them, see [Imai-99] for the influence of external information and physical constraints in human robot interaction.

The second recurrent issue is related to *geological knowledge* required to perform some tasks. How can you explore an area if you are not able to recognize what you are looking for? Or if you are not able to make the difference between the common and the interesting feature (see [Ruzon-97] for geologic feature detection, linear layer in that case)?

IV.3. Data gathered

Figure 4 presents[1] for each day the number of rock samples gathered, of pictures taken and of sketches made by the geologist.

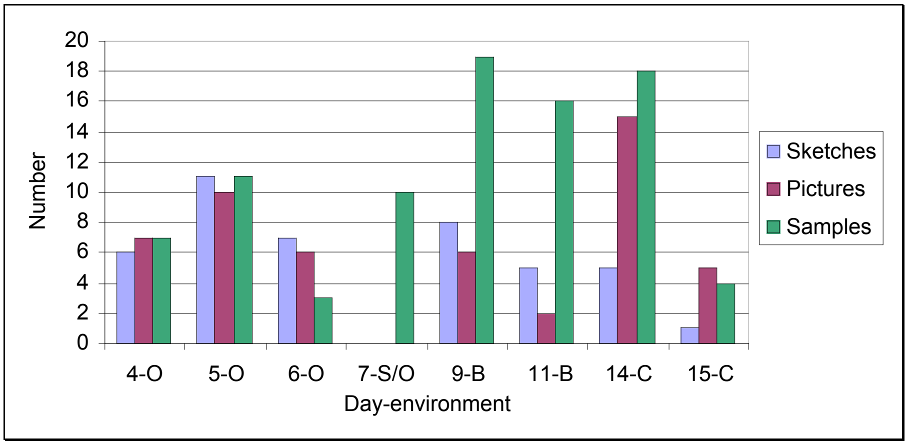

Figure 4: Data gathered per day

The main factors to explain the differences are:

- *The influence of the environment*: data gathered on breccia or outcrop are not the same
- *The influence of preliminary exploration*: less data were gathered if the current exploration was done to complete another one (see day 14 and 15)
- *The influence of the ATV availability*: when the ATV was far fewer samples were gathered (15).
- *The length of the exploration*: when the geologist was tired or bored he tended to be less investigative and tended to reduce his energy expenses.
- *The spacesuit influence*: the geologsit's mobility, visibility and dexterity radically changed with the spacesuit as well as his way of working (see day 7)

Based on this graph and field observations we proposed to implement method in order to allow geologic feature localization and to extend the amount of information gathered at each location.

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[1] For each graph the following code has been used O for Outcrop, S/O for simulation and outcrop, C for canyon and B for breccia

IV.4. ATV Status

The ATV status was “off”, “on” and moving” during traverse and “on stopped” during localization or foot exploration of the surrounding area. Figure 5 presents the % of time the ATV was in each state.

Differences can be explained by **the influence of the environment:**

- For outcrop usually the geologist parked the ATV at the bottom of the hill and climb toward the outcrop and explored it. The ATV was “off” in that case.
- For breccia the geologist explored on the ATV and stopped when he had found something interesting. A short foot exploration around the ATV was then performed. The ATV was turn off only if a long stay was expected.
- For the canyon the geologist explored outcrop but also the bedrock of the river so we have a mixed situation in that case.

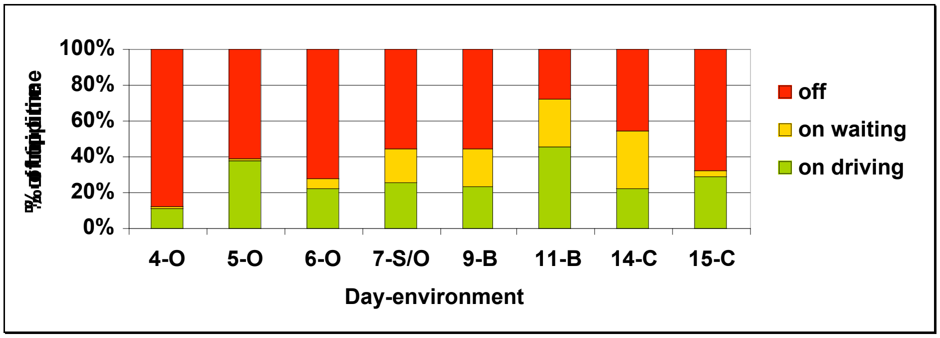

Figure 5: ATV status

This graph shows that most of the time the ATV is not used (“off” plus “on waiting”). We suggest using that time to support EVA.

IV.5. Walk Pattern

When the geologist was walking he exhibited three kinds of pattern:

- “*Close examination*” he walked around a boulder or follow the edges of an outcrop,
- “*Transit*” he walked from one point to another one between the ATV and an outcrop,
- “*Cover*” he tried to cover exhaustively a specific area in order to find some interesting feature.

As regard that graph we suggest to develop methods to:

- Limit risky travel (close examination of outcrop)
- Limit non-productive travel (transit).

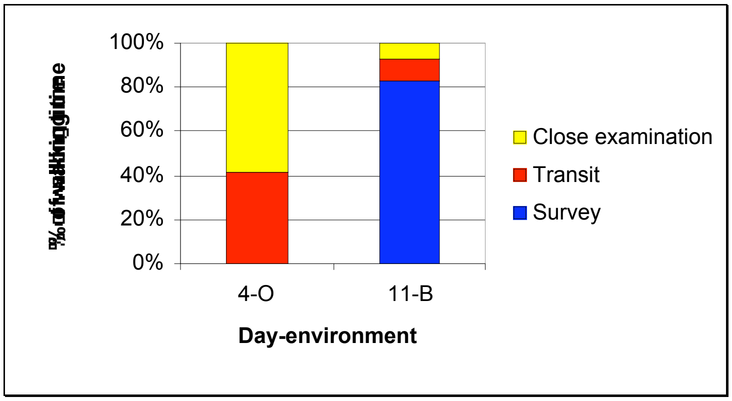

Figure 6: Walk Pattern

IV.6. Time allocation

Tasks were grouped into 6 classes: *equipment management* (GPS, ATV*), site documentation* (pictures, sketches), *rock sampling* (extracting it, identification, put in bag, pack and store it on the ATV), *ATV travel* during traverse, *walking* during exploration and *positioning*. Figure 7 represents for each day the percentage of time spent for each class.

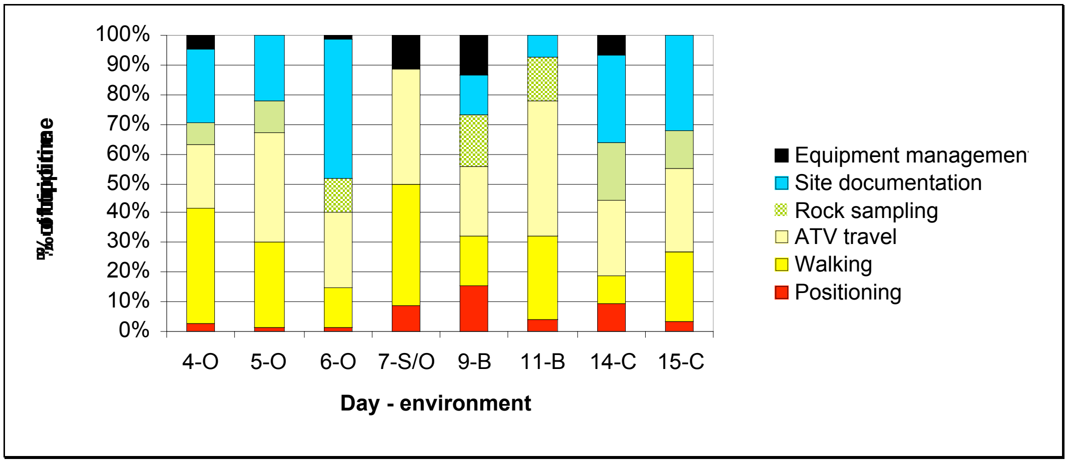

Figure 7: Time allocation per day

Based on that metric we suggest focusing on:

- Monitoring field activities (time spent walking),
- Site documentation,
- Rock sampling

V. CONCLUSION

This paper deals with the EVA Robotic Assistant Experiment on the Haughton-Mars 99 Expedition. We presented the context of this work, the approach followed with the use of **metrics**, the kind of data gathered, and quantitative results. From all the experiments conducted we choose one example - impact crater geological mapping – to illustrate our work. We detailed the action decomposition for that mission, the robotic simulation conducted, analyzed several graphs – data gathered per day, ATV status, walk pattern, and time allocation. That quantitative analysis justified the areas, where robotics should be used to support EVA, proposed.

The first step, for HMP-2K, should be an instrumentation of the scientist and his ATV in order to monitor activity and to document the site. At the same time we should continue field study by working under EVA conditions with a spacesuit, using scientific instruments (drill, radar, and spectrometer), extending Mars analog science activities (geomorphology), involving two explorers (cooperation/communication). We should also use new methods to facilitate data collection (DGPS explorer/ATV).

The second step should be centered on an autonomous vehicle to follow the geologist on breccia, on site mapping capability, on a teleoperated explorer and on a device to pack rocks.

The major challenges to support EVA are the integration of geological knowledge, autonomous exploration and human-robot interaction.

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