Human-Agent Interaction for Human Space Exploration

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ABSTRACT

Human space exploration creates unique challenges and opportunities for many scientific disciplines. From the human-agent interaction perspective, these require significant advances in the way that agents model, adapt and personalize their behavior to individual astronauts and groups of astronauts. In this paper, we highlight the key challenges and opportunities that human space exploration provides to the agent and UMAP communities and present two avenues for future research. We further propose a viable way to explore these challenges and opportunities through the world-wide analogue space programs which solicit research proposals from all scientific disciplines.

CCS CONCEPTS

• **Human-centered computing → HCI design and evaluation methods**; • **Applied computing** → *Aerospace*.

KEYWORDS

Human-Agent Interaction, User Modeling and Personalization, Human Space Exploration

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1 INTRODUCTION

There is a renewed interest among space agencies around the world to extend human spaceflight and inhabit other planets. This interest includes NASA's "Journey to Mars" [2], the European Space Agency's (ESA) "Moon village" [1], and other plans for manned missions by the Chinese and Russian governments.

Long space exploration missions would involve astronauts being exposed to isolation, confinement and other extreme conditions for prolonged periods of time, which may hinder their ability to perform safely and at peak productivity, both at the individual and group levels. These extreme conditions include sleep deprivation, fatigue, radiation, nutritional changes, stress and boredom to name a few [30, p. 370-407].

Unfortunately, costly communication and natural delays in communication between the astronauts and mission control on earth prevent us from having a human specialist (e.g., psychologist, doctor) following the astronauts and providing appropriate interventions when needed. Specifically, astronauts exploring deep space will have an unprecedented level of autonomy, making their ability to perform safely and productively, as well as their ability to work together as a team, key factors in a space mission's success [11].

In this paper, we suggest that advances in human-agent interaction technologies can assist astronauts in their missions by automatically reliving some of the challenges astronauts face. However, it is also our claim that these possible contributions are *bounded by the agents' ability to proficiently model, adapt and personalize their behavior to each astronaut and/or to a group of astronauts, with minimal to no human intervention.* To that end, we highlight key opportunities that human space exploration creates for the community.

In order to facilitate researchers in pursuing the proposed lines of research and promoting interdisciplinary collaborations, we propose a viable way to explore the discussed opportunities by collecting real-world predictive data and evaluating algorithms and methodologies in-the-field in space(-like) conditions with human subjects through the world-wide Analogue Space Programs (ASPs) [6]. An analogue is an environment on Earth that produces effects on (analogue) astronauts[1] similar to those experienced in space, both physically and/or mentally. ASPs provide extraordinary environments for exploring the many challenges and opportunities that human space exploration creates for the user modeling, adaptation and personalization community - "down here on earth" - at a minimal cost.

The remainder of the paper is structured as follows: In Section 2 we discuss the motivation for the proposed research and the limitations of existing studies from our research perspective. In Section 3 we discuss two research directions for the community along with specific tasks that we deem feasible. In Section 4 we discuss the potential use of analogues for supporting the proposed research. Finally, we summarize our proposal.

2 BACKGROUND

Extreme environments, such as space travel and habitation, commonly share similar characteristics [7, 24, 26]:

(1) High degrees of physical and social isolation and confinement.
(2) High risks/costs associated with mistakes or failures.
(3) Intense physiological, psychological, psychosocial and cognitive demands.

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[1] An analogue astronaut is a person who conducts activities in simulated space conditions (commonly as part of an ASP).

(4) Multiple critical interfaces (human-human, human-technology, and human-environment).
(5) Critical requirements for team coordination, cooperation, and communication.

For instance, the majority of aircraft accidents (both civilian and military) are due to human errors and lack of crew coordination (e.g., [27]) and the majority of medical errors in operating rooms are due to surgeons' (avoidable) mistakes and interpersonal interactions among the medical team (e.g., [28]). Clearly, human space exploration is a prime example of an extreme environment and, as such, it is expected that astronauts' frailties, both at the individual and group levels, may jeopardize the success of a mission and the safety/productivity of the crew. In fact, the study of these human factors has become central in the space exploration community [13]. In light of the many recent advances in human-agent interaction technologies (which are prevalent in Autonomous Agents and Multi-Agent Systems (AAMAS), Human-Agent Interaction (HAI) and similar conferences and associated journals), it can be expected that with appropriate inquiry and development, these technologies can be put to use in space conditions as well.

Current studies into the human factors of space travel and habitation have made significant progress in understanding and assessing the underlying factors which influence and characterize human behavior and the physical/mental condition in extreme environments. Nevertheless, in order to develop intelligent agents that can assist astronauts in the real world, two major limitations need to be addressed:

(1) Existing studies assume access to (or explicitly obtain) extensive data on both the physical (e.g., blood pressure, sleep patterns) and non-physical (e.g., mood, inter-personal communication) states of the astronauts. While this practice is acceptable, from an engineering/practical perspective, any intelligent agent designed for assisting the astronauts would be restricted by the data which we expect to be available in real-world deployment. Specifically, it may be unreasonable to expect astronauts to complete long mood assessment tests (e.g., the 37-question long Profile of Mood States test [21] which has been applied in human factor research in space analogues), have in-depth interviews with professionals or communicate their feelings and well-being via other instruments during real-world missions. Therefore, intelligent agents aimed at assisting astronauts will likely need to rely on *observational data* [29] rather than explicitly elicited data, for adjusting and personalizing their models and behavior.
(2) Existing studies of human factors in space conditions tend to adopt a "passive approach" where data is only collected and later analyzed, *offline*, by human experts. For example, data on group interactions within analogues is collected and later analyzed by psychologists in order to better identify desired personality traits and social profiles that will promote teamwork [3]. Specifically, the use of intelligent agents which reason over the collected data in real-time and (semi-)autonomously take actions in the environment (as we will discuss in Section 3) has, to the best of our knowledge, yet to be explored. Clearly, the modeling and prediction of both the short-term and long-term effects of the agent's actions on the individual astronauts, the group and the environment, are essential for allowing the agent to plan its behavior over time.

3 OPPORTUNITIES

In order to better identify the unique opportunities we are facing, we conducted a semi-structured interview with two analogue astronauts and officials of the D-MARS[2] organization (an international planetary research analogue center located in the Israeli desert) earlier this year. To the best of their knowledge, to date, no ASP-based study has studied the possible contribution of human-agent interaction technologies for mitigating some of the challenges associated with human space exploration.

The analogue astronauts further pointed out two possible avenues for such contributions:

(1) Assisting each astronaut individually.
(2) Assisting astronauts as a group.

We discuss these avenues next.

3.1 Enhancing Personal Safety and Productivity

Intelligent agents can provide several imperative services which can increase safety, performance and well-being of individual astronauts, and decrease errors, effort and frustration.

First and foremost, intelligent agents can be used to *monitor for undesired personal conditions* which require attention. For example, by monitoring an astronaut's signals (e.g., sleep patterns, movement), agents can identify increased risk of cognitive or mental conditions such as depression or anxiety [5, 18], or physical conditions such as malnutrition. Naturally, in order to identify an undesired condition, an agent first needs to quickly and accurately model what constitutes a normal condition for each astronaut, both physically and mentally. In addition, as changes in the astronauts' condition are expected due to the extreme environment, it is essential to predict the expected extent of change for each astronaut individually and identify anomalous indications accordingly.

Given that an undesired condition was identified, the second step for an agent would be to provide a *prognosis*. Namely, the agent would need predict the likely course of the undesired condition, including the possible risks to the astronaut and her work, accounting for the expected changes in the environment without the agent's intervention. For example, an agent may identify a specific astronaut as being mildly depressed, yet it predicts that the condition will be mitigated in the coming days as the astronaut is scheduled to perform an extra-vehicular activity which the astronaut is known to enjoy.

Lastly, and most importantly, an agent can (semi-)autonomously take appropriate actions. Specifically, an agent should be able to decide when is the most appropriate time to take an action, select the optimal action to take and plan its behavior over time in order to address an identified undesired condition or promote a desired condition. For example, an agent may provide an astronaut with advice or recommendations (e.g., suggest "try to get some

[2] www.d-mars.org

more sleep" before night time or "Drive robot X away from robot Y" before they collide [17]), provide entertainment or information of an appropriate nature at the right time, change the astronauts' schedule or menu while respecting the mission's goals and constraints, notify the field commander or ask for assistance from a human specialist on Earth, to name a few options. Deciding if and when to interrupt an astronaut, for any reason, is yet another key challenge [23]. Naturally, astronauts are expected to react to the agent's presence and actions. As a result, the agent should also be able to predict and account for the long-term effects of its actions, which constitutes a challenge in its own right [20].

It is therefore argued that efficient user modeling, adaptation and personalization techniques are needed in order to provide these services properly.

3.2 Facilitating Teamwork

In his seminal paper [25], Alan Turing proposed to replace the philosophical question "Can machines think?" with an operational challenge of constructing an automated agent that is able to carry out a dialogue with a person well enough to be indistinguishable from a person. Recently, it has been hypothesized that given the transformations in computer use as well as the significant advances in computer science and human-agent interaction technologies, Turing might pose a slightly different challenge today: Can an automated agent team member behave, in the long-term and in uncertain, dynamic environments, in such a way that people on the team will not notice that it is not human? [10]

In the human space exploration context, the above challenge is very ambitious. Nevertheless, we can identify a few simpler functions that an agent can fulfill in an astronaut group setting which we believe can be achieved in the near future:

(1) Promote satisfaction and fairness in social choice settings [4]. Since astronauts differ in their preferences (e.g., how to accomplish a task, what to eat for dinner, etc.), an agent may reduce some of the tensions associated with collective decision-making by providing an automated "fair" mechanism. Specifically, by modelling the different preferences, aggregating them properly and using an acceptable decision-making rule, an agent can advise the group as to which alternative should be selected. Clearly, the agent would need to balance between the different objectives that the team is trying to pursue, the environment constraints and the (dis)satisfaction of the crew members given their preferences. Note that since the astronauts may engage in the same (or similar) social choice settings over time, it is important to consider their satisfaction in an online fashion. For example, consider a team of astronauts in which, by chance, a single astronaut is always in the minority opinion (e.g., preferring to eat something that the majority does not want). It remains an open question how an agent should resolve this and similar issues since, if that astronaut does not get to enjoy her preferred food for a long time she might get frustrated which, in turn, might hinder the teamwork.

(2) Perform automated task allocation (e.g., [22]). Astronauts may have different responsibilities, qualifications and preferences. Conversely, different tasks may require different levels of effort and expertise and may differ in their importance. Clearly, it is impractical to perform the entire task allocation in advance and perfectly follow it (i.e., some tasks are unexpected, an astronaut's condition is unpredictable, etc.). As such, an agent can assist in performing an online task allocation, accounting for and balancing similar factors to the ones discussed above [16].

(3) Resolving interpersonal conflicts. Conflicts between team members are unavoidable. Automated mediators [9], negotiators and other argumentative agents [15] may provide a theoretically grounded and acceptable way to resolve these conflicts. To that end, an agent would need to properly represent the conflicting astronaut's beliefs, opinions or values and suggest that/persuade the parties to adopt a suitable resolution. Note that the application of argumentative principles to human discussions and conflicts may be extremely challenging [19].

(4) Critiquing. In a structured process such as a space mission, there are predefined guidelines that the astronauts are expected to follow. Recent advancements in Goal and Plan Recognition research focus on explainability and how to notify astronauts when they deviate from their expected goal [8, 14].

Note that in all of the above applications, both for individual astronauts and groups of astronauts, efficient elicitation of information (e.g., preferences) may prove to be very hard. In addition, providing adequate *explanations* for the agents' actions could play a crucial role in promoting the acceptance of these agents. It is also important to remember that different people prefer different types of explanations (e.g., men and women on dating sites [12]), which would in turn require the agent to adapt and personalize its explanations to each astronaut and group of astronauts.

4 THE DATA IS OUT THERE

The logistical challenge of studying human factors in space conditions has already been identified by different governments and space agencies. To that end, world-wide ASPs have been established which have built analogue environments in locations that have physical similarities to the extreme space environments such as the Moon or Mars in terms of their geology, biology, weather conditions, etc. These analogues mimic real space travel and habitation by applying artificially delayed communication with ground control, enforcing strict operation protocols (e.g., the use of spacesuits and relevant equipment), and other means aimed at replicating space conditions. Subsequently, extensive data about the strengths, limitations and validity of different human factors and human-centered technologies can be gathered through these analogues. This data is invaluable for studying and evaluating different human-agent interaction technologies, and cannot be obtained in regular laboratory settings.

The list of active ASPs keeps getting longer over the years. Among the most active ones are the well-established NASA human research program (https://www.nasa.gov/hrp), which operates and supports numerous analogue sites and programs in and outside the US, the Austrian Space Forum OeWF (https://oewf.org/), D-MARS (https://www.d-mars.org/), the ESA's Pangaea and CAVES programs (http://www.esa.int/) and others.

To the best of our knowledge, most of the above ASPs actively solicit research proposals from different disciplines in order to maximize the research impact of their analogues. While different ASPs have different conditions, regulations and demands from the proposing researchers, ASPs are commonly non-profit organizations and, as such, the associated costs of collecting data and performing experiments in their environments is minimal and, in most cases, free.

5 DISCUSSION

This paper introduces a novel challenge for the human-agent interaction community – advancing our understanding and computational abilities to model, adapt and personalize an agent's behavior for human space exploration environments. We argue that these advances, albeit demanding, can bring about a significant leap in the way intelligent human-interacting agents operate autonomously, reveal new insights into the fundamental principles of human-agent interaction and can be put to good use in promoting human space exploration. Note that these advances are not necessarily limited to space conditions and may also apply to more moderate environments such as operating rooms, flight and others.

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