Earth, Moon, and Planets (2005) 94: 233–243
DOI 10.1007/s11038-005-9012-3

THE VALUE OF HUMANS IN THE BIOLOGICAL EXPLORATION OF SPACE

C. S. COCKELL
Planetary and Space Sciences Research Institute, Open University, Milton Keynes, MK7 6AA, UK
(E-mail: c.s.cockell@open.ac.uk)

(Accepted 26 May 2005)

Abstract. Regardless of the discovery of life on Mars, or of "no apparent life" on Mars, the questions that follow will provide a rich future for biological exploration. Extraordinary pattern recognition skills, decadal assimilation of data and experience, and rapid sample acquisition are just three of the characteristics that make humans the best means we have to explore the biological potential of Mars and other planetary surfaces. I make the case that instead of seeing robots as in conflict, or even in support, of human exploration activity, from the point of view of scientific data gathering and analysis, we should view humans as the most powerful robots we have, thus removing the separation that dogs discussions on the exploration of space. The narrow environmental requirements of humans, although imposing constraints on the life support systems required, is more than compensated for by their capabilities in biological exploration. I support this view with an example of the "Christmas present effect," a simple demonstration of human data and pattern recognition capabilities.

Keywords: Life on Mars, human space exploration, robotic space exploration

1. Introduction

The biological evaluation and exploration of other planets, particularly Mars, requires the usual application of an iterative scientific process of data gathering, hypothesis development, and new data gathering based on the testing of the hypothesis, etc. This process can be implemented by humans or robots (e.g., Cockell et al., 2003).

In certain cases the value of robots over humans in the exploration of other worlds, and even to make assessments of their habitability, is clear. For example, the use of humans to take the first photographs of the surface of Titan would have been a much riskier and more wasteful approach than the use of the disposable probe, Huygens.

But these "obvious" cases hide the ambiguity in many other cases, particularly on the surface of planets that can potentially sustain a human presence indefinitely (e.g., the moon and Mars), and where we can envisage the long-term requirement for an exploratory capability, particularly for long-term biological exploration (Duke, 1992; Crawford, 2001; Landis, 2004).

In this paper I will focus on the biological exploration of Mars and make the case for a human presence.

2. Reasons for the Biological Exploration of Mars

The reasons for the biological exploration of Mars do not need detailed review here. I refer the reader to other reviews (e.g., McKay, 1997; Hiscox, 2001). However, it is of value to explain why the outcome of such searches does not matter to the biological interest in Mars.

The search for life on Mars is an hypothesis like any other scientific hypothesis, i.e., the hypothesis is "there is life on Mars," and the null hypothesis is "there is no life on Mars" (or the other way around). This may appear obvious, but it is easy to become convinced, at least if one reads the popular press, that the discovery of life on Mars is the primary objective, and the failure to find life would itself constitute a failure of space exploration. However, the discovery of no apparent life on Mars, or the actual discovery of life on Mars, are equally interesting outcomes. Below, I briefly review some of the scientific questions that would emerge from either outcome, and that would be amenable to human exploration.

The discovery of life on Mars would be important because it would open up a series of questions familiar to Earth-based microbiologists. Questions such as: what kind of life is it? How did it get there (i.e., originated there or impact-transferred)? What is the biogeographical distribution of that life? How has that life evolved during the history of Mars from the Noachian to the present-day? What geochemical cycling is it responsible for? There would also be many other questions relating to the characteristics, molecular phylogeny and origins of Martian life.

Microbiology on Earth began in the late 17th century with the discovery of microorganisms by Dutch fabric-maker, Anthony van Leeuwenhoek (Leeuwenhoek, 1684). To date, over four centuries of science have been made possible by his discovery. Thus, if life is discovered on Mars, we can expect a long future for microbiology on Mars and its various sub-disciplines. Much of this work will be undertaken by humans.

We can probably never conclusively prove that there is no life on Mars, as we can never know that somewhere there is not a refugium for a pocket of life; a tiny oasis of a microbiota. However, if all the most plausible candidatesfor habitats, e.g., dried lake beds, polar caps, deep sub-surface, show no evidence for life, then what biological exploration is there for humans to do? Despite the apparent scientific barrenness of this question, many important biological questions would be invoked. For example, are there environments where the conditions for life are met (pH, water availability, redox couples, etc.), but where there is no life, i.e., habitable, but sterile environments? Were these environments, if they exist, ever habitable? What was different about early Mars compared to early Earth that precluded the origin or transfer or life to Mars, when we know that early Earth was conducive to life? Is life on Mars, but in highly localized environments we have not yet found? And finally, and perhaps most compellingly, if we took life to Mars and implanted it would it survive and grow (i.e., is Mars sterile because life never evolved there and it is biogeographically separated from the Earth, but the environment is actually habitable)?

Thus, I argue that the discovery of life, or of no apparent life, on Mars is equally interesting. Either way, a rich future of biological exploration lies ahead, and humans can play their part in answering these questions.

3. Humans as Robots

My dictionary defines a robot as a "mechanism that can move automatically." This definition applies to humans as much as it does to mechanical robots, the crucial difference being, of course, that robots (at least so far) are created by humans and have no *telos* (purpose) outside of human design. A refrigerator does not have moral or legal rights. Humans are not the product of intelligent design (although there is a sub-culture of people that doubt this statement) and they have a *telos* independent of outside programming.

Aside from these moral and legal considerations, and focusing entirely on science (data gathering and hypothesis testing), humans can be regarded as advanced robots in the sense that they can take on board programs, carry out scientific analyses and respond to cues from their environment. If we therefore abandon the separation between humans and robots in the field of science, the question then becomes not the resolution of a "humans versus robots" debate, but rather a consideration of whether the vastly superior processing capabilities of the human brain over mechanical brains outweighs the problems encountered in life support with a biological robot as opposed to a mechanical robot. I will now examine just some of the advantages and disadvantages of humans as robots.

4. Disadvantages of Humans as Robots

4.1. Humans are stenoenvironmental

Humans have a narrow range of environmental conditions in which they can operate. Below about 0 °C they become sluggish unless they are wrapped up in clothes. Above about 50 °C they also become inefficient and liable to heat exhaustion. Robots can be designed to work at sub-zero temperatures and temperatures well in excess of the currently known upper limit for life (about 114 °C). With almost any other chemical or physical parameter one chooses to address (Harding, 1989), robots can be made to operate in ranges that far exceed the human capability. Most notable of these is the ability of robots to operate in a complete vacuum, relevant for space operations, but entirely hostile to human survival. Another notable example is the ability of robots to operate in harsh radiation environments, such as nuclear reactor cores, which again is relevant to the harsh radiation environment of space, but these environments are completely inimical to humans. To counter the extreme environment of space, humans also need rigorous exercise regimens (Hawkley, 2003). The narrow environmental tolerances of humans, together with the requirement for countermeasures, impose serious constraints on spaceships carrying humans, and mandate complex life support systems (Czupalla et al., 2004).

4.2. Humans need energy supplied in particular forms

Humans require their energy delivered in the form of "food," which can be solid or liquid, but not gas. "Food" is a mixture of proteins, carbohydrates and fats, but also includes vitamins (complex biomolecules) and trace elements of many types such as iron, selenium, potassium, etc. Robots, on the other hand, usually require only electricity as a source of energy, which can be supplied by solar panels, nuclear power, wind power, or other means. The complexity of food imposes serious life support constraints on spaceships, including, for long duration missions, the ability to grow the food itself (Stine, 1997); alternatively, the food must be taken along with the crew. Solar panels and other electrical systems can be used to generate light, which is then fed to plants as a source of energy. The plants can then be used as "food." Thus, electrical power systems can be used indirectly as a source of food, but the plants must be kept alive and they themselves need all the trace elements and nutrients required to ultimately supply the people. Thus, the availability of electrical power in space does not dramatically solve the problem of human food requirements.

4.3. Humans are prone to crash (die) and are difficult to repair

When a robot crashes or is damaged, it can rebooted or repaired, respectively (provided there are parts available for the repair). If there are no spare parts, it can be left until parts are available. Humans have no such flexibilities. If they crash (usually involving serious injury or death), there is sometimes no way to repair them. If the damage sustained can be repaired, it is often highly complex to do so. Sterile operating theatres may be required and substantial periods of healing may be needed for more serious injuries. A damaged human cannot be left to one side until spare parts or repair capability arrives, because during this time it will either become infected or simply die. Even minor injuries can consume time and impose serious risks to mission success. The requirement for rapid response to needed repairs imposes serious constraints on spacecraft by mandating on board medical facilities and expertise. Furthermore, if a person does die, for sociological reasons they may have to be returned to their loved ones, whereas a robot can be jettisoned.

4.4. Humans have programming complexities (psychological issues)

In general robots are either performing their tasks or not. There are cases where robots can be partially malfunctioned (for example, a computer that works, but has become very slow). Humans, however, incorporate a vastly greatly complexity of programming diversity (Harrison et al., 1991; Stuster, 2004). These complexities arise from genetic factors, upbringing by parents, and environmental influences. Even a human well known by its employers may be prone to do things that were not predicted when it was first employed to undertake a task. These unknown outputs (or psychological issues) can become serious problems for a mission if they manifest themselves at times critical for mission operation and are detrimental to such operations. They can be predicted to some degree by training, but they nevertheless represent a continuous "unknown."

4.5. Humans are less easily disposable when they are being inefficient

When robots are not performing well, or they are presenting a threat to mission success, they can be shut-down. Of course, this may not be an option if there is just one robot available to do the exploration task; in this case the mission may be ended. However, if many robots are landed on a planet to carry out exploration, inefficient malfunctioning ones can be shut-down. Redundancy can be purposefully built into spacecraft with the expectation that some parts of the systems may need to be shut-down or they might shut-down from a malfunction. Humans cannot be disposed of in this way. Once they are on a mission then the mission cannot be rid of them. If, for whatever physical or psychological reasons, they become slow or inefficient then there may be risks to mission success. In some ways this bears upon the points made earlier on damage, but it is a more generic point that is not necessarily related to specific medical situations.

5. Advantages of Humans as Robots

5.1. Humans can acquire samples rapidly

The dexterity and speed of movement makes humans much better than robots for acquiring statistically valid sample sets over multi-kilometre distances. The Mars Exploration Rovers, for instance, can take a single day to examine one sample. A suited human explorer could carry out the same sample acquisition or analysis in a matter of minutes. To a rough approximation humans are therefore one to two orders of magnitude quicker at collecting samples than robots.

Superposed on the rapidity of sample collection is the ability of humans to determine which samples are relevant to them (see below). This can take the form of samples that may be the object of their current scientific interests, or unexpected samples. The recent discovery of a meteorite on Mars by the Opportunity rover illustrates that robots can stumble across unexpected finds, but humans could not only find such a sample, but rapidly implement a search for other meteorites in a much shorter time span than possible with robots.

5.2. Humans have information stored over decadal time periods

Over their lives humans gather information from a variety of sensors. Eyes, ears, nose, hands and even feet gather information about the world around them, and process the acquired information. Some of it is processed consciously, some of it by underlying unconscious programs. These processes are ongoing for many years, and if we assume that the first time humans get involved in serious scientific investigations is in their undergraduate years then, at a minimum, most established human scientists have about 20 years of information processing behind them.

Unless we build robots that spend their time similarly moving around in society for 20 years, this long-term data gathering makes humans greatly superior to mechanical robots as repositories of information to be used in the field. Even if we can program robots with vast libraries of information (say, for example, from scanned library books), they are still unlikely to acquire the diversity of data that humans have access to. The reason for this is that many data sets may be relevant to a problem, but at the time of acquisition it would not be possible to predict that this data would be useful. I will illustrate this later with the "Christmas present effect." In summary, we cannot accurately predict which data will be relevant to a future problem, but by gathering information from many sources over many decades, humans gather a quantity and diversity of data which can help them solve unexpected problems. This is particularly valuable in the scientific enterprise.

5.3. Humans can recognise data of importance to them, but not part of the original program

Partly stemming from the previous section is the fact that humans can recognize data that is important to them, but may not have been at the time of programming. I may have been programmed to go and buy milk from the local shop, but I may then see wrapping paper that I need for moving house. The wrapping paper is not part of the original mission, but when I see it I know it is important. Robots are currently poor at this type of data processing. However, this type of data processing versatility is important on the surface of other planets where entirely new features may occur that, by definition, cannot be programmed as we did not know of their existence prior to the mission. Robots that can use data in the fields of geology and biology to gather samples according to a programme, but then rapidly divert their attention when they see something of else interest, are required. Humans are the most effective means to do this in a time-efficient way.

5.4. Humans are remarkable, low-power computers

The human brain functions on approximately 20 W (derived from Brown, 1999; Hart, 1975). In order words, taking Stalin, Churchill, Hitler, Roosevelt and Mussolini, we must conclude that the entire Second World War was a war effort run by a 100 W computer (actually five computers running in parallel with information being exchanged between them in various different ways) – not much more power than a standard electric light bulb. This example illustrates the processing power of the human brain with modest energy requirements. From a computer processing point of view the human brain is remarkable. In terms of total power requirement, humans are more power intensive than many computers, because they require another ~120 W to take care of walking, arm movements, lung and heart movements, etc. However, this power requirement may not be far off what would be required by a walking, exploring mechanical robot on Mars if such machines eventually develop the dexterity associated with humans.

5.5. Humans can engage other humans

Rovers and landers are fun, but humans are more exciting. Humans get enthusiastic, they get fraught or angry, they have relationships with other humans, which may or may not work out and, most excitingly, they sometimes take extraordinary risks (potentially life-threatening risks) in the pursuit of exploration goals. Frivolous though these observations may seem, it is these aspects of human exploration that engage other human beings. It is quite undeniable that many people go to watch Formula 1 racing because there is a chance of an anomaly occurring. Robots are tediously predictable, and when they are being anomalous it usually means that have shut-down or malfunctioned to a degree that makes them useless.

If we are going to explore space why should not it be exciting, potentially unpredictable, and fun to watch? Sending humans to explore space because they create more griping entertainment for the Earth-bound population seems me to be an entirely sensible and rational motivation for the human exploration of space. To retreat to an entirely scientific/economic appraisal of the human exploration of space is embedded in a strange philosophy that somehow considers that using the emotional aspects of humans as a reason for exploration is unprofessional and lacks objectivity. To me, this is simply a rejection of what it is to be a human being. But more importantly, it is a rejection of one of the most important aspects of exploration understandable to the non-scientifically employed public – the human story.

6. The Christmas Present Effect

The value of human processing capabilities in scientific field exploration can best be illustrated in a simple non-scientific analogy. I use this analogy to synthesise the discussion I have just presented and to suggest why, all disadvantages considered, I regard humans as particularly good robots to go and search for life on other planets.

Figure 1 shows the Cambridge edition of Monopoly. The Monopoly game shown here was on display in a large retail store in Cambridge, and I found it whilst I was in the shop to buy some paper clips. Before I entered the store I was not aware that Monopoly had put out a Cambridge edition at all. The game became relevant to me for two reasons: (1) Christmas was approaching and I needed to find presents, and (2) my sister was very good at Monopoly when she was very young and she spent a year in Cambridge later in her life. Thus, the Cambridge edition of the game, and specifically *that* edition of the game, became important to me.

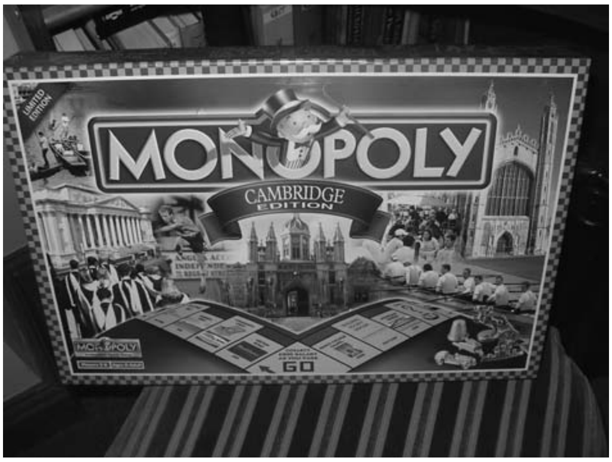

Figure 1. Monopoly Cambridge edition.

Thus, I bought the game. In fact I spent almost two orders of magnitude more on the game than the paper clips I had originally entered the store to buy. Two statements can be made about the game prior to my shopping trip:

(1) It would have not been possible for me to *plan* to go out and seek this game, because I did not know it existed beforehand. In the absence of knowledge of this game, its existence, by definition, cannot be programmed in advance; and
(2) If it had not been Christmas I probably would not have bought it. Its value was dependent upon other interests and priorities in my life quite independent from the priority to buy paper clips – the reason why I entered the store in the first place.

The Christmas present effect brings together a number of the facets of human processing I have already mentioned: pattern recognition skills; libraries of information gathered over decadal time spans; rapid acquisition of samples; and, most importantly, the ability to recognise data to be of importance that were not part of the original program.

To take the analogy further, let us say that someone had invited me to make use of a "Christmas present searching robot," especially designed to go and look for Christmas presents. This robotics group then asked me to provide information to program the machine. I might tell them that my sister had recently started a new job and bought a new house. These, at least on first inspection, would seem to be the most important facts necessary for buying a Christmas present for my sister in 2004. But could I have predicted that her dab-handedness at Monopoly when she was about 8-years-old was relevant for the search? More importantly, prior to seeing the Monopoly game, did I even have this fact available in my conscious mind to able to use it to program a robot? In truth I cannot actually remember, but I do not recall this being a fact that was on my mind at any time during last 25 years or so. I think it sprung from my unconscious when I saw the game.

The analogy with searching for unusual objects on the surface of Mars, or on any other planetary body, should now be clear. Particularly in the case of biological materials, which can contain within them complex patterns, unexpected "finds" cannot necessarily be programmed into robots. The discovery of novel rocks and deposits may require humans with their ability to match important data, some of it acquired many years ago, with their current research priorities. They will be, in essence, searching for Christmas presents on Mars.

7. Conclusion

The role of humans in space exploration is often dominated by the argument of "humans versus robots." Fundamentally, however, in terms of the fact that robots and humans are trying to accomplish the same thing (the testing of scientific hypotheses), there is no reason to recognise such a separation. Instead, I argue that humans should be judged according to their ability to carry out scientific investigations and whether the extent of their abilities makes it worthwhile to overcome some of their life support limitations. I argue that humans are the most advanced robots we have, and should be dispatched to the surface of other planets for exploration.

References

Brown, G.: 1999. *The Energy of Life*, Free Press, New York.
Cockell, C. S., Lim, D. S. S., Braham, S., Lee, P., and Clancey, B.: 2003, *J. Brit. Interplanet. Soc.* **56**, 74–86.
Crawford, I. A.: 2001, *Space Policy* **17**, 155–159.
Czupalla, M., Aponte, V., Chappell, S., and Klaus, D.: 2004, *Acta Astronaut.* **55**, 537–547.
Duke, M. B.: 1992, *Acta Astronaut.* **28**, 5–13.
Harding, R.: 1989. *Survival in Space*, Routledge, New York.
Harrison, A. A., Clearwater, Y. A., and McKay, C. P.: 1991. *From Antarctica to Outer Space*, Springer-Verlag, New York.
Hart, L.: 1975. *How the Brain Works*, Basic Books, New York.
Hawkey, A.: 2003, *Interdiscipl. Sci. Rev.* **28**, 130–138.
Hiscox, J. A.: 2001, *Earth Moon Planets* **87**, 191–211.
Landis, G. A.: 2004, *Acta Astronaut.* **55**, 985–990.
van Leeuwenhoek, A.: 1684, *Phil. Trans.* **14**, 568–574.
McKay, C. P.: 1997, *Origins Life Evol. B.* **27**, 263–289.

Stine, G. H.: 1997. *Living in Space*, M. Evans and Company, New York.
Stuster, J.: 2004, *J. Brit. Interplanet. Soc.* **57**, 126–134.

Discussion

Professor Frank Close (University of Oxford): Why do we need people on Mars to analyse the data? Why cannot we collect the data using robots and do the analysis on Earth?

Dr Cockell: The analysis is best undertaken on Mars using humans for two reasons. Firstly, it allows for rapid development of research questions. Data analysed one day can be used to refine hypotheses and direct research the next day. This iterative process, common to all scientific disciplines, is much quicker if humans are actually in the field, particularly as robots do not have the processing power and laboratory skills of humans. Secondly, the distance to Mars, which causes a 20–40 minute time delay in signals, precludes the possibility of real-time telepresence. In some sense, the human exploration of Mars is necessitated by the limit of the speed of light. Even on the Moon, just a few seconds delay will make real-time telepresence during field operations awkward. To get round this we need humans in the field.

A member of the audience: Although you have shown these advantages of humans, are not they still more expensive than robots?

Dr Cockell: Well, it depends how you look at it. If you are talking about landing on Titan, and getting some data on the atmosphere and surface, clearly a robot is more cost effective. However, when it comes to more extensive field exploration it is not clear to me that humans are more expensive. I think it cost about $20 billion for the Apollo missions, or something like that, and they returned almost half a tonne of rocks. The Soviet lunar sample return missions cost a couple of billion dollars equivalent and returned a few hundred grams of rock. So it seems that for the exploration of the Moon the Apollo programme was about two orders of magnitude cheaper per gram of material gathered than robots. So I am not convinced robots are cheaper.