TALKING TO A COMPUTER ON MARS

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ABSTRACT

Astronauts exploring Mars will probably want to use computers in the field for many purposes including communication such as e-mail, information retrieval, and command and control of both their spacesuit and off-suit equipment. Traditional computer systems present many difficulties in the field including the difficulty of operating a keyboard wearing a spacesuit and the effect of pervasive dust and extreme conditions on equipment. Speech-recognition and speech synthesis have been proposed as partial solutions for these problems.

Design studies and experiments using an analog spacesuit simulating the use of speech recognition for communication, command and control by astronauts on Mars are presented. The studies and experiments were performed by the Northern California Chapter of the Mars Society and GFT Group Inc. using state-of-the-art commercial speech-recognition products, Nuance Communications Inc. (formerly ScanSoft Corporation)'s Dragon NaturallySpeaking Professional and GFT Group's artificial personal assistant Petrana. Many of the results will be applicable to astronauts on the Moon, other planetary bodies, and in orbit.

Other related work on speech-recognition for astronauts and spacesuits is reviewed briefly. Methods for creating a controlled acoustic environment in a spacesuit so that current large vocabulary, speaker-dependent speech-recognition can be used reliably are discussed. Display options such as in-helmet displays, external projectors, and external flat screens are discussed. The advantages and challenges of in-helmet displays are detailed. Pointing devices such as trackballs and motion sensors that can be integrated into a spacesuit are discussed for operating graphical applications and traditional graphical user interfaces. User interface and operating system design with no keyboard, no mouse, and no traditional graphical user interface is discussed.

The size, weight, and power requirements for a fully speech enabled system are calculated. In-suit and off-suit speech processing are compared. Power supply options such as a battery, fuel-cell, or solar cell are discussed. The integration of speech control with sensors such as a video camera, trace gas monitors, and so forth is discussed. Partitioning applications between fast, high reliability physical input devices -- switches, buttons, motion and pointing sensors -- and slower, less reliable, more flexible and versatile speech input is discussed. In general, mission-critical and life-support functions will use physical inputs. Lower priority and support functions such as e-mail, database query, and non-essential equipment control will use speech. Strategies to avoid problems or disasters from speech-recognition errors, mispronunciations, and so forth are discussed.

What can and cannot be done in space exploration applications with current accuracy large vocabulary speech-recognition (about 95% accurate) is discussed. Some strategies to increase accuracy such as incorporating syntactic and semantic rules are discussed.

1. INTRODUCTION

The planet Mars (Figure 1) has been proposed as the next major step in the human exploration of space after the Moon. Mars has a diameter of 4219 miles. Mars has a surface area of 144 million square kilometers, about the same as all the continents and islands of earth put together. This is about 28% of total surface area of the Earth -- including the oceans. The surface gravity of Mars is 38% of the surface gravity on Earth. Mars traverses a slightly elliptical orbit around the sun ranging from 128,000,000 miles to 155,000,000 miles from the Sun. Mars has an axial tilt of 25.2°. The Martian day is 24 hours and 37 minutes. The Martian year is 687 days.

The average surface temperature of Mars is -85°F. The Martian atmosphere is about 1% the atmospheric pressure at sea level on Earth. It is comparable in density and pressure to the atmosphere on Earth at an altitude of 100,000 feet. The Martian atmosphere is 95% carbon dioxide, 3% nitrogen, and 2% other gasses. Mars receives about half the sunlight that the Earth receives. However, lacking the Earth's heavy atmosphere and ozone layer, Mars receives more ultraviolet light than the Earth at its surface. Mars lacks the global magnetic field that protects the Earth from cosmic rays.

Current proposals for humans to Mars usually involve a lengthy mission using chemical rockets[1]. About 180 days will be spent traveling from Earth to Mars. Often, a lengthy stay, such as 550 days, on the planet Mars is envisioned. An additional 180 days will be spent traveling back from Mars to Earth.

Goals for the human exploration of Mars include the search for past or present life on the planet. Astronauts will also seek resources, especially easily exploitable resources. Possible resources include mineral deposits (especially surface mineral deposits), water, and methane. Recent observations have produced evidence of subsurface water or ice on Mars. Trace amounts of methane have recently been reported in the Martian atmosphere. On Earth, most methane is attributed to past or present life. Methane is the principal ingredient of natural gas on Earth. Methane is both a fuel and a precursor to plastics and other materials in industrial processes. Methane can also be used as rocket fuel. As fluids, both water and methane do not require extensive heavy mining equipment to exploit on Mars.

Surface features of interest in the exploration of Mars include Ophir Chasma, Juventae Chasma, Hebes Chasma, Kasei Vallis, the Viking 1 landing site, and many other locations on the planet. A thorough exploration of the planet will require that the astronauts visit many locations separated by thousands of kilometers, using a vehicle such as a rover or rocket plane.

Astronauts exploring Mars will probably need to wear spacesuits for extended periods of time. This presents many problems including the difficulty of performing many tasks wearing a spacesuit. In addition, Mars is very cold. Mars has almost no atmosphere. Mars is bathed in strong ultraviolet light which degrades materials, especially organic materials. Mars is very dusty. External equipment, not protected in an enclosure, will tend to fall apart over time.

External keyboards and displays, exposed to the harsh Martian environment, will be prone to failure.

Figure 2 shows an artist's rendering of astronauts on Mars including a wrist display and wrist keyboard, a common concept that would probably fail during a long mission on Mars.

Speech-recognition and speech synthesis have been proposed as a partial solution to some of these problems. Astronauts would operate their spacesuits, computers, and equipment by giving spoken orders instead of using their hands. An in-helmet display eliminates the need to carry an external computer, keyboard, or display. Motion sensors in the astronaut's gloves can replace the traditional mouse.

In this paper, the use of speech-recognition and speech synthesis by astronauts wearing spacesuits will be analyzed. The Petrana artificial personal assistant from GFT Group Inc., Dragon NaturallySpeaking Professional from Nuance Communications Inc. (formerly ScanSoft Corporation), and Microsoft Outlook Express were used for these studies. Petrana is an artificial personal assistant who talks to the computer user in spoken English and operates computer applications for the user easily, comfortably, and enjoyably, giving the user free use of his or her hands and freedom of movement. Petrana was developed to enable voice operated wall display computers where a computer projector or very large flat screen display replaces the traditional desktop monitor. The computer keyboard and mouse are no longer used and the computer user is free to sit, stand, or move wherever they wish in their room or office. A wireless microphone system with a directional microphone clipped to the user's shirt or blouse is typically used. This eliminates the discomfort often reported by users who wear a headset for extended periods of time. The major benefits of such a system are increased comfort while operating the computer system and increased ability to multitask.

Many of the problems encountered in controlling a voice operated wall display computer are identical or very similar to those that would be encountered by an astronaut. It will be argued that astronauts will probably use an in-helmet display, probably similar to the heads-up displays used by pilots. An in-helmet display eliminates the need to carry or operate a computer leaving the hands free. An in-helmet display is protected from the extreme environment on Mars or in space.

Dragon NaturallySpeaking (Nuance Communications Inc. (formerly ScanSoft Corporation)) is the leading speaker dependent large vocabulary continuous speech-recognition product. Microsoft Outlook Express is one of the most widely used electronic-mail programs. Microsoft PowerPoint was used for tests of controlling presentations by voice. Microsoft Streets and Trips was used for tests of navigation by voice. InterVideo WinDVD 6 was used for media and video playback. Microsoft Internet Explorer was used for Web navigation. The Microsoft Windows XP operating system was used.

The use of speech-recognition for Mars missions has been studied by other researchers. A group led by Bill Clancey at NASA Ames Research Center has done extensive research at the Mars Desert Research Station. The current study is independent of these efforts.

2. SPEECH-RECOGNITION

Present-day speaker dependent large vocabulary continuous speech-recognition has an accuracy of about 95%. This means that 19 of 20 words are correctly transcribed on average. It's also means that 1 of 20 words are misrecognized, omitted entirely, or a spurious word is added to the transcription. Speaker dependent speech-recognition systems are trained to recognize a specific speaker's voice and can generally achieve higher accuracy than speaker independent speech-recognition systems. The reader may have encountered speaker independent speech-recognition using telephone help systems, automatic airline reservation systems, cell phones, and some recent automobiles.

The author has conducted extensive studies of the accuracy of Dragon NaturallySpeaking Professional 7.3 using many different types of microphones and microphone systems. The author's standard test is to recite Proverbs 11 from New Living Translation (NLT) of the Holy Bible (Tyndale House Publishers Inc. Wheaton, Illinois). The New Living Translation is a translation of the Bible into modern English, using modern idioms and language similar to the language model in Dragon NaturallySpeaking. The Bible is used as a widely available cultural document in English-speaking communities and not for any religious reason. Misrecognized words, missing words, and spurious words are counted as errors. These tests consistently produce a maximum accuracy of 95% even with excellent acoustic conditions and extensive training of Dragon NaturallySpeaking (several months of daily use).

Accuracy is a potentially contentious area in speech-recognition. Anecdotal claims of accuracy as high as 99% for Dragon NaturallySpeaking are sometimes reported. There are some claims that 99% or better accuracy can be achieved with some very expensive microphone systems. Claims of performance as high as 99% may be found in some SEC filings by Nuance Communications Inc. (formerly ScanSoft Corporation). It is difficult to rule out these claims. The author can only report that he has been unable to achieve accuracy consistently above 95%.

Speakers with precise control over their voices such as news announcers or voice actors may be able to achieve higher accuracy by speaking very clearly and suppressing normal variations in speaking pace, pitch, volume, and other factors. This is not realistic for most users of voice-recognition or astronauts in a sometimes stressful field situation.

Present-day speech recognition accuracy is almost certainly inadequate for life-support or mission-critical operations. However, this accuracy is adequate for some support operations where errors have minor consequences -- neither fatal nor catastrophic.

Table 1 shows the feasible Voice Recognition Tasks. The composition of lengthy documents is not included in the list of feasible tasks. Products such as Dragon NaturallySpeaking are marketed primarily for this task. However, the composition of lengthy documents using Dragon NaturallySpeaking is fairly difficult -- both slow and mentally taxing -- due to the high error rate.

2.1 Spoken Interface Design

Command-and-control of computer applications using Dragon NaturallySpeaking is usually slow and mentally taxing. The Petrana artificial personal assistant was developed to make it significantly easier to operate certain computer applications entirely by voice.

Several problems make spoken interface design extremely challenging. In addition to accuracy problems, these problems are probably a major reason for the lack of adoption of speech-recognition technology.

In English and other spoken languages, in a particular context, there are usually many ways of expressing the same concept and human beings naturally vary the phrasing that they use to express the same concept at different times. For example, a user might issue a spoken command to play a DVD by saying "Petrana play DVD", "Petrana play video", "Petrana play media", "Petrana play movie", "Petrana play <title of the DVD>", and so forth. The same user will often use different phrases to express the same command at different times. In order for a spoken interface to be easy to use, intuitive, and fast, it must respond as expected to all of the commands that the human user would guess based on the context.

An astronaut on Mars might ask "Petrana where am I?" Or "Petrana what is my position?" Or "Petrana what is my location?" Or "Petrana where are we?" Or many other variations. In a high-pressure field environment, the astronaut would expect Petrana to respond to any or all of these intuitive questions in a sensible way.

Another problem with spoken interfaces is that different users will expect different responses to the same command depending on the user's individual prejudices. An astronaut might expect Petrana to report his or her current latitude and longitude on Mars. They might expect Petrana to report their location relative to a landmark or landmarks. They might expect Petrana to display a map of their current location. They might expect Petrana to do all of these things at the same time. Consequently, an easy-to-use spoken interface must respond in a way that is expected by most users or makes sense to most users, and provide guidance to those users who do not expect the response such as explaining what to do to get the response that the user is expecting. Otherwise, some users will find the interface frustrating or even unusable.

In natural spoken English, human beings normally express concepts at a high level of abstraction. Frequently, the built-in commands in Dragon NaturallySpeaking and other speech-recognition products correspond to lower levels of abstraction ("press this key") that human users usually do not use when speaking. Often, an English phrase such as "Petrana play movie" corresponds to a long series of key presses, menu item selections, or other functions in a standard computer application. In many cases, an English phrase or sentence requires humanlike intelligence or the appearance of humanlike intelligence to translate into a series of operations in a computer application. Since humanlike intelligence is not yet possible in computer programs, in these cases, some work around must be found to handle the phrase or sentence that human users will intuitively choose. For example, an intuitive command such as "Petrana where am I" corresponds to a sophisticated navigation program.

The hierarchical tree structure used in many current programs, especially graphical user interfaces, does not correspond to the way that people naturally speak. For example, using Dragon NaturallySpeaking to open a file can consist of the following sequence of commands:

> "File" (pulls down the File menu)
>
> "Open" (brings up a file open dialog box)

"Look in" (selects the folder list)

"Drop List" (pulls down the list of folders)

"Move down three" (move down three folders on the list of folders)

"File Name" (move to the File Name field in the dialog box)

"document.rtf" (dictate the name of the file to open in the current folder)

"Open" (actually open the file)

This is obviously a very long and cumbersome procedure when executed by voice. The sequence can be executed easily and intuitively using a keyboard, mouse, and windowing system, but not in spoken English. In contrast, the user's natural instinct would be to issue spoken commands such as (ignoring the hierarchical menu and file systems entirely):

"Petrana open document.rtf"

or

"Petrana open report on Martian pyramid"

In spoken English, human beings frequently reference entities in several different ways usually by content or topic. Indices or tracking numbers such as license plate numbers are rarely used. A hierarchical tree data structure is not assumed and used infrequently.

It is common to forget the name of files such as *document.rtf* in the example above. It is natural in speech to reference a document or entity by its topic or content such as "report on Martian pyramid". A document or entity may be referred to in several different ways such as "last document", "report written by Buzz Lightyear", "report on anomalous structure", and so forth. Human users such as an astronaut will have a reasonable expectation that all of these references will work.

In general, easy-to-use spoken interfaces will differ substantially from traditional computer interfaces, especially the graphical user interfaces that are currently popular. There is no simple translation from traditional computer interfaces to a spoken interface. An interface for astronauts on Mars will require substantial design in order to be intuitive, easy-to-use, and fast -- all important requirements in the field.

3. MARS ANALOG SPACESUIT STUDIES

The Northern California chapter the Mars Society has constructed a number of Mars analog spacesuits for outreach and research purposes (see Figure 3). Similar spacesuits have been used for human factors studies at the Mars Society's Mars Desert Research Station (MDRS) and Flashline Mars Arctic Research Station (FMARS). The spacesuits are constructed from plastic components to simulate the difficulties in wearing a spacesuit and performing tasks while wearing a spacesuit.

A Sony WCS-999 wireless microphone transmitter and a Sony ECM-DS70P Unidirectional Condenser Stereo Microphone were added to the helmet. The speech recognition software, the Petrana artificial personal assistant and Dragon Naturally Speaking Professional 7.3 or 8.1 (following recent upgrade to system), were located on a Sony VAIO laptop with a Sony WCS-999 wireless microphone receiver plugged into the microphone jack in the laptop. Table 2 summarizes the VAIO Laptop Parameters. The astronaut's anticipated in-helmet display was emulated using an external projector and a wall or projection screen.

The Mars analog spacesuit provides significant muffling of sound. It is difficult to hear external sounds and it is difficult to hear the "astronaut" from outside the suit. This actually makes it easier to use speech-recognition when wearing the suit since background noises from outside of the suit that can interfere with the speech-recognition are suppressed.

The Mars analog spacesuits include a fan to supply the helmet with fresh air. It is impossible to wear the helmet for more than a short period of time without operating the fan. The fan is a significant source of background sound. The fan did not interfere with the speech-recognition. Authentic Mars spacesuits will be expected to include fans or other equipment that will generate some sounds.

The Mars analog spacesuits are difficult to put on and take off. Although it is possible to put on or take off the suit by yourself, this is very difficult and an assistant is usually required. This process generates a substantial amount of sound and the speech recognition will not work during this period.

Several voice command tasks have been performed successfully on several occasions while wearing the Mars analog spacesuits (see Table 3). These have all been in buildings, usually in front of audiences. No field tests in an outdoor environment have yet been conducted. Typical background sounds include talking, fans and other building equipment, and street noise from outside. The tasks are listed in Table 3.

The most challenging tasks at present have been controlling presentations using Microsoft PowerPoint in front of live audiences, including this presentation at the Mars Society Convention 2005 at the University of Colorado at Boulder as well as presentations at the Chabot Science Center in Oakland, the AIAA San Francisco Section at a hotel conference room, and several science fiction conventions in the San Francisco Bay Area. Though not as demanding as field applications that an astronaut might encounter on Mars, these live demonstrations illustrate several problems and their possible solutions.

Using a radio based wireless microphone system has several problems. Various computer devices and other equipment can generate unpredictable RF interference in the channels used by the Wireless Microphone System that prevent the voice recognition from working. In some cases, the RF noise would block human communication as well. The offending equipment can be located far from the room, elsewhere in the building or even outside the building. The risk of RF interference can be reduced by testing the system in the room prior to the presentation, but equipment can be turned on during the presentation. Radio is also not secure and travels through walls easily.

Many of these communication channel noise problems have been resolved recently by switching to an Infrared (IR) wireless microphone system. Infrared usually follows line of sight although it can bounce off of walls. This is great for security and rarely a problem in a typical presentation room. On Mars, using modulated infrared to communicate by voice with remote equipment ("rover come here! I'm in trouble!") might ensure high quality voice links but reduce communication range for astronauts and their equipment. A bright infrared signal that scatters in the Martian atmosphere might permit over the horizon communications while eliminating vulnerability to RF interference from natural or manmade sources. The infrared wireless microphone system has not been used with the Mars analog spacesuits yet.

Background sounds can be a problem in a room when not wearing the Mars analog spacesuit. In particular, when wearing a unidirectional lavalier microphone during a presentation, overhead machinery such as fans can be a problem. The lavalier microphone is pointed at the speaker's mouth and also by extension at the ceiling above. Background sound problems can be reduced by wearing a headset which is uncomfortable and often visible to the audience, also undesirable. Audiences are often unaware of lavalier microphones which are clipped on one's shirt or tie and can be largely hidden under clothing. Background sound problems have not occurred when wearing the Mars analog spacesuit. These problems can probably be avoided on Mars through proper acoustic design of spacesuits.

The biggest problem encountered in giving voice controlled presentations for live audiences has been the slow and unpredictable response time of Dragon NaturallySpeaking when operated in its "Command" mode. Dragon frequently lags behind the speaker in analyzing the speaker's speech. A delay of several seconds or even longer may occur between when the speaker says "Petrana next slide" and when Petrana executes the command advancing to the next slide. This problem has recently been greatly reduced by exploiting some poorly documented features of Dragon NaturallySpeaking. Evaluations of the new shorter delays under field conditions are proceeding. Long unpredictable delays in speech-recognition would almost certainly be a serious problem for speech recognition on Mars.

4. RECOMMENDATIONS AND FUTURE DIRECTIONS

Some general comments on the Mars analog spacesuits seem in order. The suits are difficult to put on and take off, especially by yourself. It seems likely that real spacesuits would have similar problems. For an extended stay on Mars one would probably prefer a spacesuit that was easy to put on and take off. It is also tiring to wear the Mars analog spacesuits. In one case, the author wore the spacesuit for about an hour while making a series of presentations and found the experience tiring. An extended mission to Mars will almost certainly involve wearing spacesuits for many hours or days. Current technology genuine spacesuits are significantly heavier than the Mars analog spacesuits.

These preliminary experiments support the proposition that some tasks can be performed effectively in a spacesuit using state-of-the-art speaker dependent speech-recognition technology. For the most part, mission-critical and life-support functions under voice control were not simulated. The experiments tend to support the proposition that mission-critical and life-support functions should not rely on speech-recognition. The author suggests embedding precise motion sensors (these exist today) inside an astronaut's gloves to provide precise reliable control over mission-critical and life-support computer applications without exposing buttons or switches to the extreme Martian environment where the physical input devices will tend to break down over a two-year mission.

The limited accuracy of current speech-recognition technology remains the single biggest problem. The 95% accuracy usually proves too low for the composition of lengthy documents by most users. Users who are unable to use their hands are an exception because they have little choice but to use speech-recognition. Astronauts wearing spacesuits may fall into this category in some situations. However, ease-of-use of the spoken interface is already a more serious problem than accuracy for many seemingly simple applications (for example, opening a file somewhere on the computer hard drive). While there has been significant progress in speech recognition technology in the last several years, possibly due to faster computers, the author is skeptical that the current Hidden Markov Model based speech-recognition algorithm architecture can be incrementally improved until it reaches humanlike speech-recognition performance.

Dragon NaturallySpeaking and other speech-recognition programs use statistical models to guess which words were spoken. They do not use syntax or semantic rules. As a consequence, they often make what seem like obvious errors to a human being. Approximately five to 10% of the errors may be detected by the automatic grammar checker in Microsoft Word. However, most errors do not seem to be detectable by automatic grammar checkers. Many of the errors are obvious to a human being who understands the topic being talked about. It may be possible to use syntax and semantic rules to reduce the error rate. This is an ongoing area of research but real world proof remains lacking.

In general, experiments so far suggest that the speech-recognition system should reside in a separate computer module that can be rebooted independently of other parts of the spacesuit. Although one off suit laptop is used in the experiments, it seems likely that the speech-recognition computer module should be integrated into the spacesuit for maximum reliability. This would also eliminate the need for a wireless connection to the speech-recognition module, another possible point of failure on Mars. At present, the size weight and power requirements for such a computer module are significant since speech-recognition is very resource intensive. Solar panels on the backpack and other parts of the spacesuit combined with a rechargeable battery would provide a robust power source on Mars (perhaps 50-100 W assuming 20% efficiency solar cells and 500 W per square meter of sunlight on Mars). The author suspects that astronauts on Mars will need to be able to survive in a spacesuit for several days without external assistance and this should be a design requirement for Mars spacesuits.

5. CONCLUSION

These experiments are obviously preliminary. It seems likely that speech-recognition can be used by astronauts on Mars and other locations in space, even given the limitations of current speech-recognition. The spoken interfaces require extensive testing and design. Speech-recognition should not be relied upon for mission-critical or life-support functions. Improvements in speech recognition accuracy would be very helpful.

ACKNOWLEDGMENTS

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REFERENCE

1 Robert Zubrin, The Case for Mars, Touchstone, New York 1997

FIGURES

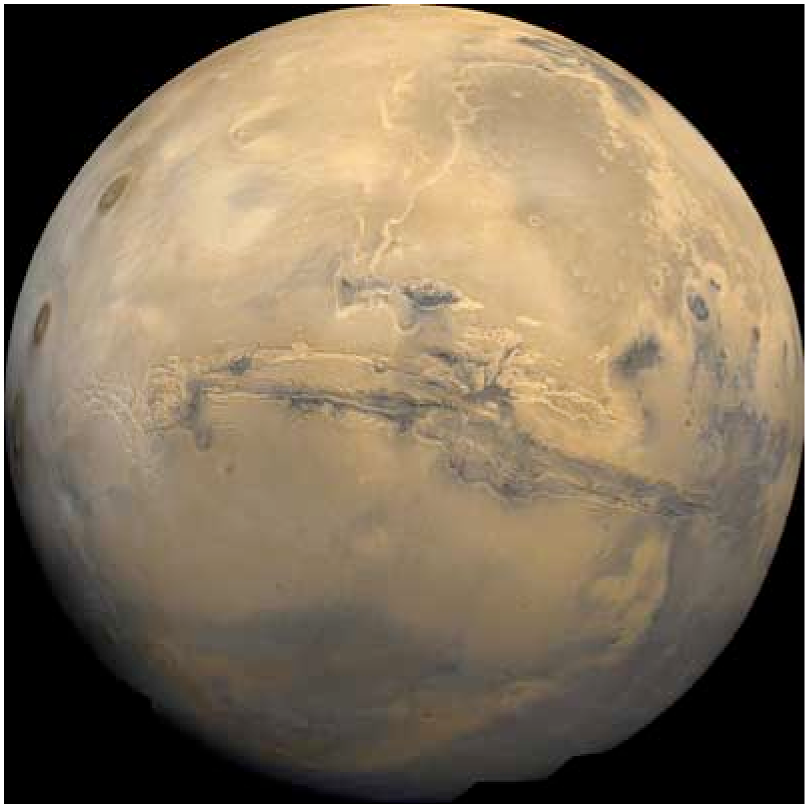

Figure 1The Planet Mars (Valles Marineris Hemisphere, NASA)

Figure 2Astronauts Exploring Mars (Distant Shores by Pat Rawlings)

Figure 3 Mars Analog Spacesuits (Northern California Mars Society)

TABLES

Task	**Example Commands**	**Comment**
Electronic Mail	Petrana new mail	Short, conversational e-mails. Composing lengthy e-mails and documents is difficult.
Information and database queries	Petrana where am I? Petrana what time is it? Petrana what is the temperature? Petrana search Google	Astronauts will need to know their location on Mars to avoid getting lost. A non-speech backup for this potentially life-saving function should exist.
Command and control of some equipment	Petrana start environmental monitor Petrana what is the temperature Petrana measure wind speed	
Presentations	Petrana start presentation Petrana next slide Petrana previous slide	Even astronauts on Mars may need to make presentations.
Simple Web Browsing	Mars Encyclopedia	Dragon NaturallySpeaking has adequate support for Internet Explorer. The user can click on a Web link by saying all or part of the Web link name
Media Playback	Petrana play media file Petrana play Movie	
Recreation and Entertainment	Petrana play music	Astronauts on Mars for two years will need to relax.

Table 1 Feasible Voice Recognition Tasks

Computer Parameter	Value
CPU Speed	2.6 GHz
System Memory	1 GB (upgraded from 512 MB in July, 2005)
Hard Disk Size	30 GB
Size	13” by 14” by 2” (approximate)
Weight	7 pounds
Power	<200 Watts

Table 2 Sony VAIO Laptop Parameters

Task (wearing Mars Analog Spacesuit)	Comment
PowerPoint Presentation	Several successful presentations to public audiences (for example, Yuri’s Night at Chabot Space and Science Center, Oakland, CA, USA, Mars Society Convention 2005, University of Colorado, Boulder, CO, USA)
Short conversational e-mail	Microsoft Outlook Express 6.0
Display maps of current location	Microsoft Streets and Trips
Web Browsing	Microsoft Internet Explorer 6.0
Enabling and disabling microphone output through speakers	Enables an audience to hear a speaker wearing a spacesuit
Requesting current date and time	

Table 3 Successful Voice Command Tasks Wearing Mars Analog Spacesuit