ORIGINAL ARTICLE

Informatics-based Medical Procedure Assistance during Space Missions

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Abstract

Currently, paper-based and/or electronic together with telecommunications links to Earth-based physicians are used to assist astronaut crews perform diagnosis and treatment of medical conditions during space travel. However, these have limitations, especially during long duration missions in which telecommunications to earth-based physicians can be delayed. We describe an experimental technology called GuideView in which clinical guidelines are presented in a structured, interactive, multi-modal format and, in each step, clinical instructions are provided simultaneously in voice, text, pictures video or animations. An example application of the system to diagnosis and treatment of space Decompression Sickness is presented. Astronauts performing space walks from the International Space Station are at risk for decompression sickness because the atmospheric pressure of the Extra-vehicular Activity space- suit is significantly less that that of the interior of the Station. Hippokratia 2008; 12 (Suppl 1): 23-27

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Medical support during spaceflight

During low earth orbit missions aboard the International Space Station (ISS) and the Space Shuttle, terrestrial medical support staff including flight surgeons, biomedical engineers, and nurses, is available to provide medical advice and direction to the astronaut crews. Astronauts can communicate with and be advised by their ground medical support via audio and/or video telecommunications links. Images can be down-linked for review. However, during long distance space missions such as Mars exploration or Moon habitations, communications to earth are subject to significant time delays so that earth-based support will most often be asynchronous. This means that astronauts will need to be self-reliant, making optimal use of available on-board resources and prior medical training to effectively handle medical events. While it is anticipated that every mission will include at least one physician ('astro-doc') this individual may herself be in need of medical attention or may have to care for medical disorders with which she is relatively unfamiliar or out of practice.

Medical References during space flight

Currently, astronauts rely on text-based procedures in paper and electronic form to guide them through many of the complex maintenance and experiment tasks required during their daily activities during space missions. Similarly, clinical guidelines represented as text-based checklists (paper and electronic) are currently available to assist the crews of the International Space Station (ISS) for diagnosis and treatment of a host of medical conditions. The selection of these conditions is based on previous space flight experience and related research including bed-rest studies. The primary medical procedure document, called the Medical Checklist[1], is a text-based reference (with illustrations) that provides procedures to guide astronauts (whose training may be in non-medical disciplines) through the performance of medical tasks ranging from examination to emergency procedures. This document also provides reference materials such as contents lists of onboard medical kits and information about the various medications and instruments available.

While text-based materials can be useful, researchers have pointed out that information delivery can be enhanced by presenting it in multiple modes simultaneously[2,3]. In[2] Mayer demonstrates that presenting information in multiple–representations for problem-solving enables improved performance over using single representations. In[3], Pavio presents a cognitive theory of multimedia learning, suggesting that human beings process visual and audio material separately, and that there is at least one verbal and one non- verbal system in the brain to process information. Presenting coherent and related information simultaneously results in reinforcement of the information content of each stream.

In this paper we describe an experimental technology called GuideView, developed at NASA Johnson Space Center and The University of Texas Health Science Center at Houston, as an alternative to text-based medical checklists, and designed specifically for the use of non-physician care providers (NPCPs). We focus on Space Decompression sickness (DCS) as an example medical condition. GuideViews have been also been developed for ophthalmic problems and triage of airway distress[4,5].

The remainder of this paper is organized as follows. Section 2 describes the medical training of astronauts. Section 3 presents an overview of the GuideView system. Section 4 briefly describes space DCS. Section 5 outlines the process by which a GuideView was developed for Space DCS. Section 6 consists of conclusions and future work.

Astronaut Medical Training

Training Overview

For each International Space Station (ISS) Expedition, at least one crewmember is designated a Crew Medical Officer (CMO) and tasked with assisting in the health maintenance of his or her fellow crewmembers. Although several astronaut physicians exist, most CMOs will not have a formal medical background and will have received only limited medical training as part of mission preparation. Approximately 30 hours is allocated to a crewmember's overall medical training, and depending on level of experience, refresher classes may be held in lieu of the formal lessons for more experienced astronauts. Less than 4 hours of formal training is specifically devoted to the physical exam skills required to gather medical data[1].

Training Focus

Due to training time constraints, limited prior medical training, and complexity of the subject matter, astronaut medical training is task focused and does not delve deeply into medical treatment methodology or human physiology. Rather, the training focuses on providing the CMO with the basic skills to perform a physical examination of a patient and, along with the direction and assistance of the ground-based physician, to recognize and respond to potential medical issues. In this way, the CMO takes on the role of the eyes and the hands of the ground-based physician. While this role may be adequate when spaceflight is in low earth orbit, CMO responsibilities may have to be expanded during long distance space missions in which significant time delays to terrestrial medical support will be the norm.

Guideview

Purpose of GuideView

GuideView is an informatics-based technology designed to aid CMOs and other non-physician astronauts to perform medical tasks. In GuideView, information needed by the user to complete a task is provided in multiple modes simultaneously with text being accompanied by video, audio, and images. The GuideView System consists of two components: Author and Viewer. The Author (see Section 5 below) enables creation of GuideView-compatible multi-modal structured guidelines (called 'guideviews') and the Viewer enables these to be executed on multiple platforms. In general GuideView may be thought of as a medical procedure assistant that can aid users to perform medical tasks according to standardized guidelines previously developed by experts. The Viewer is compatible with multiple platforms including the internet, stand-alone Windows computers, PocketPC-based PDAs, and Windows Mobile cell phones such as T-Mobile SDA and Cingular 3125[5].

Using GuideView Author, clinical guidelines can be structured into process steps and presented using text, voice, still pictures, video, or animation, simultaneously. Each mode compliments the other, resulting in a rich content delivery environment. Users navigate to the next by selecting from a small number of choices using mouse clicks. Since spoken commands can enable caregivers to use both hands to assist patients and still interact fully with GuideView, a proof-of-concept version has been created for GuideView on Windows PCs in which users navigate through the procedure by voice triggers such as "Yes", "No,", "Play Video", and similar.

The design of GuideView was informed by the following basic objectives[5]

- The system should be portable and support ubiquity
- It should be highly interactive
- Medical guidance should be provided in a structured manner, as a sequence of steps
- Cognitive load should be reduced:
- At any step in the procedure there should be only a few choices leading to the next step.
- The task to be performed at any step should be simple
- Sufficient information, but not an overwhelming amount, should be provided at every step
- Information should be given in multiple, redundant modes
- Presentation and content should be strictly separated. One important benefit is that GuideView protocols can be developed in multiple languages; the GuideView Viewer and Author are agnostic to such content variations.
- The system should be able to acquire medical data from sensors and branch through the guideline accordingly. A proof-of-concept version of this capability in which GuideView interacts with a serial-port pulse-oximeter has been developed.

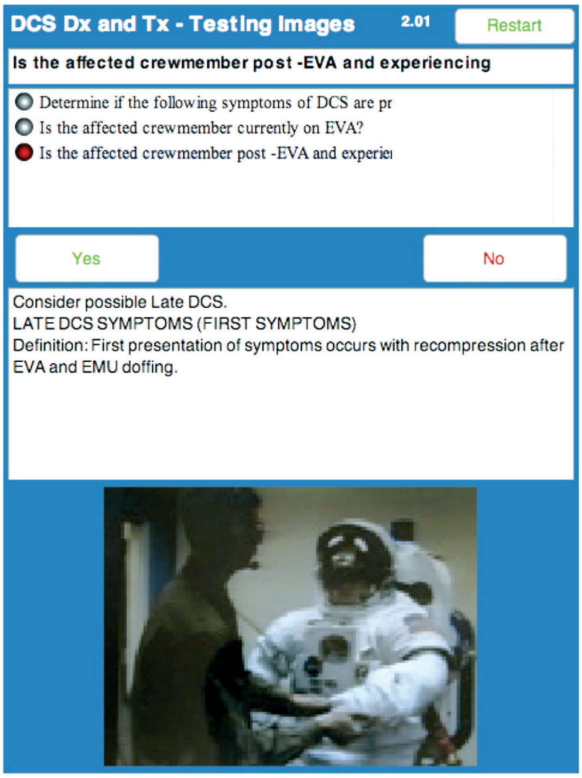

Figure 1: shows the typical GuideView user interface. The bulleted items are a history of previous steps, and are active, in the sense that clicking on a previous step enables the user to repeat that step and pursue an alternative pathway if needed.

The GuideView Interface

The GuideView Viewer interface enables users with different skill levels to consistently execute a task with similar outcomes through its interactive interface. In their book on interface design, Hutchins et al.[6] described characteristics of well designed user interfaces. Key to well designed interfaces such as that seen in GuideView is the ability of the interface to enable the user, through clear and easy to follow prompts, to carryout the desired actions. Images and information presented to the user should minimize the cognitive tasks required to achieve a desired action, objective, or outcome based on the purpose of the interface. If the interface does not externalize all information and directions required to accomplish the goal of a system, the memory retrieval and mental processing of the user must fill the void. This mental processing, referred to as cognitive load, can be seen as the distance between the achievement of a system goal such as medical data acquisition, and the users' system knowledge such as medical skill and expertise[6].

The goal of GuideView is to decrease the cognitive load of the user be presenting all of the required information related to the procedure through images, text, and video[2]. It acts as a just-in-time informatics-based procedure assistant to help bridge this distance and augment the ability of the user to perform a potentially complex set of tasks. GuideView does this through the text, voice, still pictures, video, or animation specific to the particular guideline. In a previous user acceptance study[4] ten subjects whose skill levels were similar to that of non-physician astronauts used GuideView to diagnose and treat airway distress presented on a human patient simulator. Here, the usefulness of voice instructions was rated very highly while video and text also received high levels of acceptability.

To showcase GuideView technology, a procedure was chosen from the International Space Station Extravehicular Activity (EVA) Systems Handbook[7] to convert to an interactive application. This procedure, which guides astronauts through the recognition and treatment of Space Decompression Sickness (DCS), was chosen based on its complexity and the fact that it refers the user to multiple sub-procedures to carry out the objective. Images and videos were obtained from NASA archives or produced de novo. Voiced instructions were recorded during guideview development and saved in digital format (MP3).

Example: Decompression Sickness

Brief overview

Decompression Sickness (DCS), otherwise known as "the bends" or "caisson disease" can occur when the human body is exposed to a sudden decrease in ambient pressure. This sudden pressure reduction can cause inert gas such as nitrogen found in the bloodstream and body tissues to come out of solution forming bubbles. These bubbles of gas can embolize various tissues of the body including joints, skin, lungs, and brain, causing significant pain, musculoskeletal and/or neurological impairment.

Terrestrially, DCS occurs most commonly when divers ascend too rapidly from depths of 33 feet (10 meters) where the pressure is high toward the surface where pressure is less. Boyle's law states that pressure and volume are indirectly proportional therefore as the pressure decreases, volume increases. In this case, the atmospheric pressure that the body is exposed to is reduced and the gas bubbles expand, aggregate, and form bubbles.

Astronauts performing Extra Vehicular Activities (EVA), i.e. spacewalks, are also at risk for DCS. To execute a space walk, an astronaut must don a space suit (Extravehicular Mobility Unit, EMU) and exit the International Space Station (ISS). This ISS is pressurized at 14 psia (0.986 Kg/sq cm) while the space suit (Extravehicular Mobility Unit, EMU) has an interior pressure of 4 psia (0.281 Kg/sq cm)[7]. The transfer of the astronaut into the suit's reduced atmospheric pressure or the sudden depressurization of the EMU due to a leak or tear could set the stage for DCS to occur.

If this were to occur, the affected crewmember performing the spacewalk would require assistance from the second EVA crewmember to return to the ISS and begin treatment. If additional astronauts were available within the ISS, they would have the task of communication with the ground and following text-based procedures to provide treatment. These procedures, located in several documents available in paper and electronic formats, provide text to describe the multitude of tasks required to bring the injured crewmember into the ISS and begin treatment.

Treatment of DCS

Treatment of DCS involves recognition of symptom presence and severity, re-pressurization, and breathing oxygen. Since DCS can cause substantial impairment in astronauts' health and performance leading to a significant mission impact, it is important to diagnose and treat it expeditiously[8]. Currently, the non-EVA crewmembers and the ground based support would follow a text based procedure that would assist the EVA crewmember in the classification of DCS symptoms and provide directions for the treatment of the injured crewmember if DCS symptoms were to present. Treatment of DCS that arises during an EVA could be complicated. On Earth, DCS occurs most commonly when a diver ascends to the surface and could be within reach of medical care. In space, DCS might occur when the astronaut exits from the space station to an unfamiliar and semi-isolated environment.

The injured crewmember must terminate the EVA and return to the Space Station to be treated. Fortunately, the act of returning from space to the increased atmospheric pressure within the ISS can be therapeutic for the patient suffering from DCS. Terrestrially, a hyperbaric chamber would be used to treat DCS; on-orbit the space suit itself can be pressurized to provide such treatment. Multiple procedures are involved in getting the casualty form an EVA to the interior of the space station for care. It is possible that an application such as GuideView could help to organize and present the required information and steps in a more usable way.

Developing the Guideview DCS Procedure

Project description

In the first phase of this project, the ISS DCS System Handbook[7] and the ISS Medical Checklist[1] text procedures related to the recognition and treatment of DCS were reviewed by clinician subject matter advisors. These procedures, developed by NASA Flight Surgeons, were used to create an interactive procedure modeled after the current one that could guide an astronaut through the necessary actions of DCS treatment.

The GuideView Author, an authoring program special to this application, enabled the creation of the GuideView interface content. This software facilitated the encoding of guideline structure and embedding of text and multimodal content (Figure 2). For example, clicking on the Upload button (see Figure 2) under 'Narration' on the left of the author screen for a node (highlighted in yellow in Figure 2) brings up a browser window that enables selection of an audio file in mp3 format for embedding into that node.

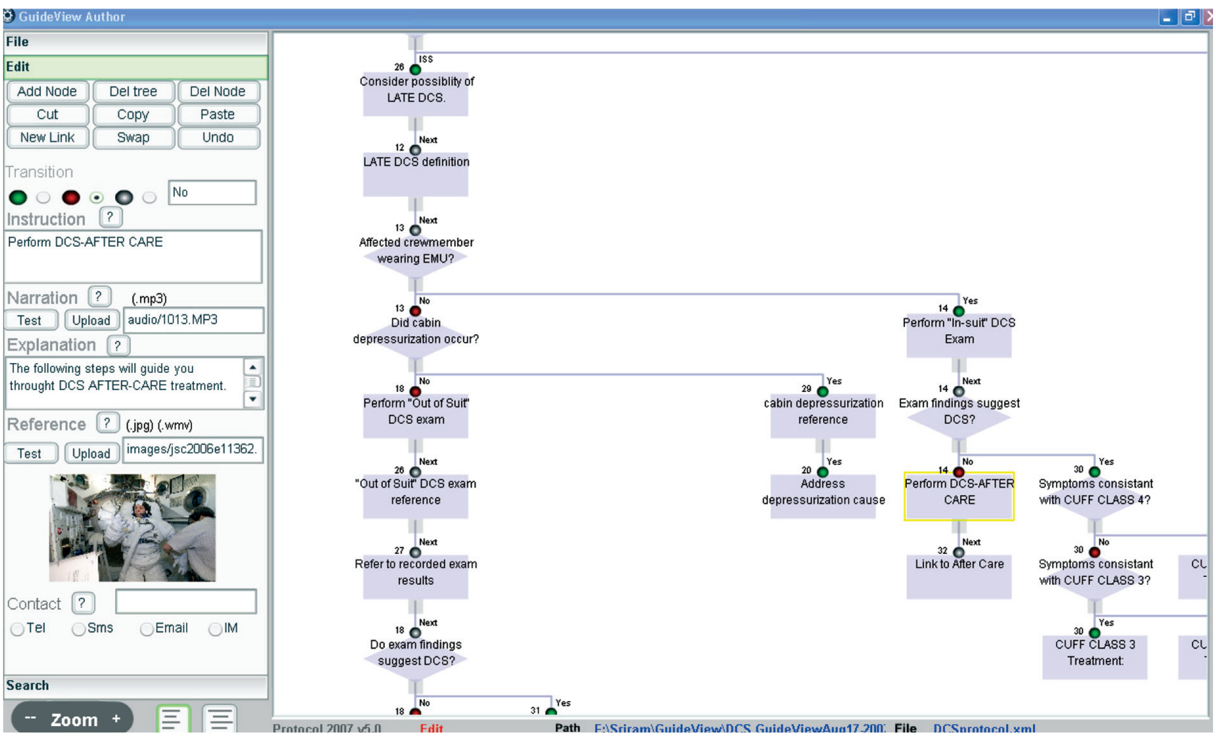

Figure 2: GuideView Author screen with part of a clinical guideline for diagnosis and treatment Space Decompression Sickness.

A necessary first step is to reorganize the existing text-based DCS procedure into linear flow-chart logic compatible with GuideView. In other words questions posed to the user in GuideView have to be written in a format that requires the user to choose from two alternate paths such as "Yes/No" or "1" or "2" when a decision had to be made. For example, when following the text procedure in its flow chart form, the user could choose from Type 1 through type 4 DCS symptoms and follow the corresponding treatment path. When inserting the logic into GuideView, the problem had to be addressed by presenting the symptoms of the first DCS type and asking if the patient's symptoms were limited to that class. If the answer is Yes, users were led down that particular treatment path. If they answered No, the application would move to the next DCS type and repeat a similar question related to that class. Again, a Yes answer led to the treatment and a No answer led to the next class.

Another change to the current procedures, enabled by an interactive application such as GuideView, was to augment information to the user by adding explanations of acronyms, video demonstrations of required tasks, inserting images to support the tasks, and other multimedia functions to minimize the cognitive load of the user.

Conclusion and Future Work

This paper presented an overview of GuideView, an experimental informatics-bases technology for creating and executing interactive structured multi-modal clinical guidelines. The system was designed to assist non-physician astronauts perform medical diagnosis and treatment during long distance and long duration space missions such as Mars exploration or moon habitation. During such missions astronauts cannot be in synchronous communications with terrestrial medical support. The initial stages of this project included analysis and conversion of components of a complex, text-based procedure such as the treatment of DCS into an interactive an intuitive, user friendly procedure assistant. In addition, voiced instructions, images, and video segments were integrated using GuideView Author.

In the second phase of the project, further refinement and expansion of the current GuideView content will occur. This will include addition of steps of tangential procedures related to the evaluation and treatment of DCS during space flight to the current GuideView application. Following completion, a heuristic evaluation of the software performance utilizing typical astronaut users and CMOs will be performed. The results will be used to improve the DCS guideview.

GudeView technology is being enhanced in a number of directions. On Windows Mobile PDAs (Personal Digital Assitants) it has been integrated in a context-sensitive way with an EMR system[5]. Communication features by means of e-mail, telephone calls or Instant Messaging are being added. Other applications of GuideView technology are also being considered. These include cellphone-based GuideView technology to assist community health workers in developing countries improve compliance with clinical guidelines[9]. In such environments GuideView appears to have intriguing potential to greatly reduce referral errors and to improve identification of case severity, thus enhancing medical care outcomes.

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