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# FIDOE: A Proof-of-concept Martian Robotic Support Cart

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# FIDOE: A PROOF-OF-CONCEPT MARTIAN ROBOTIC SUPPORT CART

by

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## Abstract

The National Aeronautics and Space Administration (NASA) plans to send a human exploration team to Mars within the next 25 years. In support of this effort Hamilton Standard Space Systems International (HSSSI), current manufacturers of the Space Shuttle spacesuit, began exploring alternative solutions for supporting an astronaut during a Martian surface exploration. A design concept was developed by HSSSI to integrate a minimally equipped Martian spacesuit with a robotic support cart capable of providing life support assistance, communications, and independent navigational functions. To promote NASA's visionary efforts and increase university relations, HSSSI partnered with Worcester Polytechnic Institute (WPI) to develop a proof-of-concept robotic support cart system, FIDOE – Fully Independent Delivery of Expendables.

As a proof-of-concept system, the primary goal of this project was to demonstrate the feasibility of current technologies utilized by FIDOE's communication and controls system for future Martian surface explorations. The primary objective of this project was to procure selected commercial-off-the-shelf components and configure these components into a functional robotic support cart. The design constraints for this project, in addition to the constraints imposed by the Martian environment and HSSSI's Martian spacesuit, were a one-year time frame and a $20,000 budget for component procurement. This project was also constrained by the protocols defined by the NASA demonstration test environment.

The final design configuration comprised of 37 major commercial off-the-shelf components and three individual software packages that integrated together to provide FIDOE's communications and control capabilities. Power distribution was internally handled through a combination of a main power source and dedicated power supplies. FIDOE also provided a stowage area for handling assisted life support systems and geological equipment.

The proof-of-concept FIDOE system proved that the current technologies represented by the selected components are feasible applications for a Mars effort. Specifically, the FIDOE

system demonstrated that the chosen technologies can be integrated to perform assisted life support and independent functions. While some technologies represented by the proof-of-concept system may not adequately address the robustness issues pertaining to the Mars effort, e.g., voice recognition and power management, technology trends indicate that these forms of technology will soon become viable solutions to assisting an astronaut on a Martian surface exploration.

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# Chapter 1: Introduction

## 1.1 Overview

The following section delineates the events that lead to the initiation of the prototype, Martian robotic support cart - FIDOE. In detail, this section describes NASA's vision to explore Mars, the preliminary research done towards the Mars effort, and Hamilton Standard Space Systems International's (HSSSI) involvement in the Mars effort. In addition, this section describes the collaboration between HSSSI and Worcester Polytechnic Institute (WPI) in designing and developing the FIDOE system.

## 1.2 NASA and Mars

NASA's primary goal is to expand the boundaries of human exploration beyond low orbit Earth. As proof of their commitment, NASA plans to send a human exploration team to Mars within the next 25 years.[1] Preliminary efforts are underway to determine the feasibility and cost issues associated with these endeavors.[2][3] One particular report, "The Mars Design Reference Mission" addresses the critical issues involved in a Mars mission set for the early part of the 21st century.[2]

The Mars Design Reference Mission (DRM) presents a human-based mission scenario to Mars that could begin as early as the year 2007. The Mars venture would begin with a set of cargo flights carrying essential equipment for sustaining a base of operations e.g., the habitat, the nuclear power plant, and the in-situ resource utilization facility.[1] With a launch window available every two years, due to the orbital velocity of Mars relative to the Earth, the next launch would occur in the year 2009. By this time, NASA plans to launch the first six-person crew to Mars. The human crew would spend approximately 180 days in transit to Mars and upon landing and connecting with the surface habitat, would investigate the surface for approximately 500-600 days. At the end of their two-three year period on Mars, the crew would spend approximately six months in transit travel back to Earth.

The crewmembers are expected to perform approximately four to eight hour extravehicular activities (EVAs) on a daily basis, potentially up to 1000 EVAs, while on the Martian surface. Specifically, the crewmember would explore the Martian surface and collect geological samples and gather other geological data. The crewmembers would also have access to robust information transfer and data collection as well as access to robotic elements for transportation purposes and other heavy force-type operations.

## 1.3 Motivation - Hamilton Standard Advanced EVA Program

HSSSI is aware of NASA's efforts to explore Mars and would like to contribute towards their efforts. As manufacturers of the current Space Shuttle spacesuit, HSSSI seeks to maintain a presence as a strong supporter in the Mars venture.

In September 1996, a dedicated team of HSSSI engineers began meeting on a weekly basis to discuss the design considerations and constraints involved with a Martian EVA spacesuit. The result was the initiation of an Internal Research and Development program that would demonstrate the concepts mentioned in the Mars DRM. The overall goal for this project is to

[1] The in-situ resource utilization facility is used to convert carbon dioxide and hydrogen gas into methane and water. The hydrogen gas is initially provided by the cargo flights and the carbon dioxide is taken from the Martian atmosphere.

provide NASA with spacesuit concepts currently not explored by their "in-house advanced spacesuit development program".[2]

### *1.3.1 Mars DRM Constraints*

Due to the change in the mission environments, HSSSI needed to determine the constraints and limitations associated with a Martian surface exploration and how these constraints would effect their Martian spacesuit design. The Mars DRM states that EV crewmembers are expected to perform daily EVAs with limited maintenance. The Mars DRM also requires that EV crewmembers have immediate access to geological tools such as a hand shovel or containers to hold geological samples. They are also expected to send and receive information i.e., terrain maps, biological data, and system schematics, in real time. While these requirements may seem feasible when EV crewmembers are within close distances to pressurized rovers, problems could arise when EV crewmembers need to explore areas where pressurized rovers cannot enter.

Unlike the current spacesuit environmental conditions, EV crewmembers will have to operate in a gravity-based environment. Data gathered from the Viking missions have determined that the Martian gravity is approximately 38% of the Earth's gravity.[4] The Martian gravity will not only prevent EV crewmembers from carrying multiple tools but more importantly it will affect the weight parameters for the Martian spacesuit. In order to meet the minimal four hours of EVA operation, it is necessary to minimize the weight of the Martian spacesuit so that EV crewmembers may comfortably work on the Martian surface.

Another factor to consider is the Martian temperature. On a typical Martian day, temperatures will vary from as low as –133° F in the morning to 68° F during midday.[4][5] This temperature range raises thermal control issues in the Martian spacesuit, specifically during

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[2] Advanced EVA System Presentation by Ed Hodgson, June, 1997.

daytime operations. The current Space Shuttle spacesuits can tolerate these temperature variations via its liquid cooling ventilation garment and its nine outer layers on the spacesuit.[3] Unfortunately, this method of thermal control would restrict the EV crewmember's flexibility and inhibit his ability to work.

Additionally, EV crewmembers will need protection against dust, wind, and radiation storms.[3] Typical wind velocities range from 33 mph to 66 mph on the Martian surface although velocities of up to 100 mph have been recorded.[4] It is important to note though that these wind velocities do not induce high pressures against the EV crewmember since the atmospheric density is considerably less ($\sim 1.76 \times 10^{-2}$ $kg/m^3$) than the Earth's atmospheric density at the surface.[5] While pressurized rovers and the habitat will be able to shield them from these foreseen weather conditions, EV crewmembers that are unable to reach the pressurized rover or habitat will need to protect themselves from unpredictable storms.

### *1.3.2 FIDOE and the HSSSI/WPI Joint Venture*

HSSSI's solution was to develop a radical spacesuit system equipped with the minimal basic life support components combined with a dedicated robotic cart that would provide the astronaut with the necessary back-up life support equipment, geological tools, and a robust communications relay station. The robotic support cart, FIDOE – Fully Independent Delivery of Expendables, would serve as an integral part that would meet the demands for Martian EVA operations. In accordance with the Lunar/Mars Design Reference Mission (LMS TRD), FIDOE will "provide transportation for the EV crewmembers and will conserve spacesuit consumable supplies by providing oxygen, power, and thermal control."[3] FIDOE would also resolve the potential accessibility and communication issues and provide the EV crewmember with a shield for protection against unexpected storms.

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[3] http://www.hamilton-standard.com/space/spacefacts/a6.html#6: "Space Facts".

In an effort to increase university relations and to expose students toward potential career opportunities, HSSSI sought to invest in a partnership with a robotics-oriented university. In May 1997, HSSSI and WPI embarked on a joint venture to design and produce the prototype robotic support cart. This collaboration proved to be beneficial in two ways; 1) WPI's past experience with robotic projects and their high interest towards HSSSI's Martian spacesuit concept provided an added value; 2) the collaboration between industry and academia promotes the goals stated within the NASA Strategic Plan.[1]

As a first-stage proof-of-concept system, the FIDOE system was designed and developed by HSSSI and WPI to address the following issues; 1) the ability to provide the EV crewmember with assisted life support; 2) the ability to provide the EV crewmember with thermal control; 3) the availability of current technologies as potential applications for the Mars EVA operation, and 4) the need for a compact and lightweight, robotic system that can handle the environmental constraints within the Martian EVA scenario. Specifically, HSSSI and WPI would collaborate together to define the required interfaces between the Martian spacesuit system and FIDOE’s on-board assisted life support system and thermal control system. WPI addressed the third and fourth issues, namely the feasibility of current technologies for a Martian EVA operation and the need for a compact and lightweight robotic support cart system, respectively.

In chapters two and three the design methodology and the design implementation of the proof-of-concept FIDOE system are described in detail, respectively. Specifically, in the second chapter the design requirements, the design constraints, and the chosen design configuration are discussed. The third chapter describes the integration of the selected components within the FIDOE system. The fourth chapter then describes the results of the FIDOE design configuration, focusing on the performance of the current technologies used, and the integration issues related to HSSSI’s Martian spacesuit. This document ends with a discussion of the conclusions and recommendations based these results.

# Chapter 2: FIDOE System Design

## 2.1 Overview

The following chapter discusses the goals and objectives of the proof-of-concept FIDOE system. This chapter also discusses the constraints associated with each objective and the design components chosen to meet the objectives. Specifically, this chapter describes the FIDOE system's functional requirements and its limitations imposed by the LMS TRD, the Martian environment, and the available resources within HSSSI and WPI.[3][5][6][7]

## 2.2 Goals and Objectives

The primary goal of the proof-of-concept FIDOE system is to interface with HSSSI's prototype Martian spacesuit and demonstrate the integrated system as a possible solution to meeting the requirements stated in the LMS TRD. Specifically, the FIDOE system must demonstrate key, current technologies, e.g., robotic elements, speech recognition algorithms, and obstacle avoidance techniques that can benefit the EV crewmember while performing a Martian EVA operation. Through these key technologies, the FIDOE system must demonstrate the advantages of a robotic system as a viable tool for EV crewmember support.

To meet these requirements, the FIDOE system must be capable of performing a variety of EV crewmember support functions as well as a number of independent, robotic functions. The subsystems were designed and developed to perform the following:

- ♦ provide a video and audio communications link between the EV crewmember and the habitat
- ♦ provide the EV crewmember with robotic control via voice command input
- ♦ track and search for the EV crewmember

- navigate in immediate, unknown surroundings
- avoid obstacles within its immediate vicinity
- carry geological tools and equipment
- supply and manage internal power

The FIDOE system must also address the issue of EV crewmember life support assistance and payload size and weight requirements, although these issues were not the primary focus of this project. The subsections below provide a detailed explanation of each function.

### *2.2.1 Provide a video and audio communications link*

It is envisioned that the FIDOE system will have the ability to send and receive video and audio information between the EV crewmember and the habitat and pressurized rover. While it is possible to send and receive these types of information directly to and from the EV crewmember, versus using the FIDOE system as an intermediate point, the rationale for tasking this capability to the FIDOE system is to allow for a more robust, physical and functional-wise, communications relay station. This relieves the EV crewmember from potentially carrying heavy communications equipment and, in effect, enables the EV crewmember to freely move around during a Martian EVA.

Video communication is an integral mode for transferring information between the EV crewmember and the habitat or pressurized rover. Video information will be primarily used for recording the EV crewmember’s daily activities and displaying geological samples to the other crewmembers at the habitat. A video communications link will also allow the crewmembers in the habitat to inspect any on-site equipment that might fail during the EVA operation.

In addition, the transfer of audio information is an important function as it serves as the primary mode for EV crewmember communication with the habitat and the pressurized rover. In situations where the EV crewmember is a considerable distance away from the habitat, e.g., greater than 300 feet, FIDOE would function as an intermediate station for audio transmissions and receptions.

For the demonstration scenario, the FIDOE system must provide the EV crewmember a means of gathering video information and sending it to the habitat. The FIDOE system must also be capable of saving the video information into its computer database for purposes of recording geological information. Additionally, the FIDOE system must be capable of transferring audio information between the EV crewmember and the habitat as well as saving the audio information into its computer database. These types of information must be wirelessly transferred and performed in real time.

### *2.2.2 Provide Voice Command and Control*

One of the specific functions that will utilize FIDOE's audio transceiver capabilities is the use of voice command and control. In a Martian EVA the EV crewmember is expected to use voice command and control to operate the FIDOE system's navigational control systems and obtain various types of information. For example, the EV crewmember could command the FIDOE system to follow him while he is exploring the surface. Additionally, the EV crewmember could command the FIDOE system to retrieve surface maps, EV crewmember biological status reports, or mission objectives.

A minimum of five voice command inputs were integrated into the proof-of-concept FIDOE system. The voice commands were:

- FIDOE Command Follow
- FIDOE Command Come
- FIDOE Command Go (Forward/Back/Left/Right) (X)

- FIDOE Command Stay
- FIDOE Command Stop

**2.2.2.1 FIDOE Command Follow**

The ‘follow’ command would be used primarily when the EV crewmember is exploring the surface. For example, if the EV crewmember plans to investigate a specified area that is a considerable distance away from the habitat or pressurized rover, e.g., greater than eight feet., the EV crewmember would command FIDOE to “follow”.

The ‘follow’ command will initiate the FIDOE system to track the EV crewmember, as described in section 2.2.3, and maintain a following distance of 7 ± 2 feet between the EV crewmember and itself. In instances where the EV crewmember is greater than the maximum following tolerance, i.e., greater than nine feet, the FIDOE system will increase its traversal speed until the EV crewmember returns to the predefined ‘follow’ range. Conversely, if the EV crewmember is less than the minimum tolerance of five feet, the FIDOE system will reduce its traversal speed until the EV crewmember returns to the ‘follow’ range. Also, if the EV crewmember is too far to the left or too far to the right, i.e., ± 30° from the centerline of FIDOE’s facing direction, the FIDOE system will initiate a search mode as described in section 2.2.3.

**2.2.2.2 FIDOE Command Come**

The ‘come’ command would be used when the crewmember requires FIDOE to come to his side, either to bring geological equipment, to provide the EV crewmember with electronic data or possibly a secondary Primary Life Support System (PLSS). The ‘come’ command requires that FIDOE tracks the EV crewmember and move towards him, up to a predefined distance of four feet. Once FIDOE is four feet away from the EV crewmember, it will stop and initiate a ‘standby’ mode, which puts the FIDOE system into a ‘pause’ state. At this point, FIDOE will disable the track and search functions and wait for the next command.

**2.2.2.3 FIDOE Command Go (Left/Right/Forward/Back) (X)**

The 'Go (Forward/Back /Left/Right) (X)' command provides the EV crewmember with the ability to manually control FIDOE's navigational systems. This command allows the EV crewmember to steer the FIDOE system towards his direction if FIDOE were to lose sight of the EV crewmember. Also, the 'Go' command allows the EV crewmember to guide the FIDOE system when it has difficulty passing an obstacle.

The 'Go (Forward/Back/Left/Right) (X)' command requires that FIDOE switch to EV crewmember-control and move to, or turn towards, the specified direction. Specifically, the 'Go Forward (X)' and the 'Go Back (X)' commands will cause the FIDOE system to move forward or back the desired distance (in feet). The "GO Left (X)" and "GO Right (X)" commands, on the other hand, will cause the FIDOE system to *rotate* the desired circumference (in increments of 10°) about its center axis. For example, if the EV crewmember commanded FIDOE to 'Go left 7', FIDOE would rotate 70° (7×10°) to the left. Figure 2.1 illustrates the actions of this command. During this mode of operation, the FIDOE system will disable tracking and searching functions until the EV crewmember initiates the 'Follow', 'Come', or 'Stay' commands.

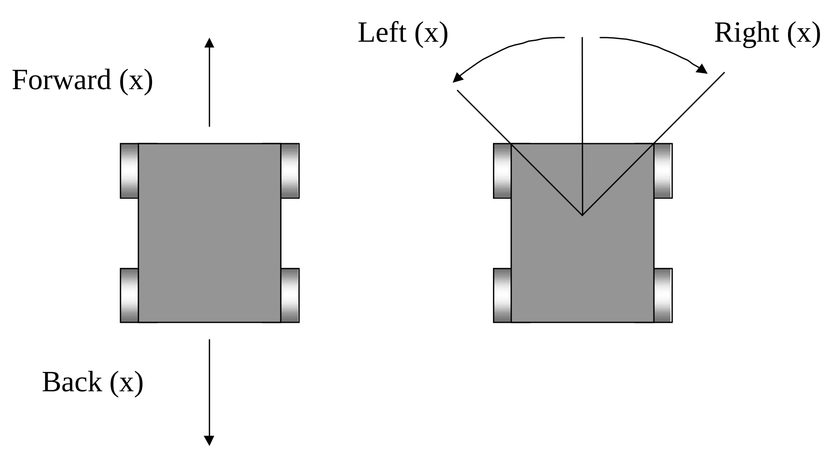


**Figure 2.1: FIDOE Command Go (Forward/Back/Left/Right) (x)**

#### 2.2.2.4 FIDOE Command Stay

The ‘Stay’ command requires that FIDOE track the EV crewmember while maintaining its position until the EV crewmember initiates a ‘Follow’, ‘Come’, or ‘Go’ command. Specifically, the FIDOE system will monitor the EV crewmember’s current position and distance relative to itself. The ‘Stay’ command can be useful in situations where the EV crewmember wishes to explore areas that are difficult for FIDOE to traverse through, i.e., craters or extremely rugged terrain, and still keep a record of the EV crewmember’s latest position and location.

#### 2.2.2.5 FIDOE Command Stop

The ‘Stop’ command is self-explanatory; if the EV crewmember wishes to work in a specific area, he would command FIDOE to “stop” and maintain its position. When the EV crewmember wishes to continue explore other areas, have FIDOE by his side, or maneuver FIDOE around an obstacle, he would command the FIDOE system to ‘follow’, ‘come’, or ‘go’ again. The FIDOE system will perform the ‘stop’ function by disengaging power to the drive motors. Tracking and searching functions will also be disengaged until the EV crewmember initiates the ‘Follow’, ‘Stay’, or ‘Come’ commands. Table 2.1 summarizes the functions of each voice command:

| FIDOE COMMAND | FUNCTION | TRACKING ENABLED? (Y/N) |
|---|---|---|
| FOLLOW | Maintain a distance of 7 ± 2 feet between EV crewmember and FIDOE. | YES |
| GO (Forward/ Back/Left/Right) (X) | Transfer navigational control to EV crewmember. | NO |
| COME | Move towards EV crewmember until EV crewmember is four feet away. If EV crewmember is four feet away, stop. | YES, but will disengage after reaching the EV crewmember. |
| STAY | Maintain position until EV crewmember initiates next command. | YES |
| STOP | Maintain position until EV crewmember initiates next command. | NO |

**Table 2.1: Summary of FIDOE commands and their functions**

In order to assure the EV crewmember that the correct commands were recognized by the FIDOE system, FIDOE will return an associated acknowledgment. For example, if the EV crewmember commands FIDOE to ‘follow’ him, the FIDOE system will acknowledge the “FOLLOW” command by responding with “Command – Follow, acknowledged.” Hence, all commands to the FIDOE system will return an acknowledgement statement. Table 2.2 defines all the corresponding acknowledgements.

| Voice Commands | FIDOE Command Acknowledgements |
|---|---|
| FIDOE Command Follow | Command, Follow, acknowledged. |
| FIDOE Command Come | Command, engage collision, acknowledged. |
| FIDOE Command Go Forward/Back/Left/Right | Command, override collision, acknowledged. |
| FIDOE Command go to sleep | Going to sleep |
| FIDOE Command wake up | Waiting for next command |

**Table 2.2 :FIDOE voice command acknowledgements**

### *2.2.3 Track and Search for the EV Crewmember*

One of FIDOE’s independent functions is to determine the position and distance of the EV crewmember. Although it is possible that a robust tracking system, e.g., a global positioning system, could be implemented into the Mars effort, a more feasible alternative to finding the EV crewmember’s position is to provide this capability locally within FIDOE.

The envisioned FIDOE system would determine the EV crewmember’s position and distance relative to its own position. This information would most likely be interpreted as a set of Cartesian or polar coordinates. These coordinates, along with FIDOE’s coordinates relative to the habitat or pressurized rover, could be interpolated to provide the EV crewmember’s coordinates relative to the habitat or pressurized rover. In addition, this information would also be stored within FIDOE’s on-board computer database for record purposes.

In the event that the EV crewmember is outside the field of tracking, i.e., if the EV crewmember is beyond FIDOE's tracking limits, FIDOE will initiate a 'search' function. The search function will call upon the EV crewmember tracking data to determine the last known position and distance and begin a scanning procedure from that location. It is envisioned that FIDOE will be capable of tracking and searching for the EV crewmember at maximum distances of approximately 100 feet in any direction.

As a requirement for this project, the FIDOE system will demonstrate a scale-down version of the track and search capability. Specifically, the proof-of-concept system will track the EV crewmember at a maximum distance 30 feet and perform a search scan of 180° (90° to the left and 90° to the right) along the horizontal plane.

### *2.2.4 Navigate in Immediate, Unknown Surroundings*

In accordance with the LMS TRD, the envisioned FIDOE system will have the ability to navigate in immediate, unknown surroundings without EV crewmember assistance. While it is expected that detailed, topographical maps, which could provide recommended routes and pathways, will be accessible to the FIDOE system, it is unlikely that information pertaining to the exploration site's surface roughness will be provided. The following function addresses this issue.

In a Martian environment, the envisioned FIDOE system must be capable of independently propelling and steering itself across rugged terrain. Typical speeds of travel will be based on the EV crewmember's walking speed, which, under normal conditions, will most likely be on the average of 1½ ft/sec. On the Martian terrain, the FIDOE system must be capable of rolling over obstacles that are up to six inches in height and avoid obstacles that are greater than six inches in height. Additionally, the FIDOE system must be capable of traversing across slopes that are up to $\pm$ 30° along the horizontal plane while carrying maximum payloads.

However, the proof-of-concept system only needs to demonstrate the fundamental aspects of autonomous navigation. Hence, the FIDOE system will demonstrate the capability of independent propulsion and steering in immediate, unknown surroundings under minimally rough surfaces such as a flat, hardwood or carpeted floor.

#### *2.2.5 Avoid Obstacles Within its Immediate Vicinity*

Based on descriptions of the Martian terrain and the recent information gathered from NASA Jet Propulsion Laboratory's Mars Sojourner rover, the need for robust obstacle avoidance techniques becomes apparent.[7]

In conjunction with the FIDOE system's navigational capabilities, the envisioned FIDOE system must perform obstacle avoidance techniques in real time. Due to the constraints imposed by the Martian atmosphere and terrain, it is appropriate to focus on methods and their respective components that would satisfy the envisioned FIDOE's requirements. For example, the use of contact sensors as a form of obstacle avoidance could be sufficient for the proof-of-concept system although this would be unacceptable for Martian EVAs. As a means of providing a robust obstacle avoidance system, two types of techniques are required to ensure that the envisioned FIDOE system avoids obstacles greater than six inches in height, 1) long range obstacle avoidance techniques ranging from 5 – 15 feet, and 2) short range obstacle avoidance techniques ranging from ½ – 5 feet. The governing rationale for implementing two types of obstacle avoidance systems versus a single system is to provide FIDOE with a back-up and redundant system.

Again, as a proof-of-concept system, the robotic support cart must demonstrate this function as a benefit to a Martian EVA operation. The demonstration has a fewer number of obstacles and are also more dispersed compared to the Martian terrain. Nonetheless, the FIDOE system must be minimally capable of traversing along a path while avoiding obstacles that are within a short distance away i.e., up to three feet, from its physical borders. Specifically, the

FIDOE system must avoid obstacles that are within three feet of its direct path. The FIDOE system must also avoid obstacles that are within six to eight inches of its left-front, right-front, left-back, and right-back sides (Figure 2.2). In general, the FIDOE system must be capable of maintaining a reasonable distance between itself and the EV crewmember despite any obstacles in its immediate path and as a result, must perform obstacle avoidance techniques in a minimal amount of time.

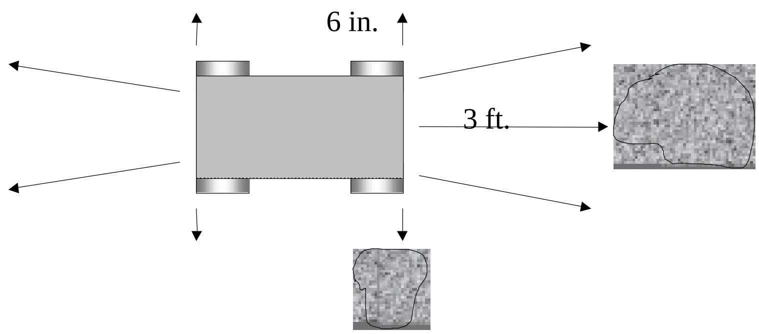


**Figure 2.2: FIDOE Obstacle Avoidance Technique**

***2.2.6 Carry Geological Tools and Equipment***

The envisioned FIDOE system will carry a variety of geological tools and equipment that the EV crewmember will use during Martian EVA operations. Items can vary from simple excavation equipment, i.e., a hand shovel and sample containers, to sophisticated devices such as a soil analysis-type tool or a powered hand drill. These types of equipment must be small and lightweight in order to meet the weight and size requirements stated in the LMS TRD. These types of equipment must also be easy to stow inside the FIDOE system. For this project, the proof-of-concept FIDOE system will provide stowage space for simple geological equipment.

### *2.2.7 Provide Internal Power Storage and Power Management Methods*

It is important to include an on-board power supply and power management system in order to support the above mentioned subsystems. Under normal Martian EVA operation conditions, the envisioned FIDOE system must be capable of maintaining independent functions in addition to EV crewmember support functions for a minimal period of approximately 16 hours, or two eight-hour EVAs. Also, in situations where a contingency campout is required (due to dust, wind, or radiation storms), the FIDOE system must be capable of maintaining the minimum EV crewmember support functions such as life-support assistance per section 2.2.8, video and audio communications, and the track and search function. As a proof-of-concept system, the FIDOE system must provide internal power and power management for the duration of the demonstration (approximately 30 – 40 minutes). Specifically, the FIDOE system must provide and manage power to the audio and video communications relay station, the on-board main computer system and the components that provide EV crewmember tracking and locating capabilities, FIDOE propulsion and steering, and obstacle avoidance capabilities.

### **2.2.8** ***Preliminary Analyses of EV Crewmember Life Support Systems***

As a robotic support cart, a main objective is to provide the EV crewmember with assisted life support, primarily through oxygen re-supply, power re-supply and thermal control. Through collaborative efforts with HSSSI, the envisioned FIDOE will provide this capability via three methods:

1) Carry two replacement PLSSs and one replacement Secondary Oxygen Pack (SOP) and provide a purge flow system for use while replacing a PLSS.
2) Provide an independent Life Support System (LSS) built into the FIDOE system that would accommodate up to 20 hours of life support for one EV crewmember.
3) Carry thermal overgarments for one EV crewmember.

The first method requires that FIDOE carry two replacement PLSSs and one replacement

SOP. One replacement PLSS can provide up to eight hours of life support while the SOP can provide 30 minutes of oxygen. The replacement PLSSs and SOP allow the EV crewmember to exchange the current PLSS and/or SOP with a fully supplied PLSS and/or SOP. This would be necessary if the EV crewmember either had a low expendable level (i.e., a low oxygen supply, an expendable $CO_2$ removal canister, or a low battery) or equipment failure and needed to continue the EVA operation. A purge flow system is included to remove any remains of $CO_2$ in the Martian spacesuit. Additionally, the purge flow system will be used during scheduled or unscheduled change-out of a PLSS or SOP. HSSSI anticipates that this change-out could occur at a maximum of three times during an eight hour EVA, at approximately one and a half minutes per exchange. The two replacement PLSSs and the replacement SOP will be stowed onto FIDOE while the purge flow system will be permanently attached to FIDOE.

The second method, a 20-hour independent LSS on FIDOE, consists of an oxygen storage and regulation system and a water storage/recirculation system. These components are permanently attached to the FIDOE system and require that the EV crewmember use a tethered connection. The 20-hour LSS serves as a redundant back-up system that would alleviate life-threatening situations caused by a failed PLSS or SOP. The 20-hour LSS would also be used if the EV crewmember were trapped in a location for an extended amount of time. For example, if the EV crewmember were caught in a dust storm, he would connect with the 20-hour LSS and wait until the dust storm passes or until other EV crewmembers come to retrieve him.

The third method provides the EV crewmember with thermal protection against typical Martian temperatures. Based on data gathered from the Mars Pathfinder, the EV crewmember would normally experience extremely cold temperatures during the start and end of the Martian day as well as experience relatively warm temperatures during midday.[5] To accommodate these temperature variations, the EV crewmember would don the thermal overgarments prior to leaving the habitat and doff the thermal overgarments during midday. Towards the end of the day, the EV crewmember would re-don the thermal overgarments and return to the habitat. The thermal overgarments would be appropriately stored in a location that is easily accessible to the EV crewmember.

The proof-of-concept FIDOE system must address all three capabilities with regards to their weight and volume requirements. Specifically, the FIDOE system must allocate space necessary for stowing the three support systems as well as support the combined weights of the systems mentioned above. Additionally, the proof-of-concept FIDOE system must allocate space and support the weights of these systems' proper supports, adapters, and other associated interfaces.

### *2.2.9 Preliminary Analysis of FIDOE Payloads and Size Requirements*

The envisioned FIDOE system must carry all equipment related to the subsystems mentioned above. Specifically, the FIDOE system must carry equipment connected with:

- Audio and video communications subsystems
- Track and search subsystem
- Obstacle avoidance subsystem
- Life support systems
- Power supply and management subsystems

Additionally, the FIDOE system must carry geological tools and equipment along with any geological samples gathered during the Martian EVA.

In the event that the EV crewmember is injured and cannot independently return to the pressurized rover or habitat, all expendable equipment, e.g., geological samples and equipment, will be removed from FIDOE in order to carry the EV crewmember back to the pressurized rover or habitat.

The size and weight requirements imposed on the envisioned FIDOE system are dependent on three external factors; 1) the gravity of Mars; 2) the size and weight requirements of the Mars launch vehicle; and 3) the size and weight requirements of the pressurized rover. The first factor requires that total weight of the FIDOE system must be relatively light, i.e., approximately less than 500 lbs., Martian weight. The second and third factors require that the FIDOE system must be small and light-weight enough to meet the weight requirements of the Mars launch vehicle and the pressurized rover, respectively. For this project, the size and weight requirements of the FIDOE system will be limited to a predefined footprint area of 2 ft. × 4 ft. and a total Earth weight of 500 lbs.

## 2.3 FIDOE Design Constraints

In compliance with the proof-of-concept FIDOE system's primary objective, the FIDOE design was constrained to the configuration of 'commercial, off the shelf' (COTS) components. Specifically, COTS components were used for configuring all communications and control subsystems. Also, COTS materials were used for constructing the physical frame for the robotic support cart's chassis and storage bays. The total cost of all COTS components was limited to a total of $20,000. Time is another design constraint associated with the FIDOE system; the time frame for design and development of the FIDOE system was approximately one year. Due to these constraints, the proof-of-concept system had to be functional yet simplistic.

The demonstration scenario imposed a set partial constraints to the proof-of-concept FIDOE system. Consequently, the selection of some COTS components were based on whether or not the components will function during the NASA demonstration environment. For example, if loud, background noises are commonly heard in the environment, the FIDOE system's speech recognition subsystem may need to incorporate a special filtering device to its voice input module.

The demonstration protocol (see Table 2.3) describes the demonstration environment.

| **Planetary Exploration EVA System Concept Demonstration Test**[4] | |
|---|---|
| *Location* | Large room that is approximately 30 ft. × 30 ft. |
| *Test Surface* | Carpeted or hardwood floor surface with minimal slope. Surface unevenness will be limited to discontinuities typical of carpet edges, doorways, power cords, etc. |
| *Obstacles, clearance* | Minimum clear passage to be negotiated will be four feet wide. Continuous traverse length at this width will be as great as 20 feet.<br>Obstacles to be detected and avoided include structures such as a 1 $ft^3$ cubic box, a Martian spacesuit donning station for the EV crewmember, and a habitat. |
| *Time Period* | The maximum operation time will be 30 minutes. |

**Table 2.3: Demonstration Scenario Requirements**

While it is ideal to design a robotic support cart that can meet all of the Martian environmental constraints, the focus of this project is to demonstrate the feasibility of key technologies as future applications for the Martian EVA operation. Thus, it is important to address the COTS components' technology trends and the validity of their fundamental concepts independent of the constraints imposed by the NASA demonstration environment.

## 2.4 FIDOE Communication and Controls Component Selection

The subsections below define the COTS components selected for the video and audio communications subsystems, the speech recognition subsystem, the tracking and searching subsystems, the navigational control subsystem, and the obstacle avoidance subsystem.

[4] The demonstration protocol was developed by HSSSI and WPI.

Furthermore, the components selected to manage the information from these subsystems and the components selected to supply and manage power for these subsystems are defined below.

It is important to note that the COTS components described below represent two development phases of the proof-of-concept system. The COTS components selected for the first development phase represent WPI's initial attempt to meet the requirements of the project. As the project progressed, portions of the design configuration were modified by WPI and HSSSI; this represents the second development phase. Some COTS components listed below were eventually excluded from first development phase and as a result, the final proof-of-concept FIDOE system represented a combination of the first and second development phases. COTS components that were selected in the first development phase are identified with a (PH1) suffix while COTS components that were selected in the second development phase are identified with a (PH2) suffix. Additionally, components selected by HSSSI are denoted by the $_{\text{(HSSSI)}}$ subscript.

### *2.4.1 Video/Audio Communications Hardware*

The ability to gather and store video information into the FIDOE system requires using a video camera, a video transmitter, a video receiver, a video capture card, and a dedicated information storage database. Ideally, the video camera and video transmitter would be mounted onto the EV crewmember's Martian spacesuit, presumably on the outside of the Martian spacesuit, so that video information would reflect what the EV crewmember sees during the Martian EVA operation. Then the video receiver would gather the video information and send it to the computer storage database through the video capture card. The video capture card provides this capability by converting the video signal, e.g., NTSC or PAL format, from analog to digital information, compressing the digital information, and saving it in the computer storage database for record purposes.

The transfer of audio information from the EV crewmember to the FIDOE system requires an audio transmitter, an audio receiver, and a microphone for audio input. Additionally, the audio communications system requires a filtering device to remove any background noise. This device is an important component because it is expected that the Martian spacesuit will generate large background noises from its internal air-circulation fan. The audio receiver sends the information to a computer storage database via a direct connection to the computer system.

The requirement states that both types of information must be wirelessly transferred between the EV crewmember, the FIDOE system, and the habitat. This eliminates the option for a tethered connection, i.e., RCA or optical cables. The selection of wireless video/audio transmitters and receivers minimized the selection to either radio frequency (RF) or infrared (IR) based devices. Yet, due to IR technology's need for a direct line of sight, coupled with signal degradation due to Mars' dusty environment, the option to transfer video and audio information over the required distances via an IR connection was rejected. An RF interface, on the other hand, is not restricted by these limitations. In fact, RF technology was successfully implemented with the Mars Sojourner robot; this validates RF technology as a proven method for transferring information.

The video communications components (Figures 2.3 – 2.7) that met these requirements and constraints are listed in Table 2.4.

| PHASE I (PH1) | PHASE II (PH2) | FUNCTION |
|---|---|---|
| Pragmatic Communications Systems TrueView color camera | Sony Camcorder video camera (HSSSI) | Gather video information |
| Pragmatic Communications Systems 900 MHz video/audio transmitter and receiver | <excluded> | Transfer video information (EV crewmember to FIDOE) |
| Pragmatic Communications Systems 2.4 GHz video transmitter and receiver | <same components> | Transfer video information (FIDOE to habitat) |
| Hauppauge WinMotion60 PCI video capture card | Nogatech PCMCIA Conference Card and associated cable connections (HSSSI) | Capture and record video |
| Dell Workstation 400 Pentium 233 mini tower system | Toshiba laptop (HSSSI) | Provide video storage |

**Table 2.4: Video communications component selection during Phase 1 and Phase 2**

The audio communications components (Figures 2.8 – 2.10) that met these requirements are listed in Table 2.5.

| PHASE I (PH1) | PHASE II (PH2) | FUNCTION |
|---|---|---|
| Pragmatic Communications Systems 900 MHz video/audio transmitter and receiver | 3Com Systems, Inc. portable transceivers and base station (HSSSI) | Transfer audio information (EV crewmember to and from FIDOE) |
| Dragon Dictate microphone headphone set | 3Com Systems, Inc. microphone headphone set (HSSSI) | Input voice commands |
| Dragon Dictate signal amplifier/filter | <same component> | Minimize noise and increase signal amplitude |

**Table 2.5 : Audio communications component selection during Phase 1 and Phase 2**

### *2.4.2 Voice Command and Control Software and Hardware*

The associated hardware for the voice command and control subsystem are a microphone/headphone set, a signal filtering/amplifier device, and a computer sound card that can accept audio inputs. Since these selected components match the audio communication's hardware, it was decided to incorporate both hardware subsystems into a single unit. As a result, the EV crewmember will utilize the audio communications equipment as a tool for 1) communicating with the habitat, 2) sending voice commands to the FIDOE system, and 3) receiving acknowledgements from the FIDOE system.

Speech recognition software selection was dependent on the software's high performance rates, ability to add custom vocabularies, ability to interface with custom software, and cost. Specifically, the speech recognition software must exhibit the ability to increase recognition accuracy through continuous use and eventually achieve accuracy rates of up to a minimum of 95%.[3] The speech recognition program must also allow the user to add the FIDOE commands as well as output the corresponding acknowledgements, either through use of macro rules, scripts, or through use of the speech recognition program's software development tools. The software's platform environment must conform to the platform environment used by FIDOE's information management system, as described in subsection 2.4.6. The cost of the speech recognition software program was based on the lowest available cost.

Based on these specifications, the available COTS speech recognition software programs were IBM's ViaVoice and Dragon System's Dragon Dictate. Both software programs were capable of performing at the expected performance rates as well as providing the ability to include custom vocabularies. Additionally, both software programs functioned on the same platform environment as FIDOE's data management system's platform environment (Win95 OS). Unfortunately, IBM's ViaVoice did not provide a software development toolkit, which was an important feature for this subsystem. The cost of the Dragon Dictate software program was comparable to IBM's ViaVoice software program. As a result, **Dragon System's Dragon Dictate (PH1)** speech recognition program was selected for this requirement.

### *2.4.3 Tracking and Locating Hardware and Software*

The ability to track and search for the EV crewmember requires a set of RF or IR-based components that can determine position and distance. Ultrasonic-type equipment was initially considered, but due to the thin atmosphere of Mars, ultrasonic devices would be inefficient, and thus this type of media was not chosen. Also, IR-based equipment depended on an un-obscured, direct line of sight between the EV crewmember and the support cart. Hence, RF-based equipment was chosen as the primary media for determining the EV crewmember's position and distance.

Different techniques were considered in determining position and distance. Position can be determined via triangulation or trilateration.[5] Triangulation requires knowing and using the relative bearings of the target (commonly expressed in θ) while trilateration requires knowing and using the relative distances of the target. Both technologies require using a minimum of three signal emitters/detectors, commonly known as transponders, and a retro-reflective target.

Distance determination can be achieved via pulse timing or phase comparison.[6] Pulse timing techniques would require equipment that can measure the signal's time-of-flight from the FIDOE system to the EV crewmember. Alternatively, phase comparison techniques would require equipment that can measure the phase shift between the transmitted signal and the reflected signal.

Unfortunately, due to the high costs (>$5,000) associated with RF-based position and distance determination COTS components, commercial IR-based equipment were selected. A

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[5] http://www-dse.doc.ic.ac.uk/~nd/surprise_97/journal/vol4/jmd: "Mobile Robot Navigation".

[6] http://lenti.med.umn.edu/~mwd/sensors.html: "Sensors-Rangefinding devices".

preliminary attempt was made to design and develop a proprietary position and distance determination system but this option was considered unfeasible due to time constraints. Section 3.2.1 explains this in detail.

The IR-based COTS components selected to track and search for the EV crewmember were **Origin Instruments' Dynasight sensor (PH1)**, an **RS-232 serial cable (PH1)**, and a **retro-reflective, passive target (PH1)** (Figure 2.11). The methods used to determine position and distance are unknown due to the Dynasight sensor's proprietary nature, although it is assumed that the sensor determines position via trilateration and distance via phase comparison. The information is passed in the form of streaming packetized data from the Dynasight sensor to the FIDOE system's information management system via an RS-232 cable. This information, in turn, is interpreted via Dynasight's proprietary software to provide the retro-reflective target's Cartesian coordinates.

The Dynasight sensor provides the tracking capability by outputting the coordinate information at a maximum rate of 65 Hz. Additionally, the sensor provides the searching capability by starting the search at the last known position of the target prior to its disappearance. From that starting point, the sensor emits the IR-signal and looks for a return signal with the highest intensity. Upon locating the target, the sensor returns to the tracking mode.

### *2.4.4 Navigational Hardware*

As a critical subsystem of the robotic support cart, the navigational hardware must include a drive train system as well as a means of autonomously controlling the drive train system. One option was procure a pre-configured drive train assembly, i.e., a robotic golf cart, and re-engineer its control system to interface with FIDOE's information management system. Another option was to procure the individual components, i.e., the motors, wheels, and motor controllers, and configure a more specialized system. Unfortunately, a major limitation to purchasing most pre-configured systems was that suppliers would not allow their systems to be re-engineered due to company proprietary reasons. Time constraints prevented the option to develop a specialized drive train system. As a result, a hybrid of the two design options was chosen.

The selected COTS components were a **HoverRound MPV4 motorized wheelchair (PH1)** (Figure 2.12), which included two motorized wheels, two caster wheels, and a dedicated 12VDC battery for each motor, **two 4QD NCC-35-24 motor controller cards (PH1)**, **two Clare magnetic reed switches (PH1)**, and **two SCAN-O-MATIC optical relay switches $_{\mathbf{(HSSSI)}}$ (PH2)** (Figure 2.13 – 2.15). The HoverRound MPV4 motorized wheelchair provided the required carrying capacity as well as the required traversal speeds. The 4QD motor controller cards provided the necessary interface to the on-board main computer system and the power supplies for the drive train system's motors. In the first development stage, two magnetic reed switches were selected to obtain feedback information, i.e., the number of revolutions per second for each motorized wheel, and send it to the information management system. In the second development phase, reed switches were replaced with HSSSI's optical relay switches.

In addition to these components, WPI included **two SPDT contact switches (PH2)** (Figure 2.16) and a **remote-control car transmitter and actuator (PH2)** (Figure 2.17) in the navigational hardware list. The SPDT contact switches serve as a 'kill switch' to the motors' power supply which can be remotely controlled via the remote-control car transmitter and actuator. The primary purpose was to provide a safety mechanism to stop FIDOE in the event that the support cart loses navigational control.

### *2.4.5 Obstacle Avoidance Hardware*

COTS components that would suit the long range obstacle avoidance subsystem depended on the method used to detect obstacles. Possible methods for long range obstacle avoidance are stereo vision, depth from defocus, light striping techniques, and the use of laser range finders. Based on previous surveys and results from other sources[7], the chosen method for real-time obstacle avoidance and range finding is the laser striping technique. This technique requires laser emitters, a coupled charged device (CCD) camera with a specific filter, an image grabber card, and software capable of processing information from the image.

Although there are a variety of ways to implement the laser striping technique, the concept specifically used for FIDOE is to mount the lasers at the front of FIDOE, pointing outward and to mount the CCD camera above the lasers and view the area where the laser stripes exist. Through the use of the specific filter the CCD camera will obtain a dark image with white stripes; the white stripes represent the reflections of the laser beams as they hit an obstacle. The image is sent through the image grabber card and processed via FIDOE's information management system into information which "tells" the FIDOE the location of the obstacle(s). Knowing this information, the FIDOE can initiate certain obstacle avoidance tactics.

COTS components that met the design constraints and could perform the laser striping technique were:

- **Lasiris SNF-509L-670-30-F.A. laser line generators (PH1)**
- **ImageNation frame grabber card (PH1)**
- **ImageNation camera interface cable (PH1)**
- **Pulnix TM7-CN Black and white CCD camera (PH1)**
- **Cosmicar Lens with 88° horizontal field of view (PH1)**
- **One inch diameter 665 nm Filter (PH1)**

[7] http://jpl.robotics.nasa.gov/tasks/scirover/factsheet/homepage.html: "Mars Rover Fact Sheet".

The types of COTS components that were considered for the short range obstacle avoidance subsystem were divided into three types of sensors: 1) electromagnetic, 2) infrared, and 3) ultrasonic. Contact sensors were not considered as an option since the envisioned FIDOE system could damage these sensors when traversing through rough terrain. Example products that use electromagnetic flux to determine the distance are capacitive sensors and inductive sensors. Unfortunately, commercial and inexpensive capacitive and inductive sensors normally have a low level of detection (typically in the range of 5-10 cm.). Inductive sensors also require that the object to be detected have strong magnetic characteristics, which would require that all obstacles either pose strong magnetic properties or the EV crewmember must plant magnets on every potential obstacle. Additionally, recent data from the Mars Sojourner robot shows that Martian dust is highly magnetic, which can pose potential problems when determining whether or not an obstacle is in the traversal path during windy situations.[6] Hence, capacitive and inductive sensors were disregarded.

While IR sensors are not the primary choice for tracking and searching for the EV crewmember, they can provide some benefits to this application. Due to the relatively short distances, and thus the smaller amount of dust interfering with the IR sensor, IR sensors can be a potential choice for use in this obstacle avoidance system. Though one unique limitation of IR sensors is that they require a return signal to determine if an obstacle is within range or not. To do so would imply that the obstacle’s surface is sufficiently reflective. Since a majority of the obstacles will be sizable rocks that seem to show low reflective surfaces, it is important to procure IR sensors that can emit a powerful infrared signal, which results in a strong return signal, in order to compensate for this limitation.[7]

Ultrasonic sensors pose the same benefits as IR sensors with regards to obstacle avoidance applications but they are limited, again, by the inherent low atmospheric density.

Despite their similar need for a powerful output signal, ultrasonic sensors do not rely on the obstacle's reflective characteristic.

The COTS components selected for providing FIDOE's obstacle avoidance capability were **four Hamamatsu light modulation photoreflectors (PH1)** (Figure 2.18) and **five Velleman parking radars (PH2)** (Figure 2.19), which apply IR and ultrasonic methods, respectively. The four infrared sensors provided a maximum detection distance of 18 inches based on 90% reflectivity surfaces such as a piece of white paper. Grayish objects limited the detection distance to approximately six inches. The five ultrasonic sensors could detect objects up to a maximum of 4.5 feet.

### *2.4.6 Information Management Systems Hardware and Software*

In addition to the overall constraints, the selection criteria for the information management system COTS components, also known as the main computer system, were dependent on two main factors; 1) the ability to interface with the other sub-systems; and 2) the robustness of the computer system's operating environment.

The first issue refers to the computer system's ability to properly communicate with the other subsystem components, which requires that the computer system's operating platform is conformable to the external subsystems' operating platform. Specifically, the computer system selected must use the Win95 operating system. The ability to interface also refers to compatibility of hardware components between the computer system and the external subsystems. One example is the computer system's available serial ports and their compatibility with the Dynasight sensor's RS-232 serial cable.

The second issue refers to the computer system's ability to handle large amounts of data without potentially crashing the FIDOE system's main program. Specifically, the computer system's hardware and software algorithm must be able to continuously capture and interpret audio information from the EV crewmember and distinguish voice commands from normal conversation. Also, the computer system be able to interpret streaming data from the Dynasight sensor into direction and velocity-type information for the navigational subsystem. Additionally, the computer system must be able to interpret information from the obstacle avoidance subsystem and relay the corresponding obstacle avoidance algorithms to the navigational subsystem.

Based on these selection criteria and the design constraints, WPI selected a **Dell 400 Workstation Pentium 233 mini tower system (PH1)** and **two CyDAS 1602 Data Acquisition Boards (PH1)** (Figure 2.20). The Dell 400 Workstation was pre-configured with 128 Mb ECC RAM, proprietary 16-bit Soundblaster sound card built into the motherboard, and 2 GB SCSI hard drive. The two CyDAS 1602 Data Acquisition (DA) Boards were selected to provide the required interfaces from the computer system to the navigational subsystem's motor controllers. These boards also provided the required interfaces between the obstacle avoidance sensors and the navigational subsystem's feedback control switches.

The software selected to manage information from the voice command and control subsystems, the track and search subsystems, the navigational control subsystems, and the obstacle avoidance subsystems were **Visual C++ (PH1)** and **LabView 4.0** $_{\mathbf{(HSSSI)}}$ **(PH2)**.

### *2.4.7 Power Supply and Power Management Systems Hardware*

Prior to selecting the power supply and power management systems, a preliminary design analysis was performed. Results from this analysis showed that the subsystems that were designed to use AC voltage, i.e., the Dell computer system, the Dynasight sensor, and the 2.4 GHz video transmitter, needed a peak wattage of approximately 280 watts. Subsystems that required DC voltage for operation, i.e., the obstacle avoidance sensors, needed approximately a peak wattage of approximately 2 watts.

The following COTS components were selected to supply and manage power to the aforementioned components:

- **Die Hard 12VDC Marine/Deep Cycle battery (PH1)**
- **Tripplite PV400W inverter (PH1)**
- **Typical household surge protector (PH1)**
- **Pragmatic Communications Systems 120 VAC plug-in adapter (PH2)**
- **Dynasight 120 VAC plug-in adapter (PH1)**

The Tripplite PV400W inverter (Figure 2.22) handles a maximum of 600 Watts (peak) and 400 Watts (continuous). This device was selected to convert the DC voltage from the Die Hard battery (Figure 2.21) into AC voltage in order to comply with the power interfaces of the computer system, the Dynasight sensor, and the 2.4 GHz video transmitter. Due to the lack of plugs on the inverter, a **surge protector (PH1)** was included to accommodate the three corresponding plug-in adapters. The obstacle avoidance sensors did not interface with the inverter.

The remaining communications and controls COTS components are powered through individual, dedicated power supplies. The following power supplies were provided:

- **Two 9VDC Alkaline batteries $_{\textbf{(HSSSI)}}$ (PH2)** for the 3Com Systems audio transceiver
- **Dedicated 9VDC battery pack (PH1)** for Pragmatic Communication Systems Inc., 900 MHz color camera/transmitter.
- **Dedicated 9VDC battery pack (PH1)** for Pragmatic Communication Systems Inc., 900 MHz receiver.
- **(12) 1.5 VDC, AA Alkaline batteries (PH2)** for remote controlled ‘kill switch’ (4) and remote controlled ‘kill switch’ transmitter (8)
- **Two 1.5 VDC, AA Alkaline batteries (PH1)** for the Dragon Dictate filter/amplifier
- **Two dedicated 12 VDC batteries (PH1)** for drive train motors
- **Dedicated Ni-Cad battery $_{\textbf{(HSSSI)}}$ (PH2)** for Toshiba laptop

- **Dedicated battery $_{(HSSSI)}$ (PH2)** for Sony Camcorder video camera
- **Dedicated battery pack (PH1)** for Pulnix black and white CCD camera

The governing rationale behind this design decision was to reduce the power loads imposed on the Die Hard battery.

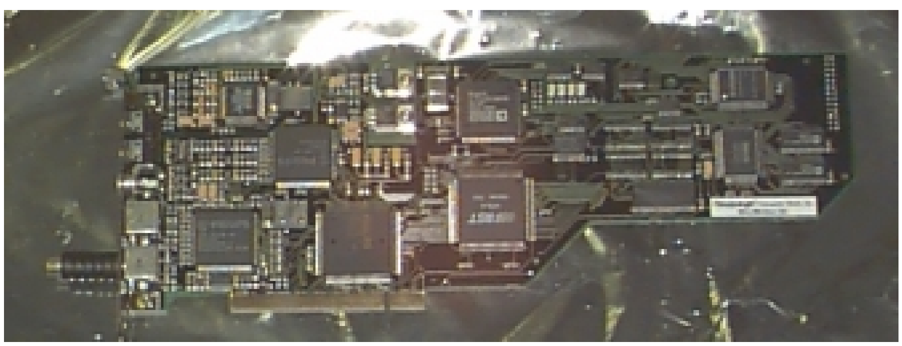
## 2.5 FIDOE Chassis and Housing Component Selection

Knowing the final selection of COTS components for the communications and control subsystems and their approximate weights and dimensions, the materials chosen to construct the FIDOE system's chassis and storage bays were **80/20 aluminum extrusions (PH1)**, **3/8 inch thick Lexan sheets (PH1)**, and fasteners such as nuts and bolts. These materials were primarily chosen due to the materials' implicit ease of assembly (80/20 components are perceived as an 'industrial erector set'). Also, these materials met the minimal weight and structural requirements to contain and support the COTS components as well as the LSS equipment. Although these materials would not be considered for a 'flight-ready' system, the focus of this project is more towards the communications and controls components than the robotic support cart's structural integrity.

**Figure 2.3: Pragmatic Communications Systems True View color camera, 900 MHz transmitter and receiver, and RCA cables**


**Figure 2.4: Sony Camcorder**

**Figure 2.5: Pragmatic Communications Systems 2.4 GHz transmitter and receiver**

a) 

b) 

**Figure 2.6: a) HauppaugeWinMotion60 PCI card**
**b) Nogatech PCMCIA Conference Card**

a)

b)

**Figure 2.7: a) Dell Workstation 400 Pentium 233**

**b) Toshiba laptop**

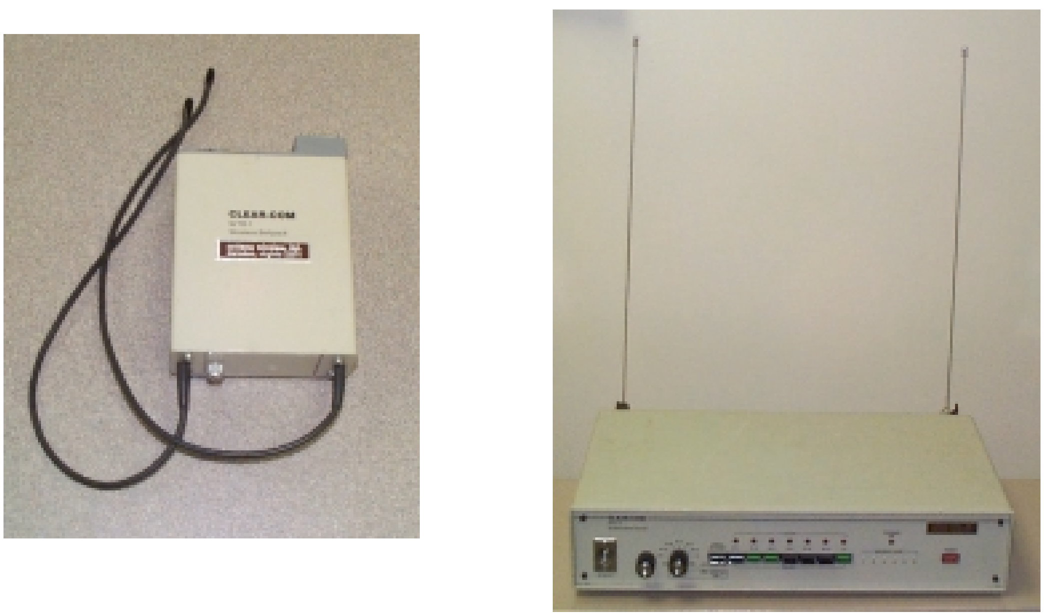


**Figure 2.8: 3Com Systems Inc., ClearCom transceiver and base station**

a)

b)

**Figure 2.9: a) Dragon Dictate microphone headset**
**b) 3Com Systems Inc., ClearCom headset**

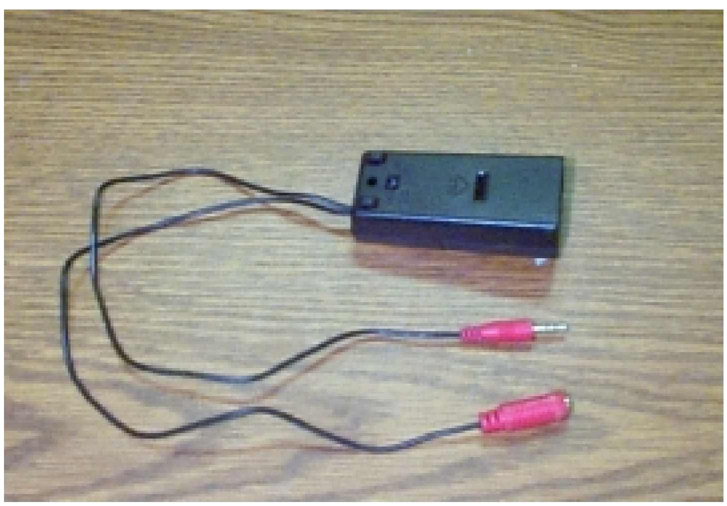


**Figure 2.10: Dragon Dictate signal amplifier**

**Figure 2.11: Dynasight sensor, RS-232 serial connector, retroreflective targets, and power adapter**

**a)** **b)**

**Figure 2.12: a) HoverRound MPV4 motorized wheelchair, b) Stripped-down motorized wheelchair with chassis modification**

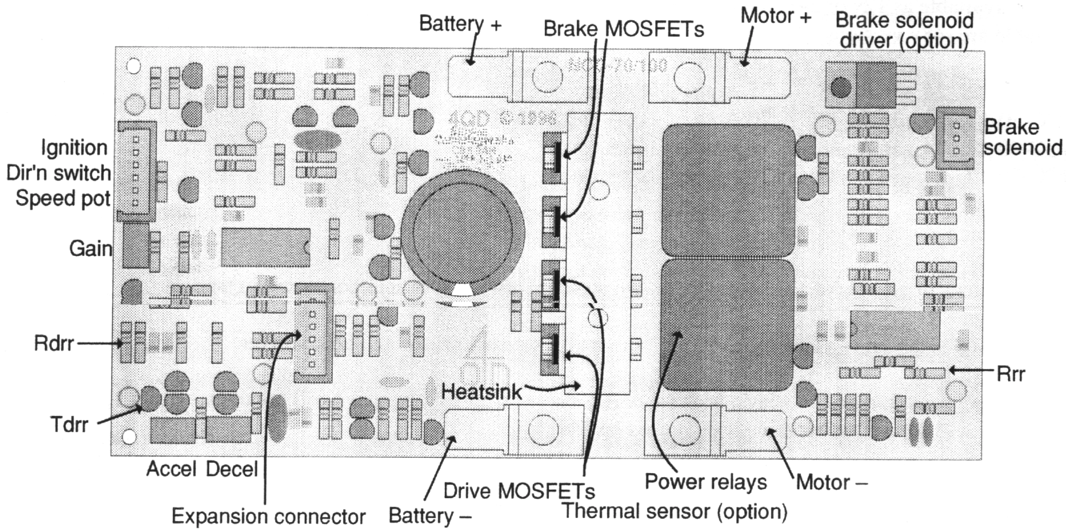



**Figure 2.13: Sketch of a 4QD NCC-35-24 motor controller card**

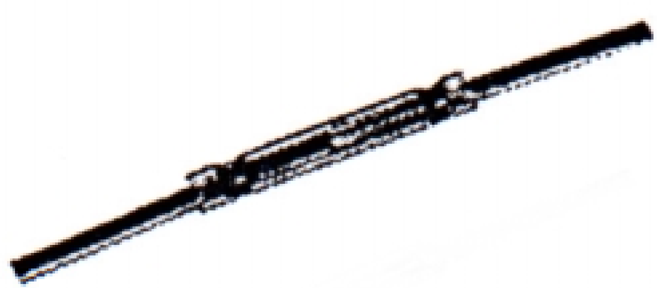


**Figure 2.14: Clare magnetic reed switch**

**Figure 2.15: SCAN-O-MATIC optical relay switch**

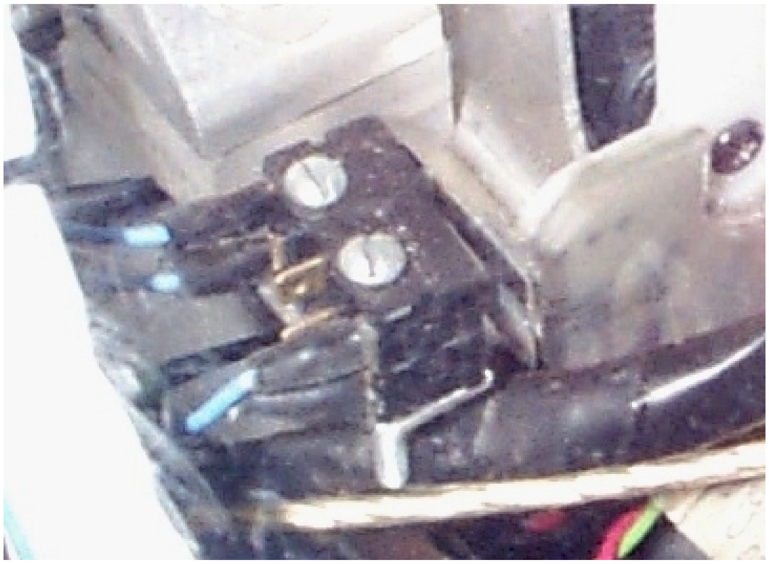
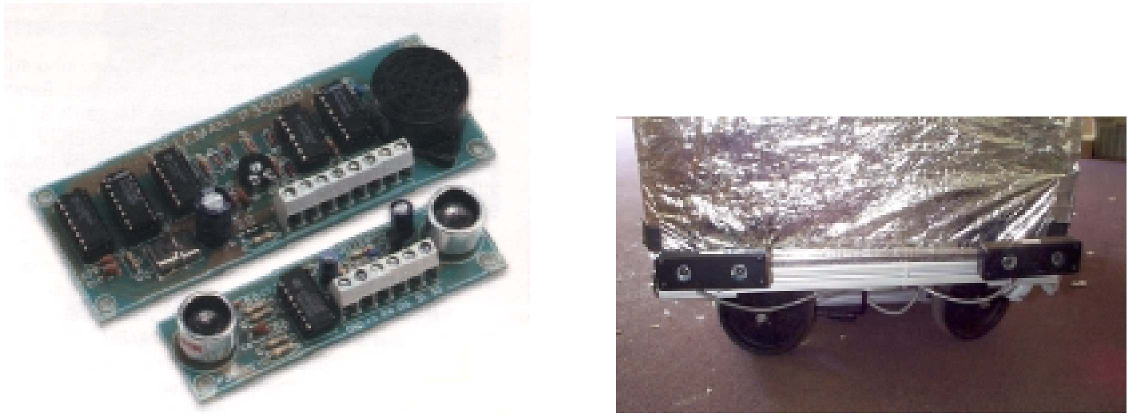


**Figure 2.16: (2) SPDT contact switches**


**Figure 2.17: Hitec Ranger II RF remote control transmitter, receiver, and actuator**

**Figure 2.18: Hamamatsu Light Modulation Photoreflector**



**a)** **b)**

**Figure 2.19: a) Velleman parking radar, b) Velleman parking radars in project boxes mounted onto FIDOE**

**Figure 2.20: CyDAS 1602 Data Acquisition board**


**Figure 2.21: Die Hard Deep Cycle/Marine battery**

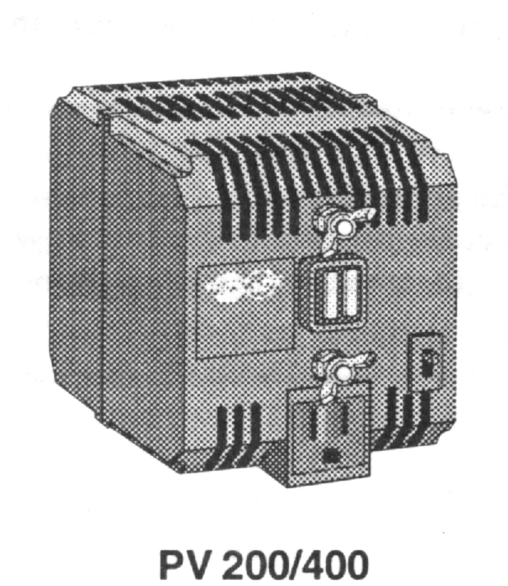



**Figure 2.22: Sketch of Tripplite PV400 Inverter**

# Chapter 3: FIDOE System Implementation

## 3.1 Overview

The following chapter discusses the FIDOE system topology conceived during first and second development phases. Specifically, this chapter discusses the system topology of the first development phase, Phase I, implemented by WPI. The results and modifications of this design phase are also discussed. Then, this chapter discusses the second development phase, Phase II, which represents a working prototype system developed by WPI and HSSSI. In detail, this chapter describes the top-level components layout of the defined components within the FIDOE system during the first and second development phases, including the 20 hour life support system, the geological tools, the thermal overgarments, the secondary PLSSs and SOP, and the communications and controls sub-systems. This chapter then focuses on the interfaces within the communications and controls sub-systems of the second development phase, specifically between the main computer system and the different inputs i.e., the information from the audio and video components, the obstacle avoidance sensors, and the tracking and locating sensors. Also, this chapter describes the interfaces between the main computer system and the different outputs i.e., the audio and video components, the voice command acknowledgements, and the motors and wheels sub-assembly within the second development phase.

## 3.2 Components Layout of FIDOE System (Phase I)

The FIDOE components can be divided into five main functional areas: 1) information inputs, 2) information outputs, 3) the information management system, 4) power supply systems, and 5) stowage equipment. The information inputs refer to COTS components that provide information about the external environment, such as audio and video information inputs, incoming obstacles, and EV crewmember position and distance. Specifically, these 'information input' components were:

**Video/Audio Information and Voice command**

- ♦ Pragmatic Communications Systems True View wireless color camera/audio system
- ♦ Pragmatic Communications Systems 900 MHz wireless A/V transmitter and receiver
- ♦ Dragon Dictate microphone headset
- ♦ Dragon Dictate signal amplifier

**EV crewmember tracking and searching**

- ♦ Dynasight sensor

**Short range obstacle avoidance sensors**

- ♦ Hamamatsu Light Modulation Pholoreflectors

**Long range obstacle avoidance sensors**

- ♦ Lasiris SNF-509L-670-30-F.A. laser line generators
- ♦ ImageNation frame grabber card
- ♦ ImageNation camera interface cable
- ♦ Pulnix TM7-CN Black and white CCD camera
- ♦ Cosmicar Lens with 88° horizontal field of view
- ♦ One inch diameter 665 nm Filter

The second functional area, information outputs, defines the COTS components that output information from the information management system. These types of outputs are in the form of video and audio information sent from the FIDOE system to the habitat or pressurized rover, voice command acknowledgements, and direction and velocity of the motorized wheels. The Phase I 'information output' components were:

**Video/Audio Information Outputs Voice command acknowledgements**

- Pragmatic Communications Systems 2.4 GHz wireless A/V transmitter and receiver

**Navigational components**

- 4QD motor controller cards
- HoverRound MPV4 motorize wheelchair
- Clare magnetic reed switches

The third functional area, the information management system, serves as the junction between the information inputs and outputs. In detail, the information management system comprised of the **Dell computer system**, the **Hauppauge WinMotion60 PCI card**, and the **two CyDAS 1602 DA boards**. The Dell computer system would utilize the Dragon Dictate and Visual C++ software to process the information inputs into information outputs.

The fourth functional area defines the power supply interfaces between COTS components that use the **Die Hard 12VDC Deep Cycle/Marine battery** and **Tripplite PV400 Inverter** and COTS components that use a dedicated power supply. The COTS components that were selected to utilize the Die Hard battery were the Dell computer system, the 2.4 GHz transmitter, the Dynasight sensor, and the short-range obstacle avoidance sensors. All other COTS components utilized their own power supply to provide power.

The fifth functional area refers to the LSS equipment, the thermal overgarments, the secondary PLSSs and SOP, and the geological equipment. These components are appropriately located in a separate area within FIDOE's chassis.

### *3.2.1 Results and Modifications based on Phase I efforts*

The PHASE I development stage reflected present technologies that are feasible and potential applications for a Mars EVA operation. During the PHASE I development stage, only a portion of the selected components were procured, simply because the cost of important individual components were relatively high. In detail, WPI rated the importance of the selected components and procured the components that were considered essential to the system, e.g., the Dell Computer system and the HoverRound MPV4 motorized wheelchair. Nonetheless, the technologies represented by the chosen COTS components met the project goals.

The Pragmatic Communications Systems components reflected the ability to utilize RF-methods for video communications with a robotic system. Specifically, the color camera, the 900 MHz transmitter and receiver, and the 2.4 GHz transmitter and receiver successfully demonstrated the ability to wirelessly transmit streaming video from the color camera’s transmitter to FIDOE’s on-board receiver. Furthermore, the Hauppauge WinMotion60 PCI card successfully captured the streaming video with no significant time delays.

However, the Pragmatic Communications Systems components did pose some limitations. The most significant limitation to this integrated subsystem was the large amount of CPU processing involved when attempting to display and save the streaming video onto the computer’s hard disk. This limitation prevented other processes, namely the retrieval and interpretation of EV crewmember tracking/searching information and obstacle avoidance sensor information, from performing in real-time. The video information also contained white noise, similar to the “snow effects” that one might see when watching RF-based channels on a TV. This was due to the sensitivity of the antennas of the 900 MHz transmitter and receiver. Another significant limitation of the color camera was the abnormally larger amounts of heat generated within the unit during its operation. This problem was due a manufacturing error within the camera’s circuit board. Consequently, the camera posed a hazardous problem and could not be mounted onto the Martian spacesuit. Additionally, the audio portion of the Pragmatic Communications Systems components did not meet the requirements of the project objectives. In detail, the audio signal was too weak to be recognized by the Dragon Dictate software as it entered into the Dell computer system, despite the use of the Dragon Dictate signal amplifier.

HSSSI replaced the Pragmatic Communications Systems color camera with a Sony Camcorder, which was mounted onto the FIDOE system. Consequently, the 900 MHz wireless transmitter and receiver were excluded. A tethered connection was used to transfer video information from the Sony camcorder to a dedicated Toshiba laptop system through the Nogatech PCMCIA Conference card. The addition of the Toshiba laptop to handle the video display and video storage reduced the CPU processing loads previously experienced by the Dell computer system.

Since the removal of the Pragmatic Communications Systems color camera, the 900 MHz transmitter, and 900 MHz receiver also eliminated the ability to transfer audio information from the EV crewmember to the FIDOE system, HSSSI implemented their 3Com Systems ClearCom audio transceivers and base station to provide this capability. Despite the component modification to the PHASE I development phase, the method of delivering audio communications, i.e., RF-methods is still represented in the FIDOE system.

The Dynasight sensor reflected the ability to utilize IR-methods for EV crewmember tracking and searching functionality. Although this method for determining the position and location is prone to dusty Martian environment, the fundamental techniques are assumed to be trilateration and phase comparison, respectively. At first, an RF-approach was considered to meeting this objective, but the search for these components revealed that the costs associated with the RF components were beyond the cost constraints and hence, were not procured. For example, most RF-components that could perform distance determination were designed for larger and more complex systems, i.e., aircraft systems. Also the costs associated with these systems were greater than $5000. An alternative option was to design a proprietary tracking and searching system using only simplistic components such as three remote controlled car transmitters and receivers or conventional walkie-talkies, but time constraints prevented WPI from pursuing this option.

The Dragon Dictate software demonstrated the ability to recognize voice commands and implement the corresponding tasks. Through proper voice training with the Dragon Dictate software, the FIDOE system was able to interpret the ‘follow’, ‘go’, ‘come’, ‘stay’, and ‘stop’ commands and send the appropriate direction and velocity information to the motorized wheels. More important, the speech recognition software demonstrated that this technology is a feasible application for a Martian EVA.

The integration of the HoverRound MPV4 motorized wheelchair, the 4QD motor controller cards, and the magnetic reed switches with the information-input components showed that this system had one major limitation; that feedback control was extremely difficult due to the large amount of electromagnetic interference (EMI) generated by the motors. In many instances, the magnetic reed switches would generate false counts and relay this information back to the information management system. This resulted in FIDOE travelling at the wrong speeds and the wrong distances. While the fundamental concepts behind this system are feasible for a Martian EVA scenario, HSSSI sought to alleviate this problem by replacing the magnetic reed switches with the SCAN-O-MATIC optical relay switches. These optical relay switches were less prone to EMI generated by the motorized wheelchairs.

Due to cost constraints, the long-range obstacle avoidance components were not procured. Although the light striping technique was successfully used on the Mars Sojourner robot and hence, this technique is a feasible option.[8] In an effort to demonstrate the fundamental aspect of obstacle avoidance integration with the navigational control system, WPI incorporated five Velleman ultrasonic sensors into the FIDOE system. Despite the fact that ultrasonic methods

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[8] http://jpl.robotics.nasa.gov/tasks/scirover/factsheet/homepage.html: “Mars Rover Fact Sheet”.

are most likely inefficient in the thin Martian atmosphere, WPI chose these components because 1) the components provided a longer range of detection compared to the Hamamatsu IR-sensors, 2) the components were cost efficient (>$50), and 3) the components were readily available.

**3.3 Components Layout of FIDOE System (Phase II)**

The FIDOE component topology follows the same structural interface as first development phase, with the exception that Phase II components are utilized. The alternative COTS components separate video information inputs from the audio information inputs. The video information inputs were sent from the Sony Camcorder video camera. The audio information input was handled by the ClearCom audio transceiver (see Figure 3.2). In addition, WPI included the remote controlled kill switch's receiver. This COTS component also receives information from the external environment, i.e., the user-controlled transmitter, in the form of an RF signal although this type of information is unique in that it is not processed by the main computer system.

In the second functional area, information outputs, the video and audio information are also separated into two sets of components. While the 2.4GHz transmitter is still used to send out video information, the Phase II COTS component that sends out the audio information to the habitat is the ClearCom audio transceiver.

In the third functional area, the Toshiba laptop and the Nogatech PCMCIA Conference Card were added to the information management system. The Dell computer system utilizes the Dragon Dictate and LabView programs to process the information inputs into information outputs.

The fourth functional area was altered such that dedicated power supplies are added to the Sony Camcorder, the Toshiba laptop, and the ClearCom transceivers. Figure 3.2 distinguishes the components that used a dedicated power supply by representing these components with a 'Batt' icon box.

## 3.4 Phase II FIDOE inputs within the Communications and Control subsystems

The following subsections describe the first functional area in greater detail. In particular, the interfaces between the video and audio information inputs, including the voice command inputs, as well as the inputs from the Dynasight sensor and the obstacle avoidance sensors to the FIDOE information management system are defined.

### *3.4.1 Video information inputs*

The video information from the Sony camcorder is transferred to the FIDOE system via RCA cabled connections (see Figure 3.3). Specifically, the Sony camcorder sends out NTSC video signals through an RCA cable connection from its video output RCA jack to the 2.4 GHz transmitter. A 2-to-1 RCA plug adapter is attached to the 2.4 GHz transmitter's video input RCA jack, which allows incoming video signals to be transmitted to the habitat and simultaneously redirected to a storage database within the Toshiba laptop. The Nogatech Conference Card receives the NTSC video signal through its RCA-to-PCMCIA card and digitizes the signal. The video signal is then displayed on the laptop's monitor. The video signal can also be manually saved onto the hard disk using the conference card's propriety software.

### *3.4.2 Audio information inputs*

The EV crewmember's voice is the primary source of audio information input. Initially, the EV crewmember speaks into his microphone headset that is tethered to a duplicate ClearCom transceiver (ClearCom#2). The transceiver transmits the audio signal via radio frequency to the base station, which, for purposes of the demonstration, is located at the habitat. The base station receives the audio signal, amplifies it, and retransmits it to the FIDOE system's ClearCom transceiver (ClearCom#4). Once the audio signal is received, the ClearCom transceiver sends the audio signal to the Dragon Dictate signal amplifier (see Figure 3.3). Specifically, the ClearCom transceiver outputs the audio signal from its XLR connector to the signal amplifier/filter's 1/8-

inch stereo plug via a tethered connection. Then the signal amplifier/filter sends out the audio signal to the main computer system's microphone input jack.

### *3.4.3 Voice command inputs*

The FIDOE system receives the five voice commands through the same audio connection mentioned above. In addition to this audio transfer, the voice commands are processed through the Dragon Dictate software within the main computer system.

Prior to using Dragon Dictate software, the user must complete a training mode. Once this training mode is complete, the Dragon Dictate software can be configured to continuously 'listen' to the EV crewmember's speech and search for phrases that resemble the voice commands. The Dragon Dictate can distinguish the voice commands from normal speech conversation by listening for a 2 – 3 second pause prior to the invoked command. Once Dragon Dictate identifies a voice command, it runs an associated macro rule, which then initiates a process within the main program . Specifically, each macro rule opens a text file (fidoe.txt), enters the spoken voice command into the file, e.g., 'come', 'follow', or 'left 9', and saves it to a location on the hard drive. The main program immediately checks the text file for the most recent command and performs the associated processes until another command is saved into the file. Since it is unlikely that the EV crewmember will be issuing two or more commands simultaneously, only one text file is used by all voice commands.

### *3.4.4 Tracking and searching information inputs*

The Dynasight sensor provides the main program position and distance information by sending out the EV crewmember's X, Y, and Z coordinates in streaming packetized data. The axis of orientation is such that the positive X is in the right direction, the positive Y is in the upward direction, and the positive Z is in the outward direction. These coordinates are sent to the computer system via an RS-232 interface using two DB-9 connectors (see Figure 3.4). The coordinates are updated every 1/3 second (~30 Hz) and passed through at a data rate of 19,200 baud.

Upon initial start-up, the Dynasight sensor reports a target value of X=0, Y=0, and Z=1 meter.[9] Then the Dynasight sensor begins to search for the retroreflective target within its limited 75° azimuth × 75° elevation conical field-of-view until it acquires and tracks the target. The Dynasight sensor performs this task by ‘following’ the object that returns the highest intensity of its emitted signal. In the event that the target is lost, either because the EV crewmember walked behind a rock or walked around a corner, the Dynasight sensor reports the last good measurement value until the target is re-acquired. Meanwhile, the Dynasight sensor begins a focussed search around the last good measurement and continues to propagate its search until the target is found. The last good measurement is still reported if the target is not found.

Once the main computer system receives the information, the main program extracts the X and Z coordinates and discards the Y coordinates. The Y coordinates are discarded because the EV crewmember is not expected to climb up or down during the demonstration.

### *3.4.5 Short range obstacle avoidance information inputs*

The IR and ultrasonic sensors provide FIDOE’s main computer system information on the presence (or absence) of an incoming obstacle. The outputs from the IR and ultrasonic sensors are in form of a digital and analog signal, respectively. The IR sensors send out a 5 volt TTL-level signal while the ultrasonic sensors send out a 0 – 12 volts signal. Since the CyDAS DA boards accept only 0 – 5 VDC, ± 5VDC, and 0 – 10 VDC signals, it was decided to step down the

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[9] The original purpose of the Dynasight sensor is to assist computer users in three-dimensional visualization. Hence, the “Z=1 meter” value is based on the distance between the user’s head and the monitor.

ultrasonic sensors' signals to ± 5 VDC. The IR and ultrasonic sensors apply the 5V signals to the CyDAS 1602 DA boards through a direct connection to the boards' 37 pin 'D' connectors.

The IR sensors operate as a Normally Open optical switch, sending out a constant IR beam to the environment. Once an object is in front of the sensor (approximately six inches or less), the IR beam reflects back to the sensor's IR detector and closes the switch. The closed switch sends a 5 volt TTL-level signal to the main computer system's CyDAS 1602 DA boards.

The ultrasonic sensors function in the same manner as the IR sensors with the exception that the detection distance is approximately four feet and the field-of-view is 10° azimuth × 10° elevation. When an object is within the detection range, the ultrasonic sensor will send out a 12V analog signal. The 12V analog signal passes through a voltage divider that steps down the voltage to ± 5VDC. Then the ± 5VDC analog signal enters into the CyDAS 1602 DA board (Figures 3.5 and 3.6).

When the main program initiates the obstacle avoidance routine, it 'pulls in' the IR and ultrasonic information from the CyDAS DA boards. When the FIDOE system is moving forward, the main program first checks the middle front sensor for an obstacle. If an obstacle is not directly in front of its path, FIDOE will continue to move forward. If an obstacle is detected by the middle ultrasonic sensor, FIDOE will default to turn right. While turning right, the information management system obtains the front right IR sensor's information to determine if an obstacle its in its side sweep turn. If an obstacle is not detected, the FIDOE system will continue to turn 45°, move forward three feet, turn back 45° to the left, and move on. If an obstacle is detected, the FIDOE system turns to the left 90° and checks the front left IR sensor. If an obstacle is detected during this turn, the FIDOE system returns to its original position and goes into a 'standby' or pause mode.

## 3.5 PHASE II FIDOE outputs within the Communications and Control subsystems

The following subsections describe the second functional area. These subsections specifically describe the hardware and software interfaces between the video/audio communications subsystem and the information management system. Also, the interfaces between the information management system and the motor control subsystem are described.

### *3.5.1 Video information transfer to the habitat*

The video information sent from the Sony Camcorder uses the same interface to the 2.4GHz transmitter as described in subsection 3.3.1. Once the 2.4GHz transmitter receives the video information, it is sent wirelessly to the 2.4GHz receiver, located at the habitat. The receiver outputs the signal to a TV through a tethered connection, using an RCA cable (Figure 3.3).

### *3.5.2 Audio information transfer to the habitat*

As mentioned in subsection 3.3.2, the EV crewmember's voice is wirelessly transmitted to the 3Com Systems base station. Originally, the base station was located on the FIDOE system and could send the incoming audio signals to the habitat. Unfortunately, the size limitations imposed by FIDOE's dimensions forced the base station to be relocated to the habitat.

### *3.5.3 Voice command responses*

The FIDOE system's main program sends out a specific voice command acknowledgement immediately after receiving a voice command from the EV crewmember. Specifically, the main program calls a specific audio file (.wav format) that corresponds to the input voice command and outputs it to the computer system's audio output port. A tethered connection from the audio output port to the ClearCom's XLR connector allows the voice command acknowledgements to be wirelessly transferred back to the base station and ultimately to the EV crewmember.

The corresponding voice command acknowledgements are:

| FIDOE commands as stated by the EV crewmember | FIDOE Command Acknowledgements |
|---|---|
| FIDOE Command follow. | Command, follow, acknowledged. |
| FIDOE Command come. | Command, come, acknowledged. |
| FIDOE Command go forward/back/left/right (X). | Command, go forward/back/left/right, acknowledged. |
| FIDOE Command stay. | Command, stay, acknowledged. |
| FIDOE Command stop. | Command, stop, acknowledged. |

**Table 3.1: Voice command acknowledgements**

### *3.5.4 Motor Control sub-system interfaces*

The motor-control subsystem relays processed information transferred from the information management system to the motor controller cards and ultimately to the motors. The processed information pertains to information obtained from the Dynasight sensor, the voice command text file, and the obstacle avoidance sensors. Specifically, the main program gathers the EV crewmember's current position and distance data, the most current command in the voice command text file, and the voltage values for the IR and ultrasonic sensors.

Each CyDAS 1602 DA boards sends out a set of speed and direction values via hardwired connections to its corresponding 4QD motor controller card in the form of a 0/5 VDC signal for direction and a 0-5VDC signal for speed (see Figure 3.7). The forward direction for each wheel is represented as 0 VDC while the reverse direction is represented as 5 VDC. The maximum speed on each wheel is represented as 5 VDC and can decrease in increments of 0.01 VDC to a complete stop at 0 VDC.

Upon receiving the 0 – 5V speed voltage values, the 4QD motor controller cards re-scale the speed voltage range to 0-12 VDC. The motor controllers send the speed voltages to the motors via a hardwired connection.

### 3.5.4.1 Feedback control

In order to properly synchronize the speed and direction of the wheels to the EV crewmember's motion, HSSSI replaced the magnetic reed switches with optical relays switches to the feedback control loop subsystem. In detail, an optical relay switch was mounted onto the motor frame along with a cardboard disc displaying alternating black and white 'pies', which was mounted onto the inside face of the wheel (see Figure 3.8). A total of 40 white and 40 black pies were displayed on each cardboard disc, where each black and white pie pair was a 9° increment angle on the disc.

The optical switches are directly connected to the main computer's CyDAS 1602 DA boards. Each optical switch is connected specifically to a DA board's input counter port and constant 5VDC output port. The optical switches operate using the same principle as the IR obstacle avoidance sensors; when the white pie is in front of the optical sensor, the optical sensor's IR beam reflects back and closes the switch. The closed switch completes the circuit and the DA board receives a count. As the wheels turn, the main program can determine the number of revolutions and derive the speed of the EV crewmember based on the number of counts.

### 3.5.4.2 Remote controlled kill switch

In line with the DA boards' hardwired connection to the motor controller cards is the remote controlled 'kill switch'. The 'kill switch', or Normally-Open SPDT contact switches, is connected in-line with the wires that output the motor speed values. As a result, leaving the kill switch open will open the circuit and prevent the motors from turning.

The kill switch closes and opens via a rotational arm on the remote controlled actuator (Figure 3.9). The arm is positioned to open the circuit when the actuator arm receives the RF signal from the remote controlled transmitter.

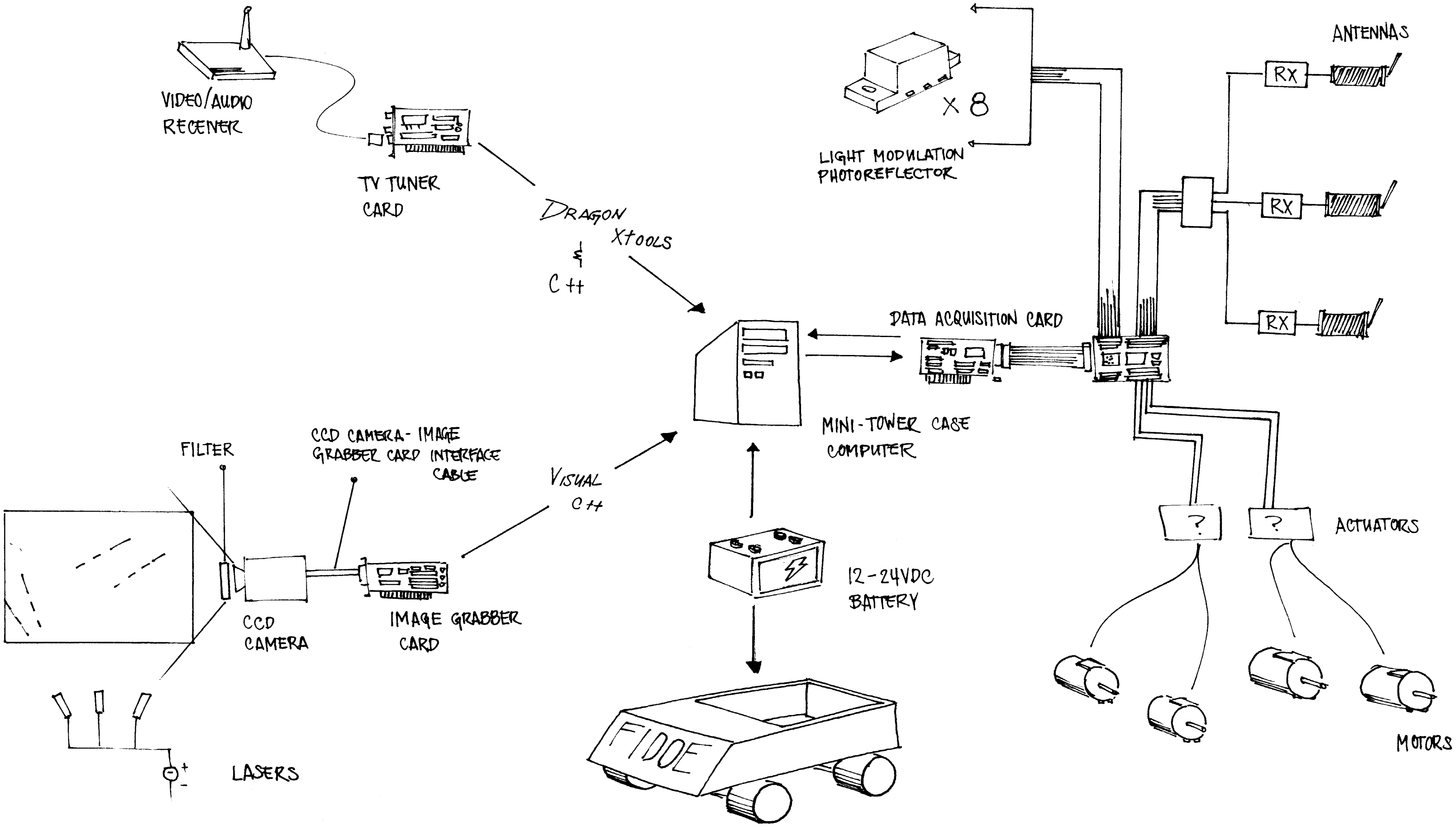


**Figure 3.1: PHASE I topology of FIDOE Communications and Controls system**

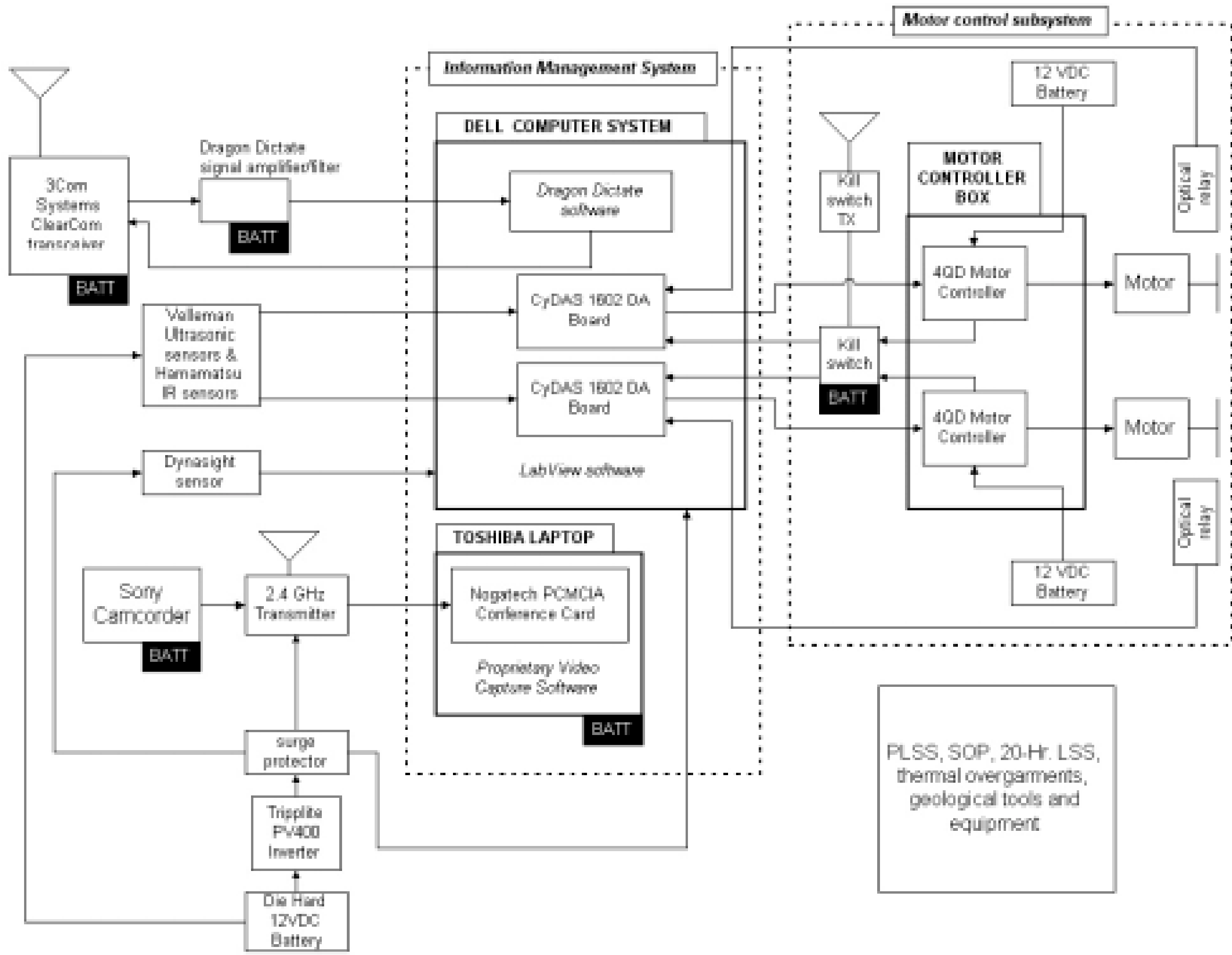


**Figure 3.2: PHASE II topology of FIDOE Communications and Controls system**

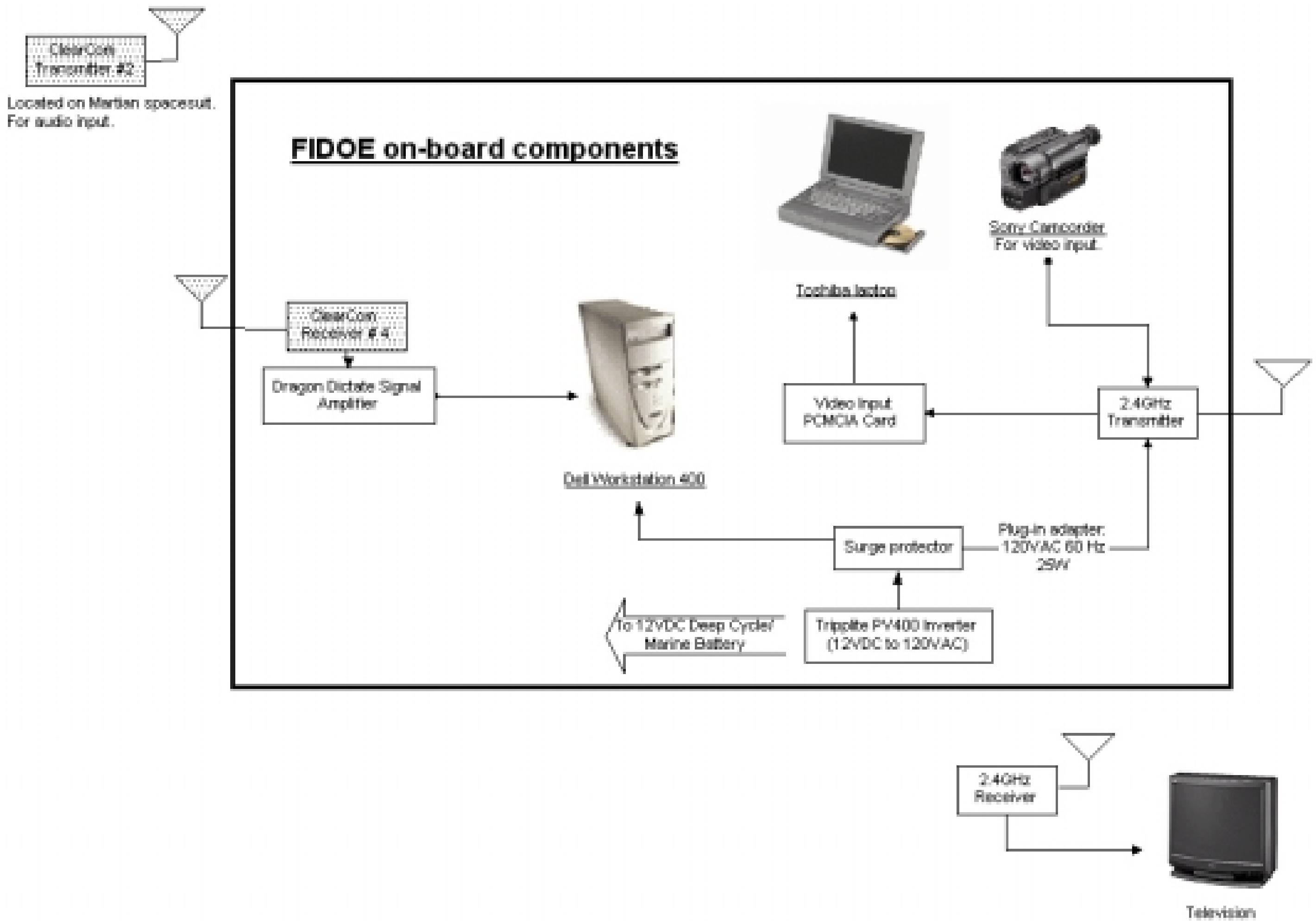


**Figure 3.3: Schematic diagram of video/audio communications subsystem**

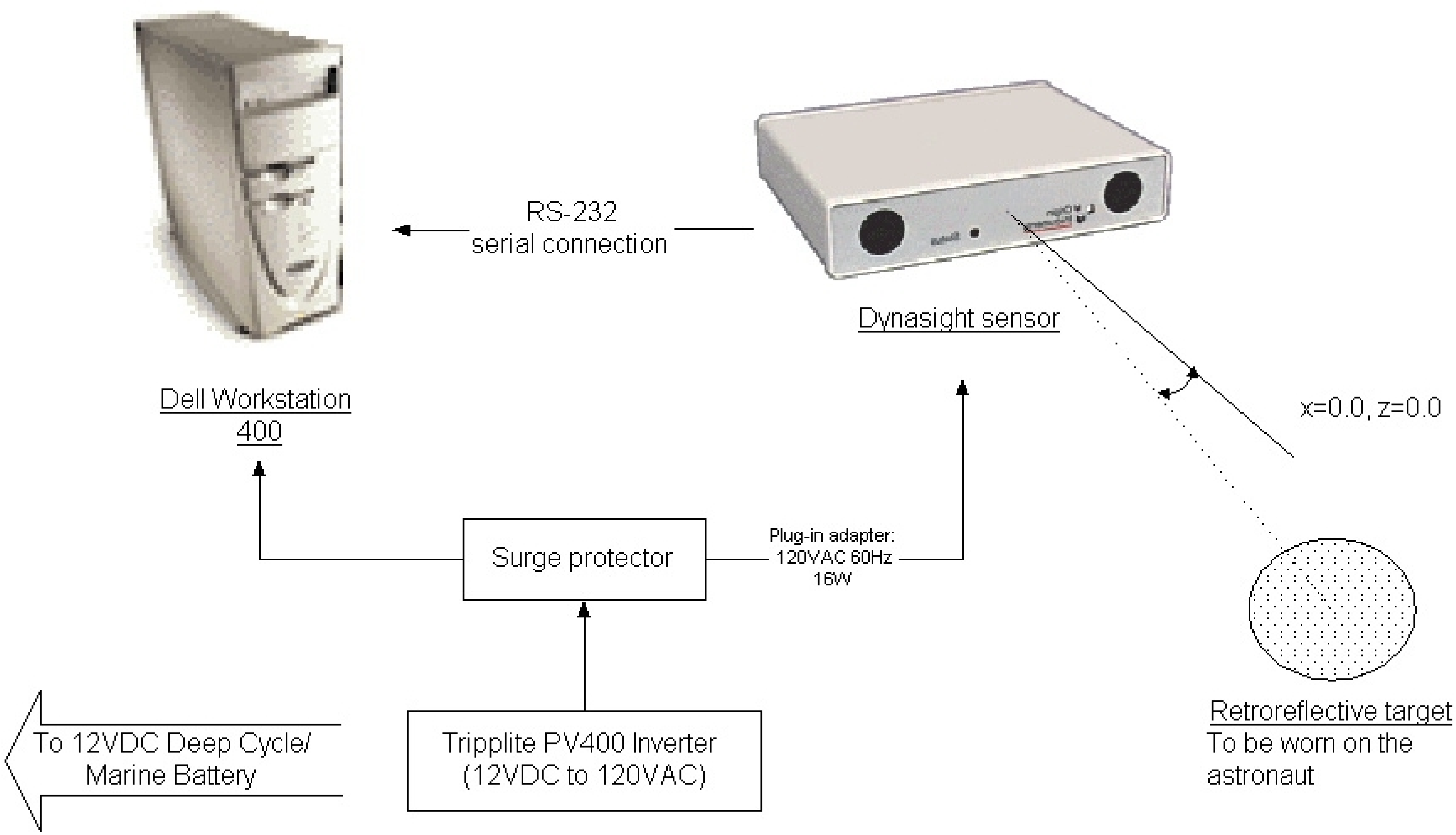


**Figure 3.4: Schematic diagram of tracking and searching subsystem**

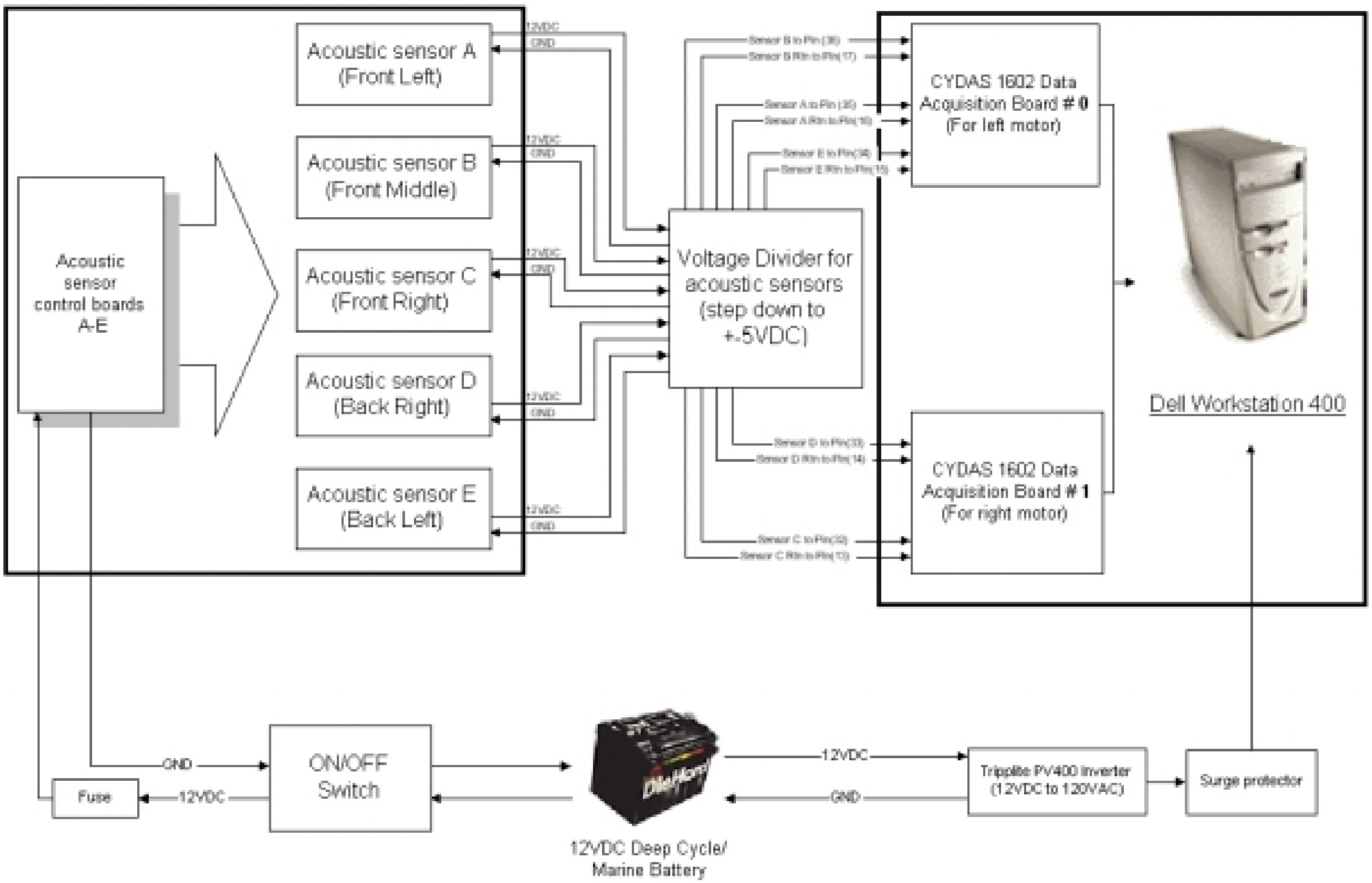


**Figure 3.5: Schematic diagram of analog obstacle avoidance subsystem inputs**

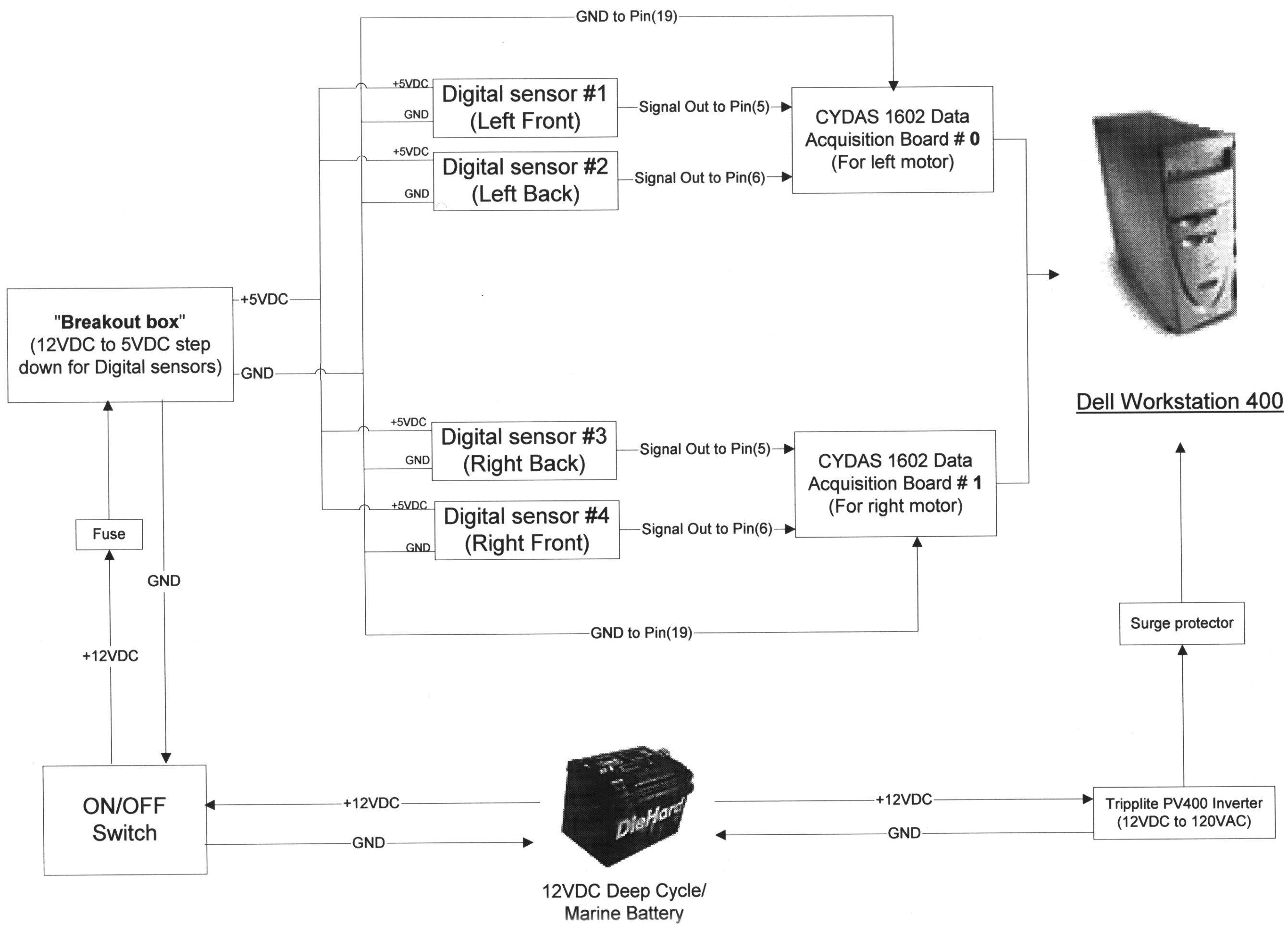


**Figure 3.6: Schematic diagram of digital obstacle avoidance subsystem inputs**

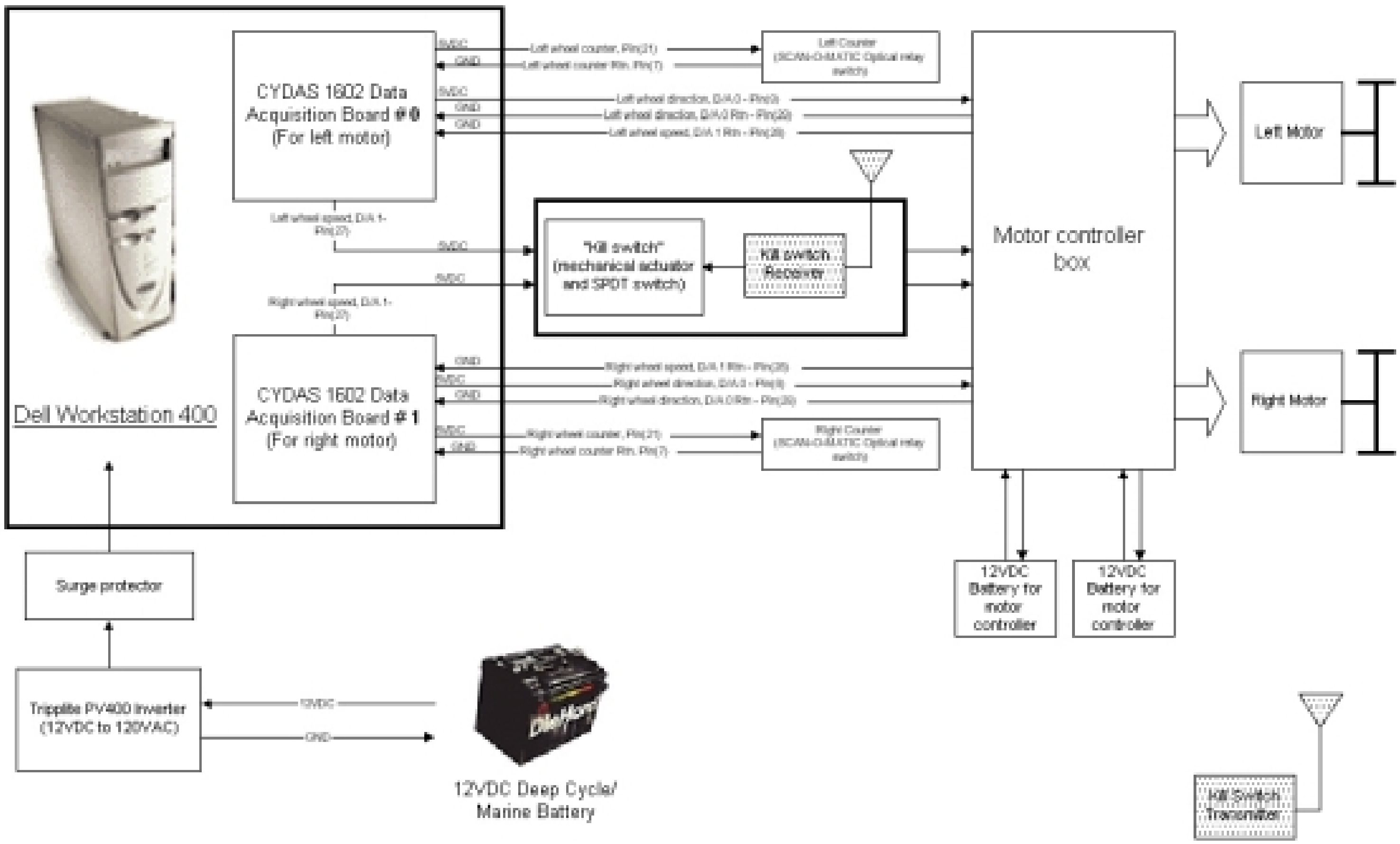


Figure 3.7: Schematic diagram of motor controller subsystem

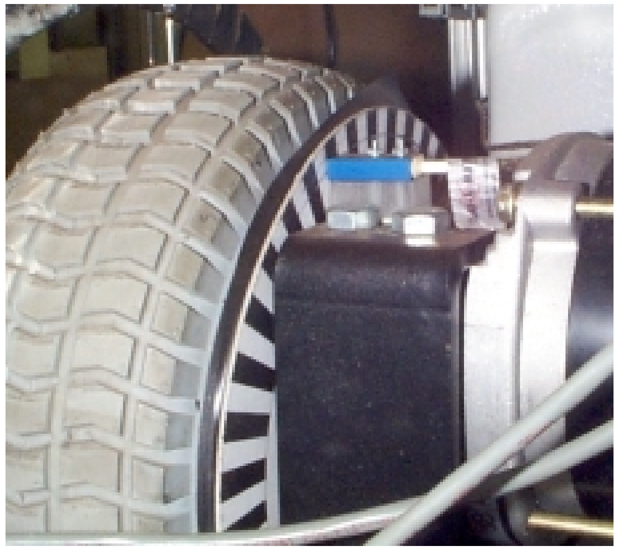

**Figure 3.8: Feedback control subsystem**

**Figure 3.9: Kill switch subsystem**

# Chapter 4: Results

## 4.1 Overview

The focus of this chapter is to present and discuss the FIDOE system's accomplishments and limitations based on the design and development methods used. Furthermore, this chapter discusses whether the fundamental concepts demonstrated within the FIDOE system could be integrated to produce a feasible system for a Mars EVA scenario. The factors that determine the FIDOE system's feasibility as an integrated system are its ability to integrate with the life support systems equipment, its ability to handle the required payloads and size parameters, its ability to perform communication and control functions, and its ability to manage power.

## 4.2 Integration with Life Support Equipment

The FIDOE system provided a stowage area that is approximately 33 ¼ in. (L) × 24 in. (W) × 21 in. (H). The stowage area carried the EV crewmember's thermal overgarments and the on-board LSS, and geological equipment. The EV crewmember can gather the thermal overgarments and geological equipment by swinging the top panel of the stowage area (Figure 4.1).

## 4.3. FIDOE System Payloads and Size Parameters

The FIDOE system currently stows the following items within a 24 $ft.^3$ volume (51 in. (L) ×27 in. (W) × 30 in. (H)). This volume contains the information management systems equipment, video/audio communications equipment, tracking and searching equipment, obstacle avoidance equipment, motor control sub-assemblies, power management equipment, stowage space for the thermal overgarments, the on-board LSS equipment, and geological equipment and tools. Approximately 35% of the total volume was allocated to the stowed life support systems i.e., the on-board LSS and thermal overgarments while the remaining 65% were allocated to all other sub-systems. The secondary PLSSs were stowed on top of the FIDOE unit. The total weight of the FIDOE system, not including the secondary PLSS, was approximately 445 lbs. A breakdown of these components' volumes and weights are shown in Appendix A.

## 4.4 FIDOE Communications and Control Systems

The following sections below describe the benefits and limitations of the Phase II communication and controls sub-systems in detail. The results described below are based on qualitative data gathered during preliminary testing and the NASA demonstration test.

### *4.4.1 Video Communications between EV crewmember, FIDOE, and the habitat*

The FIDOE system was capable of transferring video information from the Sony Camcorder to the habitat and the Toshiba laptop. Specifically, the Nogatech PCMCIA Conference Card was capable of transferring the video images from the Sony Camcorder to the Toshiba laptop without any noticeable lag time. There was also no noticeable lag time between the video images from the Sony Camcorder and the images displayed at the habitat's TV set. These observations were based on a qualitative comparison between the Sony Camcorder's miniature LED display, the laptop, and TV set.

A major limitation of the video communications subsystem was that the Sony Camcorder required a videotape to record and send video data. This design characteristic resulted in additional set-up procedures during system start-up. Additionally, the functionality of the video communications subsystem was dependent on the battery life of the Sony Camcorder, thus requiring a routine recharge after every preliminary testing. The 2.4 GHz transmitter also proved to be a concern mainly because the transmitter displayed occasional break-ups in the video transfer; this was due to a poor power connector selected by the manufacturer.

### *4.4.2 Audio Communications between EV crewmember and the FIDOE system*

The audio communications system was able to transfer the EV crewmember's speech to the habitat and the FIDOE system. The base station provided an audible signal at distances greater than the dimensions of the demonstration area. Additionally, the Dragon Dictate signal amplifier somewhat 'refined' the input signal to the main computer system and thus reduced the inherent fan noise associated with the Martian spacesuit.

A major limitation to the audio communication system setup is that the audio information transfer between the EV crewmember and the FIDOE system requires using the base station. This configuration ultimately limits the travel distance between the EV crewmember and the habitat. Another limitation to the audio communications configuration is the inability to record the audio information into the main computer system. This is due to the computer system's inability to simultaneously use multiple sound-dependent software programs. Specifically, the computer system's operating environment prohibited the use of the 'Sound Recorder' program while processing the audio input with the Dragon Dictate program.

### *4.4.3 Voice Command and Control function using Dragon Dictate Hardware and Software*

Despite the audio communication system's limitations discussed in the previous section, the voice command and control function was able to operate under these conditions. Specifically, the FIDOE system was able to distinguish voice commands from the EV crewmember's normal speech under the predefined conditions stated in subsection 3.3.3. Voice command responses were also functional; the delay times between the voice command and the command response were within 2 – 3 seconds. Although this delay increased whenever the Dragon Dictate program intermittently refreshed its allocated cache.

During the Phase II development stage, it was decided to expand the list of voice commands. The additional voice commands and voice command acknowledgements were:

| Voice commands | FIDOE Command Acknowledgements |
|---|---|
| FIDOE Command heel | Command, heel, acknowledged |
| FIDOE Command engage collision | Command, engage collision, acknowledged |
| FIDOE Command override collision | Command, override collision, acknowledged |
| FIDOE Command go to sleep | Going to sleep |
| FIDOE Command wake up | Waiting for next command |

**Table 4.1: Additional FIDOE voice commands and their voice command responses**

These voice commands were added to the FIDOE system in order to give the EV crewmember more control. The “HEEL” command allowed the EV crewmember to maintain closer distances between himself and FIDOE when traversing through more complicated pathways. The “ENGAGE COLLISION”/ “OVERRIDE COLLISION” commands allowed the EV crewmember to enable or disable the obstacle avoidance sensors. This capability allowed the FIDOE system to traverse through mild pathways without having to continually process needless obstacle avoidance information. The “GO TO SLEEP” and “WAKE UP” commands allowed the EV crewmember to converse with other crewmembers without having FIDOE mistakenly interpret a voice command. Normally, these voice commands would be used during initial start-up and shut down of the FIDOE system. A summary of these voice commands is shown in Table 4.2.

| FIDOE COMMAND | FUNCTION | TRACKING ENABLED? (Y/N) |
|---|---|---|
| HEEL | Maintain a distance of 6 ± 1 foot between EV crewmember and FIDOE. | YES |
| ENGAGE COLLISION | Activate obstacle avoidance sensors. | YES/NO |
| OVERRIDE COLLISION | De-activate obstacle avoidance sensors | YES/NO |
| GO TO SLEEP | De-activate Dragon Dictate's command recognition function and 'stop' FIDOE. | NO |
| WAKE UP | Activate Dragon Dictate's command recognition function. | NO |

**Table 4.2 Additional voice command functions**

A major setback to the voice command and control function was the need to compensate for the inherent noise in the audio communications pathway. This required manipulating the sound volume level of every audio component. Specifically, the sound volume level was first adjusted at the EV crewmember's ClearCom transceiver, followed by adjusting the volume level at the base station, and then to the ClearCom transceiver on the FIDOE unit. Once the audio signal's input volume entered the computer system, further adjustments were performed on the main computer system through the operating system's volume control panel.

#### *4.4.4 Tracking and Searching function using the Dynasight sensor*

The Dynasight sensor and the software algorithm used to interpret the EV crewmember's current position and distance performed well during the preliminary testing phases and during the demonstration. Despite the limitations associated with IR technology for use on a Mars EVA operation, the Dynasight sensor proved to be very effective in this task.

The major benefits of the Dynasight sensor was its ability to retrieve the current Cartesian coordinates approximately every 1/3 second and its ability to quickly search and re-acquire its target within its field-of-view. Another benefit was the target's distinctive retro-reflective characteristics, which enabled the Dynasight sensor's detector to search for a specific range of intensity levels.

Unfortunately, the Dynasight sensor is limited to a 75° azimuth × 75° elevation, conical field-of-view. This predefined search space requires that the FIDOE system physically rotate about its center axis in order to increase size of the search space. In the demonstration, the FIDOE system rotated 45° to the right, 90° to the left, and back 45° to the right. Initially though, the angles were set to 90°/180°/90°. Yet this wide angled search was deemed unnecessary due to the excess amount of time taken to complete the search.

#### *4.4.5 Navigational functions using a motorized wheel chair and 4QD motor controller cards*

The motorized wheel chair and the 4QD motor controller cards proved to be a sufficient integrated subsystem for navigating in unknown surroundings. During the demonstration test, the FIDOE system was able to maintain the same speeds as the EV crewmember. Also, in situations where the EV crewmember turned slightly left or right, the FIDOE system was able to change its direction accordingly. Another benefit of this navigational system is its ability to traverse with a full payload.

One limitation was that the performance characteristics of the motors were not equal to each other. In particular, the same input speed voltages to each motor produced a different speed. This difference required calibrating the voltages of each motor to obtain the same maximum and minimum speed values. While this crude method assumes that the voltage range of each motor is characterized as a linear function, this design strategy was sufficient for the task.

#### *4.4.6 Short Range Obstacle avoidance function using Velleman ultrasonic sensors and Hamamatsu IR sensors*

The obstacle avoidance sensors used performed the minimal functional requirements during the demonstration test. In detail, the Velleman ultrasonic sensors were able to detect objects that were directly in its field of view at distances of up to three feet and the Hamamatsu IR sensors were able to detect obstacles that were in its line-of-sight at distances of up to six inches.

While these obstacle avoidance sensors provided the minimal functional requirements for the demonstration test, numerous limitations were evident. For instance, both types of sensors required that the obstacle had a flat surface, which was perpendicular to its line of detection. This required that the obstacles have flat surfaces and be positioned in a specific orientation. These two requirements are unfeasible due to the nature of the Martian rocks. Another limitation associated with the IR sensors is that the obstacles must possess a high degree of reflectivity, which is another unfeasible requirement. Also, the limited number of obstacle avoidance sensors created gaps within the detection range large enough for sizable obstacles (9 – 11 in. wide) to pass through and potentially collide with the FIDOE system. An alternative design strategy to alleviate this limitation would be to include additional sensors around the FIDOE system's perimeter. Yet, due to the high costs associated with this procurement, this design strategy was disregarded.

#### *4.4.7 Information management systems interface using Dell computer and CyDAS DA boards*

The Dell computer system and CyDAS DA boards were able to transfer input information to the motor controller subsystem in real time during the demonstration tests. Also, the Dell computer system was able to simultaneously perform the voice command processes from the Dragon Dictate software with the navigational processes from the LabView software without any noticeable lag times. Despite the inherent instability issues associated with the computer system's operating environment, no significant problems i.e., a system failure, occurred during the demonstration test.

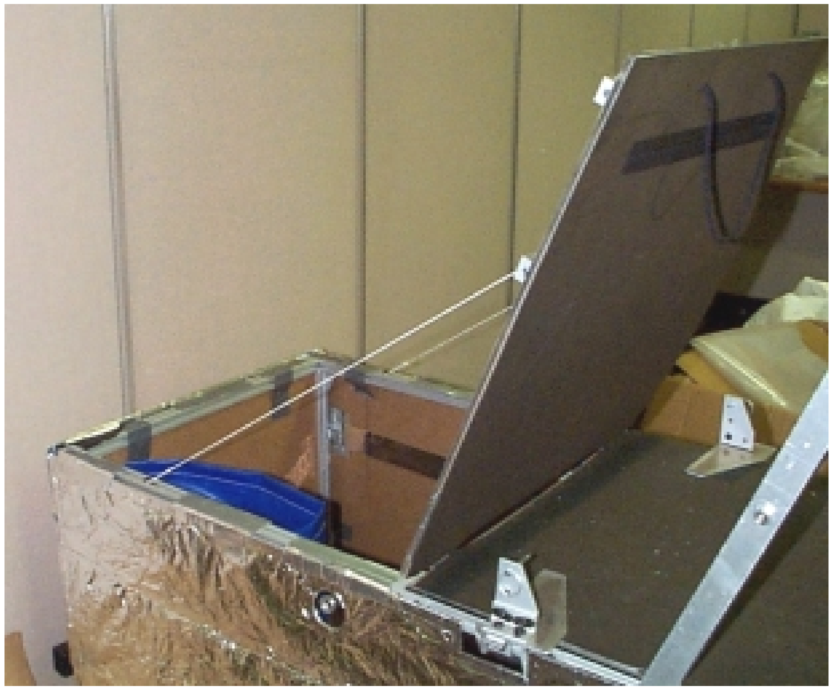

**Figure 4.1: Open hatch of FIDOE's stowage area**

# Chapter 5: Conclusions and Recommendations

## 5.1 Further Work

Based on the results, it is evident that the FIDOE system is able to perform all the required functions to a minimal degree. However, a number of critical issues need to be addressed prior to developing further iterations of the FIDOE system. Specifically, further work towards this effort needs to address video/audio information recording, voice command functionality and robustness, RF-based tracking and searching functionality, and navigational and obstacle avoidance control in rugged terrain. Also, the issue of information management robustness and power supply management must be addressed.

Robust video information recording requires a video capture card and computer system capable of transferring large amounts of data from the video camera and allocating the data to a storage database. Specifically, the video capture card and computer system must be able to capture video at rates of up to 30 frames/sec (typical NTSC video format), digitize and compress the video, and store the digitized information into the hard disk. If the recorded information were to be transmitted to the habitat, the digitized information must be decompressed and sent out to the video transmitter. A typical size for an uncompressed 10 second video file (using a Microsoft AVI format) is approximately 8-10 Mb of hard disk space, implying that one minute of uncompressed video data can occupy as much as 60 Mb of hard disk space. Compression techniques can substantially reduce the size although the quality of the video is sacrificed. Methods to improve video capture and recording include increasing the computer system's RAM and hard disk speed.

Audio information recording can be achieved simultaneously with video information recording if the video camera can record audio information. It is not necessary for the video capture card to record the audio information. In fact, it may be beneficial to segregate the video signals from the audio signals in order to reduce CPU processing time as was proven in the Phase II FIDOE system.

Speech recognition technology still requires further research and development before applying it to a Martian EVA scenario. Critical issues such as the level of dependency towards voice command interaction and the degree of tolerance against background noise must be addressed prior to extending the application. Currently, tests and evaluations are being conducted to determine the degree of accuracy in recognizing voice commands with the Dragon Dictate system.

Tracking and searching functionality via RF technology is feasible with today's technology, although the cost of implementing a robust system to the current FIDOE system would have violated the cost constraints. Although it is expected that future improvements to RF based positioning and distance measuring devices will lower the cost of current devices.

Robust navigational control and obstacle avoidance techniques that are capable of meeting the Martian environmental conditions is also feasible with today's technology, given the sufficient resources.[8][9][10] Although, one issue that must be addressed in implementing the long-range obstacle avoidance technique is how to discriminate the EV crewmember from surrounding obstacles.

## 5.2 Conclusions

The proof-of-concept FIDOE system was able to demonstrate key technologies during the demonstration test. Specifically, the proof-of concept FIDOE system was able to demonstrate the integration of video and audio communication systems on a semi-autonomous robotic support cart, voice command and control of robotic elements, real time tracking and searching capabilities, simplistic navigational control, simplistic obstacle avoidance algorithms, and life support assistance capabilities.

More important, the proof-of-concept FIDOE system addressed key issues concerning its use as an assisted life support system and equipment stowage cart and the feasibility of voice command and control in an EVA scenario. The proof-of-concept system also addressed the need for a robust video and audio communications system, navigational control system, and an obstacle avoidance algorithm.

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# Appendix A: Volumes and Weights of FIDOE system components

| ITEM | DIMENSIONS (L×W×H) | WEIGHT (lbs.) |
|---|---|---|
| *Information Management Systems* | | |
| Dell computer system w/ (2) CyDAS 1602 Boards | 21” × 8” × 17 ¾” | 31 lbs. |
| Toshiba Laptop w/ Nogatech PCMCIA Conference Card | 12” ×9 ½” × 2” | 7 lbs. |
| *Video/Audio Communications Equipment* | | |
| Sony Camcorder | 7 ½” × 4 ¼” × 4 ¼” | ~2 lbs. |
| Pragmatic Communications Systems 2.4 GHz transmitter | 8” × 3 ½” × 2” | ~1 lb. |
| 3Com Systems ClearCom transceiver | 6” × 4” × 1 ½” | ~2 lbs |
| Dragon Dictate signal amplifier/filter | 3” × 1 ¼” × ¾” | $^{1}/_{3}$ lb. |
| Associated cables and connectors | -N/A- | 1 ½ lbs. |
| *Tracking and Searching Equipment* | | |
| Dynasight sensor w/ RS 232 cable | 7 $^{1}/_{3}$” × 5 ¾” × 1 ½” | 3 lbs. |
| *Obstacle Avoidance Equipment* | | |
| (5) Velleman ultrasonic sensors | 6” × 2” × ¾” | ~1.5 lbs. |
| (4) Hamamatsu IR sensors | 1 $^{1}/_{3}$” × $^{2}/_{5}$” × $^{1}/_{5}$” per sensor | -N/A- |
| Associated cables and connectors | -N/A- | -N/A- |
| *Chassis and Drive-train sub-assy.* | | |
| 80/20 Aluminum and steel chassis | -N/A- | ~180 lbs. |
| HoverRound MPV4 motor sub-assy. | -N/A- | ~145 lbs. |
| Motor controller box w/ 4QD motor controllers | 12” × 8” × 3” | ~8 lbs. |
| *Power management systems equipment* | | |
| Die Hard Deep Cycle/Marine battery | 11 3/8” × 7” × 10” | 50 lbs. |
| Tripplite PV400W Inverter | 7 ¼” × 4 ¼” 5 ½” | 10 lbs. |
| Surge Protecter | 14” × 2 ½” × 4” | 1 ½ lbs. |
| **TOTAL** | 33 ¼ ”× 24” × 21”* | ~445 lbs. |

* The total volume includes stowage space for geological equipment and LSS equipment.

# Appendix B: Images of PHASE I and PHASE II FIDOE system

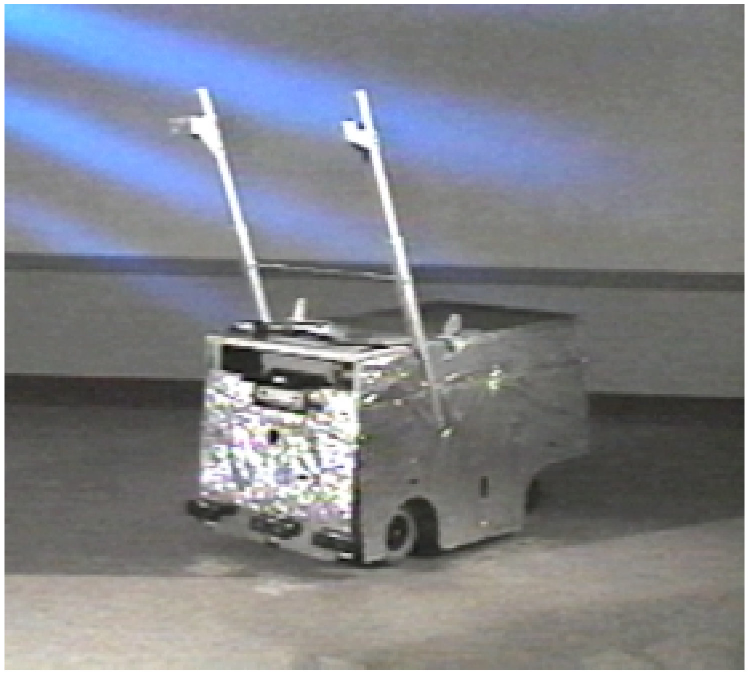

**Figure A2.1: Proof of concept FIDOE system**

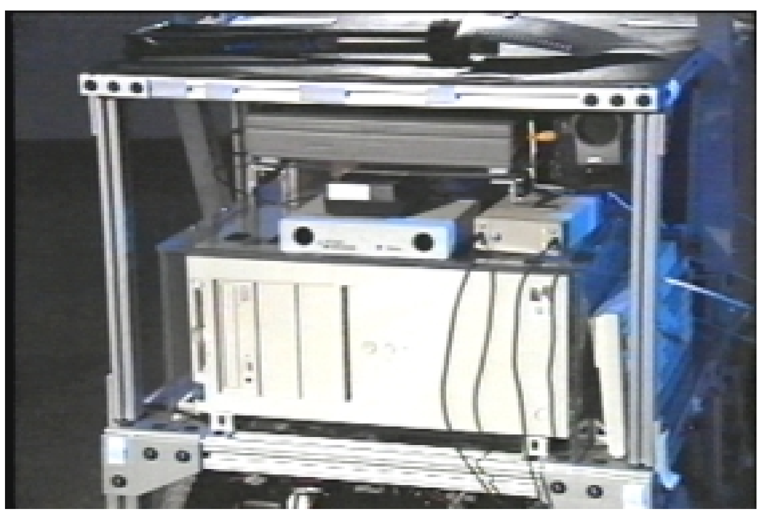

**Figure A2.2: FIDOE system- Integration of Dell computer system, Sony Camcorder, Toshiba laptop, 2.4 GHz transmitter, Dynasight sensor. and ClearCom transceiver**

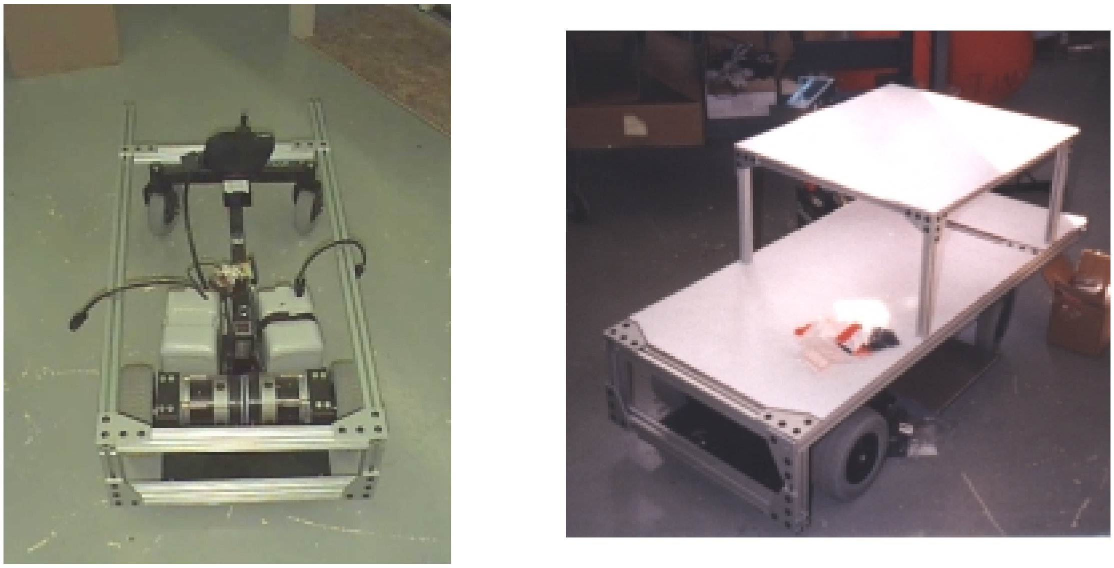

**Figure A2.3: FIDOE chassis development**

**Figure A2.4: EV crewmember interfacing with FIDOE's on-board LSS via the $O_2$ port**

**Figure A2.5: Front and side views of PLSS supports for EV crewmember donning/doffing**