Moon Rover (MR) Subsystems for the VagaLune Project

Software Modules – Developed by the VagaLune Team

Power Management (PM)

The Power Management (PM) routines will be responsible for adjusting the power usage levels on the MR. An X-prize requirement is that the rover survive a lunar night, a 14-day period when the MR will be in darkness. In this period, the MR will shut down all major systems and operate off an internal lithium-ion battery. The PM will be responsible for managing the MR entering and leaving hibernation. During normal operations the PM will adjust the power usage based on the available solar power. The PM will interface with the power hardware on the MR, as well as provide power usage metrics to the earth station. The PM will have an autonomous power management routine that can operate without earth station control. The PM software can also be overridden with commands from the earth station to manually control the power usage of the MR.

Moon Rover Autonomous Navigation Software (MRANS)

The Moon Rover Autonomous Navigation Software (MRANS) is an application of a previous software component to the VagaLune project. The MRANS will be responsible for interfacing with the onboard still image camera and determining the best route to move the rover on the lunar surface. This software is an extension of the software used on the NASA JPL Mars Rover missions. Instead of manually issuing the rover commands to avoid small rocks and other terrain obstacles, commands will be issued to tell the rover to move to a particular point, indicated by selecting a region on a transmitted still photograph. The MRANS will then move the rover to that point; it will then identify a path free of obstacles and begin moving the MR. The MRANS was chosen to reduce the amount of support personnel required to control the MR and because of its success on the previous Mars expeditions. Manual override functionality will be integrated to allow for earth station operators to manually control the movements of the MR

MR Communication Monitoring Software (MRCMS)

The MR Communication Monitoring Software (MRCMS) is responsible for formatting the spacecraft transmissions to the ground station, as well as decoding the received message traffic. The Earth station and the MR will communicate via a predefined message format. The message format is covered in an additional project report. The fixed format of the messages will relay the information to and from the MR. The MRCMS's task is to decode the messages and pass the appropriate commands to the software modules operating on the LM. Also, the LMCMS is tasked with formatting messages for downlink to the Earth station. The MRCMS will periodically query the other operating tasks for status, position, and fault codes, encapsulate this data into a downstream message and then pass the information off to the RF communications chain. The MRCMS is tasked with relaying the encoded video and image data from the respective encoding elements to the RF transmit hardware. Due to the high priority of sending near real time video and image information from the moon, the MRCMS will have the highest operating priority over the other software modules operating on the MR. Lastly, during the initial stages of MR operation, when the craft begins to exit the LM payload bay the MRCMS will be responsible for the antenna direction finding. The MRRSCS will issue commands to move the antenna, while the antenna is moving the MRCMS will transmit query messages to the earth station. If the MRCMS receives a response to the message, it will indicate to the MRRSCS that a communication link with the earth station has been achieved.

Image and Video Control Software (IVCS)

The Image and Video Control Software (IVCS) is the software module tasked with controlling the video encoding settings for the still images and High Definition Television (HDTV). While the encoding is handled in hardware, the IVCS operates to control the encoding settings, and issue commands to stop and start video recording. The IVCS also operates to take periodic images from the still camera for use in the AutoNav processing routines. The IVCS is tasked with constructing the video and image data packets for transmission back to the earth station. The IVCS will interface with the hardware encoding systems, buffer the encoded data, then encapsulate it in the predefined transmit message format.

Moon Rover Robotic Systems Control Software (MRRSCS)

The Moon Rover Robotic Systems Control Software MRRSCS is responsible for interfacing with the hardware robotic systems operating on the MR. While the motion systems are handled by the MRANS, other systems such as solar panels and camera positioning systems are controlled by the MRRSCS. The MRRSCS is also tasked with issuing the commands to free the MR from the LM payload bay after landing. The LM systems will issue commands to deflate the large airbags, and expose the rover, but the unfolding of the solar panels and the positioning of the antenna are to be handled by the MRRSCS. The antenna will deploy, and then move in a full range of motion. While the antenna is moving the MRCMS will be querying the earth station, when a link is established the MRRSCS will cease moving the antenna. The MRRSCS is tasked with the initial task of unfolding the solar panels, due to the limited power provided by the onboard battery, if the panels do not begin to generate power, the mission will be incomplete. As such, the MRRSCS will have complete control over the MR after it has landed, all other tasks cannot begin until the MRRSCS has established a solar power source, and the communication link to earth has been established. After the initial set up of the MR, the MRRSCS will be responsible for updating the antenna position as the MR changes orientation on the moon. Any commands to move the camera position will be executed by the MRRSCS.

Commercial off the Shelf (CotS) microprocessor components

The VagaLune project will use several COTS components as the hardware for the software modules to run on, and to manage the interfaces with the hardware systems. For the microprocessor VagaLune has selected a BAE Systems RAD750 Radiation Hardened Microprocessor Single Board Computer. The RAD750 comes packaged with 128MB of Hardened RAM and VxWorks tm Real Time Operating System. The use of a common processor core will assist in the software development cycle. For hardened Read Only Memory (ROM) we will use eight BAE Systems C-RAM 4MB chips for a total of 32MB of ROM. The

ROM chips will be set into a separate card from the single board computer. The need for radiation hardening electronics is critical, due to the possibility for large scale solar events impacting the MR on the lunar surface. The 32MB of ROM will store the email messages loaded onto the rover prior to launch, as well as the operational software. The MR will be powered down for the journey from earth to the moon; the ROM will store the operational software and begin operation when the LM initiates the lunar descent. The MR will also use several commercial cameras for the HDTV and still image encoding. Adimec makes ruggedized HDTV and megapixel cameras for military and space applications. Specifically, the exterior HDTV camera used on space shuttle missions is made by Adimec. VagaLune will work with Adimec to develop a HDTV and still image camera based off their military grade cameras. The HDTV and JPEG encoding routines will be commercial IP cores synthesized to our Actel Radiation Hardened FPGA's.

Built In Test Equipment (BITE)

The Built In Test Equipment (BITE) is a software combination of software and hardware subsystems tasked with monitoring the health of the MR. The BITE software schedules the execution of the built in test routines within each of the MR software modules. The hardware components of the BITE system are integrated into the electrical subsystems of the MR. The hardware components are used to observe the status of electrical components of each system, and report the information back to software modules. BITE consistently queries the status of each sub-system, if a problem is identified it has functionality to attempt to correct the malfunction. If BITE cannot correct the problem, it initiates the transfer of fault code messages to the ground station.

Lunar Module Electronic Subsystems – Integration and Assembly handled by VagaLune

Rover Power Systems (RPS)

The Rover Power Systems (RPS) will be tasked with the power generation and hardware level management for the MR. The RPS will interface with the SpectroLab solar panels mounted on the rover, and perform the necessary voltage conversions to power the various components within the MR. Also the RPS will charge the onboard Lithium-Ion battery cell. The RPS will be tasked with regulating the power going to each of the component systems. During the lunar night phase of the mission, the RPS will shut power down to most systems on the MR, limited processing capability will be provided by RAD750 and the RPS controls must operate with minimal power during this period. When the craft reenters a period of sunlight, the RPS will return full power to the remaining components on the MR.

Robotic Controls – Antenna and Solar Panel Positioning

The Robotic Systems on the MR will be divided into several subsystems; the first of these systems is the mechanisms for positioning the antenna and unfurling the solar panels. The servos and actuators mounted on the top of the MR will unfurl the panels from their transport configuration to one that can generate power. The antenna positioning will unfurl the antenna from its transport position as well, and then begin changing the antenna orientation to find the correct orientation for communication with the ground station.

Robotic Controls – Moon Rover Motion Systems

The Robotic Controls tasked with moving the rover are separate from the other robotic systems on the MR. These systems will be directly controlled the MRANS and move the rover on the lunar surface. The design of the rover is influenced by the Mars Exploration Rovers; six independent wheels connected to motors will provide the ability to move on the lunar surface. The wheels will be connected to robotic arms that can bend to drive over small rocks and other obstructions on the lunar surface. The wheels will be individually powered by electric motors, while the arms will be connected to several servos to adjust their positions based on the terrain.

MR Communications Chain (MRCC)

The communications chain for the MR is specified in the section of the VagaLune web based presentation labeled communications systems. As the MRCC relates to the other digital systems operating on the LM, one FPGA will operate as a Turbo Code Encoder/Decoder to process the Forward Error Correction (FEC) data streams specified by the communications link. The FPGA will pass the decoded data stream over to the MRCMS routines operating on the microprocessor.

Video Encoding System (VES)

The Video Encoding System (VES) on the MR is tasked with compressing the data from the HDTV camera for transport. The problem of transmitting HDTV video from the lunar surface requires several levels of consideration. Uncompressed HDTV video requires a large amount of bandwidth to transmit even small amounts. Given the limited transmit power and bandwidth available for the transmission from the Moon the video must be compressed. The compression of the video brings up another interesting point, the Google X-Prize stipulates that the mission must transmit HDTV video back to earth, if the video is heavily distorted by compression, then the data quality of the mission could be compromised. Also, the images from the moon from the Apollo era are grainy and poor compared to what is available today in imaging. A balance must be struck between the levels of compression and the available transmit bandwidth. The MR will use the H.264 video compression standard; the H.264 standard provides an exceptional level of compression versus the required data rate. Using H.264 the MR will be able to transmit 1920X1080 HDTV video at 24 fps using only 20Megabits / second as the data rate. The drawback to H.264 is the extensive computational complexity of the encoding algorithm; fortunately commercial IP cores exist to synthesize the algorithm to FPGA's. The MR will synthesize the 4i2i communications H.264 encoder onto an Actel FPGA. The use of the encoding algorithm in a dedicated hardware chip frees up resources on the microprocessor, and also allows for near real time encoding and transmission of the HDTV images. The VES will pass the encoded H.264 data to the IVCS routines for encapsulation and eventual transmit to the earth station.

Image Encoding System (IES)

The Image Encoding System (IES) will take the output from the still Adimec camera and compress it using the JPEG compression standard. The limited transmit requirement of the MR dictates that the image data must be compressed from the camera. The IES will interface with a separate, lower resolution Adimec camera. Actel offers a JPEG-E encoder IP core that can be synthesized to an FPGA for dedicated hardware encoding of the image data. The output of the image encoding will be passed to the IVCS for encapsulation and transmission to the earth station. The images for use in the MRANS will be encoded into the JPEG format as well, given the memory limitations on the system it prudent to compress all images coming from the still camera. The IES can be remotely controlled by the IVCS; the IP core for JPEG compression can accept parameters for image size, as well as the level of compression.

Robotic Controls -- Camera Positioning System

The Camera Positioning System (CPS) is tasked with orienting the HDTV and still cameras on the MR. The HDTV camera will be internally mounted on the MR body, but will be mounted on a servo platform to move the camera without requiring a position change. The still camera will be mounted on an external arm, and the CPS is tasked with moving the arm. The separate level of control for these devices is needed to allow for the still camera to be moved to generate a panoramic picture.

Lunar Module Payload Exit Systems (LMPES)

The Lunar Module Payload Exit Systems (LMPES) consist of the systems for freeing the MR from the LM payload bay. These systems include the explosive bolts to disconnect the rover from the LM, and unfold the panels and wheel assemblies on the MR. Also the LMPES is the only system on the MR that can be remotely activated by the LM. This system will be initiated when the LM is in its descent phase, and store the current position of the LM as well as any updated commands to the MR that were received by the LM. After the LM has completed its landing maneuvers and is on the lunar surface, the LMPES will activate to disconnect the MR from the LM, power on other systems, fire the explosive bolts to sever tie downs, then hand control over to the MRRSCS to issue the commands to unfold the solar panels and arrays. The LMPES will be the hardware cold start of the MR, initiating the power on of the RAD750 and the software modules.

REFERENCES

C. Pearson et al., "Qualification of Next-Generation Lithium-ion Small Space Cells by ABSL Space Products," 4th IECEC, June 2006, pp. 1-12.

J. Carsten et al., "Global Path Planning on Board the Mars Exploration Rovers," IEEE Aerospace Conf. 2007, March 2007, pp. 1-11.

A. Stadter et al., "A scalable small-spacecraft navigation and communication infrastructure for lunar operations," 2005 IEEE Conf. Aerospace, March 2005, pp. 595-600.

Commercial Product Specifications

4i2i Communications H.264 Encoder IP Core http://www.4i2i.com/h264_video_codec_ip_core.htm

Actel RTAX-S/SL Space Hardened FPGA's http://www.actel.com/products/milaero/rtaxs/default.aspx

Actel JPEG-E Encoder Core http://www.actel.com/products/ip/search/detail.aspx?id=601

Adimec Ruggedized Cameras http://www.adimec.com/main.php?cm=p104_1hv7Ti1_yrtLTrZlg16pdx__2

BAE Systems RAD750 Radiation Hardened Microprocessor
http://www.baesystems.com/ProductsServices/bae_prod_s2_rad750.html

BAE Systems C-RAM http://www.baesystems.com/ProductsServices/bae_prod_eis_cram.html

iCoding Turbo Encoder / Decoder http://www.icoding.com/pdfs/S2002.pdf

SpectroLab Solar Panels http://www.spectrolab.com/prd/space/panel-main.htm