Lunar Module (LM) Subsystems for the VagaLune Project

Software Modules – Developed Internally by the VagaLune Team

Flight Control Software Program (FCS)

The Flight Control Software (FCS) will be preloaded with the orbital transfer program prior to the launch of the VagaLune probe. The software shall maintain a representation of the probes position in an earth-centric coordinate system. The FCS will be responsible for issuing commands to the thruster control systems to adjust or correct the position and velocity of the probe. The FCS will access several sensor systems to compute the initial current position of the spacecraft. The Inertial Navigation System (INS) will provide information on the changes in the spacecraft's position. The INS, coupled with an internal chronometer to provide time elapsed, allows the FCS to automatically direct the craft into lunar orbit. In the event of an INS failure, the FCS can be remotely overridden; ground tracking information can be remotely relayed to the VagaLune probe via communication link to the earth station.

Spacecraft Robotic Control Software (SRCS)

The Spacecraft Robotic Control Software (SRCS) is a section of the LM software routines responsible for interfacing and controlling several of the robotic systems on the LM. The SRCS will primarily be responsible for controlling the unfurling and positioning of the solar panels on the LM. Due to the LM's orbital path from Earth to lunar orbit, the solar panels may require repositioning to maintain maximum solar efficiency. The SRCS issues commands through the microprocessor to the various control elements on the LM to adjust the position of the panels. The SRCS is also tasked with the critical task of initially unfurling the solar panels after launch. To fit the LM into the Falcon 1e launch vehicle, the panels must be folded tightly against the LM. After launch they must be positioned to power the onboard propulsion system. The SRCS also must interface with the LM antenna position robotics to ensure that the antenna initially unfurls and remains in a desired position relative to the Earth. Additionally, the SRCS can be remotely instructed from the Earth station to manually correct for any robotic errors.

LM Communication Monitoring Software (LMCMS)

The LM Communication Monitoring Software (LMCMS) is responsible for formatting the spacecraft transmissions to the ground station, as well as decoding the received message traffic. The Earth station and the LM 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 LM. The LMCMS'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 LMCMS 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 front end of the RF communications chain.

LM Lunar Descent and Landing Routine (LDLR)

The LM Lunar Descent and Landing Routine (LDLR) is responsible for the final stages of the LM flight. The LM will be placed into stable EL40 lunar orbit by a combination the FCS and commands issued from the Earth station. The final stage of the mission is to control the degradation of the stable orbit and place the Moon Rover (MR) safely on the lunar surface. The LDLR will be invoked by the Earth station; it will query the FCS and access the INS to control the descent. Additionally, the LDLR will access the onboard laser altimeter to gain information on the altitude of the LM. While the LDLR will access the information from the INS, due to the possibility of INS drift, a laser altimeter will be used to ensure altitude accuracy. The LDLR will override the FCS and begin to degrade the lunar orbit of the LM. As the LM begins to descend towards the lunar surface, it will fire the retro-thrusters located on the bottom of the craft to control the descent. While monitoring the readings from the laser altimeter and INS, the LDLR will deactivate the retro-thrusters, inflate the Airbag Landing System (ALS) then control the opening of the LM payload bay. As the craft nears the lunar surface, the LDLR will transfer the last known position of the LM to the MR, and initiate a time driven electrical system to fire the explosive bolts and open the payload panels of the LM. There is a possibility that during the landing, the computer payload bay of the LM may become damaged, as the rover cannot free itself from the bay, a failsafe system must be activated to deflate the bags and fire the explosive bolts once the craft has landed. The LDLR is a critical aspect of the software subsystems on the LM, and shall be subjected to flight certification testing beyond that of the other sub systems.

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 LM. The BITE software schedules the execution of the built in test routines within each of the LM software modules. The hardware components of the BITE system are integrated into the electrical subsystems of the LM. 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.

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 6 BAE Systems C-RAM 4MB chips for a total of 24MB of ROM. The ROM chips will be set into a separate card from the single board computer. The need for radiation hardened electronics is critical, due to the possibility for large scale solar events, and the extended amount of time the VagaLune probe will pass through Earth's radiation belts in its orbit. While it is possible to shield conventional electronics through insulation, the added weight coupled with the limits of the launch vehicle dictate the use of integrated radiation-hardened electronics.

Lunar Module Electronic Subsystems – Integration and Assembly handled by VagaLune

Inertial Navigation System (INS)

The Inertial Navigation System (INS) will be responsible for computing changes to the spacecraft's velocity and acceleration and passing corrected changes to the FCS. The INS shall have multiple three components, a Ring Laser Gyroscope (RLG) , six Accelerometers (two For Each Axis), and a Kalman Filter operating on an FPGA to process these changes and produce error adjusted values for changes in each velocity. The Kalman filter is needed to process this information for several reasons: 1) the RLG can become misaligned and provide errant data over time and the Kalman Filter can correct these errors. 2), the accelerometers can degrade over the course of the mission or provide misaligned information and the Kalman Filter can correct for these errors as well. 3) The sampling rates of the RLG and accelerometers may not meet the requirements of the FCS. The Kalman filter can accurately approximate the changes in velocity between the sampling intervals, providing change information to the FCS at an increased rate over what the hardware alone can provide. For the RLG, VagaLune has selected the L-3 Communications RGA-20 High Performance Gyro Assembly. The L-3 Gyro has been used on multiple satellite missions and provides a robust support base for integration into the LM. For the accelerometers the LM will use six Honeywell QA3000 units to provide two inputs for each axis of motion. The devices will be interconnected in a classical manner used in space missions since the 1960's

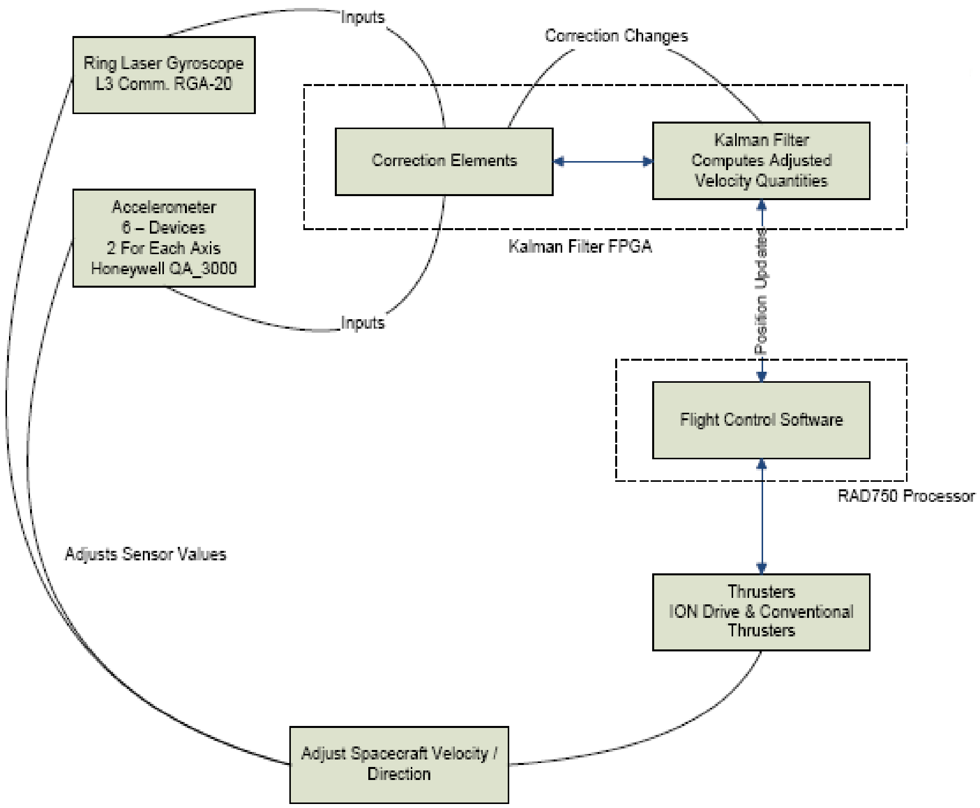

Figure 1 – INS Design

The Kalman Filter will be synthesized onto an Actel Radiation hardened Field Programmable Gate Array (FPGA). Advances in logic compilation tools allow for a complex system such as a Kalman Filter to be designed and tested in a software environment such as MATLAB, then synthesized directly into an FPGA. The software that allows for direct synthesis is commercially available from Xilinx in the form of the AccelChip Synthesis package. Also, several designs of Kalman Filters have been implemented directly into logic circuits [Lee97]. Depending on the needs derived in the development process, the VagaLune project could use either of these design methodologies to realize the desired FPGA implementation of the Kalman Filter. The use of established INS design, coupled with the increased processing power provided by the advances in semiconductor design will provide a robust and stable INS platform for the VagaLune.

Robotic Control System (RCS)

The RCS is the electrical and control side of the VagaLune LM robotic systems. There will be several actuators and micro switches connected via relays to the microprocessor architecture to implement movement commands from the SRCS software. There will be three sub robotic systems: solar panel positioning, antenna orientation and Flight Termination System (FTS). Solar panel orientation is critical to LM operation. Because of the ion drivem the LM requires a constant power supply of at least 1200W to function. A series of actuators and switches will be tasked with continuously positioning the solar panels as well initial unfurling. The antenna orientation robotic subsystem will position the antenna, and issue the initial commands to actuators to move the antenna from launch position into flight mode. The FTS system is used as a failsafe should the spacecraft pose a danger to any other bodies in flight. Due to the dynamics of the orbit, the LM could enter into a collision path with another earth orbiting satellite. If the satellite is critical or contains human occupants it may be necessary to abort the mission. The autodestruct charge is commercially available from ATK-Thikol space products and can be integrated into the LM. The FTS is shock hardened, and is rated to survive the lunar landing. The abort subsystem can only be initiated by the Earth station.

LM Communications Chain (LMCC)

The communications chain for the LM is specified in the section of the VagaLune web based presentation labeled communications systems. As the LMCC 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 LMCMS routines operating on the microprocessor.

Spacecraft Ion and Conventional Propulsion Control (SICPC)

The propulsion for the VagaLune probe will be handled by a Snecma PS-1350 ion propulsion unit, and eight conventional hydrazine thrusters. The ion drive will operate using 80kg of stored Xenon fuel, and the power provided by the solar panels. The Snecma drive comes with a control subsystem. An additional FPGA will be used to interface the ion drive controls to the common data bus on the spacecraft. The FPGA will also be tasked with interfacing the controls from the eight conventional thrusters. The spacecraft propulsion systems will be managed by the FCS and the LDLR modules operating on the microprocessor.

Spacecraft Landing System (SLS)

The Spacecraft Landing System (SLS) is the system responsible for ensuring a soft landing of the LM. The orbital transfer maneuvers will place the LM into lunar orbit with a perigee of 100km. The SLS coupled with the conventional thrusters on the SICPC will move the LM from its orbit to the lunar surface. The thrusters will be controlled by the LDLR and the LM will degrade its orbit when it is at perigee. When the craft reaches a velocity of 40 meters / second, SLS will take over to ensure a soft landing. The SLS will first fire a series of explosive blots to jettison the solar panels, the forward thrusters, LM antenna, and ion drive. These components are removed to allow for the Airbag Landing System (ALS) to inflate and cover the spacecraft with the required level of protection. The spacecraft will be powered by an internal lithium ion that will provide the reserve power for the SLS to operate. Once the external devices are removed, a high pressure helium tank located in the fuel compartment will expel its air into the air bag modules located over the space craft. The airbags will use a lighter than air element, such as helium to further reduce the weight of the spacecraft. The bags will rapidly inflate providing the craft a cushion as it encounters the lunar surface. The craft will bounce on the surface and come to a rest. Once the craft has come to a rest, the preprogrammed explosive bolt sequence will detonate, releasing the panels over the MR, and allowing the rover to drive out of the LM. The LM will be counter weighted in such a way to ensure it stops with the proper orientation. This is a variation on the Mars Spirit and Opportunity Rovers deployed by NASA. Due to the moons lack of an atmosphere, the LM will use conventional rocket thrusters to slow the craft, whereas the Mars probe used a hypersonic parachute.

REFERENCES

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C. R. Lee and Z. Salcic, "High-performance FPGA-based implementation of Kalman filter," Elsevier Sci. J. Microprocessors & Microsystems, vol. 21, Dec. 1997, pp. 257-265.

Commercial Product Specifications

L-3 Communications. RGA-20 High Performance Gyro Assembly Specifation Sheet. http://www.l-3com.com/products-services/docoutput.aspx?id=433

Honeywell Aerospace. QA3000 Flex Accelerometer. http://www.inertialsensor.com/qa3000.shtml

Snecma Aerospace. Plasma Thrusters.
http://www.snecma.com/rubrique.php3?id_rubrique=43&lang=en

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

ATK. Space Products and Catalog
http://www.atk.com/Customer_Solutions_MissionSystems/cs_ms_space_sp.asp

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

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