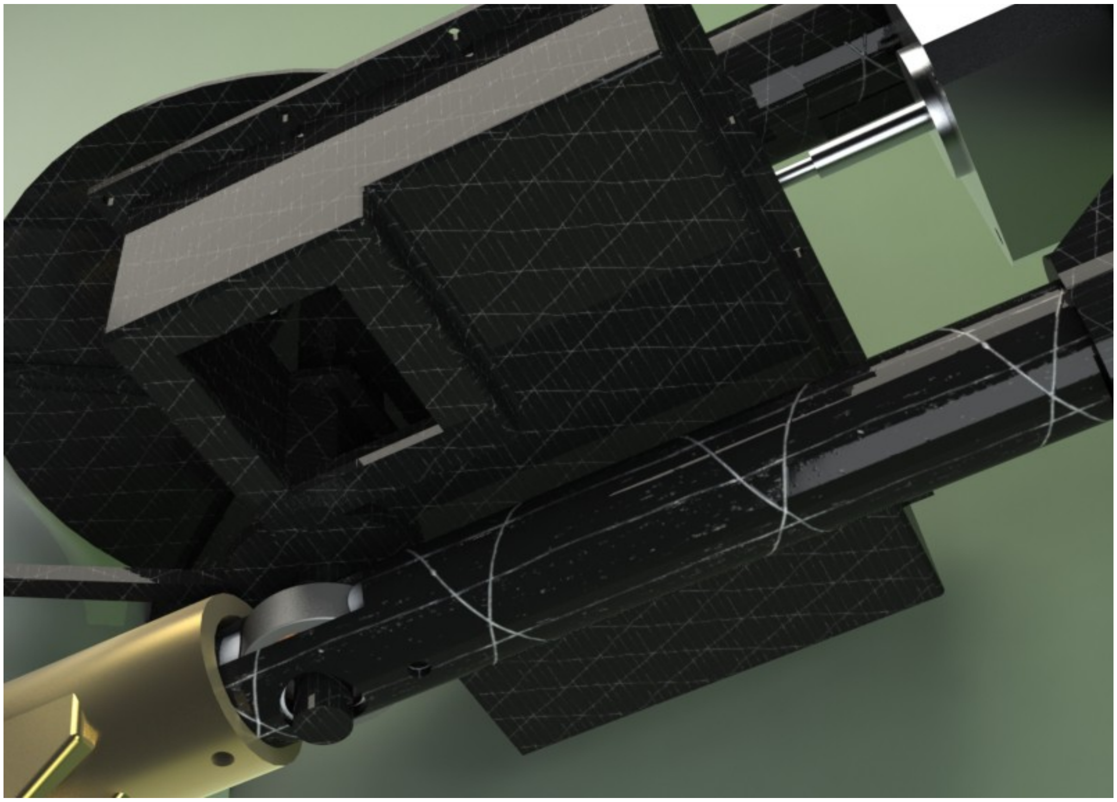
Team PlanB, Imaging Subsystem, Technical Risk Assessment



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October 2013.

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Acknowledgments

The Team PlanB wishes to thank the support of all volunteers for their input in design of the mission, rover, and critical components; especially in a "plan B" scenario, because "plan A" is considered as "plan for Dreams" of the way to the moon. The Team Plan B would also like to acknowledge that technical information from Boris Chertok's books was extremely valuable in designing the blueprint for the mission.

1.0 Summary

The imaging subsystem includes hardware and software that support a camera capable of up to 4 simultaneous low-resolution still pictures, and 1 HD video camera. There is software running on 2 separate microprocessors to support storage for the HD video and still pictures. The storage capacity reserved is triple the estimated capacity necessary to complete the mission in order to support redundant storage of the mission data. A special stand houses the box for the camera with 4 low-resolution sensors. The mechanical design of the stand and the position of the box housing the camera are optimal for recording observations of the mission. The housing box has 4 pinholes to take 4 directional images simultaneously with the imaging sensors of the camera. The stand is a carbon fiber rod with 16 copper wires to support power and data transfer from cameras to main micro-controller PCB board. The rotation mechanism of the stand is powered by a stepper motor.

The motor can lift the camera's box up to 0.5m from the lunar surface. Key components of the rotation mechanism include:

1.1 Mechanisms for retracting the low-resolution camera and pointing the HD camera.

The mobile rover needs to perform a good observation before choosing proper direction of a movement. This could be done either by placing the camera on highest point of the rover, or by periodically lifting cameras for brief observation of terrain around. The design of the rover chooses the latter method, as the method is most compatible with the travel of an unstable, two-wheeled rover. The camera stand is a carbon fiber rod with a gear wheel mounted on it.

A third leg is important to the stability of the rover while in motion. The third “sliding” leg is formed by the camera box when the imaging subsystem stand is rotated to a 45-degree position.

The pinholes of the camera box are susceptible to jamming with lunar soil dust. A software solution has been designed to “shake” dust from the pinholes. The “shaking algorithm of the software applies different rotation momentums to the camera stand.

It was not possible to mount the HD resolution camera at a high point without going out of the weight limit of 4kg for the rover. Instead, the HD video camera is located low to the ground in a sealed carbon fiber box. The epoxy for sealing the box uses small additions of graphene to enhance the strength of the epoxy and protects the sealed box from leaking pressure. The optics of the HD camera will be separate from harsh conditions of the space vacuum by a window of triplex glass. By sealing the HD camera box, all the mechanics and optics of the HD camera are protected in one atmosphere of pressure for at least one month. The HD camera box is mounted on the antenna rotation mechanism. Distance from rotation axis of the antenna arm to the tip of the box is chosen so that the box digs 1-2 cm into the lunar surface when the antenna is positioned properly and oriented towards the earth. In this position, the HD camera will make clean and detailed pictures of the lunar surface for 3D technical printing experiments. While the antenna is in the travel position, parallel to the surface, the HD camera observes travel through the box's window at only 20 cm from the surface. As part of the mission, it is desirable to travel from the landing point to the tip of a nearby crater, and in this case, the HD camera will present a nice observation of the detailed geological structures of the terrain and such a crater. At such a distance from the surface, each HD video frame may be scientifically valuable as well as the additional media value of an HD video.

1.2 Image processing capability

The low-resolution camera uses an on-board microprocessor to convert the captured images into JPEG files. Commands to capture images can be sent. First, images are stored in internal memory as 640x480 color RGB pixels. Then, the capture command further converts the images to JPEG images and saves them as files on the FLASH memory storage. Another command allows image files to be retrieved over a serial interface. Data to be retrieved is stored in FLASH memory. This FLASH storage is connected via switches to and from the HD camera's FLASH storage. Thus, all recorded low-resolution and 5 megapixel resolution images, as well as the 720p HD video, share the same FLASH storage units. The FLASH memory storage has a redundant architecture of 3 FLASH memory devices. Each write operation is performed to each of the 3 FLASH memory devices. The read operation is executed by a majority algorithm where at least 2 FLASH memory devices agree on the data read. All 3 FLASH memory devices are located separately, as far as possible from each other. This redundant design helps to keep data protected from loss in case of damage from high-energy particles.

1.3 Camera thermal control

Thermal control includes a combination of passive and active methods to keep the electronics and mechanisms within proper operational temperature boundaries. Passive thermal control measures include a layer of gold on the boxes of the low-resolution camera and the HD camera to reflect solar radiation. Temperature is further stabilized by including 6 water-filled containers, with a total of 0.01kg water, in the walls of the HD camera box. The containers are filled with water and sealed under a 5 mm/Hg vacuum. The passive thermal control system also includes thermal heat conductors for all of the surface mount electronic components. The components are thus thermally coupled with the copper layer on the PCB. Heat conduction is provided by a carbon fiber composite made with a thermally-conductive epoxy.

The active thermal control system of the HD camera has 2 temperature sensors located inside the box and the tip of the box is placed in contact to the ground. A temperature control processor checks the temperature value and signals the main microprocessor when there is an "about to be out of limit" condition. Logic for temperature control has 2 modes: an "on orbit" and an "on moon" mode. The "on orbit" temperature is monitored in the HD camera's power-off state and in each of the different craft orientation positions. Samples of temperature variations at 26 different points are for two conditions of a craft: (A) exposed to the sun, and (B) in the shadow of the earth. Derivatives are calculated on 26 recorded samples and these derivatives are stored as indicators of the cooled or heated state of the HD camera.

When the "on orbit" mode temperature rises to +80C, the power is switched off and a request is sent to the main microprocessor to rotate the craft to a more desirable orientation with respect to the calculated heat sources. An algorithm has been devised to best-fit the stored derivatives and calculate the direction of temperature flow within the box. Thus, the orientation of the craft will change to counteract rising temperatures. Also, when in "on orbit" mode and the temperature falls to -20C and a check for an available level of power returns an "OK to power on the HD camera" state, the HD camera is powered constantly. If the HD camera should be powered constantly, yet the sensors still experience a fall of the temperature to -25C, the power is switched off and a request to rotate craft to a position with high value of the derivatives of the temperature curve is sent to the main micro-controller. Thus, the orientation of the craft will change to counteract falling temperatures.

In the "on moon" mode, while the antenna is in a travel position, the temperature of HD camera is recorded for some period of time, and derivatives for the temperature sensor values are calculated and stored to predict the rise or fall of temperature of the HD camera. The same monitoring of the temperature is performed while in a communication session. At this moment, the HD camera box will be touching the lunar surface and the recorded temperature indications will depend on the heat exchange that is occurring with lunar regolith. This change of temperature is recorded and derivatives of the temperature values are stored to predict the temperature rise or fall when the HD camera box is in contact with the lunar regolith. When in "on moon" mode temperature rises up to +80C, the power is switched off. Touching the lunar regolith may lower the temperature and the effect of lowering the HD camera box will have been predicted by the last communication session. If all conditions are met, a request to touch the lunar regolith will be sent to the main microprocessor. While in "on moon" mode and the temperature has risen to +80C, the power has been switched off, and the HD camera box is already touching lunar regolith, the HD camera may not operate until the temperature within the box reaches operational conditions.

Similar logic is applied in a case of an "about to be out of limit" state detected near a low temperature of -20C in the "on moon" mode. If proper operating temperature can be maintained while powering the HD camera, then the HD camera can maintain the power-on state. If maintaining temperature within operational limits is not possible and the temperature can be raised by touching lunar regolith, a request to touch the lunar regolith is sent to the main microprocessor. If neither operation is possible, then the HD camera is maintained in the power-off state.

A special mode of the HD camera can override the temperature out of operational range condition. The HD camera can be switched on or off, it can make a video recording, or an image can be captured.

The camera box with 4 low-resolution sensors is also monitored for temperature in a similar manner as the HD camera box. There are also two modes of temperature regulation: an “on orbit” mode and an “on moon” mode.

In the "on orbit" mode, the power-off state of all cameras and the temperature within the boxes are monitored, recorded, and derivatives of temperature samples inside the boxes are calculated. The temperature derivatives are stored for the 26 possible orientations of the craft exposed to sun and 26 orientation positions of the craft in the earth’s shadow. If the temperature is out of operational limits, then based on the stored derivatives of the temperatures, a request is sent to change the orientation of the craft to cause a rise or fall of the temperature inside box.

Requests for different orientations are supported from each of the different subsystems onboard and are fulfilled by performing maneuvers in many directions as are requested by the different subsystems. Each orientation request is serviced in turn and after both achieving the commanded position to heat or cool a specific subsystem and reaching operational conditions for that subsystem, the gyro-platform accepts commands to orient the craft to each subsequent position. Orientation maneuvers continue to execute for all requests for temperature control. Time to maintain an orientation is calculated based on the temperature of the onboard subsystems; in this case, the low-resolution camera and the HD camera. When moving from the last orientation, the gyro-platform is able to switch off the solid-state gyroscopes without external command as the sequence to move and rotate back to the original position has been pre-recorded by the orientation system. The pre-recorded data may be used with precision and without analyzing data from the gyro-sensors for each specific maneuver. During each of these maneuvers, infrared detectors of the sun and infrared detectors of the edge of a nearby celestial body are switched on and the time between the peaks of these derivatives are calculated (*e.g.*, crossing the edge of the earth). The calculated data are stored and used to determine points within the orbit. The calculations detect the direction of the sun and earth edges while the gyro-platform is powered on and the directional data is used for corrections with respect to the sun and the center of the earth while the gyro-platform is powered off.

In the "on moon" mode of the low-resolution camera, the stand is used for travel assistance. The temperature recorded inside the box is correlated to the temperature of the regolith. This allows the prediction of the temperature of the regolith and the prediction of the operational temperature range within -20C to +100C. When the low-resolution camera's box temperature is out of operational range, the subsystem either may wait for the temperature to come within range or the lunar regolith will be used to cool or heat the camera.

1.4 Interfaces to other subsystems

An HD Camera is picked off-the-shelf and tested for functionality in different conditions. It is equipped with a socket for a micro SD FLASH card, lithium-ion battery, and an interface cable for connection to a PC. All of the connectors are extended via an additional multi-wire cable. The cable extends out of the HD camera carbon fiber box. The lithium-ion battery is also connected to a cable outside of the box. The lithium-ion battery is sealed inside epoxy and the package is mounted outside of HD camera box. Two wires from the cable provide +5V of power to the camera from the rover power plant. Wires from the micro SD FLASH connector connect to the main microprocessor PCB.

The imaging subsystem's interface includes a connection to the communication subsystem, and eventually, via a ground station, to mission control. Mission control sends a sequence of commands to control the low-resolution cameras, the HD camera, and to control the mechanisms related to each subsystem's operation. A sequence of commands will typically be: (A) commands to attitude control subsystem that orient the craft in a specific direction. These commands will be related to the direction of the sun and the earth. When the attitude control subsystem finishes executing a command for orientation, it sends a command, and (B) to the camera to capture and image. These typical commands could also happen in reverse order. The command to capture images can be sent followed by a command to the attitude control subsystem to resume original orientation of the craft.

An inter-unit communication protocol for exchanging data as well as the specific commands designed in such a way that each micro-controller can send a particular sequence to each other without the involvement of mission control. Each micro-controller has an independent "state machine" that has been designed to perform independent tasks. The state machines are implemented in the software for the micro-controllers.

2.0 Risk assessment

2.1 Mechanisms for retracing low resolution cameras

Mechanisms for retracing low resolution cameras depends on the functionality of the stepper motor, gear with 1/5 ratio, gyro-sensor mounted on stand, accelerometers, power plant, electrical controls, software. Failure of each component can jeopardize the mission because there is no backup for those devices.

Stepper motor is 17H118D10B. Due to temperature conditions there is a risk that the stepper motor can lost its magnetic property and torque created by stepper motor will be less than originally anticipated.

Bigger wheel is made from carbon fiber. It is mounted on stand and is around rotation axis of the stand. Small wheel of the gear are made from titanium -80% silver -19% graphene -1% composite. There is a risk that a gear can be jammed by lunar soil, be broken, main wheels is less strong and can broke.

Gyro-sensor ATG-3200 mounted on stand. There is a risk that gyro-sensor can fail because of the out of temperature operation conditions, or because of high energy charged particles.

Accelerometer ADXL342 is mounted to the stand. There is a risk that accelerometer can fail because of the same reasons as gyro-sensor.

Power plant supposed to deliver power to create torque by stepper motor. One risk is that the power plant will fail to accumulate enough energy to perform the required movement.

The same risk is for the low resolution camera's stand and for mechanism of movement of the antenna, and on antenna mount located HD camera box.

There is a risk that in time of the movement low resolution camera stand can break, this will not allow the retraction of the box to high observational point, plus ability of the rover to move will be crippled.

There is high risk that during movement Pin holes in low resolution camera's box can be jammed with a dust.

2.2 Image processing capability, low resolution JPEG, HD -JPEG, MP4, storage flash memory

Image Processing Risks:

- Low resolution cameras sensor can be out of operational temperature conditions
- For imaging processing of a low resolution picture there is a risk of damaged by high energy particle
- Imaging micro-controller, can be also out of operational temperature conditions
- FLASH memory to be damaged by high energy particles, while on the path to the moon, and on lunar surface (where its 40% less than that on the orbit). Damage can be to micro-controllers programming FLASH memory, to individual (belong to each micro-controllers) FLASH memory storage, and to memory storage like micro SD FLASH.
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2.3 Camera thermal control

Active and passive thermal control for a both HD and low resolution camera can fail.

Thermal Control Risks:

- High than expected heat flow from sun radiation because there's damage to reflection gold layer.
- box with low resolution cameras and HD camera's box will not be able to move to a position with less/more heat flow, as a result cameras will not be only out of temperature's operation conditions, but can sustain damage
- In "on orbit" mode not enough power to orient craft in position to support balance of a heat flow to low resolution, HD camera
- Li-ion battery can be damaged by out of operation temperature conditions
- Failure in software algorithms to keep stable temperature condition. That risk is higher than any other. Reason is - heat transfer via radiation and contact passing between electronic equipment are commonly assumed to be described (heat equation) as a parabolic partial differential equation. That type of equations are described by non-stationary processes, which mean that heat transfer process

changes its characteristics with a time as time depends on the function's parameter. Even modern computation methods, available for finding numerical solution, are hard to apply with lots of unknown parameters belonged to real structure. Controlling that processes is hard, because a long, hard to calculate, delays between "control action" and temperature respond of the system. Best recommendation for control (functions describing process of thermo stabilization) are useless, unless the thermal system has a big "heat flow", which are in contradiction with craft / rover condition when heat "expenses" can "drop" only by the heat radiation.

2.4 Risk assessment. Interfaces to other subsystems.

For exchange between microprocessor we developed special serial protocol. That protocol allows for the exchange of any data between each unit (micro-controller). HD Camera stores video and picture in the same storage as low resolution picture obtained by low resolution cameras.

Risk of failure for interface are:

- Failure, partial or total, of a micro SD FLASH memory because of external events
- Algorithms bugs/errors in implementation of data exchange between units, or between units allocated remotely from each other (mostly this is a failure in algorithms inside RF communication protocol).

3.0 Scope of the subsystem being developed

3.1 Being developed. Mechanisms for retracting low resolution cameras, mechanism for pointing HD camera

Mechanism for retracting low resolution camera was designed, prototype was manufactured. We estimated a time for manufacturing flight ready mechanical components from chosen materials - carbon fiber made with special epoxy withstanding -70+300C. With 3D printed dissolvable molds for stand, camera's box, was measured a time of manufacturing parts ready for flight certification - it is 7 days (10 days for 3D printing molds from dissolvable material. Those 10 days can be to reduce to 1 day with multiple printers, and 3 days required getting proper carbon fiber parts with required gassing parameters. 2 days are needed to manufacture in-house titanium gear.

Mechanism for antenna orientation and HD camera box also was designed, prototype was manufactured, and time required for operations to produce flight ready parts was measured. Material (carbon fiber for rover) requires 24 hours process for curing epoxy that is done because for outgassing performance was chosen AREMCO-BOND-526N. For initial curing and solidifying 24 hours are required. Space in curing oven is one of limitations in manufacturing process. For simultaneous heat treatment of carbon fiber parts it’s better to have oven with big chamber's size. Another time limitation is a 3D printing process itself. Dissolvable mold creation is slow process. One printer can create one part for a mold in 10 hours. Use of multiple 3D printer for such mold creation could be a solutions to speed manufacturing time.

Gear was designed and prototyped. Technological operation for creation of the two gears (for low resolution stand and for HD camera/antenna mechanism) require less time than for carbon fiber - that gear's part is printed from a mixture of Ti, Ag, and graphine powder. Curing process in vacuum chamber takes 3 hours.

3.2 Being developed. Image processing capability

For low resolution camera was chosen NNNN sensor, optics was removed, and imaging sensor was adapted to work in vacuum conditions. Low resolution camera allows retrieval of pictures with the sizes of 640x480 RGB pixels. Serial interface performed slow but reliably. Thermal tests (-75C +125C) was not performed on low resolution camera's sensor / camera's imaging processioning micro controller.

HD camera selection process includes drop text of a camera from 1.7 m, and -70C temperature expose 3 times for 5 min with followed +125C expose for 5 min. Temperature rise was around 10 degree per minute, temperature fall was around 20degree per minute. Temperature test was done without Li-ion battery, and micro-SD FLASH memory card. Temperature was measured by 0.5C precision thermocouple electronic thermometer. From 6 cameras candidates only 2 passed the drop test. Both of them without any modification passed temperature test -75C +125C. Functionality of a camera after exposed to heat or low temperature was tested after camera's temperature returned to 25C.

For HD camera was designed special technique to fit camera into carbon fiber sealing box. Harness (aluminum) cut to fit camera's existing mounting points, then harness embedded into box in a time of box's manufacturing (curing epoxy). Box is made from carbon fiber with additions of a graphite < 0.05%. Curing of epoxy is done according to the schedule and temperature profile required for low outgassing in vacuum conditions. Last step in manufacturing (after mounting HD camera inside the box) is sealing everything with another epoxy component. That epoxy is different from original used in the box's carbon fiber manufacturing. It does not require high temperatures (like +200C) to cure. This allows us to seal HD camera box under 25C under air conditioning. Epoxy for a sealing is mixed with graphene and hallow spheres. All areas inside the box are filled with that "sealing" composite. Additionally for the sealing used indium metal and M1 screws and bolts. That bolts keep cover of the box. In time of box's manufacture 15 copper wires embedded through the walls of the box and allow for the connection of data transfer and electrical lines from outside the box. Triplex glass for a window was obtained on a car junk yard, and cut for a desired size. Original HD camera chosen in 2010 has mechanics with retrieving of the optics before making picture. In 2012 we chose another camera without such big empty area required inside box.

3.3 Being developed. Camera's thermal control.

Temperature sensor DS1822 was chosen to monitor the temperature. Accuracy of the measurement is +-2C from -55C +150C. Sensor has special interface to communicate with multiple device over the same power and data line. This makes it minimum power requirement to get digitized temperature readings. Two micro-controllers can read all temperature measurements for all rover.

Thermal control study for HD camera box and low resolution camera's box was done during experiments performed on extruder system of a workable 3D printer in 2012. In case of extruder task will be to keep temperature 185C as stable as possible. To control temperature extruder uses heating element which can add heat flow into a system. Passive (convention) outflow of a heat is done by cooling elements of extruder. The mechanical characteristics of the extruder provide different characteristics for heat flow in parts of the extruder. Additional airflow can be introduced to increase outflow of the heat from the extruder. 3D printing was chosen because that technology was already designed and implemented with different technique for temperature control.

Temperature sensor on extruder gives temperature readings with precision of 1C. All source code was available to analyze. First we analyzed "bang-bang" temperature control method - basically it is a type of control when temperature reached some level then heating element was switched off or on. This technique allows us to keep fluctuation of a temperature in +-10C range. That method was assumed as a "basic" starting point for the study. Then we used another technique, with accounting dynamics of the heat flow throw the extruder. That technique claimed to be +-1C degree accuracy, but in real tests with independent measurements it did not show any improvements better than +-5C. Logic of the formulas with the explanations of temperature control was clear but it did not reach claimed values. More experiments followed to improve/adapt/change control based on formulas, but without success. Finally an attempt was done to increase heat flow by applying additional cooling fan, and by increasing speed of extracted filament, that improved performance but fluctuation of a temperate still was +-5C. Testing technique with software controlling, used on 3D printers, was assumed to be the same for target HD camera box and/or for low resolution camera's box. Instead of cooling fan in the craft we will use the technique to rotate craft to position with biggest temperature derivative. This derivative will supply the "real" characteristics of a HD/low res camera's boxes. And "real" performance values will be in calculations to keep all cameras equipment under operation’s temperature conditions.

3.4 Being developed. Interfaces to other subsystems

Schematics have been developed (two sequential versions was tested) for connection of a low resolution camera in multiplex mode to main micro-controller. The serial interface of a camera is multiplexed with GPS device serial interface, memory storage serial interface. Software for process the picture from low rec camera allow to be flexible in choose 3 different types of micro-controllers. JPEG compression / decompression developed and debugged on 2 types of processors. HD camera interface includes 6 switches allowed to make turn on/off HD camera, take picture, and a video. That interface was connected to main computer. Main microcontroller can be chosen from one of 3 different types of microprocessors.

Software was implemented to process data from gyro- sensor (ITG-3200) and accelerometer (ADXL345) to properly orient low resolution cameras and antenna with HD camera's box.

For alternatives for a FLASH memory was tested two type of memory – magneto-resistive and ferromagnetic. Both were found capable to substitute FLASH type. Similar footprint of serial FLASH memory surface mounted component. Same protocol of data exchange are used. Benefits - low write memory time, but better withstand of radiation levels. Disadvantage - low memory capacity. We decided that switch from FLASH to magneto-resistive or ferromagnetic memory type can be done even 1 month before flight, by re-soldering already assembled electronics’ components.

4.0 Scope of the subsystem being verified

4.1 Being verified. Mechanisms for retracing low resolution cameras, mechanism for pointing HD camera.

Mechanism for rotation was prototyped.

Verification of the control system for stepper motors, and gyro-sensor / accelerometer processing.

Stepper motor control software uses low power in stepper motor steps movements. Modern stepper motor controller can make 1/4 even 1/8 of steps originally performed by motor. Such approach requires keeping a current over coils to perform precision steps.
Designed gear for low resolution camera stand was prototyped, second version of a gear was designed. Estimations of time for manufacturing flight ready gear.

4.2 Being verified. Image processing capability.

Process of retrieving pictures from low resolution camera was confirmed, retrieving data from micro SD FLASH storage of HD camera. Process of taking picture / HD video by HD camera was also verified.

4.3 Being verified. Camera thermal control.

Temperature sensor reading software was verified along with temperature controlling technique with applying heat, applying cool capability.

4.4. Being verified. Interfaces to other subsystems.

Technique to store data in separate 3 FLASH devices was verified. It has 2 solutions - software and hardware. 3 devices (with serial FLASH interface or micro-SD FLASH memory card) used one output data serial pin to store data, and majority voting (2-from-3) from 3 devices on read operation. Software solution works on all 3 types of micro-controllers, and allows flexibility to tailor power consumption of flight electronics. Software can work in 2 different configurations - with 3 output pins for each FLASH device, or with one output pin. Majority voting implemented also in software. Hardware solution is a software solution too. In this case additional micro-controller with small SMD footprint can be added. In that case it will be additional 2g weight. Additional schematics with hardware implementation will include 1 micro-controller, which will require additional routing of connection traces to FLASH memory. Hardware and software solutions allow work with max speed 25MHz with FLASH memory device.

5.0 List the key functional performance and interface requirements of the subsystem and the environments in which it must operate and survive.

5.1 Mechanisms.

Assumption was made that the operation temperature for all mechanism used in imagining system -70 + 125C.

Dust conditions for mechanisms - particles size 10% < 5mkm < 10% < 20mkm < 10%, < 50mkm < 30% < 0.5mm < 40%

Temperature operation conditions for electronics used in imagining sTemperature operation conditions for low resolution imagining sensors -20+85C.

Temperature operation conditions for HD camera -20+85C. Temperature operation conditions for HD camera -20+85C.

Performance by mechanisms - stand for box with low resolution camera has dual use - as a sent to lift camera for high observation point, and as a leg for movements of all rover.

Resonance frequency for mechanics must not be equal to the frequencies of another part of the rover and craft's frame, or crafts engines. Low resonance frequency of a mechanism of imagining subsystem must be higher than 30 Hz.

5.2 Image processing capability

- High resolution camera needs to delivery 5megapixel picture and HD video 720p
- common storage FLASH memory 1Gb
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5.3 Camera thermal control.

Thermal control should keep temperature

- Range of -20C+85C inside box with low resolution cameras
- Range -20C +85C inside HD camera's box

5.4 Interfaces to other subsystems.

Interface with communication subsystem need to be capable to delivery (via ground station) to mission control pictures and video, with ability to restore received packets "on the fly", or ability to restore data later by analyzing stored data of communication packets. Restoration of broken packets is essential for all imagining system functionality. Any modern communication protocols design divides all communication to subsystems, named "network protocol layers". That allow group of developers to concentrate on small task, and to deliver another "protocol layer" designers the interface to communicate from one layer to another. Usually that assumes each layer has limited ability to know what is going on inside. Noisy environment around a ground station is not only the main reason mostly that is because pictures and video needs to be delivered from the lunar surface. As a result the "standard" approach with separation of a communication to the layers can be expensive. Data from low level needs to be traced back to command processed, and from opposite side delivery of a video from micro SD FLASH storage needs to be traced as low as possible to broken/lost packets, in this case restoration can be done by applying brute force computing to approximate payload data. In that case restoration can be done even days after communication session with retrieving video/pictures from rover/ craft.

6.0 Critical technical risks that must overcome to bring the subsystem to flight ready status

We as a team do not have any experience in space flight. And we cannot buy any flight experience, because usually anything that we are doing is considered "restricted" information and technology. On the market there are available solutions, however after our initial investigation it shows that those solutions are useless to reduce main risk. Open source solutions do not contain key element require for risk reduction. One possible way to reduce risk is to stay closer to Space Agencies, which is probably the same dream as the dream of reaching the moon.

To overcome that technical risk logical step will be used to fly nano-satellite. Imagining system in this case can show it performance in flight. All mechanical parts for the imagining subsystem including rover can be tested. For such task we have taken steps to make that testing mission possible. We designed and manufactured frame of Nano satellite and designed and prototyped for all mechanics and electronics for Nano satellite mission. An arranged launch was made, which was unfortunately postponed numerous time. Planned time was a spring of 2014 the date was shifted because of technical challenges faced by the launch provider.

Special tests required for certification of the flight on launch vehicle.

Testing on vacuum outgassing test, for such test we need to place an assembled rover into a vacuum chamber and as vacuum level reached 8 mTor heat applied to structure till 70C, vacuum level in chamber measurements will be taken during 2 hours. Confirm the "good" outgassing of the rover will mean that there isn’t a "big" increase of pressure inside the vacuum chamber.

Second important test is a vibration test. It is done on full assembly of the craft. Lunch vehicle provider needs to make sure that craft, placed in cargo bay, will not be loose, broken, and mostly will not create problem to lunch vehicle itself. Basically, such testing is performed by lunch vehicle's provider. To prepare for "passing" such tests we need to know resonance frequencies of all parts / frames of the craft. Such study can be done today on

CAD simulation software. Requirement is not only to have 3D model to have 3D assembly as one solid structure in CAD simulation software.

Testing, to confirm that manufactured hardware parts of the rover/imaging system are the same as they were in the design we'll need to do a study on in-house vibration table and acoustic system to confirm resonance frequencies of manufactured parts.

Vibration testing requires regular access to vibration table with frequencies 0-200Hz. Furthermore, acoustic test equipment is able to detect resonance vibration on frequencies 200-1000Hz to detect resonance vibration on frequencies 200-1000Hz.

6.1 Mechanisms for retracting/orienting HD and low resolution cameras

To reduce the risk we will perform testing of the imagining system in Nano satellite flight. For flight's testing imagining subsystem split into two major parts. One part included mechanics for ground station. It is the same mechanics to be used on a rover- (a) stand of a low resolution camera box, (b) mechanics on a rover for the antenna mount of the ground station (on antenna's mounted HD camera's box). Second part of a mechanics (for imagining subsystems), is attitude control on a Nano satellite. Attitude control of Nano satellite includes 3 orthogonally placed stepper motors intended to compensate/create rotation around 3 axis of a Nano satellite. Attitude control on Nano satellite includes gyro-sensors and software designed to control rotation around 3 axis, that software is the same as on a ground station to control direction of the antenna and the same as on rover to control stand of a low resolution camera's box, and mount for HD camera box. They are no difference in software for all mechanical configuration. Software has to adapt itself to a responses performed by mechanical actuators (stepper motors with different amount and type in all configuration) and corresponded readings from sensors. Adaptive capabilities of the software (to control different mechanical configuration) must give autonomy from mission control.

To reduce the risk before test flight of a Nano satellite mission considered a range tests which will include ground station, Nano satellite, and mission control. During this tests imaging system have to perform on ground station (mechanical equivalent of the rover) with low resolution camera

A vacuum test is required to reduce risk before test flight of the Nano satellite. These tests are planned to place full functional Nano satellite into a vacuum chamber with RF and visible light transparent cover. The tests will confirm full Nano-satellite functionality in vacuum conditions.

To reduce risk before test flight and main flight all mechanical components of a rover and Nano-satellite will be exposed to temperature limits of operation conditions on regular bases. Cycle is performed weekly - 6 hours -10C, 1 hour -75C, 30 minutes heating to +25C, then 1 hour under +125C with cooling to +25C.tes heating to +25C, then 1 hour under +125C with cooling to +25C.

To qualify for a flight on a launch vehicle vibration and acoustic study must be performed on the nano-satellite, which will include vibration table tests to confirm that resonance frequency is in a designed range for nano-satellite, same goes for the stand of the low resolution camera box, for antenna with HD camera box, and for gears.

Will be mandatory test require for certification of a Nano satellite and craft to fly on launch vehicle.

To qualify for a flight we'll be performed vibration and acoustic test to match vibration and acoustic profile of the launch vehicle. That requires two tests first one for Nano satellite test mission, and second test provided (probably) on the launch vehicle provider facility.

To qualify for a flight outgassing tests must be performed in a vacuum chamber. There also has to be two tests first for Nano satellite mission and second for frame and rover of a main mission. Outgassing parameters for the engines will be obtained from the engine manufacturer.

6.2 Image processing capability

To reduce risk we have considered alternative technique for use low resolution camera with operational temperature ranges from -40C +125C. That development will require solution to port existing JPEG compression library.

To reduce risk of damage by high energy charged particles in PCB added patches with special gold layer formed on top of a lead-alloy's half-filled holes. Holes located under the core of each electronic surface mounted component. That will reduce chances of high energy particles, flying from the side of PCB, to collide with electronics' core. From a side of SMD mount, less protection means fewer chances to collide with secondly generated particles produced by original collision of cosmic/sun particles with a protection shield. All SMD electronics component chosen with as low as possible profile to reduce risk of radiation damage, and location of the core of the component analyzed. Basically for a design it means placing additional hole(s) with various diameters under SMD. To reduce risk for FLASH memory damage (or if decision will be made to use magneto resistive / ferromagnetic memory) we have decided to have software and hardware solutions with 2-from-3 majority voting logic for reading of FLASH memories, with simultaneously writing onto 3 memory devices. Software solutions will include software algorithms for majority voting, that solution already tested for 3 different types of micro-controllers selected for a mission. Hardware solution includes additional microcontroller performing such logic on operation read/write for FLASH memory. All 3 FLASH devices will be allocated as far as possible from each other on PCB to reduce chances of damage memory from radiation to a core of FLASH SMD. No tests are planning to verify radiation risk - we simply cannot afford it. Nano satellite test flight should give some assurance, but that risk will be unknown until main mission flight to the moon (not much information is available from public domain about radiation levels).

The risk of static discharge on pins of imagining system electronics will be reduced by applying special coating of urethane on all electronics PCB. Urethane coating is also necessary for elimination the risk of a circuit short-cut created by tin's crystal growing from soldering alloy. Micro-controllers chosen for a Nano-satellite and for a main mission (PIC micro-controller family) was tested for a static discharge and previously was used in a space flights, we hope that static discharge will not be a problem for micro-controllers used in imagining subsystem.

Risk for on board FLASH memory of micro-controllers to take damage by high energy particles is really high. A design is done to allow re-program each micro-controller used on flight of Nano-satellite or main mission flight. Binary for re-programming can be downloaded from mission control at main communication session time, or from FLASH memory storage pre-recorded before launch. Two binary versions with same functionality will be compiled, with different location of a compile code allocated in FLASH memory. Storage in this case has to be twice of the original required capacity. If first image fails to execute, (or check-sum of self-tests fails), second binary will be used to re-program micro-controller.

6.3 Camera thermal control

To reduce risk of a failure planned to use special heat/cool, on/off tests/design technique - source of the heat capable to delivery heat flow over surface of the box (low res camera / HD camera) will be switched on /off and energy flow will be measured. Cooling will be provided with ether with 0C cooling reservoir, or with -75C cooling container. Camera's thermal control will be tested to produce on/off signal that will switch on/off heat source (capable to heat imagining system component up to +125C). In a real flight of a Nano satellite (or on a craft in main mission) thermal control subsystem will give recommended orientations command for the best heat/cool. To confirm proper processing / collection of a thermal data will be performed test, when ground station will exposed to a heat radiation (with +125C) and cooling source with -75C, in this case software has to detect cooling and heating orientation (directions) for antenna/imagining subsystem mechanics and issued a commands, send over inter-unit serial communication to perform temperature stabilization.

Test flight of the imaging subsystem on board of Nano satellite is considered as a main camera's thermal control tests. Temperature data collected and calculated from sensors can be downloaded to confirm software performance.

6.4 Interfaces to other subsystems

Standard automatic software testing technique are used in software development. Tests confirm the functionality of the inter-unit communication protocol. That tests are a routine checks performed in development daily. For double conformation, a list of test's cases for all commands in imagining control will be considered. That list will be included in the main test list for all functionality on Nano satellite and craft. Mission control will be able to initiate test list for imagining subsystem. Tests will be performed before flight.

Same automatic test's sequences of a functionality of common FLASH memory storage will be incorporated into a mission control. In time of Nano satellite flight tests for imagining subsystem will be performed by mission control request.

Risk for algorithm's bugs/errors in data exchange between units, or between devices allocated remotely from each other (mostly those are bugs in algorithms inside RF communication protocol) can be reduced by heuristic process only. Nothing can be done, except capability to upgrade software in-flight. It is mandatory to reduce such risk. Test in Nano satellite test flight will include of upload of software version of all available micro-controllers, with upgrade of all software on board.

7.0 Demonstration planned

"Ground" demonstration with transmitting data over 100km distance in BC mountains, Ground demonstration rehearsal with reducing transmitting power and transmission data over noisy environment (city noise, with 1 mWt transmitter, over 25 km range). Both tests will be recorded and available over Youtube channel. Judges will be invited to attend.

"Flight-to-Ground" demonstration, with Nano-satellite during communication session, this is the most important test which will include one communication session over the ground station from mission control. Judges will be invited to attend ground station.

"Flight-to-Ground" demonstration will include taking low resolution and high resolution pictures by low resolution and high resolution cameras on demand. Also for flight ground demonstration on demand will be recorded on Nano-satellite two 15 minutes video clips with 720p HD quality.

“Ground” and “flight-to-ground” demonstrations, judges will have access to a mission control over web mission control web server.

“Ground” demonstrations will have transfer data with pictures and HD video data from Nano-satellite to mission control.

Another “ground” demonstration - low resolution pictures obtained by modified version of the rover (ground station) will be delivered to the mission control.

For the “ground” demonstration we have planned two events. First, pictures of the earth and moon exposed to a Nano satellite suspended by a wire. First demonstration will be combined with a long communication range 100km test. Rehearsal of a long communication range test (first “ground” demonstration) will be at 25km communication range test. Second, “ground” demonstration event planned after Nano satellite flight (or instead of a “flight-to-ground” demonstration in a case of a delayed Nano-satellite flight test). That will be with build rover (exception- for a rover’s frame - epoxy for carbon fiber will be different from originally chosen for a rover). Another adjustment for the second “ground” demonstration event - on wheels’ stepper motors will be additional gear boxes, 3D printed from titanium (ether in-house or from 3D factory), that is done to accommodate gravity difference of original rover and it’s ground version.

For the second “ground” demonstration will be a short communication distance between ground station and a rover. Transmitting signal will be 0dBm (1 mWt) for ground station and rover.

For second “ground” demonstration event the lunar regolith will be simulated by a ray flower - it gives the same texture and dusty conditions as on lunar surface will have realistic view.

For second “ground” demonstration event, typical craters and rocks/boulders will be simulated by a mockup.

The GLXP logo cluster will be mounted on top of impact shield placed under the rover for a second “ground” demonstration event.

In second “ground” demonstration event the parts of the frame with mockup of the brake engine, and destroyed impact shield (from tests of impact shield) will be used.

Illumination conditions - sunrise will be simulated by projector, pointing to solar panels.

“flight-to-ground” demonstration with Nano-satellite test flight will include pictures obtained on demand from mission control:

- Earth low resolution (at least one picture)
- Moon low resolution picture (at least one picture)
- Earth HD resolution (at least one picture)
- Moon HD resolution (at least one picture)

- earth HD video 15 min, one clip
- moon HD video 15 min, one clip

Frame rate for HD video will be 30 frames per 1 second.

Before “flight-to-ground” (Nano satellite’s test flight) demonstration and “ground” demonstration will be produced and presented "Content Plan for the Moon-cast Ground Demonstration" document.

The low / high definition pictures HD video will available for view and download from mission control server. Password and log-on will be provided.