TELEMETRIC INTERPLANETARY REGOLITH EXPLORER FOR SEISMIC INVESTIGATION OF ASTEROID SURFACES (TIRESIAS)

PROJECT DEFINITION DOCUMENT

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Contents

TIRESIAS Senior Project
Project Definition Document

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I. Problem

The Binary Asteroid in-Situ Explorer (BASiX) mission will consist of a mothership sent to orbit an asteroid and deploy spherical CubeSat-sized modular probes to the surface to gather data about the composition of the asteroid's surface motivated by NASA. These probes will be limited to one of two functions: the "blast pod" will explode after all the probes have settled on the surface to generate a seismic pulse, and the GeoPods deployed to the surface will collect the seismic vibration data in-situ and transmit this data back to the mothership, which will relay the data back to Earth. The BASiX mission will provide a new method of characterizing the asteroid's surface using a distributed set of GeoPods, presenting challenges in the design of a CubeSat-sized probe that must survive impact on an asteroid. This characterization will allow evaluation of the safety of the surface for human exploration or analysis of the asteroid composition for mineral development purposes. The Telemetric Interplanetary Regolith Explorer for Seismic Investigation of Asteroid Surfaces (TIRESIAS) student project group will design, build, and validate a terrestrial GeoPod data acquisition module in support of the BASiX mission. The TIRESIAS student-constructed probe will provide for acquisition and communication of accelerometer data and housekeeping telemetry, structural support and integration within the spherical constraints of the mothership storage space, and electrical power for the GeoPod system. Demonstration of the operational terrestrial GeoPod with functioning bus in the laboratory will aid in the construction of additional GeoPods from flight hardware, which will allow for the realization of the BASiX asteroid exploration mission.

II. Previous Work

Near Earth asteroids have been a key area of study of the scientific community for the last few decades, particularly because of the threat they pose to colliding with the Earth. Between NASA's Sentry and NEAT programs[2], most of the asteroids close to Earth are being tracked with great accuracy. These asteroids are not just seen as threats to Earth, but also a window into the makeup of the formation of our universe.

Currently, many methods are used to determine the geological composition of asteroids. These methods are mostly based upon imaging and radio wave emission, such as analyzing infrared spectroscopy from ground based telescopes or radar[2]. These methods can be effective in determining the minerals that are present based upon the absorption of different wavelengths of light, or can analyze the reactions of the wave reflections from the body[3]. These techniques have limitations due to range, low light intensity, and unpredictable asteroid orientation[4]. Therefore, a more effective method for studying an asteroid's composition is by sending a spacecraft to the body itself. Current satellites that have intercepted asteroids such as NASA's NEAR-Shoemaker are limited in that they usually only provide imaging and no physical data[2]. Therefore, the future in asteroid study will rely on physical methods to alter the surface of the body through sample collection or surface perturbation.

Two comparable missions, Rosetta and Deep Impact paved the way for the BASiX system. The Rosetta spacecraft will attempt to take physical samples of the asteroid when it reaches its destination in January of 2014[2]. It will feature a small lander named "Philae," designed to take ground samples and use advanced imaging[2]. The Philae lander will prove that the use of a small-scale cubesat lander, similar to the BASiX probes, are effective in asteroid surface study. Another project that has influenced BASiX is NASA's Deep Impact Satellite, which was able to create a crater using an impactor on the surface of the 9P/Tempel asteroid[2]. This proved that the unique method of crater creation is an effective way to study the composition of an asteroid by the behavior of the blast region. Unfortunately, the debris from the impact created too much dust for the cameras on the Deep Impact Satellite to visually analyze the crater, which limited the mission's success[2]. Since BASiX will not solely rely on imaging to collect data because of its use of physical perturbation measurements, it will be advantageous to the Deep Impact mission.

The uniqueness of the BASiX system is that it will be the first of its kind to utilize the creation of craters, coupled with physical sensors (geophones), on the asteroid surface to determine the fundamental mechanical and strength properties of the body[4]. Not only will the visual behavior of the crater creation provide valuable information such as Deep Impact, but the perturbations and shock waves through the surface will set BASiX apart. Through its physical measurements by way of geophones, which measure infinitesimal displacements to determine perturbations; the geomorphology, dynamics, and composition of the NEA can be found[4].

Currently in development by Ball Aerospace, the BASiX probe is in TRL 4[4], inincluding the avionics, power system, impact damping system, structure, and detonation device. Technology readiness level 4 constitutes that the component/subsystem has been validated in a laboratory environment[5]. The design of the communication system is still in its preliminary stages and requires further development, which will be the primary focus of this project. Brief trade studies have been performed by Ball on only commercial communication radios. All of these radios have been or will be been used on a cubesat, which constitutes the fact that they meet BASiX requirements and have been demonstrated in LEO[4]. A few examples of these systems include L3 Communication's CadetU, a Microhard MHX2400, an AstroDev Li-1, and Vulcan Wireless technology[4]. Additionally, Ball has developed dual-band Tx/Rx UHF (ultra-high frequency) patch antennas that have been demonstrated to be compatible with a COTS (commercial off the shelf) radio system[4]. Two of these antennas will be used per probe and will be oriented to minimize interference pattern and maximize coverage[4]. Although these communication system components have been found to be feasible options, complete trade studies on the aforementioned and unstudied hardware need to be completed to find the design that fully meets all mission requirements.

III. Specific Objectives

The primary objectives of team TIRESIAS are listed below:

Level 1: Develop communications subsystem to store and forward accelerometer data at 128 kbps and receive state commands from a transmitter. Design an internal structure to hold a communications subsystem based on Commercial off the Shelf (COTS) hardware customized for the BASiX mission. Test the communication subsystem to show accelerometer data transmission during simulated accelerometer disturbance.

Level 2: IIntegrate communications subsystem onto GeoPod platform with successful data transmission test. Power, structural, and accelerometer subsystem components fully designed and functionally modeled. GeoPod physical components modeled into restraints of pod design.

Level 3: Fully independent and integrated GeoPod, functional only under its own hardware, delivered to customer passing structural and communication testing.

The communications subsystem will be designed into a derived GeoPod design based on the current probe. It will be proven that communication between the BASiX satellite and probe is possible at 95% of all orientations of the probe using a simulated ground station (built by TIRESIAS) under independent GeoPod operation. At minimum the communications system shall prove that a subsystem can be designed for 128 kbps uplink rate, 2kbps downlink rate, and fit into the GeoPod form factor, per customer requirements. The subsystem must function from 0.1-10 km at stated rates. A telemetry board shall be designed to handle uplink and downlink data requirements and shall handle commands sent to the system (up to 512 commands).

A test simulating the shock of landing on an asteroid surface shall be conducted using low-cost and simple parts to increase the TRL of the probe design to level 4, a breadboard test bench functionality level. Additionally the subsystem must be designed from current space components proven in previous missions to ensure functionality.

The power subsystem will be designed to support the new GeoPod configuration. The system shall undergo functional demonstration of a low-cost and simple prototype unit after integration of the Electrical Power Distribution System (EPDS). This will successfully increase the TRL of the entire GeoPod system to level 4 as required by the customer.

Deliverables include a detailed design of the GeoPod system derived from the current probe, a mock-up of a single GeoPod unit, and ground support equipment for verification of the subsystem .

IV. Functional Requirements

Figure 1 shows the outline of the design focus of this project. A prototype GeoPod will be developed that shall communicate with a simulated BASiX spacecraft. The power and communications systems shall be designed to transmit the data of the accelerometer with similar resolution and range of the instrument to be used on the Ball spacecraft. This accelerometer data shall be stored onboard the GeoPod until commanded by the BASiX spacecraft, at which point it will be transmitted back to the BASiX spacecraft at 128 kbps. The 128 kbps is a requirement of the BASiX mission given by Ball Aerospace. In the actual BASiX mission there will be five GeoPods used for seismic measurements of the asteroid, but this project will only focus on building a single prototype. The prototype shall be designed within the size and mass requirements of the GeoPod given by Ball. The GeoPod subsystems shall have a mass of less than 5000 grams and fit within a volume of less than 3000 cm3. Because of this, there are mechanical concerns with the design of the structure in order to fit within the GeoPod requirements and also to be able to survive the impact of the asteroid at a speed of 25 cm/s.

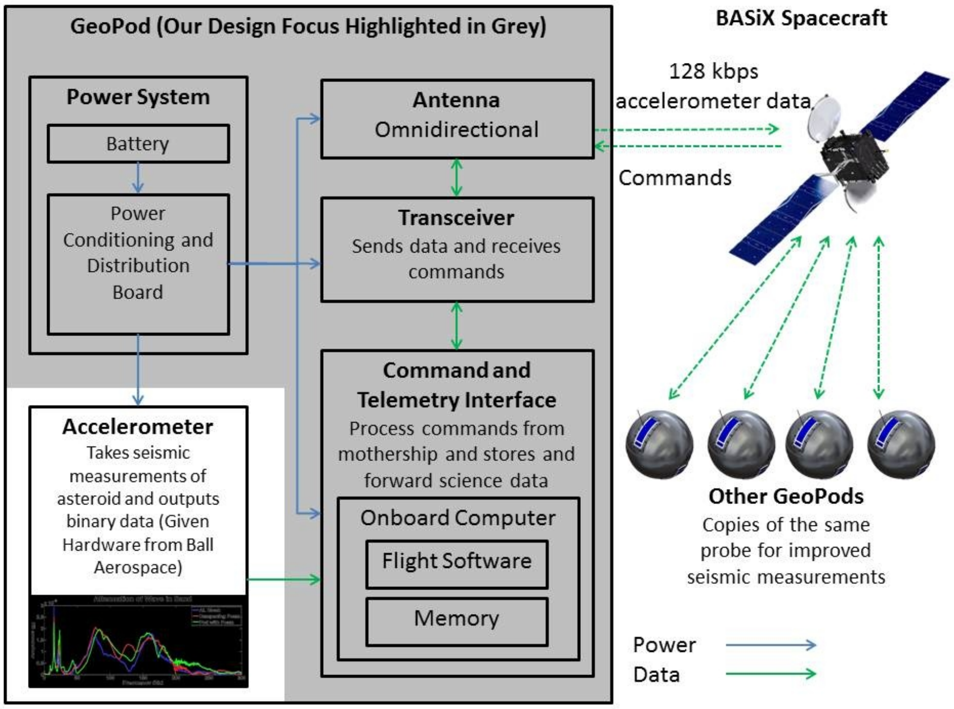

Figure 1. Functional Block Diagram

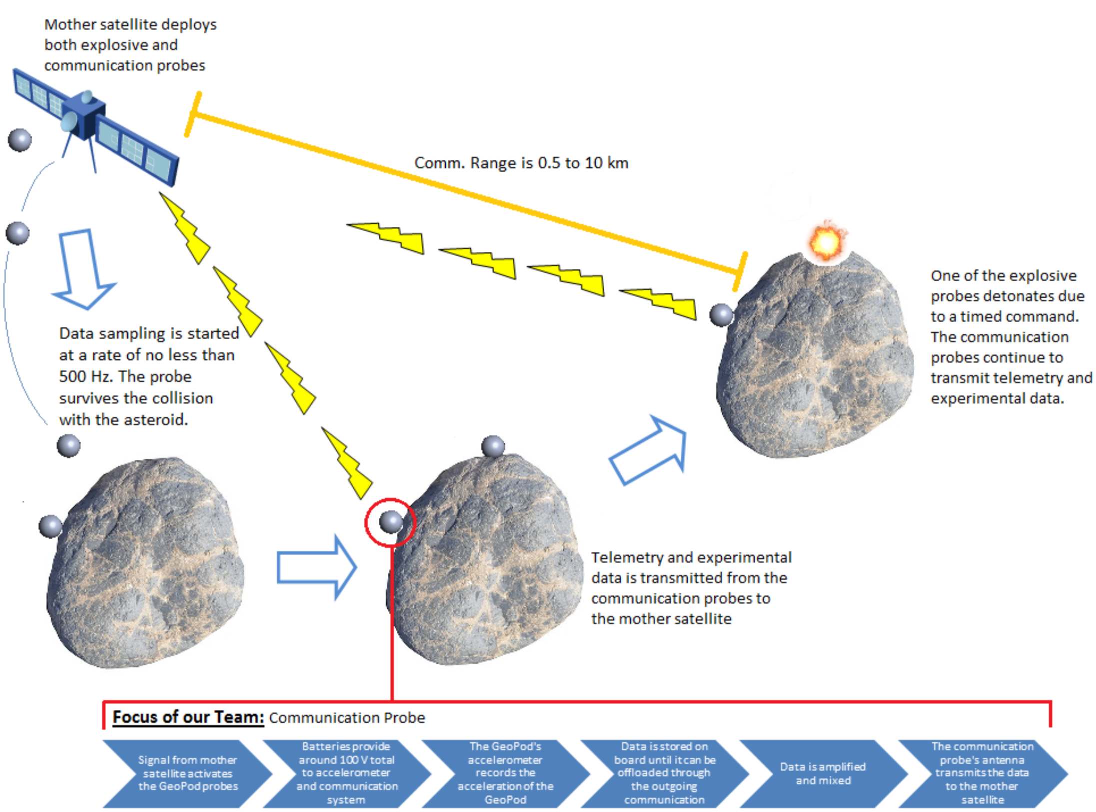

Figure 2. System Concept of Operations

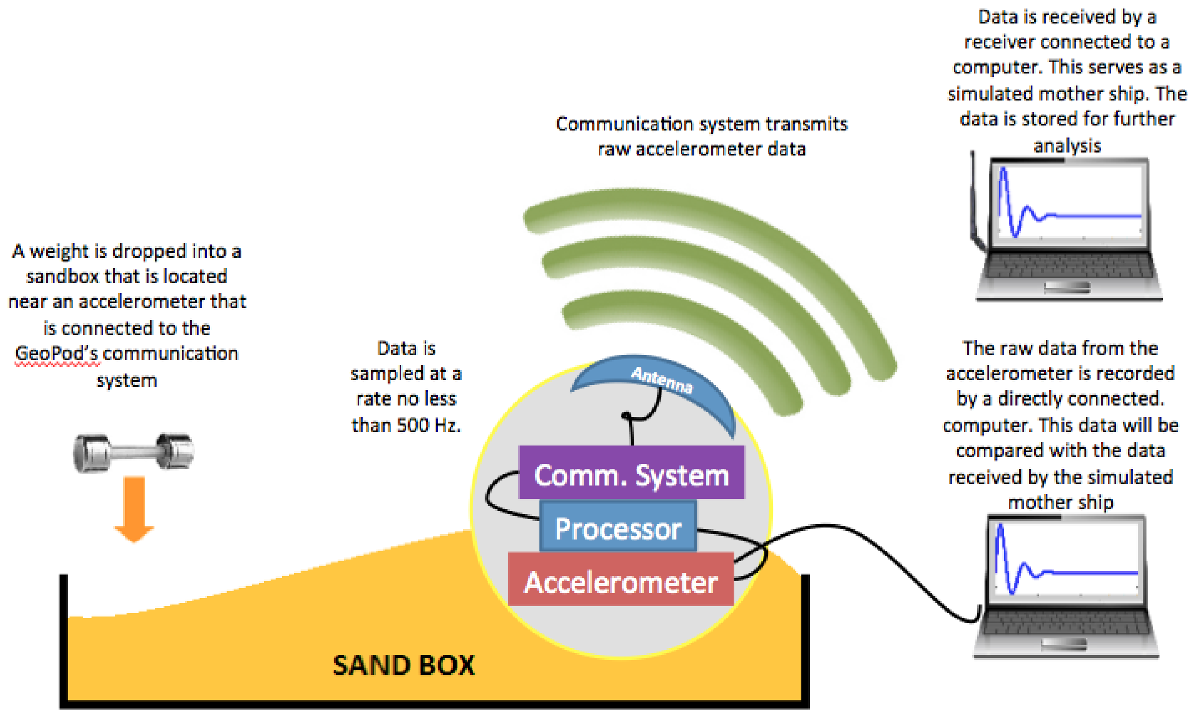

Figure 3. Testing Concept of Operations

The testing concept illustrated in Figure 3 will consist of one accelerometer placed inside a sandbox. It will be connected to the GeoPod's communication system. The accelerometer will also be directly connected to a computer. The accelerometer and the communication system will be activated. A simulated mother satellite (most likely a computer connected to a receiver) will also be activated. A weight will be dropped into the sand box. The accelerometer should record the response. This data should be transmitted through the communication system and recorded by the mother satellite. The raw data will also be recorded by the computer that is directly connected to the accelerometer. The data will be compared to determine characteristics of the system such as the bit error rate.

V. Critical Project Elements

- Receiver/Transmitter communicates with simulated mother ship. Achieving communication with the simulated mother ship is the largest concern of a communication system. This element includes proper software interfacing with the mother ship, antenna patterns that allow for communication in various orientations, and antenna protection on a simulated landing.

- Achieving the required data rate for the transmission of scientific data and the reception of commands. The transmission shall ensure undetected bit error rates (BER) less than 1×10^{-6} and uplink BER are less than 1×10^{-6}.

- The designed power supply must provide conditioned power to all of the subsystems of the GeoPod.

- Feasibility of size/weight requirements, breadboard prototype could be reduced in size/weight with an integrated circuit. It may not be necessary to meet the size and weight requirements of the mission if it can be shown that the concept can be done on a smaller scale.

- System survives a simulated impact with asteroid surface. The system must be strong enough to survive the impact with the surface. This includes the electronics inside the probe as well as the antennas on the outside of the probe.

Critical Project Elements	Team Member(s)	Associated Skills
Antenna Hardware	Ian Barry	Experience with RF Troubleshooting
	John Marcantonio	Interfacing hardware
	Scott Taylor	Experience with ground to satellite communication
	Patrick Haas	Link budget calculations
Command and Data Electronics	Ian Barry	Interface communication components
	Scott Taylor	Command and Data transfer
	Patrick Haas	Singal processing
Command and Data Software	Rachael Collins	Command and Data packetization
	Austin Lillard	Signal processing
	Tom Johnson	Programming of FPGA
Power Electronics	Ian Barry	Power circuit development
	Austin Lillard	Construction of electronics boards
Probe Structure	Austin Lillard	Thermal heat transfer analysis
	Patrick Haas	Finite element stress analysis
	Jon Fraker	Experience with computer aided design and modeling
	John Marcantonio	Mechanical design experience

VI. Team Skills and Interests

VII. Resources

Critical Project Elements	Team Resources
Antenna Hardware	Ball Aerospace - Previous Antenna Work Documentation
	Ball Aerospace - Anechoic Test Chambers
	Space Grant - Elliott Richardson and Kyle Kemble
Command and Data Electronics	Ball Aerospace - Joseph Hackel
	Space Grant - Brian Sanders and Chris Koehler
	Faculty - Scott Palo
Command and Data Software	LASP - Mike McGrath
Power Electronics	Faculty - Tim May, Zoltan Strenovsky
Probe Structure	Ball Aerospace - Probe Structure Prototype
	Faculty - Matt Rhodes

References

[1] *BASiX Pod Development Specification Draft.* Boulder: Ball Aerospace and Technologies Corp., 11 Mar. 2010. PDF.

[2] Carter, Lynn. "How Are Asteroid Compositions and Classifications Determined?" *Curious About Astronomy.* Cornell University, n.d. Web. 9 Sept. 2013. <http://curious.astro.cornell.edu/question.php?number=13>.

[3] Coffey, Jerry. "What Are Asteroids Made Of?" *Universe Today RSS.* N.p., 17 Aug. 2009. Web. 9 Sept. 2013. <http://www.universetoday.com/37425/what-are-asteroids-made-of/>.

[4] Hackel, Joe. *Small Body Lander Probe: RF for Asteroid Impacting CubeSat (RAIC).* Boulder: Ball Aerospace and Technologies Corp., 5 Sept. 2013. PPT.

[5] *Technology Readiness Levels.* 6 April 1995. Web. 5 Sept. 2013. <http://www.hq.nasa.gov/office/codeq/trl/trl.pdf>.