University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

LunaNet - Moon Communications Ground System

Approvals

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2.1 Project Customers

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3. Problem Statement

The year is 2050. We have a base for re-fueling on the moon and we have an established civilization beginning on Mars. Missions deeper into our solar system are beginning to be planned. However, as we continue to expand and explore further into space, astronauts need ways to stay connected. On the Moon, astronauts need to be able to know their position and where they are navigating to in order to explore. They need to be able to receive alerts in real-time, warnings for unprecedented space weather, such as solar flares, and incoming asteroids. Eventually, there may be a need for a networking system that expands the entire solar system. The first step to achieving this? The LunaNet Program.

Figure 1: Handheld Device with GPS and Texting Capabilities

This program calls for handheld communication with astronauts on the lunar surface; however no specific groundwork has been mapped to achieve this goal. Hence, this project focuses on developing a proof of concept system designed to demonstrate the ability to bring GPS and SMS-like reception and transmission to the moon.

This project will require an orbital analysis of the necessary satellites around the Lunar surface, where a link budget can be created to determine the requirements of the SDR. The designed SDR will then communicate with the orbiting satellites, allowing it to calculate GPS coordinates. The final goal is to develop a proof of concept prototype for a handheld device that calculates GPS coordinates to the relative accuracy of a modern cell phone, as well as show SMS-like reception and transmission. This prototype will lay some foundation for the NASA LunaNet mission for the next few years.

4. Previous Work

THe LunaNet concept was presented by NASA's Goddard Space Flight Center on June 11, 2019, with the goal of developing "a lunar communications and navigation architecture that will bring networking, positioning, navigation and timing (PNT) and science services to the moon" [2]. This highlights the overall grand scope of the project, with the ultimate goal of establishing a communications relay between Earth and the Moon, allowing astronauts on the lunar surface to stay connected with each other and back home. However, NASA is very much still in the early stages of this project. While our project focuses on a much smaller part of this overall mission, the results of this project will allow for continuation on the grand scope. It is hoped that the team's development of the proof of concept can be used to further expand the system on the moon; from a larger satellite constellation to development of more hardware to be used on the surface.

Furthermore, multiple universities, such as Stanford, California Polytechnic State University, and CSU (San Bernardino), have devoted time and resources to developing a GPS constellation system design on the Moon [3]. It has been found that the success of this project is highly dependent on deploying SmallSats with minimal weight and volume usage with the purpose of reducing mass and increasing the number of satellites to be deployed [3]. These are more desirable than larger satellites as they are smaller in size, cost less, and take a shorter time to develop. In terms of positioning accuracy, chip-sized atomic clocks are also included in the satellites to improve accuracy measurements, while the transmitters have been predicted to have a higher power range to reduce satellite orbit altitude needs. This research is usable, as it pertains to the orbital mapping and determination aspect of the team's project. However, certain aspects of this research, such as the actual make-up of the satellites, is out of scope of the project, but will be taken into consideration as it helps with the understanding of the system as a whole.

5. Specific Objectives

Shown in Table 1 are the various levels of success for this project. The levels of success for this project are designed to provide a risk reduction for the future development of the communication and positioning link between astronauts on the surface of the moon and the supporting satellite constellations. Levels one and two focus on the communication aspect of the project, while levels three and four aim to achieve the GPS functionality of the handheld device.

Table 1: Specific Objectives for the System

Level	Electronics	Software	Orbital	Testing
1	Handheld device receives data.	Handheld device receives RF signals and decodes message.	N/A	Data transfer and recognition over cable connection.
2	Handheld device transmits and receives data at 100 bits/second.	Handheld device transmits RF signals with encoded data/message.	N/A	Two way data transfer and recognition over cable connection.
3	N/A	Use known satellite data and known location to prove GPS functionality for time and position.	Determine speed, altitude, and location for 4 satellites required for GPS functionality. Calculate link budget.	Demonstrate MATLAB model for small satellite constellation and demonstrate positioning calculation in a small-scale test. Start testing cableless communications
4	N/A	Demonstrate GPS functionality for time and position, accurate to sub 10 (m) with a basic API for demonstration purposes.	Determine number of satellites, speed, and altitude, for a constellation around Lunar surface, calculate new link budget to meet Level 4 objectives.	Obtain 30ns 1-sigma transfer time, sub 10 (m) positioning for SMS-like capabilities and GPS

6. High Level Functional Requirements

6.1 Concept of Operations (CONOPS)

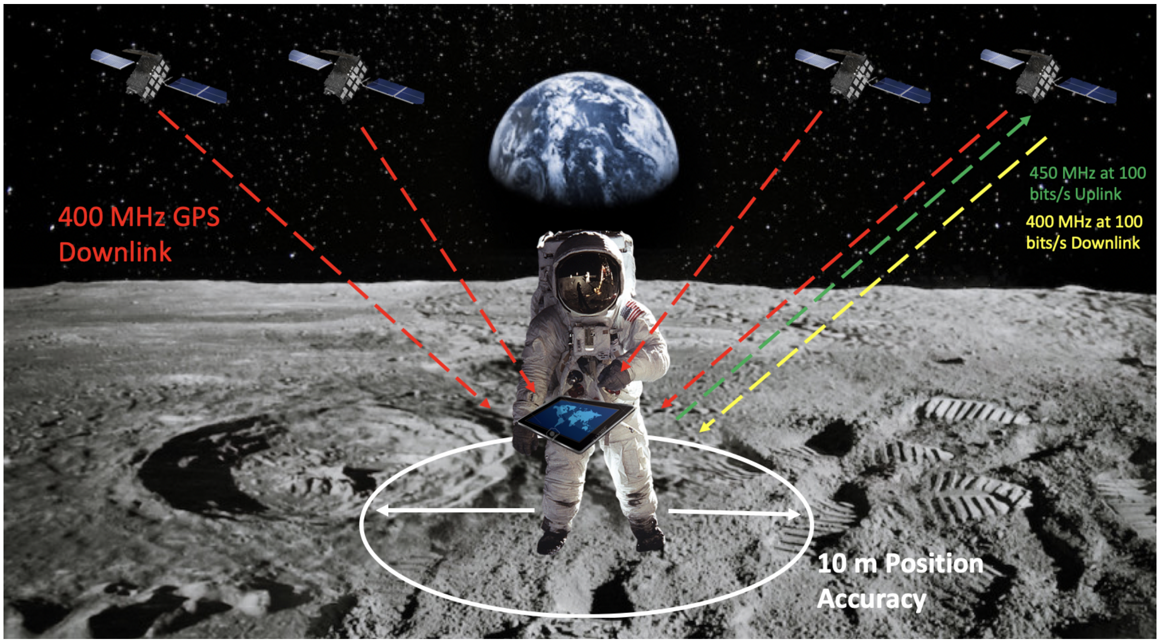

Figure 2: Concept of Operations, SMS messaging on the moon and GPS like positioning: Team will be designing a proof of concept communication system to meet mission objectives.

In order to begin reducing risk in the development of SMS-like lunar communication, the team will primarily be focusing on two specific portions of the overall mission objectives: demonstrating a proof of concept communication link between two software defined radios, and perform a trade study to determine satellite constellation requirements to provide GPS positioning to within 10 meters, assuming that no current system exists.

6.2 Communication Link

In order to develop viable communication system on the lunar surface, the team will be leveraging software defined radios such that messages can be transmitted and received. While in the overall mission, the hardware utilized will need to be radiation hardened, our team will not be responsible for that aspect and our proof of concept will leverage commercial, off-shelf hardware. The team will be required to leverage existing antennas and power systems provided by the customer and will focus on designing and utilizing software defined radios to communicate and decode messaging between two systems. The team will demonstrate communication over small distances in a testing environment, however validating our CONOPS by transmitting signals at power levels similar to what could be expected within the lunar requirements. Team will: **develop prototype for two way communication between two software defined radios at 100 bits / second, transmitting signals.**

6.3 Lunar Positioning

Following the development of the communication link, the GPS-like functionality of the system will be developed. In order to meet the specific objectives, a satellite constellation around the Lunar surface needs to be mapped out, with the ultimate goal of establishing location calculations to the accuracy of a modern day cellphone. Systems Tool Kit (STK) will be extensively utilized to first map out the the location, speed, and altitude of at least 4 satellites required for navigation capabilities. After defining the necessary requirements for this small-scale constellation, the team will expand the constellation such that it covers the whole lunar surface. In these calculations, it will be assumed that these satellites know position, and have accurate timing. The team will focus on the orbital parameters, such that the constellation meets the mission's objectives. These include the eccentricity, semi major axis, inclination, longitude of the ascending node, argument of periapsis, and the true anomaly. In addition, a Matlab script will be written to determine different errors and uncertainties of the GPS-like position based on the given satellite constellation. The ultimate goal is to **develop preliminary model to determine satellite constellation requirements to meet mission objectives of sub 10 (m) GPS positioning and 30 ns 1-sigma transfer time.**

7. Critical Project Elements

SMS Communications:
The communication system will facilitate SMS-like interaction between users interacting on the network at the specified data rates (at least 100 bits/second). RF communication and transmitting hardware integration are key to create the framework for an SMS-like communication system that falls within the high level requirements and the financial restrictions of the project. Furthermore, a testing experiment will be conducted to demonstrate the feasibility of communication between SDR devices, and provide a framework for the tooling to be leveraged in the eventual lunar implementation.

Lunar GPS
The lunar communication device's success revolves around the lunar GPS system. The system will determine the position, to within 10 meters, of the handheld device on the lunar surface. This requires various STK lunar orbit simulations that depend on the power-range specifications of the transmitters and receivers (TBD) . Software development will be performed to handle, decode and interpret the received GPS data within the desired pinpoint accuracy, assigned frequency and data rate.

Handheld GPS and Communication Module (Proof of Concept):
The handheld device must be portable and usable for astronauts on the lunar surface to gain anything from this technology. While our team is not focused on designing a prototype that is capable of functioning in the lunar environment, designing a communication system that implements voice to text technology would prove to be beneficial in mitigating difficulties that comes with operating a device in a spacesuit. Our prototype will consist of multiple software defined radios connected to laptops, with potential to scale down to a smaller, portable system. This will provide the foundation to design a handheld GPS and communication module.

Testing:
Since our project is a proof of concept and we have no method of testing the capabilities on the lunar surface, we will need to develop a testing environment, as well as a series of tests to scale up results. To validate our **level 1 objectives**, we will conduct a test that demonstrates a software defined radio, transmitting, receiving, and decoding a simple message ('Hello World'). To validate our **level 2 objectives**, we will demonstrate the level one objectives over a distance of 10 (m) between transmitter and receiver. To validate our **level 3 objectives**, we will construct the level 2 distance test again but instead transmit signals at the same power a lunar satellite will be transmitting signals. In a separate test, GPS signals will be replicated from each transmitter to verify that the SDR can pick up the various signals and correctly solve for position, position error, and time. The **level 4 objectives** will add performance objectives to the functional requirements of level 3. We will conduct testing to minimize position error and provide a path to the goal of 10 (m) position error and 30 ns 1-σ transfer time. This test would include testing at typical satellite transmission power on a large real-world scale outside the lab (TBD, ex: NCAR to HWY 36 scenic overlook).

8. Team Skills and Interests

Table 2: Team Skills and Interests

Team Member	Skills/Interests	CPEs
Sam D'Souza	Agile Software development, Matlab, C++, Python, Soldering, 3D-Printing, Laser Cutting Arduino/Raspberry Pi	Software, Electronics, Hardware
Ponder Stine	Matlab, Python, C++, Rapsberry Pi, Arduino, Raspberry Pi RF transmitter/receiver, Matlab App Designer	Software, Electronics, RF Communications, UI Design
Alexander Lowry	Matlab, C++, C, Python, Scala, Qt, STK, Arduino, Soldering	Software, Electronics, Orbital
Dawson Weis	Matlab, Python, C/C++, Arduino,3-D Modeling, STK, Scala, Laser Cutting	Software, Electronics, Orbital,Mechanical
Ruben Hinojosa Torres	Matlab, C/C++, Python, PIC Microcontrollers, Arduino	Software, Electronics
Nathan Jager	Matlab, C/C++, Python, CSWA, Arduino	Software, Electronics
Brendan Palmer	Matlab, Python, C++, Arduino	Software, Electronics
Ventura Morales	Matlab, Python, Hardware Integration, Soldering, Arduino, Business Management, Financial Budget and Logistics Determination	Software, Hardware, Electronics, Finance
Fernando Palafox	Matlab, experience w/ GNSS,	Software
Ian Thomas	Matlab, C/C++, Python	Software, RF Electronics

9. Resources

Critical Project Elements	Resource/Source
Lunar GPS	Dr. Penina Axelrad (GPS and Orbital Dynamics Expertise) Dr. Nicholas Rainville (Small Satellite and GNSS expertise) Remote Access to Pilot Staff for the use of software such as STK Dr. Dennis Akos(Astrodynamics/Satellite Navigation)
SMS Communication System	Trudy Schwartz (Microprocessor/Micro-controller Knowledge) Dr. Jade Morton (Remote Sensing, Communications Expertise) Dr Scott Palo (Electrical and Computer Engineering Expertise) Aerospace Engineering Building Frontal Field (Testing Open Area) Farrand Field (Testing Open Area)
Handheld Device Usability	Bobby Hodgkinson (Manufacturing) Dr Allie Anderson (Bio-astronautics) Aerospace Engineering Staff AES Facilities(Integration and Testing)

10. References

[1] LunaNet: Establishing a Flexible and Extensible Lunar Exploration Communication and Navigation Infrastructure : NASA Goddard Space Flight Center.

[2] D. J. Israel et al., "LunaNet: a Flexible and Extensible Lunar Exploration Communications and Navigation Infrastructure," 2020 IEEE Aerospace Conference, Big Sky, MT, USA, 2020, pp. 1-14. doi: 10.1109/AERO47225.2020.9172509 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=arnumber=9172509isnumber=9172248

[3] Jerry Colen, "NASA Selects Universities for Collaborative Development of Small Spacecraft Technologies." NASA Ames Features, Published on March 11th, 2020, https://www.nasa.gov/feature/ames/nasa-selects-universities-for-collaborative-development

[4] Christina Kitova, "Russia Announces GPS-Like System for the Moon." Communal News, Published on September 3rd, 2020. https://communalnews.com/russia-announces-gps-like-system-for-the-moon/

[5] David Israel, ESC Architect at NASA, David.J.Israel@nasa.gov

[6] Dr. Allie Anderson, Assistant Professor at Smead Department of Aerospace Engineering Sciences at the University of Colorado, Boulder. allison.p.anderson@colorado.edu

[7] Robert W. Proctor and Trisha Van Zandt. 2017. Human Factors in Simple and Complex Systems, Third Edition (3rd. ed.). CRC Press, Inc., USA.