System Requirements Specification

for

Low-Cost Laser Communications

Version 3.3

Prepared by:

Troy Clifford

Andrew Marinello

Sarah Shiffer

Daniel Unger

Max Willson

Ashley Young

Embry-Riddle Aeronautical University

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Revision History

Name	Date	Reason For Changes	Version
Max Willson	9/28/2023	Initial setup	1.0
Troy Clifford	9/28/2023	Update Software requirements	1.1
Max Willson	10/18/2023	Update requirements	1.2
Max Willson, Sarah Shiffer, Troy Clifford	10/30/2023	Adding/updating requirements	2.0
Max Willson	1/30/2024	Updated equipment	3.0
Max Willson	2/20/2024	Revisions, specifying requirements	3.1
Max Willson	2/21/2024	specifying requirements, changing Stimulus/Response Sequences	3.2
Max Willson	3/26/2024	Final changes and formatting	3.3

1. Introduction

Laser communication harnesses the power of laser technology to transmit data through free space using light pulses. This cutting-edge method offers high-speed, secure, and efficient data transmission over long distances without the need for physical cables or wires. By utilizing lasers to encode data onto light beams, this technology enables seamless communication between devices, satellites, or even across vast distances in space. Its applications span a wide range of fields, including telecommunications, aerospace, and military operations, revolutionizing the way we connect and exchange information in the modern world.

1.1 Purpose

This document defines the requirements of a low-cost, laser driven, optical communication system (OCS). In which, the goal is to use commercial-off-the-shelf (COTS) materials and components to reduce the financial requirements of an OCS.

1.2 Document Conventions

This document follows standard SRS guidelines.

1.3 Intended Audience and Reading Suggestions

This laser communication system is designed for educational institutions, aerospace companies, and prospective systems requiring an OCS, or interested in the technology. Any organization or corporation that can benefit from high-bandwidth, rapid-speed communication can benefit from this product.

1.4 Product Scope

The development of this project involves a low-cost OCS that is capable of one-way communication. This will be in the form of two physical devices that can be connected to two separate monitors and keyboards to initiate the process, further testing, and to see the final product having been transmitted. This will provide the customer with a data signal that is transmitted through free space while being simplistic enough to allow the customer to configure the OCS to their application requirements. The result of this project is to construct an OCS that could be integrated into a larger aerospace device and/or satellites, such as a CubeSat.

1.5 References

Çelik, A., Romdhane, I., Kaddoum, G., & Eltawil, A. M. (2023). A Top-Down Survey on Optical wireless communications for the Internet of Things. IEEE Communications Surveys and Tutorials, 25(1), 1–45. https://doi.org/10.1109/comst.2022.3220504

Cossu, G., Gilli, L., Vincenti, N., Pifferi, E., Schena, V., & Ciaramella, E. (2023). Demonstrating Intra-Spacecraft optical wireless links. IEEE Access, 11, 30920–30928. https://doi.org/10.1109/access.2023.3261803

Martinez, Cameron, et al. 3rd ed., Embry-Riddle Aeronautical University, Daytona Beach, FLORIDA, 2023, pp. 1–10, System Requirements Specification for Optical (Laser) Communications Low-Cost Payload.

Zhou, B., & Rojas-Nastrucci, E. A. (2022). Modeling and Simulation of Small Satellite Optical Communication System based on PathWave System Design. Department of Electrical Engineering and Computer Science Embry-Riddle Aeronautical University. https://doi.org/10.1109/wamicon47156.2021.9444293

2. Overall Description

2.1 Product Perspective

The OCS is designed to bring a low-cost, simplistic product capable of satellite communications through free space. It is a new, self-contained product focused on emerging studies and technologies. Figure 2.2.1 shows the layout of the system and how all the components of this system operate with each other.

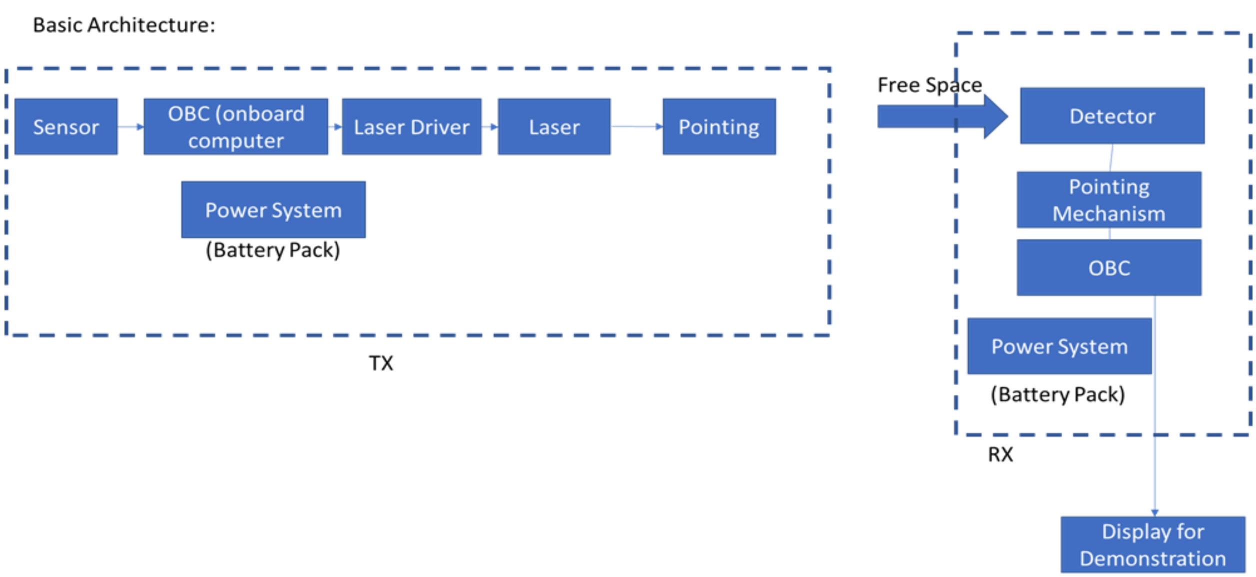

Figure 2.2.1 Top-View of System Architecture Demonstrating Product Functions

2.2 Product Functions

Req. 2.2.1: The system shall use a NVIDIA Nano to process input image data from a Raspberry Pi Camera.

Req. 2.2.2: The system shall use a laser to transmit the serial bit stream through free space.

Req. 2.2.3: The optical sensor shall receive the transmitted laser.

Req. 2.2.4: The system shall use a NVIDIA TX2 to transcode the received serial bitstream back into the original file.

2.3 User Classes and Characteristics

2.3.1 Ground Station Operator

The Ground Station Operator controls the signal received by the OCS and monitors the satellites to confirm proper operation.

2.3.2 Test Engineer

The Test Engineer validates every part of the system by using tests laid out in a test plan document. The Test Engineer shall also be able to diagnose and repair any faults found during testing.

2.3.3 Sensor Operator

The Sensor Operator is at the TX of the system and controls the input signal to the OCS. This is optional because the sensor may not need any user operation. User class has the ability to turn on and off the TX system.

2.4 Operating Environment

This section will delineate the data flow within the system, detail the software versions employed, and outline the prerequisites for data collection.

2.4.1 Data Transmission

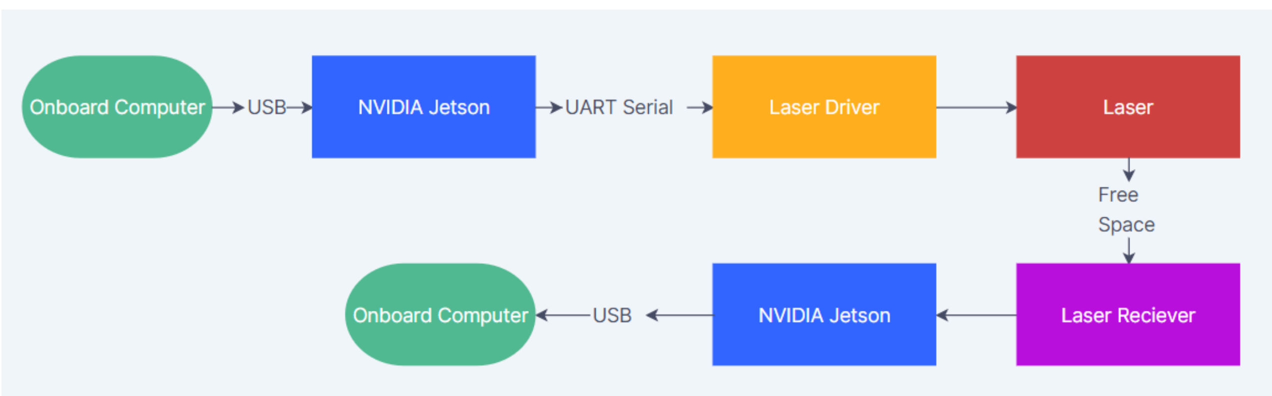

Figure 2.4.1.1 Block diagram of passing of information throughout the system.

The integrated NVIDIA Jetson systems will be running the following software along with their version:

2.4.1.1: Python ver. 3.10.7 September 6, 2022

2.4.1.2: Linux for Tegra (L4T) ver. September 22, 2022

2.4.1.3: PL011 SoC UART ver. Nov 1, 2005

2.4.1.4: NumPy ver. 1.23.4 Oct 12, 2022

2.4.1.5: OpenCV ver. 4.6.0.66 June 8, 2022

The data flow through the system can be seen in Figure 2.4.1.1. The data input is collected through a Raspberry Pi camera, which is then transmitted to a NVIDIA Jetson for transformation into a serial signal using OpenCV libraries. This data is then sent to the laser driver via serial transmit pin 18. The laser driver will then send the data as an on-off keyed serial signal over free space to the RX. The receiving NVIDIA Jetson will decode, then transcode the data and send it to a web display, the format will be an image stream.

2.4.2 Data Collection

Req. 2.4.2.1: The NVIDIA Jetson Nano shall receive a jpeg from the Raspberry Pi Camera over the Camera Serial Interface (CSI) at least 30 times per second.

Req. 2.4.2.2: The incoming jpeg shall then be converted to a binary bit stream using the OpenCV library at least 30 times per second.

Req. 2.4.2.3: The binary bit stream shall be sent through Port 18 of the NVIDIA Jetson Nano using 3.4V as a 1 and 0V as a 0.

Req. 2.4.2.4: Port 18 from the NVIDIA Jetson Nano shall be connected to the analog modulation pins of the laser driver board.

Req. 2.4.2.5: The binary signal shall activate or deactivate the laser, based on the state of the signal: 3.4V is on and 0V is off.

Req. 2.4.2.6: The photo sensor shall output 5V when receiving the laser signal and 0 when not receiving a signal.

Req. 2.4.2.7: The photo sensor shall transmit the binary bit stream to a NVIDIA Jetson TX2 via a 50 ohm coax cable.

Req. 2.4.2.8: The NVIDIA Jetson TX2 shall reconstruct the serial bitstream into the original jpeg.

Req. 2.4.2.9: The jpegs shall be displayed on a connected display monitor at a rate of at least 30 per second.

The data collected will depend on the specific needs of the project, however, the first implementation will use a video stream collected from a Raspberry Pi camera. This could be replaced by any other form of information sensor or collector. Anything that is used to transmit data could send information to the RX from the TX.

2.5 Design and Implementation Constraints

2.5.1 Design Constraints:

Req. 2.5.1.1: The transmitting system shall fit within 1U (10x10x10 in).

Req. 2.5.1.2: The system shall cost under $20000 USD.

Req. 2.5.1.3: The transmitting system shall weigh less than 20 pounds.

2.5.2 Implementation Constraints:

Req. 2.5.2.1: The system shall use COTS components.

Req. 2.5.2.2: The transmitting laser shall use a 1500 nm wavelength Diode.

Req. 2.5.2.3: The transmitting laser shall use a 1500 nm wavelength laser driver (IR-B class).

Req. 2.5.2.4: All system code implementation shall be written in C++.

2.6 User Documentation

Req. 2.6.1: The system shall have a basic procedure user manual.

Req. 2.6.1.1: The manual shall contain information on how to set up and operate the device.

Req. 2.6.2: The system shall have operational/technical manual references to the off-the-shelf components.

Req. 2.6.2.1: These operational/technical manual references shall display the recommended schematic for all the components.

2.7 Assumptions and Dependencies

2.7.1: The system will only be tested in an enclosed space with proper safety equipment in place.

2.7.2: The system must maintain Line of Sight (LOS) between the TX and RX while operating.

2.7.3: The system will maintain power to all components during the entire length of operation.

2.7.4: The system will be turned on by the user when ready to use, test or demonstrate.

2.7.5: The system will not be left on when not in use.

2.7.6: The system will have access to AC 120V, 60 Hz power.

3. External Interface Requirements

3.1 User Interfaces

The user will plug in the power sources and activate the laser using the laser driver. Then they will only need to provide input into the NVIDIA Jetson for an output on the display monitor at the RX side. All activation of the system will be software based and initialization will be performed via startup script or a secure shell.

3.2 Hardware Interfaces

Req. 3.2.1: The NVIDIA Jetson Nano shall interface with the Raspberry Pi Camera to receive a jpeg input.

Req. 3.2.2: The system shall use the NVIDIA Jetson Nano to send a serial bitstream to the laser driver.

Req. 3.2.3: The serial bitstream shall be sent over the serial interface to the laser driver.

Req. 3.2.4: The serial bitstream signal shall be sent over the serial interface to the laser diode.

Req. 3.2.5: The optical sensor shall send the received serial bitstream to the NVIDIA Jetson TX2 over the serial interface.

Req. 3.2.6: The system shall use an HDMI/VGA cable to send jpeg data to the physical display monitor.

Req. 3.2.7: The system shall use a physical display monitor to show the received image feed to the user.

3.3 Software Interfaces

Req. 3.3.1: The system shall use OpenCV, to transcode the image feed from the Raspberry Pi Camera.

Req. 3.3.2: OpenCV shall transcode the image feed from the Raspberry Pi Camera into a serial bitstream.

Req. 3.3.3: The system shall use a NVIDIA Jetson Nano to run OpenCV.

Req. 3.3.4: The NVIDIA Jetson Nano on theTX side shall use port 18 to transmit the serial bitstream to the laser driver.

Req. 3.3.5: The NVIDIA Jetson TX2 on the RX side shall use the port 15 to receive the serial bitstream.

3.4 Communications Interfaces

Req. 3.4.1: The system shall communicate asynchronously from theTX to the RX modules by an optical communication system.

Req. 3.4.2: The system shall communicate with the data display monitor through HDMI and VGA ports.

Req. 3.4.3: The system shall only communicate with external systems if it contains data requested by the customer to be transmitted by laser communication.

Req. 3.4.4: The system shall record a copy of the restreamed incoming data on the onboard SD card.

4. System Features

4.1 Transmit Signal

4.1.1 Description and Priority

Upon selection of data to send, the onboard computer shall process and send the data via On-Off-Keying (OOK) to the RX .

4.1.2 Stimulus/Response Sequences

Order	User Action	System Response
1	Input image or video	Transmit binary bitstream

4.1.3: Functional Requirements

Req. 4.1.3.1: Software shall allow the transmission of the signal, through an OOK modulation scheme.

Req. 4.1.3.2: The original jpeg shall be viewed via the RX physical display monitor.

Req. 4.1.3.3: The RX physical display monitor shall verify data being sent through free space is matching the input jpeg.

Req. 4.1.3.4: The TX shall only transmit through free space.

Req. 4.1.3.5: The TX speed shall be at a minimum 1 Gb/s.

4.2 Receive Signal

4.2.1 Description and Priority

Upon receiving the signal the data will be reconstructed back into its original form by use of the NVIDIA Jetson, where it will be displayed on either an onboard display or a web interface.

4.2.2 Stimulus/Response Sequences

Order	User Action	System Response
1	Input binary bitstream	Decode the binary bitstream into a PNG

4.2.3 Functional Requirements

Req. 4.2.3.1: The serial bitstream shall be received at a rate of at least 1 Gb/s.

Req. 4.2.3.2: The serial bitstream shall be decoded at a rate of at least 1 Gb/s.

Req. 4.2.3.3: The decoded signal shall be recorded on the onboard SD card.

Req. 4.2.3.4: The RX shall receive the serial bitstream through only free space.

4.3 TX Power Distribution System

4.3.1 Description and Priority

The TX side of the system shall be portable, meaning an onboard power system using batteries is needed. Not crucial for main system requirements.

4.3.2 Stimulus/Response Sequences

Order	User Action	System Response
1	Press power button	Distribute power to all parts of the system

4.3.3 Functional Requirements

Req. 4.3.3.1: All parts of the TX shall receive 120V AC.

Req. 4.3.3.2: All parts of the TX shall receive 120V AC.

4.4 RX Display and Storage System

4.4.1 Description and Priority

The RX side should display the sensor information via a computer monitor as well as save the information for future retrieval. Display is a main priority while storage is not.

4.4.2 Stimulus/Response Sequences

Order	User Action	System Response
1	Turn on system	Display PNG file on the monitor
2	Input binary bitstream	Save PNG files

4.4.3 Functional Requirements

Req. 4.4.3.1: The optical sensor information shall be displayed via a physical display monitor.

Req. 4.4.3.2: The latency between the RX and display shall be less than 1s.

Req. 4.4.3.3: The received serial bitstream shall be stored on the NVIDIA Jetson TX2's SD card.

5. Other Nonfunctional Requirements

5.1 Performance Requirements

Req. 5.1.1: The hardware shall be able to transmit a signal via free space

Req. 5.1.2: The hardware shall transmit the serial bitstream at a rate of at least 1Gb/s.

Req. 5.1.3: The speed from the TX shall be limited to thermal or computation speed caps from the transmitting computer.

Req. 5.1.4: The hardware shall transmit the signal at a speed such that the receiving computer is able to adequately decode all data.

Req. 5.1.5: The receiving computer shall decode all data into a jpeg.

Req. 5.1.6: The hardware shall transmit data with an error rate of less than 5%

Req. 5.1.7: The data loss rate shall be less than 5%.

Req. 5.1.8: The system shall transmit data with a one-way latency of less than 1s.

Req. 5.1.9: The system shall transmit data through less than 4 inches of free space.

Req. 5.1.10: The TX system shall not draw any more than 15 watts.

Req. 5.1.11: The RX system shall receive the data stream at a minimum rate of 1 Gb/s.

Req. 5.1.12: The RX system shall save the data stream at a minimum rate of 1 Gb/s.

Req. 5.1.13: The RX system shall display the data stream at a minimum rate of 1 Gb/s.

5.2 Safety Requirements

Req. 5.2.1: The carrier signal (laser) shall only be oriented at the RX.

Req. 5.2.2: The laser shall only be operated with a member of the project team to verify its proper use.

Req. 5.2.3: The laser shall always be used in a fixed position.

Req. 5.2.4: The laser shall change positions for testing.

Req. 5.2.5: The laser shall change positions for maintenance.

Req. 5.2.6: The system should have no possible shorting hazards.

Req. 5.2.7: The system should have no exposed wiring.

Req. 5.2.8: The laser diode output shall not exceed 20 mW.

5.3 Security Requirements

Req. 5.3.1: The system shall only be used by authorized project members .

5.3.2 Authorized members:

5.3.1.1 Project Owner, Eduardo Rojas.

5.3.1.2 Project Team Members.

5.3.1.3 Any other individual designated by the Project Owner or Team Members.

5.4 Software Quality Attributes

Req. 5.4.1: The system software shall be written in a way that is readable.

Req. 5.4.2: The system software shall be commented at each major function.

Req. 5.4.3: The system software comments shall clearly inform any user about the program.

5.5 Business Rules

Req. 5.5.1: The project members shall be authorized to use and test the product.

Req. 5.5.2: The owners shall be authorized to use and test the product.

Req. 5.5.3: The assistants shall be authorized to use and test the product.

6. Other Requirements

No other requirements.

Appendix A: Glossary

#	Name	Nickname(s)	Description
1	Commercial-off-the-shelf	*COTS*	A product that can be purchased, leased, or licensed by the general public.
2	Line of Sight	LOS	A straight line between objects with no visible obstructions.
3	On-Board Computer	OBC	Computing system physically attached to a component.
4	Optical Communications System	OCS	Communication at a distance using electromagnetic waves to carry information over free space.
5	On-Off Key	OOK	Modulation scheme that varies the power level of the carrier signal between two discrete power levels.
6	Receiver	RX	Subsystem responsible for receiving data and decoding data.
7	Transmitter	TX	Subsystem responsible for encoding and transmitting data.

Appendix B: Analysis Models