Design and Implementation of a Raspberry Pi-Based Free Space Optical Communication System for Real-Time Video, Audio, and Data Transmission … or LIFI project for short

PHD supervisor of project: Francisco Hernandez

Project sponsor: Mike Mckee and UCF Optica Chapter

Project Description

- This project aims to develop a robust, cost-effective free-space optical (FSO) communication system utilizing Raspberry Pi's as the core processing units. The system will enable the transmission and reception of real-time video, audio, and data over a laser-based communication link.
- A laser diode with supporting PCB circuitry will be modulated for data transmission, while a photodiode, also with supporting PCB circuitry, will receive and convert optical signals back into electrical signals for decoding. Optical components, including beam-expanding optics, will be used to widen the laser beam to improve ease of detection, allowing for minimal optical alignment between transmitter and receiver. To further enhance reliability, beam-steering mechanisms will be implemented to maintain an uninterrupted optical link, even if the transmitter or receiver experiences movement, dynamically re-aligning the beam path as needed.
- This setup demonstrates the practicality of FSO communications by leveraging the computational capabilities of the Raspberry Pi for modulation, demodulation, data processing, and storage, alongside optical engineering techniques to optimize data transmission.
- This project offers a hands-on approach to experimenting with optoelectronics, single-board computers, and optics for effective data transmission. Serving as an outreach platform, it will provide engaging demonstrations at middle schools, high schools, STEM/Optics day events, and the Orlando Science Center, promoting optics and photonics, to inspire future engineers in these fields.

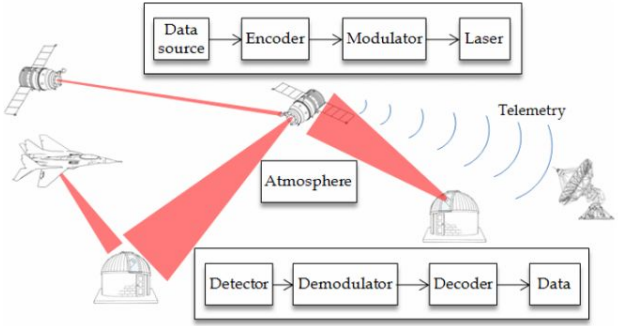

***Figure 1**: Block diagram of free-space optics communication. Many companies/agencies like L3 Harris, CACI, NASA, General Atomics, the European Space Agency, and more are involved in real-life applications on FSO. It all starts from small projects like this one !*

***Figure 2**: Outreach opportunities each year to demo cool Optica sponsored projects. Spark Fest for instance, hosted at the Orlando science center every spring semester is an exciting place and opportunity to display long terms projects like LIFI. It looks good to be involved as an optics & photonics promoter whether its for a resume booster, job application, recommendation letter, PHD fellowship application, etc.*

Project Motivation

- Free-space optical (FSO) communication is an emerging technology that uses light to transmit data through the air, rather than relying on traditional radio frequency (RF) waves. FSO offers several compelling advantages over RF communication, particularly in terms of data rate, security, and interference resistance. With its higher frequency range, FSO can achieve significantly higher bandwidths, allowing for faster data transmission rates that are especially useful in high-demand applications like real-time video streaming and broadband internet.
- Unlike RF links, FSO communication does not require a licensed spectrum, making it a cost-effective option for a wide range of applications. Additionally, FSO links are highly secure, as laser beams are more challenging to intercept compared to RF waves, which propagate more widely. This feature makes FSO attractive for secure data links, especially in defense, corporate, and government applications where data privacy is critical.
- FSO also benefits from immunity to electromagnetic interference, a common issue with RF systems in crowded environments. For instance, in urban areas where RF spectrums are often congested, FSO can provide a reliable alternative with minimal signal degradation. However, FSO does have limitations due to atmospheric conditions like fog or rain, which can disrupt the optical path. To mitigate this, hybrid RF/FSO systems are sometimes deployed, combining the strengths of both technologies to ensure robust communication across diverse environments.
- While RF communication remains essential for broad coverage and resilience to environmental factors, FSO presents an attractive solution for applications requiring high data rates, low interference, and enhanced security, making it a valuable alternative or complement to traditional RF links.

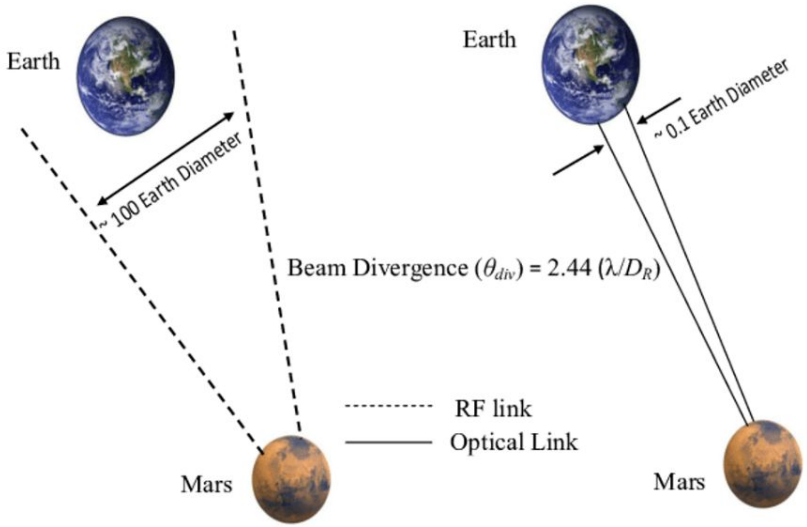

***Figure 3**: RF vs Optical Communication link*

Project Block Diagram

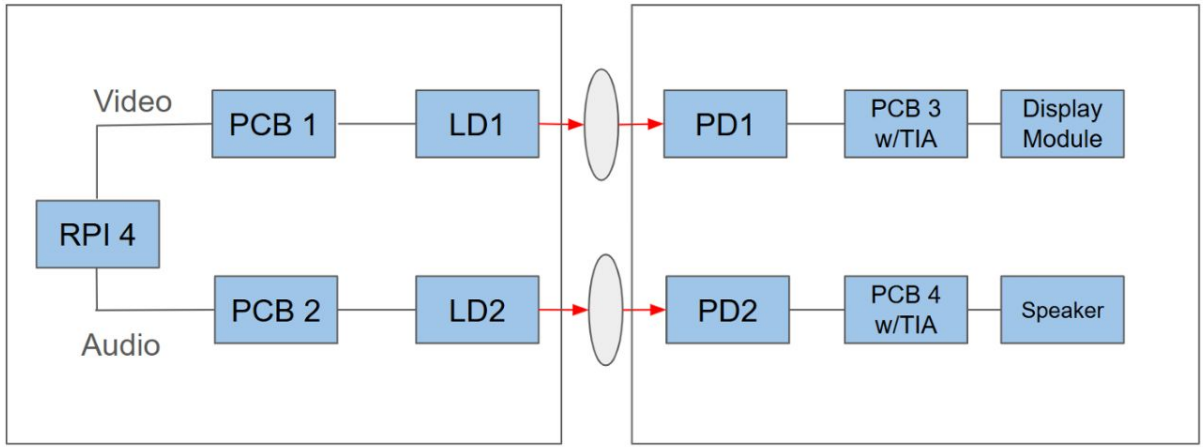

***Figure 4**: Block Diagram of LIFI project with the transceiver side (left), optics (middle), and the receiver side (right). The optics here are simplified, but will consist of (1) collimating optics (2) beam expansion (3) and beam focusing*

We Want People !

- We are very interested in having people join us to make this project possible.
- We are looking for anyone with an interest in free-space optics and those willing to design optical systems (whether on paper, in Excel, or Zemax) for critical tasks such as laser collimation for transmission, laser focusing onto photodetectors for reception, beam expansion, and beam steering.
- We are also seeking individuals with electronics experience to create PCBs for reliable transmitter and receiver subsystems, enabling easy data transmission and reception using light.
- We definitely need people with CAD/3D printing experience for housing and essentially bringing every subsystem integrated together. Any CAD experience fine whether with SolidWorks, Fusion 360, or On shape.
- Lastly, we would like to find individuals with programming experience, preferably with Raspberry Pi, to facilitate data modulation, processing, display, and storage.

***Figure 5**: We want optics people ! (must be an Optica member tho)*

***Figure 6**: We want people with PCB and electronics experience !*
(Could be an ECE major or CREOL student with experience)

***Figure 7**: We want people with Raspberry Pi experience !*
(Could be a CPE major or CREOL student with experience)

Who to Contact for Interest?

Discord: franciscoh or email: fr936377@ucf.edu

When do we meet?

- By default every Friday's at 4:30pm this semester
- Meeting location: The CREOL snack-room (A203)

Current Members:

- Francisco Hernandez
- Max Baryshnikov
- Noah Wilfond
- Luke
- We are open to more members

Proposed Schedule for LIFI project

People needed	Task	Date
Optics students	Work on Optical Design	11/4/24 to 11/9/24
Optics students	Finalize Optical Design	11/11/24 to 11/15/24
Optics students	Select the optics components from the desired vendors, fill out purchasing forms for each vendor we wish to purchase from, have Mike Mckee finalize purchasing	11/18/24 to 11/22/24
N/A	let people study for finals, also components may take 1 to 3 weeks to arrive depending on vendor	N/A
Optics and EE students	First week of spring semester, test optoelectronic components (laser diodes, and photodetectors) using breadboard circuits and dc power supplies	1/6/25 to 1/10/25
Anyone with CAD experience	Design and 3D print any optical mounts/housings using solidworks/onshape	1/13/25 to 1/17/25
Optics students	Integrate lenses/optical fibers with laser diodes and photodetectors, and perform far-field testing and optimize optical alignment on an optical table (**At this stage the optical subsystem should be complete**)	1/20/25 to 1/31/25

Proposed Schedule for LIFI project (Continued)

People needed	Task	Date
EE students	Design PCBs for photodiodes and laser diodes for to create an optical transmitter and transimpedance amplifier (TIA); may allow 2 weeks for this as PCB design is somewhat challenging	2/3/25 to 2/14/25
EE students	Order electronics components (Digikey or Mouser electronics) and PCB (JLCPCB or PCBWAY)	2/17/25 to 2/21/25
EE students	Solder surface mount or though hole electronic components on PCBs	2/24/25 to 2/28/25
EE students, and anyone with CAD experience	3D print a housing/shield for PCB's and integrate them with the optics subsystem (**At this stage the electrical subsystem should be complete**)	3/3/25 to 3/7/25
CPE and EE students	Integrate the Raspberry Pi's to electrical subsystems, to send modulated signals carry information like Audio, Video, text files, etc.; may allow 2 weeks for this as this is the hardest part of the entire project	3/10/25 to 3/21/25
Anyone with CAD experience	Create or buy a final housing, to store all the subsystems	3/24/25 to 3/28/25
Everybody	Perform a final testing, with everything integrated	3/31/25 to 4/4/25