Free Space Optics Link Alignment System

A PROJECT REPORT

by

Shaswat Tripathi

Under the Supervision of

Dr Manish Tiwari
Head of Department Electronics and Communication
(Department of Electronics and Communication Engineering)
MANIPAL UNIVERSITY JAIPUR
JAIPUR-303007
RAJASTHAN, INDIA

05/2021

ABSTRACT

The project Free space optics link alignment system is a line-of-sight technology which is an optical communication using laser and that can transfer data in both air and vacuum. The system does not require any cables or any spectrum licence. Which led us to implement a small-scale model of the communication.

The methodology of the system design was to be implemented using Arduino and sensors that replicate the working of the system in small scale. The tools used in this implementation were stepper motor and laser and LDR sensors.

The important conclusions I took from the implementation of the project were that this communication system is a very efficient and can be implemented anywhere to establish a high-speed point to point communication.

LIST OF TABLES

LIST OF FIGURES

Contents

1. INTRODUCTION

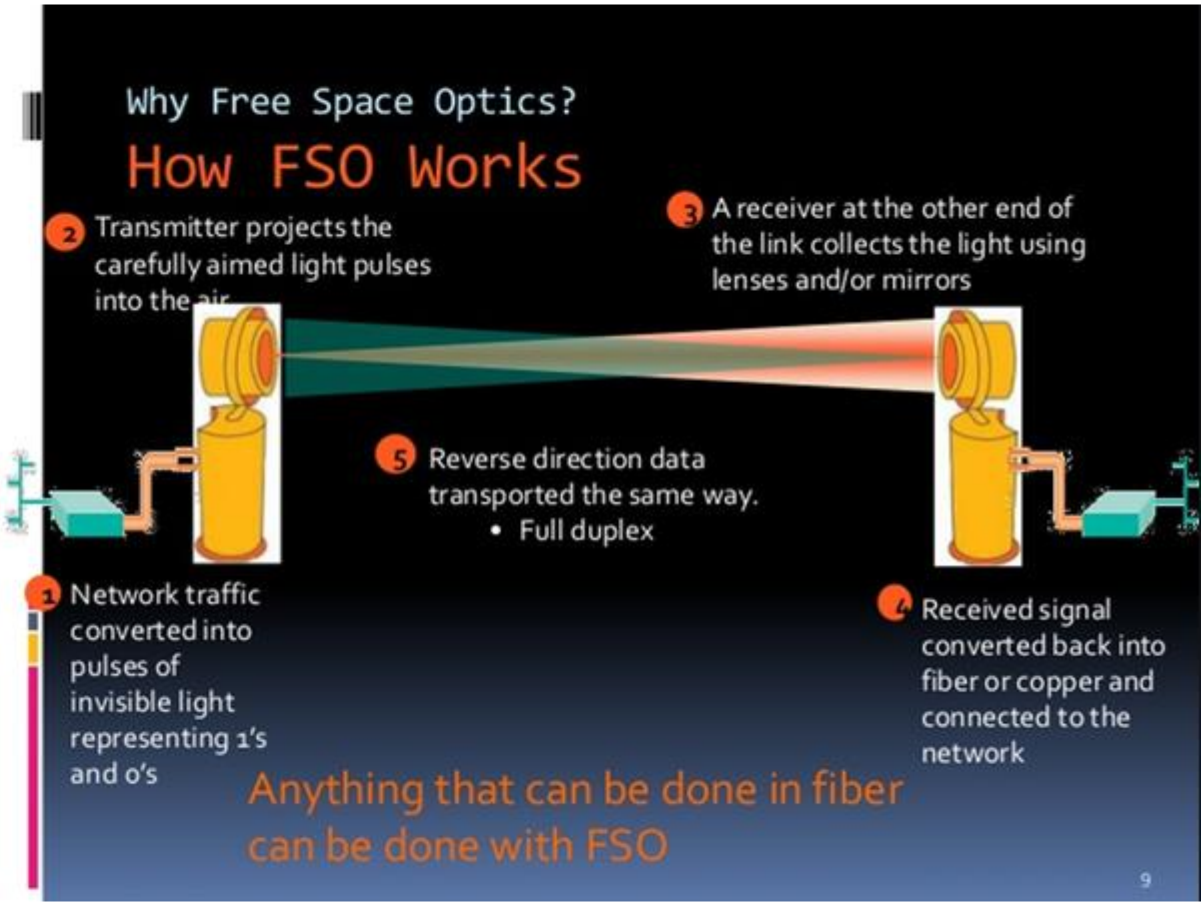


Figure. 1- Working of a free space optics system.

FSO is a line-of-sight technology that uses lasers to provide optical bandwidth connections or FSO is an optical communication technique that propagate the light in free space means air, outer space, vacuum, or something similar to wirelessly transmit data for telecommunication and computer networking. Currently, FSO is capable of up to 2.5 Gbps of data, voice and video communications through the air, allowing optical connectivity without requiring fibre-optic cable or securing spectrum licenses. Operate between the 780 – 1600 nm wavelengths bands and use O/E and E/O converters. FSO requires light, which can be focused by using either light emitting diodes (LEDs) or lasers (light amplification by stimulated emission of radiation). The use of lasers is a simple concept similar to optical transmissions using fibre-optic cables; the only difference is the transmission media. Light travels through air faster than it does through glass, so it is fair to classify FSO as optical communications at the speed of the light. FSO communication is considered as an alternative to radio relay link line-of sight (LOS) communication systems. FSO components are contain three stages: transmitter to send of optical radiation through the atmosphere obeys the Beer-Lambert's law, free space transmission channel where exist the turbulent eddies (cloud, rain, smoke, gases, temperature variations, fog and aerosol) and receiver to process the received signal. Typical links are between 300 m and 5 km, although longer distances can be deployed such as 8–11 km are possible depending on the speed and required availability.

1.1 Motivation-

Free space Optical communications, in various forms, have been used for thousands of years. The Ancient Greeks used a coded alphabetic system of signalling with torches developed by Cleoxenus, Democleitus and Polybius.

Its first practical use came in military communication systems many decades later, first for optical telegraphy. German colonial troops used heliograph telegraphy transmitters during the Herero and Namaqua genocide starting in 1904, in German South-West Africa (today's Namibia) as did British, French, US or Ottoman signals.

The invention of lasers in the 1960s revolutionized free space optics. Military organizations were particularly interested and boosted their development. However, the technology lost market momentum when the installation of optical fibre networks for civilian uses was at its peak. Many simple and inexpensive consumer remote controls use low-speed communication using infrared (IR) light. This is known as consumer IR technologies.

Free-space point-to-point optical links can be implemented using infrared laser light, although low-data-rate communication over short distances is possible using LEDs. Infrared Data Association (IrDA) technology is a very simple form of free-space optical communications. On the communications side the FSO technology is considered as a part of the optical wireless communications applications. Free-space optics can be used for communications between spacecraft.

Hence the Free space optics is a major part of our lives and we have no Idea how it works and that was the motivation for this project and would help others understand the pros and cons and the easy implementation of these types of system and how they benefit the world around us.

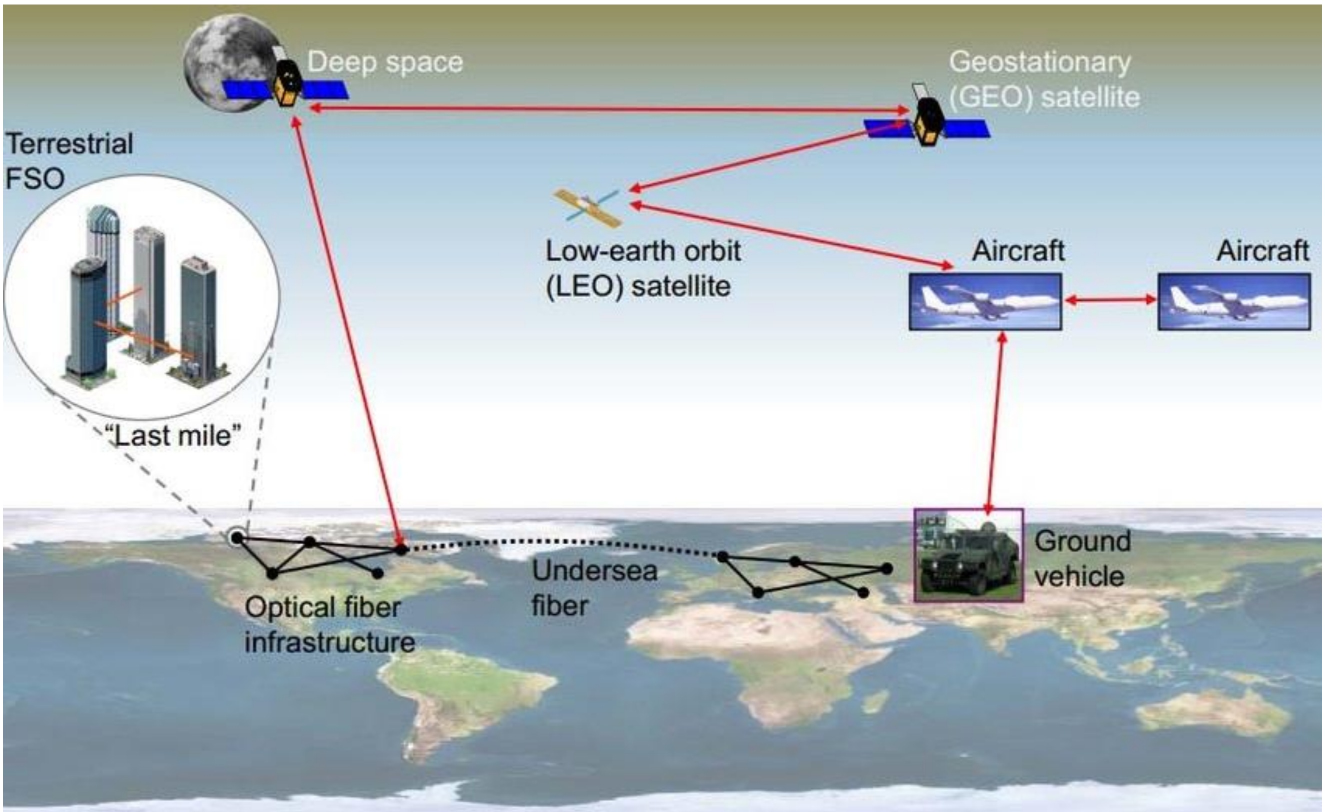


Figure 2- The use of Free space optics in the world.

1.2 Advantages and Uses.

-FSO Advantages

- Long distance up to 8 km.
- High bit rates speed rates: the high bandwidth capability of the fiber optic of 2.5 Gbps to 10 Gbps achieved with wavelength division multiplexing (WDM). Modern systems can handle up to 160 signals and can thus expand a basic 10 Gbit/s system over a signal fiber pair to over 1.6 Tbit/s.
- Immunity from electromagnetic interference: secure cannot be detected with RF meter or spectrum analyser, very narrow and directional beams
- Invisible and eye safe, no health hazards so even a butterfly can fly unscathed through a beam
- Low bit error rates (BER)
- Absence of side lobes
- Deployment of FSO systems quickly and easily
- No Fresnel zone necessary
- Low maintenance (Practical)
- Lower costs as compared to fiber networks (FSO costs are as low as 1/5 of fiber network costs).
- License-free long-range operation (in contrast with radio communication)

-FSO applications

- Telecommunication and computer networking
- Temporary network installation for events or other purpose as disaster recovery
- For communications between spacecraft, including elements of satellite constellation
- Military application: (its potential for low electromagnetic emanation when transferring sensitive data for air forces)
- Metro network extensions: carriers can deploy FSO to extend existing metropolitan area fiber rings, to connect new networks, and, in their core infrastructure, to complete SONET rings.
- Enterprise connectivity: the ease with which FSO links can be installed makes them a natural for interconnecting local area network segments that are housed in buildings separated by public streets or other right-of-way property.
- Fiber backup: FSO may also be deployed in redundant links to backup fiber in place of a second fiber link.
- Backhaul: FSO can be used to carry cellular telephone traffic from antenna towers back to facilities wired into the public switched telephone network.
- Service acceleration: FSO can be also used to provide instant service to fiber-optic customers while their fiber infrastructure is being laid.
- Last-Mile access: In today's cities, more than 95% of the buildings do not have access to the fiber optic infrastructure due to the development of communication systems after the metropolitan areas. FSO technology seems a promising solution to the connection of end-users to the service providers or to other existing networks. Moreover, FSO provides high-speed connection up to Gbps, which is far more beyond the alternative systems.

1.3 Problem Statement

Design an FSO link alignment system that uses Inter-Arduino communication to control the stepper motor that rotates the laser and an alignment detector that aligns both sender and receiver to start communication and from a point-to-point network.

1.4 Objectives-

The Objective of this project is to implement a small-scale model for the FSO system using Arduino. The project work on the link alignment part of the free space optical communication. The project demonstrates that how distance between communicating entities can affect the degrees and steps that the scanner and receiver must move to align and start communicating. As the Distance between the two-communication system increases the stepper motor has to Increase its steps to scan and align with the receiver.

2. Background Theory

2.1 System Design Blocks-

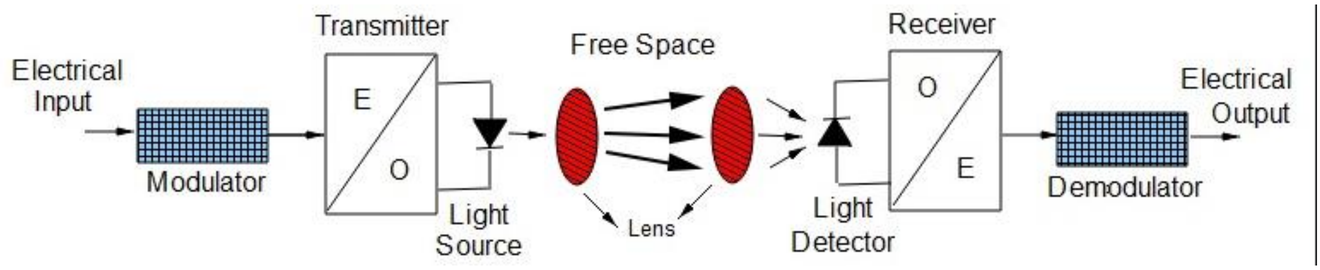


Figure 3- A typical Laser Free space optics system.

The above system represents a good picture of working of a Free space optics system. FSO contains three components: transmitter, free space transmitted channel line of sight, and receiver. Transmitter is considered as an optical source 1-laser diode (LD) or 2-light emitting diode (2-LED) to transmit of optical radiation through the atmosphere follows the Beer-Lamberts' law.

The selection of a laser source for FSO applications depends on various factors. It is important that the transmission wavelength is correlated with one of the atmospheric windows. As noted earlier, good atmospheric windows are around 850 nm and 1550 nm in the shorter IR wavelength range. In the longer IR spectral range, some wavelength windows are present between 3–5 micrometres (especially 3.5–3.6 micrometres) and 8–14 micrometres [5]. However, the availability of suitable light sources in these longer wavelength ranges is pretty limited at the present moment. In addition, most sources need low temperature cooling, which limits their use in commercial telecommunication applications.

Other factors that impact the use of a specific light source include the following:

1. Price and availability of commercial components
2. Transmission power
3. Lifetime
4. Modulation capabilities
5. Eye safety
6. Physical dimensions
7. Compatibility with other transmission media such as fiber.

Our main motive with the project was to implement a link alignment system that can adjust its divergence angle according to the distance between the Sender and a receiver. Which is why we used a Stepper motor that can adjust its steps or shorten the angle per step when the distance is increased.

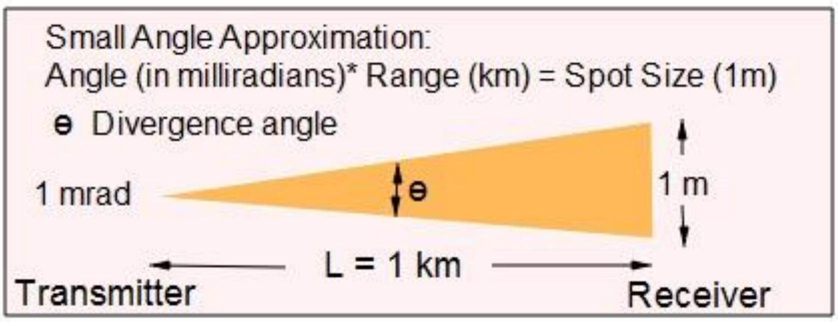


Figure 4- Small angle divergence and spot size between transmitter and receiver

2.2 Component theory-

The List of components used in this Project were-

Arduino Boards-

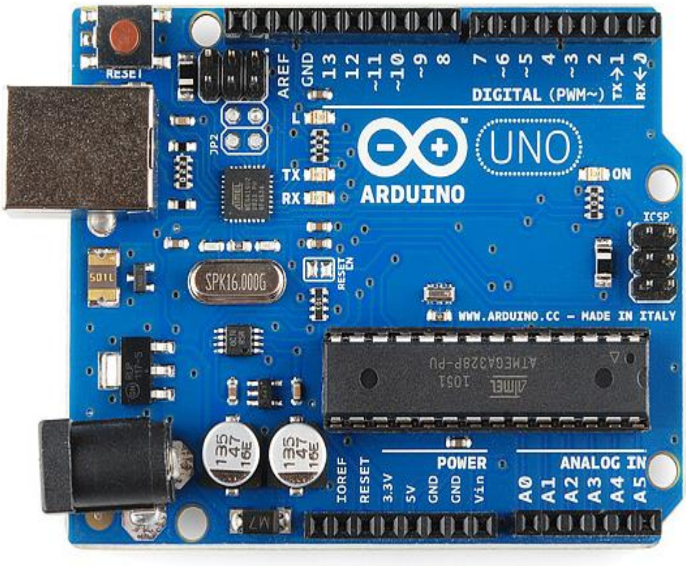


Figure 5- Arduino Uno Development Board.

- **Objective-**The Boards were used on both sides to be the heart and soul of the system and the whole system was designed around it. Everything was controlled from the Arduino board and the code pushed in its micro controller.
- **Theory-** Arduino is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on your computer, used to write, and upload computer code to the physical board.
  - i) **Pins-**The pins on Arduino are the places where we connect wires to construct a circuit. They usually have black plastic ‘headers’ that allow you to just plug a wire right into the board. The Arduino has several different kinds of pins, each of which is labelled on the board and used for different functions.
    - (1) **GND (3)**: Short for ‘Ground’. There are several GND pins on the Arduino, any of which can be used to ground your circuit.
    - (2) **5V (4) & 3.3V (5)**: As you might guess, the 5V pin supplies 5 volts of power, and the 3.3V pin supplies 3.3 volts of power. Most of the simple components used with the Arduino run happily off of 5 or 3.3 volts.
    - (3) **Analog (6)**: The area of pins under the ‘Analog In’ label (A0 through A5 on the UNO) are Analog In pins. These pins can read the signal from an analog sensor (like a temperature sensor) and convert it into a digital value that we can read.
    - (4) **Digital (7)**: Across from the analog pins are the digital pins (0 through 13 on the UNO). These pins can be used for both digital input (like telling if a button is pushed) and digital output (like powering an LED).
    - (5) **PWM (8)**: You may have noticed the tilde (~) next to some of the digital pins (3, 5, 6, 9, 10, and 11 on the UNO). These pins act as normal digital pins, but can also be used for something called Pulse-Width Modulation (PWM). We have a tutorial on PWM, but

for now, think of these pins as being able to simulate analog output (like fading an LED in and out).

(6) **AREF (9)**: Stands for Analog Reference. Most of the time you can leave this pin alone. It is sometimes used to set an external reference voltage (between 0 and 5 Volts) as the upper limit for the analog input pins.

Stepper Motor-

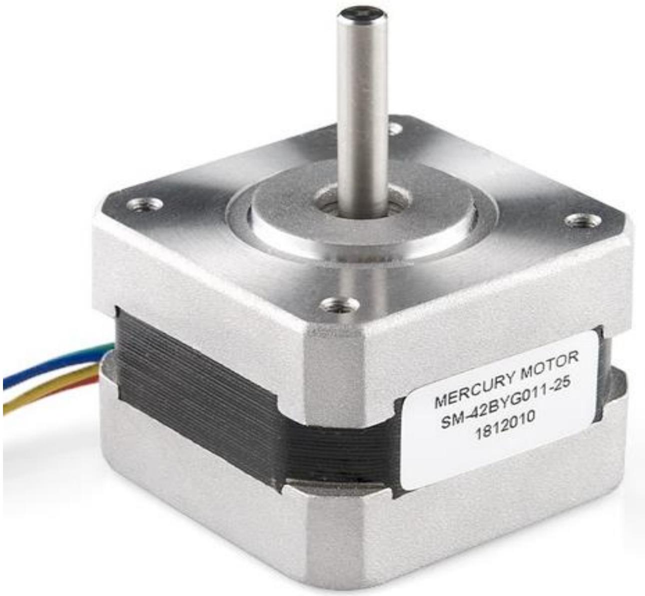


Figure 6- 12v Stepper motor

- **Objective-** The Stepper motor is to be controlled by the Arduino. The laser is mounted on the stepper motor and will be used to align it with the receiver. The steps of the stepper motor are to be controlled according to the distance between the sender the receiver. The number of steps is directly proportional to the distance between the buildings.
- **Theory-** Stepper motors are DC motors that rotate in precise increments or “steps”. They are very useful when you need to position something very accurately. They are used in 3D printers to position the printhead correctly and in CNC machines where their precision is used to position the cutting head. If your digital camera has an autofocus or remote zoom feature chances are a stepper motor is being employed to do that. Stepper motors have a magnetized geared core that is surrounded by a number of coils that act as electromagnets. Despite the number of coils electrically there really are usually only two coils in a stepper motor, divided into a number of small coils.
  - **Phase**: This refers to the groupings of the individual coils in the stepper motor. A stepper motor may have several coils but they are wired together and controlled in phases. Two, Four and Five phase stepper motors are common. There will often be a phase diagram included with a stepper motor that indicates the sequence that the motor phases are driven in.

  - **Step Angle:** This is the amount that the shaft of the motor will spin for each individual full step, measured in degrees, In some stepper motors this is referred to as Steps Per Revolution and the two figures are just different ways of expressing the same thing. As an example, a common rating for a stepper motor is a 1.8-degree step angle. As there are 360 degrees in a full rotation this is equivalent to 200 steps per revolution (1.8 x 200 = 360).

- **Voltage:** Simply the voltage rating of the motor coils. It is also a function of the current rating and the coil resistance and you can use Ohm's Law to calculate one from the other.

- **Current**: The maximum current at the rated voltage. This is a useful specification as it will allow you to select a suitable driver and power supply for your stepper motor.

- **Resistance:** The coil resistance, measured in ohms.

- **Inductance:** The inductance of each motor coils, measured in millihenries. This is an important specification as inductance will limit the maximum speed you'll be able to efficiently drive your stepper at. Typically unipolar stepper motors have an advantage here as they only use half a coil and thus have lower inductance than their bipolar equivalents.

- **Holding Torque**: This will be the amount of force that is created when the stepper motor is energized.

- **Shaft Style:** The physical shape of the motor shaft. You will need to know this in order to mate your stepper motor with gears, pulleys and other external connections such as shaft couplers. There are several common shapes used, in addition, the shaft length can be important for obvious reasons.

TB6600 Stepper Motor Driver-

Figure 7- TB6600 Stepper motor driver.

- **Objective-** The stepper motor driver is used to control the number of steps taken by the stepper motor to complete one rotation. The driver also controls the current supplied to the motor. The driver also prevents the motor from heating.

- **Theory-** The TB6600 micro stepping driver is built around the Toshiba TB6600HG IC and it can be used to drive two-phase bipolar stepper motors. With a maximum current of 3.5 A continuous, the TB6600 driver can be used to control quite large stepper motors like a NEMA 23. Make sure that you do not connect stepper motors with a current rating of more than 3.5 A to the driver. The driver has several safety functions built-in like over-current, under-voltage shutdown, and overheating protection.
- **Connections-**

TB6600	Connections
VCC	9-42 VDC
GND	Power supply ground
ENA+	Not connected
DIR+	Arduino GND
PUL-	Pin 2
PUL+	Arduino GND
A- , A+	Coil 1 Stepper
B- , B+	Coil 2 stepper

- **Microstep settings-**

S1	S2	S3	Microstep Resolution
ON	ON	ON	**NC**
ON	ON	OFF	Full step
ON	OFF	ON	1/2 Step
OFF	ON	ON	1/2 Step
ON	OFF	OFF	1/4 Step
OFF	ON	OFF	1/8 Step
OFF	OFF	ON	1/16 Step
OFF	OFF	OFF	1/32 Step

- **Current Table**

Current	Peak current	S4	S5	S6
0.5	0.7	ON	ON	ON
1.0	1.2	ON	OFF	ON
1.5	1.7	ON	ON	OFF
2.0	2.2	ON	OFF	OFF
2.5	2.7	OFF	ON	ON
2.8	2.9	OFF	OFF	ON
3.0	3.2	OFF	ON	OFF
3.5	4.0	OFF	OFF	OFF

NRF24L01-

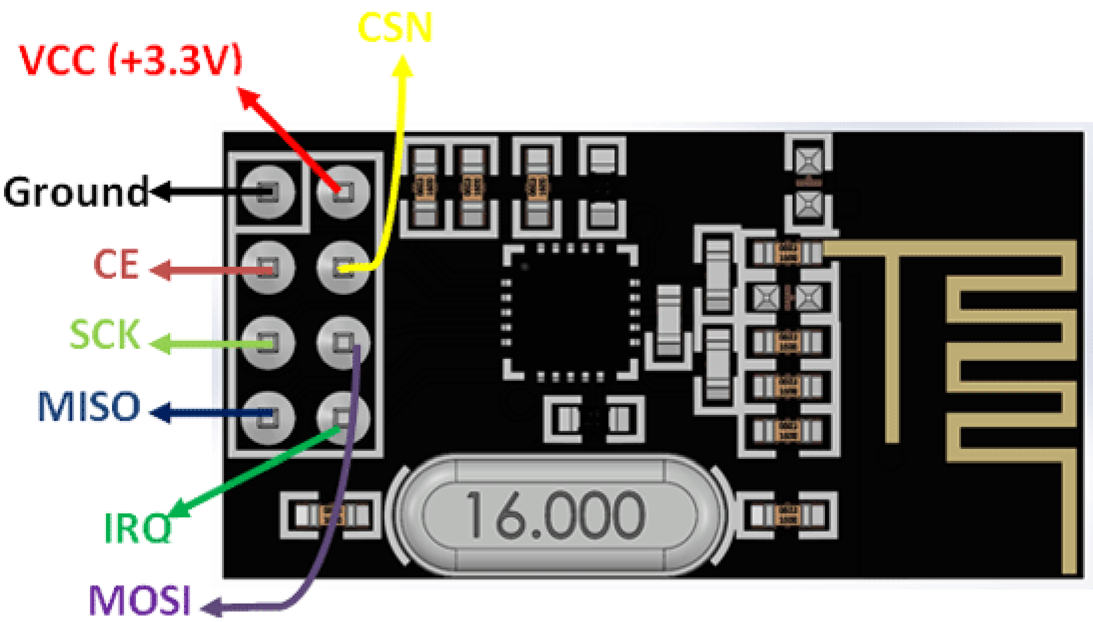


Figure 8- NRF24L01 Module

- **Objective-** The nrf24l01 wifi module is used for the purpose of wifi communication between the sender and the reciver. The module tells the sender if the reciver is aligned and the stepper motor stops scanning for the reciver.
- **Theory-** nRF24L01 is a single chip radio transceiver for the world wide 2.4 - 2.5 GHz ISM band. The transceiver consists of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator, a demodulator, modulator and Enhanced ShockBurst™ protocol engine. Output power, frequency channels, and protocol setup are easily programmable through a SPI interface. Current consumption is very low, only 9.0mA at an output power of -6dBm and 12.3mA in RX mode. Built-in Power Down and Standby modes makes power saving easily realizable.

- **Pin configuration-**

Pin no.	**Pin Name**	**Abbreviation**	**Function**
1	GND	Ground	Connected to the ground of the system
2	Vcc	Power	Powers the module using 3.3v
3	CE	Chip Enable	Used to enable SPI communication
4	CSN	Ship select Not	This pin must be kept always high else it will disable SPI.
5	SCK	Serial Clock	Provides the clock pulse using which the SPI communication works.
6	MOSI	Master out slave in	Connected to MOSI pin of MCU, for the module to receive data from the MCU
7	MISO	Master in Slave out	Connected to MISO pin of MCU, for the module to send data from the MCU
8	IRQ	Interrupt	It is an active low pin and is used only if interrupt is required

- **Working-** The nRF24L01+ transceiver module transmits and receives data on a certain frequency called Channel. Also in order for two or more transceiver modules to communicate with each other, they need to be on the same channel. This channel could be any frequency in the 2.4 GHz ISM band or to be more precise, it could be between 2.400 to 2.525 GHz (2400 to 2525 MHz).
  Each channel occupies a bandwidth of less than 1MHz. This gives us 125 possible channels with 1MHz spacing. So, the module can use 125 different channels which give a possibility to have a network of 125 independently working modems in one place.

Laser Module-

Figure 9- 5V Laser module

- **Objective-**The Laser is used for the communication. The laser is used to represent the actual modulation and demodulation that happens in FSO systems.

LDR Sensor-

Figure 10- 3.3V LDR sensor Module

- **Objective**- The LDR sensor detectes the laser and that the sender and reciver have aligned. It sends the signal to the NRF module to stop the stepper motor.

3. Methodology

3.1 System Design

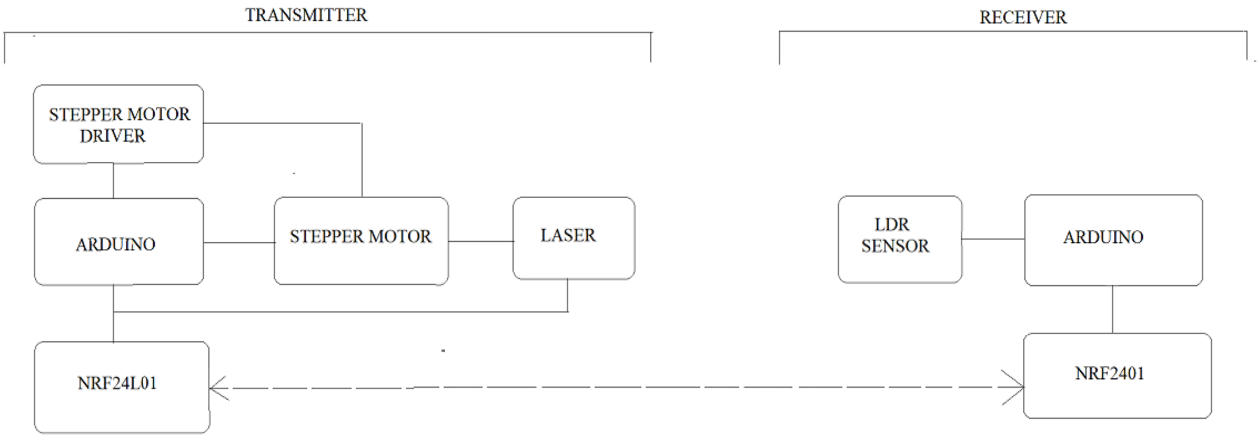


Figure 11- Block diagram of the FSO link alignment system

The system is deisgned with functional blocks that help align the transmitter and the reciver. The Laser and the LdR sensor . The nrf modules communicate to control the movement of the stepper motor and stop if it finds the sensor.

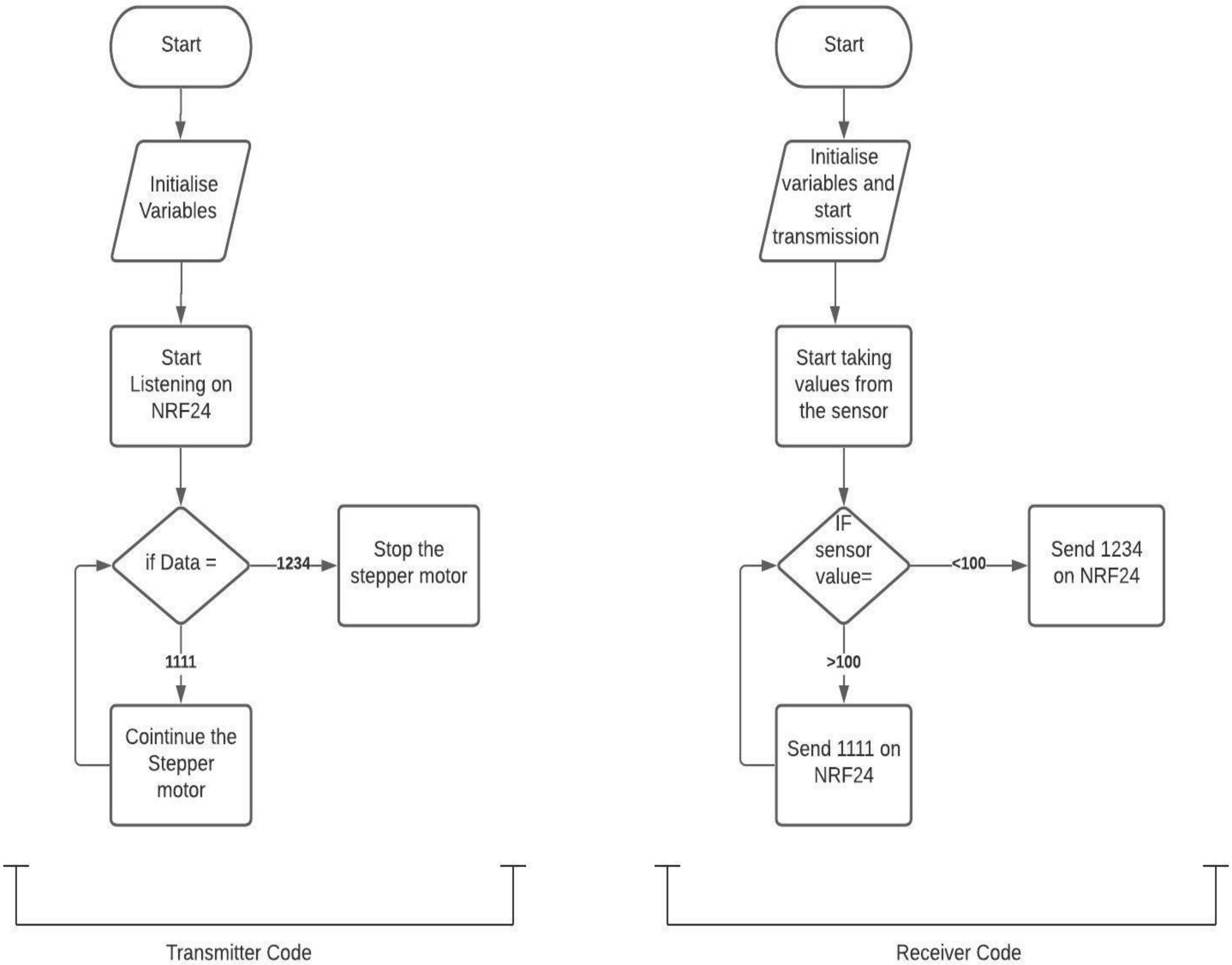
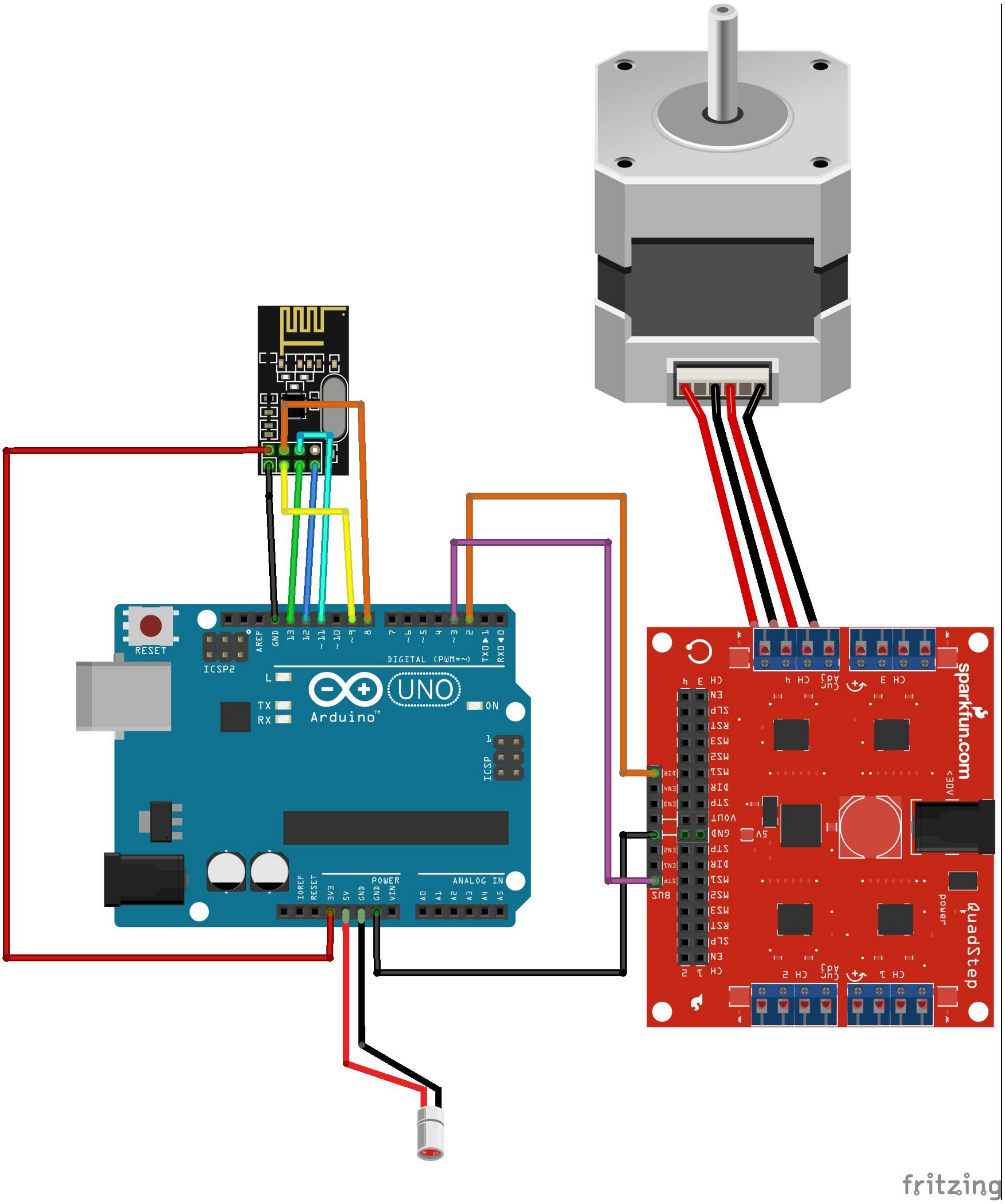


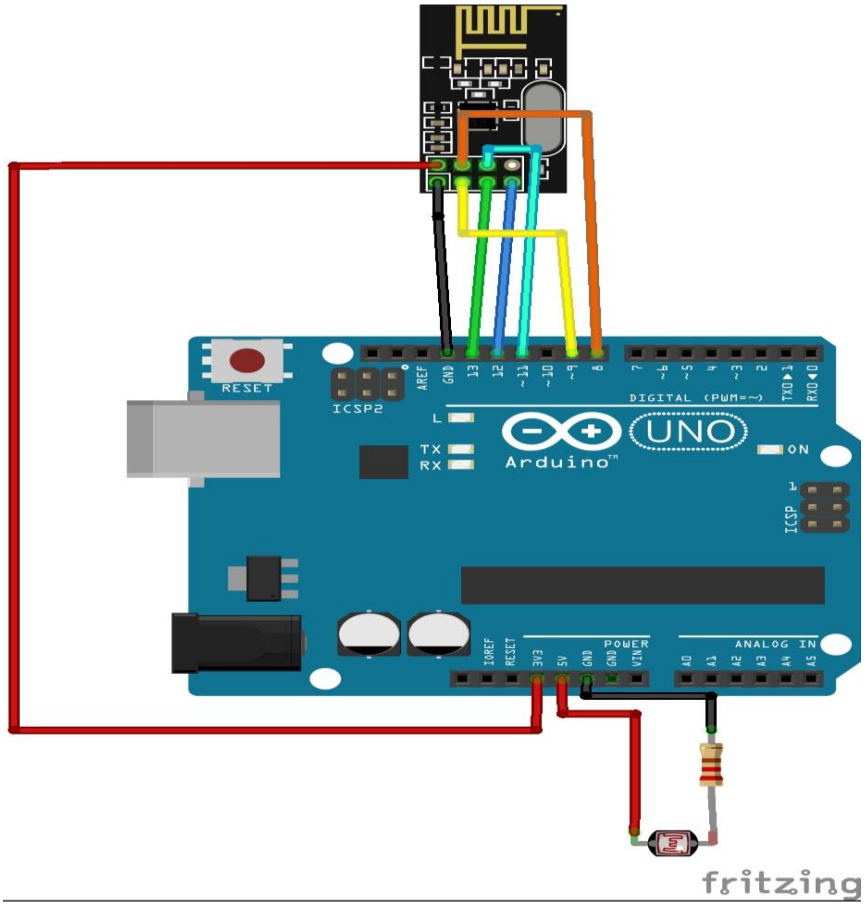
Figure 12- Flow chart of the Working of the system.

3.2 Circuits

Transmitter-



Receiver-



RESET
ICSP2
DIGITAL (PWM=~)
UNO
Arduino
POWER
ANALOG IN
fritzing

4. Conclusion and Future Scope

4.1 Conclusion

The Project was implemented to give people a sense of how effective Free space optics systems are. It also highlights the price and availability of the components needed to build a system like this. The project makes a sense of how the free space optics systems work and how the work communication system is implemented.

4.3 Future Scope-

Optical fiber installation is typically expensive due to the requirement for huge infrastructure investment. Radio frequency communications is currently the technology of choice to avoid these issues but requires expensive licenses to use a few bands of a scarce and strictly regulated spectrum. Free space optical (FSO) communication can provide high-bit-rate line-of-sight transmissions over long distances of up to several kilometres over a broad unlicensed spectrum. As such, FSO is an attractive solution for terrestrial last-mile connectivity in communication networks, especially where fiber connectivity is scarce. Access to abundant, affordable, and reliable connectivity can significantly improve the quality of life of those living in remote and rural communities. In particular, as evidenced by the conditions imposed by the COVID-19 pandemic and other recent natural disasters, the Internet is vital to ensure an uninterrupted access to information, healthcare, education, commerce and employment systems and services.

FSO is equally expected to be a significant part of the future 6G era to scale down bandwidth challenges. Furthermore, with the satellite internet service race gearing up to bring fiber-like throughput via space satellite networks, FSO systems are already being pursued for inter-satellite connectivity and are also expected to augment existing microwave satellite feeder-links in the near future. With our increasing capabilities to harness the power of the quantum-mechanical nature of photons, FSO is also likely to play an important role in the future of quantum information networks, as exemplified by steady progress in single-photon level quantum key distribution demonstrations. Therefore, FSO systems and networks are also likely to play a significant role in paving the way toward a global secure quantum Internet.

REFERENCES

Books

[1] Contemporary Issues in Wireless Communications

[2] Next Generation Free Space Optical Communication Technologies

Web

[1] NRF24L01, Lastminuteengineeres.com

[2] Stepper Motor- HowtoMechatronics.com

[3] Arduino Arduino.cc