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Parameter Extraction and Profile Study of Optical Wavefront in Near Earth Atmosphere using Zernike Polynomial

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Abstract **- Free-space optical communication (FSO) is an optical communication technology that uses light propagating in free space to wirelessly transmit data for telecommunications or computer networking. Refractive index in homogeneities of the turbulent air cause wave-front distortions of optical waves propagating through the atmosphere, leading to such effects as beam spreading, beam wander and intensity fluctuations (scintillations). The required corrections are determined and applied by the wave- front corrector-often a deformable mirror. We wish to develop a wave-front sensor less correcting system. In this project we employ a method in which a correcting element with adjustable segments is driven to maximize some function of the image which is acquired by science camera. In our project Zernike polynomial can be used to represent the instantaneous shapes of wave-fronts generated by atmospheric turbulence. It can be used for analyzing wave- fronts, but also as a possible basis for compensating atmosphere turbulence effects. Experiments performed under strong scintillation conditions as well as with higher resolution wave-front control demonstrate the mitigation of wave-front distortions and the reduction of signal fading. The wave-front aberration that can occur in FSO can be graphically visualized by the MATLAB software by using the ZERNIKE POLYNOMIAL method.**

I . INTRODUCTION:

A. Free-Space Optics (F.S.O) Defined:

Free Space Optics, the industry term for “Cable-free Optical Communication Systems”, is a line-of-sight optical technology in which voice, video and data are sent through the air (free space) on low-power light beams at speeds of megabytes or even gigabytes per second. A free-space optical link consists of 2 optical transceivers accurately aligned to each other with a clear line-of-sight. Typically, the optical transceivers are mounted on building rooftops or behind windows. These transceivers consist of a laser transmitter and a detector to provide full duplex capability. It works over distances of several hundred meters to a few kilometers.

B. **Emergence of FSO in Today’s Fiber Optic Networks:**Fiber optics provides an excellent solution for high bandwidth, low error requirements and can serve as the backbone for the internet infrastructure. Most of the recent trenching to lay fiber has been to improve the metro core (backbone). Carriers have spent billions of dollars to increase network capacity in the core, of their networks, but have provided less lavishly at the network edges. This imbalance has resulted in the "last mile bottleneck." Service providers are faced with the need to turn up services quickly and cost-effectively at a time when capital expenditures are constrained.

From a technology standpoint, there are several options to address this "last mile connectivity bottleneck" but most don't make economic sense.

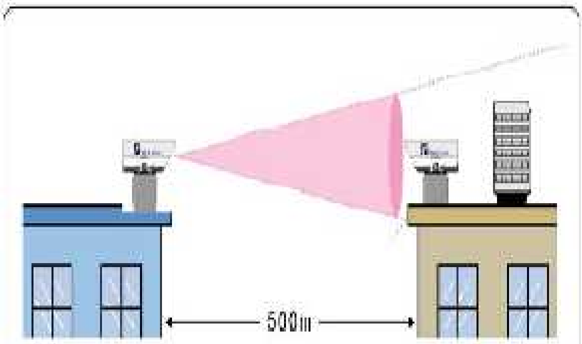
C. **Fiber - Optic Cable**: Without a doubt, fiber is the most reliable means of providing optical communications. But the digging, delays and associated costs to lay fiber often make it economically prohibitive. Moreover, once fiber is deployed, it becomes a "sunk" cost and cannot be re-deployed if a customer relocates or switches to a competing service provider, making it extremely difficult to recover the investment in a reasonable timeframe.

D. **Radio frequency (RF) Wireless**: RF is a mature technology that offers longer ranges distances than FSO, but RF-based networks require immense capital investments to_acquire spectrum license. Yet, RF technologies cannot scale to optical capacities of several gigabits. The current RF bandwidth ceiling is 622 megabits. When compared to FSO, RF does not make economic sense for service providers looking to extend optical networks.

E. **Wire & Copper-based technologies:** (i.e. cable modem, T1s or DSL): Although copper infrastructure is available almost everywhere and the percentage of buildings connected to copper is much higher than fiber, it is still not a viable alternative for solving the connectivity bottleneck. The biggest hurdle is bandwidth scalability. Copper technologies may ease some short-term pain, but the bandwidth limitations of 2 megabits to 3_megabits make them a marginal solution.

Providing last mile connectivity is extremely difficult and expensive. In metropolitan areas, an estimated 95 percent of buildings are within 1.5 km of fiber-optic infrastructure. But at present, they are unable to access it. Connecting them with fiber can cost US $100,000-$200,000/km, with 85 percent of the total figure tied to trenching and installation. Street trenching and digging are not only expensive, they cause traffic jams (which increase air pollution), displace trees, and sometimes destroy historical areas.

But, light travels through air for a lot less money!!



In summary, FSO emerges as "The Golden Mean" between speed and expense.

F. FSO vs. RF:

There is little doubt that RF communications will provide mobility outside and over large coverage areas. In this environment however **the data transfer rates to individual users are likely to be limited.** At lower data rates RF is excellent at providing coverage, due to the scattering and the diffraction of the radio waves, and the sensitivity of the receivers that can be constructed. Channels are robust to being blocked by obstacles and coverage can be achieved between rooms.

Higher data rates require higher frequencies. At these frequencies the radio signal propagation becomes line of sight, and problems become similar to that using light. Components operating at these frequencies are expensive, and the advantages of radio (coverage, and receiver sensitivity) become less clear.

G. FSO vs. Fiber Optic Cables:

In one free-space optics business case, a competitive local exchange carrier (CLEC) has an agreement with a large property management firm to provide all-optical 100-Mb/s Internet access capability to several buildings located in an office park. The carrier is building its network by leasing long-haul capacity from a wholesale fiber provider. It has identified a potential hub, or point-of-presence, less than a kilometer from the office park and within sight of one of its central offices. The CLEC currently has no fiber deployed to target customer buildings

When fiber was compared with free-space optics, deployment costs for service to the three buildings worked out to $396 500 versus $59 000, respectively. The fiber cost was calculated on a need for 1220 meters at $325 per meter. Free-space optics is calculated as $18 000 for free-space optics equipment per building and $5000 for installation. Supposing a 15 percent annual revenue increase for future sales and customer acquisition, the internal rate of return for fiber over five years is 22 percent versus 196 percent for free-space optics.

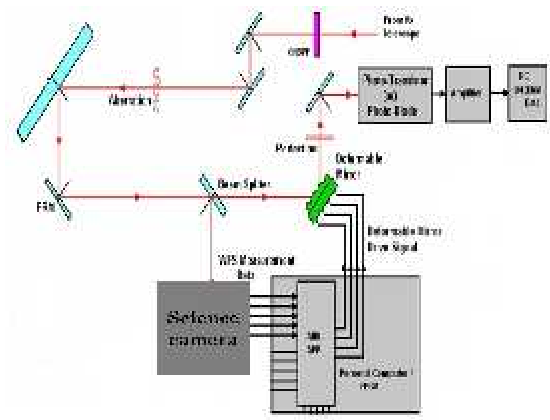
II. APPLICATION:

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.

- Last-mile access: FSO can be used in high-speed links that connect end-users with Internet service providers or other networks. It can also be used to bypass local-loop systems to provide businesses with high-speed connections.
- Enterprise connectivity: The ease with which FSO links can be installed makes them a natural choice 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 back up fiber in place of a second fiber link. The diversity that comes from backing up fiber with FSO may provide better protection than backing fiber up with additional fiber.
- Service acceleration: FSO can be also used to provide instant service to fiber-optic customers while their fiber infrastructure is being laid.

Backhaul: FSO can be used to carry cellular telephone traffic from antenna towers back to facilities wired into the public switched telephone network.

III. SCHEMATICE REPRASENTATION:



The transmitted beam collected at the receiver section. Then the received beam is given to the optical narrow band pass filter section. The aberrated wave form is get reflected from the pure reflection mirror. That wave is given to the beam splitter which splits the beam into to parts one is given to the science camera the part of the waveform given to the deformable mirror. The science camera is high resolution camera the rang in KHZ. That absorbs the beam and given to the ANN/APP which is the PC or FPGA. Then the waves go to the deformable mirror which adjust their position to the wavefront shapes. The necessary corrections are done in that part. After from the DM wave is a perfect wave. This wave given to the photo detector circuit then it given to the amplifier circuit for amplification process. At finally the original signal get and stored in the PC.

IV. OBJECTIVES OF THIS PROJECT:

To develop a analytical model for modeling and simulation of atmospheric characteristics that relates the received optical signal fluctuation with the atmospheric turbulence changes using a simplex communication link for an appropriate range viz 5km. To develop and demonstrate a wavefront sensorless

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adaptive optics test bed for developed FSOC in order to correct wavefront aberrations using imaging optics. i.e. research work aims to correct for wavefront aberrations without the use of a conventional wavefront sensor. Aberrations in the Received light beam will be measured by using a high resolution science camera in order to extract the various parameters that are needed to correct them using the proposed neural controller architecture.

V. LASER SOURCES:

Today a variety of laser sources are available:

1. Diode
2. Helium-Neon
3. Argon/Krypton ion
4. Carbon Dioxide lasers
5. Helium-Cadmium (HeCd) lasers.

Of particular interest to FSO applications is the diode laser source - which is hence described in detail below.

A. DIODE LASER:

A 'laser diode', refers to the combination of the semiconductor chip - driven by low voltage power supply.

B. Wavelengths: Nowadays, laser diodes with wavelengths around 635 nanometers are available which is a very visible red wavelength (actually may appear slightly orange-red). Deep Red (670 nm) and beyond, IR (780 nm, 800 nm, 900 nm, 1550 nm, etc.) up to several micromts are also available. Green and blue laser diodes which have been produced in various research labs, only operated at liquid nitrogen temperatures, had very limited life spans (~100 hours or worse), or both. Recent developments suggest that long lived room temperature blue and green diode lasers will be commercially available. Violet (around 400 nm) laser diodes are just going into production.

C. Beam quality: lasers generally don't have ideal beam characteristics, but they are fairly easy to focus to the degree that the beam does not widen by more than a millimeter or two per meter. Most diode laser "pointers" and collimated diode laser modules should achieve this.

D. Power: .1 mW to 5 mW (most common), up to 100 W or more available. The highest power units are composed of arrays of laser diodes, not a single device.

E. Sensitivity: The "junction" or main light-emitting working part of a typical laser diode is about the size of a bacterium and can overheat within a microsecond if its limits are exceeded. Furthermore, the minimum current to achieve laser operation ("laser threshold") can easily be near or over 80 percent of the "fatal dose" of current. There is a maximum current which must not be exceeded for even a microsecond - this depends on the particular device as well as junction temperature. This sensitivity to over current is due to the very large amount of positive feedback which is present when the laser diode is lasing. In other words, it is not sufficient in most cases to just use a constant current power supply. Laser diodes can also be damaged by exceeding the maximum safe optical output, which may be hardly at all over the rated optical output. Damage can occur in this way even if no other limits are exceeded or reached. LEDs, laser diodes require much greater care in their drive electronics or else they will die instantly. It quite easy to fry expensive laser diodes through improper drive or handling. Once blown, laser diodes don't even work very well as visible LEDs.

Size: Laser diodes are very compact - the active element is about the size of a grain of sand, low power (and low voltage), relatively efficient (especially compared to the gas lasers), rugged, and long lived if treated properly.

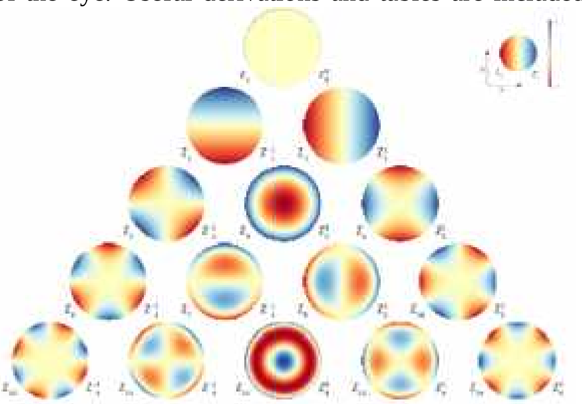
VI. RECEIVING LASER BEAM USING A PIN PHOTODIODE:

For reception we need an optical receiver within the optical spectral range of the transmitted laser beam. This receiver should have a high enough switching speed to sustain the required data rate as well. LDRs or Phototransistors are unsuitable due to their sluggish response. A PIN photodiode has a much faster response time than the other 2 and is hence used here.

The PIN Photodiode operates as a voltage source as well a current source in response to the incident light in the wavelength range of 600 nm to 1050 nm. The current measurement is preferred since the output current changes linearly with incident light power - it is linear from a few pico-amps up to few milli-amps. The voltage output, however, changes logarithmically with incident light power.

VII. ZERNIKE POLYNOMIAL:

The Zernike polynomials are a set of functions that are orthogonal over the unit circle. They are useful for describing the shape of an aberrated wave-front in the pupil of an optical system or true height corneal topography. There exist several different normalization and numbering schemes for these polynomials. The purpose of this outline is to describe a standard for presenting Zernike data as it relates to aberration theory of the eye. Useful derivations and tables are included.



The first 15 Zernike polynomials, ordered vertically by radial degree and horizontally by azimuthal degree

VIII. SIMULATION RESULTS AND DESCRIPTIONS

8.3.1 Aberration correction through MATLAB – Results

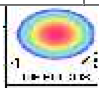
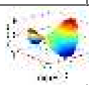
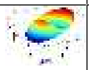
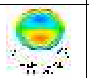
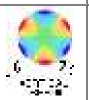
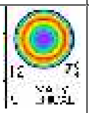
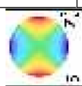
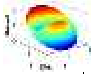
Polynomal order	Type of aberration	Before correction	After correction	Description
m=0 n=0	Piston			In optics, **piston** is the mean value of a wavefront or phase profile across the pupil of an optical system.
m=1 n=1	Tilt			Tilt quantifies the average slope in both the X and Y directions of a wavefront.
m=0 n=2	Defocus			**defocus** is the aberration in which an image is simply out of focus.
m=2 n=2	Astigmatism			An optical system with **astigmatism** is one where rays that propagate in two perpendicular planes have different focus.
m=1 n=3	Coma			In optics (especially telescopes), the **coma**, or **comatic aberration**, in an optical system refers to aberration inherent to certain optical designs.
m=3 n=3	Trefoil			A simple trefoil shape in itself can be symbolic of the Trinity.
m=0 n=4	Spherical aberration			**Spherical aberration** occurs due to the increased refraction of light rays
m=2 n=4	2nd order astigmatism			**astigmatism** is one where rays that propagate in two perpendicular planes .
m=4 n=4	Quatrefoil			A simple quatrefoil shape in itself can be symbolic of the quatreant.
m=1 n=5	2nd order coma			In optics (especially telescopes), the **coma**, or **comatic aberration**, in an optical system refers to aberration inherent to certain optical designs.

Table 8.1 aberration correction through MATLAB

IX. CHALLENGES AND RELIABILITY ISSUES IN FSO SYSTEMS:

A. Atmosphere/Weather: Exposure to weather variations will remain the No. 1 challenge for FSO systems. The major disruption for any free-space optics system is fog. Fog is vapor composed of water droplets, which are only a few hundred microns in diameter. Fog can modify light characteristics or completely hinder the passage of light through a combination of absorption, scattering and reflection. The frequency at which the light signal travels is very high, which means that the band that it travels through is very small (in nanometers).

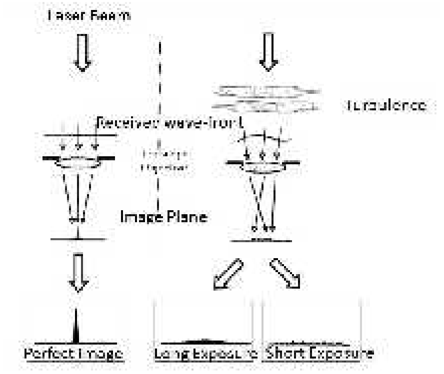
B. Scattering: Scattering is caused when the wave collides with the scatterer. In scattering-unlike absorption-there is no loss of energy, only a directional redistribution of energy that may have significant reduction in beam intensity for longer distances. The physical size of the scatterer determines the type of scattering. Dealing with fog, is more formally known as Mie scattering. There seems to be some evidence that Mie scattering is slightly lower at 1550 nm than at 850 nm.

C. Absorption: Absorption occurs when suspended water molecules in the terrestrial atmosphere extinguish photons. This causes a decrease in the power density (attenuation) of the FSO beam and directly affects the availability of a system. Absorption occurs more readily at some wavelengths than others. However, the use of appropriate power, based on atmospheric conditions, and use of spatial diversity (multiple beams within an FSO unit) helps maintain the required level of network availability.

D. Scintillation: Scintillation is best defined as the temporal and spatial variations in light intensity caused by atmospheric turbulence. varying densities and therefore fast-changing indices of optical refraction. These air pockets act like prisms and lenses with time-varying properties. Scintillation can cause fluctuations in signal amplitude which leads to "image dancing" at the FSO receiver end. Refractive turbulence causes two primary effects on optical beams.

E. Beam Wander: Beam wander arises when turbulent eddies bigger than the beam diameter cause slow, but large, displacements of the transmitted beam. beam wander is readily handled by active tracking.

F. Beam Spreading: Beam spreading-long-term and short-term-is the spread of an optical beam as it propagates through the atmosphere.



X. CONCLUSION:

A circuit for laser transceiver has been successfully implemented. System has been tested to guarantee transfer rates upto 56Kbps.The laser link works upto a distance of 200 m.Software programs for file transfer and chat have been successfully implemented. and wave-front aberrations can be tracked that can occur in the free space optics (FSO),by using the Zernike polynomial method the wave-front aberration can be graphically represented and simulated.

XI. ACKNOWLEDGMENT

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