A SURVEY ON WAVEFRONT SENSORLESS TECHNIQUES FOR FREE SPACE OPTICAL COMMUNICATION SYSTEM

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Abstract: **Free Space Optical Communication is a wireless optical technology in which the laser beam is travelled through the atmospheric channel. The line-of-sight is maintained at the atmosphere between the transmitter and receiver. When the laser beam is propagated through the free space atmosphere, it can be severely affected by the atmospheric turbulence. Adaptive Optics is used to compensate the atmospheric turbulence thereby improving the quality of an optical system, in which the wavefront sensor (WFS) plays an important role in measuring the phase aberration. In this paper we presented an overview of different sensor-less techniques that can be used for FSOC to compensate the atmospheric turbulences.**

Keywords: **FSOC, Adaptive Optics, deformable mirror, wavefront sensorless techniques.**

I. INTRODUCTION

Free space optical communication is the technique that propagate the light in the free space which is similar to that of the wireless transmission. Growing commercial deployment of FSOC leads to increase in the research and development activities over the past few years. Currently, FSOC allows the transmission of data upto the rate of 2.5 Gbps. Unlike microwave and RF wireless communication it is the secured licenece free technique. The main concern which has to be consider in the FSOC is the Line-Of-Sight(LOS). The Line-Of-Sight should be maintained during transmission inorder to achieve the better BER(Bit Error Rate).The block diagram of the FSOC system is as shown in the figure 1.

The major advantages of the FSOC system is the High-rate of data transmission at the very high speed [3],high security, license free. Comparing to the fiber optics communication the cost of installation is less. Immunity to electromagnetic interference and it is invisible and eye safe hence there is no health hazards.

Most widely used in the Telecommunication and Computer networking, cellular communication backhaul, Military and security applications and disaster recovery among other emerging applications.

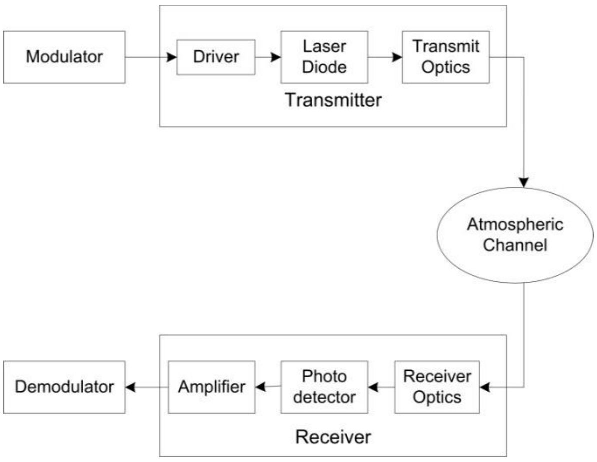

Fig 1.Block diagram of the FSOC system

The only limiting factor of the FSOC system is the atmospheric turbulence. Since the outdoor environment which acts as the transmission medium for this technique could be depend on the unpredictable weather conditions. Effect of fog, rain, dust and other dispersing particles in the atmosphere could leads to the beam dispersion, scattering, beam attenuation beam spreading and scintillation takes place. This results in the wave distortion and fluctuations in the phase and amplitude of the wave.

To overcome the limiting factors in the external environment various corrective techniques are adapted. Some of the wavefront correction techniques used in the sensorless Adaptive optics system are:

(i) Modal-based Tabu Search(MBTS) algorithm[4].

(ii) Stochastic Parallel Gradient Descent (SPGD)[5].

(iii) Simulated Anneling(SA)[7].

II.CONVENTIONAL ADAPTIVE OPTICS

Adaptive optics is used to correct the waveform distortion in the astronomical and optical communication system. This technique is implemented to recover the waveform which is degraded by the atmospheric turbulence.

In a Conventional adaptive optics system, the disturbance in the optical wave could be detected by the wavefront sensor. In this design, the laser beam that propagates in the free space is compensated with the actuators of the deformable mirror. The sensed information could be decoded by the control system. The system monitor the disturbance and control the actuators of the deformable mirror for the compensation of the distorted wavefront. The design of adaptive optics system is illustrated in the fig.2.

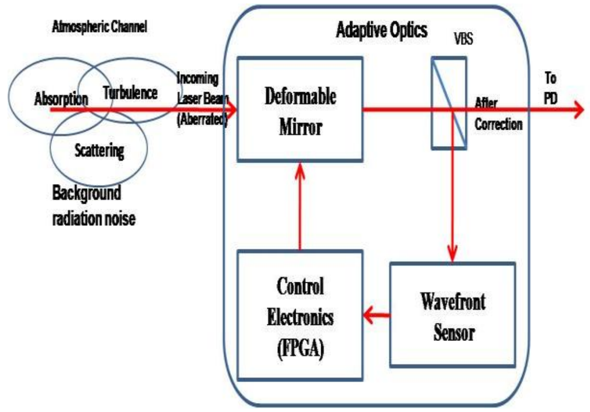

Fig 2. Schematic diagram of adaptive optics system.

Adaptive optics application was first applied in the retinal imaging , astronomical imaging[1], microscopy[12], vision science[11], laser communication system[13].

III.SENSORLESS ADAPTIVE OPTICS

For last few years, the wavefront sensor such as Schack-Hartmann sensor is used for the detection of the atmospheric aberration in the incoming laser beam and the deformable mirror is one of the adaptive elements used to introduce some additional distortion that eliminate other aberration in the system. Since there is complexity in the hardware of the wavefront sensor of conventional AO system,we are going for the wavefront sensorless approach.

The major concern of the sensorless AO system is to determine the DM shape that removes all other aberration in the laser beam. The control algorithm is designed for providing the relationship between the second order atmospheric aberration and far-field intensity. The main advantage of the wavefront sensor-less system is the far-field intensity is acts as the feedback signal.

The algorithm for wavefrontsensorless adaptive optics system is widely classified into two: Image based and stochastic algorithm. The stochastic based algorithms which is widely in use are Genetic algorithm and Ant colonies. The image based algorithms are sensorless modal correction, low spatial frequency, point spread function,Optical Coherent Tomography(OCT) and Laser process optimization.

1.Stochastic algorithms for wavefront sensor-less correction:

A.Genetic Algorithm:

In Genetic Algorithm, the solution of a problem could be searched by the simulation of the evolutionary process. The algorithm selects the strongest element that can survive from the possible solutions of the population and they have ability to reproduce to generate the new generation[10]. This algorithm help us to solve the large class of problems without any reference and the basic knowledge.

The major steps of the Genetic Algorithm is selection function, reproduction function and evaluate population.

Step 1: In the selection process, the function may be either deterministic or probabilistics. In the case of probabilistic, the strongest element could have the chance of being selected and reproducing the next generation.

Step 2: The reproduction produces the new generation from the old ones.

Step 3: In evaluation process, there are two different functions, they are: mutation and crossover.

Crossover: It is the process of mixing of two parent genes by slightly modifying them and obtaining the new generation.

Mutation: In this process, the genes of the parents could be modified randomly.

The above steps are followed for finding the strongest individual with better survival of fitness function. Thus the algorithm is repeated to determine the strongest element from the large class of random population.

The application of the genetic algorithm in the adaptive optics is the laser focalization is explained as follows.
In the optical communication system, laser beam alignment is not that much simple to reach accurately. The intensity of the laser beam in the focal spot is depends on its focal point and it could be eliminated with the adaptive optics system. When the laser beam reached at the end, the genetic algorithm is provided as the feedback which has the harmonic distortions to select the better focal point to obtain the undistorted laser beam.

B.Ant colonies:

Ant colonies optimization is one of the successful algorithm for finding possible path to reach the destination with the desired outcomes. In general, it has adapted the behavior of the ant in nature. The following steps explains the algorithm for ant colony optimization.

Step 1: Initially, the position of ant is set on the trail.

Step 2: Calculate the length of the path.

Step3: Update vector value.

Step 4:Change the position of the ants on the trail.

The application of the ant colony in the optical system is the quantum optics.

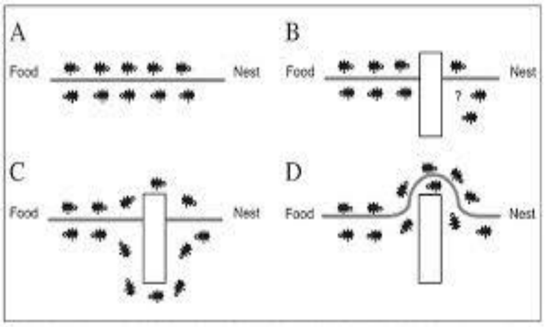

Fig 3: Ant Colonies Algorithm.

2.Image based algorithms:

Even the stochastic algorithms have been implemented to analyze the important parameters of the optical communication, the new methods are adapted to be more efficient. The modal based approach of the aberrations, help us to sorted the some of the drawbacks such as need of preliminary knowledge to find the algorithm terms and long consumption of time. This image based algorithm is effective in both in laser optimization and visual optics.

A.Devices for sensor-less modal correction:

Electrostatic membrane deformable mirrors depend on the electrostatic pressure between an actuator pad array and a thin metalized membrane[8]. To that extent, the mirror can be controlled by the better wavefront analysis and the more actuators. The optimization algorithm was used in the deformable mirror which generates the each electrode with deformation acquisition.

B.Low Spatial Frequencies:

In the optical imaging system, the sharpness of image depends on the quality of the wavefront. In an image, low spatial frequency can be used to perform the optimization in the form of metric. It performed by the acquisition of a images in series with the help of a predefined aberration. To remove the aberration, the image having the information which is to be corrected. The special feature of the equation is that the image sharpness I(ai) result of the Lukosz polynomials coefficients {ai}[8], which is quadratic:

$$I(ai) \approx \Sigma iai2.$$

The above equation implies that the each mode optimizaton can be carried out independently. Then, the result is interpolating with the quadratic function which is used to find the best point for each aberration.

C.Point spread function :

By using software, wavefront sensor-less AO system is analysing the images by optical system and getting the shape of the information using point source image . The required optimization technique is continued until the given aberration is reduced. In this method ,the image can be detected much more difficult. By using the application of camera, light can be passed to the retinal as a source and the wavefront aberration can be analysed .The visual optics is one of the application for PSF optimization is detecting the aberration of the system and it is stable. The limitation of this method is having poor signal. In this function , the images can be improved by using many paths and the aberration can be improved by using deformable mirror and the images can be developed.

D.Optical Coherence Tomography (OCT):

In this method, an optical three-dimensional imaging can be detected by the samples of an image. The given optimization is having axial and lateral resolution. The axial resolution can be calculated using bandwidth and wavelength of the light source. The lateral resolution can be calculated using laser and image of an adaptive optics system. OCT is having high potential and isotropic resolution. The OCT method can be joined to AO system and it can be classified into interferometric and adaptive optics subsystem. The wavefront sensing and correction could be added in the adaptive optics subsystem .In the adaptive optics-OCT subsystem is to calculate and correct aberration of the adaptive optics system. The correction of the sensorless system can be developed in OCT by using important type of deformable mirror.

E.Laser process optimization:

The laser source was an optical parametric amplifier with highly tunable mid IR energy which was at the repetition rate of 10Hz. In the experimental setup[8], laser souce reflected by the two elements (i.e) plane mirror (M1,M2) and a resistive MDM. There was a interaction chamber which is used for generation of the laser harmonics. A krypton gasjet in the interaction chamber was interacted with laser pulse thereby producing the laser harmonics.

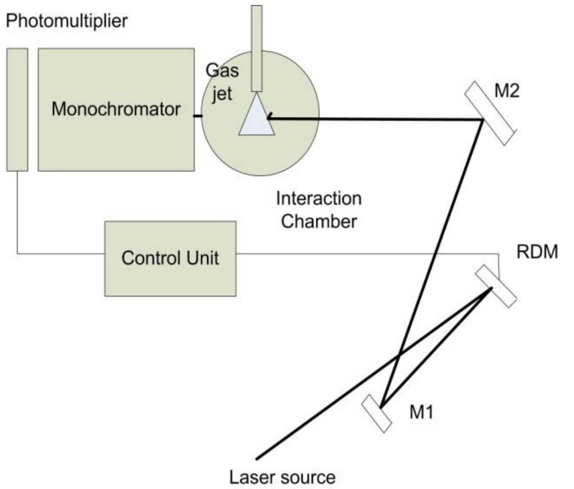

Fig 4: Schematic diagram for laser beam optimization.

The photomultiplier present at the output of the monochromator which detects the increases of the harmonics signal. The photomultiplier visualized the result on the photon flux.

IV.CONCLUSION

The main problem in the FSOC links results from attenuation and fluctuation of optical signal at the receiver . In this paper , we are attempting to improve free space optical communication by use of several sensorless adaptive optics. Sensor-less adaptive optics having a great strength for finding new application in current and future technologies.

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