A New Optics Design of Free-Space Optics (FSO) Communications Module for Providing a High-Speed Dedicated Data Service to a Moving Car

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Abstract. We present a new composite lens system for FSO communications to the moving cars, in which not only transmitter lenses for optical data and beacon, but also the collecting lens for receiving optical data and the imaging lens of the beacon are integrated. Potential uses of the light weight, small size, and low cost transceiver modules for providing 1.25Gbps data link to the moving cars will be presented.

Keywords: mobile free-space optical communications, composite lens, pointing acquisition and tracking, net-brain cloud car

1 Introduction

A high speed, security, and dedicated communications link is essential for a smart unmanned vehicle in future transportation systems, through which not only information required for maneuvering can be obtained, shared and exchanged with the control center and the other cars, but also broadband data and multimedia services can be provided to the passengers in the vehicle. In the case of future autonomous smart car system, 100s of Mbps or even Gbps dedicated communications service may be required for each individual vehicle[1,2]. In these senses, free-space optical (FSO) communications may be an ideal solution for providing broadband communications to moving platforms such as cars, trains, airplanes, ships, and so forth. A FSO link can easily provide Gbps link from one point to another. Since a FSO link is high directional, it is inherently secure and can provide exclusive link to the specific vehicle. It requires, however, a precision pointing, acquisition, and tracking (PAT) to establish a link between a moving vehicle to a base station (BST) or to the another moving vehicle. A multi-input and multi-output (MIMO) arrangement can be applied for providing services from the BST to the multi-users simultaneously [3].

The cars in the future autonomous and smart transportation system will eventually move to the net-brain cloud system. The mobile FSO (MFSO) system is especially advantageous in this future transportation system because of the reasons mentioned above. To the best of our knowledge, no other wireless communications schemes can provide such a broadband exclusive service to the moving cars on the road. The only concern may be its vulnerability to a bad weather, especially a thick fog, and an instantaneous obstruction caused by a moving object in the beam path. It is not a major problem, however, in car applications, because cars may not be allowed to move in such a poor visibility situation.

In this paper, we are presenting a new design of optics in MFSO transceiver module which can be suitable for providing broadband connectivity to the cloud computer for net-brain cloud autonomous car applications.

2 Transceiver Module for MFSO

As mentioned in the previous section, PAT is very important in MFSO communications. The transceivers at both ends of the communication link must be aligned within less than 1 mrad with respect to each other. Transceiver module (TRM) at each end of the communication link possesses the beacon and the quadrant photodiode (QPD) for sensing the position of the received beacon image. Angular position of the TRM at the other end of the communication link can be calculated from the output signals of the QPD and it can be used as the error signal for active feedback control of the optic axis of the TRM at each end of the link Even though wavelength division multiplexing or polarization division multiplexing schemes can be employed to integrate the transmitter, receiver, beacon, and position sensing optics together, it requires very complicated alignment procedure and precision positioning components, which result in not only high manufacturing cost but also relatively heavy equipment. It may be too heavy to steer the TRM for PAT. For this reason, a large area mirror was used for PAT in many MFSO applications.

In order to circumvent the problems mentioned above, we designed a new TRM by using a properly designed composite Fresnel lens. In principle, four lenses, the transmitter lens, receiver lens, beacon lens, and beacon image lens, can be integrated into one sheet of the Fresnel lens. In this preliminary research, in order to prove the principle of operation, the transmitter and receiver lenses are integrated as shown in Fig. 1. The beacon lens and beacon imaging lens are mounted separately, but carefully aligned and permanently fixed by using the standardized alignment and packaging procedure. The lens assembly are very simple, rugged, and light enough that the TRM constructed by our new method can be mounted on a servo motor pan/tilt stage for PAT. It should be emphasized that these lens assembly can be molded on the single sheet of Fresnel lens and additional laborious alignment procedures may not be necessary. In order to reduce the weight, both the transmitter (Tx) and beacon are delivered from the main unit by using the corresponding single mode optical fibers. The wavelengths of the Tx and beacon are 1550nm and 980nm, respectively. The collected light from the receiver (Rx) lens is sent to the high-speed APD by using the 50μm core diameter multi-mode fiber. The beacon signal from the other end of the FSO link is imaged onto the QPD, and the error signal for active PAT is obtained by processing the QDP output signals. Customized SFP module is used for the transceiver for data communications. The Tx power and the APD sensitivity are approximately 3dBm and -34dBm, respectively. Size of the Rx collecting lens and the diameter of the collimation lens for the Tx are 7.5×7.5cm^2 and 2.5cm, respectively. The geometrical loss caused by the integrated Tx lens is 11%. The focal lengths of the Tx and Rx lenses are 90mm and 160mm, respectively. Size of the beacon and beacon imaging lenses are the same, 3.8×3.8cm^2, but the respective focal lengths are 135mm and 160mm. In Fig. 1, a, b, c, and d are the Tx lens, Rx lens , beacon imaging lens and beacon lens, respectively.

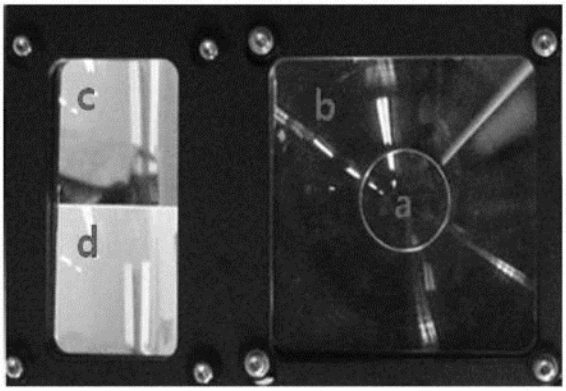

Fig. 1. Composite lens system used for the MFSO link.

The assembled TRM is shown in Fig. 2. The Tx and beacon fiber is mounted on a motorized translation stage for other research purposes, but in practical applications it can be fixed on the body frame by using a packing method to make the TRM sufficiently small, rugged, light, and cheap for net-brain cloud car applications.

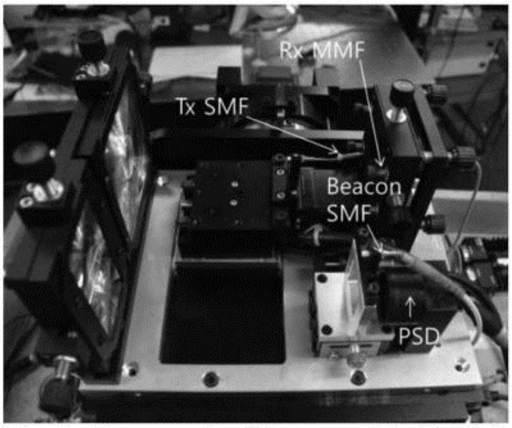

Fig. 2. Photograph of the assembled TRM.

In order to test the performances of our new design, the TRM modules were mounted on the hand carts. The bit-error-rate was measured when one of the carts was moving around the corridor in the lab building. The maximum distance between the TRMs are ~50m. Eye diagrams for the indoor measurements for 622Mbps and

1.25Gbps are shown in Fig. 3.(a) and (b), respectively. Error-free operations were confirmed when the carts are in motion

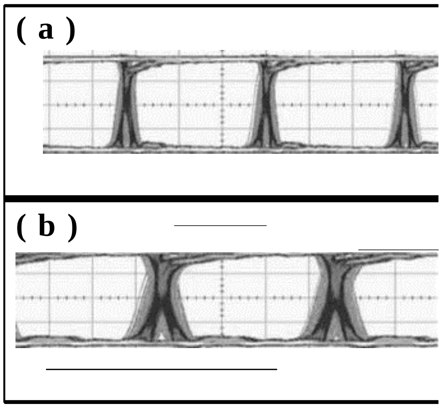

Fig. 3. Eye-diagram for (a) 622Mbps and (b) 1.25Gbps.

Field tests were performed by using a golf cart. One end of the MFSO link was mounted on the golf cart and the other end was mounted on the ground by using a stand specially designed for the test. High definition images were exchanged while the golf cart was moving approximately 10km/h.

3 **Summary**

A new composite lens design for integrating all lenses in TRM has been proposed, for which a small size, light weight, reliable, and low cost TRM for FSO communications can be constructed. The evaluation results in both indoor and outdoor field test show that an error-free 1.25Gbps communication link can be established from a BST to the moving cars and in between moving cars. We are sure that this new scheme can be used for a high-speed, low cost, dedicated, secure communication link for future smart car system.

This work was supported by the Sogang University Research Grant of 2012 (20121400401) and by the IT R&D program of MKE/KEIT. [10039176, Researches on the Gbps wireless technology for providing multimedia services to the group of subscribers in a platform moving faster than 300km/h]

References

1. Haruyama, S., et al.: New Ground-to-train high-speed free-space optical communication system with fast handover mechanism. Conf. Proceed. OFC/NFOEC 2011, OWX4 (2011).
2. Urabe, H., et al.: High data rate ground-to-train free-space optical communication system. Opt. Eng. **51,** 031204 (2012).
3. Akella, J., Liu, C., Partyka, D., Yuksel, M., Kalyanaraman, S., and Dutta., P.: Building blocks for mobile free-space-optical Networks. IEEE WOCN 2005, 0-7803-9019-9/05 (2005).