Demonstration of Robust Mobile Free Space Optical System using High-speed Beam Tracking and 2D-PDA-based Spatial-Diversity Reception

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Abstract: We show the first-ever live demonstration of a robust mobile free space optical system using three-stage high-speed beam tracking technology including 2-dimensional photodetector array based spatial diversity combining, which enables the mobility support in 6G.

1. Overview

Optical wireless communications (OWCs) have been regarded as the appropriate alternatives/complements to the millimeter-wave (mm-wave) or terahertz (THz) based wireless communication systems in the 6th generation (6G) technology [1, 2]. To meet the minimum requirement of the 6G hotspot, free space optical (FSO) communications is a promising OWC solution because FSO systems can provide much higher data rate over 20 Gbit/s (peak data rate in 5G). Furthermore, the infrared (IR) laser diode based FSO systems also equip with the advantages such as high-capacity, low-latency, license-free, low atmospheric attenuation, and high security in the physical layer. Previous literatures have been focused on the outdoor applications with FSO link, whereas the indoor or short-range communications also need to be properly considered in the 6G technology. In this scenario, the adaptive alignment and mobility support are some of the major challenges in 6G applications such as industrial robots and human support robots. To fulfill the demands, some beam tracking technologies for 6G mobile FSO systems have been proposed and demonstrated [3–5]. However, the field of view (FoV) still has some rooms for improvement because the residual misalignment impacts such a system and limits the mobility support as well.

In this demonstration, we combine [3] with [4] and introduce the three-stage high-speed beam stabilization technology for the mobile FSO systems, which includes the high-speed two-stage optical beam tracking and the high-speed 2-dimensional photodetector array (2D-PDA) based spatial-diversity reception. The high-speed two-stage beam tracking includes two main processes: "coarse tracking" by fast steering mirrors (FSMs) and "fine tracking" based on optical beam stabilizer (OBS). Besides, the 2D-PDA is employed to mitigate the residual misalignment in the mobile FSO system. By combining the three-stage high-speed beam stabilization processes, we have achieved 40-Gbit/s data rate (fits 6G criterion) with 11.5°-FoV in the mobile FSO system (moving speed of 11.5°/s), which is also submitted to the 2024 OFC contributed submission [6].

2. Innovation

The three-stage high-speed optical beam stabilization technology in mobile FSO systems will be live demonstrated for the first time. The high-speed coarse tracking and high-speed OBS-based fine tracking enable the C-band laser beam steering and tracking in mobile FSO systems. Besides, by mitigating the residual misalignment from the two-stage high-speed beam tracking, the spatial-diversity reception based on 2D-PDA further improves the robustness of the mobile FSO systems, and extends the FoV while maintaining the receiver bandwidth. In addition, to the authors' best knowledge, no previous demonstration shows the mobility support and adaptive alignment for the mobile FSO systems in real-time.

3. OFC Relevance

This demonstration is relevant to the 2024 OFC Demo Zone topic category of "*systems/sub-systems for free-space or fiber transmission*". In addition to this, the aforementioned work [6] has also been submitted to the contributed submission category of "*Free-space (FSO), Ranging (LiDAR), and Radio-over-fiber (RoF)*" subsection in 2024 OFC. However, it is more promising to demonstrate the robustness of such a mobile FSO system in real-time than simply on the paper. Hence, the authors believe that this demonstration attracts the OFC attendees in the fields of FSO communications or OWCs.

4. Demo content & implementation

4.1 The Objective and the Configuration of the Demo

Fig. 1 illustrates the entire concept and the photos of some core parts in the robust mobile FSO system. Based on the three-stage high-speed beam stabilization technology, the mobile FSO system provides a robust 40-Gbit/s uplink for a moving unit at 11.5°/s in a 2.1-m free-space distance by a C-band laser beam at 1552 nm, which is sufficient for industrial robots or human support robots in 6G. To make the robustness of such a mobile FSO system more promising, the core parts (blue background color blocks in Fig. 1) are proposed to be shown in the OFC Demo Zone, which are the three-stage high-speed beam stabilization technology in real-time demonstration.

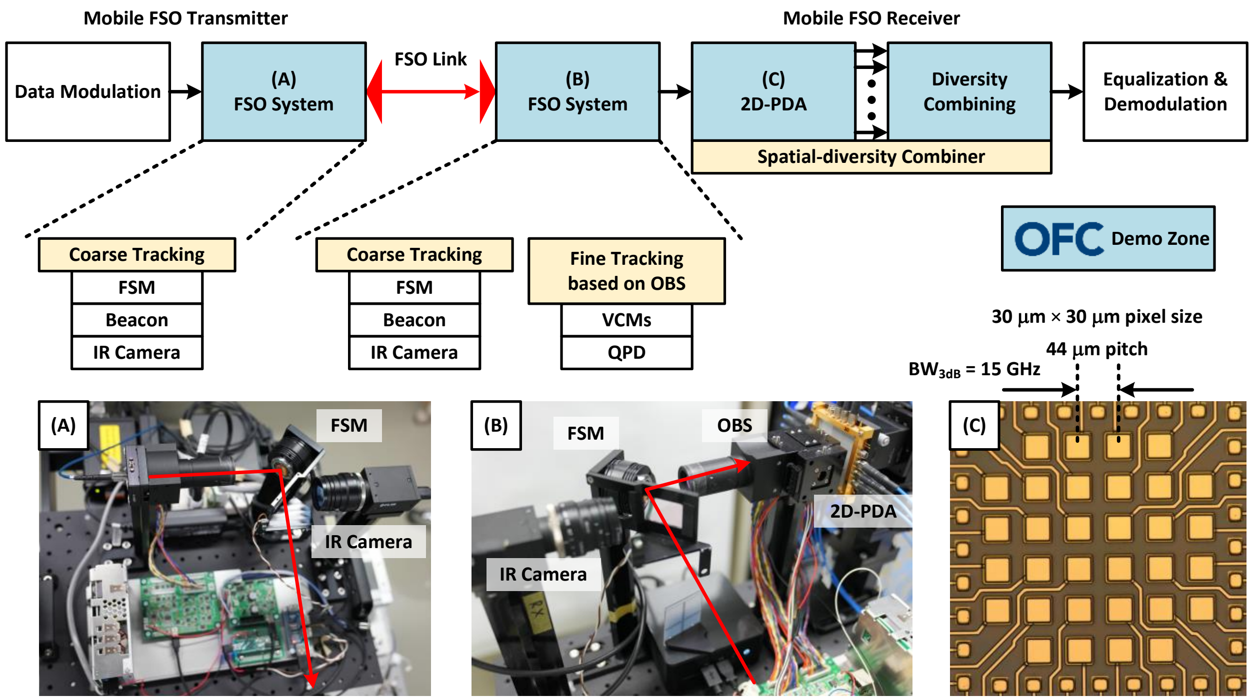

Fig. 1 The entire concept of the three-stage high-speed beam stabilization technology in the mobile FSO systems with corresponding photos.

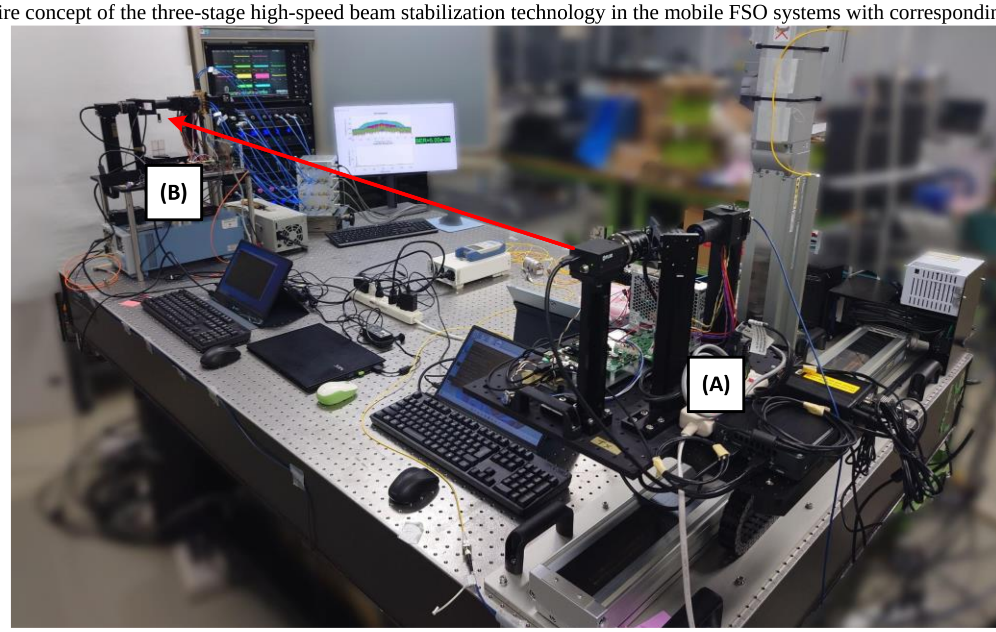

Fig. 2 The full picture of the mobile FSO system taken in the laboratory.

The first two stages of the high-speed beam stabilization process include coarse tracking and OBS-based fine tracking. During the implementation, a pair of FSMs, IR beacons, and IR cameras are employed by the mobile FSO transmitter and receiver sides for the coarse tracking process. On the other hand, 4 voice-coil motors (VCMs) and a quadrature photodetector (QPD) are employed to the mobile FSO receiver side for fine tracking process, which is called OBS control. The photos of the aforementioned devices are shown in Fig. 1 (part A and part B). For the third stage of the high-speed beam stabilization technology, a spatial-diversity combiner is adopted as part of the mobile FSO receiver, which includes a 32-pixel 2D-PDA and diversity combining technology. The pixel size of the 2D-PDA is 30 μm × 30 μm with 44-μm pitch, and the 3-dB bandwidth (BW_{3dB}) is 15 GHz, as shown in Fig. 1 (part C). Fig. 2 shows the full picture of the demonstrated mobile FSO system. From Fig. 2, part (A) and (B) correspond to the blocks and photos in Fig. 1, and the red arrow denotes the IR light beam.

4.2 The Demonstration Setup

In the OFC Demo Zone, the equipment shown in Fig. 2 will be exhibited. In the real-time demonstration, the shape of the light beam spot changes, and tens of μm-scale residual misalignment can be observed after the OBS if the transmitter is moving. The 2D-PDA with a multi-input-single-output (MISO) signal processing efficiently mitigates the issue, which provides a robust mobile FSO link with sufficient signal-to-noise ratios (SNRs). As a proof, we will show the power distribution and the system SNR after the maximum ratio combining in real-time. To do this, we replace the 12-channel oscilloscope with a higher speed 16-channel data logger, and visualize the real-time (resolution < 1 ms) power distribution on the 2D-PDA. Besides, the core parts including two-stage high-speed beam tracking and 2D-PDA with spatial-diversity combining are also proposed to demonstrate in the OFC Demo Zone in real-time.

4.3 How the Demo will be Presented to the Attendees

The three-stage high-speed beam stabilization technology will be presented to the attendees. During the demonstration, the speed of the moving stage at the mobile FSO transmitter side can be adjusted, which corresponds to different optical power distributions on the 2D-PDA, and these results will be visualized to the attendees.

4.4 Interaction with the Attendees

During this demonstration, we will have deep discussions about system advantages, improvements, requirements with the researchers in the fields of wireless communications in either RF or OWCs. The attendees can also test the setup by adjusting the moving conditions of the transmitter or the shadowing effect of the mobile FSO system.

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