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Beam shaping DOE for controlled laser tracking in indoor free-space optical communications

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Summary

We show how custom diffractive optical elements (DOEs) can be used in a loop-controlled free-space optical communication link to optimise both the signal-to-noise ratio at the receiver and the tracking performance of the transceiver pair.

Introduction

The increasing bandwidth demand for indoor communications with embedded terminals has led researchers to study optical wireless communications (OWC). When compared to radio-frequency links, OWC presents advantages such as data security, limited power consumption and immunity to electromagnetic interference. As a promising option when high bitrates are required, narrow line-of-sight (LOS) laser beams can be used in both the visible and the infra-red region [1], with the major constraint that the power emitted in free-space should respect the international standard levels for eye safety. In addition, maintaining LOS links between mobile objects requires specific beam tracking procedures.

In that framework, we propose a compact OWC module which maintains the mutual pointing angles between compact bidirectional communicating transceivers. The transmission/tracking module is shown in figure 1a. It consists of an optical transmission head (OTH) mounted on a pan-tilt positioning module with 0.1° angular accuracy. The beam emitted by the OTH both transmits digital data streams and performs beam alignment using a feedback loop procedure based on the relative irradiance levels captured by a quad photodiode array (QPA, fig. 1b). The laser source and the photo-receivers are arranged in a concentric monostatic configuration and the optimal coupling between two communicating OTH is assisted by a custom beam shaping DOE placed ahead of the laser source (fig 1c).

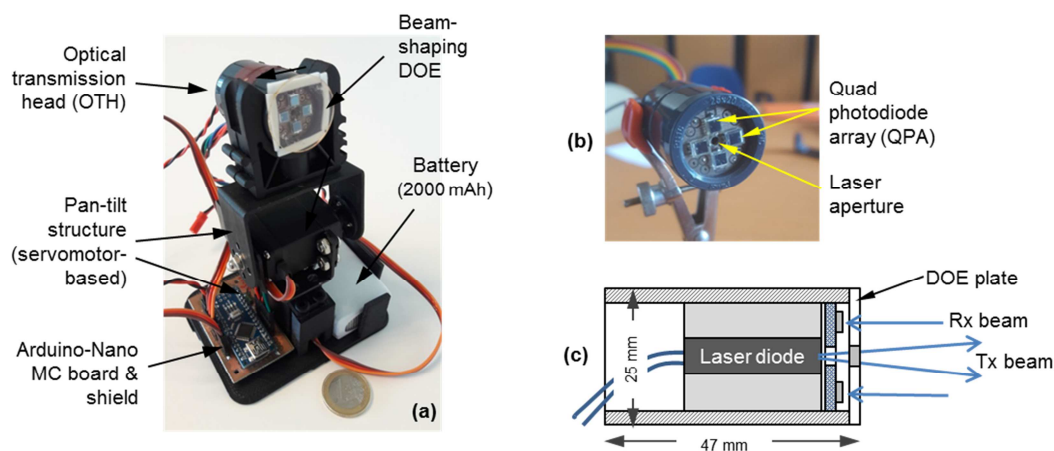


Fig.1. (a) OWC terminal, (b) Optical head front view (DOE removed), and (c) cut view schematic.

Discussion

The diameter of the addressing beam at the receiving plane is constrained by (i) eye safety conditions and (ii) the power sensitivity and overall size of the receiver. Using

a 1 mW laser source ($\lambda_0 = 650$ nm), a link length of 2.5 m and 4 mm square Si-PIN photodiodes yields a 25 mm optical cell diameter, and optimal pointing and tracking is achieved when the centroid of the incoming beam coincides with the center of the QPA (fig. 3a). When the terminals move, a proportional control is applied to the servomotors for 2D beam re-positioning, and the command “pan” and “tilt” angles $\theta_P(t)$ and $\theta_T(t)$ are estimated with feedback gains K_P and K_T , and QPA output voltages $V_{N,E,S,W}$ by the expressions $\theta_P(t) = \theta_P(t - 1) + K_P(V_W - V_E)$ and $\theta_T(t) = \theta_T(t - 1) + K_T(V_N - V_S)$. Different beam distributions can be envisioned, but we focus here on simple circular symmetric shapes like a uniform disk (upper fig. 3b), to ensure a constant SNR over the cell, and its subgaussian version (upper fig 3c), to test the reactivity of the feedback loop. The DOE are designed in the form of binary phase elements ($0/\pi$), offering a good compromise between design/fabrication complexity and performance for the symmetric diffraction patterns used here.

We compute the DOE phase functions using a flexible and efficient Iterative Fourier Transform Algorithm (IFTA), with a three-stage optimization procedure to improve the array uniformity [2]. We fabricated the DOE structures (5x5 mm) in a photoresist layer on a glass substrate by custom parallel direct write [3]. These master structures were then copied into a sol-gel ormocomp layer by nano imprint, a technique that can be used

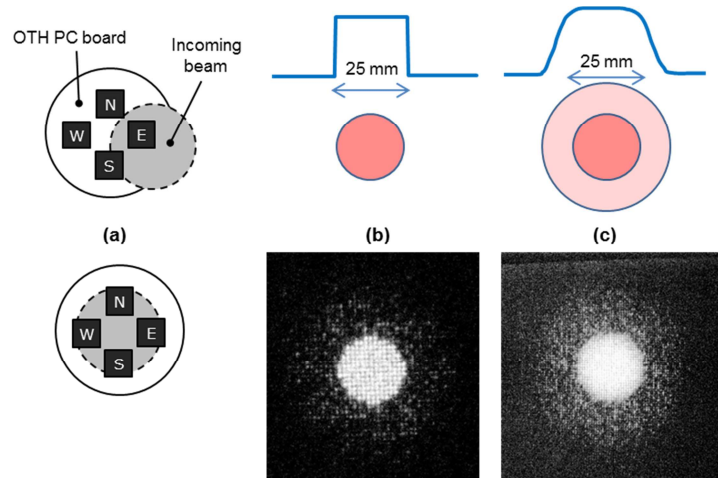


Fig.3. (a) beam alignment at the receiver – (b) and (c) theoretical and reconstructed circular and subgaussian distributions.

for mass production. The lower figures 3b and c show the optical reconstructions generated in the Fourier plane under illumination at λ_0 . The beam irradiance is captured using a SXGA CMOS camera. The π phase-shift of the binary DOE is optimized at λ_0 so that the 0th-order diffracted light is very weak, increasing the average irradiance value over the cell while improving the eye-safety configuration. The DOE diffraction efficiency is defined as the ratio of the overall power diffracted within the circular area to the illuminating optical power. It is measured at 73% and 75% for the two reconstructions shown in Fig. 3, respectively.

In our presentation, we will describe the performance of the optical link tracking and the influence of the address beam characteristics. Perspectives will also be given in terms of system integration, with a view to on-body worn embedded terminals.

Conclusions

The versatility of DOE technology shows in the OWC field that smart and high performance illumination modules can be designed in a highly compact format, with fabrication techniques that are consistent with low-cost mass production.

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