Study of Orbital Angular Momentum Mode Crosstalk Induced by Propagation Through Water

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Abstract: We present measured inter-channel crosstalk for a set of OAM modes propagating through 2.5m of slowly flowing water, similar to that found in oceanic environments. The water induces both tip-tilt and higher order optical aberrations.
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1. Introduction

The implementation of spatial multiplexing has become an area of great interest for free-space communication links, particularly for its use in last-mile links within larger optical networks. Light carrying orbital angular momentum (OAM) has emerged as a potential candidate that could be utilized for multiplexing independent channels. Beams with a transverse amplitude profile of $A(r)\exp(i\ell\phi)$ carry $\ell\hbar$ angular momentum per photon. The integer ℓ is unbounded giving a potentially infinite number of independent multiplexed channels [1,2]. In recent years the utilization of visible light communications (VLC) has become an emerging technology with the potential to improve the currently widely implemented ultrasound underwater communication technology, where a native bandwidth of 2.5G is readily available [3,4]. Such VLC schemes could potentially be enhanced through the addition of OAM multiplexing. To assess the feasibility of such OAM multiplexing in an underwater communications channel it is important to analyse the degree of observed channel degradation induced by flowing water.

In this paper we present measured inter-channel crosstalk for a set of OAM modes propagating through 2.5m of slowly flowing water, similar to that found in Oceanic conditions.

2. Experimental Design and Results

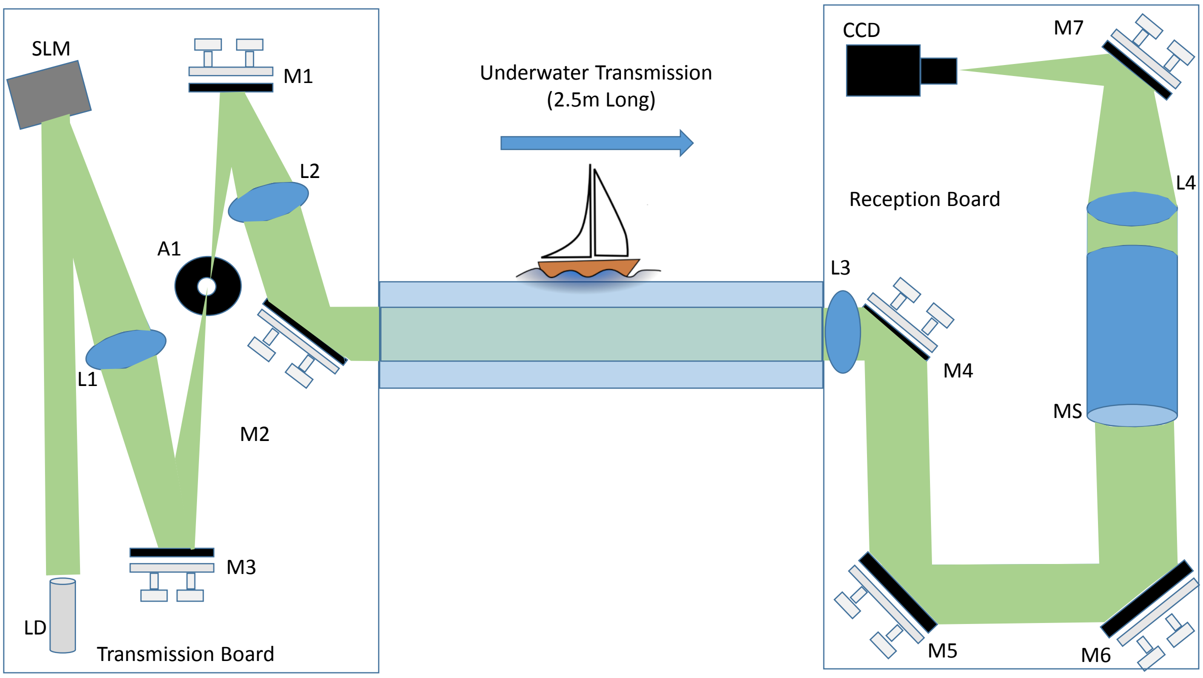

Fig.1: A collimated laser diode (LD) of frequency 532nm illuminates the surface of a liquid crystal Spatial Light Modulator (SLM). To prepare a beam carrying OAM a ℓ -forked hologram is displayed on the surface of the SLM. Fourier filtering lens, L1, followed by an aperture, A1, selects the desired first order. A further lens, L2, collimated the light from the selected order. After propagation across the 2.5m underwater link the light is collected by a 25 mm lens of 200 mm focal length, L3. The collected light is then passed through a passive optical device known as an OAM Mode Sorter [4], MS, which analyses the inter-channel crosstalk induced by the underwater propagation. The output of this device is focussed with a lens, L4, on to a 120 frame per second camera, CCD.

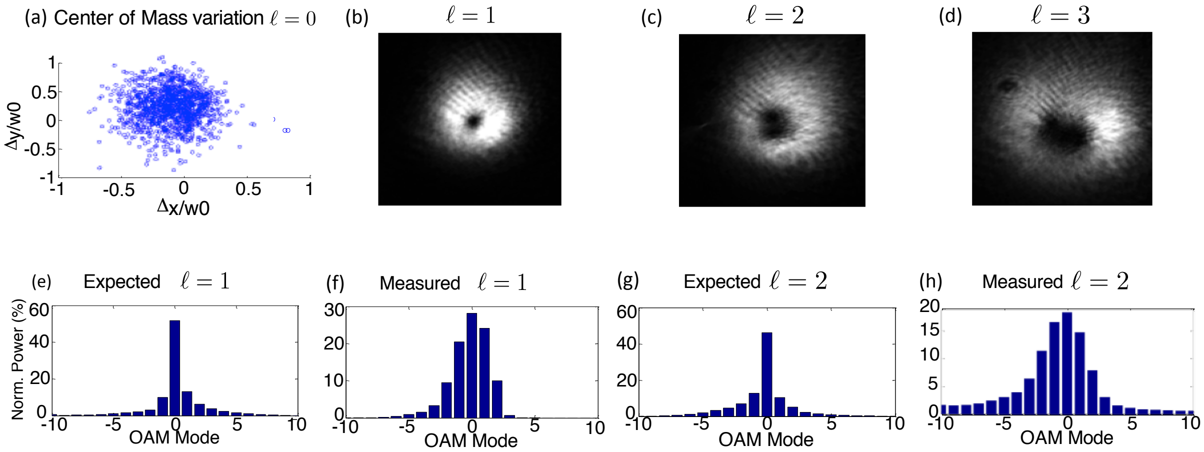

Fig.2: (a) The flowing water induces a tip-tilt aberration to the optical beam resulting in a change of the propagated modes optical axis as compared to the axis of the optical system. One method to characterise this change in position is by tracking the centre-of-mass (CofM) position of the received beam. Over a 10 second time period this CofM is tracked with a sampling window of $16\mu s$. (b-d) Selected images of the received beam after propagation through 2.5 m of flowing water for $\ell = 1, \ell = 2$ and $\ell = 3$ respectively. Using computational modelling the expected OAM channel crosstalk arising from Tip-Tilt aberration can be calculated (e) and (g). The output from the OAM mode sorter yields the experimentally measure channel crosstalk, (f) and (h). We postulate the difference between the expected and modelled crosstalk arises from higher-order optical aberrations induced by the beams propagation through water.

Our system comprises of periscopic transmitter and receiver apertures placed 2.5m apart within a larger (approximately 15 m long, and 0.3 m wide) water tank, Fig. 1. This tank has an adjustable flow regulator allowing control over the flow rate of the water within the tank. We chose a low flow rate, similar to that of oceanic conditions, for this initial proof-of principle study. Within any point-to-point to communications link tip-tilt aberration is one of the largest concerns. Within oceanic conditions the flow of the water potentially places added stress on the optical system. We first characterize the degree of tip-tilt aberration within the link by tracking the CofM of collected beam at $16\mu s$ intervals over a measurement time of 10 seconds, Fig. 2 (a). At the receiver we observe a maximum variation in the centre of mass approximately equivalent to the beam waist, w0, of the received OAM mode. Such a misalignment between the beam axis and measurement axis of the system will result in channel crosstalk. The expected average channel crosstalk arising from this measured misalignment with respect to the centre of the receiver aperture was calculated for the OAM inputs $\ell = 1$ and $\ell = 2$, show in Fig. (e) and (g) respectively [5]. From this modelling it can been seen that a substantial amount of channel crosstalk is induced solely from the observed tip-tilt aberrations. When comparing the expected channel degradation to that measured by the passive modal analyses [4], Fig 2. (f) and (h), we do observe additional inter-channel crosstalk. This additional crosstalk could be the result of high-order optical aberrations induced by underwater propagation. The non-uniform intensity profiles of the received optical modes indicate the presence of high-order aberrations in the light collected at the receiver aperture, Fig.2 (b-d).

In conclusion we have experimentally measured the crosstalk between OAM modes propagating through slow moving water. Our initial results indicate that tip-tilt aberration is a considerable contributing factor to the expected inter-channel crosstalk. Further study will focus on attempting to reduce this aberration through mechanical strengthening of the periscopic transmitter and receiver apertures, along with potentially the integration of active tip-tilt migration techniques.

References

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