Title

Review on Integrated structured light architectures

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Review on Integrated structured light architectures

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Abstract: This paper provides a brief review of the adaptive synthesis of key structured light and polarization control, with further discussion of the polarization topography chart based on the data point on the sphere of Poincaré.

INTRODUCTION

Structured light, including shapes of illumination proles with spatial and time-dependent structures, is the basis of numerous sophisticated techniques in photonics. In the paper, a new approach to creating scalable structured light is described as phased arrays interacting with the modular field controls, allowing for tremendous progress in shaping and controlling optical elements for communication, particle manipulation, and quantum computing applications [1]. This review focuses on some fundamentals of SL synthesis technology and polarization control while underlining important photonics principles, including Poincaré sphere mapping for polarization and discretization impact on wavefronts. Using these aspects, it is possible to build on the principles formulated in the Principles of Photonics to isolate polarization calculations specific to the nature of the experiment.

METHODS

Lemons et al. employ coherent phased-array beamlines to shape light with polarization, amplitude, and phase characteristics in their architecture. The paper outlines an architecture of a seven-channel phased array that can independently set the phase, amplitude, and polarization state of a beamline through FPGA feedback control [1]. This architecture has a crucial element of maintaining the coherency of the beams across beamlines through CEP stabilization and FPGA-based LOCSET phase-locking so as to synthesis complex wavefronts with programmable structure.

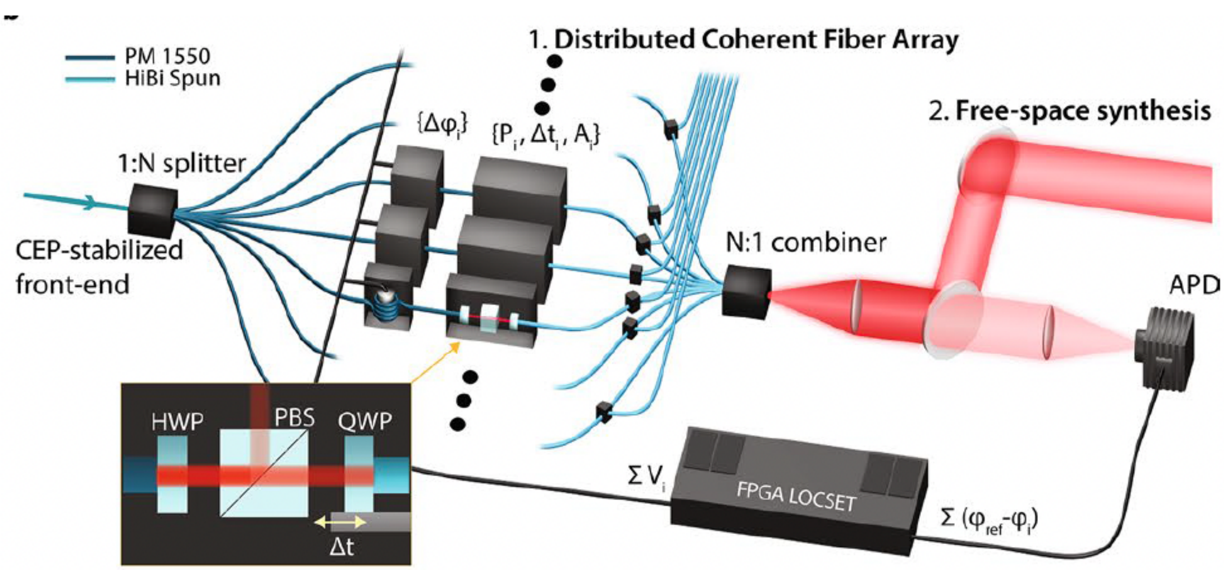

Fig 1: Experimental setup [1]

Thus, to further the discussion, we will narrow our focus to polarization mapping within the Poincaré sphere approach established to describe various states of light polarization according to a three-axis coordinate system [1]. To do this, Stokes parameters were employed to quantify the intensity and the field orientation of the polarization states in each structured beamline output. The Poincaré sphere uses S1, S2, and S3 as coordinates, where:

$$S_1 = I_H - I_V \quad , \quad S_2 = I_{+45} - I_{-45} \quad , \quad S_3 = I_R - I_L$$

To confirm this mapping, we calculated polarization topography for other structured light patterns with different polarization patterns. For each beamline, points in the Poincaré sphere were computed and compared with the Poincaré sphere to visualize the polarization dynamics and singularities of the synthesized beams [2]. These calculations indeed carried information on how modifications in beamline parameters impact the overall polarization topography toward manifesting the observations made by Lemons et al. on polarization tunability.

The Jones vector describes the electric field of light in terms of its components

$$E = \begin{pmatrix} E_x \\ E_y \end{pmatrix} = \begin{pmatrix} |E_x|e^{i\phi_x} \\ |E_y|e^{i\phi_y} \end{pmatrix}$$

The Stokes parameters provide a way to represent the polarization state and are defined as

$$S_0 = |E_x|^2 + \left|E_y\right|^2$$

$$S_1 = |E_x|^2 - \left|E_y\right|^2$$

$$S_2 = 2|E_x|\left|E_y\right|\cos\,(\phi_x - \phi_y)$$

$$S_3 = 2|E_x|\left|E_y\right|\sin\,(\phi_x - \phi_y)$$

The Poincare sphere is a three-dimensional representation of the polarization state as Cartesian coordinates.

$$s_1 = \frac{S_1}{S_0} \quad , \quad s_2 = \frac{S_2}{S_0} \quad , \quad s_3 = \frac{S_3}{S_0}$$

The Huygens-Fresnel principle states that every point on a wavefront serves is the source of spherical secondary wavelets. The resulting wavefront is the superposition of these wavelets. The electric field $E(x, y, z)$ at a point (x, y, z) can be expressed using the Kirchhoff-Fresnel integral:

$$E(x, y, z) = \iint E(x', y', 0)\frac{e^{ikR}}{R}\,dx'dy'$$

$$where\ E(x', y', 0) is\ the\ initial\ field\ distribution\,, \quad k = \frac{2\pi}{\lambda} \quad , \quad R = \sqrt{(x - x')^2 + (y - y')^2 + z^2}$$

The intensity $I(x, y) = |E(x, y, z)|^2$

Another significant field of study is the impact of discretization on wavefront quality, which is important for manufacturing high-quality structured beams used in optical communications and nonlinear optics. Therefore, we employed a Fourier transform-based beam propagation scheme to assess the effect of discretization level on the wavefront in structured light with 7, 19, and 35 beamlines [2]. This allowed the evaluation of the advantages of increasing the channel count to enhance fidelity, minimize artifacts, and maintain the right spatial density in far-field readings.

RESULTS AND INTERPRETATION

As expected, our assessment of polarization using the Poincaré sphere verified the adaptability of Lemons et al.'s structured light architecture. Coordinates on the sphere demonstrate points plotted in a clear transition of the two polarization states, affirming the feasibility of generating personalized polarization profiles with accuracy and precision in the architectural design [2]. Of particular interest is the specific structure in some configurations, which displayed phase singularities that create specific polarization patterns – another argument supporting the paper's arguments on the versatility of structured light creation.

Regarding discretization, the wavefront fidelity calculations revealed that resolution increased with communications channels. In detail, the MSE between the ideal and discretized wavefronts has reduced from 0.0016 when using 7 channels to 0.0006 when applying 35 channels [7]. This reduction supports the conception that higher discretization levels improve the topological charge selectivity in structured beams, which agrees with the work on the dependency of channel counts for fidelity in wavefront generation.

CONCLUSIONS

Structural light synthesis has been discussed with respect to this review, and the discussions focused on polarization control and discretization effects on the wavefront. Therefore, our analysis of the Poincaré sphere mappings confirmed the versatility of structured light architectures to attain the necessary polarization management required for quantum computing and particle trapping. Furthermore, there is a clear indication of how discretization is especially important for enhancing wavefront quality as needed through higher waves for applications in high-precision systems.

Potential work can be done to reduce more granularity in channel discretization and real-time feedback control to improve the performance of high-power optical applications and complex wavefronts. However, structured light, as illustrated here, presents a great opportunity for the future development of photonics and can have a great impact on the fields of optical communication, precision sensing, and new light-matter interactions.

REFERENCE

1. Lemons, R., Liu, W., Frisch, J. C., Fry, A., Robinson, J., Smith, S. R., & Carbajo, S. (2021). Integrated structured light architectures. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-020-80502-y
2. Liu, J.-M. (2017). *Principles of photonics*. Cambridge University Press.