Title

Reviewing Integrated Structure Light Architectures and Beyond

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Abstract: The manipulation of structured light holds diverse and revolutionary applications, but current technologies have major limitations. The presented laser architecture uses multiple beamlines to form a hexagonal pattern and effectively create adaptable light bullets. In addition, there has recently been the idea of switchable quarter and half-wave plate based on phase change which may increase versatility of the system.

INTRODUCTION

Structured photonics is a field that focuses on manipulating light to achieve variations in field vector, amplitude, and phase distribution. The manipulation of light waves enables the creation of complex structures with intriguing outcomes. Artificial structuring of light has led to the creation of unique beams with properties such as optical vortices and topological vector fields. Optical modulation involves various components that influence the characteristics of the wave, including phase, amplitude, polarization, and timing [1]. There are then many benefits that arise from being able to manipulate light using structure photonics such as quantum information processing, laser systems, imaging technologies, communication systems, and optical signal processing.

However, the potential applications of structured photonics face challenges due to inadequate technologies. Spatial light modulators are commonly used for engineering structured light by controlling intensity and phase, but they have limitations. These devices struggle with parameters like temporal intensity distribution and active control of the carrier-envelope phase. Additionally, their operational damage threshold is a significant limitation, especially in applications involving ultrashort pulses and high-power levels [1].

The paper "Integrated structured light architectures", by Lemons, Randy, et al. presents a new laser design that creates customizable light bullets with adaptable structures. It uses phased arrays with controllable field properties like amplitude, phase, and polarization, called beamlines. The concept involves seven fiber-based beamlines from a femtosecond laser. The carrier-envelope phase is stabilized for consistency, and a custom FPGA technique synchronizes inter-beamline phases. Each beamline is actively manipulated before synthesis and the resulting laser can deliver programmable pulses as light bullets [1].

METHODS

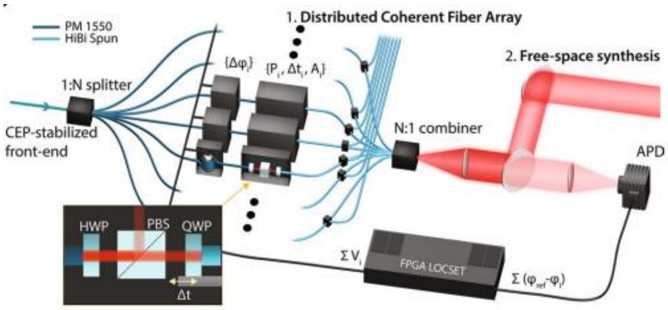

Figure 1: The experimental, proposed configuration of laser architecture

Figure 1 illustrates the proposed laser architecture outlined in the paper. The system begins with a 1:N splitter, where a CEP stabilized splitter generates N independent waves. These waves traverse N distinct modulators, adjusting the wavefront parameters. One beam functions as a reference, and all other beam lines synchronize their phases to that reference, allowing for an arbitrary phase relationship. According to Lemons, this synchronization is achieved through a self-synchronous and self-referenced custom field-programmable gate array (FPGA) phase-locking technique, facilitating monitoring and control of the relative inter-beamline phase offset [1].

The FPGA is essential in adjusting each beamline using a piezoelectric transducer shaped like a fiber stretcher. Afterward, the beam goes through a modulator that controls both intensity and polarization. This modulator includes a half-wave plate to rotate optical polarization, a polarizing beam splitter to decrease intensity, and a quarter-wave plate for timing. The amplitude, polarization, and timing are manipulated by the half-wave plate, while the quarter-wave plate changes polarization type. The delay stage governs timing, and the polarizing beam splitter modifies both polarization and amplitude [1].

Finally, the composite beam is collimated and synthesized in an N:1 combiner, with the seven beamlines arranged hexagonally to achieve spatio-temporal overlap at a photodiode. This results in a laser setup that can produce programmable laser pulses as a synthesized light bullet in free space, an array of distributed coherent beamlines, or a combination of distributed fiber and free-space beams [1].

RESULTS AND INTERPRETATION

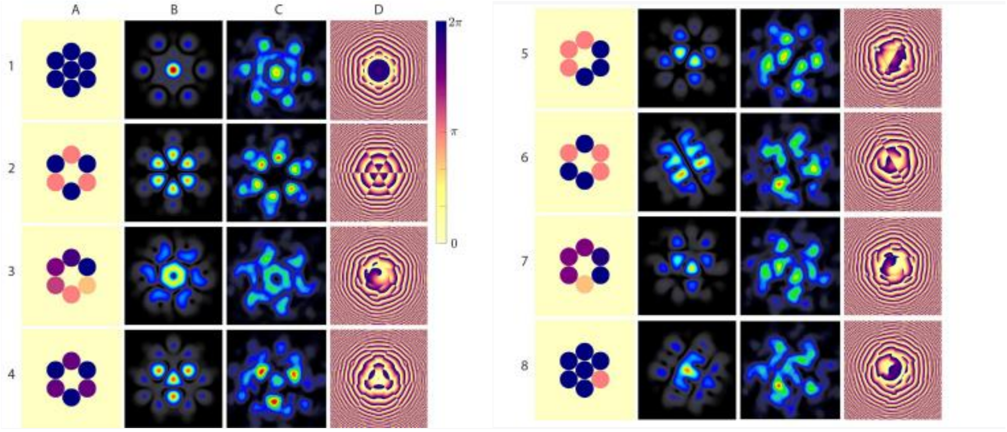

Figure 2: Near field phase and amplitude inputs resulting in far-field intensities and phase distribution.

The design underwent various tests to showcase its practicality and adaptability. Column A represents the near-field phase and amplitude combinations. Column B represents the retrieved far-field intensity and Column C represents the measure synthesized far-field intensity. Lastly Column D corresponds to the phase distributions [1].

A potential application for using additional beamlines would be the capability to generate higher-order Laguerre-Guassian or Hermite-Guassian modes. Laguerre-Gaussian modes describe the spatial distribution of laser beams and have applications in various areas, including optics, laser physics, and communication. They are particularly useful in representing the transverse structure of laser beams with orbital angular momentum. Hermite-Guassian modes have a characteristic intensity profile with multiple peaks along the x and/or y axes. While both Hermite-Gaussian and Laguerre-Gaussian modes are solutions to the paraxial Helmholtz equation and describe the spatial characteristics of laser beams, their differences lie in the coordinate systems used and the resulting intensity distributions. Hermite-Guassian modes have peaks along both x and y axes, while Laguerre-Guassian modes have a doughnut-shaped intensity profile in polar coordinates [2].

As stated previously, the polarization vector maps were acquired by transmitting light through a sequence of optical components, including a half-wave plate, polarized beam splitter, and quarter-wave plate. The half-wave plate changes the orientation of linear polarization in a wave. Equation 1 shows the calculations for the thickness of the half-wave plate. Once the thickness of the plate is determined, polarization angle is changed by selecting a certain value for θ (angle between incident linear polarization and principal axis), it is possible to rotate the polarization direction of a linearly polarized wave by any desired angular amount [2].

$$l_{\lambda/2} = \frac{1}{2} \cdot \frac{2\pi}{|k^y - k^x|} = \frac{\lambda}{2|n_y - n_x|} \qquad (1)$$

The quarter-wave plate is designed to transform a linearly polarized wave into a circularly or elliptically polarized wave and vice versa. Equation 2 shows the calculation for the thickness of a quarter plate.

$$l_{\lambda/4} = \frac{1}{4} \cdot \frac{2\pi}{|k^y - k^x|} = \frac{\lambda}{4|n_y - n_x|} \qquad (2)$$

As you can see from equations 1 and 2 above, typically to convert a quarter-wave plate to a half-wave plate, you would need to change the thickness of the plate or use a different birefringent material with different optical properties. There are recent new discoveries and innovations that suggest that it is possible to create a quarter-wave plate . In the article “Switchable Quarter-Wave Plate and Half-Wave Plate Based on Phase-Change Metasurface.” Li, Luo, et al. have proposed a design of a “switchable metasurface wave plate based on the rectangular antenna GST phase-change material” [3]. The metasurface functions as a quarter-wave plate within the 10.0–11.9 μm wavelength range. Following the transition to a crystalline state, the metasurface assumes the role of a half-wave plate within the 10.3–10.9 μm wavelength range [3]. The possibility of a convertible wave plate may be beneficial in multiple ways. First of all, a variable waveplate would be versatile and could replace both quarter-wave and half-wave plates in the system as both types are needed at different times. Another benefit comes from the ability to fine-tune the polarization state for optimal performance. Being able to adjust between quarter-wave and half-wave states provides a means of tuning the system based on specific needs.

CONCLUSIONS

The presented design proved effective in manipulating structured light in a more flexible, user-controlled manner and clearly surpasses spatial light modulators and other modern attempts in generating programmable structured light. It synthesized a novel, generalized laser architecture to manipulate light bullets and successfully worked towards overcoming limitations of current light manipulation tactics. A possible next step could be increasing the scale with a higher number of channels, and it would be interesting to include a switchable metasurface waveplate.

REFERENCES

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