Title

Reviewing Integrated Structured Light Architectures

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Abstract:

The FPGA-based LOCSET system is analyzed. Real-time feedback, an active phase control, is used to maintain coherent beam combination by having the system dynamically correct phase errors, ensuring stable and precise structured light synthesis.

INTRODUCTION:

Photonics research is evolving. Programmable and structured fields are a big reason for this. Light can be modified quite extensively, not limited to phase, amplitude, timing, and polarization thereof. Quantum communication and high-precision sensing–two relatively different domains–are a few of such applications. Generally, coherent beam combination (CBC) has a primary objective in significantly increasing laser power[4], impacting how lasers are used. FPGA-based LOCSET is used because light is actually pretty difficult to manage. In trying to manage light–its properties in particular–this LOCSET uses real-time feedback to make sure that light pulses are characterized by constructive interference[1], shown in Figure 1. Basically, these systems lock the phases in such that if there is even a slight change in the phase, then it is set back automatically. Thus, this feedback loop is more sensitive than the self-regulative mechanism of each channel regulating itself[1]. As a result, well-structured light output is induced. There are some situations where it might be needed to have particular temporal or spatial structures; in such cases, for instance adaptive optical vortices or orbital angular momentum beams being used[1], then the LOCSET is essential. Either way, the foundation of custom-made light patterns is the spatio-temporal control that is induced by a phased array system[1]. Starting off, a carrier envelope phase gives each channel a uniform phase. Between then and when they either reach the distributed carrier fiber array or the avalanche photodiode, the channels go through modulation and demodulation to help with their own self-regulating phase. The whole time, it's the FPGA that has the control over these corrections in order to maintain coherency[1]. Thus, the LOCSET opens the opportunity to study structured photonics and its applications, in particular regarding CBC's foundational role in enabling adaptive optical vortices[1]; not to mention the impact thereof.

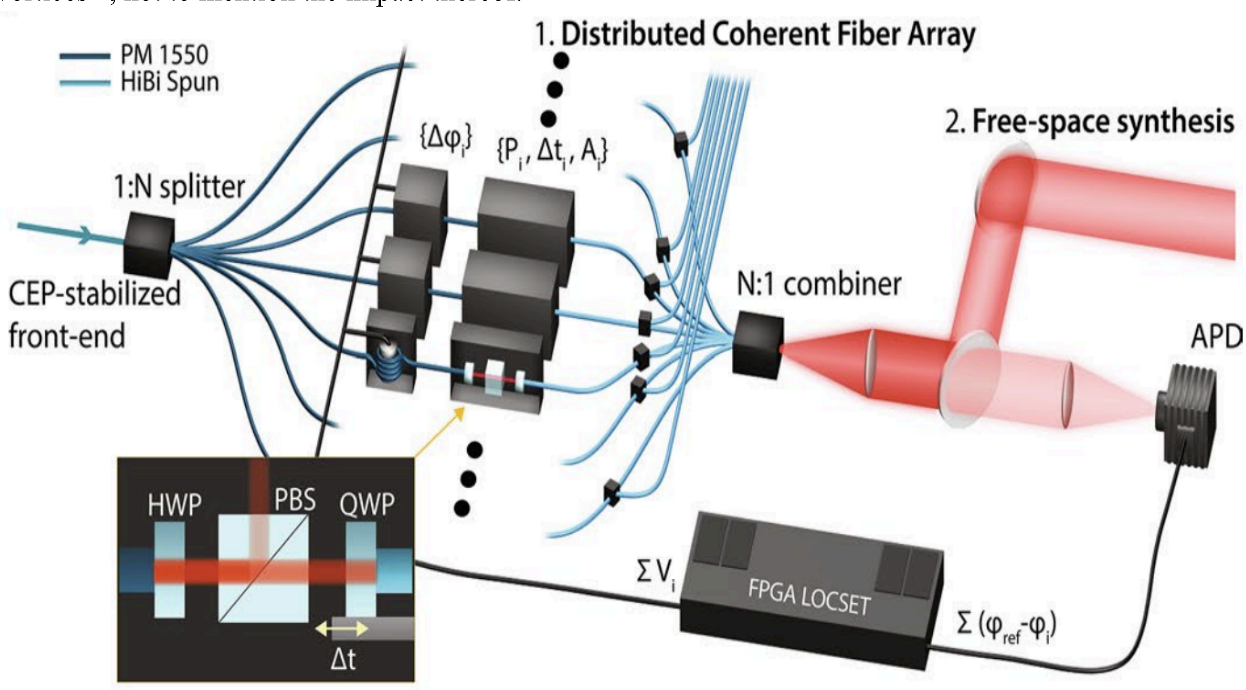

Fig. 1. The experimental configuration via coherent multi-channel coherent fiber array with a common CEP-stabilized front end, independent phase ($\Delta\phi_i$), amplitude (A_i), polarization state ($\wp_i$), and timing (Δt_i) controls, and active locking via FPGA LOCSET using a single avalanche

photodiode (APD) in the far-field. The output coherent output can be delivered in the form of a distributed coherent fiber array or the form of a free-space synthesized pulse (Lemons 2021).

METHODS:
Largely due to the importance of the aforementioned applications working, the central role of phase error correction is studied, relating back to the LOCSET. If in error, the LOCSET works by having the FPGA modulate the beam phase to bring about uniform alignment with the other channels, ensuring complete constructive interference[3]. Naturally, one might want to know how much of a difference a subtle phase difference might make on a practical application, like adaptive optical vortices. So, I used Matlab to plot a fundamental wave optics equation, $I = I_1 + I_2 + 2\sqrt{I_1 I_2} cos(\Delta\phi)$[3], as an interference intensity pattern, which is used to describe the intensity of light resulting from two coherent light beams interfering, shown in Figure 2. Though the plot may overly simplify real-world conditions, it accurately depicts the challenges of practically using light with a varying phase difference.

RESULTS AND INTERPRETATION:

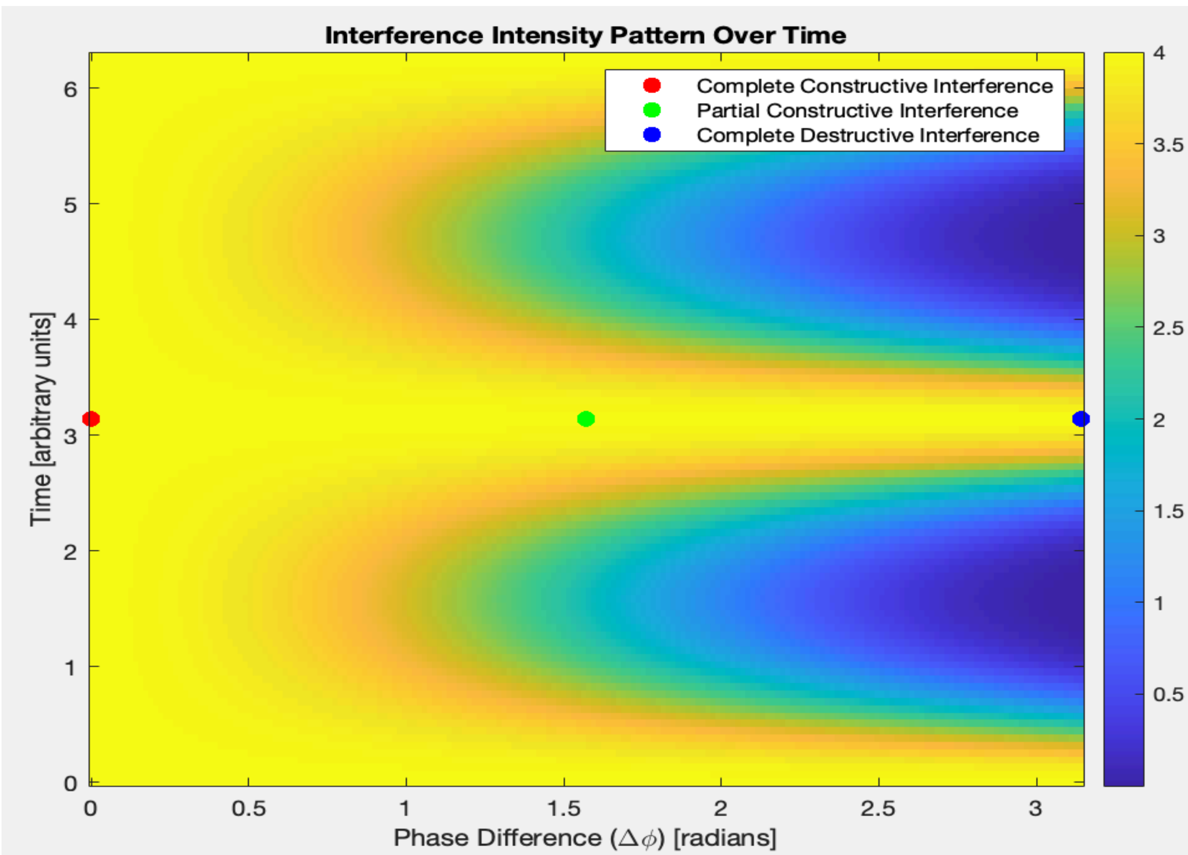

Fig. 2. $I = I_1 + I_2 + 2\sqrt{I_1 I_2} cos(\Delta\phi)$ is plotted, where $\Delta\phi$ ranges from 0 to π, showing the contrast in intensities of light during this time. There is no intensity at the blue spots; on the other hand, yellow appears at the brightest spots. At one extreme, there is complete constructive interference, where $\Delta\phi = 0$, at the red dot. In the middle, there's partial constructive interference, where $\Delta\phi = \frac{\pi}{2}$, at the green dot. Toward another extreme, there is complete destructive interference, where $\Delta\phi = \pi$, at the blue dot. Between the extremes, the intensity reduces as $\Delta\phi$ increases. Another variable, time, impacts intensity of light as well. Environmental fluctuations and system instability from the real-world are simulated in the form of darker spots appearing even at a phase difference of $\Delta\phi = \frac{\pi}{2}$, which exacerbates as $\Delta\phi$ increases.

Knowing we need well-structured light, if we even let light drift into partial constructive interference, that is potentially a lot of light's intensity gone, simply due to variations in intensity, potentially caused by environmental fluctuations (e.g. temperature) or system instability (e.g. aging of components) that occurs over time[3]; hence, the LOCSET's importance in real-time correction thereof. But, that perspective doesn't fully appreciate the LOCSET. With artificial structuring of light, it is worth seeing the impact of this difference. For instance, the LOCSET needs to have a stable, coherent phase relationship among the beamlets[1]; if that ceases to be the case, then for example, partial constructive interference could cause the phase front of the vortex beam to distort for adaptive optical vortices, lessening the defineness of the beams while increasing intensity variations[2]. Thus, if it was desired to do advanced imaging or optical manipulation, then the beam wouldn't be effective[2]. That's how important FPGA LOCSET's role is to correctly implement active phase control to realign the beams. In contrast, if there was approximately complete constructive interference, conditions would be right for CBC to occur, which is fundamental for proper adaptive optical vortices[1]; making advanced imaging and optical manipulation feasible.

CONCLUSIONS:

This review showed that FPGA-based LOCSET plays a crucial role in using active phase control to maintain stable and coherent light. In simulating conditions of phase difference, it was realized that even modest differences from complete constructive interference can drastically reduce intensity, depending on factors relating to time. Thus, LOCSET, in reality being sensitive to much smaller phase differences than was discussed in this paper[1], is vital for inducing real-time phase correction. Adaptive optical vortices, an advanced optical application, greatly reflects this notion via CBC. A possible new direction: LOCSET could perhaps be made even more sensitive to phase differences. Additionally, it can be looked into concerning what materials can make it most prone to time-varying intensity changes. Perhaps most importantly, future work may attempt to find use in making environmental fluctuations instead as a resourceful way to tap into the asset that is intensity of light.

REFERENCES:

1. Lemons, Randy, et al. "Integrated Structured Light Architectures." *Scientific Reports*, vol. 11, no. 1, Springer Science and Business Media LLC, Jan. 2021, https://doi.org/10.1038/s41598-020-80502-y.
2. Wang, L.-G., Wang, L.-Q. & Zhu, S.-Y. Formation of optical vortices using coherent laser beam arrays. Opt. Commun. 282, 1088–1094 (2009).
3. Liu, J. Principles of Photonics. Springer, 2016.
4. Mills, B., Grant-Jacob, J. A., Praeger, M., Eason, R. W., Nilsson, J., & Zervas, M. N. (2022). Single step phase optimisation for coherent beam combination using deep learning. *Scientific Reports*, 12, 5188. https://doi.org/10.1038/s41598-022-09172-2