Title
Review on Integrated Structure Light Architectures

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Abstract

This paper will further discuss one method used in the “Integrated Structure Light Architectures” called Beam Propagation Model (BPM), which was used to simulate the free-space of the system used in the research paper.

Introduction

With light possessing multiple degrees of freedom, some devices have bottlenecks that cannot fully take advantage of these freedoms to reach a desired structure of light. One device today is a spatial light modulator with a limitation to high impulses -MW or average power -W hence impeding progress in structured light applications [1]. To avoid these bottlenecks and limitations, the research paper suggests a method to generalize laser architecture to enable designs of light bullets with a built-in programmable structure that can be exploited [1]. To simulate their system, the researchers chose the BPM to efficiently simulate the field's evolution by evaluating the Rayleigh-Sommerfeld diffraction formula.

Beam Propagation Model

The Beam Propagation model is used to numerically estimate an incoming field distribution through a structure such as a waveguide. It is important to note that the BPM is on a grid with no layers where the dominant direction of propagation is longitudinal. The model works by initializing the first column or row of the grid with what the field looks like. Then using, the discrete fast Fourier transform to relate the field to the next column or row. Repeating this process multiple times until the grid is filled it will efficiently simulate the field’s evolution through the use of the Rayleigh-Sommerfeld diffraction, which gives an exact solution to the output field [2].

The numerical model for BPM uses a discretized Rayleigh-Sommerfeld diffraction (RSD) and is treated as a Riemann integral since the RSD does not have a generalized analytic solution [2]. This is why the fast Fourier transform is used because, without a fast algorithm, diffraction theory for digital computers would not be possible since it would take an unreasonable amount of run time since an FFT can convert O(n^2) to O(n*log(n)) time.

Since the BPM uses the discrete Fast Fourier transform to solve the RSD equation, a sampling frequency must satisfy the Nyquist criterion (i.e. $f_s \leq 2f_{max}$) such that there is no aliasing. After solving for the sampling frequency, the minimum propagation distance can be calculated.

$$U(x,y,z) = \frac{1}{i\lambda}\iint U(x',y',0)\frac{ze^{ik\sqrt{(x-x')^2+(y-y')^2+z^2}}}{(x-x')^2+(y-y')^2+z^2}dx'dy' = \frac{1}{i\lambda}\iint U(x',y',0)\frac{ze^{ikr}}{r^2}dx'dy',$$

$$r = \sqrt{(x-x')^2 + (y-y')^2 + z^2}$$

Equation 1: Rayleigh-Sommerfeld diffraction formula [3]

In the RSD formula U(x,y,z) is defined to be field distribution in the observation plane, k is the wave number, x and y are defined to be the axes on the observation plane(i.e., the plane where light arrives), x' and y' are the axes of the aperture plane (i.e., the plane where light leaves), and r is the distance between the departure plane and the observation plane.

To solve for the sampling frequency, we know from the RSD formula (eqn. 1) where the phase propagation term is, $\varphi = kr \text{ where } k = \frac{2\pi}{\lambda}$ and we know the spatial frequency of the propagation phase is $f_{x,max} = \frac{1}{2\pi}(\frac{\partial\varphi}{\partial x})_{max}$. Using calculus, one can find that $f_{x,max} = \frac{x+x'}{\lambda\sqrt{(x+x')^2+z^2}}$ [2]. Thus, applying Nyquist criterion solving for z, which represents the diffraction image of the object at a distance between plane 1 and plane 2 which gives us the minimum propagation distance to avoid aliasing $z \geq ((\frac{2}{\lambda f_s})^2 - 1)(x + x')^2$. Therefore, the simulation will be efficient and accurate as long the propagation distance is set such that aliasing is avoided, which was done in the paper since the propagation distance was in units of meters [1].

Conclusion

In conclusion, the Beam Propagation model was elaborated on how the algorithm works, the numerical model it uses, and the minimal propagation distance such that the DFFT does not get aliasing. The paper successfully simulated Integrated Structure Light Architectures using the discrete fast fourier transform and the Rayleigh- Sommerfeld diffraction formula. Proving useful to solve bottleneck and limitation problems devices may encounter since new methods can be simulated and tested to improve the devices performance.

References

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