Light Interference Fringe Detection with DBSCAN for Integrated Mirrors

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Abstract -
This paper presents a method for detecting light interference fringes and designing integrated optical mirrors using DBSCAN clustering. Conventional edge detection methods struggle with gradual intensity changes in fringe patterns, but DBSCAN effectively identifies peaks while filtering noise. The detected fringe profiles are processed and input into FDTD simulations to analyze the interaction with an aluminum mirror. The results show 78% upward transmission efficiency and a clear far-field distribution. This approach improves mirror design for applications in communication systems and photonic circuits.

1 Introduction

Integrated optical mirrors provide significant advantages in applications requiring broadband coupling and beam manipulation, such as communication systems, sensing, and signal processing. Unlike grating couplers, which are limited to narrow wavelength ranges, these mirrors offer the flexibility to work across a wide range of wavelengths [1]. Additionally, they can function as antennas, enabling precise beam steering for tasks like free-space optical communication, LiDAR, and on-chip beam routing. To further enhance performance, we developed a tool that calculates optimal mirror geometries based on light interference patterns, ensuring maximum coupling efficiency. This approach tailors the mirror's design to the specific wavelength range and system geometry, improving overall device performance [2].

2 Fringe Detection

Detecting light interference patterns, such as fringe interference, is challenging for conventional methods due to gradual intensity variations. Techniques like Canny Edge detection, designed for sharp transitions, fail to capture the smooth changes in these patterns, leading to poor results. However, by designing optical devices that follow the fringe pattern geometry from the start, more precise beam shaping and light control can be achieved, enhancing optical system performance.

Detecting peaks in intensity profiles is further complicated by overlapping constructive interference peaks, especially in noisy environments. Standard peak detection methods often struggle here. Clustering peaks using

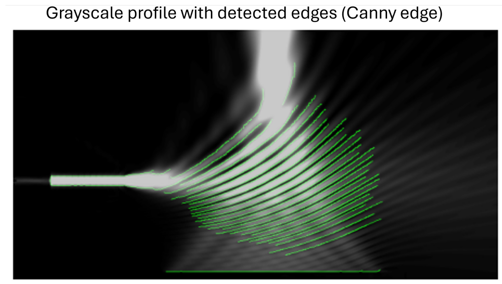

Figure 1. Canny edge detection from the profile.

DBSCAN (Density-Based Spatial Clustering of Applications with Noise) improves accuracy by grouping closely packed peaks while ignoring noise and outliers.

The fringe pattern shown in figure [2] results from the interference between a mode launched from the integrated photonic waveguide and a Gaussian beam, the wavelength of the sources 1 μm. The Gaussian beam's polarization at 90° interacts with the Transverse Magnetic (TM) mode, generating constructive and destructive interference and leading to the observed fringe pattern.

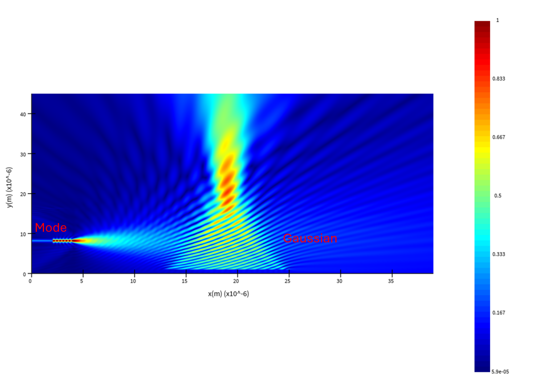

Figure 2. Fringe pattern highlighting the interference between the sources.

DBSCAN (Density-Based Spatial Clustering of Applications with Noise) is a clustering algorithm that groups closely packed data points while identifying and excluding outliers. The fig. [3] shows the clustered fringes, highlighting the detected regions corresponding to the interference pattern. These clusters were identified using DBSCAN, which effectively isolates the peaks while filtering out noise [3].

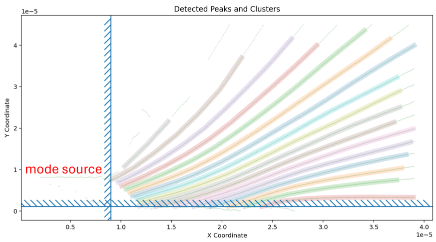

Figure 3. Detected clusters with DBSCAN.

3 Simulation Result

Now that the clusters have been identified, a specific fringe of interest can be selected and passed to a simulation tool such as FDTD for further analysis. The image below shows the selected fringe after extraction. A polynomial extrapolation has been applied to smooth the fringe profile, ensuring a more continuous and physically realistic input for simulation. The fringe profile is made of Aliminium for reflectivity.

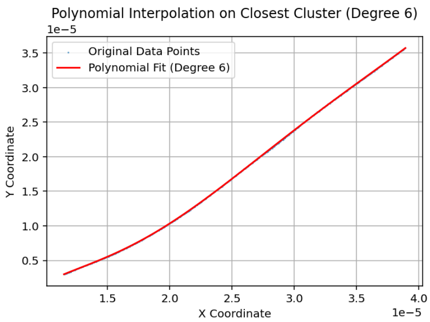

Figure 4. Fringe of interested with polynomial fit.

The image [5] below shows the electric field (E-field) profile resulting from a mode source interacting with an aluminum mirror. The mode propagates upward, heating the mirror surface upon impact. The upward transmission through the mirror structure is calculated to be approximately 78%, indicating high upward directionality.

The far-field profile of the simulated fringe is shown in figure [6], illustrating the angular distribution of the transmitted optical field.

4 Conclusion

This work presented a robust method for detecting and processing optical interference fringes using peak detection and DBSCAN clustering. The extracted fringe profiles were smoothed with polynomial extrapolation and used as input for FDTD simulations. A TM mode interacting with an aluminum mirror yielded 78% upward transmission with a well-defined far-field distribution. Current efforts are focused on optimizing the far-field response and fabricating the designed mirror structures using a Nanoscribe system, enabling precise realization of complex geometries informed by the simulated fringe data.

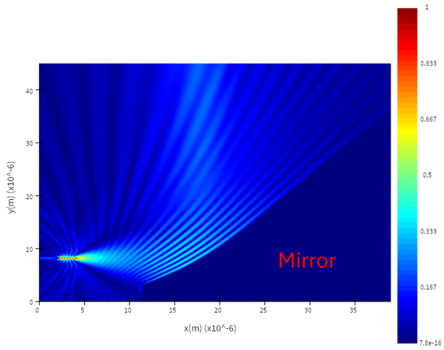

Figure 5. E-field profile with the fringe as a mirror.

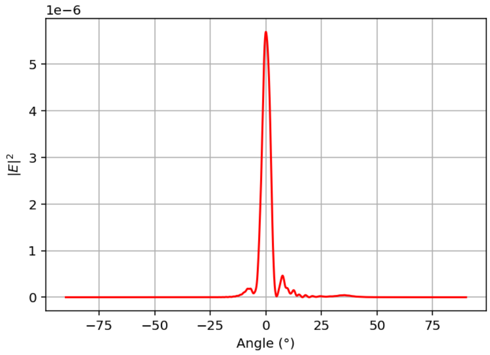

Figure 6. Farfield profile of selected fringe.

References

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