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Introduction

The purpose of this research is to investigate Fresnel diffraction as a means of obtaining absolute distance measurements with micron or greater accuracy. It is believed that such a system would prove useful to the Next Generation Space Telescope (NGST) as a non-intrusive, non-contact measuring system for use with secondary concentrator station-keeping systems. The present research attempts to validate past experiments and develop ways to apply the phenomena of Fresnel diffraction to micron accurate measurement.

This report discusses past research on the phenomena, and the basis of the use Fresnel diffraction distance metrology.

The apparatus used in the recent investigations, experimental procedures used, preliminary results are discussed in detail. Continued research and equipment requirements on the extension of the effective range of the Fresnel diffraction systems is also described.

Background

The present investigation is based upon research first performed at the University of Tennessee at Knoxville and Oak Ridge National Laboratory. This research was first published in a Master's Thesis by Duncan Earl and was elaborated on in a report from the Oak Ridge National Laboratory (1,2). The Master's Thesis attempted to prove the technique analytically and suggested ways that the process could be applied in various applications requiring **extremely** accurate measuring or positioning.

The metrology system is based on the fact that the central intensity of a Fresnel Diffraction pattern on a screen changes as the screen is moved. This change in the intensity of the center spot, or the airy disk, is directly related to the pinhole's distance from the source, the equation of this relationship is:

$$I_c = 4\, I_0 \,\mathrm{Sin}^2\, [R^2\, \pi / 2\, \lambda\, (1 / L_{source} + 1 / L_{observe})]$$

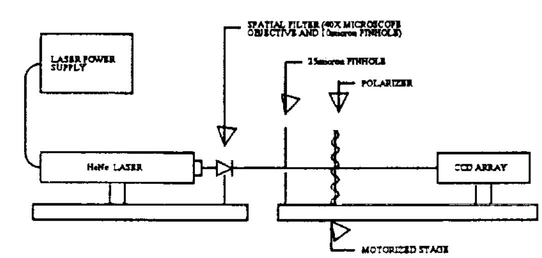
Two problems arise when one looks at developing a distance metrology method using Fresnel diffraction. The first arises because for any single intensity value in the oscillation of the intensity pattern, many different distances can exist. The second problem is that the oscillation of the intensity of the central spot of the Fresnel pattern only exists up to a range of approximately one meter. Ways of side-stepping each of these problems are discussed below.

The simplicity of the hardware involved in the proposed metrology method makes the system ideal for space based applications, especially with the NGST. It could potentially be used to aid station keeping of the secondary concentrator in a two component space telescope design, and/or aid in alignment of the optical components.

Hardware and Software

(1) Hardware

The hardware part of the apparatus consists of a Uniphase1201 laser power supply and 1103p-laser head that produces a 4mW, monochromatic, coherent light source in the 632.8nm wavelength. A Melles-Griot spatial filter that uses a 40x microscope objective and 10μm pinhole to create an optically clean point source that impinges upon a pinhole. The pinhole then creates a Fresnel diffraction pattern that is imaged upon a Cohu 4912 high performance CCD camera. The image of the diffraction pattern is sent to a Data Translations DT3851 video board for processing. A Daedal motorized translation stage with power source was used to move the laser and spatial filter for the experiments (Figure 1).



BASIC FRESNEL DIFFRACTION SETUP

Figure 1

(2) Software

The software part of the apparatus is based upon a Visual Basic program developed by Duncan Earl, of ORNL and further customized during the researched performed during this project. The software displays a real time image of the diffraction pattern on the screen. The mouse is used to select the center of the diffraction pattern. When the mouse is clicked over the area to be analyzed, the program will add all of the pixel intensity values over an area surrounding the mouse, and is capable of capturing 100 pictures per event. The average of the intensity values are taken and displayed on the screen, while at the same time sending the same data to an Excel worksheet. The data in the Excel worksheet can then be further analyzed.

Experiment

To obtain the over all stability of the apparatus and reliability of the data, the laser and the CCD camera are turned on 30 min to an hour before any data can be taken. This insures that the thermal noise will have time to settle before taking any data.

An area in the center of the pattern is chosen and analysis begins. The motorized stage is moved a step and the analysis is begun again. This procedure is repeated until the desired number of data points are obtained for a given step size. The procedure is the same for any arbitrary step size and pinhole diameter. However it is obvious that this is a cumbersome and labor intensive procedure that needs to be addressed in the future.

Preliminary Results

Preliminary results of the first experiments indicated a strong correlation between the theoretically predicted oscillation of the intensity with distance and the data obtained from experiment. Although substantial error was found between the theoretically predicted oscillations and the experimental data, it is consistent with results reported by Earl in his thesis. The optical quality of the apparatus and the inability to control some environmental conditions account for the majority of the error in the experiment. Given better quality optical components and better control of environmental conditions it is reasonable to assume that better results can be obtained.

Making an Absolute Measuring System

The present system is incapable of making an absolute measurement. The oscillation of the intensity with distance - the very thing that makes it attractive for distance measurement - means that one certain intensity corresponds to a large number of distances. To make the system an absolute measuring system Earl, suggested it in his thesis, that two point sources of different wavelengths be used to get rid of this distance ambiguity. Each of the point sources would have its own distinct oscillation pattern. A particular intensity of one wavelength when compared to the particular intensity at the other wavelength would match to only one particular distance; thereby producing an absolute distance value (Figure 2). This method of absolute measurement was described as "technically challenging" (1).

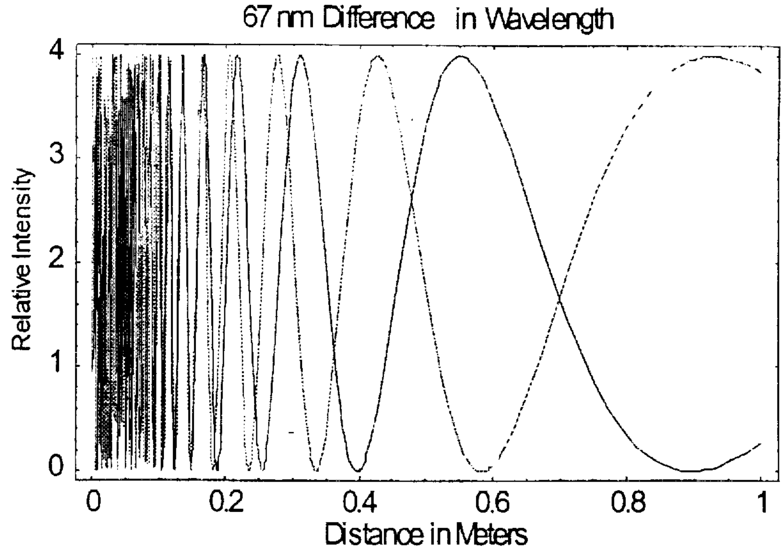


Figure 2

As can be seen in the Fresnel equation, the oscillations depend not only on the wavelength of the point source, it also depends upon the size of the pinhole. This led to the idea that one point source illuminating two pinholes would produce similar results to the two point source method. While it may prove to be as technically challenging as Earl's above suggestion, it is believed to be a simplification of the system. It would also make a much lighter and more compact package for space based applications (Figure 3). This application should be pursued in future investigations.

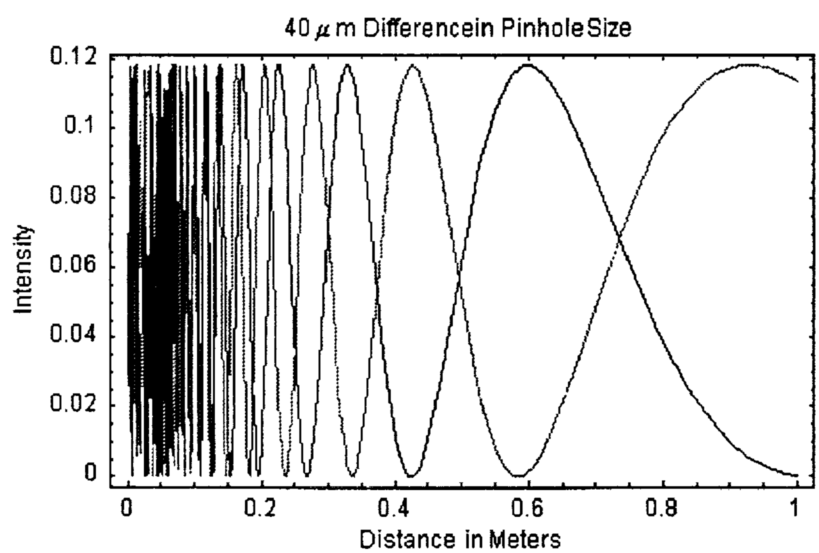


Figure 3

Extending the System

The Oak Ridge report suggests various ways that the phenomena could be extended to longer ranges by the use of a technique called pattern inversion (2). There is also another possible technique for extending the distance. It consists of moving the point source closer to the pinhole. It uses a collimated beam that is sent through a converging lens where it is concentrated down to the focal point of the lens. The light at the focal point will act like a point source to the pinhole thereby extending the system out to greater ranges.

Conclusions

Although preliminary experiments show that the theory is valid for distance metrology; a lot of work remains to be done to make it workable the system that require longer ranges such as for the NGST. The phenomena needs to be made absolute, perhaps by one of the above methods, and the phenomena needs to be extended to longer distances. The relative simplicity of the hardware requirements should help to ease a lot of the technical problems and aid in the miniaturization of the system for flight hardware. The Fresnel diffraction pattern is so rich in information content that it may hold other secrets of interest to distance metrology. Only future research will tell.

Suggested Extensions

It has become apparent that the **major** requirement for extending the conclusions of this preliminary research effort, the accessing of data must be made more automated. To carry out this task will require enhancements such as a motorized, "long-throw", 3-D translation stage coupled to a computer-driven data-interface that will pass signals to a software system such as LabView.

A novel trick for extending the range of a system based upon Fresnel diffraction patterns is to analyze the distance dependence of the off axis diffraction pattern. It is noted that these oscillating patterns persist off-axis at larger ranges than for the central maxima. This technique is some what similar to using the off-axis interference patterns in the analysis of line shifts in a Michelson interferometer.

References

Earl, D.D. (1997), Application of Fresnel Diffraction to Distance Metrology, Master's Thesis for the University of Tennessee, Knoxville

Earl, D.D., et.al. (1996), High Accuracy Long-Range Distance Measurement Technique Using Fresnel Diffraction Inversion, Annual Report from Oak Ridge National Laboratory, Publication ORNL-27 (3-96)