

MOTION SENSING BY MOIRÉ IMAGING TECHNIQUE – A TYPICAL APPROACH FOR BIOMEDICAL APPLICATION

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ABSTRACT

Moiré fringes are generated due to the interference between two sets of repetitive gratings. Although, these patterns are widely used in metrology, recently it is approached as an emerging tool in the field of biomedical engineering as well. Conventional Moiré interferometry evaluates the interference of two light waves being reflected on a reference surface and the object to be profiled. However, difficulties in satisfying the requirements for the significant issues in obtaining accurate dimensional information are dealing with micro-level and nano-level on-line inspection. Particularly, in real-time biomedical inspection of auto-inspection and auto-operation of inner organs of human body needs precise information of inner movements. In that case the single light wave system makes the Moiré sensing system easier and applicable. Moreover, how to avoid employing expensive bio-imaging facilities or taking strict operation requirements in 3-D measurement has become a critical problem to tackle. Therefore, research has been conducted focusing on the objective of developing a single wave Moiré imaging technique for multidimensional motion sensing.

Keywords: Moiré Imaging, Single Gratings Method, Biomedical Motion Sensing.

1. INTRODUCTION

The word moiré refers to the meaning as watered or wavy appearance which evolved from the ancient French word *mouaire*. The scientific earlier application of moiré phenomena was for testing the quality of replicated diffraction gratings [1]. However, modern scientific research into the moiré phenomenon and its application has been started at the last of the 19th century. Since then the theoretical analysis of moiré phenomena has been based on purely geometric or algebraic approaches. Based on these approaches many special purpose mathematical developments have been devised for the needs of specific applications such as strain analysis, metrology, etc. More recently several new approaches have been proposed for studying moiré phenomena respectively, based on non-standard analysis, on elementary geometry and potential theory, or on algebraic geometry. It is, however, undoubtedly the Fourier-based approach that most significantly contributed to the theoretic investigation of the moiré phenomenon.

Moiré fringes are the results of the interference produced by the superimposing two sets of repetitive gratings. These patterns are used in vibration analysis as well as in 3D surface reconstruction as well. Moiré images are normally obtained using a camera to capture the patterns generated by superimposing of two alternating opaque-transparent Ronchi gratings or two projected light patterns [2].

In the present work a single repetitive grating is

used instead of two gratings. The imaging device itself plays the role of one of the grating with its regular 2D repetitive arrangements of the CMOS sensor (camera). This CMOS camera is then used to observe another grating. The interactions between these two gratings result in the formation of moiré patterns, which can be simply captured by the camera itself.

The passive-pixel sensors (without their own amplifiers) were being investigated as a solid-state alternative to vacuum-tube imaging devices, when the MOS passive-pixel sensor used just a simple switch in the pixel to read out the photodiode integrated charge [3], which suffered from many limitations, such as high noise, slow readout, lack of scalability etc. The CCD was invented in 1970 at Bell Labs. Because the MOS process was so variable and MOS transistors had characteristics that changed over time, the CCD's charge-domain operation was more manufacturable and quickly eclipsed MOS passive and active pixel sensors [4]. The CMOS sensor (an active pixel sensor or APS sensor which was first devised by Tsutomu Nakamura, when he was in charge at Olympus and more broadly defined by Eric Fossum for developing the charge modulation device active pixel sensor [5]) was well established as a well controlled stable process at the early 1990s and was the baseline process for almost all logic and microprocessors. There was a resurgence in the use of passive-pixel sensors for low-end imaging applications, and active-pixel sensors for low-resolution high-function applications such as retina simulation and high energy

particle detector [6]. APS pixels solve the speed and scalability issues of the passive-pixel sensor. They generally consume less power than CCDs, have less image lag, and require less specialized manufacturing facilities. Unlike CCDs, APS sensors can combine the image sensor function and image processing functions within the same integrated circuit. CMOS-type APS sensors are widely used, from high-end digital photography down to mobile-phone cameras, such as digital radiography, military ultra high speed image acquisition, security cameras, optical mice etc.

Therefore, research has been conducted focusing on the objective by using a CMOS camera and single optical gratings to develop a single wave moiré imaging technique for multidimensional motion sensing in the field of biomedical imaging techniques. The experimental results are analyzed and discussed for the planar inclination with OpenCV algorithm.

2. MOIRE PATTERNS WITH CMOS SENSORS

The classical examples of moiré patterns generated by the superposing of two gratings are shown in Fig. 1.

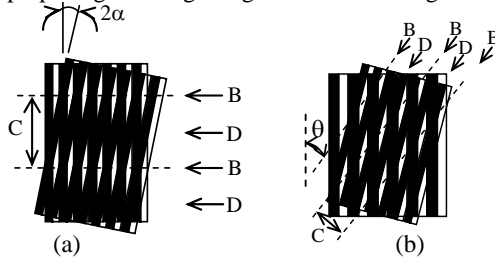


Fig 1. Moiré images with two gratings (2 wave image); (a) for same grating-spaces, (b) for different grating-spaces.

Figure 1(a) indicates the moiré patterns for the interference of two gratings with same grating-spaces where as, figure 1(b) indicates the moiré fringe pattern for the interference of two gratings with different grating-spaces. The spacing of moiré fringe is indicated by C when, the angle that the moiré fringe generates with the vertical axis is indicated by θ . The rotational angle of the gratings is indicated by 2α . B and D indicate the bright and dark fringes respectively.

Again, the classical approaches for calculating the interval of moiré fringes as well as its angle with the vertical axis can be explained by the following equations:

$$C = \frac{\lambda_1 \lambda_2}{\sqrt{\sin^2 \alpha (\lambda_2 + \lambda_1)^2 + \cos^2 \alpha (\lambda_2 - \lambda_1)^2}} \quad (1)$$

$$\tan \theta = \tan \alpha \left(\frac{\lambda_2 + \lambda_1}{\lambda_2 - \lambda_1} \right) \quad (2)$$

where, λ_1 and λ_2 are the intervals of two stripes. From Eq. 2, it is found that if the intervals of two gratings are same, the angle that the moiré fringe generates with the vertical axis is 90 degrees, however, when they are not similar they generates acute angle with the vertical axis. These results can be seen in Figures 1(a) and 1(b).

3. EXPERIMENTAL ANALYSIS

3.1 Experimental Setup

An experimental set-up has been developed capable of measuring the 6D motion of an object by using of a single gratings moiré fringe technique. Moiré fringes have been generated by applying a simple grating (vertical straight pattern) as well as by a compound (cross shape line pattern) grating with a grating interval of 0.6 mm respectively. The optical gratings are designed by AR-CAD soft-wear and are printed by an inkjet canon printer on to the adhesive printing paper which can be attached to an acryl board with out making any air-gap. The acryl board was attached to a gonio which can move with 6 degrees of freedom. A small CMOS camera with 6.35mm (1/4 inch) optical format and $2.8\mu\text{m} \times 2.8\mu\text{m}$ pixel size has been used and mounted on a height adjustable stand and is connected to a personal computer (PC) by USB cable for storage of images for further analysis. The camera-stand and the gonio-stand are mounted on an optical rail upon which all the base positions can be precisely measured. The panoramic view of the experimental setup is shown in Fig. 2. The properties of CMOS camera, consisting of an integrated circuit and array of pixel sensors (photodetector and active amplifier), are shown in Fig. 3 and Table 1 respectively.

The data acquisition and modulation of moiré images through the CMOS camera are conducted by OpenCV (Intel Open Source Computer Vision Library) algorithm inside the PC.

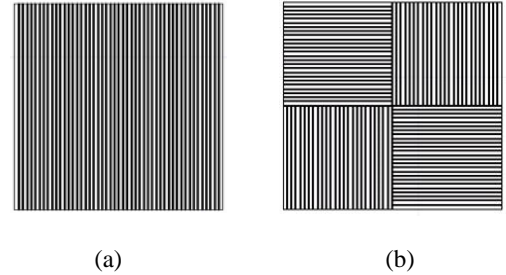


Fig 2. Gratings for moiré fringes. (a) Sharp straight-line gratings, (b) cross-shape straight line gratings.

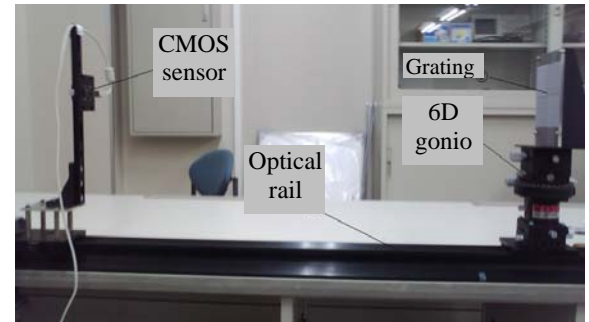


Fig 3. The panoramic view of the experimental setup for moiré imaging.

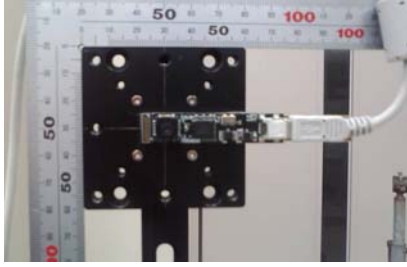


Fig 3. The detail view of the camera and its attachment.

Table 1: Specification of CMOS camera

Optical format	6.35mm (1/4 inch)
Image size (pixel)	1280(H)×1024(V)
Pixel size	2.8μm×2.8μm
Filter	RGB Bayer pattern
Output	USB 2.0, 8 bit
Focal length	3.4mm

3.2 Experimental Results

Experiments have been conducted focusing on the objective of developing a single wave moiré imaging technique for multidimensional motion sensing. In that respect the images of moiré fringe have been taken for different angular positions of the gratings acryl board. However, the camera has been kept constant in its original position. Therefore, according to the theory as explained before, the moiré fringes have been generated for different angular positions of acryl body. The angular positions have been varied from 0 degree to 45 degrees with an angular interval of 5 degrees. Several images of moiré fringe for the angular positions of 5degrees, 15degrees, 25degrees and 45degrees for both simple and cross type gratings patterns are shown in Fig. 4.

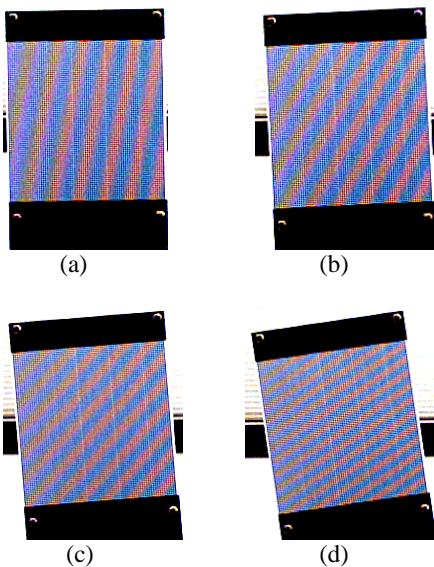


Fig 4. (i) Moiré fringes for (a) 5°, (b) 15°, (c) 25°, (d) 45° with simple straight patterns.

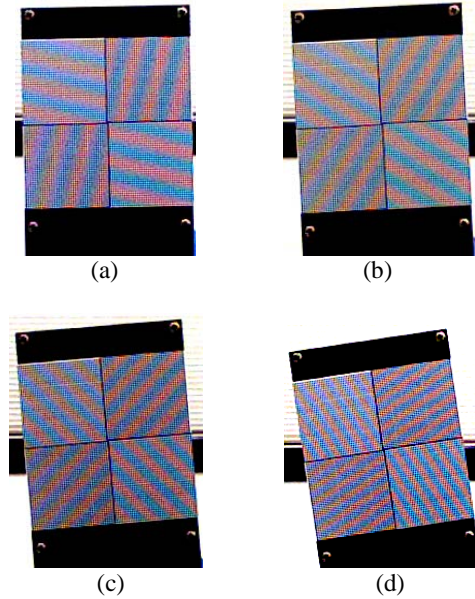


Fig 4. (ii) Moiré fringes for (a) 5°, (b) 15°, (c) 25°, (d) 45° with cross-shape patterns.

The changes of moiré fringe patterns for the changes in angular positions are remarkably identified in Figs. 4(i) and 4(ii). The major changes are noticed in the interval (C) of moiré fringe and the angle (θ) that the moiré fringe generates with its vertical axis. It is found, as the angular distance of the gratings position increases, the interval of the moiré fringe decreases. However, concerning to the angle of moiré fringe (θ), the result is opposite, which means that the fringe angle also increases when the gratings angular movement increases. Thus, these experimental results also satisfy the theoretical explanations. Same observations are found in both the simple straight line pattern as well as in the cross-type patterns. Therefore, by calculating fringe intervals and its angular positions simultaneously, the rotational movements of an object containing grating patterns can be identified by the proposed technique.

A lot of procedures are tried to be employed now a days to calculate these two parameters, the fringe interval as well as its angle for different places of application. For the present research, these parameters are calculated by applying the image processing techniques employing the Intel OpenCV libraries as well as statistical modeling. By applying the OpenCV algorithms, the accurate extraction of interested area and appropriate filtration of the moiré fringe images are conducted. Moreover, the binary conversions of the image of moiré fringes are also done for the appropriate data analysis. The averaging of the fringe data are conducted by applying the statistical formula. Thus, the converted figures for example of 15degrees grating-rotation are shown in Fig. 5, for both the simple and cross-type patterns. Similar techniques are adopted for all other fringe data. Finally, the straight line formula has been applied for calculating the intervals of two moiré fringes. The fringe angle has been calculated by calculating the tangents of the fringe lines.

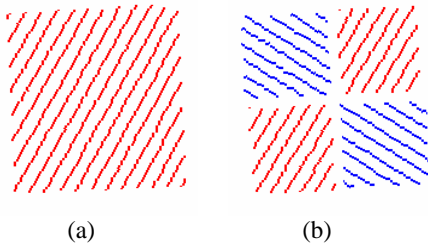


Fig 5. Averaging of moiré fringes for calculation; (a) simple grating, (b) cross-shape grating.

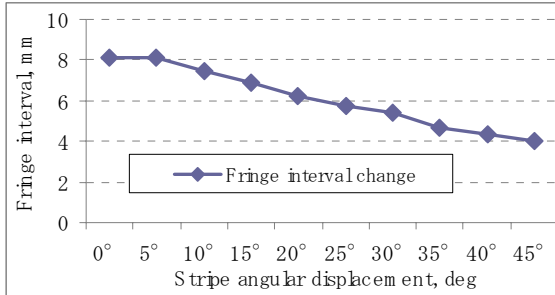


Fig 6. Moiré fringe interval (simple pattern)

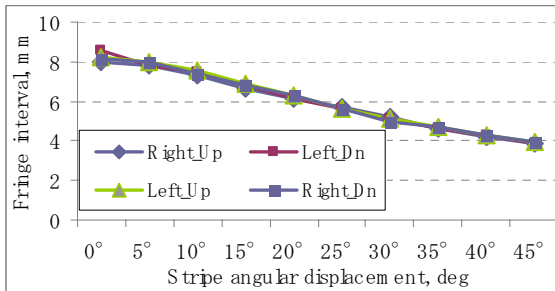


Fig 7. Moiré fringe interval (cross-shape pattern).

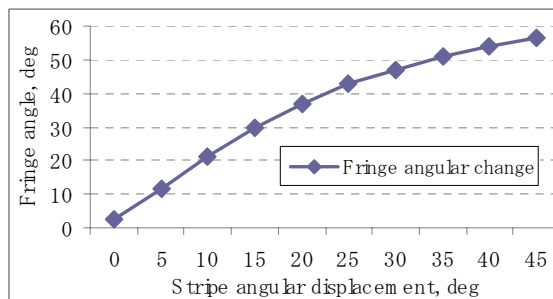


Fig 8. Fringe angle with vertical axis (simple pattern).

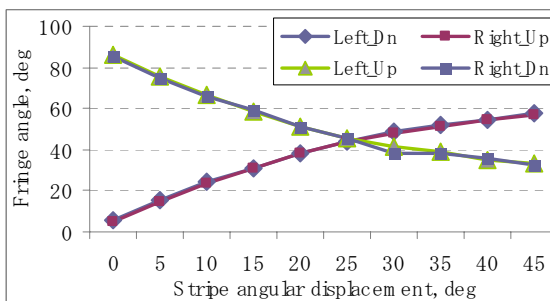


Fig 9. Fringe angle with vertical axis (cross pattern).

The results of calculations for the intervals and angles of moiré fringes for the angular movements of the body (acryl board in the experiment) with different types of gratings are shown in Figs. 6 to 9.

4. CONCLUSIONS

The main attempt of the proposed research is to develop an appropriate technique by applying the moiré imaging phenomena for motion sensing in a macro as well as in micro level. The major advantage of the proposed moiré imaging technique is that it is simple, however, applicable with minimum of accessories.

Motion sensing by moiré technique of a single wave grating is possible. Although, some artifacts due to the differences in intervals of the camera and the specimen gratings are available, however, the calculations of the interval and the angle of moiré fringe are successfully performed by the proposed single grating moiré technique.

The difference in gratings-design has some effects in fringe patterns, however, with due calibration, the proposed motion sensing technique becomes appropriate for its desired applications.

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6. REFERENCES

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