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Designing of an optical fiber sensors of statistical mode via image processing of speckle pattern changes

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Abstract- To investigate the possibilities of employing speckle patterns alterations, to be noticed in an emerging light spot from step index multimode optical fiber, due to outer perturbation for sensing purposes; first order moment statistical feature is used to design the optical fiber sensors of statistical mode. The experiments of optical fiber sensor of statistical mode are performed for different applied weights and the related images were captured by using a CCD camera. First moment statistical feature is taken out from these images after suitable image processing. A definite weight was applied on a fiber optic in which beams of a He-Ne laser were propagating then variations in speckle patterns were noticed. To achieve the application of effective weight on the fiber optic, a part of load application which has some ridges positioned between two parallel flat plates was employed. The achieved results illustrated that when fiber optic was positioned so that corrugation of bending was made by the application part of load (by means of ridges)and when loads were applied on the optical fiber, the difference in first order moment increased as weight was applied. The effect of area size of contact between fiber optic and ridges was set by employing some different preparations for the application part of load. With these results and by using statistical mode feature it was assured that speckles observation in a light spot emerging from a fiber optic can be used for realization of fiber optic sensor having statistical mode for sensing the application of load applied on the fiber optic. For enhancement of load application effects, appropriate arrangements were used with ridges having convenient dimensions which are alternately organized against the fiber optic.

Index Terms- Optical fiber, Image processing, Laser, sensor of Statistical mode, Speckles, application of load, Statistical feature.

I. INTRODUCTION

Optical fiber sensors have begun to have great role in the technology of sensing in the last ten years because of the cost reductions and the improvements in the technology of the optical fiber. A great number of researches have been done about optical fiber sensors. In many applications optical fiber sensors are still limited in use, in spite of their advantages over the mechanical and the electrical conventional sensors. Problems of standardization and mass production lack cause these limitations. There are four groups of optical fiber sensors according to the principle of modulation named as (wavelength, polarization, phase and intensity). Wavelength, polarization, phase modulated optical fiber sensors have higher sensitivity, but they need complicated hardware, techniques for signal processing and they are costly. While intensity modulated optical fiber sensors are economical and simple to build [1].Sensors of spatial intensity modulation that depend on analyzing patterns of light intensity emerge from the sensors, which are called modal sensors as well. Sensors of statistical mode depend on distributions of different output intensity resulting from inter-modal interference among all modes that are guided in the optical fiber. Sensors of modal power distribution concentrate on the transformation of modes having higher order into modes having lower order, which are tested as a radial distribution change of the signal that is transmitted [2]. Some limitations that affect the sensors sensitivity and variations of the optical output power are the main problems of the intensity modulated sensors. When light is emerging from a multimode optical fiber and form on a screen then a pattern of a uniform circle will be observed. A pattern with an intensity of a smooth distribution happens if an incoherent optical source is used, but the pattern will be granular with speckles of variable intensities when the source is coherent. Modes of different propagation will form a speckle pattern when they interfere randomly. Speckles distribution changes quietly over time, while the total pattern intensity doesn't change. This pattern will change while applying a disturbance like a force on the fiber [3]. Since the pattern emerging from the optical fiber depends on the outer perturbation, so it's used in sensing applications and for getting cheap and sensitive sensors named optical fiber sensors of statistical mode. Measurements of displacement, vibration, temperature and force have been registered when sensors of statistical mode were used. For analyzing of speckle image various parameters of statistics were used [4]. The speckle pattern observation as a data of image looks to be more favored for providing much information [5]. In the field of this research, for designing of sensors with statistical mode, first moment statistical parameter was used and then the difference was taken between the first moments of two main cases; the first without using weight and the second one with applying weights of 500g till the total weight became 6 kg.

II. THEORETICAL BACKGROUND

2.1 Principle of statistical mode optical fiber sensors

In multimode optical fibers, modes propagate in several paths and then interference happens, forming speckle pattern at the rear end of the optical fiber. Generally, at the end of optical fiber, the total intensity of (N) guided modes is formulated as …

$$I(x,y) \approx \left|\sum_{m=1}^{N}\vec{E}_m(\vec{r})exp[i(\vec{k}_m\cdot\vec{r}-\omega t)+i\Phi_m]\right|^2 \quad \ldots\ldots \quad (1)$$

Where: km, the propagation constant, ϕm, the phase of the mth optical fiber mode, ω, the light angular frequency. When applying an outer disturbance to the optical fiber, the fiber refractive index and the optical path length will be changed and the guided mode phase will be modified, so the total intensity will be …

$$I(x,y) \approx \left|\sum_{m=1}^{N}\vec{E}_m(\vec{r})exp[i(\vec{k}_m\cdot\vec{r}-\omega t)+i\Phi_m+i\Delta\Phi_m]\right|^2 \quad \ldots. \quad (2)$$

Where: Δϕm: the change in phase of the mth optical fiber mode that is caused by the outer disturbance. This shows a changing in speckles or distribution of intensity with disturbance [6].The lengths of the optical path of each guided mode will be differently changed and the pattern of the intensity will also change when the optical fiber is subjected to disturbance. Detecting of this change is by the analysis of the resulting patterns by using statistical parameters for the analysis of the image.

2.2 Algorithm of Statistical analysis

Image correlation and image difference parameters are used for the analysis of speckle image, and based on these parameters; many various algorithms are recorded in a report. [4]. First order moment is also another technique for image analysis which is preferred to the correlation and it's the better alternative for statistical mode sensors design in sensor applications where characteristics like (high linearity or/and precision)are important [7].

2.2.1The Moment parameter

When I(x, y) is the emerging pattern of the intensities, the mean values in x and y directions is given by:

$$\mu_x = \frac{\sum_{x,y} xI(x,y)}{\sum_{xy} I(x,y)} \quad \ldots\ldots.. (3) \text{ and } \quad \mu_y = \frac{\sum_{x,y} yI(x,y)}{\sum_{xy} I(x,y)} \quad \ldots\ldots.. (4)$$

The radial moment of pth order is :

$$\mu_p = E\{r^p\} = \frac{\sum_{xy}[(x-\mu_x)^2+(y-\mu_y)^2]^{p/2}I(x,y)}{\sum_{xy} I(x,y)} \quad \ldots\ldots. (5)$$

By using equation (9), the first moment will be:

$$\mu_1 = \frac{\sum_{xy}[(x-\mu_x)^2+(y-\mu_y)^2]^{1/2}I(x,y)}{\sum_{xy} I(x,y)} \quad \ldots\ldots\ldots (6)$$

III. EXPERIMENTAL SETUP AND RESULTS

The experimental system set-up used in the study was shown in Fig 1.

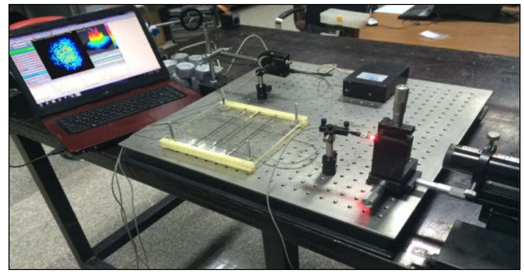

Figure (1): Actual setup photo

A multimode step-index optical fiber having total length of 10m with a 62.5µm diameter of core was used. As an optical source, a Helium Neon laser operating at 632.8 nm wavelength including a cylindrical head with output Power of 5mwwas employed. The light of laser was guided into the optical fiber, and emerges from the other side then projected onto a CCD camera (Gentec-EO). The observed output light spot image, which includes an output light intensity patterns(speckle patterns) was recorded onto a Laptop, then processed and analyzed by Matlab program. In addition, a laser power meter (Gentec-EO) was located in front of the emerging light from the optical fiber for recording the output power after applying of each weight .For the aim of applying load on the optical fiber, a section of load application was used. It consists of two acrylic plates (upper and lower plate) having the same dimensions. The fiber optic was traveled two times inside this section, this mean that the fiber optic was sandwiched between the two plates. The two plates are provided with three extended parts (Ridges); these ridges are elevated towards the fiber and placed alternately as illustrated in Fig 2.

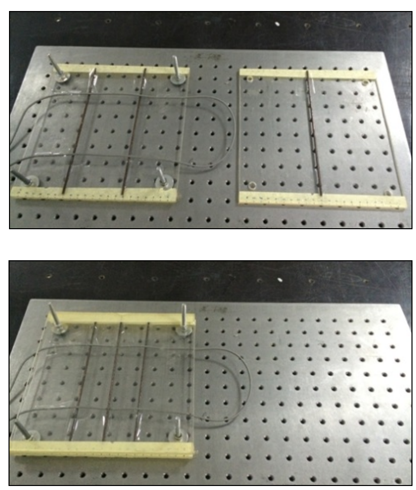

Figure (2): A section of load application before and after fiber sandwiching

Each one of these extended parts had a cylindrical shape with 3mm diameter. With this configuration the optical fiber sandwiched between the two plates will compressed alternately with these elevated parts, resulting in bending having corrugated form, as shown in Fig 3.

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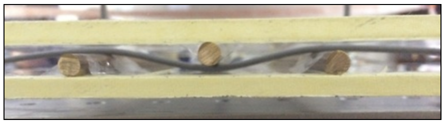

Figure (3): A photo shows an optical fiber bending by ridges

The above configuration was employed to apply weights on the optical fiber then several changes in speckle pattern observed in the emerged light spot. To achieve application of load, 12 weights each one weighing500g were placed on the top plate of load application section one by one until 6 kg of load was attained. When one weight was applied on the optical fiber, the observed speckle pattern at the emerged light spot was recorded. Same procedure of the measurement was repeated when the second weight was applied. After finishing of all the procedure, the noticed data of the pattern image were analyzed as will be mentioned later and the whole speckle pattern radius appears to reduce in general upon raising the weights that are placed over the fiber optic. Fig.4 illustrates the patterns before and after load application.

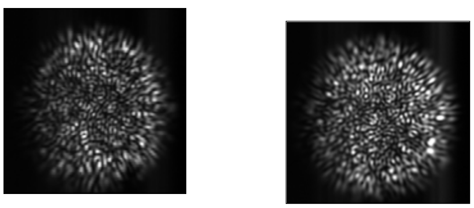

Figure (4): The patterns before (left) and after (right) load application

For the reason of extra study influences of load applying on alteration in the experimental speckle pattern, extra experiments were carried out with some dissimilar preparations of load applying section. They had principally the same arrangement excepting for the number of extended elevated segments (ridges) offered between the plates when applying weight. Specially having three situations, one of them had the full amount of three ridges offered between the opposed plates (one onto the lower plate and the other two ridges onto the upper plate). Other system had four ridges (two ridges for each plate) or the five ridges (three onto the lower plate and the other two ridges onto the upper plate). Intervals between ridges were equal. The ridges were steel rods of a 3mm, 5mm and 7mm in diameter. The results that obtained from suitable processing to the images given in figures 5, 6 and 7, they illustrate the difference in first moment statistical feature against applied weights for each situation respectively.

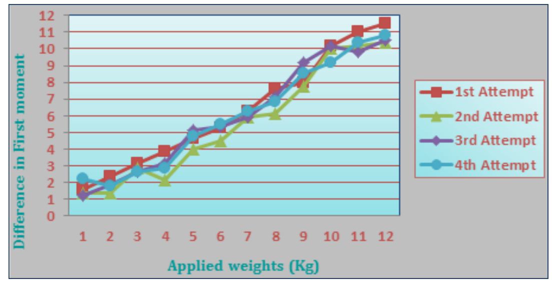

Figure (5): Difference in first moment against the applied weight with three ridges of 3mm diameter

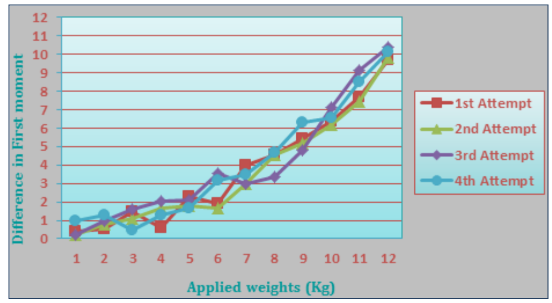

Figure (6): Difference in first moment against the applied weight with four ridges of 3mm diameter

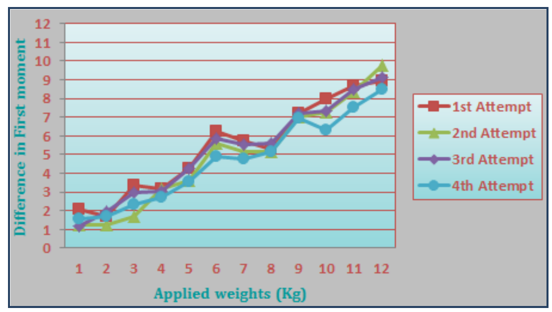

Figure (7): Difference in first moment against the applied weight with five ridges of 3mm diameter

From these figures it may be noticed that the difference in first moment is positively correlated with the applied weight and there is constant outcome for both increasing weights. So, this feature used in the sensors of statistical mode planning. The measuring procedures were repeated four times for each arrangement and the respective calculated data were shown. The results show that the difference in first moment was expected to increase with increased number of weights means larger load onto the optical fiber, with moderately excellent reproducibility of the achieved data. Moreover, a bigger slope was familiar with the lesser ridges number. Difference in first moment decreased a lot in the case with five ridges when compared to the case with three ridges as in Figure 8.

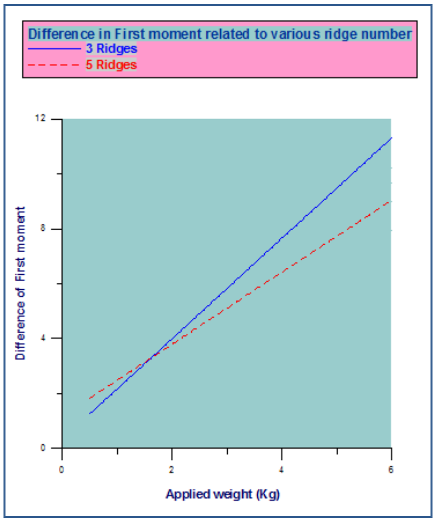

Figure (8): Comparison between differences of first moment vs. applied weight with 3 and 5ridges of 3mm diameter

Such disposition is clarified by taking into account the fact that with lesser number of ridges, the applied weight per ridge increases, resulting in much fiber bending which will induce in turn more significant effects on the speckle pattern observed in the output light spot. When the applied load on the fiber will be distributed with the bigger quantity of ridges; the resultant will be not so much of bending of the optic fiber and less important effects on the noticed speckle pattern. The same result could be predicted to be observed with different contact area sizes between the ridges and the fiber through which load was applied. So, additional application of load arrangements were arranged in which the ridges were offered as the similar bar but having different diameter of 5 mm and 7 mm rather than 3 mm. Number of ridges was found to be three in each case. Figures 9 and 10 illustrate difference in first moment in agreement with rise of the applied weight for the particular arrangements with the ridges of the different diameter. The procedures of measuring were four times recurred for each case.

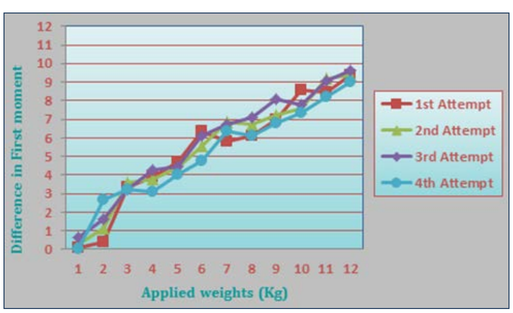

Figure (9): Difference in first moment against the applied weight with three ridges of 5mm diameter

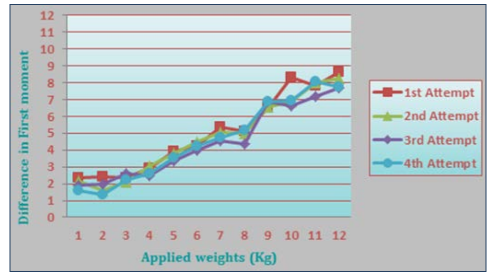

Figure (10): Difference in first moment against the applied weight with three ridges of 7mm diameter

Difference in first moment decreased a lot in the case with 7mm ridges when compared to the case with 3mm ridges as in Figure 11.

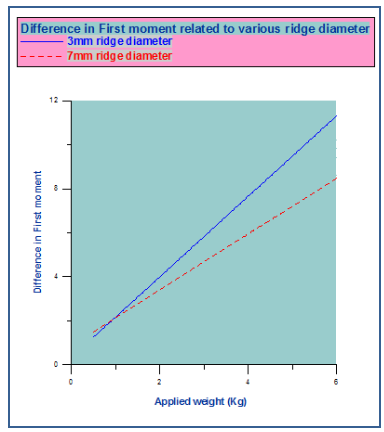

Figure (11): Comparison between differences of first moment vs. applied weight with three ridges of 3mm and 7mm diameter

The outcome of Fig.11 shows that with 7 mm diameter ridge, there is more decrease in the difference of first moment than those with 3 mm diameter ridges. Furthermore a bigger diameter of a rod to be used as a ridge in the section of load submission means an increased contact area size between the ridge and the fiber. So, the results given in Fig.11 do not oppose the results given in Fig.8 with the different quantity of ridges. Figure.12 explains more experimental data about the characteristics of transform of the speckle pattern according to the load applied onto the fiber optic. Specially, when using the weight application arrangement using 5 ridges each with 3mm in diameter, weight was applied on the fiber optic by putting weights one by one like in previous measurements.

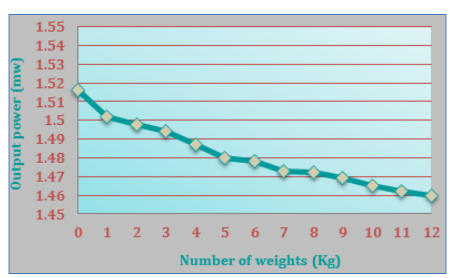

Figure (12): Changing in the output light intensity

In this situation, beside the image data gaining and analysis, the output level of power from the laser power meter was recorded at every level of weight. The results show that the level of output power from the laser power meter or the intensity of light emerging from the fiber optic, reduced according to the increasing level of weight applied onto the fiber optic in a manner related to the increasing in difference of first order. So, increasing in the difference of first order is deemed to be correlated to the reduction in intensities of laser beams that propagating in the fiber which are thought to be induced through fiber deformation because of load application. So, from the above results, it was established that watching speckle patterns in a light spot emerging from a fiber optic may be employed to realize sensing of application of load on the fiber optic by using suitable arrangements with suitable ridges that are alternately disposed adjacent to the fiber optic to increase load application effects.

IV. CONCLUSION

The first order statistical feature was used in this work for designing of optical fiber sensors with statistical mode a definite weight was applied on a multimode fiber optic in which beams of He-Ne laser were propagating and the resulting speckle patterns alterations in a light spot emerging from a fiber optic were noticed. However, as an outcome if weight was applied on a fiber optic by means of load application part that produce optical fiber bending with corrugating form when a definite number of extended elevated segments(ridges) were employed, it was concluded that the difference of first order moment increased as load applied on the fiber optic. The increase tendencies of the differences in first order moment were more influenced by load application part arrangements, like ridges number and their diameters. This shows that the size of contact area between the optical fiber and ridges by which weight was applied on the optical fiber will contain definite influence on these phenomena.

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