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SRI RAMACHANDRA FACULTY OF ENGINEERING AND TECHNOLOGY

A LOW COST FBG BASED ONLINE WEIGHT MONITORING SYSTEM

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CHAPTER.1
INTRODUCTION

1.1 Fiber Optic Sensor:

Fiber Optic Sensors (FOS). FOS are gaining popularity over electronic sensors due to their attractive and superior properties such as higher sensitivity, better response, chemical inertness, higher repeatability, lightweight, etc than their electronic counterparts. These sensors are explored extensively for their application in pipeline monitoring , microseismic wave detection , structural health monitoring , acoustic wave detection , biomedical engineering , etc.

1.2 Fiber Bragg Grating:

Fiber Bragg Grating(FBG). They are one of the most preferred FOS at industrial scale and are commonly known for their simple work and high sensitivity towards strain and temperature.They are bandpass filters which possess sensing property .Any change in external parameter will be noted as wavelength (Bragg wavelength)change and does not affect the case.

1.2 Application in Weight Measurement:

From applications of FOS, FBGs we have also found their application in weight measurement through strain sensing.Load cells are the basic weighing elements which need frequent calibration and are vulnerable to temperature and other environmental changes.FBGs are glued or mounted on different types of load cells for weight estimation. Optical interrogators or optical spectrum analysers are used to find the shift in Bragg wavelength due to the strain generated on the load cell by the applied load and in other cases, match filter is used, but still the weight measurement is done for <1kg.In all these works only the strain sensors based on FBG are proposed. A full prototype for weight measurement is still missing and needs to be explored for industrial purpose.

1.4 Demand in Online Monitoring:

Apart from measuring weight, online monitoring of acquired data is the demand of the present era. So, IoT based monitoring of load is necessary. Many electronic IoT based smart weighing systems are proposed and are present in the market . Thus, there is a need to integrate optical measurement systems with IoT to compete with their counterparts.

An attempt to make a low-cost online weight monitoring system using FBG :

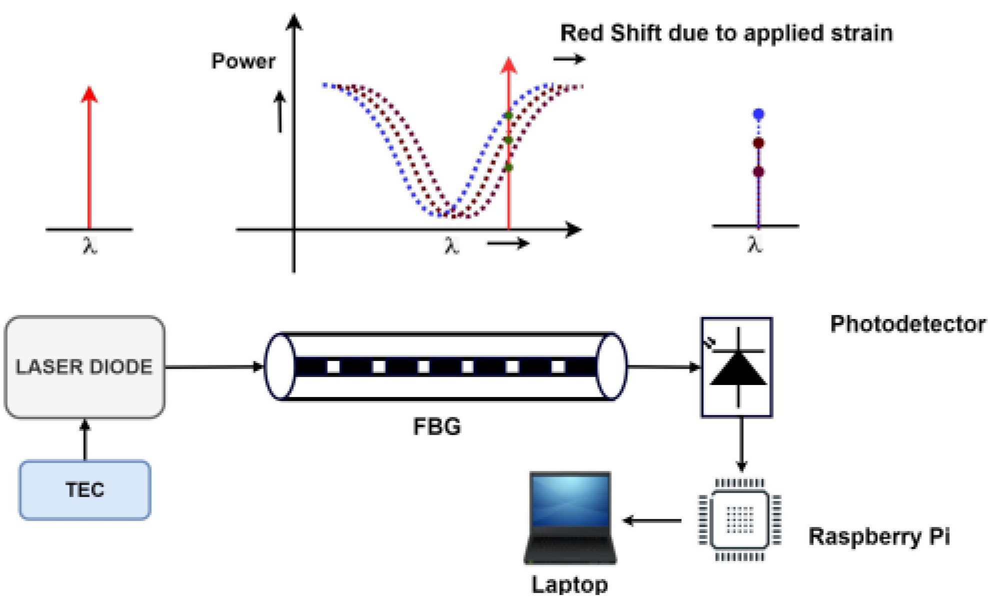
The system uses edge filter detection techniques to interrogate FBG sensing data. A weighing system using a binocular shaped cantilever type load cell embedded with FBG is proposed. This system is capable of weighing loads up to 8kg which is much better than the previous report . The optical data is converted into electronic data at the photodetector end. Furthermore, a low-cost computer interface using Raspberry Pi is used to process and transmit the data to the cloud through Wi-Fi. This real time data monitoring of applied load along with accuracy of ± 20g is successfully attained through the experimental setup.

CHAPTER-2

WORKING PRINCIPLE

The optical weighing system converts the Bragg wavelength shift of FBG into intensity variation of laser optical power. This approach was first proposed by Morey and is further expanded by Wilson . This low-cost interrogation technique is quite popular and used in a variety of applications.

Schematic of the model :



In this approach, FBG works as both an edge filter and sensing element. The transmission spectrum is utilized for edge filtering and single frequency laser with Thermoelectric Cooler (TEC) controller is utilized in this model. At the receiver end, a photodetector with transimpedance amplifier is used that converts low optical power variation into measurable voltage variation. Now, FBG can work as an optical strain gauge mounted on a load cell. This FBG has reflectivity of 80 % with bandwidth of <0.7 nm. Higher the reflectivity better will be the slope and sensitivity. The Bragg wavelength of FBG is within the C-band of the optical spectrum.

In this experiment:

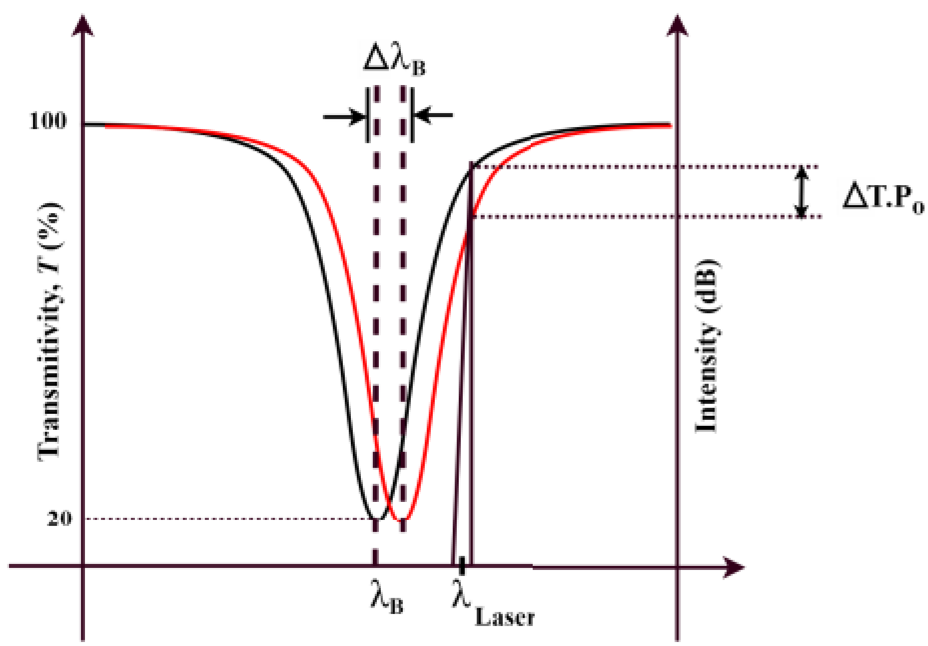


Fig. 2. Laser power variation due to the change in Bragg wavelength ($\Delta\lambda_B$).

Whenever there is change in Bragg wavelength (λB) due to applied external strain and transmissivity(T):the wavelength is comparatively small. By using the principle of small-signal model, the relationship between λB and T can be given as γ = TλB.

Thus the optical power provide at photodetector can be given as :

$$P_{out} = m(P_0.T + \gamma.P_0.\Delta\lambda_B)$$

Change in Bragg wavelength is directly proportional to applied strain and temperature variation, that can be written as :

$$\frac{\Delta\lambda_B}{\lambda_B} = (\alpha_s + \alpha_e)\,\Delta t + (1 - P_e)\,\epsilon$$

By neglecting the effect of temperature through initial temperature compensation becomes:

λB = (1 − Pe) .λB

Eqn (3) in (1) we get:

Pout = m(P0.T + γ.P0.(1 − Pe) .λB) (4)

Thus, the optical power observed depends upon the applied strain on FBG by the load cell. For weight measurement the load cell is placed in a cantilever position where one end is fixed while the load is applied on the other end. Since, there is rigid coupling of beams ,the load application point has purely vertical shift and the shape of the deformation is S-shaped. Therefore,in these types of load cells four regions are identified around the binocular structure where the maximum strain due to load is concentrated and the electronic strain gauges are mounted in an electronic load cell to maximize the strain sensing.

The dimensions of this load cell :

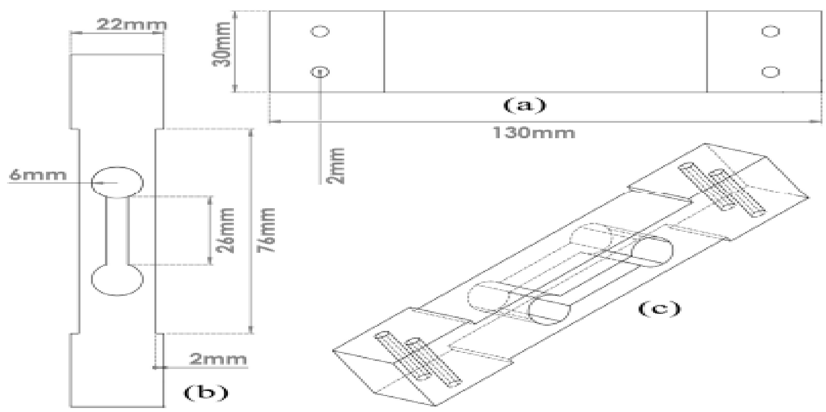


Fig. 3. Orthographic drawing of single load-cell, (a) top (b) side and (c) 3D projected view.

The voltage variation occurred due to change in optical power at the optical load cell is observed at the photodetector end. This voltage variation is further processed and analyzed for weight estimation through Raspberry Pi. Moreover, Data from Raspberry pi is sent to the internet cloud for online weight monitoring.

CHAPTER-3

EXPERIMENTAL SETUP

On the basis of the model discussed above, an experimental setup is developed in the lab. A block diagram depicting the experimental setup :

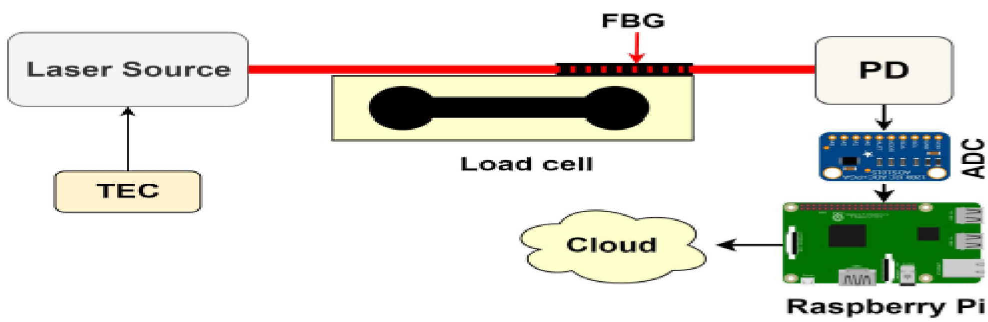


Fig. 4. Block diagram of experimental setup used for proposed model.

The Experimental Setup:

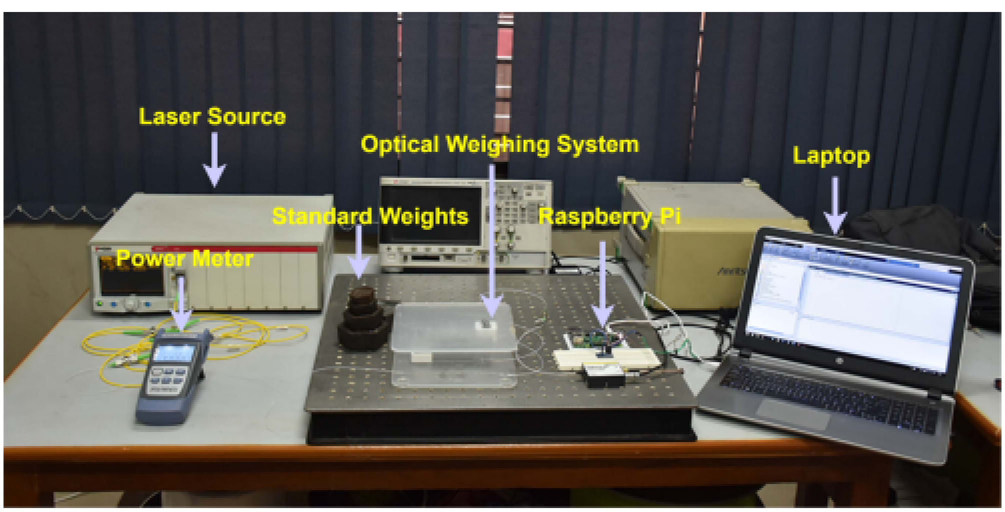


Fig. 5. Experimental setup of FBG based optical weighing system.

It consists of a laser source which helps in achieving higher sensitivity of the setup. FBG (Technica T10) is used as an edge filter and sensing element mounted on a load cell as shown:

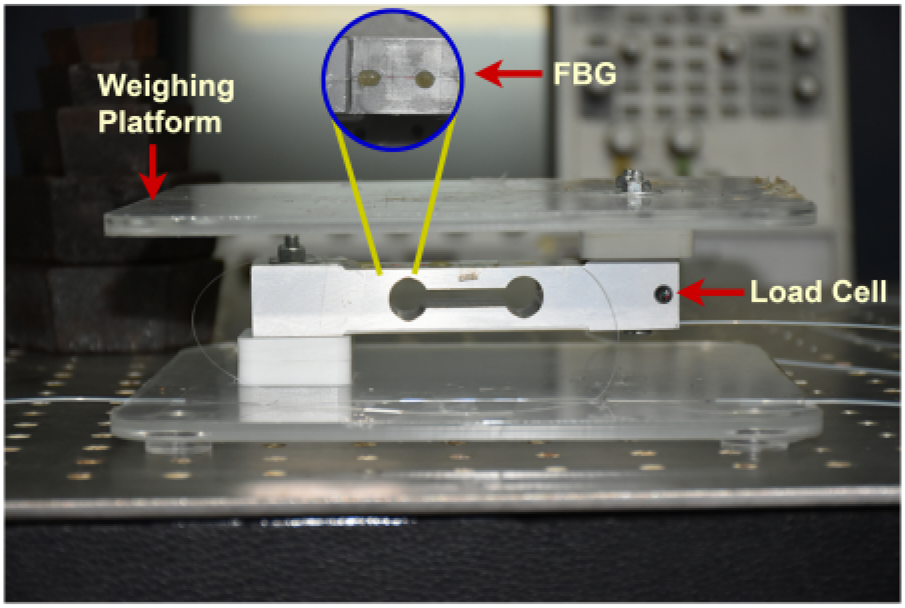


Fig. 6. Enlarged view of FBG mounted on load cell.

Variation of optical power is detected by photodetector having inbuilt low noise fixed gain transimpedance amplifier. The change in optical power due to shift in transmission spectrum of FBG is directly converted into voltage variations. This voltage variation is fed to Raspberry Pi for further processing and monitoring. To eliminate the effect of temperature on the proposed system, initial calibration and temperature compensation are done by using a TEC controller at the laser source. Under laboratory conditions by using a TEC controller the laser is tuned at the transmission spectra. This calibration is needed before initiating the experiment.

The Raspberry Pi:

It is a low cost, credit card sized single board computer that plugs into a monitor using HDMI interface and uses a standard keyboard and mouse. It runs Linux but also provides a set of GPIO (general purpose input/output) pins that allows it to control electronic components.This digital data is sent to Raspberry Pi using one of its GPIOs. A routine for data acquisition and processing from GPIO is written in Python and Message Queuing Telemetry Transport (MQTT) protocol is used to securely publish the data to the cloud. The data received at cloud is processed and is shown on a dashboard to the authorized remote user.

CHAPTER-4

EXPERIMENTAL RESULT AND DISCUSSION

In this section, an optical weighing system is extensively tested, analyzed and discussed. Optical load cell using FBG is developed in the lab. The response of this load cell is observed and optimized for measuring weight up to 8kg. A series of tests are conducted on the proposed optical load cell to ensure its viability in the industrial environment. The results acquired by Raspberry Pi are further investigated by error estimation and standard deviation analysis.

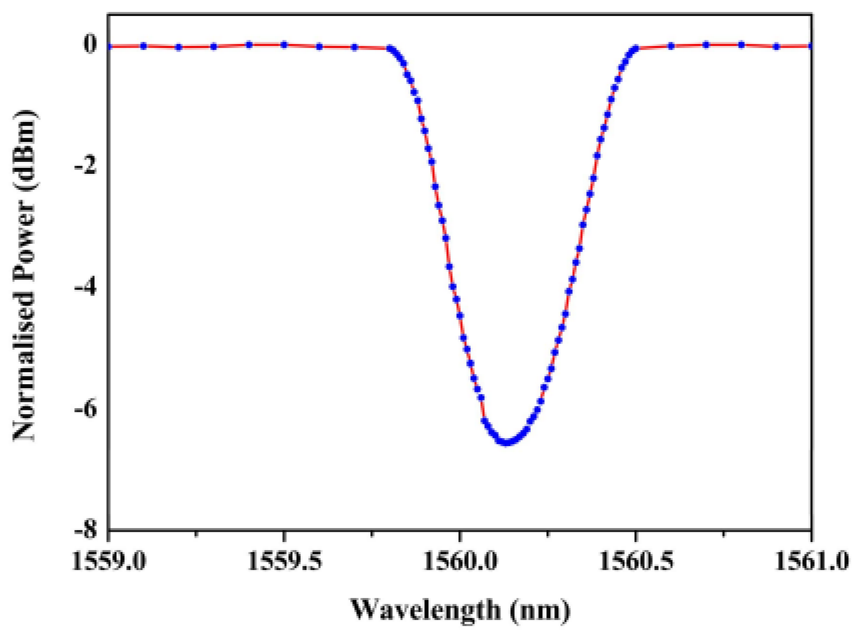
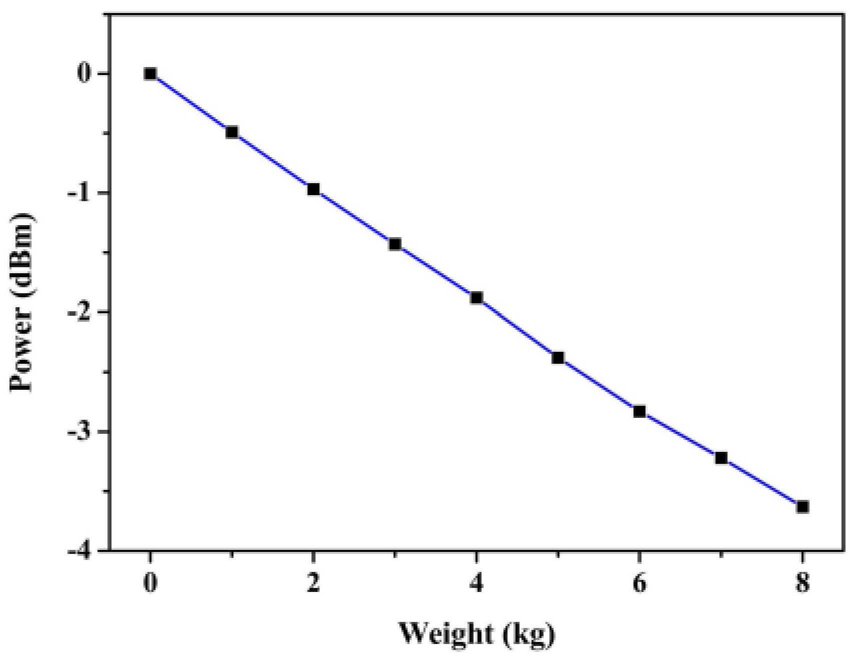


Fig. 7. FBG transmission spectrum analysed using laser source and optical power meter.

The output observed at the power meter while sweeping the laser source. From this figure, it can be observed that the linear regions formed at both sides of Bragg wavelength can be utilized for the experiment. By analyzing the right positive slope, the useful linear region gets reduced. The region that can be utilized for strain measurement is between 1560.23 to 1560.41 nm. This linear region has a slope of 20.167 dBm/nm. Now, the laser is tuned at 1560.41 nm for utilizing the maximum linear region. Whenever the redshift of Bragg wavelength occurs due to applied positive strain on FBG, the optical power decreases at the detector end. Optical power variation due to applied weight as shown:



It is analyzed using an industrial grade power meter having resolution of 0.01 dBm. The standard weights between 0 to 8 kg are used for this experiment with an interval of 100 g. The FBG transmission spectrum is analyzed by sweeping the wavelength from 1559 to 1561 nm using a tunable laser source.

After analyzing the load bearing capacity of the optical load cell, it is important to examine its mechanical properties for viability of its application in the industrial environment. Initially, hysteresis analysis is performed which is the maximum deviation of measured data for the same applied load during a single cycle of incremental loading and unloading of loads.

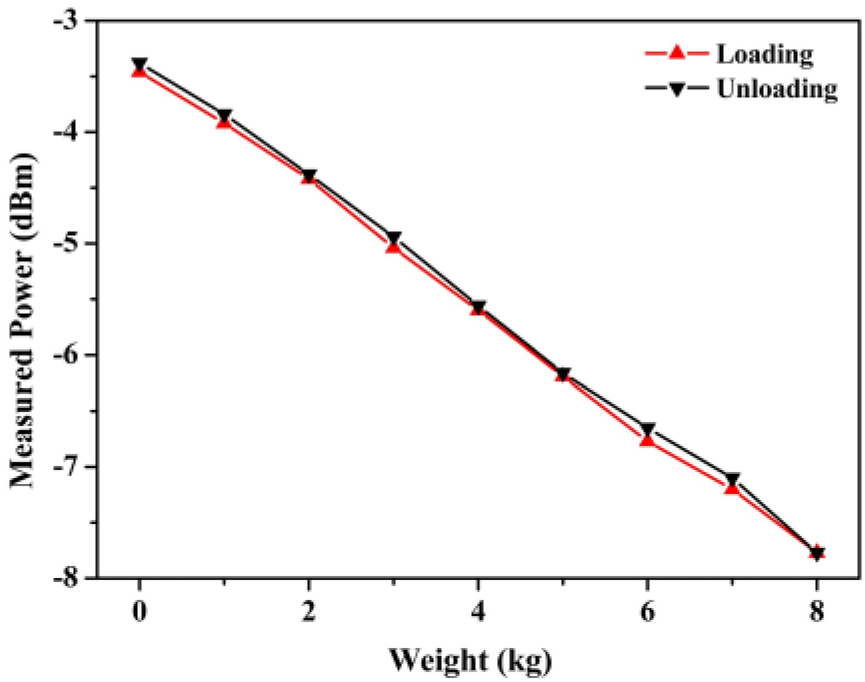


Fig. 9. Hysteresis curve attained by proposed optical load cell.

It shows the hysteresis curve from the optical load cell for cyclic loading and unloading of loads from 0-8-0 kg. From this figure it is observed that the optical load cell has nominal hysteresis which is essential for any load measurement system. Repeatability is another important parameter that affects the accuracy of the system. so, it is considered to be the limiting factor during the calibration process. During this analysis, repeatability of the optical load cell is analyzed with and without temperature compensation.

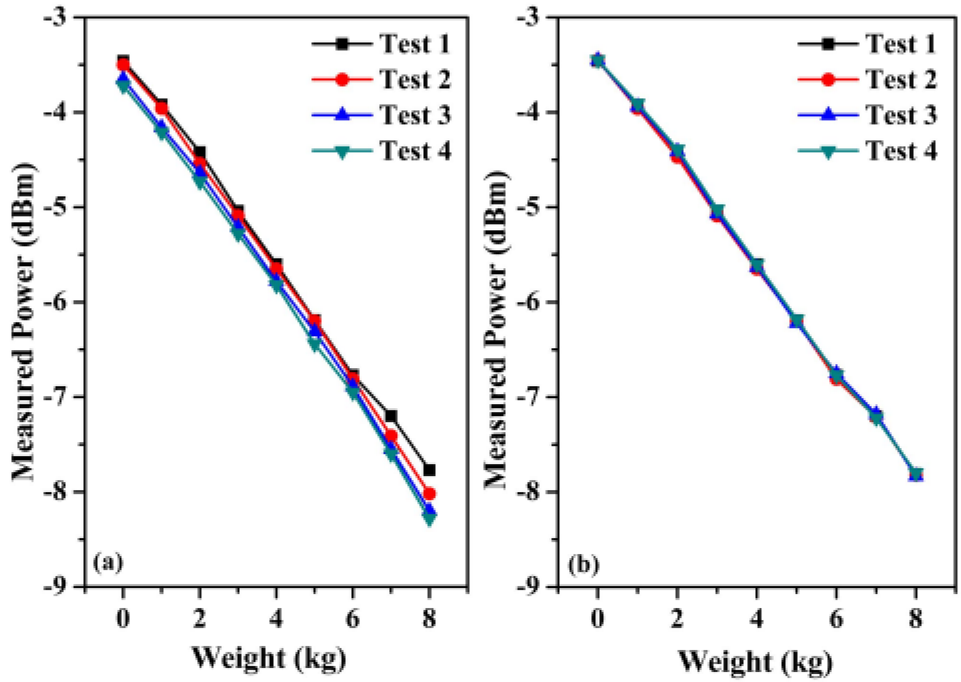


Fig. 10. Repeatability analysis on optical load cell (a) Without temperature compensation (b) with temperature compensation.

It shows repeatability properties of optical load cells with different test cases without temperature compensation. This figure shows that the optical load cell has the same slope, with offset variations which are due to temperature contaminated strain developed on FBG. The optical load cell shows a high degree of repeatability. Furthermore, strain applied on FBG due to applied load is shown in

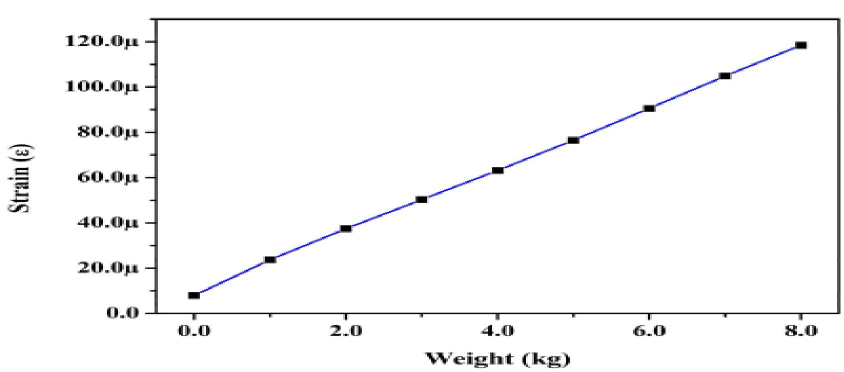


Fig. 11. Total strain generated on FBG due to weight applied on load cell.

During the experiment, it is observed that for each 100 g of load the average variation in power is recorded to be 0.047 dBm. As the resolution of the power meter used is 0.01 dBm, the corresponding resolution of the weighing system is ~20g. As the optical power has average fluctuation of around ± 0.025 dBm, the error in the optical weighing system is ± 50g which is quite acceptable. From the above two graphs, the sensitivity and resolution of the edge filter interrogation system can be determined. It should be noted that resolution of this interrogation technique depends upon the power meter as well. The calculated resolution of the interrogation system is 8.21 με with sensitivity of 0.030 dBm/με in the linear region.

In the next phase, the optical data is converted into voltage signal and is fed to Raspberry Pi through ADC (ADS1115) converter.

The noise produced by Raspberry Pi:

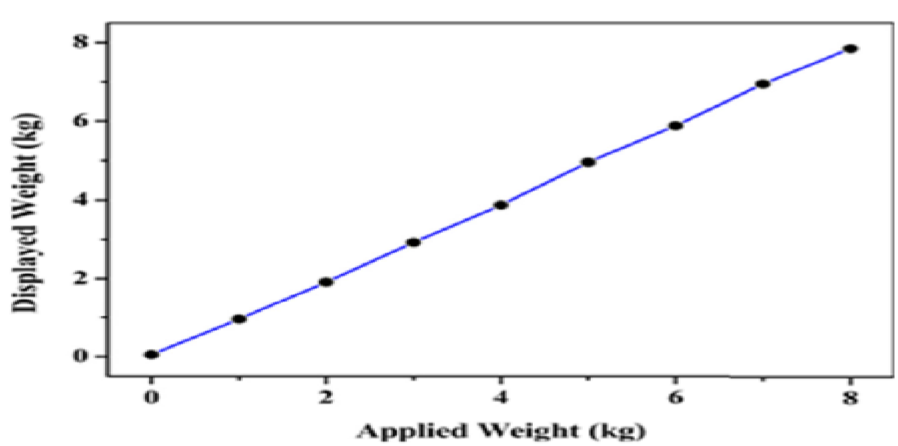


Fig. 13. Load applied on optical weighing system and corresponding weight displayed on Raspberry Pi.

It shows the relative error that has been recorded under no load condition for 10 minutes. Relative percentage error of up to 9% is recorded in this duration which is better than previously reported noise floor of FBG based commercial optical interrogators.

weight displayed online versus weight applied is shown in :

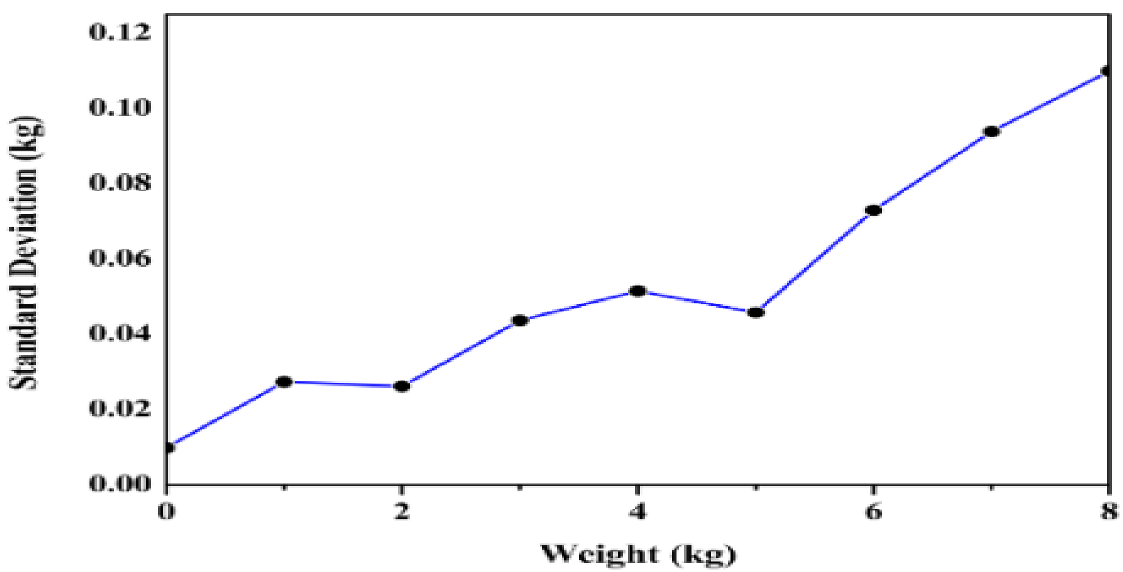
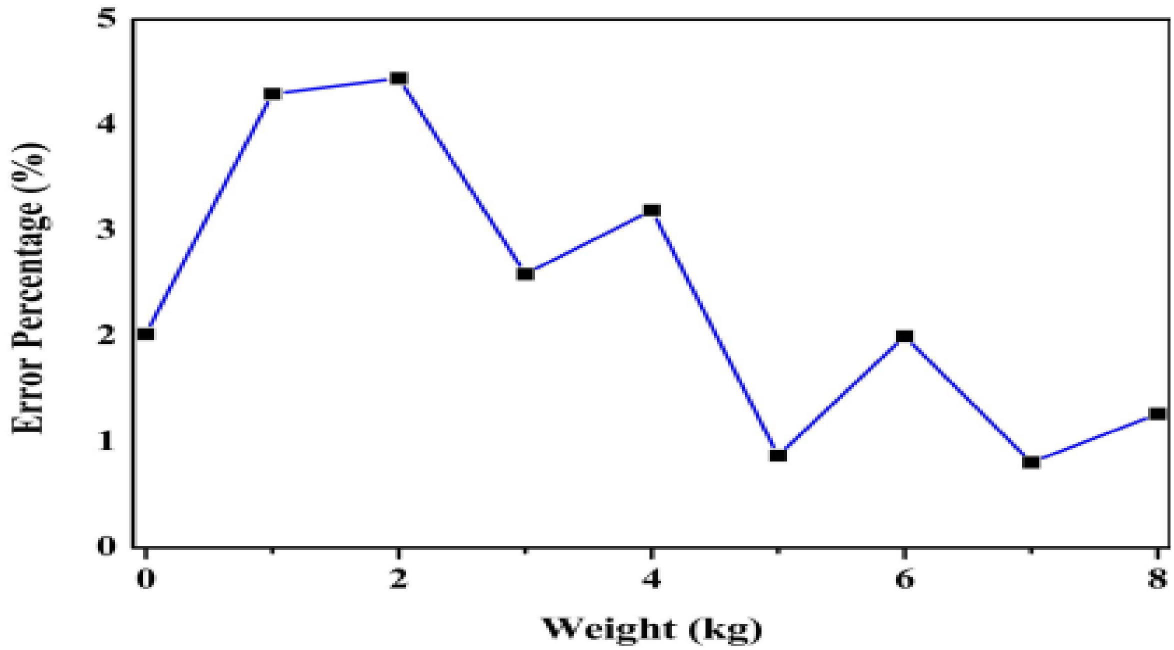


Fig. 15. Standard deviation of the weight observed on Raspberry Pi.



It shows percent error and standard deviation of the data observed through Raspberry Pi by applying standard load on the optical weighing system. From above fig. It can be observed the percent error decreases with increasing weight. This is because there is a comparatively larger increase in applied weight than the error occurred while measuring it. Also, increasing standard deviation of load can be observed in Fig. above. The primary reason behind these deviations is optical power fluctuation and unstable mechanical arrangement at higher load. At last, the proposed model has shown a wider range of capability to measure load up to 8kg. The percentage error is within the permissible limit. The detailed analysis of an optical load cell using a binocular shaped cantilever type load cell along with its mechanical properties is done for the first time. Thus, an optical weighing system with online monitoring capabilities is successfully tested and analyzed.

CHAPTER-5

CONCLUSION

An optical weighing system using a single FBG is experimentally explored, analyzed and tested. A low-cost interrogation technique is done with laser source. And characterization of the FBG is based on interrogation technique .After exploring the approximate working region of the FBG mounted on a load cell, the change in power due to applied load is calculated. Furthermore, strain generated at FBG is also calculated. Detailed analysis and optimization for real time weight measurement in the optical domain are conducted. This interrogation technique provides a resolution of 8.21 με with sensitivity of 20.21 dBm/nm.

After the optical signal is converted into an electronic signal using a photodetector, voltage variation is converted into a digital signal using ADC. This digital data is provided to Raspberry Pi for further processing and is sent to IoT cloud using MQTT protocol. Other important error estimations such as noise floor estimation, percentage error, and standard deviation are successfully done. The proposed system has shown higher range measurement capability than previously reported optical weighing systems. This weighing system has an error of ±50g with resolution of 20g. Hence, this optical weighing system can be employed for load estimation of lightweights in industries.

REFERENCE

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