Intensity Insensitive One Dimensional Optical Fiber Tilt Sensor

Badrinath Vadakkapattu Canthadai *[a], Dipankar Sengupta[b], Vengalrao Pachava[c], P. Kishore[c].

[a] Dept. of Physics, Vidya Jyothi Institute of Technology, Hyderabad, AP, India 500075;
[b] Dept. of Information Engineering, University of Padova, Padova, Italy;
[c] Dept. Of Physics, National Institute of Technology, Warangal, AP, India 506004.
* badrinath.14feb@gmail.com

ABSTRACT

The paper presents a proximity sensor based on plastic optical fiber as tilt sensor. Discrete and continuous response of the sensor against change in tilt angle of the setup is studied. The sensor can detect tilt angles up to 5.7^0 and the achieved sensor sensitivity is $97mV/^0$.

Keywords: Tilt sensor, intensity modulation, plastic optical fiber, proximity sensor

1. INTRODUCTION

Tilt sensors play an important role in today's world. There are many applications of the tilt sensors such as: measuring walls or ground movements in civil engineering projects, indication of the vehicles and aircrafts pitch and roll etc. Over the years, there have been many techniques developed for tilt measurement and commercially available such as resistive, capacitive, inductive, optical and Fiber Bragg Grating sensor etc. [1][2]. However there is a need to develop an inexpensive, simple-structured tilt sensor with wide measuring range and high accuracy that can satisfy the market demand.

A pair optical fiber based displacement sensor has many applications owing to its simple design and high sensitivity [3]. Reported results show that such a designed sensor can be used for the measurement of physical parameters like proximity, refractive index, vibration etc.[4][5][6]. A Gaussian beam approach has been presented by J. Brandao Faria et al. for the purpose of theoretically predicting not only the transfer function of the pair fiber sensor but also its sensitivity and for the measurement of tilt angle [7].

This paper presents an application of proximity sensing technique using a pair of plastic optical fiber and used to develop a simple, low-cost and high-sensitivity fiber-optic tilt sensor. In the experimental setup a pair of optical fiber as a sensor is used to measure the bending of the cantilever with a weight attached to its free end. The experimental result shows that the sensor is insensitive to source fluctuation and capable of measuring one dimensional tilt.

Fiber Optic Sensors and Applications XI, edited by Henry H. Du, Gary Pickrell, Eric Udd, Christopher S. Baldwin,
Jerry J. Benterou, Anbo Wang, Proc. of SPIE Vol. 9098, 909811 · © 2014 SPIE
CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2050821

2. PRINCIPLE AND SENSOR DESIGN

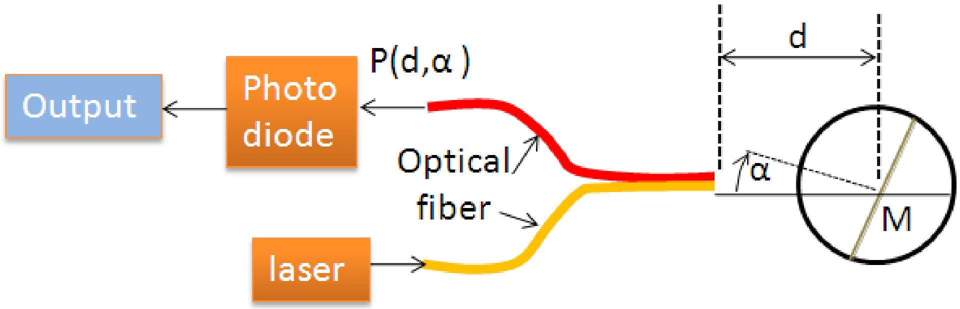
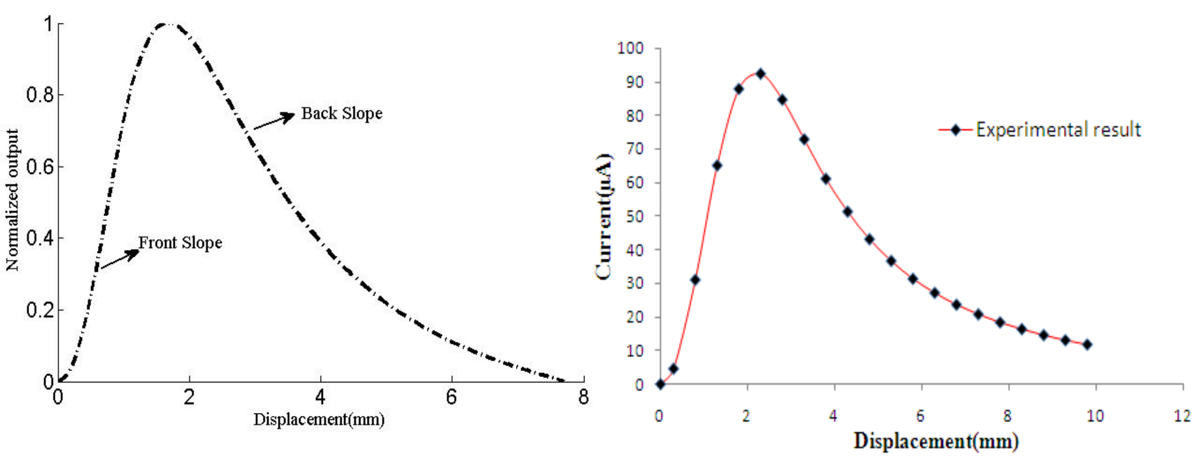


Figure 1. Schematic setup of Proximity sensor for tilt measurement

Fig.1 shows a schematic experimental setup for tilt measurement. The setup consists of a pair of plastic optical fiber (transmitting fiber and receiving fiber), a reflector (Mirror M), LED (IFE-93, peak wavelength 660 nm) and a photo detector with simple electrical circuit. The pair of optical fiber called as probe is placed in front of the reflector (M) at a distance 'd'. The light is launched into the transmitting fiber (TF) and on emergence, the modulated reflected light from the reflector is received by the receiving fiber (RF). The received light intensity is detected by a photo-detector and is displayed as output power in microampere. As the TF and RF are made up of same material and equal in diameter, the received light intensity will only vary with respect to change in the distance between fiber probe and reflector.



(a) Simulation result (b) Experimental result

Figure 2. Characteristic curve of the proximity sensor using pair fiber probe

The simulated value of optical power received by the receiving fiber against displacement, using MATLAB, is shown in Fig.2 (a). It indicates that the reflected normalized output power is a function of displacement 'd', which is the characteristic of the proximity sensor [8]. Fig. 2 (b) illustrates the displacement response of the sensor which is obtained by varying distance between the pair fiber probe and the reflector. It is evident from Fig. 2 that there is a good agreement between simulated and experimental results. When the probe and the reflector are kept at a fixed distance and the reflector is tilted, then the light entering into the receiving fiber is less. This is due to the change in angle of incidence of light falling on the reflector. J. Brandao Faria et al. demonstrated the variation output power with the angle (α) between fibers and the reflector and also monitored the occasional tilting of the surface [7].

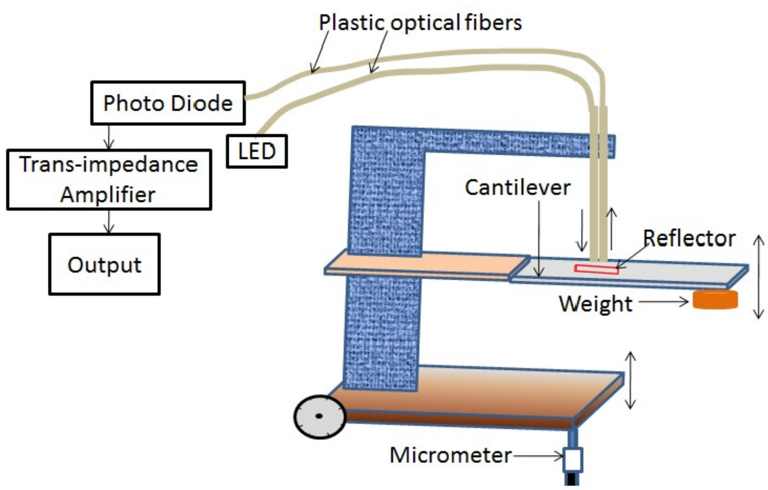


Figure 3. Schematic of experimental setup

A simple and low cost tilt sensor arrangement is conceived and developed. The schematic experimental setup is shown in Fig.3. It consists of a pair fiber probe set as transmitting fiber and receiving fiber, a cantilever beam made of stainless steel, variable weights, LED as light source, a photo diode, trans-impedance amplifier, reflector, micrometer and a digital multi-meter. Two PMMA (poly-methyl methacrylate) fibers of length 50 cm having core/cladding diameter 980/1000 µm and refractive indices 1.492 and 1.402 are used. The two fibers are aligned parallel with close proximity to each other, glued together up to 2cm at the end of the fibers with cyanoacrylate epoxy. The 50 gm weight is attached at the end of the cantilever. A small reflector (mirror) of 10mm in diameter is glued on the cantilever. The probe is vertically aligned to the reflector. With the help of a micrometer, the arrangement can be tilted as shown in Fig.4 to a desired angle with respect to the base to which the cantilever beam is fixed.

When the experimental setup is tilted by some angle with the help of the micrometer, the cantilever beam bends. This is due to the slight gravity induced movement of the weight attached to the free end of the cantilever and the light received by the RF decreases which is a measure of tilt.

3. RESULTS AND DISCUSSION

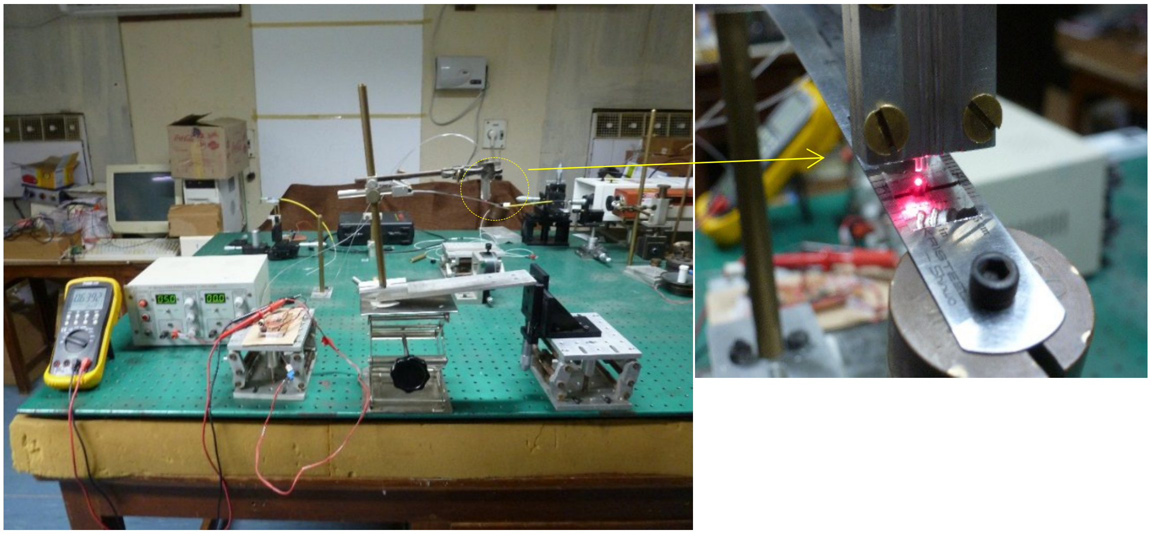


Figure 4. Experimental setup for discrete tilt sensing and close view of pair fiber probe

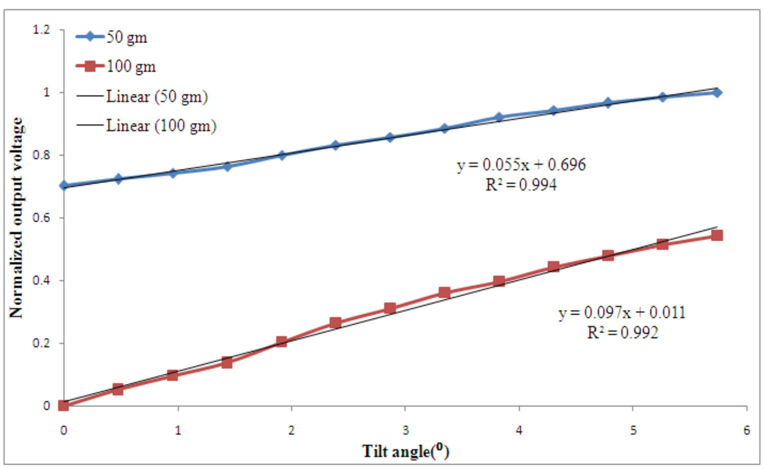


Figure 5. Tilt sensor response with different weights 50 gm and 100 gm attached to the cantilever respectively.

The experimental setup used for tilt measurement is shown in Fig.4. The normalized output voltage at the receiving fiber with the increase in tilt angle is measured and results are plotted and shown in Fig.5. The results show that a linear increase in output voltage corresponds to tilt up to 5.7^0. The sensitivity of the tilt sensor with 50 gm weight attached to the cantilever is found to be 55 $mV/^0$. In order to improve the sensitivity of the measurement 100 gm weight is attached to the cantilever, which results in an enhanced sensitivity up to $97mV/^0$.

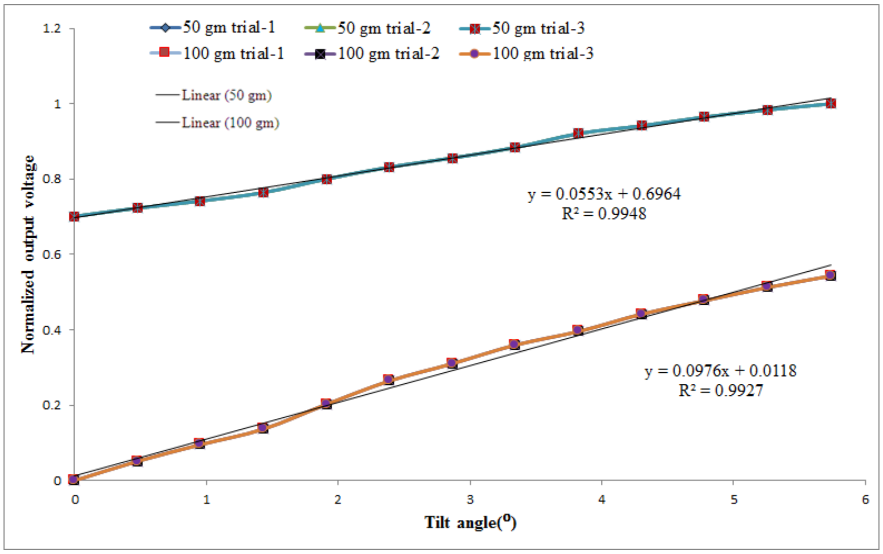


Figure 6. Repeatability response of the sensor during change in tilt angle for three trials for two different weights of 50 gm and 100 gm respectively

In order to test the repeatability response of the designed sensor, the experiment is repeated for three times for 50 gm and 100 gm weights attached to cantilever beam respectively and the results are plotted and shown in Fig. 6. It can be observed from Fig. 6 that the sensor response is linear with linearity of 99.48% (50 gm) and 99.27% (100 gm) respectively and repeatable within the range of tilt angle 0-5.7^0.

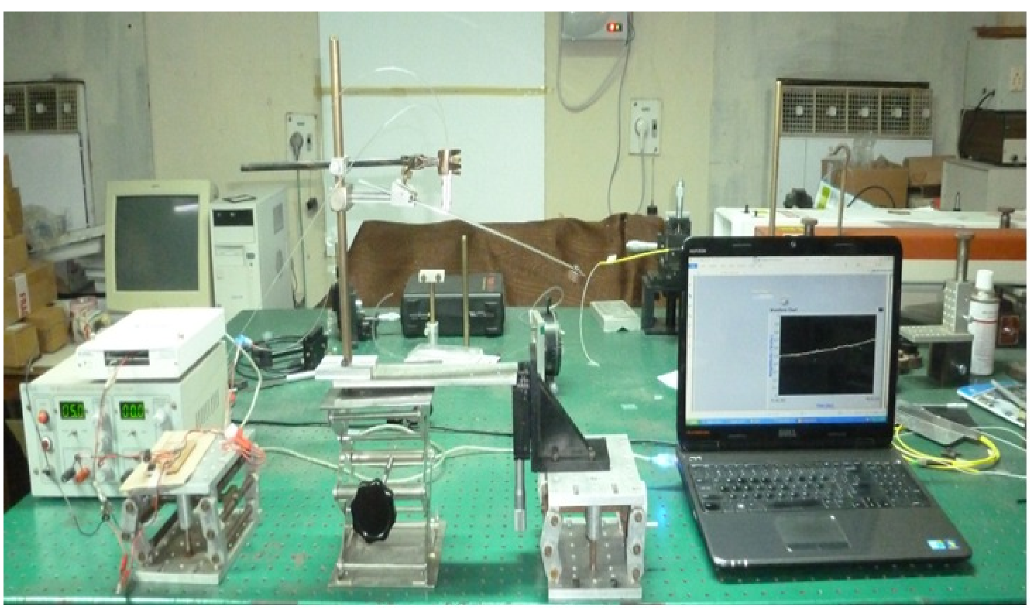


Figure 7. Experimental setup for dynamic tilt sensing using DAQ

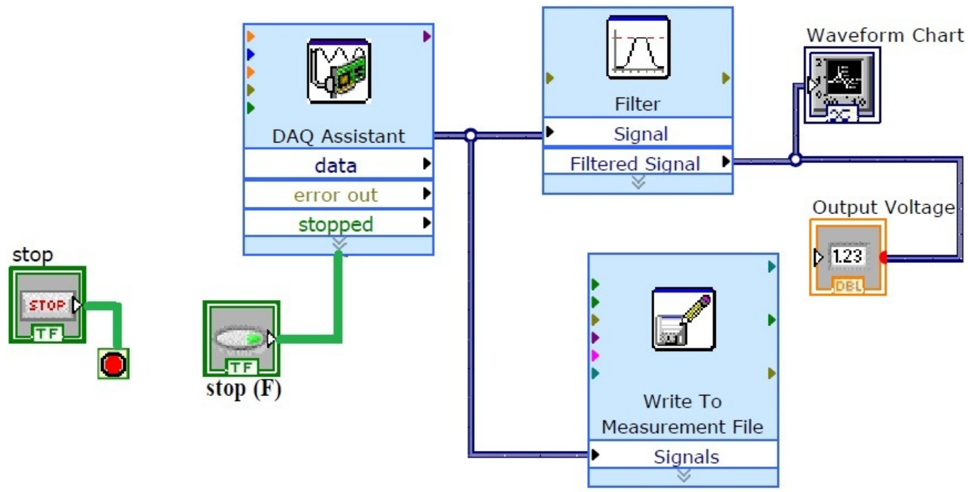


Figure 8. Block diagram of the Lab VIEW programme used to record the continuous response of the sensor against tilt angle

To measure the dynamic response of the sensor, the micrometer in the setup is replaced with 25 mm range motorized actuator (Z825B, Thorlab's). The actuator is used to tilt the setup continuously at the speed of 58µm/sec which is shown in Fig.7. The continuous response of the photo diode output corresponds to change in tilt angle, which is acquired by using NI-DAQ (6016) with Lab VIEW programme and is displayed in a pc for further analysis. Fig. 8 shows the Lab VIEW programme used to acquire the dynamic response of the sensor against tilt angle variation.

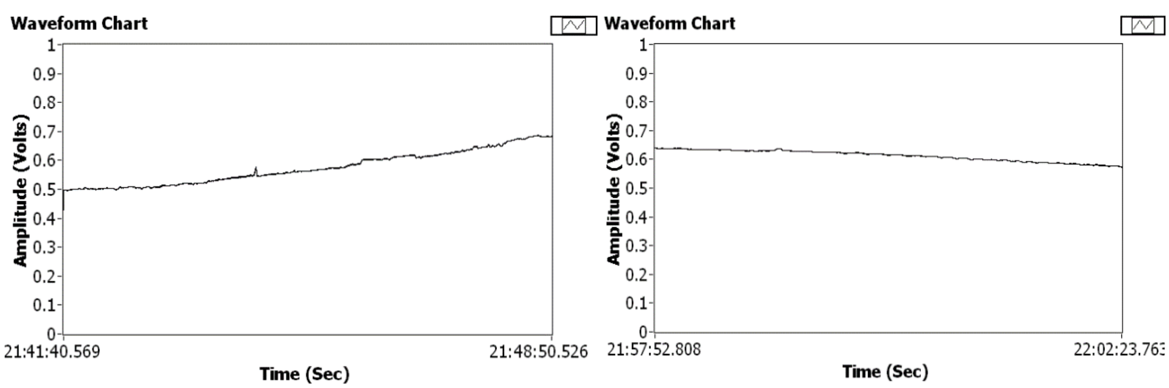


Figure 9. Dynamic response of the sensor against (a) increase and (b) decrease in tilt angle for 100 gm weight attached to the cantilever

The dynamic response of the sensor with 100gm weight attached to cantilever which corresponds to increase and decrease in tilt angle of the setup is shown in Fig 9. The effect of source intensity fluctuation may vary the response of the tilt sensor. However, a ratio metric approach can minimize the effect of source intensity fluctuation on tilt measurement [6]. Using this approach an intensity insensitive fiber optic tilt sensor can be developed.

CONCLUSION

A simple low cost portable tilt sensor using plastic optical fiber is demonstrated with sensitivity $97mV/^0$ for 100gm weight attached to the cantilever. The sensor shows a good repeatability. The sensor design is simple, easy to fabricate which has no complex structure and easy to mount.

ACKNOWLEDGEMENT

The authors would like to thank Prof. M. Sai Shankar, Department of Physics, National Institute of Technology, Warangal, India for permitting to use the Photonics lab facility.

REFERENCES

[1] Jovan S. Bajic, Dragan Z. Stupar, Lazo M. Manojlovic, Milos P. Slankamenac, Milos B. Zivanov., "A simple low-cost, high sensitivity fiber-optic tilt sensor," Sensors and Actuators A: Physical Vol.185, 33-38 (2012).

[2] Y. Zhao, J. Yang, B. Peng, S. Yang, "Experimental research on a novel fiber-optic cantilever-type inclinometer," Optics and Laser Technology Vol. 37, 555-559 (2005).

[3] D. Sengupta, M. Sai Shankar, P. Saidi Reddy, R.L.N. Saiprasad, K.S. Narayana, P. Kishore, "Extrinsic micro displacement level sensor using optical fiber," Optoelectronics and Advanced Materials-Rapid Communications Vol. 5, 491-494 (2011).

[4] H. Golnabi, P Azimi, "Design and operation of a double-fiber displacement sensor," Optics Communications Vol. 281, 614-620 (2008).

[5] S. Binu, V.P. Mahadevan Pillai, V. Pradeepkumar, B.B. Padhy, C.S. Joseph, N. Chandrasekaran, "Fibre optic glucose sensor," Materials Science and Engineering Vol. 29, 183-186 (2009).

[6] P. Kishore, D. Dinakar, D. Sengupta, P. Saidi Reddy, M. Sai Shankar, K. Srimannarayana, "Fiber optic vibration sensor using PMMA fiber for real time monitoring," Sensors and Transducers Vol. 136, 50-58 (2012).

[7] J. Brandao Faria, Octavian Postolache, J. Dias Pereira, P. Silva Girao, "Automated characterization of a bifurcated optical fiber bundle displacement sensor taking into account reflector tilting perturbation effects," Microwave and Optical Technology Letters Vol. 26, 242-247 (2000).

[8] Sulaiman Wadi Harun, H.Z. Yang, Moh Yasin, H. Ahmad, "Theoretical and experimental study on the fiber optic displacement sensor with two receiving fibers," Microwave and Optical Technology Letters Vol. 52, 372-375 (2010).