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Design of a Novel Inclination Sensor Utilizing Grayscale Image

Tuhin Subhra Sarkar, Subir Das

Abstract**—**Several research works have been done in recent times utilizing grayscale image for the measurement of many physical phenomena. In this present paper, we have designed an embedded based inclination sensor utilizing the grayscale image with a resolution of 0.3º. The sensor module consists of a circular shaped metal disc, laminated with grayscale image and an optical transreceiver. The sensor principle is based on temporal changes in light intensity by the movement of grayscale image with the inclination of the target surface and the variation of light intensity has been detected in terms of voltage by the signal processing circuit (SPC).The output of SPC is fed to a microcontroller program to display the inclination angel digitally. The experimental results are shown a satisfactory performance of the sensor in a small inclination measuring range of -40º to + 40º with a sensitivity of 62 mV/°.

Keywords**—**Grayscale image, Inclination Sensor, Microcontroller Program, Signal Processing Circuit.

I. INTRODUCTION

IN modern industrial fields such as: construction of bridges, oil drilling, industrial automation, instruments for wheel alignment, machine tool leveling and many others; the actual angular displacement of an objects needs to be detected and ideally done with or without mechanical contact type measuring systems. For this purpose, there exist varieties of suitable sensors that provide an output signal (voltage or current) proportional to the inclined position of an object within a small space range. In aspect of industrial usage these measuring systems are exactly required for reliability, ruggedness, measured angel range, accuracy and sensitivity etc. There are several kinds of sensor for measuring the inclination angle, is available in the market. But still researchers are discovered or invented new methods of measurement techniques to reduce the system complexity in existing solution and try to find out the better accuracy, sensitivity and high resolution in a small space range and low range of economic policies. The Inclination sensor measures horizontality of a system plane or the rotation of a body with respect to the gravity field.

There are many types of inclination sensors are invented by researchers such as: resistive [1], capacitive [2], inductive [3]-[6], and optical [7]-[12]. All of these exhibit some better characteristics and some imperfection depends on their operational principles and implementations. The resistive [1] type tilt measurement system gives a wide linear range and a high resolution but it is affected by temperature and electromagnetic interference. An innovative low cost micromechanical capacitive [2] type measurement system implies a good frequency response; hence they are very useful for dynamic measurement. But its major drawbacks are nonlinearity behavior on account of edge effects and high output impedance on account of their small capacitance value. Moreover, the capacitance may be changed due to the presence of dust particles and moisture. An important issue is that due to the change of surroundings temperature capacitance may be changed. The uses of magnet and magnetic fluid to measure the inclination [3]-[6] have been introduced complex experimental setup and can be affected by electromagnetic interference. Excluding these above measurement technique optical type measurement [7]-[12] system have advantages over other type of techniques, that they can provide greater sensitivity, better accuracy, wide frequency range, and dynamic ranges and it is immune to electromagnetic interference. From these advantages, optical techniques may be ideal for the development of sensors for the measurement of small inclination angel. An all refractive optical design for a beam dissector that can be used to obtain optimal tip-tilt measurements with high sensitivity is described in [7]. A tilt sensor with a large measurement range using four Fiber Bragg gratings (FBGs) attached on a cylindrical cantilever-based pendulum is demonstrated in [10], [11]. A tilt accuracy of ±0.2° and resolution of 0.013° in the range of ±40° was achieved in this invention. The paper [12] deals with the theory, design, fabrication and test results of a fiber-optic tilt sensor based upon the modulation of light intensity with the change in the level of mercury (Hg) surface with the tilt. The sensitivity of the sensor realized in [12] is 0.013 Vmrad-1 and the maximum range covered is 53.4 Vmrad. Small in size, opto-electromechanical tilt sensor fabricated by MEMS process is presented in [13] which required array of photo detector to measure the position of pendulum with the tilt angel variation and depicts a resolution of 5º. A fiber optic cantilever sensor [14] has been designed for measuring inclination of an object with the precision of 0.01° in the range of ±30°. When the sensor is tilted, the free end of the cantilever experiences deflections, caused by the tilt and unavoidable accelerations. These deflections can be measured using a position sensitive device (PSD) provided that light propagates through the fiber and creates a light spot on the PSD surface. From the measured positions, tilt angles in two orthogonal axes may be derived. An inclination sensor based on mass, suspended by springs or beam has been reported in [15] with a resolution of 0.1° in the measuring range of ±50°.

Tuhin Subhra Sarkar and Subir Das are with the Murshidabad College of Engineering and Technology, Berhampore, Murshidabad, West Bengal, India (phone: +91-9475258979; e-mail: sarkar.tuhinsubhra@gmail.com, subir.mcet@gmail.com).

This sensor determines the inclination based on the movement of a mass under the influence of the gravity field. The movement of the mass is measured optically in two directions using a PSD and LED.

In this present paper, we have designed an optical type inclination sensor based on pendulum mechanism, in the measuring range of ±40°. The sensor principle is established by light intensity variation method, due to this it is expected that the sensor constructional design would be depends on aforementioned scientific operational principle or traditional light reflection and refraction principles. But it's constructional design did not depends on traditional reflector mechanism and as well as it is free from costly non-toxic materials like as mercury [12] and complex photo detection technologies like as PSD [14] and array of photo detector circuit [13]. To build up the simplest mechanical structure and less utilization of photosensitive device to reduce the sensor cost, we have introduced a grayscale image based light intensity variation method; which is successfully executed in our previous work [16]; to determine the linear displacement of an object with small space range. As the grayscale image is based on the variation of color depth from black to white; the reflected light intensity from the surface of that image would be varied accordingly from the lowest point to highest point. This phenomenon has been employed in our proposed invention by a disc type pendulum (laminated with grayscale image) and an optical source with detector. Hence the inclined position of an object has been detected by the movement of pendulum disc under the influence of gravity field and as well as the changes in position of grayscale image upon the optical source and detector; which may cause the variation of light intensity accordingly and eventually it is transformed into voltage levels by the SPC and displayed the actual inclination angel of the surface digitally by microcontroller based embedded system. The proposed sensor exhibits good linear characteristics with measuring inclination angel and implies better sensitivity and resolution with respect to the other invented inclination sensor in small space range. The introduction is followed by a representation of the working principle, constructional details, the experimental investigation, and a series of discussion topics based on the experiment.

II. Theoretical Background

In the field of image processing and computing, a bi-tonal digital image is an image, in which mesh of rectangular cells contain a color value (information content), is called pixel. This pixel hold only possible information contents "0" or "1" are represented as black and white respectively. Now combinations of that pixel represent a black-and-white image. Unlike bi-tonal images, in the context of computer imaging grayscale images information contents have many shades of gray, varying from black to white. That carries only intensity information like black as the weakest intensity and white as the strongest intensity. In grayscale images each pixel holds 8 bit length color information i.e. combinations of 1's and 0's, resulting in 256 different gray levels to represent the variation of color in between of black and white. Where 0 is normally black and 255 is white and the gray levels are the numbers in between of 0 and 255. Now if these 256 gray levels are mapped onto a ramp scale; from black to white, is referred to as a gradient grayscale image. In this present work, we have developed a gradient grayscale image with the dimension of 50mm length and 20mm width utilizing the MATLAB programming as shown in Fig. 1. So, it is obvious that gradient grayscale image probably can make a linear change of light intensity from weakest point to strongest point.

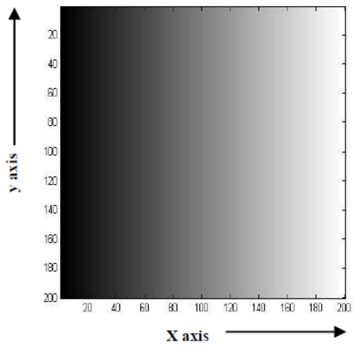

Fig. 1 Gradient grayscale image

III. Experimental Procedure

A. Sensor Module Design Architecture

For measuring the small range of inclination angle, we have designed an inclination sensor module which consists of a circular shaped metal disc (diameter 60mm and width 20mm) and an optical trans-receiver; it consists of a LED (optical source) and a LDR (photo-detector). Side wall of the disc laminated with grayscale image as shown in Fig. 2. In between of two wooden slippers this disc was suspended from its centre position by a metal rod; in that case the grayscale image was found under the bottom surface of the disc as shown in Fig. 3. Due to this mechanical implementation this disc was used as a pendulum under the influence of gravity field.

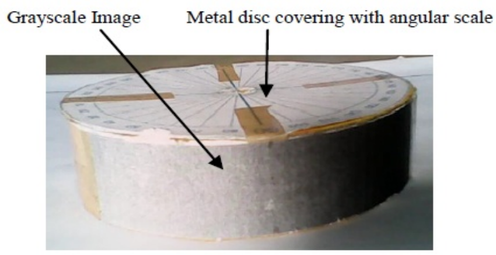

Fig. 2 Metal disc laminated with gradient grayscale image

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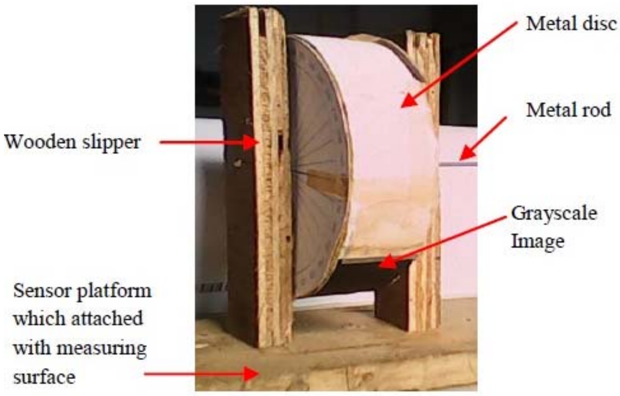

Fig. 3 Proposed sensor architecture without optical trans-receiver

The optical trans-receiver has been placed exactly underneath of the metal disc; to read the variation of grayscale image pattern in terms of light intensity according to the inclination of the measuring surface.

B. Working Principal

From Fig. 2 it is obvious that under the influence of gravity field if the sensor module tilted from its horizontal reference surface, the metal disc would be displaced to its CG (centre of Gravity) point due to the principle of pendulum design. This displacement has been detected utilizing the grayscale image; which has been displaced in same order like disc. Eventually the displacement of grayscale image has been sensed by optical trans-receiver by the temporal changes of light intensity according to the variation of gray level throughout the image. During the inclination, an optical transmitter emits light at constant intensities and reflects back with different intensities from the surface of that image; this variation of light intensity has been estimated by a mathematical model using Fig. 3.

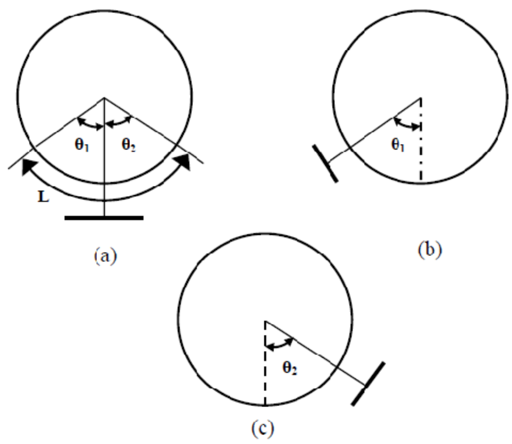

Fig. 4 (a) Graphical view of sensor module at horizontal surface (b) Maximum inclination angel of sensor module when it is tilted at clockwise direction (c) Maximum inclination angel of sensor module when it is tilted at anticlockwise direction

Our proposed sensor module has been design to measure the inclination angel in the range of ±40º, so it has inclined either clockwise or anticlockwise direction; illustrated as positive (θ_1) or negative (θ_2) inclination angel respectively. In that range grayscale image has been placed in such a way that darkest level indicates +40º and whitest level indicates -40º. Assume that the length of image is L which is shown in Fig. 4 (a). Now the light intensity (I) distributed along the surface of gradient garscale image would be linear so it can be expressed as

$$I = GL \tag{1}$$

where G is the gray level intensity factor; varies with the length. Hence, total inclination angel (θ) is expressed as

$$\theta = \theta_1 + \theta_2 \tag{2}$$

where θ_1 and θ_2 are equal so, from (2), θ can be expressed as

$$\theta = 2\,\theta_1 = 2\theta_2 \tag{3}$$

If the radius of the disc is r then L has been illustrated as

$$L = r\frac{\pi\theta}{180} \tag{4}$$

After combining (1) & (4), it is represented as,

$$I = G\,r\frac{\pi\theta}{180} \tag{5}$$

At initial condition i.e. when the sensor module was kept at horizontal surface, the optical trans-receiver has been placed at the middle region of that image hence the intensity (I_i) can be expressed as

$$I_i = \frac{GL}{2} = G\,r\frac{\pi\theta}{360} = \frac{I}{2} \tag{6}$$

Since, sensor module inclined at clockwise direction at an angel of θ_1 as shown in Fig. 4 (b). Therefore the light intensity (I_1) would be decreased gradually from its initial condition because the optical trans-receiver approaches into the darkest region of that image. So it can be illustrated as

$$I_1 = \frac{I}{2} - G\,r\frac{\pi\theta_1}{180} \tag{7}$$

From (3) it is obvious that θ_1 would be varies from 0 to $\frac{\theta}{2}$ so the intensity range can be explicit as

$$0 \le I_1 \le \frac{I}{2} \tag{8}$$

On the other side if the sensor module inclined at anticlockwise direction at an angel of θ_2 as shown in Fig. 4 (c). Therefore the light intensity (I_2) would be increased gradually because the optical trans-receiver approaches into the whitest region of that image. So it can be illustrated as

$$I_2 = \frac{I}{2} + G\, r\frac{\pi\theta_2}{180} \quad (9)$$

From (3) it is obvious that θ_2 would be varies from 0 to $\frac{\theta}{2}$ so the intensity range can be explicit as

$$\frac{I}{2} \leq I_2 \leq I \quad (10)$$

Hence it is concluded that the light intensity would be varied from 0 to I i.e. minimum to maximum level within the range of +40º to -40º. An optical receiver i.e. LDR receives this light with different intensities and resumes its output variation in terms of resistance which is inversely proportional to the light intensity i.e. at minimum level of light intensity it has depicts high value resistance rather than maximum level of light intensity. To calibrate this change of resistance with the displacement of disc and as well as the change of inclination angel of the sensor module, a signal processing circuit (SPC) and a microcontroller programmed based display unit has been used. The schematic diagram of inclination measurement system is shown in Fig. 5.

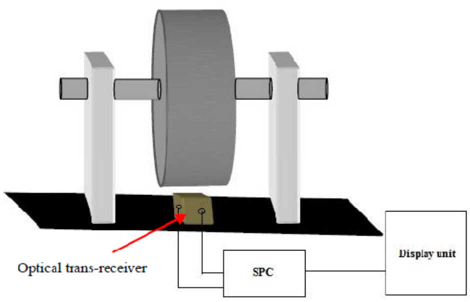

Fig. 5 Schematic diagram of inclination measurement system

C. Signal Processing Circuit

For the purpose of digitization and conversion of changeable resistance of LDR into voltage variation, signal processing circuit (SPC) has been used. The overall block diagram of SPC unit is shown in Fig. 6. This circuit performed various steps of operation; firstly it converts the LDR resistance into voltage variation utilizing a constant current source and a current to voltage converter circuit and secondly this voltage variation has been confined into 0 to 5 volt range by zero and span adjustment circuit due to the variation of inclination range of -40°to+40°. Eventually this range of voltage transformed into 256 levels of digital data using 8-bit ADC circuit.

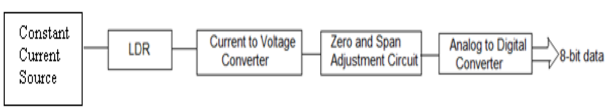

Fig. 6 Block diagram of SPC unit

D. Microcontroller Programmed Based Display Unit

A display unit has been designed in such a way that it could be able to display the value of measured surface inclination (range of -40°to+40°.) with the proper direction due to the variation of voltage range from 0 volt to 5 volt. To display the vector inclination of target the digitize value of this voltage range has been fed to port1 of ATMEL 89S52 microcontroller which interfaced with the 16 characters 2 line LCD unit at port2. The programming algorithm has been designed using the output data of ADC and Look-up-table data which is displayed "0" for the ADC data value of 128 at horizontal reference surface and displayed "-40º" or "+40º" for the ADC data value of 0 or 255 respectively.

E. Experimental Result

In the proposed scheme it has been derived that the light intensity varies linearly within the range of -40° to +40º. So it can be expected that the light intensity detectable device (LDR) has been varied its resistance linearly in the specified range and it has been successfully proved in the following experimental results. It is noticed that the LDR resistance varies linearly from 22.78 KΩ to 10.30 KΩ due the angular movement of sensor module in the range of +40 degree to -40 degree. The LDR characteristics curve due to the movement of target is shown in Fig. 7. From Fig. 6, it is obvious that the change of LDR resistance has been fed to the current to voltage converter circuit which designed by a rated 1mA current source and produced change of voltage according to Ohm's Law. After getting this voltage variation it has been calibrated in the range of 0 volt to 5 volt for the inclination angel of -40 degree to +40 degree. The calibrated output voltage (V_0) has been measured and plotted against the measurement of angel of the sensor module, which is shown in Fig. 8

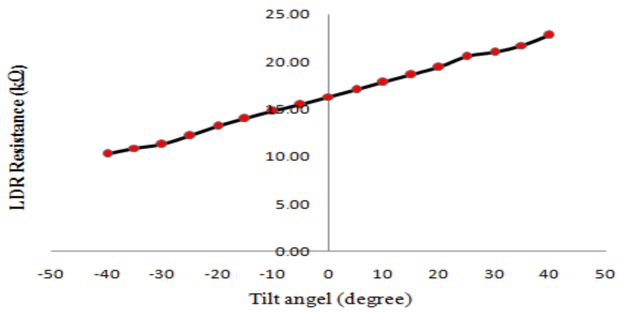

Fig. 7 LDR characteristic curve due to the inclination of sensor module

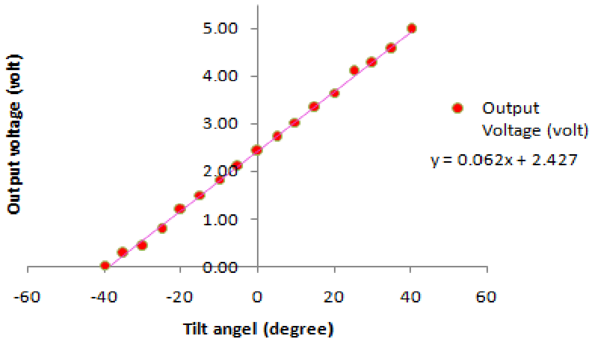

Fig. 8 Output voltage variation with respect to inclination

From Fig. 8, it is obvious that the output voltage (V_0) of SPC unit approximately linear with the inclination of sensor module. Hence we have calculated the non linearity of that curve utilizing best-fit straight line method and find the value of 2.66 & -2.54% FSO (Full Scale Output) at the inclination angel of -30º & 25º respectively. The obtained tilt angle sensitivities in linear regions is 62 mV/° for ± 40° range. The resolution of the tilt angle measurement depends on the signal/noise ratio, resolution of A/D converter and the aforementioned sensitivity. The typical value of the achieved resolution for specified linear ranges is 0.3°. The accuracy of the tilt angle measurement is 0.8°, which is defined as the maximum difference between the applied angle values and calculated values from the experimental data.

The repeatability of that sensing method has been plotted in Figs. 9 and 10 considering the inclination angel range ±40º at 10 times repeated measurements. The full scale value of output voltage (V_0) is 5 volt at maximum span of inclination angel + 40^0 so, the repeatability of that method evaluated as 0.6 %FSO.

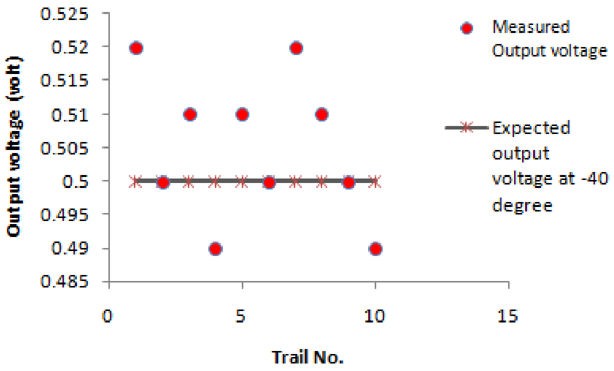

Fig. 9 Repeatability test at -40º inclination angel

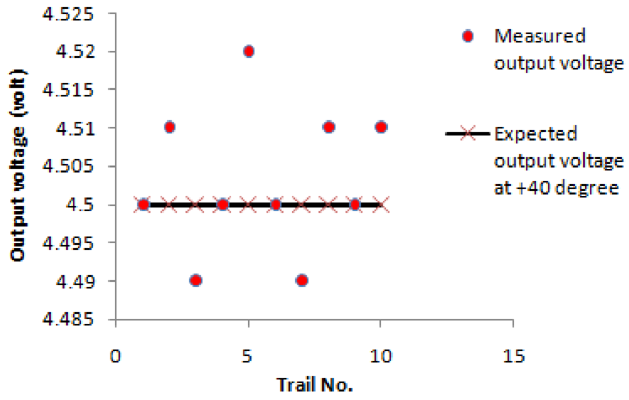

Fig. 10 Repeatability test at +40º inclination angel

IV. Conclusion

The designed sensor is efficient, in expensive and multipurpose. It could be integrated with the other primary non electrical sensors and order to get an electrical read out. Immunity to electromagnetic interference is the advantage of this fabricated sensor compared to the resistive [5], capacitive [6] and inductive [7]-[10] type sensing method. The advantage of the presented realization compared to the other scientific paper [13], [14] is utilization of inexpensive photo detector materials and also it has exhibits better linearity in extended range of ±40º with an accuracy of 0.8º and resolution of 0.3º also obtained the tilt angel sensitivity of 50mV/º which has realized better sensor characteristics in compared to [13] & [15] at very lower price.

This Inclination sensor module is applicable in various industrial fields where inclination measurement is so important, such as different types of civil constructional works, military system, robot, biomedical measuring device etc. In this case if this sensor is not embedded within the target then it can be easily tied up through a yoke to the target body externally.

This inclination sensor module can be used beyond of this measured range and also it could be used as a remote monitoring system and computer aided simulation system by interface with a DAS card; it is the future scope of work.

References

[1] C. Lin, S. Kuo, "Micro-impedance inclinometer with wide-angle measuring capability and no damping effect," *Sensors and Actuators A: Physical*, vol. 143 pp. 113-119, 2008.
[2] D. Benz, T. Botzelmann, D. Warkentin, "low cost inclination sensors made from selectively metallized polymer," *Sensors and Actuators A: Physical*, Vol. 123-124, pp. 18-22, 2005.
[3] O. Baltag, "Tilt measurement sensor," *Sensors and Actuators A: Physical*, Vol. 81, pp. 336-339, 2000.
[4] B. Ando, "A Novel Ferro fluidic Inclinometer," *IEEE Transactions on Instrumentation and Measurement*, Vol. 56, pp. 1114-1123, 2007.
[5] B. Ando, A. Ascia, S. Baglio, "A Ferrofluidic Inclinometer in the Resonant Configuration," *IEEE Transactions on Instrumentation and measurement*. Vol. 59, pp. 558-564, 2010.
[6] L. Rovati, S. Cattini,"Contactless Two-Axis Inclination Measurement System Using Planar Flux-Gate Sensor," *IEEE Transactions on Instrumentation and Measurement*, Vol. 59, pp. 1284-1293, 2010.
[7] Ragazzoni, S.R. Restaino, "An all-refractive opics for tilt sensing," *Optics Communications*, Vol. 137, pp. 6-10, 1997.

[8] M. Norgia, I. Boniolo, M. Tanelli, S.M. Savaresi, C. Svelto, “Optical Sensors for Real-Time Measurement of Motorcycle Tilt Angle,” *IEEE Transactions on Instrumentation and Measurement*, Vol. 58, pp. 1640-1649, 2009.

[9] J.H. Wu, K.Y. Horng, S.L. Lin, R.S. Chang, “A two-axis tilt sensor based on optics,” Measurement Science and Technology, Vol. 17, pp.N9-N12, 2006.

[10] H. Bao, X. Dong, C. Zhao, L.Y. Shao, C.C. Chan, P. Shum, “Temperature-insensitive FBG tilt sensor with a large measurement range,” *Optics Communications*, Vol. 283, pp. 968-970, 2010.

[11] H. Bao, X. Dong, L.Y. Shao, C.L. Zhao, S. Jin, “Temperature-insensitive 2-D tilt sensor by incorporating fiber Bragg gratings with a hybrid pendulum,” *Optics Communications*, Vol. 283, pp. 5021-5024, 2010.

[12] A. Abu Al Aish, M. Rehman, “Development of a low cost optical tilt sensor,” *4th International Conference on Autonomous Robots and Agents*, Wellington, New Zealand, Vol. 1, pp. 290-293, 2009.

[13] Timothy G. Constandinou and Julius Georgiou, “Micro-Optoelectromechanical Tilt Sensor,” *Hindawi Publishing Corporation Journal of Sensors*, Article -ID 782764, pp. 1-7, 2008.

[14] Klaus Macheiner and Fritz K. Brunner, “A fiber optic cantilever sensor for static and kinematic tilt determination in two axes”, *4th International conference on Structural Health Monitoring of Intelligent Infrastructure (SHMII-4)*, Zurich, Switzerland, Paper No. 364, July 22-24, 2009.

[15] J. Clijnen, W. Meeusen, D. Reynaerts, H. Van Brussel, R. Simons, K. Plessers, “Design and realization of an optical bi-axial inclination sensor”, *1st IEEE international conference on sensor*, Florida, USA, June 12-14, vol. 2, pp. 870-873,2002.

[16] S. Das, T. S. Sarkar, “A new method of linear displacement measurement utilizing a grayscale image”, *International Journal of Electronics and Electrical Engineering*, Vol. 1, No. 3, pp. 176-181, 2013.