VOL. 10, NO. 23, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DEVELOPMENT OF AN ANGLE SENSOR USING OPTICAL POLARIZER

Masud Rana, Masyraf Mrazib, T. Saleh and Asan GA Muthalif
Smart Structures, Systems and Control Research Laboratory, Department of Mechatronics Engineering, Faculty of Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia
E-Mail: engrmasud.ruet@gmail.com

ABSTRACT

This paper presents an effective technique to measure angle of rotation using optical polarizer. In this case combination of single wavelength partially polarised laser beam and a linear polarizer are used for the rotational angle measurement. The power of the transmitted partially polarized light was found varied according to the angle variation of the polarizer. This concept can be used to sense the angle of rotation. High and low measurement of the transmitted power was obtained at 90º interval for the entire range of angle 180°. To ensure the precision, accuracy and reliability of the sensor, the experiments were repeated and error percentage was captured in accordance of predicted model. From all experimental investigations, it has been concluded that varying the output power according to the polarizer's angle rotation could be an indicator to an angle successfully. The experiment was conducted using polarized laser source, iris, attenuator, polarizer and a photo detector to measure the transmitted polarized power coming through a polarizer. The major advantages of this type of angle sensor are its compact size, cost effectiveness, passive type without extra circuit, no effect of electromagnetic noise and flexibility in using at long distance.

Keywords: polarization, transmitted power, angle sensor.

INTRODUCTION

Typically, a polarizer is an optical filter that allows incident light having specific direction of polarization and block rest of them. If an un-polarized light passes through a linear polarizer 50% power is reduced. Polarizers are commonly used in instruments, polarizing filters, photography and in liquid-crystal display. However, over the years researchers have implemented polarizer in different field of applications for measuring angle and position as a sensor. Among them, Takashi Tokuda *et al.* [1] utilized embedded polarizer to determine angle of incident polarization. Shiguang Li *et al.* [2] showed angle measurement by transmitting light through a polarizer analyzer. By rotating polarizer at a certain entire range of 180º, Nicholas Albion *et al.* [3] reported two-phase and three-phase angle measuring sensor having orientation of the phase of polarized light beam at 45° and 60º respectively. Clark *et al.* [4] demonstrated a system where rotating polarizer was being used to measure an angle of the aero-elastic deformation of an aircraft wing. Based on the polarization phase of light, Huang *et al.*[5] showed a new method of angle measurement determined by primary angle of incidence and polarization state of light. Butzer *et al.* [6] also demonstrated polarization based angle sensor using polarization of light where the deviation of angle was identified by capturing state of polarized light through a polarized light detector. Wijntjes *et al.* [7] developed an angle encoder where a polarizer rotates simultaneously with a rotating object to measure the angle of rotation. On the other hand, Thorburn *et al.* [8] proposed a position sensor using polarizer and detector which has capability to be used in push pin sensor inside a hard disk servo system. Hutchinson *et al.* [9] also developed an angular position transducer to obtain the rotation of a shaft over a certain angle using polarizer having coded tracks. Barnett *et al.* [10] also reported a rotary sensor to detect the motion of a rotating shaft using an optical linear polarizer. Consequently, many techniques have been reported and developed angle sensor using polarizer. However they have limitations because of the complex system architecture and complicated measuring process.

In this paper, we proposed a straightforward system for measuring angle using polarizer itself as an angle sensor which employs a partially polarized light source, iris, attenuator, polarizer and polarized light detector. The light source transmit light continuously with the same wavelength, while iris and attenuator are used to adjust power of partially polarized laser coming from laser source and photo detector to capture transmitted power through a polarizer. This proposed technique shows apparatus assemblies in a more simplified way to represent polarizer itself as an angle sensor.

THEORY OF THE PROPOSED ANGLE SENSOR

Basically, according to Malus law, when a perfect polarizer is used to transmit light through it, then the amplitude of the transmitted beam show a discrepancy as the cosine of the angle of rotation of the polarizer which is presented by the given equation as

$$A = A_0 \cos\theta$$

$$A^2 = A_0^2 \cos^2\theta \tag{1}$$

Where A_0 representing the initial amplitude of the polarized beam.

VOL. 10, NO. 23, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

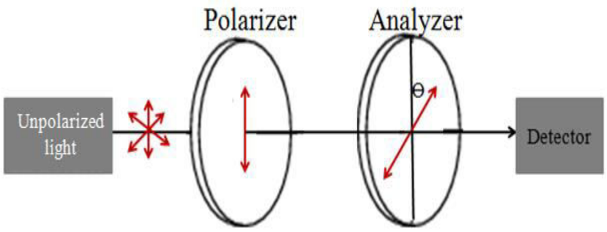

Figure-1. Schematic view according to Malus law.

Now since the transmitted intensity is proportional to amplitude square ($I \propto A^2$), then and from the above equation the intensity of the transmitted beam through a polarizer become as

$$I = I_0 \cos^2 \theta \tag{2}$$

Where, I_o is known as initial intensity of the polarized light and Θ is the angle of rotation of the polarizer. If we assume initial intensity of the polarizer 10 mW then theoretically outcomes from the above equation over the entire region of 180º can be shown as in Figure-2.

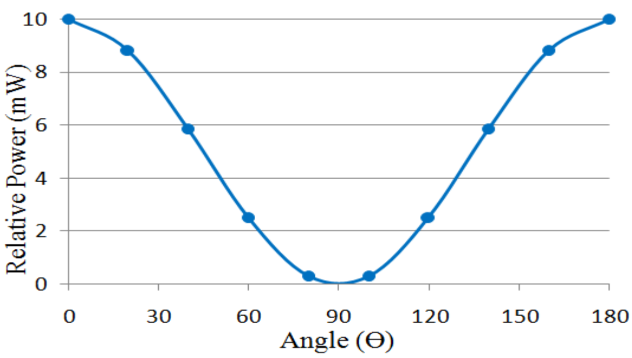

Figure-2. Reveals regarding sensitivity of the polarizer according to Malu's law.

From the above graphical representation, it is obvious that the relative power of the polarizer for the fully polarized light is supposed to be completely zero at 90° interval over the entire region which is a disadvantage for the power meter to take measurement. To overcome this issue here we have proposed partially polarized laser source. This is because the partially polarized light consists of polarized and unpolarized light. The intensity I_{in} of this light can be written as equation 3. Where I_p is the intensity of polarized light and I_u intensity of unpolarised light. As this light beam passes through the polarizer overall intensity of the light will follow equation 4.

$$I_{in} = I_p + I_u \tag{3}$$

$$I_{out} = I_p \cos^2 \theta + 0.5 I_u \tag{4}$$

Since the intensity is power (P) per unit area (I = P/A), then transmitted output power (P_{out}) of the partially polarized light through the polarizer can be written as follows,

$$P_{out} = P_p \cos^2 \theta + 0.5 P_u \tag{5}$$

where P_p and P_u indicating polarized and un-polarized light power respectively. While Θ is angle of rotation of the polarizer shown in Figure-3.

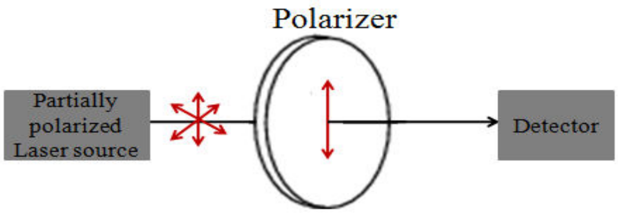

Figure-3.Schematic view for the partially polarized light transmitted through the polarizer.

Now again for the input power 10 mW with respect to partially polarized light if we assume that the polarized light is 7 mW and unpolarized light is 3 mW then by simulating the above equation (5) the graphical representation can be shown as below:

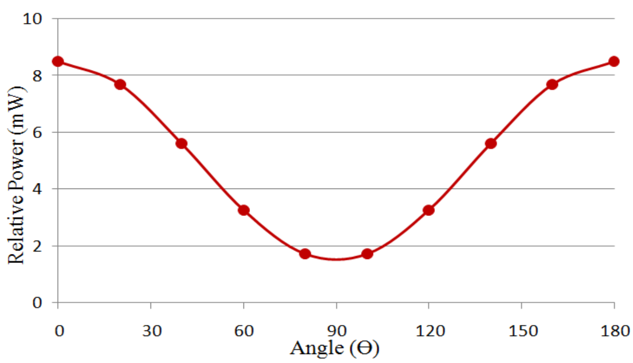

Figure-4. The graph indicates the advantages of using partially polarized light over fully polarized light to use polarizer as an angle sensor.

From the above graphical approach it is obvious that for the partially polarized light the intensity of the light after polarizer at 90° interval does not become zero which is the main reason we recommend using partially polarized light to use polarizer as an angle sensor.

EXPERIMENTAL PROCEDURE

Numbers of experiments were conducted in order to justify the use linear polarizer and partially polarized light source to measure rotational angle. Figure 5 shows a typical experimental setup that consists of a green laser source (partially polarized), iris, optical filter, linear polarizer mounted on a rotational stage, and an optical power meter. Initially partially polarized laser source was turned on for a certain period to ensure it is stabilized prior to the experiment. Thereafter, iris, attenuator and polarizer were aligned on the same alignment according to polarized beam. The measurements were taken by rotating polarizer at 15º angle shift and over the range of 180º. The transmitted power of the partially polarized beam was

VOL. 10, NO. 23, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

captured by a photo detector. Interestingly, the transmitted power varied according to the angle variation of the polarizer at each of the interval over the entire range. Moreover, the increment and decrement of the power at each of the 90° interval was almost the same except in some degrees. We also performed experiment using different setting of the power from polarized source taking measurement of the transmitted power over 0° to 90° and 90° to 0° to study on the hysteresis. Then, we performed simulation according to mathematical approach which is then compared with the experiment. It is necessary to propose a model equation for any sensor. The proposed model described in equation 5 has two unknown P_p and P_u. Therefore, two experimental data of P_{out} at $\Theta = 0^o$ and $\Theta = 90^o$ were used. In order to validate the model necessary results were compared as discussed in the results and discussions section.

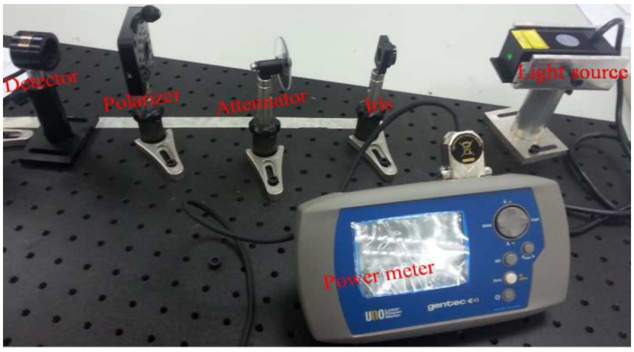

Figure-5. Schematic illustration of the whole assembly of the experiments.

RESULTS AND DISCUSSION

The unknown parameters of the proposed sensor model equation (5) were calculated using a procedure described in the earlier section. As all the model parameters are known, output optical power (P_{out}) can be predicted for different values of Θ. This predicted value was compared with the experimental value and a graph is plotted as shown in Figure-6.It was observed that transmitted power through the polarizer undergoes changes that follows the equation 5.

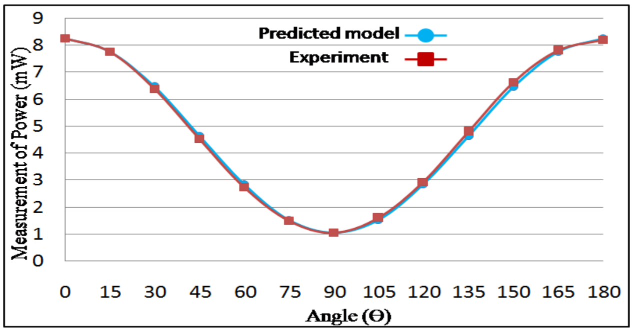

Figure-6. Graph shows comparison of predicted model, experiment and Malus law, in terms of relative intensity of the polarizer according to angle variation.

The main advantage of this sensing configuration is the use of partially polarized light instead of fully polarized light. This ensures that output light from the polarizer will not be reaching to zero for any angle of Θ as there will be always a DC component of $0.5P_u$ at the power.

PERFORMANCE ANALYSIS OF THE POLARIZER

To check out the hysteresis of the polarizer itself as an angle sensor, we carried out an experiment from 0° to 90° and its opposite phase at an interval of 10° each Figure-7. The hysteresis loop is almost overlapped which led the potentiality of the polarizer to make it as an angle sensor itself. The hysteresis characteristics of the experimental out comes also follow the same trend having bit fluctuation at some degrees. The average fluctuation over the entire hysteresis loop is obtained 3% where maximum deflection occur in between 30° to 50° which is 6%. The most probable reason behind the overall fluctuations over the entire range is due to the sensitivity of the detector to its surrounding while capturing transmitted polarized power. This is because the ambient temperature, humidity of the environment and the influence of day light commonly interrupt the sensitivity of the detector. On the other hand, impurity of the polarizer may have the effect to reduce the transmitted power from the actual one.

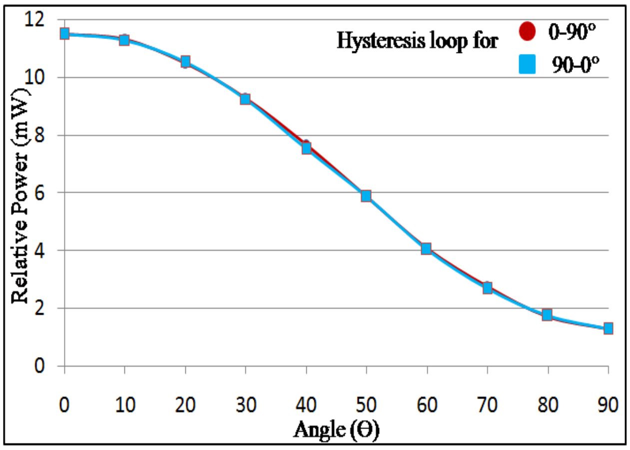

Figure-7. Indicates hysteresis loop of relative power changes of the polarizer according to variation of angle.

Later on, to check the repeatability, we performed comparison between few experiments results with simulation of the model. The graphical approach reveals that the experimental outcomes are in a range of predicted values governed by simulation. The following Figure-8 describes comparison between predicted and experimental outcomes. The experiment shows very high repeatability.

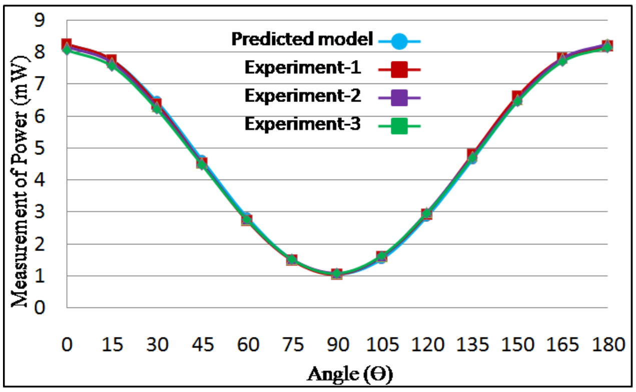

Figure-8. Indicates repeatability testing of the sensor with respect to predicted model verified experiments.

Subsequently, we determined the percentage of error as per Figure-9 for all of the experiments with respect to predicted model. Maximum error could be found at the angle measurement of 60° and 105° which only yield value of 3% and 5% error respectively.

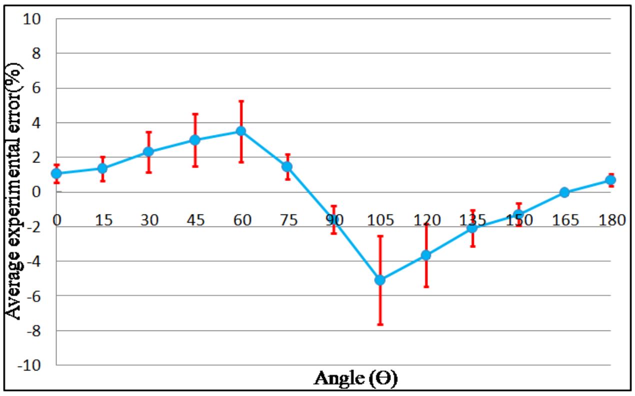

Figure-9. Exposes percentage of average experimental errors.

We obtained highly accurate and repeatable measurements according to variation of angle of the polarizer for each of the experiments.

POSSIBLE APPLICATIONS

The sensor could have the potential to be embedded in many applications such as robotic arm, transportation, instruments and military equipment. Hereby, we show one (Figure-10) example for implementation of our proposed sensor in positioning table. The table that angle of rotation or position that need to be determined is embedded with the polarizer built together with the photo detector as shown in the table could be rotated in the axis of polarizer.

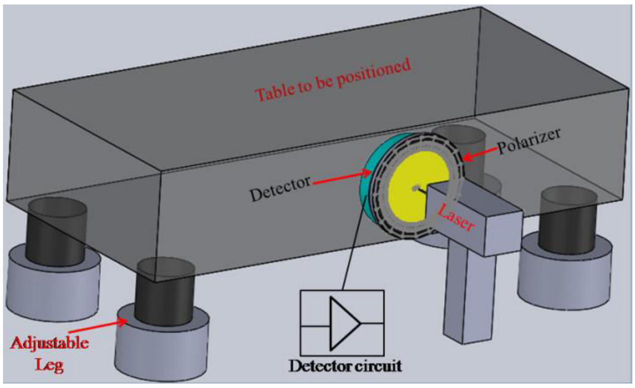

Figure-10. Potential application of polarizer as an angle sensor.

In this regard, the negative slope and positive slope from 0 to 90 and 90 to 180° need to be considered. This is because there can be positive and negative values at pair angle over the entire range. For instance, if the total entire range is 180° and interval is 20° each then the values at which angle can be similar as $\Theta_{0,180}$, $\Theta_{20,160}$, $\Theta_{40,140}$, $\Theta_{40,140}$, $\Theta_{60,120}$ and $\Theta_{80,100}$. To overcome this issue, the object need to be more tilted and value of tilt need to be checked whether increasing or decreasing. Then based on the positive and negative trend from the graphical representation shown in Figure-6 the position of the object can be determined.

.

CONCLUSIONS

Detail experiments of the proposed technique were carried out to investigate the polarizer as an angle sensor. Mathematical modelling was developed in accordance to the arranged assembly and Malus Law. Then, using the developed model, we simulate the graph using defined P_p and P_u value for the range of 0-180°. The simulated graph is then compared with the experimented graph to find error checking. The hysteresis loop, repeatability, and accuracy study confirms that a linear polarizer along with a partially polarized light source can be efficiently used as a compact angle sensor. This proposed technique can be also cost effective.

ACKNOWLADGEMENT

This work is supported by MOSTI grant SF14-008-0058 and MOHE grant FRGS13-083-0324.

REFERENCES

[1] Tokuda T., Yamada H., Sasagawa K. and Ohta J. 2009. Polarization-analyzing CMOS image sensor with monolithically embedded polarizer for microchemistry systems. Biomedical Circuits and Systems, IEEE Transactions on, Vol. 3, No. 5, pp. 259-266.

[2] Li S., Yang C., Zhang E. and Jin G. 2005. Compact optical roll-angle sensor with large measurement

range and high sensitivity. Optics letters, Vol. 30, No. 3, pp. 242-244.

[3] Albion N., Asmar R. F., Huggins R. W., Miller G. E., and Porter C. R. 1995. Optical angle sensor using polarization techniques. U.S. Washington, DC: U.S. Patent and Trademark Office. Patent No. 5, pp. 424-535.

[4] Clark L. T. 1987. Rotating polarizer angle sensing system.U.S. Washington, DC: U.S. Patent and Trademark Office. Patent No. 4, pp. 688-934.

[5] Huang P. S., Kiyono S. and Kamada O. 1992. Angle measurement based on the internal-reflection effect: a new method. Applied optics, Vol. 31, No. 28, pp. 6047-6055.

[6] Butzer D. C. 1996. Polarization based optical sensor utilizing total internal reflection. U.S. Washington, DC: U.S. Patent and Trademark Office. Patent No. 5, pp. 483-346.

[7] Wijntjes Geert and Constantine Markos.2002. Non-contact optical polarization angle encoder. U.S. Patent Application No. 10 pp. 288- 875.

[8] Thorburn William G., Donald K. Mitchell and Bruce A. Horwitz.1998, Diffuse surface interference position sensor. U.S. Patent No. 5, pp. 783-752.

[9] Hutchinson Paul L. and W. Gordon White.1993. Angular position sensor using a polarized disc with coded tracks.U.S. Patent No. 5, pp. 235-177.

[10] Barnett, Donald.2002. Optical resolver and method of use. U.S. Patent Application No.10/ pp. 095-542.