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Prototype of single degree of freedom optical resolver

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Abstract. Optical resolvers are helpful for a wide variety of application, for example, automation and manufacturing industries. Different kinds of optical resolvers are available based on different material properties. In this paper, a prototype of a single Degree of Freedom optical resolver for measuring the angle of rotation is proposed. The device is based on the combination of the single wavelength (partially polarized) laser beam, a linear polarizer and a photodetector circuit is used for the rotational angle measurement. We present the result of sensitivity, accuracy and repeatability test to ensure the proper execution of single DOF optical resolver. The sensitivity of a single DOF optical resolver is around 0.467 V/degree and the standard deviation is 0.2 Volt. We obtained highly accurate and repeatable measurements according to the variation of the angle of the polarizer. Newly developed prototype optical resolver is cost effective, compact in size, no electromagnetic interference.

Keywords: polarization, prototype, optical resolver.

1. Introduction

Resolvers are generally utilized as a part of different fields of designing for angle position and speed location because of its robust structure, high reliability and responsive in the diverse environment [1-3]. Optical resolvers are helpful for a wide variety of application, for example, automation control system and the manufacturing industry. In recent times, the necessities for resolvers have been increasing with the development of the intelligent industry. Researchers have developed an optical resolver for measuring angle and position. Among them, Takashi Tokuda et al [4] developed a CMOS sensor to measure different incident polarization angle. Shiguang Li et al [5] introduced optical roll-angle sensor and the angle measurement based on the transmitted light passed through a polarizer analyzer, the transmitted optical intensity varied at every rotation of polarizer. Nicholas Albion et al [6] invented an optical angle sensor and explained two-stage and three-stage phase angle measuring sensor having an introduction of the period of a polarized light beam at 45º and 60º separately by rotating polarizer at a specific whole range of 180º. Clark et al. [7] showed a system to measure an angle of the aero-flexible deformation of a flying machine wing where polarized light was modulated to create two transporter beams, among them one was utilized as reference electrical signal and another as target electrical signal then the two were investigated by a phase indicator to decide the angle measurement. Huang et al.[8]introduced a new method of angle measurement system determined by the primary angle of incidence and polarization state.
of light. It was based on the polarization phase of light. Wijntjes et al. [9] invented a noncontact optical angle encoder where the polarizer was rotated synchronously to determine the angle of rotation. Previously, Butzer et al. [10] demonstrated a rotary motion detection system where linear polarizer and optical photodetector were used to identify the angle of rotation of a shaft. Thorburn et al. [11] proposed a position sensor utilizing the polarizer and indicator which has the capacity to be used as a part of the push pin sensor inside a hard plate servo system. Hutchinson et al. [12] additionally built up an angular position transducer to acquire the rotation of a pole over a specific angle utilizing the polarizer having coded tracks. Barnett et al. [13] explained a revolving sensor to identify the motion of a rotating shaft utilizing an optical linear polarizer. Subsequently, numerous methods have been implemented to develop optical resolver. In any case, they have impediments considering the intricate system architecture, large in size, complex circuitry procedure, accuracy, and precision. This paper proposes a prototype of optical resolver that can undoubtedly replace a traditional optical resolver. To acknowledge exceedingly perfect signals with the commercial resolvers, this resolver is intended to produce signals which particulars are the same as those of commercial resolvers. Additionally, a new type of optical resolver has no complex circuitry system, cost-effective, compact in size and highly reliable. In this paper, we present our experience in the fabrication and testing of the newly developed single DOF optical resolver.

2. Basic principle and Design

2.1. Structure

Structural model of single degree of freedom optical resolver mainly consists of three parts: a partially polarized laser source, a polarizer, and a photodetector.

Laser is used for providing light. It is emitting partially polarized light with constant wavelength. In figure 1, the partially polarized laser is fixed in the front side of the package. Partially polarized laser light is passed through a polarizer. According to Malus law [14], the partially polarized light will not reach zero for any angle of rotation of the polarizer. Optical polarizer is fixed in between of laser and photodetector. The single wavelength partially polarized laser beam and a linear polarizer are utilized for the rotational angle measurement. The power of the transmitted partially polarized light was found differed by the angle variation of the polarizer.

Photodetector is situated in the ending part of the package as shown in figure 1. Transmitted light directed on to the photodetector circuit. Light dependent resistor is used to detect the light. It measure the voltage of transmitted light. It is situated in the ending part of the package.

Figure 1. (a) & (b): Structural model of single degree of freedom optical resolver
2.2. Working principle
A single DOF optical resolver is including a laser source for providing partially polarized with constant wavelength light, an optical polarizer through which the light passes and a photodetector for measuring the voltage of transmitted polarized light as shown in figure 2. The polarizer is essential to set up a non-zero measurement of a partially polarized laser as opposed to utilizing completely polarized light. The principle of measuring an angle is varying the polarizer rotation angle.

From the derivation of malus’s law, rana et al [14] explained input and output power of light beam. The equation of total input and output power is,
\[
\text{P}_{\text{in}} = \text{P}_{\text{p}} + \text{P}_{\text{u}} \quad (1)
\]
\[
\text{P}_{\text{out}} = \text{P}_{\text{p}} \cos^2 \theta + 0.5 \text{P}_{\text{u}} \quad (2)
\]
Here, \( \text{P}_{\text{p}} \) is the power of polarized light and \( \text{P}_{\text{u}} \) defined as the power of unpolarized light.

According to figure 3, an equation is developed from the ratio of Resistance of LDR and total output power, \( \text{P}_{\text{out}} \). The equation is
\[
\text{R}_{\text{ldr}} = 0.43 \text{P}_{\text{out}}^{-0.425} \quad (3)
\]
According to the voltage divider rule, Voltage across the known resistance is defined as the output voltage, \( \text{V}_{\text{out}} \). According to the Figure 2,
\[
\text{V}_{\text{out}} = \frac{\text{R}}{\text{R}_{\text{ldr}} + \text{R}} \times \text{V}_{\text{in}}
\]
Or, \( \text{V}_{\text{out}} = \frac{\text{R}}{\text{R} + 0.43 \text{P}_{\text{out}}^{-0.425}} \times \text{V}_{\text{in}} \quad (4)\]

**Figure 2.** Schematic diagram of single DOF optical resolver.
As per the standard, in part partially polarized laser light was passed through a polarizer. The polarizer was rotated from 0º to 360º. After the laser light went through the polarizer, it was completely polarized. The measurement was taken by the photodetector. The output voltage of transmitted light was varied by the variation of revolution of the polarizer.

3. Experimental procedure

Numbers of examinations were led keeping in mind the end goal to legitimize the utilization of the linear polarizer and partially polarized light source to measure the rotational angle. Figure 4 shows a typical experimental setup that consists of a green laser source (partially polarized), an optical polarizer and 20 mm diameter photodetector. Photodetector circuit consists of 20 mm diameter LDR, 0.1KΩ Resistance and 5VDC as an input of the circuit. Photodetector circuit comprises of 20 mm diameter LDR, 0.1KΩ Resistance and 5VDC as a contribution of the circuit. At first, partially polarized laser source was turned on for a specific period to ensure it is balanced out before the experiment. From that point, photodetector and polarizer were adjusted on a similar arrangement as per the polarized beam. The measurements were taken by rotating polarizer at 10º angle shift and over the range of 360º. The transmitted light of the partially polarized light was captured by a photodetector. Strangely, the transmitted light changed by the angle variety of the polarizer at each of the interval over the entire range. Also, the increment and decrement of the voltage at each of the 90º interval was almost the same except in some degrees. We also performed an experiment using the different setting of the power from polarized source taking the measurement of the transmitted voltage over 0º to 360º and 360º to 0º to study on the repeatability.
4. Fabrication of a prototype

4.1. Thin film optical polarizer
Thin Film Optical polarizer need to cut to make a usable shape for the prototype. A servo-controlled 3-axis Micro-CNC machine (Mikrotools Ltd) is utilized to cut the thin film polarizer in a round shape. The outer diameter across of the polarizer is 30 mm. The measurement of the inner diameter is 5 mm.

4.2. Photo detector circuit
LDR (Light Dependent Resistor) is utilized to detect the transmitted light. Circuit depends on the hypothesis of voltage divider rule. 0.1kΩ Resistance, 12 mm diameter circular shape LDR and outside 5 VDC power source is utilized to initiate the circuit. Figure 5 demonstrates output and input wire originating from photodetector circuit.

4.3. Body structure
The shape of the optical resolver is round and hollow. Measurement is 35 mm. furthermore, the length is 40 mm. 3 D printer is utilized to make the assemblage of single degree of freedom optical resolver. The real structure and state of single DOF optical resolver appear in Figure 5.
5. Speed testing experiment of prototype
A test bench has been designed and built as shown in Fig 6. This setup utilized for testing the optical resolver driven by a variable speed stepper motor. A 5mm inner diameter coupler was utilized to couple the motor shaft and optical resolver shaft. That was the mechanical piece of the precision testing of the optical resolver. Arduino GrBl used to control the stepper motor's precise speed. 24 VDC provided from DC source to enact the controller. DC source provided 5VDC to active the photodetector circuit. The tests were directed with changing motor revolution speed. Curiously, the transmitted light shifted by the angle variety of the polarizer and revolution of the output signal was varied according to the variation of the angular speed of the stepper motor.

![Figure 6. Experimental Step up of Accuracy Testing of Optical Resolver](image)

6. Results and discussion
6.1. Experimental results
From the graphical representation of Figure 7, as the rotation angle of polarizer is increased, voltage increased. According to the operation principle polarizer rotated varying from $0^\circ$ to $360^\circ$ with an interval of $10^\circ$. Higher sensitivity value is desirable for the good sensor application. In this experiment, the sensitivity achieved around 0.467 V/degree. In terms of Repeatability, standard deviation found around 0.2 Voltage. We acquired exceedingly precise and repeatable measurements as per the variety of the angle of the polarizer in each of the tests.
Figure 7. The graph represents the experimental result of the whole assembly.

6.2. Speed test result

Figure 8 demonstrates the aftereffect of the output voltage with a various angular rotation speed of the stepper motor. To look at the exactness of single DOF optical resolver. We did an examination to test the precision in various RPM. Figure 8(a) appears at 16 RPM optical resolver takes 2 sec to finish one cycle. At the point when the motor speed is increased, the time of the one revolution is decreased. At figure 8(d), it takes just 0.7 sec to finish full one cycle. Thus, we acquired from the analysis that, time is inversely proportional to speed which drove the probability of this prototype to make it as a good resolver. There is having bit fluctuations at a few degrees. The most probable explanation 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 on account of the ambient temperature, humidity of the environment and the impact of light normally interfere with the sensitivity of the photodetector. Then again, the contamination of the polarizer may have the impact to reduce the transmitted power from the real one.

Figure 8. Experimental result obtained from different RPM.
7. Conclusion
This paper proposed a new optical resolver compatible rotary position sensor. The optical resolver consists of the laser, polarizer and photo detector circuit. Transmitting light passes through the optical resolver and directed on to the photodetector. Based on the polarization of light, the operation principle was discussed. The operation was experimentally verified using a fabricated prototype. It proves its high sensitivity and accuracy. It is cost effective, compact in size. There is no electromagnetic interference as it depends on the optical standard of lasers.

References
[1] Masaki K, Kitazawa K, Mimura H, Nirei M, Tsuchimichi K 2000 Magnetic field analysis of a resolver with a skewed and eccentric rotor Sensors and Actuators A: physical 81 297-300
[2] Benammar Mohieddine, Ben-Brahim Lazhar, Alhamadi Mohd A 2004 A novel resolver to 360 degrees; linearized converter IEEE Sensors Journal 4 96-101
[3] Katakura Masayuki, Toda Asako, Takagi Yuichi, Suzuki Norihito, Kadoyama Takahide 2005 A 12-bits resolver-to-digital converter using complex Symposium on VLSI Circuits Digest of Technical Papers 15 236-239
[4] Tokuda T., Yamada H., Sasagawa K. and Ohta J 2009 Polarization-Analyzing CMOS Image Sensor With Monolithically Embedded Polarizer for Microchemistry Systems IEEE Transactions on 3 259-266
[5] Li S., Yang C., Zhang E. and Jin G 2003 Compact optical roll-angle sensor with large measurement range and high sensitivity Optics Letters 30 242-244
[6] 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 5 424-535
[7] Clark L. T 1987 Rotating Polarizer Angle System. DC: U.S. Patent and Trademark Office 4 688-934
[8] Huang P. S., Kiyono S. and Kamada O 1992 Angle measurement based on the internal reflection effect a new method Applied Optics 31 6047-6055
[9] Wijntjes Geert and Constantine Markos 2005 Non Contact Optical Polarization Angle Encoder U.S. Patent 10 288-875
[10] Butzer D. C 1996 Polarization Based Optical Sensor Utilizing Total Internal Reflection U.S. Washington, DC: U.S. Patent and Trademark Office 5 483-346
[11] Thorburn William G., Donald K. Mitchell and Bruce A. Horwitz 1998 Diffuse Surface Interference Position Sensor U.S. Patent 5 783-752
[12] Hutchinson Paul L. and W. Gordon White 1993 Angular Position Sensor Using A Polarized Disc With Coded Tracks U.S. Patent 5 235-177
[13] Barnett, Donald 2002 Optical Resolver And Method Of Use U.S. Patent 10 095-542
[14] Rana Masud, Mrazib Masyraf, Saleh T., Muthalif Asan GA 2015 Development Of An Angle Sensor Using Optical Polarizer ARPN Journal of Engineering and Applied Sciences 10 17416-17420