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Study on array of photo-detector based absolute rotary encoder

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ABSTRACT

Absolute rotary encoder is an electromechanical device which indicates the absolute position of an object. In this paper, a low cost absolute rotary encoder is presented. Proposed encoder measures the rotational position of a moveable object with accuracy of ±1° and resolution of 0.1°. Here, Encoder disc does not carry any binary or gray coded positional information, instead of that it acts as a positional pointer over the array of photo-detector based circular track. The one forth segment of fiber glass disc is kept transparent and rest portion is covered up by a semi-transparent layer. The disc is placed between the circular track and a light source. A marker at the centre of transparent portion indicates the angular position of the object. Now during the rotation of disc along with the object, high intensity of light is passed through the disc's transparent portion compared to the semi-transparent portion and impinged over a fixed circular track. Thus according to the variation of light intensity over the track surface area, absolute angular position of object is determined by analyzing the variation of photo-detector's output. In order to proof of this concept, an experimental prototype has been designed, developed and tested.

1. Introduction

In order to achieve motion control of an object, an information needs about the speed and/or the position of the moving or sliding part. Such sensing and feedback device provide this information is called as "encoder" or "position sensor". In general, an encoder generates a signal according to the measured position and/or speed, which is classified as relative or absolute. An absolute encoder generates a signal about the absolute position of moving part, even after resume the power. It plays a pivotal role in a wide range of applications such as precise position control, encompassing robotic controllers, printers, cameras, industrial machines for position detection and automotive sensors for steering angle detection [1–3] etc.

Implementation of absolute encoder with high reliability, accuracy and resolution in low economic range is most challenging job for the researchers. Traditionally, absolute encoder is designed by capacitive, magnetic and optical type methods. Various designing techniques have been adopted for capacitive type angular position sensor to simplify its construction and providing high accuracy. Gasulla et al. [4], Zheng et al. [5] and Gaurav and Pal et al. [6] developed a capacitive rotary sensor that can measure full rotor position i.e. 0°–360°. In this circuit parasitic capacitance is appeared in between of the non-shielded segments and the common electrode, which introduced noise in output signal.

Magnetic encoder is considered for low cost applications [7], where less precision, anti-vibration and immune to dust and vapor are required. Generally two kinds of magnetic encoders are commercially available: MR encoder and single-pole encoder. Manufacturing process of MR encoder is too complex and resolution varies with multiple pole number, so the structure is large. Zhang et al. [8] proposed a structure of MR encoder based on multiple pole sequence and realized into a magnetic drum. It exhibits a resolution of more than 4000 pulses per revolution of the drum. Besides that in order to improve the resolution of single-pole encoder, a novel structure is presented in Ref. [9] which consists of six separate Hall IC's and one radial magnetizing ring "alnico"; is adhered to rotor of motor. A 13-bit resolution is achieved from this experiment but it encountered with two major drawbacks, firstly Hall IC's can't be placed accurately around the ring and secondly, rough surfaces of alnico introduced noise in output signal. Also, magnetic encoder required well sealed encapsulated housing to reduce the electromagnetic interference.

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An optical encoder has become recognized as an indispensable displacement/position sensor due to its high resolution, light weight and excellent immunity to electromagnetic interference. Typically it consists of a code scale, an optical sensing head and a signal processing circuit. According to the placement of code scale and sensing head in an encoder housing, it is classified as reflection and transmission type. A reflection type encoder is designed by Hak-Soon and Sang-Shin [10] where a beam router transmits a light beam and reflects back to the sensing detector from a code scale. Thus during the displacement of code scale according to the object, coding information is translated into modulated electric signal (sinusoidal waveform, phase difference of 90°) by two semicircular silicon PDs. In Ref. [11], authors have invented a transmission type design. Where the lights passed through the coded scale and information is retrieved by one dimensional array of photo-detectors. In this method, detectors receives variant intensity of lights after passing through transparent and semi-transparent micro slits of the disc and processing unit identifies the logical high/low bits of the code as a function of light intensity. In continuation with this, Sugiyama et al. [12] reported a design where binary code is identified by opto-interruption technique using two dimensional array of photo-detectors. Besides Das et al. [13] design a two dimensional binary coded encoded disc along with a series of photo-detectors based decoding unit. In both cases [11–13], the output voltage variation of detectors exhibit the coding information electrically and by analyzing the same decoder unit produces an absolute position of an object. Such optical encoder cost is very high due to use of lithographic method to design the micro slits in a glass plate. Also, maintaining a correct air gap (0.25 mm) between code disc and detector is critical for reliable operation. As a result, optical encoders are vulnerable to shock and vibration, which may damage the rotating optical disc or detector. Presently, Bajic et al. [14] presented a novel low cost design of code disc, which is free from any slit type binary information and immune to vibration. It is based on simple grayscale transformation of RGB colored hue wheel and decoder unit consists of three optical reflection type color sensors. These are kept into a fixed plate at 120° apart from each other and placed over the disc. An absolute position of rotating disc is evaluated by processing the output of three sensors according to the color variation in the disc track. This design claimed an accuracy of ±1°and resolution of 0.1° within the range of 0–360°.

In this study, a transmission type absolute rotary encoder is developed and tested. Its design concept is very simple and comprises with three elements: a light source, a shaft coupled disc and array of photo-detectors. Here the disc does not carries any type of coded information such as binary or color code, thus its fabrication cost is low. Also, gap distance in between of disc and optical sensor is too large hence it is immune to shock and vibration. The disc is made with fiber glass and covered up by a semi transparent self adhesive tape except the circumference edge of a quadrant.

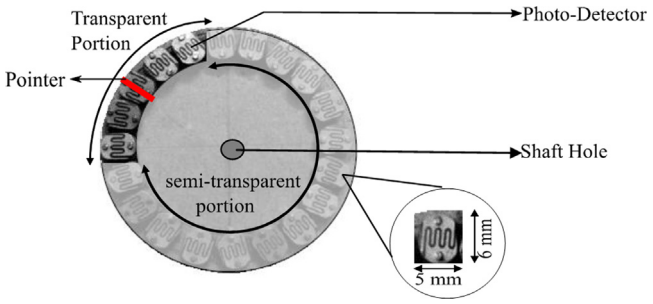

Fig. 1. Snapshot of proposed design with array of photo-detectors and disc.

An array of photo-detector is arranged in a circular track over a fixed plate and kept underneath of the disc edge. In this track, equally spaced of detectors are divided into four clusters (as per quadrant) and each cluster detectors are connected in a series circuit. Thus, during the rotation of disc in presence of lights some of the detectors are illuminated by high intensity of lights where uncovered (transparent) segment is available and others gets lesser intense of light where the semi-transparent segment is available. Hence, absolute position of rotating disc is determined by tracking the location of transparent segment over the cluster detectors array. Therefore, to track the position of transparent segment, a signal processing circuit and a PC based software has been used for analyze the output of photo-detectors. This encoder provides high resolution and accuracy within the range of 0–360°.

2. Implementation of proposed encoder

Basic idea for implementation of this proposed design has taken from traditional structure of multi-track binary/gray code encoder. In multi-track code structure, a rotating disc is fabricated with plurality of micro slits depending on binary/gray code resolution. Array of photo-detector based processing unit is used for detecting every bit of this disc code and as well as evaluates the disc position. Hence, in this present study an idea has been introduced to simplify the disc fabrication process without use of any code structure. To detect this coding free disc position accurately its processing unit requires array of photo-detector only.

A. Design overview

Here, the disc is made with transparent sheet of fiber glass (thickness: 3 mm, diameter: 32 mm) and covered up by a semi-transparent gray colored self adhesive tape but one fourth segment of the disc circumference edge is left uncovered (width of that portion is 7 mm and arc length is 25.4 mm). Thus in presence of light source, disc uncovered area will passes high intensity of light compared to the covered area. Besides that array of photo-detector (i.e. Light Dependent Resistor (LDR)) has been arranged in a circular

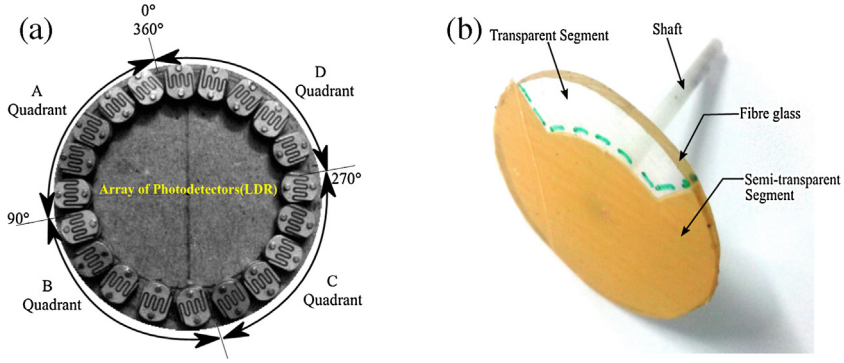

Fig. 2. (a) Arrangemnet of detectors on a fixed plate. (b) Prototype of proposed encoder disc.