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Implementation of Contactless angular Speed Measurement Based on Photo Sensor

***Abstract**. The main aim of this research is to propose a new and low cost angular speed measurement based on optical imaging technique. A photo sensor available in computer mouse is implemented as a contactless speed measurement transducer device. The photo mouse sensor output is used to convert the rotating speed of motor shaft, revolutions per minute (RPM), to linear speed. A software program written in C-sharp language is employed to determine the speed and display it in RPM. A motor with maximum rated speed of 2850 RPM is tested at different speeds. Performance comparison is founded by using speed tachometer as a reference measurement. The maximum and minimum percentage error found is 0.099% and 0.05% respectively. Results validated the effectiveness of the proposed technique and its potential applications in electric drives and automation.*

*Streszczenie. Zaproponowano tani system do pomiaru prędkoścoi katowej z wykorzystaniem czujnika optycznego. Jako czujnik wykorzystano typowy fotodetektor stosowany w myszkach komputerowych. Prograam oblicza ilość obrotów na minutę RPM. Na podstawie bada© eksperymentalnych określono dokładność pomiaru na 0.1%. (**Zastosowanie bezkontaktowego czujnika optycznego do pomiaru prędkości obrotowej**)*

Keywords: Contactless, photo sensor, RPM, speed measurement.
Słowa kluczowe: pomiar prędkości obrotowej, czujnik optyczny

Introduction

The speed measurement is of high concern in many applications. Mainly the motor speed is highly needed for control and drive systems [1-3]. Mostly the contactless speed measurement in the industry is based on electromagnetic sensors either by using electromagnetic induction, or Hall Effect or the magnetoresistive effect [4-9].

Mostly the motor speed is measured via contact devices such as tachometers and encoders. These devices normally offer a high degree of accuracy and precision. The devices that are usually used shaft includes: rotary pulse generators (encoders), proximity sensors, and photoelectric based sensors (such as photodiodes and transistors). These transducers designed to express the speed data at different manners which could be linearly or digitally in the form of pulses. The electiveness in pulses method measurements are affected by the number of pulses per revolution (PPR) of the shaft and the pulse consistency and symmetrical at which better accurate RPM data could be obtained [10,11]. In addition, devices such as hand type tachometers are available in non-contact as well with lower accuracy compared to contact speed measurement.

In many types of equipment with motors, where the precise speed of the shaft is necessary, there is always some type of sensors to translate that rotational motion into speed. It is important to know the speed shaft because if it is running too fast it may damage some parts of the systems. Rotational speed involves the number of revolutions per unit of time. The angular speed is used to determine the rotational speed which can be calculated as:

$$\omega = \frac{\theta}{t} \tag{1}$$

where: ω angular speed, θ – total distance travelled, t – total time taken.

According to Fig.1, the linear speed (v) of rotating shaft has a radius (r), can be expressed as:

$$v = \frac{\text{Arc QP length}}{t} = \frac{r\theta}{t} \tag{2}$$

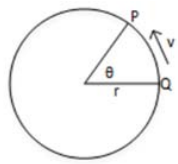

Fig.1. Linear speed of rotating shaft

Different types of devices can be used to measure the shaft speeds. They are either contact or non-contact types. The contact type requires to be in contact with the rotating motor in order to measure the speed. On the other hand, the non-contact device can measure the speed without the need to touch the motor shaft. The motor speeds normally expressed as the number of revolutions per minute (rpm).

The proposed design is a non-contact speed measurement device that uses the optical image sensor to detect the rotating motor shaft movement. The optical image sensor is accurate and can detect a very slight shaft movement. The optical sensor uses a beam of high intensity LED to shine onto the shaft and the reflected light is captured by the sensor through the focusing lens as shown in Fig.2 [12].

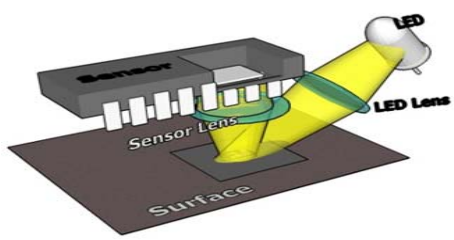

Fig. 2. Optical imaging mechanism [12]

Contactless speed measurement

The need for non-contact measurement of the motor shaft speed is highly concerned, mainly during troubleshooting and maintenance. Also, it could be much useful in some applications which have some hazards or vibrations, where the contact devices measurement could be affected [2, 13]. Imaging techniques could be used to detect the shaft rotation speed without contacting the motor shaft [14].

The basic principle of the optical mouse is based on a low-resolution mini camera, which captures the reflected light that collected through the lens. The surface is illuminated by an LED light source that normally a visible red LED or an IR LED [12-15]. The optical mouse contains an Image Acquisition System, IAS, a digital signal processor, and a four wire serial port as shown in Fig.3 [16, 17]. An IAS takes microscopic images and sends them to the DSP which determines the distance and direction.

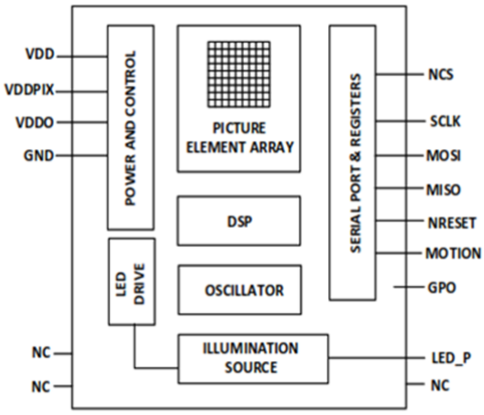

Fig.3. A block diagram of PMW3389DM-T3QU optical navigation chip

The optical sensing techniques are quite robust to any electromagnetic interference. However; it is highly affected mainly by dust, oil, and light [18]. Based on laser mouse sensors (LMSs) a new contactless rotor RPM measurement method has been experimentally investigated [18]. The optimal parameters of the sensor were experimentally characterized for obtaining a superlative sensors performance. It uses both amplitude and frequency correlation methods. The obtained results show that the frequency correlation method has linearity which is several times higher than those for the amplitude correlation method. However; this technique employed two laser mouses deferential method which will increase the cost [18].

An experimental study aimed to characterize the commercially available low cost optical motion sensors is presented in [18]. The potential for the adoption of these mouse in industrial applications utilizing their build low cost optical motion sensors is investigated as multiple degrees of freedom sensors. Results highlighted the limitations due to the sensitivity to the reference surface and the limited maximum speed that can be used [19].

The non-contact speed measurement using fiber optic technique is proposed in [20]. The presented technique aimed to achieve a remotely and precise speed measurement in the presence of axial and radial motions of the rotating members. The system principle is based on fiber optic sensor. It utilized the intensity modulation technique. It implemented LED to transmit the light through the optical fiber. The light then is reflected from a plate and captured by an optical fiber to the detector. This technique can operate at a high degree of accuracy and precision [20].

A two-dimensional linear displacement measurement sensor was proposed based on an optical mouse imaging sensor [21]. The capability of the standard optical mouse was investigated possible functioning as a two-axis displacement measurement sensor. Testing on the proposed design shows that the measurements could be obtained only for opaque objects placed at a distance limited to 1.25mm from the mouse. The captured experimental measured data were compared with the displacements introduced using a scientific opto-mechanical xyz translator. Based on this comparison it is found that the proposed design data were closely correlated with small error percentage in addition to high degrees of linearity [20].

The instantaneous rotational speed (IRS) of a rotating machine is a key factor that could be used to investigate the machine operation and potential faults diagnoses. A study of vision-based instantaneous rotational speed measurement system implemented using linearly varying-density fringe pattern is presented [22]. The study proposed a novel non projection fringe vision-based system to realize the measurement of IRS. The proposed system which composed of an artificial linearly varying-density fringe pattern (LVD-FP) as a sensor and a high-speed camera as a detector. The density of fringe period for each LVD-FP imaged changed due to the rotation of the shaft at which the rotational angle could be obtained. Results revealed that the proposed system effectively measures the IAS and tracks the IRS at a wide range. Also, the proposed measurement system provides a non-contact vision-based for IRS measurement which could be mainly implemented on the rotary shaft where the conventional speed sensor cannot be installed [22].

A contactless analysis of moving objects was carried out by the aid of the virtual instrumentation LabVIEW tool. The developed algorithms were principled on analysis of video capturing. A real physical model was created for algorithm testing, debugging and verification. Testing results of the proposed model proven that the system is capable to realize a non-contact measurement of rotational frequency effectively [23]. Table 1 showing a brief comparison of characteristics of two commercially used optical image sensor used in optical mouse [24].

Table 1. Optical mouse sensors characteristics comparison [24]

Sensor type		ADNS-3040	PMW3389DM-T3QU
General Features	Units	Lower Power	Low Power
Power Consumption Running	mA	2.9 (typ)	21
Max Speed	ips	20	400
Frame Rate	fps	Auto	Self-adjusting
Resolution	cpi	400 / 800	16000
Acceleration	g	8	50

Methodology

The method used in this research is designed to converts moving surface speed to a rotating speed. The speed is tracked by the photo sensor which is available inside the photo mouse sensor. For that, a software program is implemented based on the C-sharp language. The Software program has an interface screen. Before running the Program, the shaft radius value is needed to be determined. The RPM value will be determined by running the software program and it will be displayed on the interface window. The surface under test movement will make the mouse pointer moves on the PC screen. The mouse pointer movement speed is related directly to the surface movement speed. Hence, the RPM speed (ω) can be extracted from the mouse pointer speed by the following equation:

$$\omega = \mathrm{v}\frac{60}{2\pi r} \tag{3}$$

where: v – mouse pointer speed in cm per second, r –radius of motor shaft in cm.

The software program will track the mouse pointer position on the PC screen. For each fixed interval period of time, the moving mouse pointer displacement distance is calculated, and the linear speed is determined. As a result, the rotating shaft speed is displayed on the screen by converting the linear speed to RPM. Fig.4 shows an illustration diagram for shaft rotating speed measurement in RPM based on PMS.

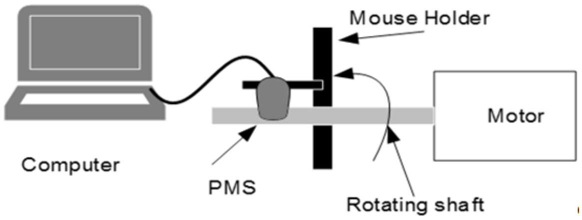

Fig.4. RPM measurement based PMS

Software program

The Software program is implemented by the C-sharp language. It generates a window where the user can enter the shaft radius value in cm. As the program is launched, the mouse pointer is set in reference point at the computer screen (xo,yo) which is the starting point. The mouse pointer will move in one direction only, either in the x direction or y direction. In the presented method the x direction is used. The pointer will move on the screen, as it reaches the maximum point on the screen (xn), the program directly forces the pointer to go back to the reference position (xo, yo). The speed of the pointer is proportional directly to the shaft rotating speed. Hence, the software program calculates shaft speed in RPM unit and displays it on the screen. Fig.5 shows the software program flow chart.

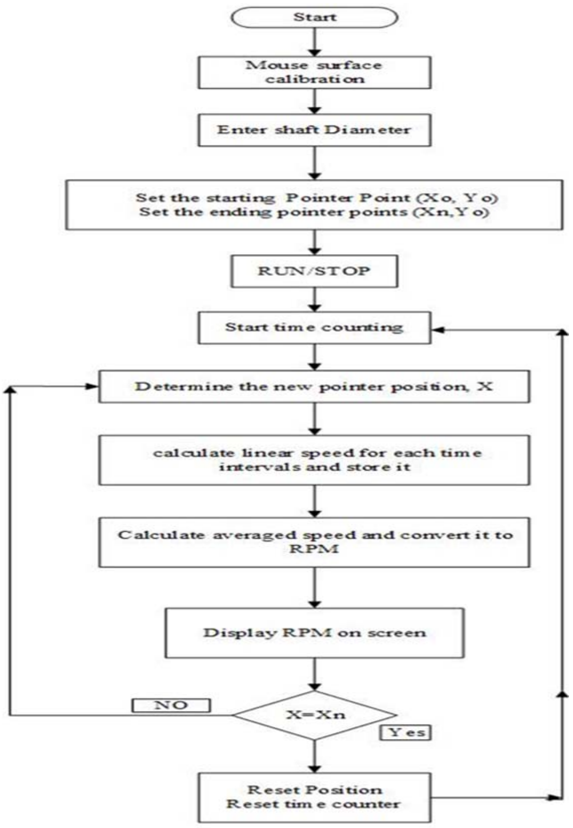

Fig.5. RPM measurement software flowchart

Experiment and results

The PMS used has 400 IPS and 16000 dpi. This type is designed for the gaming video program which needs high specifications. It uses a PMW3389DM-T3QU optical gaming navigation chip which designed to be used with LM19-LSI lens to achieve optimum performance [25]. This type has tools that give the ability to change the mouse setting. One of its features; the user can calibrate the pad surface (tracking surface) to get the best performance. This feature is important in measuring RPM speed since the tracking surface (motor shaft) color and material may differ from one to another.

The PMS is tested at different separation distances between PMS and the tracking surface (z). It was found no noticeable effect for z between 0.2 mm to 0.5 mm. The distance z is fixed at 0.4 mm to avoid any un-expectable mechanical contact between tracking surface and PMS which may damage PMS. The Computer screen used has 1366×768 Resolution and 39.6 cm diagonal size (36.8 cm width and 14.7 cm height). Fig.6 shows the test bench for motor speed measurement.

Fig.6. Test bench for motor speed measurement.

A motor with variable speed control is used. The shaft under test has a diameter of 5.52 cm. The highest RPM speed can be measured by this type is approximately 3515 RPM for the shaft diameter under test. However; the maximum speed for the motor used is 2850 RPM. A tachometer with a percentage error of 0.1% is used to measure the RPM as a reference. Fig.7 shows the relationship between measured and reference RPM and Fig.8 shows the percentage error versus measured RPM speed. The obtained results show high correlation value R2 as shown in Fig.7. The maximum percentage error is 0.099% while the minimum is 0.005%. PMS has Polling rate of 1K Hz, which mean the photo sensor will check for new position of motor shaft every 1ms which will improve the accuracy.

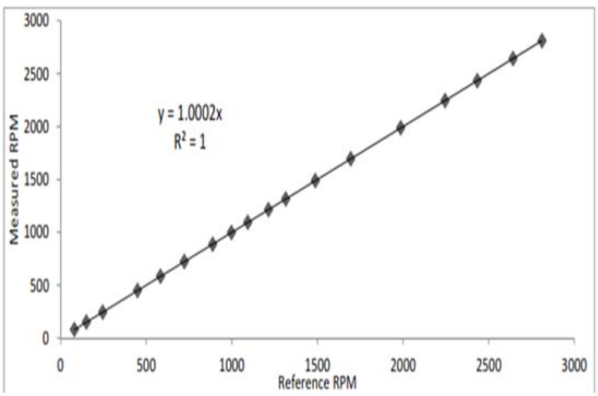

Fig.7. Measured RPM versus reference RPM

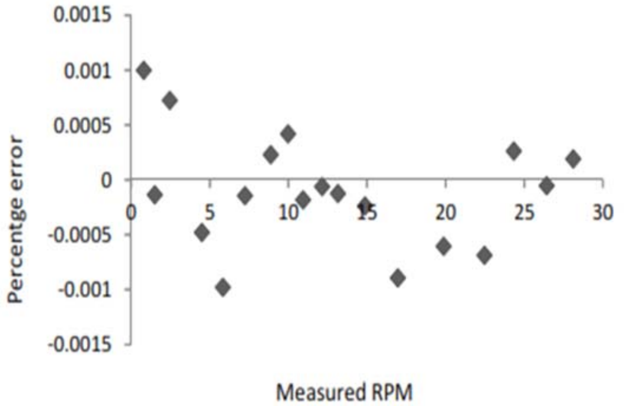

Fig.8. Percentage error versus measured RPM

Conclusion

In this paper, a low-cost and high accuracy technique for motor speed measurement was developed. The proposed method is based on a photo sensor available in the optical mouse. The need for non-contact speed measurement is highly needed especially on objects nearby hazards regions. The system effectiveness functionally is tested by comparing its reading with a tachometer speed measurement device.

The main advantage of the presented system, it does not need any connections with the rotor shaft. The PMS is widely used at low cost since it has high volume consumers. Moreover, it is not affected by electromagnetic interference. On the contrary, to get optimum results, it should be protected from oil, dust, and light. The proposed design is potentially used in various electric drives and automation applications.

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