A New Method of Linear Displacement Measurement Utilizing Grayscale Image

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Abstract—**Several research works exploring the potential of utilizing grayscale image for the measurement of many physical phenomena has been published. In this present paper we have designed a new linear displacement sensor utilizing the grayscale image. This sensor is based on temporal changes in the intensity of light by the movement of grayscale image with the linear displacement of target. The variation of light intensity detected in terms of voltage by the signal processing circuit (SPC). The output of SPC is fed to a microcontroller program to display the linear displacement of target directly. The experimental results are shown a satisfactory performance of the sensor for linear displacement in the range of 0mm to 40mm.**

Index Terms— **linear displacement sensor, intensity of light, grayscale, SPC, microcontroller program**

I. INTRODUCTION

In modern industrial production processes the actual linear or angular displacement of fast moving objects needs to be detected and ideally done with or without mechanical contact measuring systems. For this purpose, there exist varieties of suitable sensors that provide an output signal (voltage or current) proportional to the displacement or position of moving objects within a small space ranging from several millimeters to several centimeters. In aspect of industrial usage these measuring systems are exactly required of reliability, ruggedness, measuring range, accuracy & sensitivity etc. Likewise, electrical parameters such as supply voltage range, output signal and EMC requirements are firmly defined in such norms and standards. Except of traditional industrial application the displacement sensor is also very useful in various field of sensitive & accurate systems such as a robot and biomedical measuring devices.

Various researchers have been developed varieties of linear displacement measurement methods in aspect of range of displacement, sensitivity, linearity and accuracy. Like Linear variable differential transformer (LVDT) [1], capacitive transducer [2], potentiometeric transducer, etc. Each of these transducers has its drawbacks and imperfections.

Where linear displacement measured in the range of millimeter or less by applying very small force, capacitive displacement sensors are useful for that operation. They have a good frequency response; hence they are useful for dynamic measurement. Major drawbacks are nonlinearity behavior on account of edge effects and high output impedance on account of their small capacitance value; add to this, that the cable which connects the transducer to measuring point is a source of error. Moreover, the capacitance may be changed because of the presence of dust particles and moisture or because of temperature changes.

Potentiometric or resistive transducer operating range is limited by the size of potentiometer and it is also affected by the friction caused to obstruct the slider movement. Although it is quite useful in some applications they have noticeable friction and need physical coupling with the object. One problem is associated with a wire-wound potentiometer. The wiper may while moving across winding, make contact with either one or two windings, thus resulting in a variable resolution. Wiper friction and excitation voltage may cause heating in potentiometer. On the other side, drawbacks of LVDT is that it has larger body length, affected by magnetic field and complicated signal conditioning circuit

All of these tribulations are trying to rectified by Dhiman et.al [3], implementing a strain gauge based displacement sensor & A.K.Alia et.al [4], implementing an Acoustic Displacement Transducer. The strain gauge based displacement sensor have introduced mechanical error in terms of ruggedness and acoustic displacement sensor suffering from the environmental noise and self oscillating detector by means of reflected sound energy.

Excluding these above measurement technique optical sensors have advantages over other type of sensors in that they can provide noncontact operation, greater sensitivity, better accuracy, freedom from electromagnetic interference, wide frequency range, and dynamic ranges. From these advantages, optical techniques may be ideal for the development of sensors for the measurement of small linear displacement.

Optical incremental and absolute digital encoders are the most common rotational position optical transducers. Absolute encoders overcome some disadvantages of incremental type, but are more expensive. Generally optical encoders find use in relatively low reliability and low resolution applications. Both types may suffer from

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damage in harsh industrial environment. For sensing the linear displacement, linear encoder and quadrature encoder are traditionally used. Historically, the practical disadvantage of optical encoders have included pattern inaccuracies, concentricity errors between disc and shaft, susceptibility to electrical noise, vulnerability to shock and lose of data in power failure. One of major problems with optical encoders; ice crystal formation and resultant pattern damage when the shaft turns has not really been completely solved. Instead of optical encoder some of the researcher's works on the principle of variation of light intensity due to reflection of optical signal from the target or moving objects which is the source of displacement and also it is called reflector. Advantage of such systems has simple in design, low cost & free from ice crystal formation. Maiti.et.al [5] & Mhdi.et.al [6] developed a linear variable differential displacement sensor based on optical light intensity variation method. The drawbacks in such systems are the reflected light could not attain the same incident angle and reflection angle between the source and detector after variation from steady state position of the reflector, it was scattered from the detector. So the expected variation of light intensity due to the displacement makes an error.

Building on the above, it becomes obvious that there is a wide range of engineering activities still needed to be done for the improvement of the existing industrial displacement measurement systems or for the development of new types based on new perspectives. In this present paper, we have introduced a new method of linear displacement measurement system which contributed better accuracy, linearity, repeatability and also industrial requirements within a small space range. This method has been designed by the principle of optical light intensity variation method by the linear movement of grayscale image plate with the linear displacement of moving objects. As the moving objects displaced from its steady state position the grayscale image plate moves over the optical sensors accordingly. The optical sensor consists of a transmitter and a photo-detector. Due to the movement of grayscale plate the emitted light intensity of a transmitter has been varied and detected by the photo-detector. Finally it makes output variation in terms of voltage & displayed the changes of displacement utilizing the SPC unit & microcontroller programmed based display unit. Since it has an advantage over the optical sensor like reflector arrangement that the light intensity largely independent of the reflector position & very simple in design. Also its enclosed structure prevents the system from harsh industrial environment disturbance. The prototype module operates in the linear scale of 0 mm to 40 mm displacement range. We proved successfully that this system works as a small linear-displacement sensor. 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.

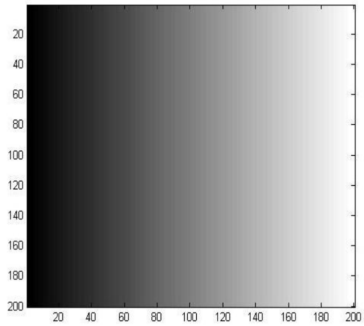

Figure 1. Gradient grayscale image

II. THEORETICAL BACKGROUND

In the field of photography and computing, a bi-tonal discrete image is such a type of image in which mesh of rectangular cells contain a color value (information content), is called pixel. This pixel hold only smallest possible information content with a "0" are referred to as black and "1" are referred to as white. If images are presented by these two colors, obviously those images are known as black-and-white images. Unlike bi-tonal images, in the context of computer imaging grayscale information contents have many shades, varying from black to white. That grayscale images carries only intensity information of light, viz. black as the weakest intensity and white as the strongest intensity of light. In grayscale images each pixel holds 8 bit length color information, resulting in 256 (i.e.2^8=256) different gray levels to represent the variation of color in between of black and white. Where, all 8-bit 0's (i.e. zero in decimal) represents as normally black and all 8-bit 1's (i.e. 255 in decimal) represents as white and the gray levels are the decimal numbers in between of 0 and 255. Now if these 256 gray levels are mapped onto a ramp scale, it is seen that the pixel color information is changed gradually from black to white. More specifically, when gray levels are increased gradually i.e. from 0 to 255, black color decreased gradually along with gradually increasing of white color, is referred to as a gradient grayscale image. Now if this gradient grayscale image is placed under the light source, it is found that the reflected light intensity level is mostly weakest at 0th gray level and strongest at 255th gray level of pixel. So, it is obvious that when gray levels of pixels are increased gradually, the intensity of light is changed accordingly i.e. from weakest intensity to strongest intensity and it seems that it might be changed linearly. In this present work, we have developed a gradient grayscale image with the dimension of 40mm length and 30mm 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.

III. Experimental Procedure

A. Working Principal

To measure the linear displacement we have designed a sensor module which consists of a plate with laminated gradient grayscale image and an optical sensor. The optical sensor designed by a LED (optical source) and a LDR (photo-detector), to read the variation of grayscale image pattern in terms of light intensity. The optical sensor was kept under the laminated surface of the plate and in between of two parallel tracks, where the plate travels smoothly by any kind of external force. Hence as the target displaced, the plate as well as the grayscale image shifted accordingly due to the coupling between plate and target through a shaft. The LDR resumes its output variation in terms of resistance as the effect of light intensity variation due to the shifting of grayscale image. To calibrate the change of resistance to the displacement of target a signal processing circuit and a microcontroller programmed based display unit has been used. The schematic diagram of linear displacement measurement system is shown in Fig. 2.

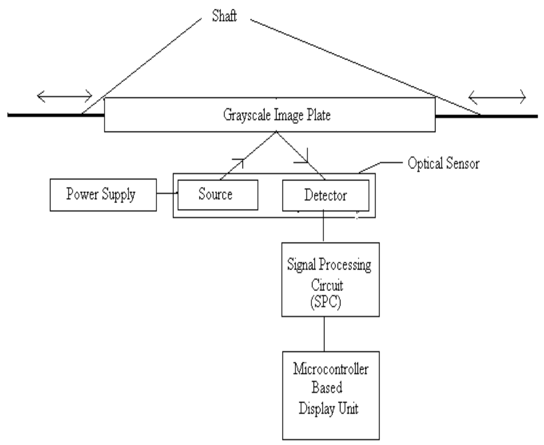

Figure 2. Schematic diagram of linear displacement measurement system

B. Sensor Module Design Architecture

The sensor module consists of a solid plastic plate with laminated gradient grayscale image and an optical sensor based on a LED (optical source) and a LDR (photo-detector). The plate constructed by a 40 mm length, 30 mm width and 5 mm height solid plastic block, where the horizontal surface laminated by a gradient grayscale image sheet as shown in Fig. 3. This plate was firmly attached with a metallic shaft for connecting with the target or moving objects and placed over two parallel 5 mm width and 80 mm long track by a gap distance of 15 mm where it can moved easily by any kind of external force. In between of track an optical sensor; an optical light source and a photo-detector like Light Dependent Resistor (LDR) have been placed in a same line as shown in Fig. 4. The top view of sensor module is shown in Fig. 5.

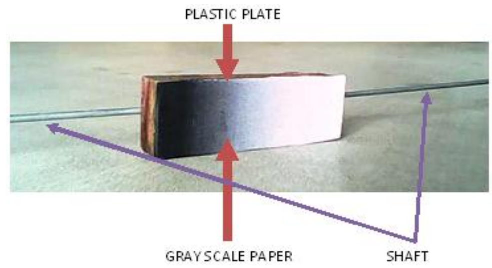

Figure 3. Solid plastic block laminated with grayscale image at horizontal surface

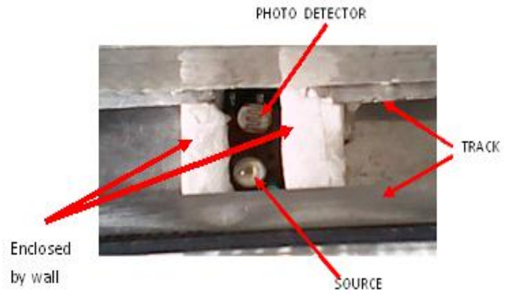

Figure 4. Position of optical sensor (source & photo-detector) in between of track

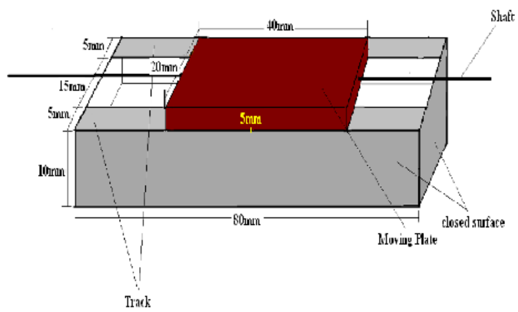

Figure 5. Top view of sensor module

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 confined in 0volt to 5volt range by zero and span adjustment circuit is shown in Fig. 7. Finally this range of voltage transformed into 256 levels of digital data using 8-bit ADC circuit.

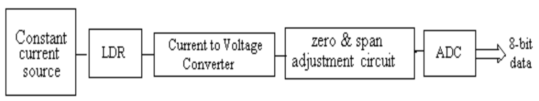

Figure 6. Block Diagram of SPC unit

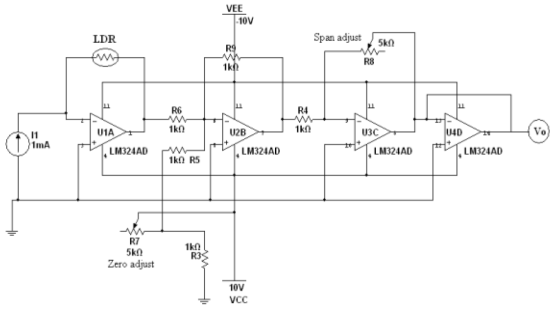

Figure 7. Circuit diagram for detection of LDR resistance into voltage variation (0 to 5 volt)

D. Microcontroller Programmed based Display Unit

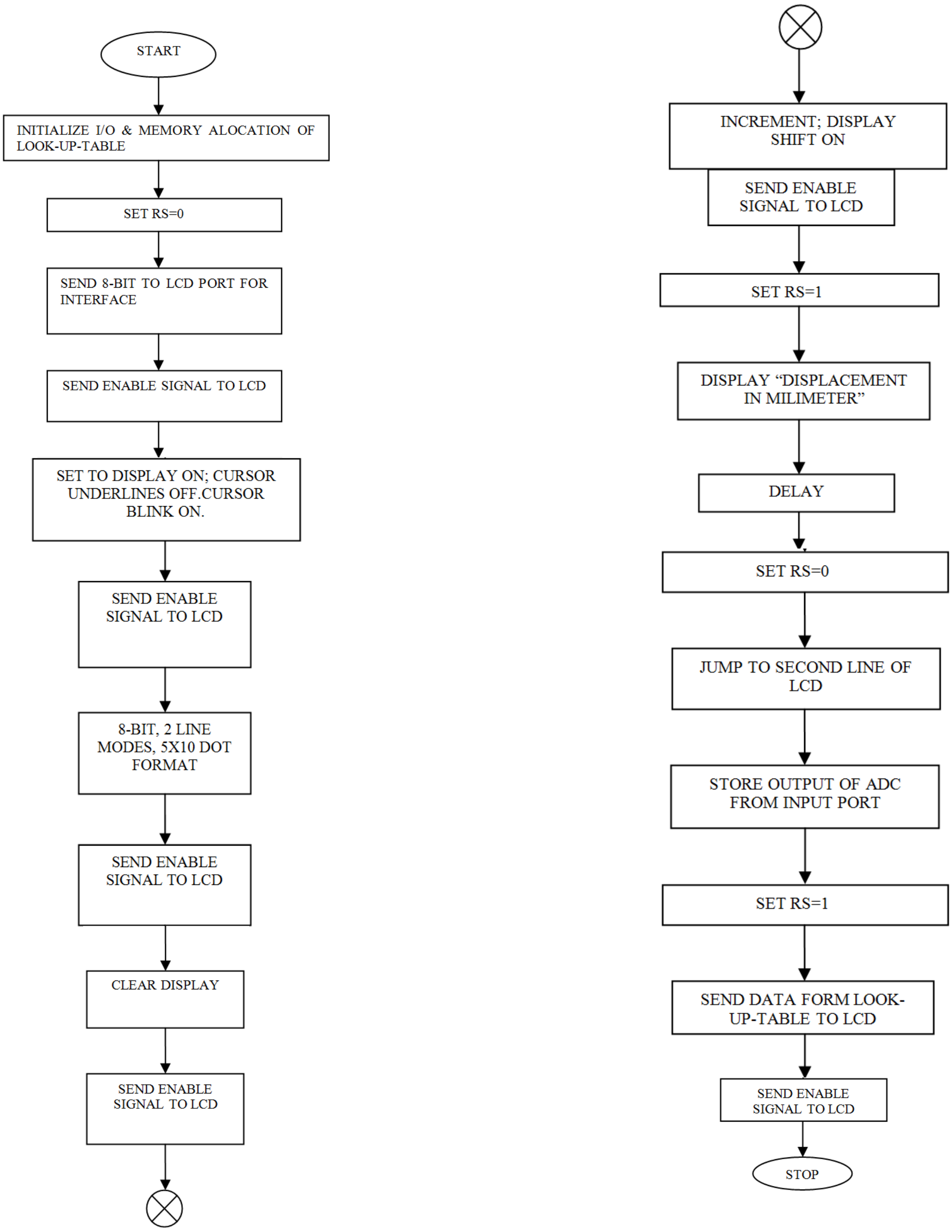

Figure 8. Flowchart of Microcontroller program

The SPC unit developed a voltage range of 0 volt to 5 volt due to the displacement of 40mm to 0mm. Hence a display unit has the capability to display the actual displacement of 0 mm to 40 mm due to the variation of voltage range from 5 volt to 0 volt. To display the actual displacement of target the digitize value of this voltage range is fed to port1 of ATMEL 89S52 microcontroller which interfaced with the 16 characters 2 line LCD unit at port2. The programming of microcontroller displayed the actual displacement of target using the output data of ADC and defined Look-up-table data. The detailed flowchart of microcontroller program is shown in Fig. 8.

IV. Experimental Result

In *the* proposed scheme the linear displacement of target or moving objects has been measured by the movement of gradient grayscale image over an optical sensor. The optical sensor transmits light by a LED and reflects back from the surface of grayscale image to the photo-detector (LDR). At initial condition, the weakest intensity point of grayscale image i.e. heavy dark region belongs over the optical sensor. In this state the output of LDR resistance was high due to absorption of more light by the dark region of grayscale image. Hence as the target moves linearly from its initial position the grayscale image moves accordingly from its weakest intensity point to strongest intensity point i.e. heavy dark region to white region. So the output of LDR resistance has been decreased linearly. It is noticed that the LDR resistance varies linearly from 7.74 KΩ to 4.68 KΩ due the movement of target in the range of 0mm to 40mm. The LDR characteristics curve due to the movement of target is shown in Fig.9. In Fig.7, 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 linear displacement of 40mm to 0mm. The calibrated output voltage (V_0) has been measured and plotted against the linear displacement of target, which is shown in Fig.10

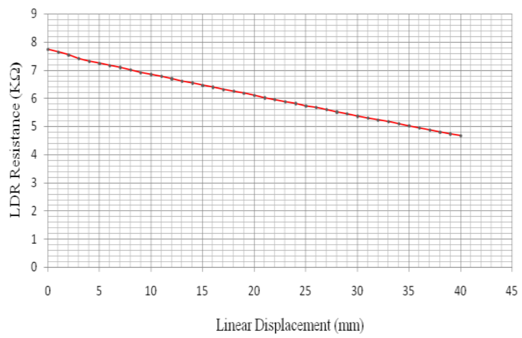

Figure 9. Plot of output resistance of LDR vs. Linear displacement of target

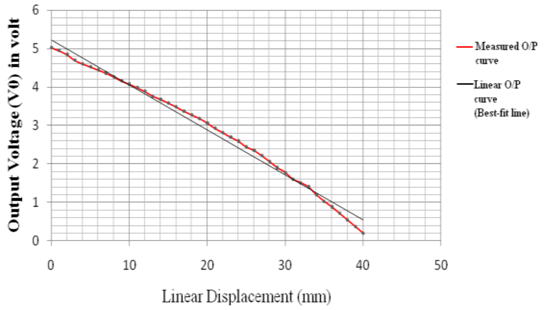

Figure 10. Plot of output voltage (V_0) of SPC vs. linear dispalcement of target

In Fig.10, it is obvious that the output voltage (V_0) of SPC unit approximately linear with the displacement of target. Hence we have calculated the non linearity of that curve utilizing best-fit straight line method and find the value of -6.67% FSO (Full Scale Output) at the dispalcement of 40mm. In the contrast of the other displacement sensor like LVDT[1] and strain gauge based dispalcement sensor[3] has exhibits linearity only in 0 to 5mm and 0 to 10mm range respectively. Also the accuracy factor of that measurement method is -2% FSO at 4mm.

The proposed sensing method can measure the smallest displacement of 1mm i.e; resolution of this method is 1mm. So it exhibits better resolution than optical LVDT[5] and Acoustic displacement transducer[4] which shown 10mm and 5mm respectively.

The repeteability of that sensing method has been plotted in Fig.11 considering the displacement of 10mm at 10 times repeated measurements. It has been found that the maximum value of output voltage (V_0) is 4.07 volt, minimum value of output voltage (V_0) is 4.068 volt and average value in that displacement is 4.069 volt. The full scale value of output voltage (V_0) is 5.02 volt at maximum span of displacement about 40mm so, the repeteability of that method evaluated as 0.04%FSO.

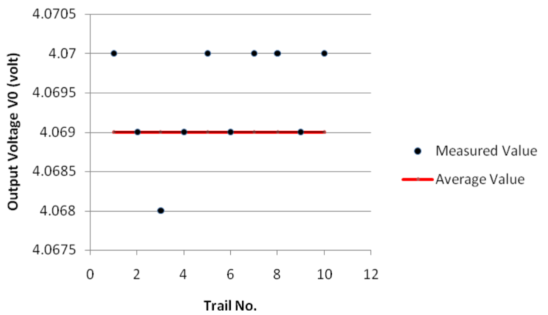

Figure 11. Repeatability test at 10 mm displacement

V. Conclution

The designed sensor is efficient, in expensive, and multipurpose. It could be integrated with other primary non electrical sensors and order to get an electrical read out.

This displacement sensor module is applicable in various industrial fields such as robot, biomedical measuring device, rectilinear motor & position feed back of a pneumatic or hydraulic cylinder rod. In this case the sensor is not embedded within the target, but externally tied through a yoke to the target body.

From *Fig*.10 it is obvious that the output voltage (V_0) variation of SPC unit with the variation of displacement has been found approximately linear in the range of 0mm to 40mm. So accurate measurement of displacement in linear range, computer based programming can be used by interfacing this sensor with the DAS card & PC, it is the future scope of work.

This *displacement* sensor module can also be used beyond this measured range; it is also the future scope of work.

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