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Precise Positioning Based on Pixel Differential in Linear Optical Sensor Array

Abdallah Alsayed*, Muhammad Razif Mahadi

Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Abstract

Precision farming emphasis on the efficient use of resources for optimizing the output. In the production of paddy, measurement of water level and the rate of rising are important factors. Sensing techniques suffer from some restrictions which restrict obtaining high accuracy and high resolution measurements such as noise of electrical sensor, sensing clear response, potential error, and environmental effects. This paper presents a non-contact method to measure position in linear motion. Moreover, this work is going to be background and concept for water level measuring system.

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Keywords: Position measurement; water level; linear array sensor

1. Introduction

Precision farming concentrates on development of techniques to minimize input while optimizing output. In paddy production, factors such the amount water used on paddy field must be controlled to an acceptable level rather simply flooding the area. One of the backlash in uncontrolled water used in paddy field is the development of softsoil whereby eventually that would lead to limited machinery traversability (Muda Agriculture Development Authority).Beyond agriculture and other industries, monitoring the water level is an important process (Isa et al., 2011). Common practice currently, water level measurement was observed manually for rivers, ponds, and in paddy

* Corresponding author. Tel.: +060-1111-568-370 .
*E-mail address:*eng.abdallah.2013@gmail.com

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fields. Manual readings are susceptible to error (Saraswati et al., 2012). There are transducersbased onresistive,inductive, or capacitive being used in automatic liquid level sensing systems, but, these transducers are not meant for long field measurement, when submerged in water for long period, they would suffer from corrosion, short life span, and water composition (Rosolem et al.,2013). There are also transducers based on contact sensors, which are not ideal due to vibration, sensitive applications, long time readings, and high resolution systems (Linboet al., 2011). In order to overcome the abovementioned problems and restrictions, this paper presents the development of a transducer, based on non-contact method to measure position in linear motion.

The objective of this paper is to describe the development of a precise positioning system based on pixel differential in linear optical sensor.

2. Methodology

A photodiode is sensitive to the level of illumination. Consider this simple concept, displacement of an object can be determined from a simple count based on vector differential from a linear array of photodiodes.

2.1. The setup of position measuring platform

Fig.1 shows the proposed measuring system in which a linear optical sensor was mounted above the ruler grating scale in such a way that the optical axis of the sensor was perpendicular to the surface of the scale. Forbetter reading accuracy, the distance between the optical original and the scale needs to be taken into account. Two sliding rods were designed to carry the transducer, and to allow it move freely in two directions. The movement of the transducer can be done by manual action or DC motor attached to the pulley. The platform was fabricated to measure long range displacement, so the vibration and the fluctuation affect on the transducer movement. However, when the belt moved, it generated vibration in sensor view which leaded the system to be unstable. In order to provide better stability, two sliding rods were positioned to move in parallel with the belt; furthermore, to carry the sensor transducer. Note that the measured range was 1000mm while, the distance between black stripes was 1 mm.

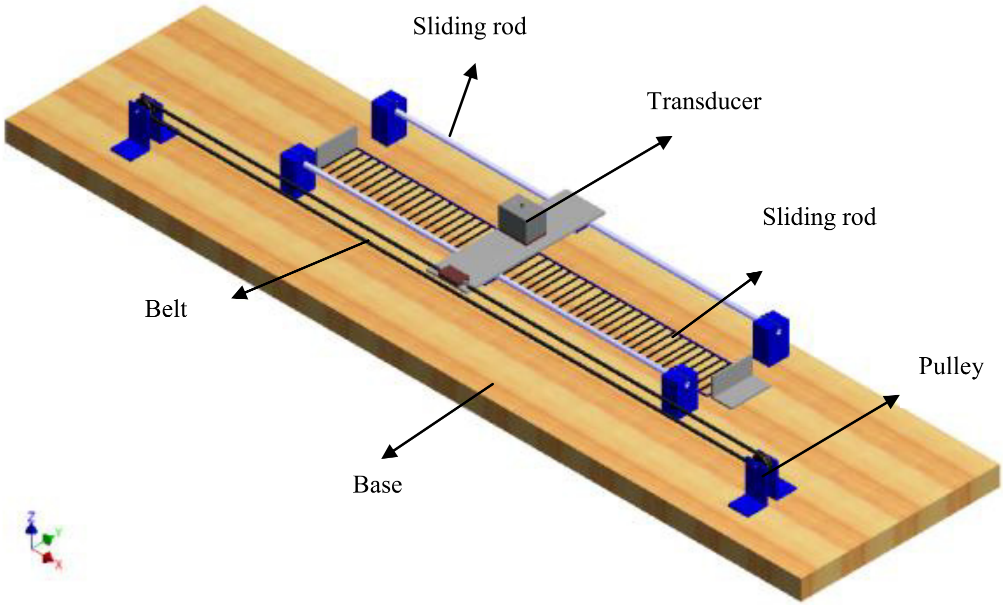

Fig. 1.Proposed position platform system.

2.2. The setup of sensor transducer

The transducer was designed to resemble a black camera with a linescan sensor as the sensing element(Fig. 2). The sensor was perfectly covered in a box which prevented leakage of external illumination. The lens focal length was8 mm,and the lens was mounted above the line scan chip directly in order to form images on the sensor array. The distance between the grating scale and the frontal apertures (Dw) was observed based on the relationship in Eq.(1). Here, $L_{focal}$is the focal length of the lens while, L_{object} represents a length of the image and $L_{array}$is the length of the line scan chip. The length of image was designed to be equal to the length of the array. Therefore, the length of the array was 8.128 mm which was the same value for the length of the image (Mahadi, 2011).

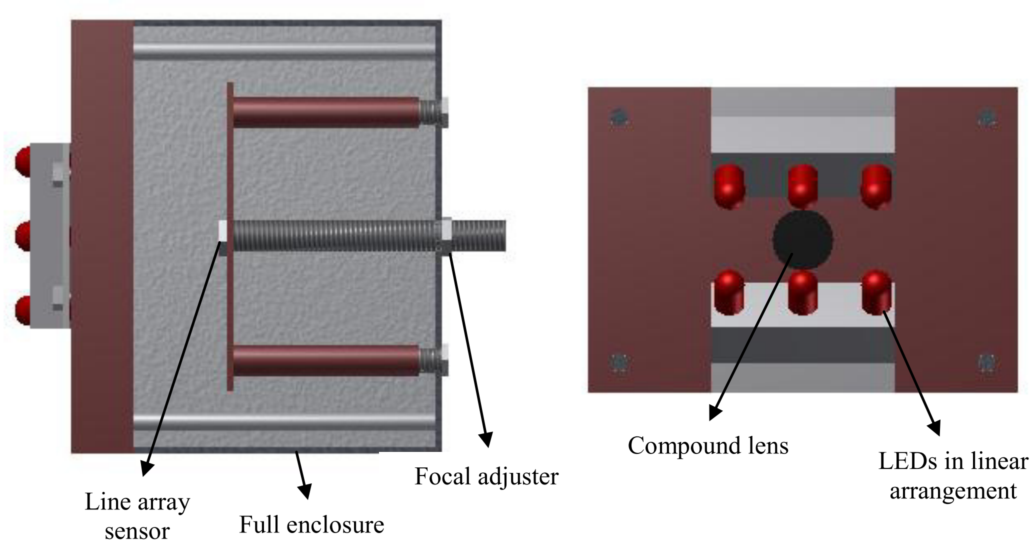

Fig. 2.Conceptual design of the direct image encoding transducer.

$$Dw = \frac{L_{focal} \times (L_{focal} + L_{image})}{L_{array}} \quad (1)$$

In order to have the sharpest focus on the grating scale, the lens had an adjustment capability. In case of the distance between the frontal aperture of the lens and the plane of the sensor was adjustable, the improvement in the image was allowed. In our design, the distance between the lens and the sensor was fixed, but the distance between the gratings and the lens was adjustable. Two arrays of LEDs were fixed around the external aperture of the lens in order to control the level of illumination. The focal length of the lens was critical effect such that the shorterfocal lengthgot shorter distance between the grating scale and the frontal aperture.

2.3. Relationship between pixel counts and displacement

The displacement has scalar and vector components, so that the position based on the magnitude of movement. This magnitude was calculated by summation of pixel cycles which were the result of line scan movement through grating scale. One cycle consists of two sequential black and white stripes, which generated 0 Volt (black) and 5 Volt (white). As shown in Fig. 3, the displacement of 1 mm was equal to the difference between two successive rising or falling edges.The falling edge is known as the transition between the white stripe to black stripe; in contrast, the transition between the black stripe to the white stripe is defined as rising edge. Now, the equation which described the displacement for the linescan sensor movement in one direction is shown in Eq.(2). Dw is the displacement function, and the size of the cycle is the distance between two cycles which is equal to 1 mm. So, the displacement as shown is the product of the number of cycles and the size of the cycle. This technique to observe the displacement is called incremental codes which is used for long travelling range. In addition, it is feasible to generate a high resolution measurement (Merino et al., 2007).

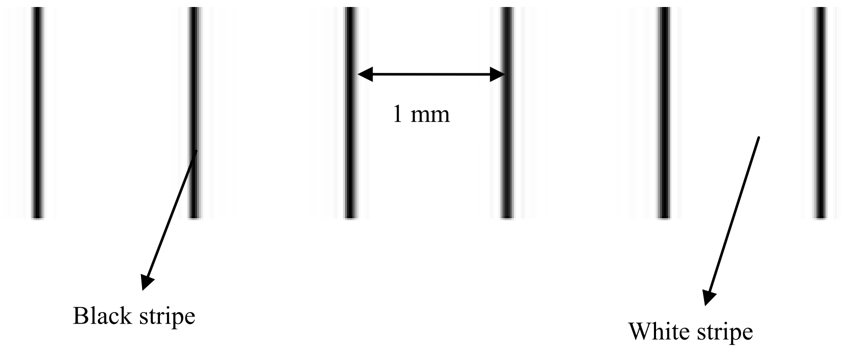

Fig. 3. Section view of grading scale.

$$D = (\text{Number of cycles} \times \text{Size of cycle}) \quad (2)$$

When the sensor moved in either forward or reverse, a robust technique was required to measure the displacement for two direction movement. The phase manipulation concept was exploited to know the direction of travelling. On linear array sensor, there was a 128 photodiodes set which generated 128 pixels as output. While the sensor was moving, the first pixel or the last pixel determined the direction of sensor movement. For example, when the sensor passed through the black stripe, the output of the first pixel was 0 volts while the output of the rest stilled 5 volts which mean the sensor was going in (x) direction. In contrast, in (-x) direction, the last pixel was 0 volts and the output of the rest was 5 volts. The next section discusses the position for the sensor which moved in two directions.

2.4. Determine the position based on linear array sensor anddisplacement function

The optical relation (Eq.(1)) describes the parameters of image view. The length of the sensor array and image was 8 mm; however, the linear array sensor had 128 pixels which captured 8 mm of image length. In other words, the linescan sensor scanned 8 mm of grating scale, thus 16 pixels covered two successive white and black stripes which represented as 1 mm. Because of the uniform division in grating scale, the position was measured using read the outputs of 16 pixels in order to count the number of cycles. Cycle counting for sensor movement in linear motionis explained in Fig. 4.

In Fig. 4, the black stripe image is shown as 0 in the first pixel, while the pixels from 2 to 16 represent the image of the white stripe. The move array function is an array contains the values of 16 pixels that 0 values for black and 1 values for white. This function was varied rely on the position of the sensor. Move array (1) was the starting position for the sensor and the reference array for cycles counting. When the sensor moved, pixel number 2 or 16 in move (2) determined the direction of motion either in (x) direction or (-x) direction. If the second pixel in move (2) was 0 that mean the sensor moved one pixel displacement in (-x) direction. However, if the sensor kept travelling in (-x) direction, the black stripe image shifted one pixel in the next move array function as shown in Fig. 4(a). A 1 mm displacement was the sensor movement from move (2) to move (17) in (-x) direction. Conversely, if the last pixelin move (2) was 0, the sensor moved one pixel displacement in (x) direction. While the sensor was moving, the black stripe image jumped one pixel displacement as shown in Fig. 4(b). At move (17), one cycle was counted, and 1 mm displacement was shifted in (x) direction.

Black stripe image

Number of pixels

White stripe image

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
move(1)	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
move(2)	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
move(3)	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
move(4)	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
move(5)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
move(6)	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
move(7)	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
move(8)	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
move(9)	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
move(10)	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
move(11)	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
move(12)	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
move(13)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
move(14)	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
move(15)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
move(16)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
move(17)	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

(a)

White stripe image

Number of pixels

Black stripe image

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Move(1)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Move(2)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
Move(3)	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
Move(4)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
Move(5)	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Move(6)	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
Move(7)	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
Move(8)	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
Move(9)	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
Move(10)	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
Move(11)	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
Move(12)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
Move(13)	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Move(14)	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Move(15)	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Move(16)	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Move(17)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0

(b)

Fig. 4. (a) description of 1 mm displacement in (-x) direction; (b) description of 1 mm displacement in (x) direction.

Eq.(3) illustrates the position for long range travelling in linear motion; the size of one cycle was 1 mm.

$$Postion = (\text{Number of cyles in (x) direction - Number of cyles in (-x) direction}) \times \text{Size of one cycle} \quad (3)$$

3. Hardware

The measurement described in the previous section was implemented on a linescan array chip. The chip was TSL1401CL (Fig. 5), and it consisted of a single row of 128 photodiodes. The dimension of each pixel was 63.5 µm heights by 55.5 µm widths. There was 8 µm spacing between pixels, while the distance was 8.128 mm measured from edge to edge of pixels array. The sensor had three signals which needed to be considered: CLK (digital output to the sensor: clocked the pixel out and latched SI), SI (digital output to the sensor: began ascan), and AO (analog pixel input from the sensor: 0 – Vdd). AO signal was the image of pixels of the positioning marker (Mahadi and Billingsley, 2008).

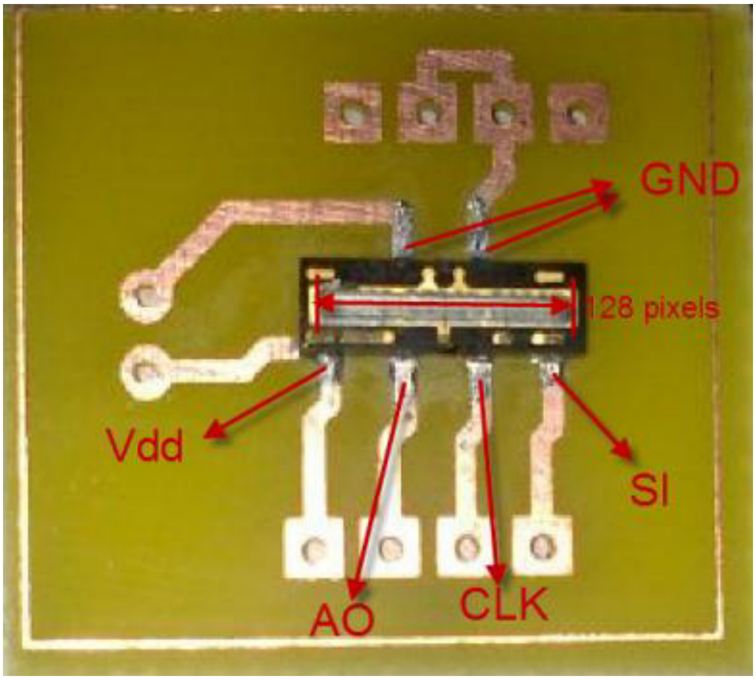

Fig. 5. TSL1401CL line array sensor connection.

4. Results and discussion

Fig. 6 shows the image reflected to the line scan elements. A series of stripes (white and black) with 1 mm spacing was printed on a paper. As shown in Fig. 6, the waveform at white stripe is 5 volts, while it is less than 5 volts at black stripe. This waveform was processed using internal comparator to observe pure 5 volts and 0 volts. The difference between the rise edge and next rise edge was converted to the measured length. The average measured length was 0.998 mm that means the error was the difference between the actual length (1 mm) and measured length (0.997 mm) which was equal 0.003 or 0.3%. Table 1 shows the position measured at various points and the measurement error at every point. The result was acceptable to keep working on vertical motion. The highest resolution can be executed by line scan module is .0635 mm which is harmonious with water level application. The two linear arrays of LEDs gave a suitable illumination level that was uniformly distributed across the view scope.

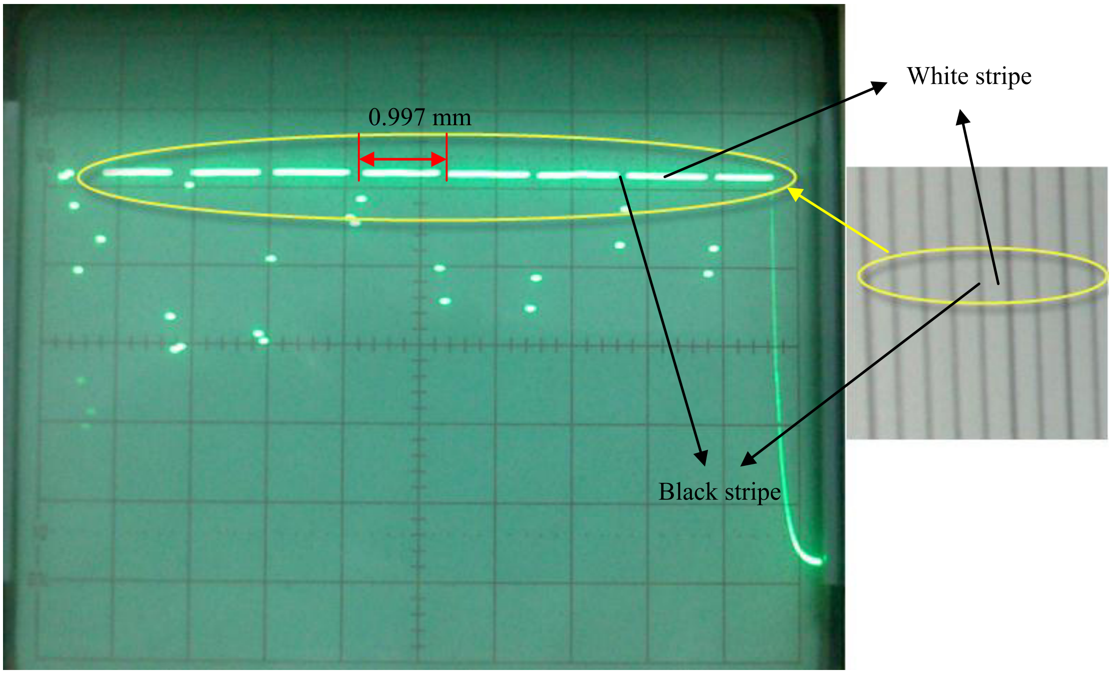

Fig. 6.A 8 mm stripes as seen on the oscilloscope.

Table 1.Measurements of position for a sensor movement at some points.

Actual position (mm)	Measured position (mm)	Error (%)
20	19.9	.005
100	100.2	-.002
250	250.1	.001
500	500.4	-.004
800	799.7	.003
1000	1000.4	-.004

5. Future work

There are a lot of developments for this project design. This project is a concept for water level system. The platform will be designed as a water proof model with 1 meter measured distance range. In addition, the improvement will be done for the sensor design, especially illumination, focal length, and stripes image. Moreover, the transducer must have a variable focus to the grating scale to get clearest image.

6. Conclusions

Pixel counting approach was able to measure the pitch of a stripe within 36 µm. Linear array sensor adapted to the design, whereas the use of grating scale with 1 mm resolution was justified. Some improvements will be required for both electrical and mechanical aspect in order to design it as reliable sensor.

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