

Precise Measurement of Displacement using Pixels

Razif Mahadi, and John Billingsley

Abstract—Manufacturing processes demand tight dimensional tolerances. The paper concerns a transducer for precise measurement of displacement, based on a camera containing a linescan chip. When tests were conducted using a track of black and white stripes with a 2mm pitch, errors in measuring on individual cycle amounted to 1.75%, suggesting that a precision of 35 microns is achievable.

Keywords—Linescan, microcontroller, pixels.

I. INTRODUCTION

A vision based sensor permits real time monitoring and non contact measurement of precise displacements within a manufacturing system. Although much theoretical work in the area of machine vision concentrates on feature recognition [1], [2], here there is a need to measure only a single parameter, the displacement. Such a system is useful for setting up and controlling the machine and for measuring critical parts of the workpiece in real time, before it is transferred to another operation.

There is a conflict between the frequency at which readings can be taken and the level of illumination required. For very short apertures, a millisecond or less, bright lighting is required. Of course this can be visible or infrared. There are two ways to apply lighting. Firstly, the light source faces the sensor, while the object is placed in between them. This is called direct illumination. Some optical sensors use this arrangement [3].

Alternatively the light can be reflected by the object to the sensor [4], [5]. In this arrangement, the sensor can have a compact design and easily fit into small sections of the machine.

Another aspect that must be considered is the device used to produce the light source. In recent years, advancement in the design of LED has produced numerous LED types of reasonable cost. High intensity LEDs have been seen as the potential light source provider for vision sensor application [6].

This paper describes the design of an instrument to measure the displacement precisely. The design is based on a linescan

chip. The design also considers compact and low cost components.

II. THEORY AND DESIGN

Two-phase incremental optical encoders are a familiar way to measure displacement. The relative phases give a clear indication of the direction of travel and 'bounce' errors are virtually eliminated. It is possible to go much further and use a linescan chip with 128 elements to monitor the motion. This goes beyond the incremental encoder by allowing position to be detected to the width of a single pixel, or to even less if the average is taken over several cycles 'in view'.

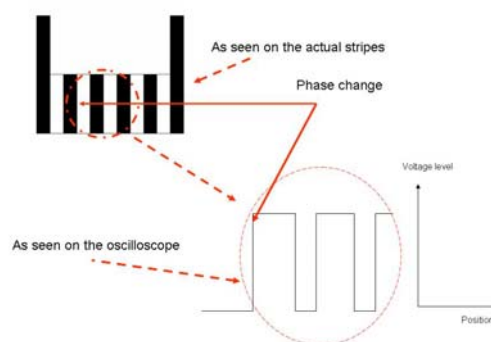


Fig. 1 Phase change in a square waveform

Provided the information rate is sufficiently high that the axis does not move by more than half a strip per sample, cycles can be counted without ambiguity. There remains the task of assessing the remaining displacement in terms of a fraction of a strip. For this, the pixel pitch must be calibrated in terms of the pitch of the scale's cycle.

In one complete cycle, a square wave consists of a binary high and low or vice versa. The cycle has a fixed ratio to a unit of length. An optical encoder for instance generates square waves by interrupting the light's energy being transmitted to the photo sensor. Alternatively, consider a photo sensor with two identical elements in a row, sensing a black and white stripe in front of it, the element that sees white transforms the signal as a high, while the element that sees black transforms the signal as a low. In a case where the black and white coexist within one element, the voltage generated by the image will be compared to a value of threshold in order to set the element as a high or a low. Therefore, the sensitivity of the sensor, S mm is half of the

Manuscript received March 31, 2008.

M. R. Mahadi is with the University of Southern Queensland, Toowoomba, QLD 4350 Australia (corresponding author to provide phone: 617-4633-2633; e-mail: mahadir@usq.edu.au).

J. Billingsley is with University of Southern Queensland, Toowoomba, QLD 4350 Australia (e-mail: billings@usq.edu.au).

width of a pixel, P_w mm (1).

$$S = 0.5P_w \quad (1)$$

One of the drawbacks of counting with pixels is the possibility for two successive elements indicating false high or low. In this situation, the sensor will have erroneous measurement. As a safety measure, the threshold must have a value slightly different than half of the peak value.

The transition between stripes constitutes a phase change in the waveform. For example, if there are two cycles in one sample, the sensor is able to detect four phase changes (Fig 1). These phase changes can be classified into two, such that the transition between a black/white is *rise*, while the transition between white/black is *fall*. The distance from the first *rise* or *fall* to the second *rise* or *fall* is equal to the length of a cycle. If the number of pixels is mapped accordingly, we are able to count the number of pixels required to reach the first *rise/fall* and the second *rise/fall*. Hence the number of pixels for a cycle, P_{cycle} is equal to the number of pixel of the second *rise/fall* P_{II} minus the number of pixel of the first *rise/fall* P_I (2). In this case, P_{cycle} is also the pitch of the stripes.

$$P_{cycle} = P_{II} - P_I \quad (2)$$

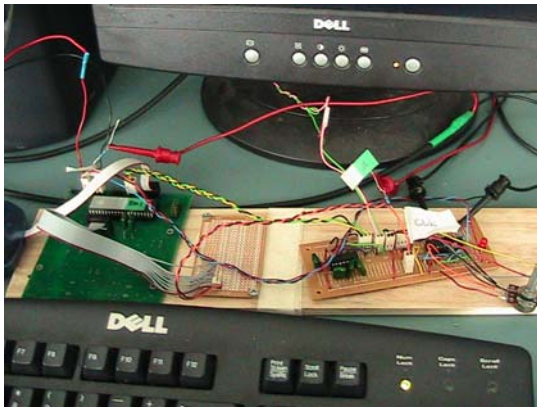


Fig. 2 Sensor controller circuit

In one measurement sample, at least two cycles must appear in the measured zone. More than one cycle improves the iteration if they are averaged, but the codes execution is time consuming.

In digital measurement, the sampling time is crucial, because shorter sampling time limits the amount of exposure and the clarity of the image. This problem is major for the reflective type system. One of the solutions is to provide high level of illumination. However, there is a possibility that if the illumination is excessive, the difference between the black and white images would diminish.

Instead of increasing the illumination of the light source, the design could vary the threshold according to the sampling time. Nevertheless, the threshold should not be set too low because a low level threshold reduces the sensitivity of the sensor.

III. EXPERIMENTAL SETUP

A vision based sensor was designed for the experiment (Fig 2). The design was based the method of reflecting the lights from the light source. Therefore, the sensor could detect any stripes printed on any materials as long the material reflects the lights energy. The light source was provided by two high intensities white LEDs.

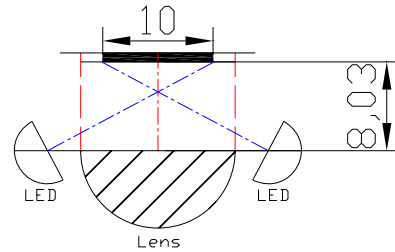


Fig. 3 Led arrangement

Greater illumination is achievable if more than one LEDs illuminating a common area (measured zone). For example, if the measured zone has a diameter of 10 mm and the LEDs are installed pointing straight to the plane of the stripes, the minimum viewing angle for that LED is 62° . However, LEDs with this value of viewing angle is rare and expensive. An alternative solution is to point the centerline of the LEDs to intersect with the furthest edge of the measured zone. Therefore, the LEDs must be installed at 62° from the axis normal to the stripes (Fig. 3). This arrangement will be suitable for LEDs with common viewing angle (i.e. 15° or 20°).

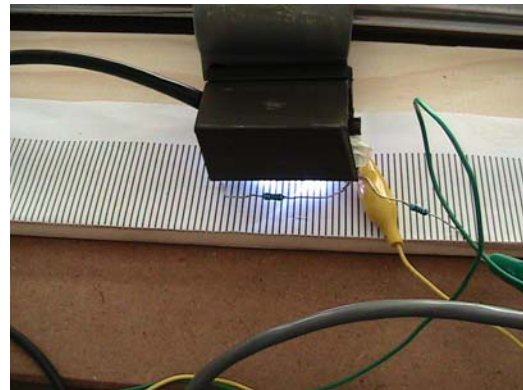


Fig. 4 Sensor measuring the stripes

The instrumentation consisted of a linescan chip, a microcontroller, a comparator and an RS232 chip. The linescan chip was a TSL1401R with 128 photodiodes in a single row. An Atmega8535 microcontroller initiated the linescan by transmitting a series of high and low bits to activate the clock and signal. The comparator collected the analogue output signal and compared the value with the threshold (controlled by a variable resistor). The RS232 transmitted the processed output to a PC.

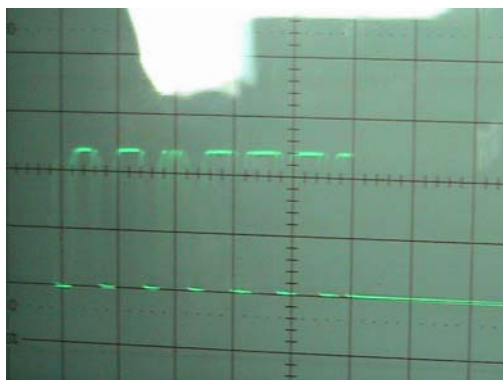


Fig. 5 A 2 mm pitch black and white stripe as seen on the oscilloscope

The sensor sensed the stripes through the image reflected to the linescan elements (Fig. 4). A series of black and white stripes with 2 mm pitch was printed on a piece of paper. Two high intensity white LEDs, installed on each side of the lens illuminated the measured zone. The waveform was monitored on an oscilloscope (Fig. 5).

The code was written in C. The interrupt cycle was programmed to occur every 4 ms and the data were recorded. Another measurement that corresponded to the different level of interrupt cycle and the peak volts generated were also recorded.

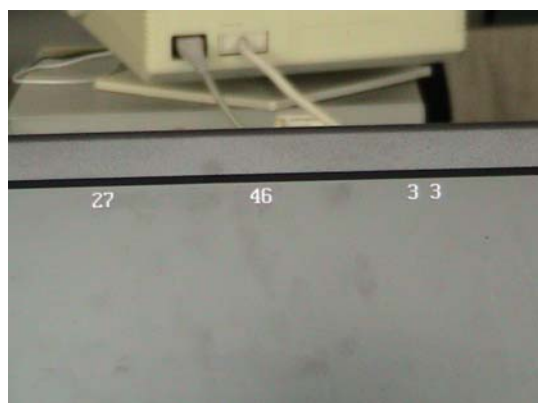


Fig. 6 Pixels data obtain from RS232

IV. RESULT AND DISCUSSION

Measurements were taken at random spots (Fig. 5 and Fig. 6). The number of pixels for the first *rise* and the second *rise* were recorded.

The first number in Fig. 6 shows the number pixels for the first cycle as measured from the first element in the linescan. The second number in Fig. 6 indicates the number of pixels for second cycle, also measured from the first element in the linescan. The third number in Fig. 6 shows the difference between the first rise of the initial and the latest measuring samples.

The difference between the second rise and the first rise was converted to the equivalent length. From observation, the average measured pitch was 1.973 mm. If we assumed that the

printed stripes had exactly 2.00 mm actual pitch, the difference between the measured and the actual pitch was 0.035 mm (35 μ m) or 1.75%.

V. FUTURE IMPROVEMENT

There are a number of future improvements for the sensor design. For instance, the linescan sensor requires improvement in the design of the LED housing in order to provide sufficient illumination to reflect the image of the objects on the photodiodes. If the illumination is sufficient, the noise in the signal will reduce significantly. Moreover, the linescan chip will need a 'black box' enclosure in order to prevent external light source to disturb the image. Then, the mechanical design of the sensor must have a variable focus between the linescan sensor and the collimated lens in order to obtain the sharpest image. A parallel gap between the lens and the linescan sensor is vital so that the size between the first and second cycles appear as equal.

VI. CONCLUSION

The result indicated that a pixel counting method was able to measure the pitch of a stripe within 35 μ m. However, a number of improvements will be needed. Improvement is needed for both the mechanical and electrical aspect in order to design it as a reliable sensor.

ACKNOWLEDGMENT

The authors thank to the Buchanan Advanced Composite (BAC), Toowoomba and the Government of Malaysia for supporting this project.

REFERENCES

- [1] C. Connolly, "Vision enabled robotics," *Industrial Robot: An International Journal*, vol. 32, pp. 456-459, 2005.
- [2] A. Shafi, "Machine vision in automotive manufacturing," *Sensor Review*, vol. 24, pp. 337-342, 2004.
- [3] I. Alexandre and M. Artes, "Method for evaluation of optical encoders performance under vibration," *Precision Engineering*, vol. 31, pp. 114-121, 2007.
- [4] C.-F. Kao and M.-H. Lu, "Optical encoder based on the fractional Talbot effect," *Optics Communications*, vol. 250, pp. 16-23, 2005.
- [5] S. Merino, A. Retolaza, A. Juarros, and S. Landis, "A new way of manufacturing high resolution optical encoders by nanoimprint lithography," *Microelectronics Engineering*, vol. 84, pp. 848-852, 2007.
- [6] H. Houghton, "LEDs: A flexible option for machine vision," *Sensor Review*, vol. 22, pp. 130-133, 2002.

Razif Mahadi is a research student at the Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba Australia.

John Billingsley holds a personal Chair of Mechatronic Engineering at the University of Southern Queensland. He is a Fellow of the IET and of Engineers Australia. He is co-chair of the IEEE RAS Special Interest Group on Robots in Agriculture. In 2006 he was awarded an IET Achievement medal.