High Resolution Measurements Using a Low Resolution System

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Abstract:
The resolution of any measuring device influences significantly the achievable accuracy of the system. In this paper, the resolution limitation of measuring devices has been addressed. A theory is developed that allows a measuring device to measure beyond its resolution capability. It is theoretically proved that a very high resolution can be achieved with a very low resolution system. The application of the theory is suggested to be employed by vision system; however, the methodology is applicable to other digital measuring devices.
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INTRODUCTION

Dimensional measurement is an essential activity almost in any part manufacturing industry and in many quality control departments where bough-in parts have to be controlled. Traditionally, mechanical and optical equipment have been used to measure the dimensions of parts. Manual mechanical/optical equipment is usually inexpensive but they have limited use due to a variety of reasons such as low speed, lack of accuracy, and human dependant accuracy. Higher accuracy systems such as CMM's, and Laser Scanners may be used, but a CMM is both expensive and the process is very slow. Although laser scanning is very fast relative to a CMM but it is very slow when compared with a vision system. Using a matrix array camera provides a large amount of data in a single image capture at a rate of typically 30 frames/second. The speed becomes important when a very large number of points (an edge or a surface) has to be scanned for measurement purposes.

Machine vision (MV) has a widespread use in a variety of applications. The majority of MV applications lay in inspection. In terms of methodology and processing complexity in many cases visual metrology is far simpler than some complex inspection routines. The use of MV in two dimensional (2D) metrology is fairly simple. Interestingly most of actual measurements required in actual applications are two dimensional. Use of MV in metrology has many advantages over traditional methods. These include the high speed of the measurements, flexibility, being non-contact, low cost, and ease of seamless integration, however, MV has some limitations. In addition to difficulties to apply MV in real applications, the accuracy achieved using MV for metrology purposes in many instances are not satisfactory. Although improvements in processing speed of computers and increased number of sensor elements in cameras have made higher accuracies available but still the accuracy required in many metrology applications is either far from achievement or it requires very expensive and dedicated systems that are not justified economically for many applications [1, 2].

This paper addresses the resolution limitation of MV and deals theoretically with the problem. It is shown that higher resolution measurements can be achieved using a low resolution system.

LIMITED RESOLUTION AND MEASUREMENT

There are several factors that determine the resolution of an MV that include the resolution of the lens, camera, A/D process, and the memory. The system's resolution is limited by the lowest part's resolution. Very often the resolution of the camera is simply considered as the system's resolution. Although, this is not usually true but it actually gives the theoretical resolution.

Today's Mega pixel cameras employ millions of pixels that provide higher resolutions but they are limited and that limits the smallest measurable value. The physical dimension of the object being measured by the system is determined in terms of pixels, which can be converted to physical dimensions.

Supposing a camera with an N * M sensor is used to measure an object L (mm) in length then in a very simplified system the maximum resolution that can be theoretically achieved is L/N in *mm.*

A mega-resolution camera with 1000 * 1000 sensor elements when measuring an object 100 *mm* in length can at its best result in a resolution of 0.10 (*mm*). With uncertainty at two edges the camera would read the length as $L \pm 0.1$, hence, 0.20 (*mm*) uncertainty. However, by considering other limitations and sources of errors [3, 4] the accuracy that can be achieved would be less. The accuracy required for most of part manufacturing is usually in the order of 0.01 to 0.1 (*mm*). The need for higher accuracies in most of part manufacturing applications disqualifies MV technology for metrology purposes.

The problem has been addressed by researchers in the past and ways to overcome have been studied. The next section reviews previous works.

PREVIOUS WORKS

Attempts to increase the resolution/accuracy of MV include hardware and software solutions. Increasing the number of sensor elements of sensing array is the most obvious way of increasing the resolution, however, other affecting factors such as the lens resolution and the sampling rate (for TV standard signals) have to be conforming. High resolution systems incorporating a large number of sensor elements are very expensive yet limited in resolution and not being able to achieve the level of accuracy required in many applications.

Use of traveling camera, zoom in/out camera, multi camera where the scene is divided into smaller divisions have been employed in different applications [5-7].

Again such systems are expensive and more importantly require long set up and operational times.

Use of prior knowledge about the scene, subpixel algorithm, are examples of methods based on software to improve the accuracy of MV in metrology applications [8]. These methods are not applicable in instances where prior knowledge is not available or it is difficult to employ.

It worth noting that, some methods can be used in conjunction with others improving the total accuracy.

BEYOND THE RESOLUTION CAPABILITY

Assuming that a sensor with $N \times M$ elements is employed to measure the length of an object L in length. It is further assumed that the system works as a binary system or the image is converted to binary. When measuring the Length of the Object of Interest (LOI), regardless of the threshold value, the round off process will result in a reading as L_r, (see Fig. 1);

Where $L_r = [L - X] + 1 \pm 1$

Therefore, the uncertainty on the measured length is 2 pixels.

Repeated measurements can only reduce the random errors and produce no improvement over errors originated as a result of lower resolution. In this paper it is suggested that to repeat measurement while each measurement is carried out at a different relative object to sensor position. Provided that enough number of such repeated measurements is performed the accuracy could achieve the desired level.

The position of the object relative to the sensor array has a random nature and the edges of the objects can lies anywhere within a pixel, then the measured value L_r can be expressed as:

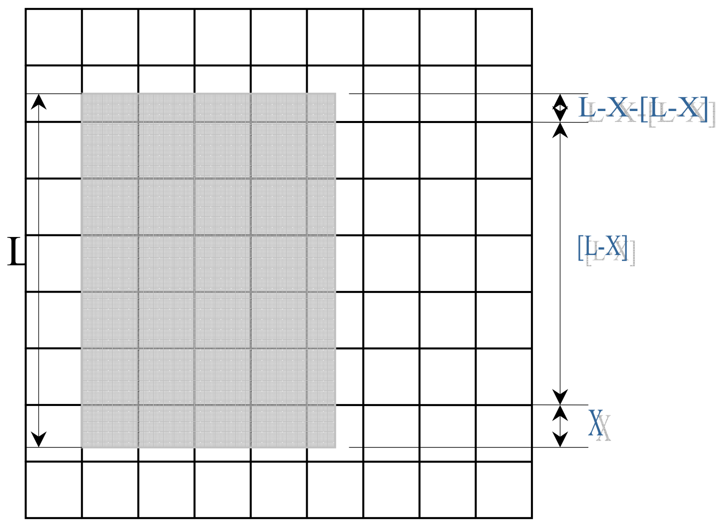

Fig. 1 : Measuring the length of an object along vertical axes, where the uncertainty

$$L_r = [L - X] + T_r(X) + T_r(L - X - [L - X]) \quad (1)$$

Where $T_r(*)$ is the threshold function defined as

$$T_r(Z) = \begin{cases} 1 & Z \geq T \\ 0 & Z < T \end{cases}$$

(2)

T is the threshold value.

Since L_r is a function of the Random Variable (RV) *X*, the statistical mean of the measured value can be expressed as;

$$\mu_{L_r} = E(L_r)$$

(3)

where *E*(.) denotes the expected value. Substituting (1) into (3) yields

$$\mu_{L_r} = \underbrace{E([L - X])}_{(I)} + \underbrace{E(T_r(X))}_{(II)} + \underbrace{E(T_r(L - X - [L - X]))}_{(III)}$$

(4)

To calculate the μ_{L_r} each of the three terms are calculated separately which will result in;.

$$E(L_r) = L - 1 + 1 - T + 1 - T = 1 - 2T$$

(5)

or equivalently

$$E(Error) = E(L_r - L) = 1 - 2T \quad \because$$

(6)

(See [9] for full development).

It is observed that the error becomes zero if the threshold is set to 0.5.

$$T = 0.5 \longrightarrow E(Error) = 0$$

(7)

This is achieved when the measurements are carried out in many different (random) relative positions between the object and the camera.

RESULTS AND DISCUSSION

It was shown that the error of a vision system when measuring dimensions can be reduced to zero. This requires a large number of measurements carried out in different relative object to sensor array positions.

Although it is practically impossible to perform indefinite number of measurements, but it will however improve the accuracy with limited number of repetitions. A very accurate measurement can be obtained in the expense of time.

Performing repeated measurements is very simple and need not any further equipment. After each measurement either the object or the camera is moved manually by an amount of a fraction of Millimeter to any amount.
The method is not substitutive to many other methods, it is rather complementary.

CONCLUSION

It was theoretically shown that a low resolution vision system can produce very accurate measurements. The error originated from a lower resolution system approaches zero as long as there exists enough repeated measurements, each taken at a different position.
Application of the method in practice is very simple and requires no further equipment. It is fast and requires no further processing power.

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