PRODUCT:	**iGauge**
SUBJECT:	Accuracy and Repeatability
DATE:	May 16, 2003

iGauge™ is an easy-to-use machine vision system for gauging – measuring distances, hole diameters and other dimensions on parts. Although gauging using machine vision is physically different from contact and laser gauging methods, the objectives are the same: how accurately can measurements be made and how repeatable are the results.

Comparing specifications for machine vision gauging systems can be confusing and expensive if you make the wrong choice. ipd's mission is to provide you with easy-to-use tools and understandable measurable specifications. In this Product Note we examine the general performance characteristics for any gauging system and actual specifications for our iGauge Vision Appliance.

What are Accuracy, Repeatability and Precision?

Repeatability, accuracy, and precision are important performance characteristics for any gauging system.

- *Repeatability* says how close together repeated measurements are, or the variance of the measures (see Figure 1- next page).
- *Accuracy* says how close the measures are to the true value. You can think of it as the mean difference between repeated measures and the true value.
- *Precision* means the number of digits to which the measurement gauge can be read.

A machine vision system, such as iGauge, can return measurement results with 7 digits, but only repeatability and accuracy tests will tell you how many of these digits are significant. In this case, precision is limited by the accuracy and repeatability characteristics, so we need not discuss precision further.

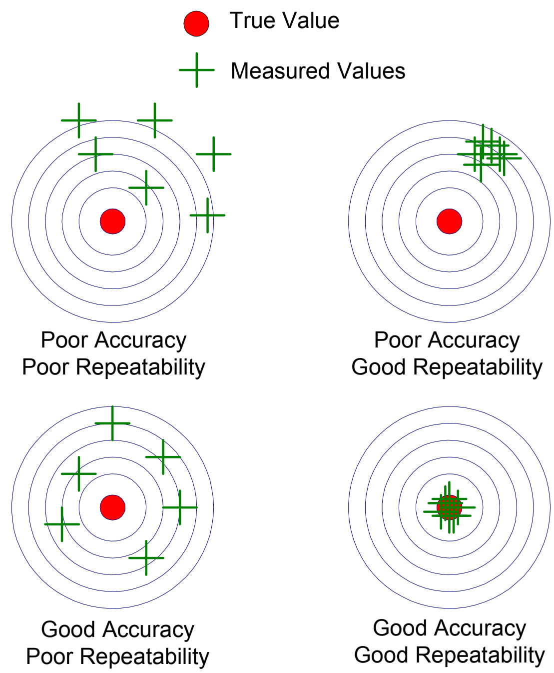

Figure 1. Accuracy is how close you are to the center (the true value) and repeatability is how close together the measurements are

<u>How are Accuracy and Repeatability Specified?</u>

Machine vision measuring systems can specify accuracy and repeatability in terms of physical units, like microns, but only when the image field-of-view, lens and camera are known and fixed. Because iGauge can be used with a range of fields-of-view and lenses, we must specify accuracy and repeatability in terms of *pixels*, the size of the individual camera image elements when projected into the field-of-view.

You can estimate physical values for the accuracy and repeatability if you know:

- Your field-of-view (the dimensions of the area seen by the camera) and the number of elements in the camera's image sensor. From these you can compute your projected pixel size in physical units.
- The gauging system's accuracy and repeatability, measures in projected pixels.

For example, a 6-inch, horizontal field-of-view viewed by a 640 x 480 element sensor will have an projected pixel size of about 6/640 = 0.0094 inches or 9.4 mils (thousands of an inch). If accuracy is specified as ½ of a pixel, then you should be able to measure to within 0.0047" or 4.7 mils.

How Does iGauge Work?

To effectively measure parts, dimensions, holes, etc. with iGauge, you must:

- Provide lighting (illumination) that clearly shows the things you want to measure
- Select a lens and working distance (the distance from the lens to the object being measured) that give a good field-of-view. A good field-of-view includes the areas of the part to be measured and a little more to allow for part movement and alignment, but nothing else.
- Properly fix the part being measured in the field of view of the camera.
- Make sure that the accuracy and repeatability offered by iGauge are appropriate to your measurement task.

iGauge takes measurements between "edges" in the image. An "edge" is an abrupt change in intensity (brightness) and often, but not always, corresponds to a physical edge, like a hole in a part. Besides physical edges, printing, marks, scratches and shadows can be seen as edges. Some of these non-physical edges are fine to use for measurement but others, such as shadows, can be too variable for reliable measurement. You also cannot measure something that does not appear as an edge in the image. For example, a smooth change in intensity or fuzzy blobs are not appropriate things to try and measure with iGauge.

Once you have specified the edges you will use for measurement, iGauge uses information around the edges and proprietary algorithms to measure the edge positions to a fraction of a pixel.

What Factors Influence Measurement Accuracy and Repeatability?

In any machine vision measuring system, there are several influencing factors to consider:

1. Lighting – Select lighting (illumination) so iGauge can see the "edges" you want to measure. Good lighting will amplify the edges you are interested in and reduce edges you don't want to see. Bad lighting can make any measurement impossible! ipd's web site and manuals provide an introduction to lighting and ipd can recommend lighting professionals to help you with this.

2. Positioning – You have to put the part being measured in the camera's field of view. If you can position the object precisely in the field of view then iGauge will work better and faster. This is often done by a mechanical "stage" or "fixture" that holds the part being measured for the duration of the measurement.

3. Optics (lens) – how clearly is the image being projected onto the sensor? A vision measuring system is only as good as the image it is processing. The lens must be good enough to faithfully present the image to the sensor. Distortions in the lens can lead to measurement error in the part. Selecting the right lens is also important to maximize the features of interest. Magnifying these features leads to more accurate measurements. ipd provides a lens selection program to help you pick lenses to try.

4. Camera – The camera must be specifically designed for machine vision measurements. This includes having square (1:1 aspect ratio) pixels, sequential read-out of the pixels, low "jitter" when the pixel intensity values are digitized, and other features. The cameras designed for and optionally supplied with iGauge are precision machine vision cameras.

5. Algorithms – We mentioned iGauge's algorithms that measure between edges to a fraction of a pixel. Other important algorithms in gauging include *search* (the ability to locate a part in the field of view) and *calibration* (the ability to translate pixels into real measurements and compensate for image distortion introduced by the lens). The iGauge algorithms are outstanding, but you must pay attention to proper lighting, positioning, and the lens quality to get quality measurements.

Given the many potential sources of measurement error – illumination, variable positioning, lens distortion, algorithms, camera response, etc -- some suppliers of vision gauging systems give theoretical specifications as opposed to measured performance. As a result, you might see specifications like 1/40th of a pixel, but it will be impossible to achieve this accuracy or repeatability in practice. This might look good on a specification sheet, but will not tell you what you need to know to evaluate the system's performance. So, instead of fluffed-up theoretical specifications we give real, measured performance values.

iGauge Performance

Here we describe the experiments we performed to determine the effective performance of iGauge. We used an iGauge Vision Appliance, a 640x480 pixel camera pointing directly down at the target, a 9mm lens, and a standard Fostec ring light. The target was two white stripes mounted to a precision X-Y stage (see Figure 2). One stripe was fixed and the other moveable. The target positioned about 3 inches below the lens.

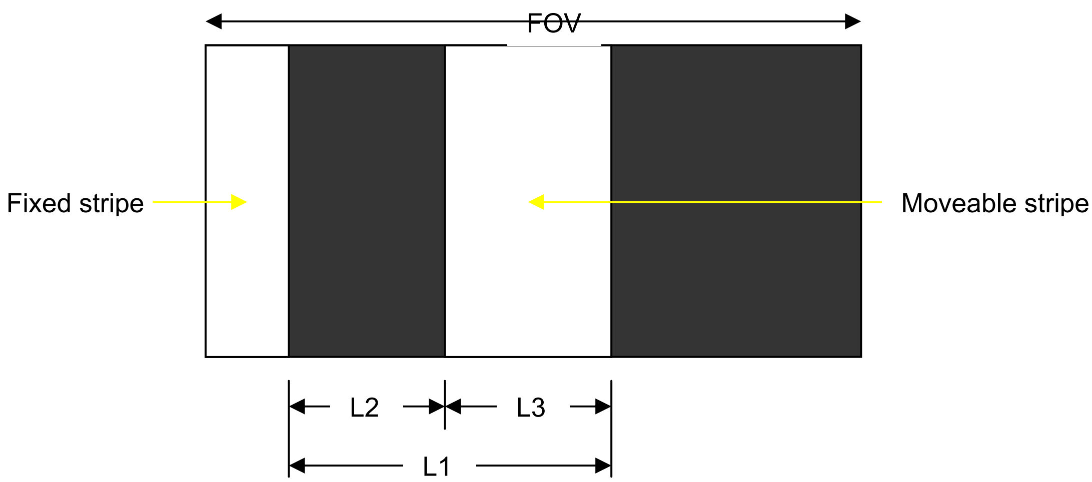

Figure 2. This drawing of the target shows the measured distances

Test 1 – Accuracy

We measured L1, the distance between the fixed stripe and the right edge of the movable stripe, and L2 the distance between the fixed stripe and the left edge of the moveable stripe (see Figure 2). The moveable stripe was moved from the starting position by 0.025, 0.05, 0.075, 0.1 inches. The movement was performed manually using a micrometer with a digital readout on the X-Y stage. Five measurements were taken at each position and averaged to reduce system noise.

Our field-of-view is 0.42307 inches, within which are 452 pixels. From this, the pixel size is calculated to be 0.935996 mils (thousands of an inch), and there are 1.0684 pixels per mil. Multiplying this last value by the movement steps in mils gives the predicted edge position in pixels for each of the four movement positions. The positions determined by iGauge were then compared with the positions read from the micrometer. Accuracy was taken to be the largest error between the predicted and actual movement. The average error between the actual and measured edge positions was accurate to better than 1/16th of a pixel.

To put this into physical units, suppose the field-of-view was 0.5 inches (12.5 mm) and 550 pixels are used for this field-of-view. The projected size of a pixel is then (12.5mm/550)*1000 = 22 microns. iGauge's accuracy would then be about 22/16 = 1.4 microns. Micron resolution requires a high-quality lens.

Test 2 – Repeatability

In this test we used the same setup as before, except that this time we measured the width of the moveable stripe L3. We took two measures of the width of L3 and at 24 positions as we moved the stripe horizontally. This movement introduces some of the variability you would see in practice – variations due to changes in position (relative to the camera's sensor array elements), lighting variations, and system noise such as shot noise and sampling errors.

For each of the two measures at the 24 positions, we computed the variance and standard deviation of the width. Because there are two measures (the left and right edges), we divide the variance by 2 and the standard deviation by the square root of two.

The scaled variance in the worst (larger) of the two measures was 0.0017 pixels and the scaled standard deviation was 0.0386 pixels. This standard deviation calculation indicates that iGauge measurements are repeatable to better than 1/25th of a pixel.

To put this into physical units, suppose the field-of-view was 0.5 inches (12.5 mm) and 550 pixels are used for this field-of-view. The projected size of a pixel is then (12.5mm/550)*1000 = 22 microns. iGauge's repeatability would then be about 22/25 = 0.88 microns. Micron resolution requires a high-quality lens.

Summary

Under the conditions we describe, iGauge can make line measurements that are accurate to 1/16th of a pixel and repeatable to 1/25th of a pixel. This outstanding performance comes from the use of multiple edge pixels in ipd's edge detection algorithm, error control and calibration methods.

You can translate these test results into physical measure by computing the size of a pixel when projected onto the object you are measuring. ipd's lens tool will do this calculation for you. You then multiply the projected pixel size by 1/16 and 1/25 to get an estimate of physical accuracy and repeatability, respectively, for your application.

In your gauging application many factors – such as poor lighting, noise, and lens quality – can reduce the accuracy and repeatability offered by iGauge. Our tests are meant as an estimate of what you can expect under good conditions, rather than a guarantee of performance in your application.