Machine Vision Gauging Accuracy

FSI Machine vision offers a broad range of products and expertise, which are particularly well suited for use for high accuracy gauging. It is all-too-common for machine vision applications to fail, and, unfortunately this is even more common on gauging applications. Under its APS™ (Assured Path to Success™) program FSI has batted “1000” on these applications. A first step of this program is to work with the customer to thoroughly define the requirements in a way that obtains the required performance, is technically credible, avoids ambiguity, and avoids making the mission overly expensive or impossible. A mission definition, which has the latter types of problems, will generally “scare off” the best vendors leaving only those who are either oblivious-to or ignore the technical issues involved.

The intent of this paper is to provide practical technical information in the areas that are most often confusing; first regarding accuracy, and then regarding measurement definitions.

Three Often-Confused Accuracy Areas

Three common mis-statements or errors in machine vision gauging are:

1. Confuse work piece tolerance with required accuracy of the measurement process.

2. At the other extreme, inadvertently specifying a requirement which requires an infinitely accurate / expensive system.

3. Discuss accuracy of the machine vision unit (array resolution etc.) as if it was the accuracy of the measurement process. Often this is done by someone who is either unaware of the technical issues involved; or who achieves sales or advertising benefit from this mis-impression.

The Numbers and Structure of Accuracy

As a starting point, let’s create and dissect an example. This is a requirement to inspect the dimension of a part which must be 1.000” +/- .001”. Let’s also say that the mission of the vision system is to make absolutely certain that no bad parts go out the door. This is actually two inspection missions, precisely stated as follows:

A. Reject all parts where this dimension is over 1.001”

B. Reject all parts where this dimension is less than .999”

An example of error #2 would be to add “Pass all parts between .999” and 1.001” to the requirements. This addition sounds reasonable but actually is not because it changes the requirement to a system of infinite accuracy/cost. For example, it would need to be able to make the distinction between a 1.00100000000000000001” good part and a 1.00099999999999999999999” bad part

An example of error #1 would be to assume that required accuracy of the machine vision equipment is simply the part tolerance, +/- .00”1. This will often be too inaccurate to do the job.

An indicator that an error #3 is in progress is when a person or company discusses imaging array resolution and sub-pixeling figures as being synonymous with the overall accuracy, or as an answer to a question about overall accuracy. As a reference point, the following is what our FSI Machine Vision’s accuracy statements could be in such a vacuum:

Our wide range of available imaging hardware combined with extremely powerful sub-pixel resolution algorithms would give us the ultimate bragging rights and astounding accuracy figures in this area, but they would not be meaningful regarding the actual accuracy of the implemented system. For example, regarding FSI’s **Machine Vision Unit accuracy** we could specify the use of a Line-Scan CVS-700, and rotate / move the part to create a 16k long line-scan image of that dimension. Then, our system’s spatial resolution would be

.0000625” per pixel, and our gauging accuracy using our sub-pixeling algorithms would be +/- .000003”, and scaling/lensing this down to doing so with a .01” part dimension, our unit’s accuracy would be +/- .00000003”. (+/- one 30,000th of one thousandth of an inch!). Accuracy with area scan imaging would be these figures with one less zero.

Other than for comparison with other advertising claims, these figures have little practical usefulness.

Now let’s develop and dissect our example further. Let’s say that someone has read this entire paper and now specifies the required accuracy of the *measurement process* as +/- .0002”. (I.E. 5 times more accurate than the required part tolerance.)

While the measurement process has inaccuracies, the comparison process of the measurement number against a standard is simple math, with practically infinite accuracy. (a ruler has errors, but a $5 calculator has practically infinite accuracy!)

So now the important mathematical details of what the system does are:

- Measure the part. Understand that in the worst-case scenario this measurement can be up to (but not over) .0002” off from the actual dimension.

- Compare the measurement result to a criteria set at 1.0008”. (1.001 minus a .0002” safety margin for measurement error) If the result is over 1.0008”, fail the part.

- Compare the measurement result to a criteria set at .9992 (.999” plus a .0002” safety margin for measurement error). If the result is under .9992, fail the part.

- Otherwise, pass the part.

Note that the byproduct of the .0002” setting that “plays it safe” is that there is a .0002” wide band of dimension scenarios for each test where “borderline but good” parts may be rejected. In some inspections, borderline parts inherently do not exist (for example, when checking for just a common process fault which always causes a large error when it occurs). In other cases, a degree of possible false rejects is the downside of the tradeoff between this and cost.

So, when following this (normal) approach, rejection of all bad parts is achieved regardless of accuracy. Then the need for and benefit of higher accuracy is to reduce the number of good parts rejected. A better understanding of this statement can be gained by the mental exercise of exploring its absurd limits. Even the most horribly inaccurate system ever built can be set for 100% confidence of rejecting all bad parts by setting it to reject ALL parts. Also, a system of infinite accuracy/cost can be set to have zero false rejects. In both cases there is an assurance of never passing bad parts, and the benefit of higher accuracy is reduction of the amount of false rejects.

What exactly is accuracy, and what determines it?

Measurement accuracy is the desirable attribute of minimizing measurement errors. An accuracy *specification* is a figure and an implicit statement (or a requirement for one) that the amount of error will never exceed that figure.

The most technically rigorous and conservative basis for such a statement is that the sum of the worst-case scenario of all possible errors will never exceed that figure. Under this approach, the typical accuracy achieved will be much better than the minimum, which has been guaranteed. Here is a list of the most common contributors to this total error. (Note: the common “error #3” described above ignores all of these except for #1)

1. Granularity induced by the resolution of the imaging array. Where applicable, this figure is reduced / improved by sub-pixel resolution capabilities of the software.

2. Geometric / parallax distortion. Basically, errors induced by varying feature distances from the machine vision unit. This is most extreme for 3D objects, but also occurs for planar objects.

3. Simple optical distortion created by the lens.

4. Smaller chromatic and diffraction errors created by the lens (the latter usually being ignorably small).

5. Errors caused by edge definition instability or problems. Instability or inaccuracy in the apparent location of the edges to be gauged due to lighting and thresholding issues.

6. Degradations and errors caused by array and imaging selection. These can be outright or via interaction with other capabilities (interlaced imaging, pixel shape, type, location accuracy, undesirable automatic changes in the image by the camera)

Strategies for Improving Machine Vision Accuracy

A wide range of strategies obtains higher accuracy; emphasis is best placed on the largest sources of potential error, and the remedies that give the most improvement for the price. Here are a few examples:

- Switching to software (such as NeuroCheck) with powerful, reliable, sub-pixeling capabilities can dramatically help #1.

- Higher resolution arrays help #1, although they usually don't help much because (except with line-scan) changes are proportionately small, and (if a good sub-pixeling capability is already included) they are usually reducing what is typically already one of the smallest sources of error.

- Moving up in the FSI lens families will help #3. From CLA series to CLC series to CLG series for standard lenses, or from CLTE to CLTG series in telecentric lenses.

- Lighting geometry engineering (available in FSI's APS™ program) will help #4 and #5.

- Monochromatic light sources will help the first part of #4

- Engineering of the camera / work piece/ light source configuration and geometric relationship (available in our APS™ program) will help #2, #3, #4. and #4

- Use of FSI CLTE (telecentric) and CLTG (telecentric-gauging) series lenses will help #2 significantly. (the transition from CLTE to CLTG within this group was covered separately)

- Consistent work piece at imaging-time will help #2, #3, #4 and #5 directly, but more importantly by enabling use of the next strategy item.

- Switching to software (such as NeuroCheck) with the unusual ability to implement individual dimension-by-dimension correction factors helps #2 and #3 significantly if work piece position is consistent at the time of imaging. This may add a small or large amount of work and complexity to the implementation depending on the details. This can be used to compensate for any consistent (repeatable) errors.

- Selection and use of proper imaging type, array and electronics for high accuracy gauging will help #5 and #6, generally eliminating all the #6 problems. This is handled automatically behind-the-scenes by FSI on reviewed applications.

Type of Accuracy Spec. Varies with Scope of Vendor

First, the accuracy spec varies with the scope of the prospective vendor. Let's review three scenarios from the top down:

- **Turnkey or Implemented System** For example, by an FSI certified Solution Provider. In this case, the implemented system will achieve the required accuracy.

- **Full Equipment Set and Engineering Review from Single Source** For example, as available from FSI under it's APS™ program, and then either self-implementation or separate implementation by an FSI solution provider. Specify that the equipment set shall be capable of achieving the required accuracy.

- **Equipment-Only from Multiple Sources** Example: Machine vision unit from one manufacturer, lighting from another. Assign maximum contributions to each error source listed later in this paper, and then determine and specify appropriate maximum error contributions from each hardware piece.

Specifying a Degree of Accuracy

Specification approaches may or may not utilize the fact that a technically sound vendor will furnish a system with typical accuracy much better the specified accuracy. Here are two general approaches:

Specify a required machine vision accuracy equal to the part tolerance. On it's surface, this appears to violate important concepts covered in this paper, and provide insufficient accuracy. But this method is often actually viable and used. And if the mission is simply defined as rejecting all bad parts (without adding "pass ALL good parts") this will allow technically thorough vendors to stay in the running (along with those who are oblivious to theses issues). This capitalizes on 2 practical realities to save money:

- Actual measurement error (accuracy) is usually better than the formally specified accuracy

- Actual practical needs may be less stringent than formally specified needs.

Specify a measurement system accuracy that is a certain multiple better than the part tolerances.

The common range here is 2 to 6 times better than the part tolerance. 6 times is generally accepted as a high quality norm and is usually the highest cost-justified factor.

Economics of specifying accuracy in machine vision systems

Accuracy is determined by:

Software capability
Hardware
Implementation (services)

Recommendations are:

Have an interchange with an expert to refine the specification. This is best handled in a technical discussion. Exchanging a draft spec or draft proposal is also a helpful tool in this area.

- Select good quality software, for this and many reasons. For example, one that has a wide range of gauging tools, powerful sub-pixeling algorithms, individual compensation capability, and other capabilities.
- Then, the equipment (hardware / software) accuracy is limited by the hardware. Avoid over-specifying in this area. For this stage, specify only the minimum accuracy that will accomplish the mission. Additional accuracy *capability* of the hardware generally comes free automatically, or costs a large

amount of money. Also, the “free automatically” range will generally cost money if the hardware vendor is required to guarantee it, as they would perceive a risk of capability being confused with performance of the implemented system.

- Use the same principles when specifying, doing or purchasing implementation

Notes on Evaluating Machine Vision Systems Gauging Performance.

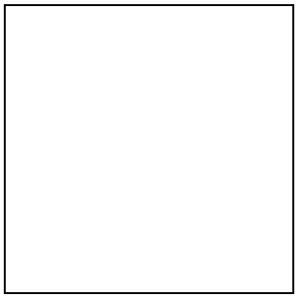
If measurement process (“process B”) is used in the evaluation evaluate the performance of another measurement process (“process A”), then the errors contributed by process B must be known and allowed for and incorporated into the evaluation process. The result will to interpret the data instances into these three bands: “Confirmed Success”, “Indeterminate”, and “Confirmed Failure”. The most common error is to consider any difference between the measurements to be an error in the process being evaluated.

Precise Measurements On More Complex Objects Need Precise Definitions

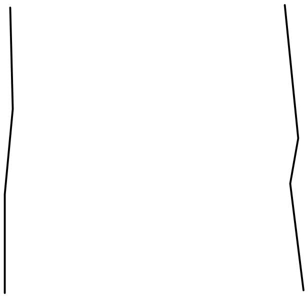
No product being inspected is perfect. For example, no “circle” is exactly a circle, no “line” is perfectly straight, and no 2 lines or surfaces are exactly parallel. Each has minor departures from geometric perfection, and so any mission definition / defect definition which presumes that they are perfect is, in reality, ambiguous until detailed further.

Here is an example illustrating the issue and possible solutions.

The general mission (loosely stated) is to measure the distance between the right and left sides of the square:



In reality, these two sides are not exactly straight, and not exactly parallel. A drawing of the 2 sides which vastly exaggerates these departures from perfection might look like this:



A basic mission definition (and the one that is normally followed) might be: Presume that the lines are straight, parallel, and vertical. Choose any height, and measure the horizontal distance between the lines, and use that result as being representative of the distance between the sides.

Here are 5 examples of more sophisticated definitions…any or all of them can be used if required:

- Locate and measure the closest distance between any 2 points on the lines.
- Locate and measure the closest distance (measured horizontally with respect to the paper) between any 2 points on the lines.
- Locate and measure the farthest distance (measured horizontally with respect to the paper) between any 2 points on the lines.
- Locate & measure the horizontal distance between the right-most point on the left line and the left-most point on the right line.
- Using curve-fitting type algorithms, construct the straight lines which best approximate the right and left sides. Find the maximum and minimum distances (measured perpendicularly to the left line), and calculate the average of those two distances.

Error has a more Complex Definition than Perfection

When the result of an inspection is a single numerical value, the magnitude of the measured error has a simple definition…the mathematical difference between that value and the ideal. Such is generally not the case with 2d and 3d objects. An example is to verify the co-planarity of 2 surfaces. First, in a 2d image inspection, this is reduced to co-linearity of 2 profiles (“lines”) which (hopefully) represent the surface attributes as viewed from that direction.

First, since there is no such thing as perfection, the “confirm co-linearity” mission is really the following mission: Measure the degree of lack of co-linearity, and then compare that to a standard. Now, how do we define “degree of lack of co-linearity”? Here’s an example of perfection, and then actual imperfections exaggerated (for simplicity, we chose a horizontal example):

Line A

Line B

Perfection

“Line” (Contour) A

“Line” (Contour) B

Actual, with imperfections exaggerated

Using the line terminology as a basis, the “degree of imperfection” is not a single value / parameter, but several:

Degree of departure of contour A from a perfect line
Degree of departure of contour B from a perfect line
Degree of difference (error) between the vertical location of Contour A and the vertical location of Contour B
Degree of angular mis-orientation of Contour A
Degree of angular mis-orientation of Contour B

(more complex general-case definitions would apply if the overall reference plane direction is not horizontal)

A powerful software such as NeuroCheck has the ability to determine all of these, and also to mathematically weight and combine the results if desired. This includes / starts with creating best-curve-fit line model geometries for each contour.

Summary

Our goal in preparing this document is to share selective practical useful information in key areas. We hope that we have succeeded. We always appreciate feedback including suggestions on changes to this document or additional topics for coverage.

FSI has a full range of products & services to handle all areas covered in this paper.