The Vision System Acceptance Test: Defining Done

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INTRODUCTION

How do you know when a machine vision project is completed? How can you be sure all contractual obligations are met? The acceptance test answers these and other questions. This whitepaper explains what the acceptance tests covers, where the criteria for the acceptance test come from, when and who performs the acceptance test, and some common difficulties and how they can be handled.

This whitepaper does not encompass all testing that may be required. It certainly does not encompass what is needed to meet FDA (Food and Drug Administration) or other government mandated requirements.

In explaining the acceptance test, there is an assumption there are two parties: an end-user or purchaser and an integrator or seller. In some situations, the end-user may integrate the system themselves. In that case, for the purposes of this whitepaper, the end-user's staff who design and build the system are the integrator and the end-user's people who will use, operate, and maintain the system are the end-users.

Even though a vision system passes the acceptance test, there may still be issues or events that raise the possibility of liability. This whitepaper does not offer legal advice. If there are concerns about any form of liability, consult with an attorney for advice.

WHAT IS AN ACCEPTANCE TEST?

The short answer to, "What is an acceptance test?" is what testing needs to be done to ensure the system is acceptable.

More specifically, it is the method of verifying that the system meets requirements. This means requirements must be written out as unambiguously as practical. The belief that "everyone knows" is unacceptable. Some people may actually not know. Even the people who know may know slightly different versions. Anything not written is always at risk for being overlooked.

In the biomedical equipment field, there are three parts to an acceptance test. While following FDA mandated guidelines would be burdensome for equipment in unrelated fields, the three parts provide a useful outline for acceptance testing.

IQ (INSTALLATION QUALIFICATION)

Checks that all elements of the system are present and installed according to their manufacturer's requirements. These checks may include:

- Ensuring all system components are present
- Examining the equipment for damage (after shipment) and workmanship.
- Checking all documentation to make sure it is present and acceptable.
- Checking for installed software and their versions.
- Verifying connections with peripherals.

OQ (OPERATIONAL QUALIFICATION)

Checks that all controls work as expected and that the system can perform each specified procedure. These checks may include:

- Equipment startup works are expected.
- Light source(s) illuminate.
- Camera(s) deliver(s) image data.
- Parts are moved into and out of position as expected.
- Mechanical operation and range of motion.
- Environmental controls (e.g., fans) are operating.

- Displays and other controls operate as expected following the operation manual.
- Security features (if any) are in place.
- Expected failure modes and system responses work as intended.
- Calibration procedure(s) work.
- Maintenance procedures can be executed reasonably.

PQ (PERFORMANCE QUALIFICATION)

Checks that the system performs all its functions to the requirements or better. These checks may include:

- Tests for accuracy of results.
- Tests for reliability of results.
- Test to verify product throughput (takt time).
- Data collection works and is reliable.

WHERE DOES IT COME FROM?

There are several sources for the development of acceptance tests:

- Requirements document
- Operation and maintenance manuals
- Industry standards and specifications
- The acceptance test procedure itself
- Other

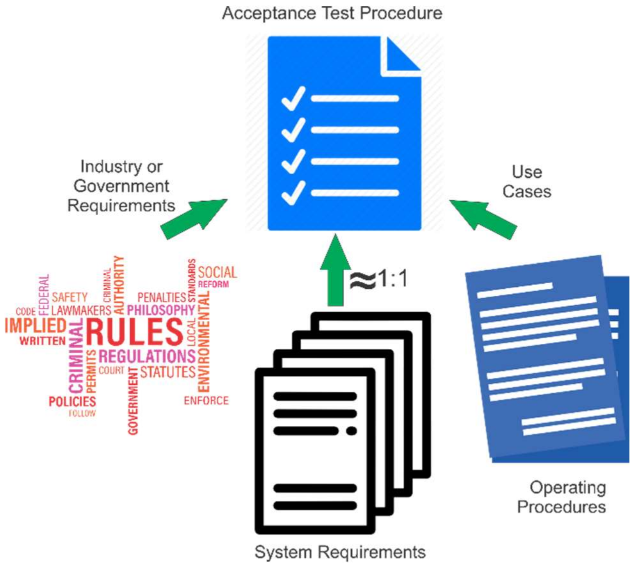

Figure 1 -- Sources of Acceptance Test Information

REQUIREMENTS DOCUMENT

In principle, the requirements document, or specification, is prepared by the end-user to specify the performance required and the interfaces to other factory equipment. In practice, the requirements document is often produced as a collaborative effort between the end-user and the system integrator.

In principle, each element of the requirements document translates directly into a test that is part of the overall acceptance test.

The requirements document generally specifies the input, parts and method of presentation to the vision system, the output, what action the vision system must perform as a result of its process, any auxiliary equipment (e.g., plant network) connected to the vision system and what data and format is needed, and important characteristics of the user interface. The vision system is left as a black box for the integrator to design and implement.

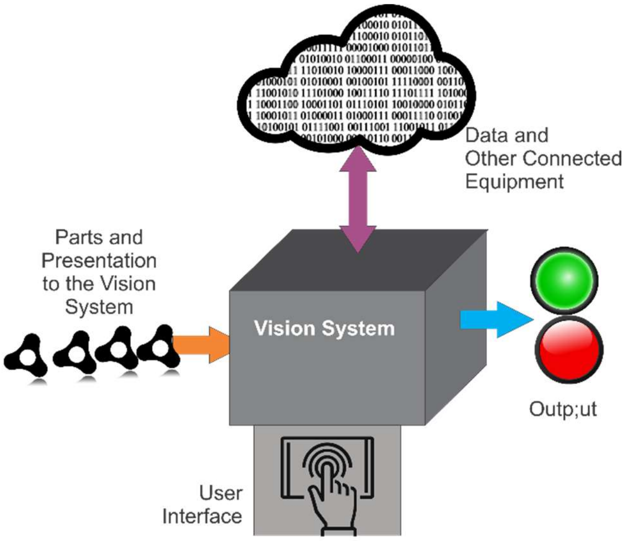

Figure 2 -- Vision System as a Black Box

OPERATION AND MAINTENANCE MANUALS

The manuals give procedures for the system's operation and its maintenance. Part of the acceptance test must be to ensure that these procedures are effective in accomplishing what they are intended to do.

The system integrator usually provides the operation manual and maintenance manual with input and feedback from the end user.

INDUSTRY STANDARDS

Often, the end-user desires the system to meet standards or certifications such as UL, CSA, CE, FCC, NFPA 79, and RoHS. Because certification is often quite expensive, unless the volume of systems is high, the end-user and system integrator will agree to use acceptable workmanship standards and perhaps have some limited outside design assistance or appraisal as an acceptable alternative.

THE ACCEPTANCE TEST

It might seem irregular for the acceptance test procedure to be an input to the acceptance test. While the acceptance test can't add or subtract requirements, it does often define how the tests will be performed and what equipment, fixtures, and procedures will be needed.

OTHER

There may be other documents that are incorporated into the requirements document by reference. These other documents may require inspections or tests to ensure conformance.

HOW IS IT PERFORMED?

WHEN AND WHERE

The acceptance test is typically performed twice – a Factory Acceptance Test, or FAT, at the system integrator's facility before shipment to the end user, and a Site Acceptance Test, or SAT, at the end-user's facility after installation.

The acceptance test is also useful to the vision system engineer during the system development as a way to measure the development progress.

WHO

The tests can be performed by the system integrator, the end-user with coaching by the system integrator, or by the end-user without coaching.

When performed by the system integrator, testing will be most efficient and the system will have the highest chance of passing. This is because of the end-user's limited familiarity with the system and the procedures for using the system.

When performed by the end-user without coaching, the end-user will be following instructions, and is likely to make mistakes. The test will go more slowly. Because of errors by the end-user, errors in the system are more likely to be made evident. Since errors are a real possibility during the operation of the system, the earlier they can be identified, the more reliable the system will be in operation.

WHAT

In most instances, it is not possible to test everything at the FAT because the system is not interfaced, mechanically or electrically, with the actual factory equipment. Therefore, the FAT is a very large subset of the acceptance test.

Likewise, the SAT does not need retest some of the procedures verified during FAT unless there is a possibility something could change during shipment and installation that would cause the procedure to give different results.

DOCUMENT

It is critical that the acceptance test be documented. Each step should have data recorded if any is taken and the signature of the person certifying that the system past that step.

COMMON CHALLENGES

THE SYSTEM PASSES THE ACCEPTANCE TESTS, AND THEN DOESN'T WORK

This is most commonly caused by just witnessing the system integrator perform the test. Then when the end-user goes to operate the system, they make all kinds of mistakes that cause the system to malfunction.

CORRELATING MANUAL MEASUREMENTS WITH VISION SYSTEM MEASUREMENTS

A machine vision system makes measurements differently than most manual measurement methods. So, it's not uncommon during the acceptance test to have larger than anticipated discrepancies when running the acceptance test.

Correlation is best anticipated early in the vision system development with a review of the purpose of the measurement and a comparison of the manual measurement technique and the chosen machine vision measurement technique.

THE SYSTEM DOESN'T QUITE MEET A SPECIFICATION

The end-user and system integrator should work together to find the root cause of the underperformance. Then decide on a course of action: to either fix the design or implementation or negotiate an exception to the requirements.

DEFINING RELIABILITY

There are two, and possibly more, definitions of reliability. Both can be difficult to implement in an acceptance test.

Availability

One definition of reliability is how long can the system work without failing. A more measurable metric is availability – what percentage of the time is the system available for use. Calculating Availability requires knowing the mean time between failure (MTBF) and the mean time to repair (MTTR). A good vision system has a very long MTBF that cannot be evaluated during the relatively short acceptance test. The MTTR can be estimated by performing several maintenance functions during the acceptance test.

Availability is calculated using the equation:

$$Availability\ (\%) = \frac{100 * MTBF}{MTBF + MTTR}$$

Process Reliability

Process reliability, or sometimes reliability, is a statement of how dependable the vision system is in providing the right answer. It is most easily understood by considering the case where products are identified as acceptable (Positive) or rejectable (Negative) (see Figure 3).

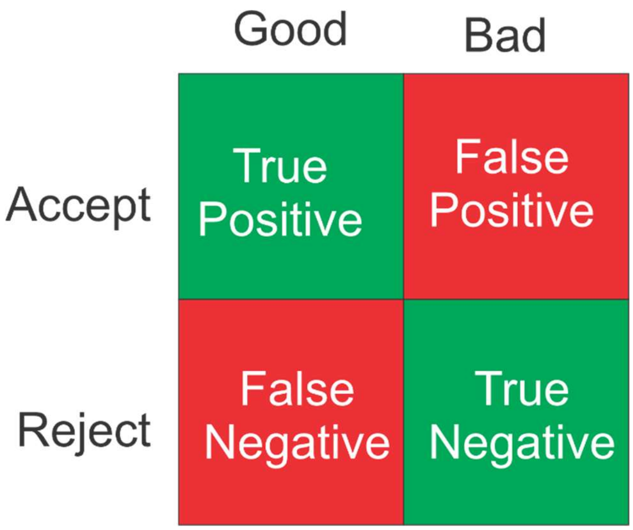

Figure 3 -- Process Reliability

What becomes important is the fraction of mistakes the vision system makes – identifying a good part as rejectable (False Negative) or a bad part as acceptable (False Positive).

The equations for false positives and false negatives are:

$$False\ Positive\ (\%) = \frac{100 * False\ Positive}{All\ Rejects}$$

$$False\ Negative\ (\%) = \frac{100 * False\ Negative}{All\ Accepts}$$

In many requirements documents, the percentage of false positives and false negatives are set equal. However, a much better approach is to consider the costs of false positives and false negatives and set the percentages so the weighted costs are equal.

DEFINING ACCURACY

There are two ways of looking at accuracy. One is the system design approach, and the other is the expectation of the end user.

System Design

The traditional ("old school") approach was to require a measurement tool to have an accuracy 10 times better than the tolerance of the part being measured and a precision 10 times better than its accuracy. This allowed for the human factor. In today's automation ecosystem, the end user usually specifies accuracy and not tolerance. In analyzing requirements, the automation engineer usually interprets the average error as accuracy and repeatability, also known as resolution or precision as the variability in the results (see Figure 4).

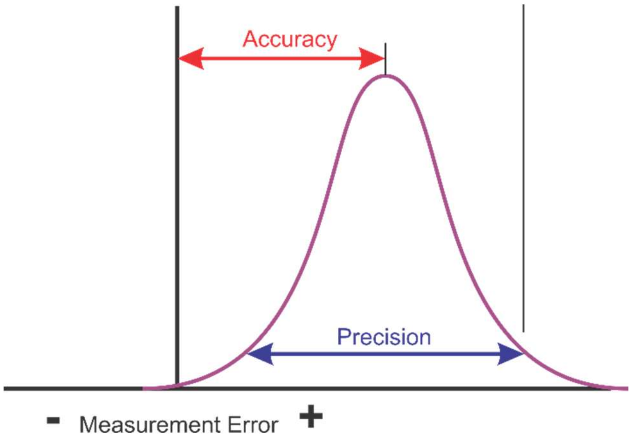

Figure 4 -- System Design Interpretation of Accuracy

End User

The end user is typically considering accuracy as defined in ISO 5725. This includes the sum of trueness, the average or expected error also called bias, plus repeatability, usually to 3 sigma, as accuracy (see Figure 5).

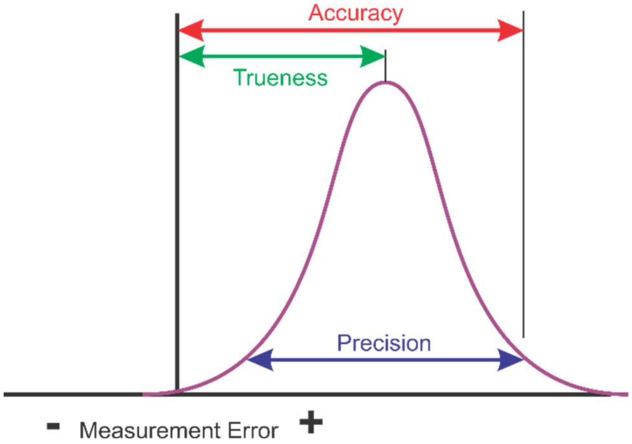

Figure 5 -- End User Interpretation of Accuracy

THE UNTESTABLE REQUIREMENT

There are requirements, such as availability, that are unreasonable to test during the FAT or SAT because it takes too long to gather the data for any accuracy. For these requirements, consider alternatives such as having the end-user monitor and record the system's performance over a longer time or building in warranty obligations.

TOO FEW SAMPLES FOR A COMPREHENSIVE TEST

A vision system development is best served by a fairly large set of calibrated or labeled samples. This can present obstacles. It may be too costly in labor to collect the samples. For systems that must find defects, sometimes the frequency of certain defects is very low and only a very few samples are available.

Samples may be perishable. For example, food products or agricultural products tend to deteriorate very quickly. Some products are prone to oxidization or absorption of moisture that change their characteristics. Appropriate storage methods might extend the useful life of the samples, but they will need to be replenished during the project.

A common approach to dealing with a limited number of samples, samples that deteriorate quickly, or samples that are unavailable because production has not started is to use proxy parts. A proxy part is one that is produced to have, in principle, the same characteristics as the real part. Experience shows that proxy parts often deviate enough from real parts, that adjustments, sometimes significant, to the vision system are needed for it to work with the actual parts.

With the trend toward using machine learning, it is becoming popular to use data augmentation to compensate for limited part availability. Data augmentation takes an image of a part and modifies it in various ways. Possible variations of an image include rotation, scaling, darkening, lightening, changing contrast, and adding noise.

REDUCING THE TEST BURDEN

Sometimes when testing for attributes, the number of parts and tests required to demonstrate a high confidence is time consuming. By recording not just the pass/fail results, but also the value of the underlying data from which the pass/fail result is determined, greater accuracy in predicting reliability can be obtained with much more limited testing. Having the quantitative data allows calculation of the standard deviations of the observations. The standard deviations are a much more reliable indication of the reliability of the inspection.

TESTS OUTSIDE THE REQUIREMENTS

Sometimes, there are tests outside the requirements that should be performed – not to accept or reject the system, but to characterize it.

Lighting

It may be desirable to measure the intensity and uniformity of illumination provided by the light source to characterize it. That way, any future departure in intensity and uniformity can be identified and addressed.

Sensitivity to Light Level

Some vision systems are more sensitive to light level than other designs. This can occur because the camera has a lower dynamic range or because the image processing algorithms are affected by scene brightness.

It is an easy matter to test the performance of the vision system with a lowered light level. If the lighting controller provides the ability to reduce the light level, that will be sufficient. Another option is the use of a neutral density filter in front of the camera lens. Still another option is shortening the exposure time.

One approach that should be avoided is changing the lens aperture. The aperture affects not only the lens' light gathering ability, but also its depth-of-field and its optical resolution.

Image Noise

Rather quick tests can provide a quantitative indication of image noise. High noise might suggest the system is providing lower reliability than would be achieved with less noise. Also, a comparable test in the future might indicate of there is some problem with the camera.

Golden Part

Another characterization is to use one or two "golden" parts. Have them measured or inspected during the FAT, record the data from the measurement or inspection, and then repeat the measurement or inspection during the SAT. It would be expected that the data would be very similar if the system was correctly calibrated during both tests. In addition, the golden part(s) can be preserved and used in the future to identify and characterize any drift or change in the system.

MANDATORY REQUIREMENTS AND PREFERRED REQUIREMENTS

Not all requirements are essential. Those that are must be met and, to the degree possible, tested. There are also preferred requirements which are desired but not essential. The end-user and system integrator must arrive at an agreement on which preferred requirements will be incorporated and which will not. Those that are accepted for incorporation must be tested to verify their incorporation.

REQUIREMENTS ADDRESSED BY BEST EFFORT

Some requirements are difficult to meet with any predictable success. For example, suppose a vision system is to inspect for small, low-contrast defects, and there are very few samples of these defects to use in the system development. In that case, the system integrator and end-user will reach an understanding that the inspection confidence for these defects cannot be determined, and the system integrator will use their best effort to implement the inspection.

The acceptance test can include testing for the inspection with the understanding that it is a characterization and no guarantee of performance is expected.

TEST EXCEEDING THE REQUIREMENTS

Quite obviously, if the acceptance test requires performance exceeding the specified requirements, that constitutes a change in scope. A change in scope will impact the system cost or delivery time or, more commonly, both.

SUMMARY

The acceptance test is a critical part of the development of a vision system – it defines when the project is complete. The acceptance test criteria are derived mainly from the system requirements document with some references to other sources.

Having the acceptance test procedure available early allows for the design of the vision system to accommodate the testing and boost testing efficiency.

There are potentially three principal parts to the acceptance test: IQ – qualifying the installation (components), OQ – qualifying the basic system operation, and PQ – qualifying the performance of the vision system.

The acceptance test is performed twice – once at the system integrators facility (FAT) before shipment and again after installation (SAT).