Attribute Data Treatment of Automated Inspection Vision System For Product Mix-Up Detection

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Abstract *— The pharmaceutical industry continues to grow at an exponential pace, with number of medications being mixed, molded, stamped, and packaged every day in the millions. Regardless of the amount, the margin for error never changes. To prevent any mistakes, the human factor has been reduced and replaced by high speed vision inspection systems. This paper presents a statistical evaluation of product mix-up detection confidence levels, confidence intervals and sample size considerations for a filler vision system (i.e., Optel Vision Inspection) in bottle packaging line using executed engineering studies of "XYZ" Pharmaceutical Industry located at Puerto Rico. An Attribute Agreement Analysis will be used to investigate whether this system can be used for detect different tablet's defects as broken, different shapes or colors presentations to assess the consistency of responses of appraisers vs. standard reference for the inspection system.*

Key Terms *— Appraiser, Attribute Agreement Analysis, Confidence Intervals, Confidence Level.*

INTRODUCTION

Meanwhile the drug product's demand increases and tighter tolerances are required, more advanced measurement machines are developed to meet these challenges. The purpose of a measurement machine is to provide data accurately represent real product dimensions. By these reasons, automated vision inspection systems not only inspect individual tablets, but also their packaging. Thus, these inspection systems requires a sophisticated machine vision system, consisting of fast tablet manipulation, proper illumination, image acquisition and processing, estimation of tablet features as different shapes, sizes, colors and corresponding classification and sorting. [1]

In this automated vision system study, the pharmaceutical industry XYZ installed an Optel Vision System, model OP395 Slat Inspector composed of ten (10) cameras and lighting modules in an enclosure to inspect the products capturing images of the products with digital color cameras and compares them to reference images in bottle packaging lines. Separate analyses of the captured images are performed to determine if a defective product or incorrect solid dosage form is mixed with the correct ones as compared to the reference images. The visual inspection system can measure volume of tablet with set-up size and color within required repeatability, but it does not guarantee the system can measure the volume of tablets for different slight size and colors within the required repeatability. This paper presents an statistical evaluation to this filler vision system to analyze if it can be used successfully for measuring slight differences in shape and colors on tablets without loss their consistency and reliability.

LITERATURE REVIEW

Machine vision systems, whose goal is to create a model of the real world from images, are emerging as more and more popular solutions for industrial production, either as robot vision systems or as automated inspection systems. The main task of a machine vision system is to provide computer understandable descriptions of objects from either single image or whole array of images. A simplified diagram of a typical machine vision system is shown in Figure 1. Essentially, the image from the camera is digitized and stored in the computer where it is automatically analyzed to extract the required information. The camera can either be a standard video camera, or in the cases of products on a conveyor, a linear array sensor which

generates a high resolution image on a line-by-line basis. It is usually not necessary to store an ideal image of the item being inspected. Rather, certain features of a correct item are combined to form a model of an ideal product. The same features are extracted from each inspected item and compared with the model. In this way factors such as positional alignment, changes in illumination levels and tolerances in specifications are accommodated [2].

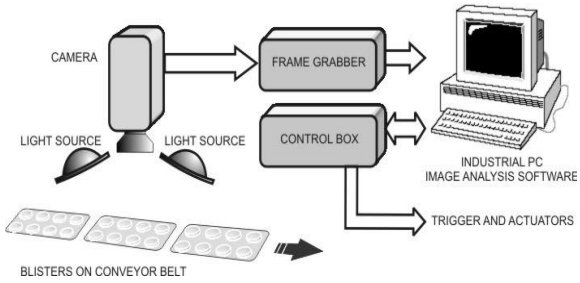
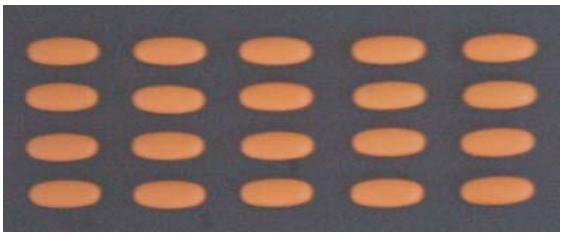


Figure 1
A Simplified Diagram of a Typical Machine Vision System

Roughly, two different approaches, namely template matching and design-rule verification can be taken to perform automated visual inspection. By template matching every pixel in the inspected image is compared with the pixels of the reference image. The design-rule verification approach checks for the violation of a set of generic rules. The methods for object inspection make use of the image of objects captured by cameras and for which colored images are frequently preferred since they contain more information than gray level images. Generally, images are captured in RGB mode (Red Green Blue) by electronic devices, each pixel being represented as a point in the RGB color space as show in Figure 2 [2].

Segmentation methods can be categorized into the following classes: edge detection, region based, methods based on physical reflectance models and statistical methods in some color feature space. The segmentation allows the system to detect missing and broken tablets, tablets fragments and the color size, and shape of individual tablets in pharmaceutical blisters automatically in real-time. Because spatial color non-uniformity may influence the accuracy and robustness of automated inspection, it is reduced prior to segmentation. [2]



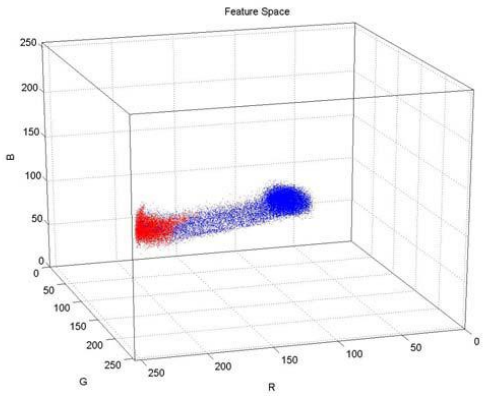


Figure 2
A Defect Free Sample Image And The Corresponding RGB Color Space

The software of these vision inspection systems operates either in the "training" or "inspection" mode. In the training mode firstly a defect tree image is captured (Figure 3). After capturing the image, the operator;

- Defines the blister borders. Training tablets are assigned to the corresponding blisters. The information is used in inspection mode to reject blisters containing defective tablets.
- Select a point on any tablet, which is required for nonparametric clustering based color image segmentation.
- Set tolerances for:
  - ✓ Position of each tablet.
  - ✓ Size of each tablet.
  - ✓ Shape of each tablet.
  - ✓ Size of surface defects.

The acquired image is then corrected for spatial color non-uniformity, segmented and its extracted

features are stored in the resulting blister model, which is composed of:

- Spatial color non-uniformity correction function.
- Nonparametric color image segmentation model of tablets.
- Feature values describing:
  - ✓ Position of each tablet.
  - ✓ Size of each tablet.
  - ✓ Shape of each tablet.
- User defined tolerances of feature values describing:
  - ✓ Position of each tablet.
  - ✓ Size of each tablet.
  - ✓ Shape of each tablet.
  - ✓ Size of surface defects.

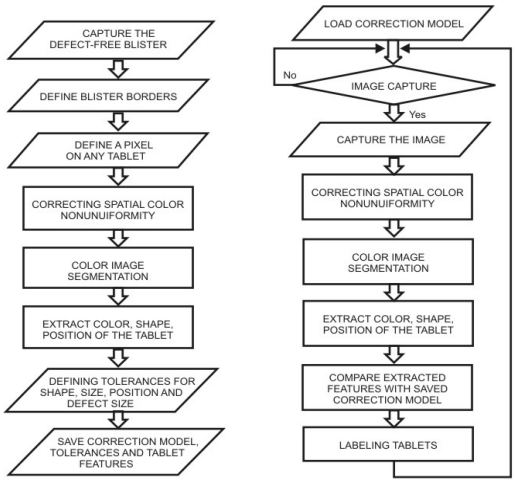


Figure 3
Training Mode Operation (Left), Inspection Mode Operation (Right)

After using the training mode just once, the tablets are inspected in the inspection mode. In the inspection mode, spatial color non-uniformity of every acquired image is corrected by the correction model which is generated in the training mode and stored in the blister model. The features of the segmented image is extracted in the same way as the training mode and the obtained results are then compared with the features values and the user-defined tolerances to detect the defective tablets. The defective tablets detected are marked and the blisters containing any defective tablet are determined. For each tablet position in the model, the nearest region in the inspected image is found. There are three cases for a tablet that is said to *fail;* the tablet may be "missing", or "defective", or it may have a "surface defect" detected by the procedures:

- A tablet is marked as "missing" if the centre of the region lies out of the position value stored in the model.
- If the size and shape of the region, labeled as a tablet in the inspection mode is larger than the size and shape tolerance values compared to the corresponding tablet stored in the blister mode; it is marked as "defective".
- A tablet is said to have a "surface defect" if the size of the region labeled as background inside the region corresponding to a tablet is greater than the tolerance value.

If the tablet does not fail, it is said to pass. All blisters containing any tablet that fails are determined in order to produce a signal in the inspection system to eject these blisters. There are another important terms to define in the statistical evaluation like confidence intervals, confidence levels, sample size, data treatment, attribute agreement analysis and binomial distributions [3].

Confidence Interval

A confidence interval (CI) is an interval estimate of a population evaluated response (e.g., detection percent) and is used to indicate the reliability of an estimate. How frequently the observed interval contains the response is determined by the confidence level. Confidence intervals consist of a range of values (i.e. interval) that act as good estimates of the unknown population response. The level of confidence of the confidence interval would indicate the probability that the confidence range captures this true population response given a distribution of samples. It does not describe a single sample. [4]

Confidence Level

The level of confidence is determined by the researcher. If a corresponding hypothesis is

performed, the confidence level corresponds with the level of significance, i.e. a 95% confidence level reflects a significance level of 0.05, and the confidence interval contains the response values that, when tested, should provide an adequate/ standard level of significance to reflect that the evaluated sample size is representative of the unknown population from where the sample was collected. [4]

Sample Size

To evaluate the suitability of sample sizes used to measure the population response (e.g., detection percent) the following points were considered:

- An increase in confidence level will result in larger/ wider confidence intervals, and less precise estimates of the response at constant sample size.
- Also, a decrease in sample size will result in larger/ wider confidence intervals, and less precise estimates of the response at a constant confidence level.

Data Treatment

The evaluation of the product mix-up detection confidence level, confidence intervals and sample size considerations for the filler vision system was performed for the bottles packaging lines. A 95% confidence level was used (i.e., significance level of 0.05), to reflect that the evaluated sample is representative or similar to the unknown population from where the sample was collected. To conduct the data treatment and analysis provided that the data for the vision system consisted in attribute (i.e., Pass or Fail) evaluations, Attribute Agreement Analysis was performed for the binomial distributions.

Binomial Distributions

The binomial distribution is a probability distribution that summarizes the likelihood that a value will take one of two independent values (e.g., Pass or Fail) under a given set of parameters or assumptions. The underlying assumptions of the binomial distribution are that there is only one outcome for each trial, that each trial has the same probability of success and that each trial is mutually exclusive. [5]

Attribute Agreement Analysis

To conduct the statistical evaluation of this paper, Minitab® statistical software was used and the "Attribute Agreement Analysis" was selected for conduct it. An attribute agreement analysis, also known as Attribute R&R (Reproducibility and Repeatability), assesses the consistency of responses within appraisers and between appraisers for an inspection method or system. It also compares the response with reference values (also called standard values). The analysis uses attribute ratings or classifications, binary data and binomial distributions considerations. An attribute agreement analysis is useful in quality systems where inspection procedures based on attributes are applied in manufacturing organizations [6].

Optel Vision System's Components

Optel Vision Systems of Quebec City Canada delivers turnkey systems to the pharmaceutical industry that not only do inspection, but perform production line control functions, too. Because of the company's expertise in the field, it was hired to develop a new inspection and quality control system to upgrade a tablet processing line for the launch of a new dual-step dissolution tablet.

Optel Vision Systems responded to the customer's requirement by introducing the tablet inspection vision system called TabletProof 360° vision system that offers pharmaceutical manufacturing and packaging companies a simultaneous 360° inspection of each and every pill, tablet, or gel capsule, with a speed up to 2,000 products/ minute (Figure 4). This system is capable of handling multiple sizes and shapes of tablets or capsules, and posses a precision ejection system that allows each detective product to be discarded without interruption. These fixtures reduces downtime and rework, thereby increasing quality and customer satisfaction and avoiding expensive

recalls, improving the quality assurance and increasing customer safety.

In terms of hardware and software, this vision system consists of an integrated computer system using an Intel-based processor board. The company uses different Intel processors for different applications, with single-core or quad-core CPUs, depending on the performance requirements of the application. Also, the system uses a camera to take a picture of each tablet as it passes a particular point on the line at a rate of 2,000 tablets per minute. Triggering the camera is handled by circuitry on a real time I/O board of Optel Vision's own design that performs high-speed counting of things like the exposure cycle of the camera and that connects to the Intel processor board over Ethernet. The I/O board also interfaces to a rotary encoder that is attached to the tablet transport mechanism on the line. The image is processes in the computer by an algorithm that decides if the tablet presents any flaw. If it does, the defective tablet is tracked through the system until it gets to the ejection station, which is also designed and supplied by Optel Vision.

Image processing is done on a dedicated core of the main processor using the Optel Vision's own proprietary algorithms. When a image is received, the algorithm compares it with a mathematical model of the correct product and then formulates a decision as to whether the image from the camera is a match. Its library includes about 50 vision algorithms, which much is capable of processing bottles, blister packs, or pill images at the rate of 10,000 per minute.

To control all the real-time processing, the system uses real-time operating system (RTOS) software. Optel Vision's engineers initially tried the embedded version of MS Windows NT but observed synchronization problems that would have caused products on the line to be missed. This occurred because Windows is primarily a human-directed operating system, designed to support the needs of servers and human users, and not high-speed machines or vision systems. The engineers search the Web for software that could be added to Windows to solve the real-time responsiveness problem. They evaluated some Windows I/O software drivers and then experimented with developing their own driver software. By automating the inspection and reject elimination processes, Optel Vision's pharmaceutical customers using this vision system can now benefit a much more efficient system. Eliminating the frequent machine stoppages and enabling their customers' operator personnel to be used more efficiently has resulted in a Return On Investment (ROI) on the upgrade investment of less than six months.

Figure 4
TabletProof™ 360° Vision Machine

METHODOLOGY

The statistical analysis of the paper was performed by evaluating the existing available data documented from engineering studies conducted during the recipe development exercises on bottle packaging lines using the Optel Vision Inspection System, model OP395 Slat Inspector. Considering this information, the following points were taken for the statistical data analysis:

- Attribute agreement analysis was stratified for one random packaging line and three (3) sample drug product recipes (B, A, D) of all their drug inventory of products.
- The attribute response results were binary data responses; only "Pass" or "Fail" responses were possible for each sample evaluation.
- "Appraisers", term defined by Minitab® software, were defined as the cameras from the

vision system were providing the "Pass" or "Fail" results. This allowed evaluation of detection percent (%) and confidence intervals for individual cameras and for the combination of the ten (10) cameras as a whole measurement system with respect to sample size.

- For the selected random packaging line and applicable drug product, mix-up detection was evaluated by identifying all the "Standards" as "Fails". Therefore the system would yield a 100% detection (100% match vs. Standard) if all samples were detected as "Fail" or rejected. A result of 0% detection was obtained if all samples were detected as "Pass" (0% Match vs. Standard). A "Pass" classification is interpreted as product that was not identified as a defect and was not rejected with respect to the recipe being evaluated.
- Since the analysis was performed using the existing data from executed engineering studies, a mix of ratio of " Pass: Fail" standard samples for each test was not possible, therefore the evaluation was performed by evaluating a standard consisting of 100% "Fail" samples, not a ratio of "Pass: Fail" samples within each trial. This point allowed the evaluation of all possible mix-ups within the packaging line, based on products that are active and packaged on the same packaging line and that fits in the same slat cavity.
- The product samples per camera varied according to the evaluated packaging line/ product recipe. Therefore, samples size per camera were n=8 or n=10, for each of the ten (10) cameras. This consideration is directly related to the slat configuration for each product in question (10 slat cavities per camera vs. 8 slat cavities per camera). Evaluations were performed at a fixed sample size, according to the specific packaging engineering study. Multiple scans per camera also varied according to the specific packaging engineering study. There were engineering studies with multiple (e.g. 3X) scans were performed. This increases the total sample size and also provides resolution by allowing evaluation of "within appraiser" variation evaluation as part of the Attribute Agreement Analysis.
- As part of the statistical analysis on Minitab® software, the following information was provided as applicable:
  - ✓ "Within appraiser" plots: If multiple scans were performed per camera (e.g., samples in triplicate).
  - ✓ "Appraiser vs. Standard" plots": To evaluate each camera performance against the know standard.
  - ✓ Statistical data output per camera: Provides percent (%) matched, percent (%) detection, and confidence interval for a 95% confidence level for each camera.
  - ✓ Statistical data output for the whole measurement system: Provides percent (%) matched, percent (%) detection, and confidence interval for a 95% confidence level for the whole measurement system (i.e. 10 cameras).
  - ✓ To evaluate the system detection confidence intervals for the evaluated recipes, the total aggregate number of samples from the whole system containing the ten (10) cameras was considered.

Statistical Analysis and Results

After using the Attribute Agreement Analysis provided by Minitab® Software to investigate whether this vision inspection system can be used for detect different tablet's defects as broken or different mix-up detection faults, the statistical analysis of the three random products resulted on three different scenarios to discuss next.

The first random product called Product B was inspected with the Optel Vision System on the selected line # 31. The 10 cameras identified as "Appraisers" had different variances on their results matching the response vs. standard. The "Appraiser vs. Standard" plot showed on the Figure 5 present the output of how many tablets does the

appraisers rate correctly each time. Each appraiser rated ten (10) tablets (# Inspected). Appraisers # 3, 4, 6, 7, 8 and 9 correctly rated all ten tablets across trials (# Matched), for 100% matched.

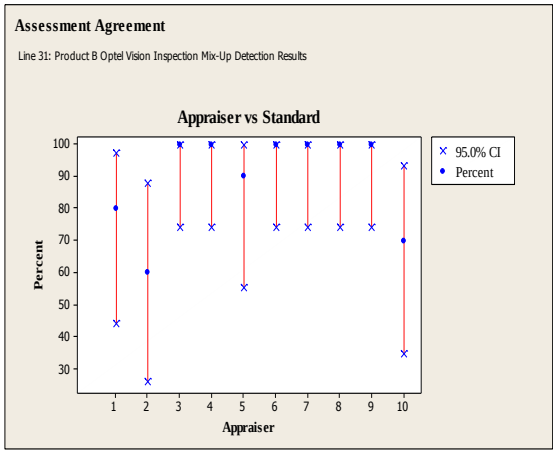


Figure 5
Line 31: Product B Optel Vision Inspection Mix-Up Detection Results

Table 1
Product B- Each Appraiser vs Standard : Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95 % CI
1	10	8	80	(44.39, 97.48)
2	10	6	60	(26.24, 87.84)
3	10	10	100	(74.11, 100.00)
4	10	10	100	(74.11, 100.00)
5	10	9	90	(55.50, 99.75)
6	10	10	100	(74.11, 100.00)
7	10	10	100	(74.11, 100.00)
8	10	10	100	(74.11, 100.00)
9	10	10	100	(74.11, 100.00)
10	10	7	70	(34.75, 93.33)

- # Matched: Appraiser's assessment across trials agrees with the known standard.

Based on the confidence interval, you are 95% confident that the true agreement for the cameras # 3, 4, 6, 8 and 9 on this line for product B is between 74.11% and 100%. Meanwhile, the appraisers # 1, 2, 5 and 10 correctly rated 8, 6, 9 and 7 tablets respectively across trials, for 80%, 60%, 90% and 70%. Based on the confidence interval, you are 95% confident that the true agreements for these appraisers have variances as presented on Figure 5 and Table 1. The Table 2 shows if an appraiser's ratings were incorrect, how were they incorrect.

The second column shows the "Pass/ Fail" rate where presents how the appraisers # 3, 4, 6, 7, 8, and 9 rated all 10 tablets correctly across trials, as indicated by the cero (0) values in the table. The other appraisers # 1, 2 and 10 rated different quantity of tables as "pass" across trials, when the tablet was actually fails. The fourth column shows the mixed (inconsistent) tablet ratings in different quantities on the appraisers # 1, 2 and 5.

Table 2
Product B- Each Appraiser vs Standard : Assessment Disagreement

Appraiser	# Pass/ Fail	Percent	Mixed	Percent
1	1	10.00	1	10.00
2	3	30.00	1	10.00
3	0	0.00	0	0.00
4	0	0.00	0	0.00
5	0	0.00	1	10.00
6	0	0.00	0	0.00
7	0	0.00	0	0.00
8	0	0.00	0	0.00
9	0	0.00	0	0.00
10	3	30.00	0	0.00

The Figures 6-7 and Tables 3-5 show the same statistical analysis for the "random products "A" and "D", but with different response and results. The "Attribute Agreement Analysis" for the product "A" resulted on totally number of mismatch tablets on the appraiser's assessment across trials agrees with the known standard. Finally, at the third scenario of the responses, the "Attribute Agreement Analysis" for the product "D" resulted on the totally number of matches tablets on the appraiser's assessment across trials agrees with the known standard.

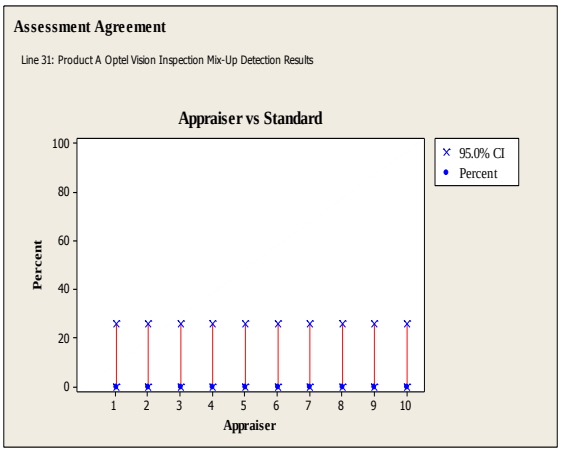


Figure 6
Line 31: Product A Optel Vision Inspection Mix-Up Detection Results

Table 3
Product A- Each Appraiser vs Standard : Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95 % CI
1	10	0	0.00	(0.00, 25.89)
2	10	0	0.00	(0.00, 25.89)
3	10	0	0.00	(0.00, 25.89)
4	10	0	0.00	(0.00, 25.89)
5	10	0	0.00	(0.00, 25.89)
6	10	0	0.00	(0.00, 25.89)
7	10	0	0.00	(0.00, 25.89)
8	10	0	0.00	(0.00, 25.89)
9	10	0	0.00	(0.00, 25.89)
10	10	0	0.00	(0.00, 25.89)

- # Matched: Appraiser's assessment across trials agrees with the known standard.

Table 4
Product A- Each Appraiser vs Standard : Assessment Disagreement

Appraiser	# Pass/ Fail	Percent	Mixed	Percent
1	10	100.00	0	0.00
2	10	100.00	0	0.00
3	10	100.00	0	0.00
4	10	100.00	0	0.00
5	10	100.00	0	0.00
6	10	100.00	0	0.00
7	10	100.00	0	0.00
8	10	100.00	0	0.00
9	10	100.00	0	0.00
10	10	100.00	0	0.00

- # Pass / Fail: Assessments across trials = Pass / standard = Fail.
- # Fail / Pass: Assessments across trials = Fail / standard = Pass.
- # Mixed: Assessments across trials are not identical.

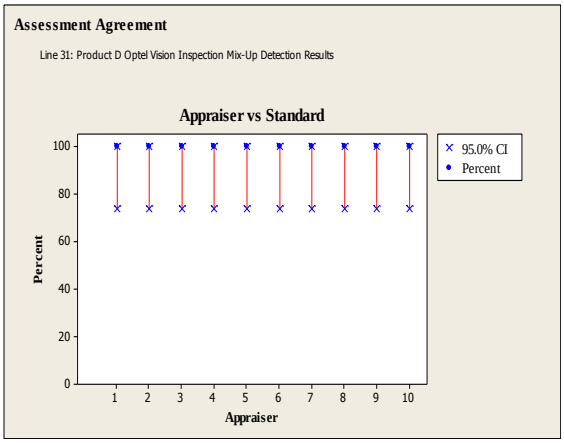


Figure 7
Line 31: Product D Optel Vision Inspection Mix-Up Detection Results

Table 5
Product D- Each Appraiser vs Standard : Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95 % CI
1	10	10	100	(74.11, 100.00)
2	10	10	100	(74.11, 100.00)
3	10	10	100	(74.11, 100.00)
4	10	10	100	(74.11, 100.00)
5	10	10	100	(74.11, 100.00)
6	10	10	100	(74.11, 100.00)
7	10	10	100	(74.11, 100.00)
8	10	10	100	(74.11, 100.00)
9	10	10	100	(74.11, 100.00)
10	10	10	100	(74.11, 100.00)

- # Matched: Appraiser's assessment across trials agrees with the known standard.

Table 6
Product D- Each Appraiser vs Standard : Assessment Disagreement

Appraiser	# Pass/ Fail	Percent	Mixed	Percent
1	0	0.00	0	0.00
2	0	0.00	0	0.00
3	0	0.00	0	0.00
4	0	0.00	0	0.00
5	0	0.00	0	0.00
6	0	0.00	0	0.00
7	0	0.00	0	0.00
8	0	0.00	0	0.00
9	0	0.00	0	0.00
10	0	0.00	0	0.00

- # Pass / Fail: Assessments across trials = Pass / standard = Fail.
- # Fail / Pass: Assessments across trials = Fail / standard = Pass.
- # Mixed: Assessments across trials are not identical.

CONCLUSIONS

The objective of this paper was achieved by presenting a statistical evaluation to this filler vision system to analyze if it can be used successfully for measuring slight differences in shape and colors on tablets without loss their consistency and reliability. The sampling/test plans in the Engineering Studies were not defined around pre-determined statistical confidence requirements, but rather to ensure that the various factors impacting mix-up detection were covered. That is, sufficient samples were tested to cover all mix-up products, all cameras, and all slat cavities, for each product code's vision system recipe. Furthermore, this analysis suggests that sample sizes utilized provided for robust statistical confidence across all engineering studies.

This analysis for the mix-up detection/rejection confidence intervals for the aggregate sample sizes with 100% detected/rejected attribute data, yielded favorable and tight confidence interval range results at a 95% confidence level. The confidence interval range results at a significance level of 0.05, suggests that the evaluated sample sizes are considered representative of the rest of the population from where the sample was collected.

Also, the Attribute Agreement Analysis method used to assess the consistency of responses of appraisers vs. standard references for the inspection system was very reliable and appropriate to use for these types of applications to measure slight differences on tablet's attributes difficult to detect by the human operators. After finish this statistical evaluation of data treatment for this automated inspection vision system manufactured by Optel Vision Company, was proved the reliability and accuracy of the system to inspect 100 percent of tablets passed per camera on each packaging line to guarantee the correct specifications of each product and the security of their patients.

Also, was proved the Attribute Agreement Analysis as an effective method for delivering a statistical interpretation of a subjective judgment decision made by people or automated cameras as in this case, allowing fact based improvements to be identified, implemented and measured. Attribute agreement analysis allows those leading projects without continuous data to measure the quality of that data and boost confidence in the capability of the system, and decisions that are made to improve it. It can be an excellent tool to reveal the sources of inaccuracies in a defect database, but it should be employed with great care, consideration and minimal complexity if it is used at all. This is best achieved by first auditing the database and then using the results of that audit to construct a focused and optimized analysis of repeatability and reproducibility.

REFERENCES

[1] Forcinio Hallie, Pharmaceutical Technology Packaging Forum (August 2003), "*Packaging Innovations*".

[2] Aktürk, Deniz (April 2008) *Thesis* "*Visual Inspection of Pharmaceutical Color Tablets"* Department of Electrical and Electronic Engineering from Middle East Technical University.

[3] Miha Mozina, Dejan Tomazevic, Franjo Pernus and Bostjan Likar (September 2011), "*Modelling imprints of pharmaceutical tablets for imprint quality visual*

inspection", Laboratory of Imaging Technologies, University of Ljublijana.

[4] Smithson Michael, Sage University, Confidence Interval Handbook., Series (2003), "*Quantitative Applications in the Social Sciences*".

[5] Lehmann E.L., Romano Joseph, Springer Text in Statistics Book (Third Edition, 2005), "*Testing Statistical Hypotheses*"

[6] Urdhwareshe Hemant, Quality World Journal (December 2006), "*Validating Measurement System Using Measurement System Analysis (MSA)"*