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Automatic Inspection of Percussion Caps by Means of Combined 2D and 3D Machine Vision Techniques

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***Abstract*—**The exhaustive quality control is becoming more and more important when commercializing competitive products in the world´s globalized market. Taken this affirmation as an undeniable truth, it becomes critical in certain sector markets that need to offer the highest restrictions in quality terms. One of these examples is the percussion cap mass production, a critical element assembled in firearm ammunition. These elements, built in great quantities at a very high speed, must achieve a minimum tolerance deviation in their fabrication, due to their vital importance in firing the piece of ammunition where they are built in. This paper outlines a machine vision development for the 100% inspection of percussion caps obtaining data from 2D and 3D simultaneous images. The acquisition speed and precision of these images from a metallic reflective piece as a percussion cap, the accuracy of the measures taken from these images and the multiple fabrication errors detected make the main findings of this work.

***Keywords*—**critical tolerance, high speed decision making simultaneous 2D/3D machine vision.
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I. Introduction

THIS work has been carried out on demand of an industrial group that sells globally all over the world its products, specialized in the development and manufacturing of civil explosives and initiation systems for the mining, quarry and infrastructure industries. It is also a leading producer of hunting cartridges and powders for sporting use, and products for the defence industry. The automatic quality control system developed inspects in real time the mass production of the percussion caps to be mounted in hunting cartridges for sporting use.

The company produces an approximate quantity of 216000 units per hour, 8 hours a day. The manufacturing of these explosive elements is very critical due to its explosive nature and the maximum tolerance in its fabrication of 200µm.

The figure 1 shows the aspect of the plates containing 600 percussion caps, used in their fabrication and inspection. These plates are the latest stage in production line where the percussion caps are produced.

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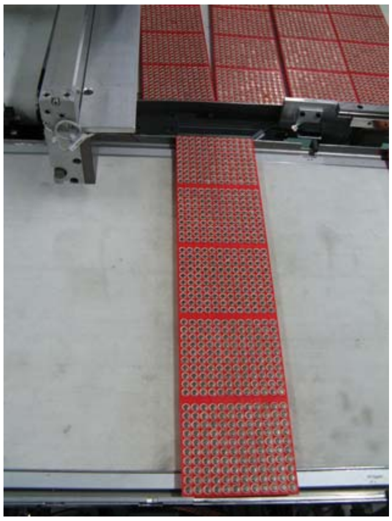


Fig. 1. Plate containing 600 percussion caps.

The errors that are suitable to appear in the percussion caps during their assembly in the production line are the following:

1) The central part of the cap is dented
2) The central capsule is badly mounted
3) The central capsule is inverted
4) There are rests of paper in the joints of the cap
5) There is no central capsule mounted
6) The central capsule is dirty
7) The external capsule is dirty or dented
8) The percussion cap is missing in the plate
9) The central capsule is mounted above tolerance
10) The central capsule is mounted below tolerance

In the actual process of fabrication, very few errors occur, estimated empirically in 1 error each 1000 units, the plates are inspected manually, and samples are extracted at random for statistics. With the system developed based in 2D and 3D machine vision, 100% of percussion caps will be inspected and statistics will be carried out in real time, using the database created with all the data and measurements of the percussion caps inspected.

II. Problem and System Description

The system to accomplish this task must comply with very demanding characteristics:

1) Obtaining of high resolution 2D images (resolution: 512 * 3300, 256 gray levels), and high precision 3D images (resolution: 512 * 3300, 16 bit values per pixel).
2) High bandwidth for image transmission and data communication.
3) Fast parallel processing of images.

The camera used is a Ranger E55 model from SICK [1]. This camera has a 1536 * 512 pixel sensor, capable of acquiring the 2D and 3D images simultaneously by dividing the sensor in different zones. It can obtain up to 35K profiles per second. The data interface is GigE standard, and provides a RS-422 encoder interface.

The lighting for the computer vision system is specially designed for this precise application and includes a 3B class line projecting red laser beam for the 3D image acquisition and a diffuse red bar light for the 2D image acquisition. Between both lights there is a separator to avoid lighting interference between them. Due to the metallic and very reflective nature of the pieces to inspect, the development of this lighting system has been one of the most complicated points of the project.

Both camera and lighting system are mounted in a linear axis to scan each plate at uniform speed. Figure 2 shows a schematic representation of the geometrical setup used for laser triangulation in the 3D image. According to [2], this *ordinary setup* provides the maximum height resolution. Figure 3 shows the real system developed following this setup.

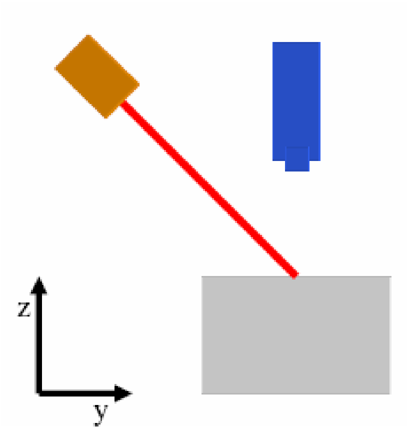


Fig. 2. Ordinary setup of the camera for 3D laser triangulation.

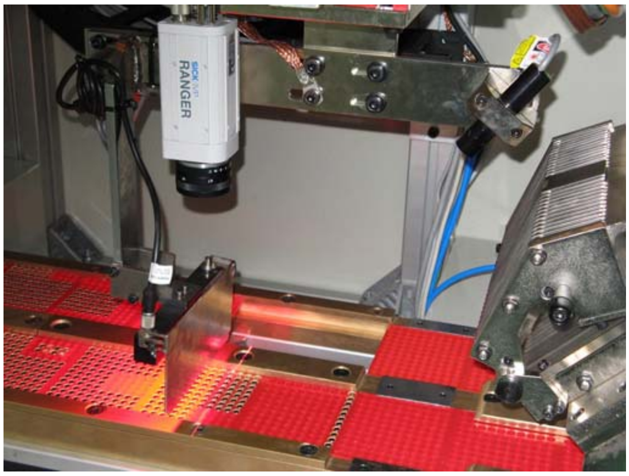


Fig. 3. System developed based in the Sick Ranger E55 camera.

The PC used for image processing and software development is equipped with an Intel Core 2 Quad Q9550 at 2,83 GHZ, 1333 MHz FSB and 12MB L2 cache. 4 GB of RAM and a 160 GB SATA II 10K RPM with 16MB DataBurst Cache[T].

For software development Halcon 9.0 Machine Vision library from MVTec GmbH has been used [3], mainly because its speed computation and its capacity to parallelize the image operations [4], taking advantage of the four cores present in the PC Quad Core processor.

The system must be capable of inspecting (image acquisition and percussion cap processing) a plate containing 600 percussion caps in less than 8 s.

III. Image Processing and Data Obtaining

The 2D and 3D images are provided by the camera separately, and different image processing algorithms are used in each of them. Figures 4 and 5 show the aspect of the images obtained. In each on the images there are established five regions of interest (ROIs), each of them corresponding to the tentative positions on the five groups of 120 percussion caps present en each plate. Within each ROI it is performed a model finder operation using a synthetic model of a percussion cap [5]. A synthetic model is a model based on geometrical shape, in this case an ellipse, and it is not obtained from previous images. By these two operations all the percussion caps in the images are perfectly located, and ready to apply local image processing operations to them.

A. 2D image processing

The figure 4 shows part of the 2D image acquired by the Ranger E55 camera. For each of the percussion caps present in this image, it has been carried out a threshold and a blob analysis of the central capsule [6]. From this analysis it can be obtained the following characteristics of a percussion cap:

1) Circularity of the central capsule after the threshold. The circularity value can be defined as follows:

$$C = \frac{A}{d_{\max}^{2} \cdot \pi}$$

Where A is the area in pixels of the region under study and $d_{\max}$ is the maximum distance from the center of the particle to all contour pixels. According to the circularity definition, the maximum value is obtained by a circle, with $C=1$.

When inspecting the central part of the percussion cap, different values are obtained depending on the state of the capsule, dented or badly mounted. Empirically, the circularity of the central capsule of a correct percussion cap is established in a value 0.45, due to its ellipsoidal shape in the image acquired.

2) Area of the central capsule in pixels and number of isolated blobs. This provides information about superficial errors. The area of the internal part of a correct percussion cap must be above 1000 pixel, and must present only one isolated blob.

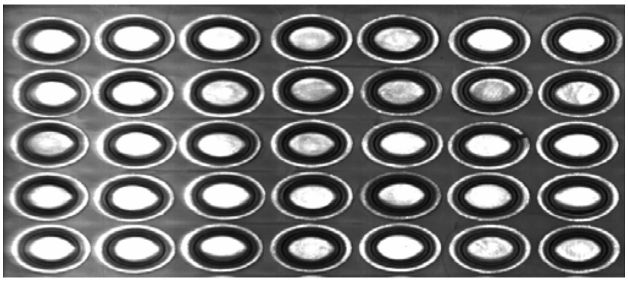
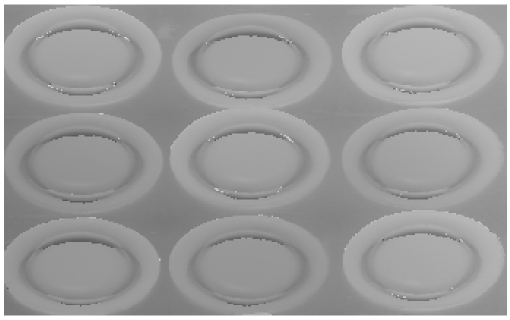


Fig. 4. Part of the 2D image acquired with the Ranger E55 camera.

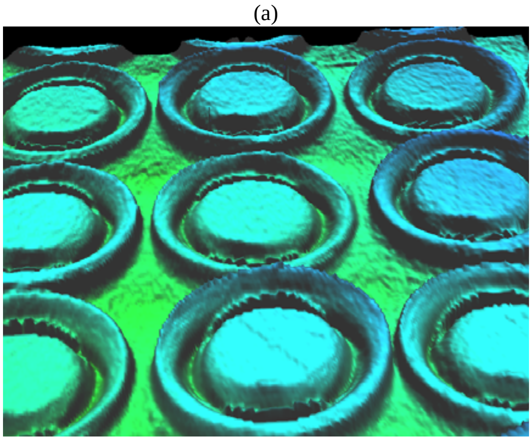
B. 3D image processing

For the 3D image processing 6 line profiles are programmed for the analysis of each percussion cap, 3 horizontal and 3 vertical. The percussion cap in the images has an elliptical shape, so the parameters of the line profiles differ depending on the type of line profile, horizontal or vertical.

Because of irregularities in the plate containing the percussion caps (it is never completely flat) and the errors in the settlement of the pieces, the profile obtained may not be perfectly horizontal in the central part. Figure 5 shows a tipical 3D image, with the line profiles and its 3d interpretation, while in figure 6 it can be appreciated a typical line profile obtained from several percussion caps.



(a)



(b)

Fig. 5. (a) Acquired 3D image from Ranger E55. (b) 3D interpretation of the image obtained.

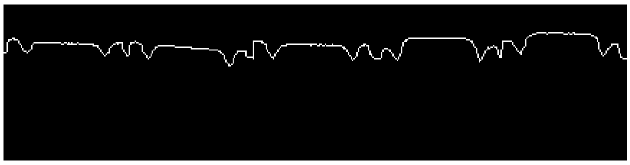


Fig. 6. 3D line profile of 5 percussion caps.

With the numerical data of the line profile, the following values are obtained [7]:

1) Maximum and minimum of the first part of the line profile (beginning of the percussion cap)
2) Maximum and minimum of the last part of the line profile (Ending of the percussion cap)
3) Mean and Standard Deviation of the values of the central capsule. The width of the central capsule is determined depending of the position of the maximum and minimum points at the beginning and ending of the percussion cap.

The detection of the majority of errors related to tolerance in the fabrication of the percussion caps is based in measurement comparison between the height values of the central capsule and the height values of the borders of the external capsule. Other error detections are based on the divergence of the height values of the central capsule of the percussion cap. To perform these measurements, the percussion cap should be placed in a complete horizontal position, and, as it has been explained before, this is very difficult to achieve due to plate irregularities and errors in percussion caps settlement. Using statistics it is possible to estimate the *regression line* ([8],[9]) of the values corresponding to the central capsule of the percussion cap. With this *regression line* it is possible to estimate the height values that the central capsule should have at the points where the maximums at the beginning and ending of the percussion cap occur, taking into account the slope of the regression line. Once this maximum values are estimated the tolerance among the maximum values of the lateral parts of the percussion caps and the central capsule can be performed.

Let the X axis of the values in the line profile be the independent value and the heights obtained in the line profile the dependent values. A value in the position *i* of the array provided in by the line profile will have an independent value in the X axis $x_i = i$ and a height value of y_i.

The *covariance* between two values can be expressed as follows:

$$\sigma_{xy} = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right) \quad (1)$$

Where $\bar{x}$ and $\bar{y}$ are the Mean values of the independent variable in the central capsule and the heights in these points, respectively.

With the covariance value calculated it is possible to establish the regression line correspondent to the heights in the central capsule of the percussion cap as follows:

$$y = \bar{y} + \frac{\sigma_{xy}}{\sigma_x^2}\left(x - \bar{x}\right) \quad (2)$$

The regression makes possible to calculate the theoretical values of the central capsule height at the points where the two lateral maximum values of the percussion cap occur, and thus, compare the difference in height between a certain maximum and the height of the internal capsule of the percussion cap at that precise point. For a x_M value where a maximum exists, the theoretical height of the internal central capsule at that point can be estimated as follows:

$$y_i = \frac{\sigma_{xy}}{\sigma_x^2} x_M - \frac{\sigma_{xy}}{\sigma_x^2}\bar{x} + \bar{y} \quad (3)$$

With this height simulated it is possible to compare it against the maximum in that point and evaluate if the difference in height is in tolerance.

This process is repeated for each of the 6 line profiles calculated in each percussion cap.

Figure 7 shows graphically this operation:

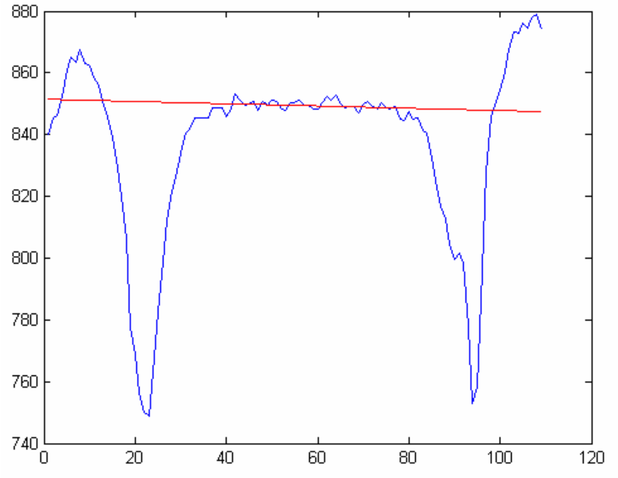


Fig. 7. Regression line estimated for the central part of the percussion cap.

To assess the validation of the regression line obtained, as well as for error detection, it has been calculated the mean quadratic error between the regression line and the real values of the central part of the percussion cap as follows:

$$Error = \frac{1}{n}\sum_{j=1}^{n}\left[y_{r_j} - \left(\frac{\sigma_{xy}}{\sigma_x^2}x_j - \frac{\sigma_{xy}}{\sigma_x^2}\bar{x} + \bar{y}\right)\right]^2 \quad (4)$$

Where y_r is the vector of real values of the central part of the percussion cap, and *n* is the number of values of the vector y_r.

The regression line will be used to detect errors taking into account parameters such as the regression line slope, $\frac{\sigma_{xy}}{\sigma_x^2}$, that must be near 0 (horizontal line).

The bias value, $-\frac{\sigma_{xy}}{\sigma_x^2}\bar{x} + \bar{y}$ is used as a discriminant value when detecting that the percussion cap is missing in the plate or when in a percussion cap does not have the central capsule mounted.

IV. Data Processing and Error Detection

In the previous section it has been explained the data obtained from the images and the characteristics of these values. From the 2D image, the circularity and the area of the blob corresponding to the central part of the percussion cap have been extracted, and from the 3D image the maximums and minimums of the percussion cap borders, as well as mean and standard deviation of the central part of the cap have been obtained. In addition to these values, it has been calculated the regression line corresponding to the central heights of the cap, giving information about its settlement in the plate and the mean quadratic error related to the regression line and heights of the central part of the percussion cap.

Taking into account of these values this section exposes the criteria used to error detection.

A. Errors in the central part of the percussion cap

In this errors (central part of the cap dented, central cap badly mounted or central capsule inverted), the regression line slope, $\frac{\sigma_{xy}}{\sigma_x^2}$, that must be near 0 (horizontal line), will present a high value in absolute terms, indicating that the central capsule of the percussion cap has an error. The 2D image parameters, circularity and area in pixels of the central cap, will also indicate an error.

The mean value of the heights of the central cap, the bias value of the regression line, and the mean quadratic error (4) are the values used to differentiate among these three errors.

B. Rests of paper in the joints of the cap

To detect this error, the 3D line profiles of the percussion cap are used. In the line profiles it is possible to obtain the two maximum height values of the percussion cap, corresponding to the borders of the external capsule of the percussion cap, and, thus, the external border of the percussion cap. Taking into account the position in the X axis of the maximum values, it is possible to calculate the difference between their value and the theoretical value of the regression line in those points. The value of this difference must be very similar in both maximums. If a big difference occurs, this indicates paper in the joints of the cap.

C. Central capsule missing or percussion cap missing

These two errors are detected using the slope and the bias value of the regression line. In these cases, the regression line slope will have a correct value, near 0, indicating an horizontal line, while the bias value will indicate the type of error detected. In a correct percussion cap, the bias value, $-\frac{\sigma_{xy}}{\sigma_x^2}\bar{x}+\bar{y}$, is between 800 and 900. In the case of the central capsule missing, this value will be close to 300, and if the complete percussion cap is missing, the bias value will be almost 0.

D. The central capsule is dirty

If this error appears the 3D data of the percussion cap will be perfectly correct, whereas the 2D image data, circularity and area of the central part of the percussion cap, will present errors. The circularity will be below 0.45 and the area well below 1000.

E. Central capsule mounted above tolerance or below tolerance

To detect this type of errors, the differences between the two maximum values of the percussion cap and the theoretical values of the regression line at those points are calculated.

If the two values are similar, the mean value of both differences is calculated.

If this mean value is smaller than the above tolerance permitted for the central capsule, the central capsule is above tolerance. On the other hand, if this mean value is greater than the below tolerance permitted, the capsule is mounted below tolerance.

V. Analysis of Results

To test the correct performance of the system developed, an increasing number of percussion caps have been analyzed in three different tests (1200, 2400 and 4800 percussion caps) and the system response has been done attending to the following criteria:

1) Correct Error Detection (CED): The system detects an error and its type (from type error 1 to type error 10) correctly.
2) Non Correct Error Detection (NCED): The system detects an error correctly but misses classifying its type.
3) Global Error Detection (GED): This value is the sum of the CED and NCED values. It comprises all the errors detected even if the type of the error is not correctly classified.
4) False Positives (FP): There is not an error in a percussion cap, but the system marks it as defective.
5) False Negatives (FN): There is an error in a percussion cap, but the system does not detect it.

Due to the small amount of errors happening in normal production process of percussion caps, several percussion caps in the plates used for system validation have been substituted randomly with pieces with errors of all types. In each plate containing 600 pieces, 20 pieces with random errors have been inserted at random positions.

Table 1 shows the results obtained in the three performance tests carried out. One thing that must be taken into account is that the priority of the system is the detection of the defective pieces to avoid its further use. From this point of view, the NCED are important but not critical, because although not correctly classified, the error has been detected and the piece will be retired. However, this value, as it will be presented in table 1, is very small.

TABLE I
VALUES OBTAINED FOR DIFFERENT TESTS

	TEST 1 (1200 pp, 40 random errors)		TEST 2 (2400 pp, 80 random errors)		TEST 3 (4800 pp, 160 random errors)	
	pieces	%	pieces	%	pieces	%
CED	37	92.5	75	93.75	152	95
NCED	2	5	3	3.75	5	3.125
GED	39	97.5	78	97.5	157	98.125
FP	0	0	1	1.25	2	1.25
FN	1	2.5	1	1.25	3	1.875

Attending to the test performed, it can be observed that the Global Detection Error (GED) value indicates a precision in error detection above 97% in all cases. This means that in the worst performance case, and taking into account the empirically established real error ratio of 1 error each 1000 percussion caps, the system will only commit 3 errors each 100000 percussion caps, 100% of the pieces inspected.

VI. CONCLUSION

This work has been developed in demand of an industrial final client to inspect potentially problematic pieces.

Nowadays the final client demanding these systems, inspects random pieces and carries out statistical studies of its production.

The system developed is capable of inspecting all the pieces in mass production, in a very fast and precise way, as explained in the previous sections.

Taking all these points into consideration, the system developed is an incredible advance towards 100% quality inspection of these potentially dangerous pieces.

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