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Computer vision based pellet gauging

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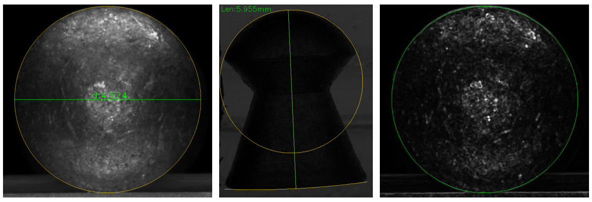

Abstract
In this paper, a method for dimensional gauging of pellets based on image processing with sub-pixel precision is introduced. The method is intended as a component of a quality control system for pellets. Object gauging from the image is on rise in demand in modern manufacturing processes. Very often, depending on the resulting precision, this is done physically in direct contact with the object itself. In case of soft objects that could be damaged in the process of gauging by standard methods (physical contact gauges) a non-contact method is needed. The method proposed in this paper uses means of sub-pixel edge detection in image combined with the interpolation-based edge methods. Resulting algorithm is fast with industry sufficient accuracy. Experimental results described in the paper show gauging accuracy of 25 micrometers for the side view and accuracy of 10 micrometers for the frontal view.

Keywords: Object gauging — Sub-pixel edge detection — Industrial image processing

Supplementary Material: *N/A*

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1. Introduction

Many products manufactured nowadays are subject to strict regulations concerning their spatial dimensions. Most of the time, those products have to be manufactured with precision up to a few micrometers. For many of the products, a contact gauging is sufficient. In the cases where the object is too soft a contact gauging might be destructive, therefore a non-contact approach is preferable.

To be able to meet or overcome the standard of contact gauging, the non-contact gauging has to be very precise. In this situation a pixel precision might not be sufficient. Thus, a method with sub-pixel precision has to be implemented to achieve higher precision than a pixel can offer.

In case of industrial applications, in our instance the pellet gauging, the algorithm has to overcome several obstacles. Firstly, the position of the pellet is not always exactly the same due to its movement throughout the machine, meaning the pellet's axis is not perpendicular to the direction of its movement and as well to the camera. Secondly, the lead from the pellets is left inside the machine causing the pellet background getting impure as the production goes. Those obstacles make the environment for precise gauging challenging.

In this paper, the approach of gauging the pellets is presented; it is a part of the larger system for the complex pellet quality control. The whole system is composed of a machine which fills carts with the pellets. Images of such pellets are then taken and processed to check their quality. The control consists of two parts. The first one looks for the physical defects and the second, presented here in more detail, checks the dimensional properties. In this case, it is the pellet length (side view) and head size diameter (frontal view). Example of the input images can be seen in

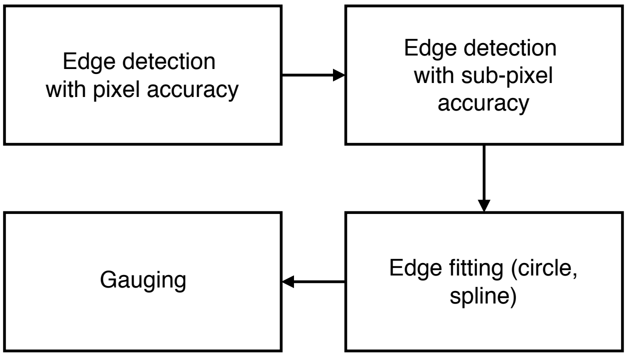

Figure 1. Pellet gauging process. The second step is skipped on side view.

Figure 2.

The proposed method includes two important steps. First step is to find the edge with pixel precision. Second step is then to interpolate the edge to find its sub-pixel representation. The implemented approach can be seen in Figure 1.

The rest of the paper is arranged as follows. Section 2 presents the related work in the industry. Proposed system description is in Section 3 In Section 4 the implemented system is described. The results are presented in Section 5 and conclusions are drawn in Section 6.

2. Related work

The algorithms generally used for the gauging task are often highly dependent on the environment and the object features. The approach chosen for the edge detection are typically selected based on the required precision of the gauging process.

Peng et al. [1] developed an algorithm for O-rings seal inspection. The edge with pixel accuracy is detected first. For the detection, an improved morphology based anti-noise method is used. Pixels of the edge are the input for the sub-pixel edge detection for which the edge profile has to be known in advanced as well, as stated by the authors. Every pixel position of the edge from previous step is a centre for the 7×7 window in which the direction of the edge is found. Pixels in the direction of the edge (biggest sum of gradients) are then used in last step where they are interpolated by cubic spline. The precision of the algorithm is not disclosed by the authors.

The approach without sub-pixel approximation was proposed by Jurkovic et al. [2]. The authors developed an algorithm based on the image gradients to locate the edge of the inspected object. The precision of the proposed approach is up to 5 µm. It is important to note that the object measured in this approach is always stable.

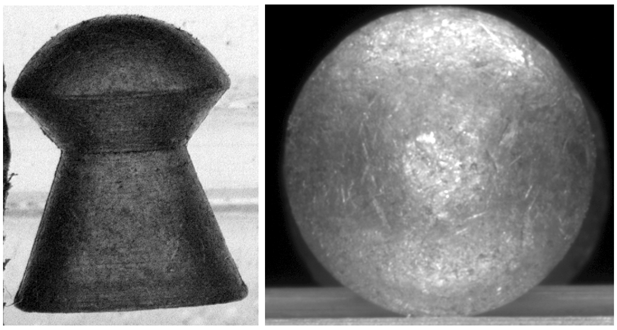

Figure 2. An example of input image for length gauging (left) and head radius gauging (right). In real scenarios, the images are much darker as you might see in other figures. For the purpose of demonstration, the images were altered.

Gadelmawla [3] created an algorithm for spur gears inspection. The approach consists of two steps. In the first step, the image is thresholded to create a binary image and the edge is then determined by the 8×8 neighbourhood of each pixel. If the colour of the examined pixel is black and the colour of any of its neighbours is white, the pixel is marked as edge pixel. The precision of the algorithm is 0.1 mm.

3. Proposed system

The system as a whole is a cooperation of hardware and software. The hardware itself consists of industrial cameras, light sources and optical lenses. Two cameras used for the gauging of the side view (length) and frontal view (radius) have resolutions of 2048×1536 and 2448×2048 respectively. Both cameras are mounted with telecentric lenses with computed pixel size of 11.2 µm mm for side view camera and 7 µm for frontal view.

Pellets are carried in carts that can hold 15 pieces at once. The whole system is controlled through the software. Every pellet is gauged whilst moving and its dimensional information are recorded and evaluated. The system ought to be able to process at least 600 pellets per minute.

4. The length and diameter gauging algorithm

Although both gauging algorithms, one for the length gauging and the other for the head diameter gauging, begin their analysis with gradient image, they both require different approach. The input images (see Figure 2) are captured with camera using the telecentric lens to minimise the distortion.

4.1 Edge detection with pixel accuracy

To detect the edge of the pellet, various approaches can be used. From popular and sophisticated Canny edge detector to the more simpler once like Sobel, Roberts, Prewitt (gradient edge detectors) or LoG [4].

Given the known conditions in both views, the gradient edge detection was used. The image gradient can be computed as a combination of Sobel operators applied in both spatial dimension of the image. Due to sensitivity of the methods to noise, the noise in the image is suppressed with median filter.

For the side view of the pellet, the edge is then detected by traversing through the image $a[m,n]$ in $x \in \{0,1,2,\ldots,M-1\}$ direction and examining every column. To avoid marking false edges, firstly all gradient values are picked from the column at the position $y \in \{0,1,2,\ldots,N/3\}$. The pixel is considered as edge to be the first one having gradient value higher than $^3/_4$ of the highest gradient in examined part of the column. The pick of the highest gradient is omitted to avoid false spike edge detection. The same is done for the bottom part of the pellet with bottom-up approach.

The same approach is taken in case of head view. Due to the roundness of the edge and its lack of clarity side, the first edge is detected in two steps. Given the better properties of pellet's head view edge on the top and bottom part, the edge is detected in the centre part from both sides. Leaving the centre part at the bottom out, because of its edge connection to the base. This fact makes it difficult to decide on the precise edge position. Segments of the pellet used for the initial approximation are highlighted in Figure 3. After obtaining the partial edge from top and bottom, a circle in least square fashion is fitted to this edge. To avoid some falsely detected edge pixels, the fitting is done iteratively with restrictions to avoid falsely detected edge pixels to move circle in wrong direction. The result of edge detection for both views can be seen in Figure 4.

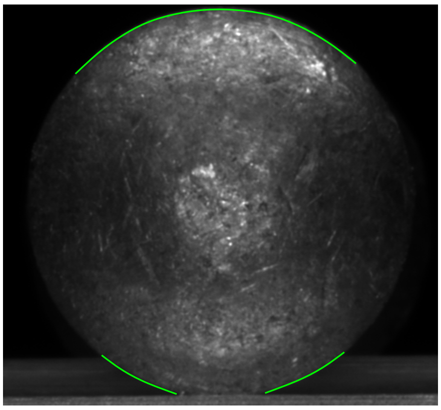

Figure 3. Highlighted segments on the head view which are used for the initial edge search and circle fitting.

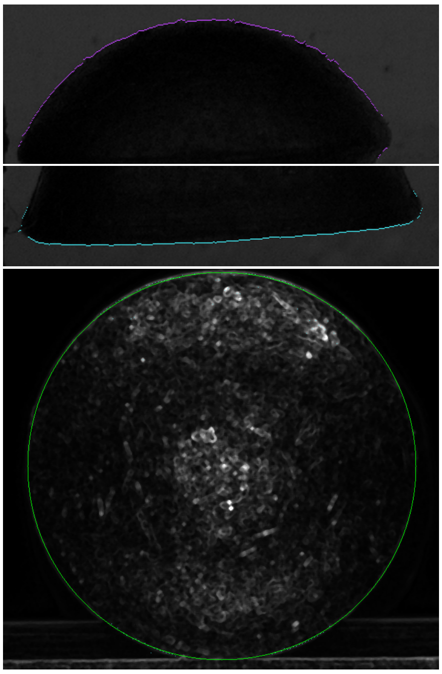

Figure 4. Location of the edge with pixel accuracy. Side view, head part (top, purple) with a few visible badly detected edge pixels which the algorithm will filter out in the process of the iterative circle fitting, bottom view (middle, blue) with the same issues and handling. Head view starting edge (blue) with approximated circle (bottom, green).

4.2 Edge detection with sub-pixel accuracy

For the side view, the edge detected with pixel accuracy is used for the final fitting. Further sub-pixel edge detection in a way of interpolation cannot be used in this view, because the edge profile is not known a priori. The top (head) edge points are fitted iteratively with the circle. The bottom edge points are fitted, again iteratively, with second order spline. The spline is a better option than a simple line due to the pellet's imperfect position in the machine. For the side view, this approach seems to be sufficient.

The head's view circle indicating the approximated edge is used for the sub-pixel edge detection. Gradient image of the head view is transformed to Log-Polar space using the circle's properties. The issue of locating the edge is now simplified to finding the highest gradient in the column given the circle's radii and its close neighbourhood. To locate the edge position more precisely, the close neighbourhood of every located edge pixel, two pixels to both sides, is used to fit with spline of second degree. Zero crossing of the first derivative of the spline gives the sub-pixel edge position. All the edge pixels are transformed back to cartesian coordinate system. A circle is iteratively fit-

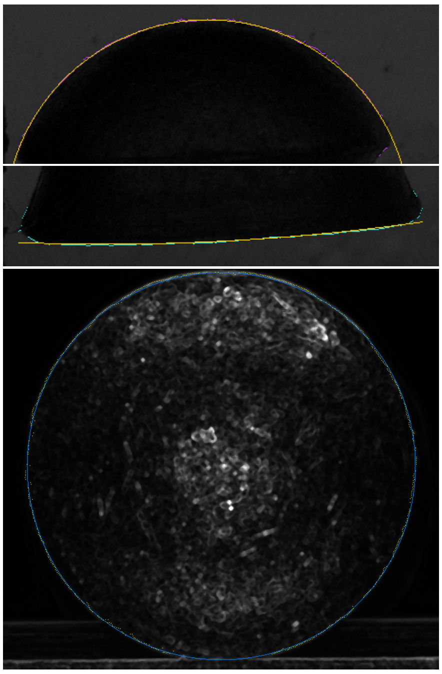

Figure 5. Final edge detection with its fitted primitives (orange). Side view, head part with its iteratively fitted circle (top), skirt part with its iteratively fitted second order spline (middle). The head view with its iteratively fitted circle (bottom).

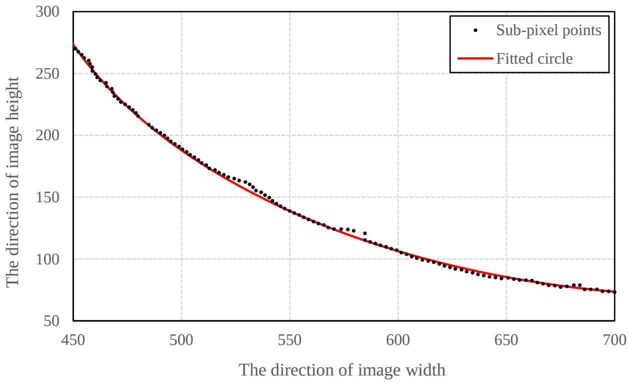

Figure 6. Part of the circle fitted to the sub-pixel edge points by the least square method.

ted to the resulting edge. Figure 6 shows a part of the circle fitted to the sub-pixel points by the least square method. Final fitted edge for both views can be seen in Figure 5.

4.3 Computing the length of the pellet

Whilst the size of the head from the frontal view is the diameter of the fitted circle, side view resulting length has to be computed from the fitted circle and the second order spline.

The tilt of the pellet has to be determined first. This can be achieved with reasonable precision by computing the y coordinate of the second order spline in the same distance from the centerline of the image. Those points define a line. Normal vector of so constructed

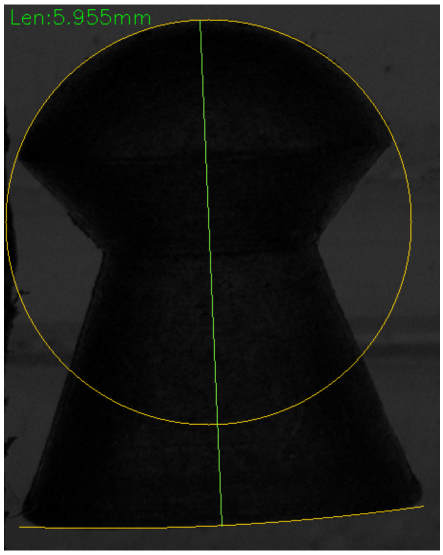

Figure 7. Resulting length of the pellet computed as the distance of two points where the vector representing the pellet axis intersects the circle fitted at the top and second order spline fitted at the bottom.

	Accuracy
Side view	25 µm
Frontal view	10 µm

Table 1. Accuracy of the proposed algorithms for side and frontal view.

line is parallel to the pellet axis. Distance of the intersections of this vector with circle (taking the furthest of two solutions away from the bottom) defining the head part and second order spline defining the bottom part is representing the resulting length of the pellet. Its visualisation can be seen in Figure 7.

5. Experimental results

The proposed method was evaluated for its precision for both views.

The accuracy was evaluated based on the gauging of a set of 15 pellets. The maximum difference between the length gauged by the algorithm and the length measured by the calibrated measuring machine is the resulting accuracy. Results for both views can be seen in Table 1.

The performance of both proposed methods was tested on a computer with Intel Core i5 3.2GHz CPU. The test consisted of 5000 individual gaugings for each view from which the 5 fastest and slowest results were removed and the rest were averaged. Results are presented in Table 2.

6. Conclusion and future work

In this paper, the algorithm for pellet length and head diameter was introduced. Both algorithms start with

	Performance
Side view	4.25 ms
Frontal view	28.3 ms

Table 2. Performance of both proposed algorithms. Frontal view method is significantly less performing due to its complexity.

the gradient image in which the edge of the pellet is located. On frontal view, the more precise sub-pixel edge location is determined by second order spline fitting.

As a result the pellet length is gauged with precision of 25 µm and head diameter with precision of 10 µm. Those are industry sufficient precisions. The expected precision for the gauging algorithm with sub-pixel approach to the edge detection would be expected to be better than a pixel size. This is due to the fact that the pellet is gauged whilst moving. Additionally, the pellet might be slightly tilted in relation to the image plane, which introduces new inaccuracies in to the evaluation of the algorithm. The repeatability of the method cannot be reliably evaluated because of those factors and the resulting precision is more a precision of the machine to stably move the pellets whilst being captured than of the algorithm itself. The precision of the algorithm is expected to be higher.

The performance of both methods is also sufficient. Frontal view being able to gauge the head diameter in average of 28.3 ms means the ability to process more than 35 pellets per second. This means that the algorithm is not introducing a bottleneck to the system as a whole.

In future work, the filtering of the edge might be implemented before the fitting of the primitives. Although the algorithm is iterative and filters out edge points being far from the fitted primitive, the filtering of the edge in advance might increase the precision altogether.

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