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Quality analysis for the production of pelletised materials using Fourier Descriptors

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Abstract We evaluate the effectiveness of Fourier Descriptors for an in-line characterization of the quality of pelletised materials. For the quality analysis we evaluate the significance of information conveyed by a limited number of low order Fourier Descriptors. Further, we investigate the influence of image resolution and shape on the outcome.

Keywords Fourier analysis, fourier descriptors, surface analysis, digital image processing

1 Introduction

Plastic pellets may be produced by pushing molten prime material through die plates into a water stream and pelletizing by cutting the extrusion with a rotating cutter to the preselected length [1]. Examples of resulting pellets are shown in Figure 1.1. The water stream simultaneously cools the pellets and transports them to the next stage of production – the dryer.

The quality of these pellets is influenced, among other things, by the temperature of the molten material, the sharpness of the cutter, and the cleanliness and temperature of the water. Some polymers, for instance, may crystallize with higher temperatures and, subsequently, change their optical appearance and become opaque [2]. Furthermore, the shape of the pellets is highly dependent on the sharpness of the

Figure 1.1: Images of two different sets of pellets. On the left-hand side the pellets are comparatively smooth. The observable difference in Gray-scale values is due to temperature differences during production which causes some pellets to crystallize. On the right-hand side the shape of the pellets is less homogeneous which might indicate a blunt cutting tool.

cutter's blade. Given the plasticity of the molten filaments the separation process of the pellets may lean more on the side of the preferred cutting instead of tearing them off in the cutting tool, which indicates wear on the tool or some other quality diminishing conditions. A blunt blade may create pellets as shown on the right-hand side of Figure 1.1 where the main body of the pellet has thin appendices or strands.

To devise an in-line system able to observe the extrusion process and characterize the resultant quality with low reaction time is not a trivial task. Since the quality is dependent on multiple parameters and only partly controlled by the process itself but always dependent on the processed materials, to attain an optimized result requires quick reaction times of the quality assertion process. In our proposed scheme pellets were sampled at random right after the dryer and shape information, as one of the early indicators of wear on the cutter, was gathered with a camera to draw conclusions regarding some of the process parameters.

2 Measurement Setup

A B&R Vision System [3] camera was used as it allows an easy integration into the PLC system of the production line. The gray-scale-camera is complemented by LEDs with different colours which by successive illumination of an object allows to gain also colour information about the analysed specimen. That information allows to detect a beginning cystallisation of the specimens, which can be accompanied by a change in opaqueness [2]. In Figure 1.1 the crystallised pellets are recognisable due to their different transparency.

The overall image acquisition and processing system is complemented by an on-board image processing system. The on-board system is capable to evaluate – amongst other things – the area in pixels, the mean gray value, the rectangularity, the circularity, and the anisometry of a detected object. In combination with a B&R PLC, additional image processing algorithms can be implemented.

The measurement setup used for acquiring the images is shown in Figure 2.1. A funnel is used to concentrate the falling pellets into the focal plane of the camera.

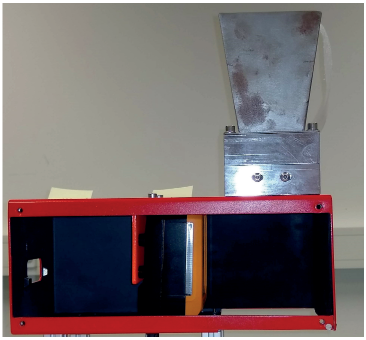

Figure 2.1: Picture of setup for testing.

3 Fourier Descriptors augmenting the feature space

The camera's on-board image parameters showed strong limitations when trying to analyse the produced pellets for production quality. Figure 3.1 shows two pellets which objectively have a very different shape, yet a distinction based on the parameters rectangularity, circularity and anisometry with values of 79/69/13 for the first and 80/69/13 for the second blob is almost impossible.

To overcome those limits the usefulness of Fourier Descriptors to assess the quality of pellets was investigated.

Figure 3.1: Images taken of two different pellets. The red line represents the detected contour of the blobs.

Image Processing In a first step the gray-scale image acquired by the camera is transformed into a binary image by thresholding the image. With this the regions, also called blobs (binary large objects), that represent pellets can easily be separated from the dark background. After labelling the regions, the boundary of each region is identified. [4] proposes a simple tracing algorithm, that returns the region's boundary as a list of points with their x- and y-components.

Following [5] the contour is transformed into a complex valued signal

$$s[n] = x[n] + iy[n], \tag{3.1}$$

with $n = 0, 1, 2, ...M - 1$ where M is the number of contour pixels. The discrete Fourier transform of $s[n]$ returns the complex valued spectrum

$$S[n] = a[n] + ib[n], \tag{3.2}$$

the Fourier Descriptors, with $n = 0, 1, 2, \cdots M - 1$ where M is the number of contour pixels.

The component $S[0]$ of the nonsymmetric spectrum represents the centre of the contour. As it is irrelevant for the evaluation of the contour's shape we won't consider it for the following calculations.

The remaining spectral components can be interpreted as rotating pointers with different rotational speeds, amplitudes and phases. The components $S[k]$ and $S[M - k]$, with $k = 1, 2, 3 \cdots (M - 1)/2$ for an uneven M and $k = 1, 2, 3 \cdots M/2 - 1$ for an even M, have the same rotational speed but opposite rotational directions and are in the following identified as k-th order Fourier Descriptors. For an even M there is only a single component of order $M/2$.

For the following analysis we consider only the Fourier Descriptors' absolute value

$$C[n] = |S[n]| \,, \tag{3.3}$$

as it describes the magnitude of each spectral component.

Exemplification Figures 3.2 and 3.3 show two different pellets. The red line represents the original contour and the green one the result of inversely transforming only the lowest 4, 20, and 32 (left to right) Fourier Descriptors.

Figure 3.2 shows a pellet with a smooth surface and no appendices. The simple contour implies that higher order Fourier Descriptors have small magnitudes. This can also be observed in the Figure, as the inverse transformation of only the first four descriptors already gives a very close approximation of the original contour. As the number of Fourier Descriptors for the inverse transformation is increased the green contour changes only slightly.

Figure 3.3 shows a pellet with a complex shape due to appendices resulting from a low quality production process.

The complexity implies larger magnitudes in higher order Fourier Descriptors, therefore the inverse transform using higher order Fourier Descriptors provide a better approximation of the contour. This is clearly visible in the figure as an inverse transform of the first four Fourier Descriptors results in an inadequate approximation of the contour. The use of 20 and 32 Fourier Descriptors results in an increasingly better approximation.

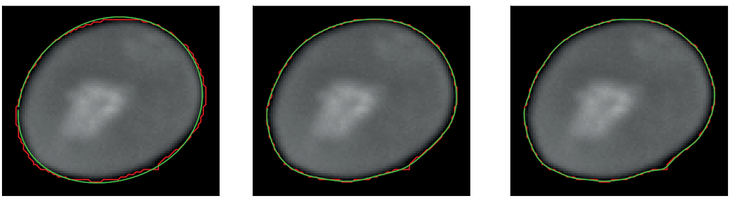

Figure 3.2: Images of a smooth pellet with its original contour in red and in green the result of inversely transforming the lowest 4, 20, and 32 Fourier Descriptors.

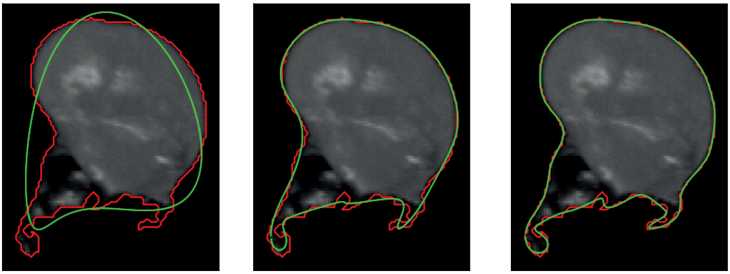

Figure 3.3: Images of complex blob with its original contour in red and in green the result of inversely transforming the lowest 4, 20, and 32 Fourier Descriptors.

Application as Shape-Descriptor In [6] the absolute values of the single descriptors are used in order to obtain information on the size of the object to be measured. Our goal, however, is not to estimate the size of the object, but rather the smoothness of the surface.

As mentioned above the smoother the surface the lower are the values in the higher order Fourier Descriptors in comparison to lower order ones. Hence, the ratio of lower order Fourier Descriptors to all descriptors would be comparatively large and, for example, for a perfect circle would be 1. Therefore we propose

$$v = \frac{\sum_{n=0}^{N} \left(C_{low} \left[n \right] \right)}{\sum_{n=1}^{M-1} \left(C \left[n \right] \right)} \tag{3.4}$$

as a measure of the smoothness with $C_{low} \in C$. C_{low} is a selection of N lowest order Fourier Descriptors.

Influence of Resolution The above considerations are made under the assumption of shapes with an infinitely high resolution. In a real world application the resolution is always limited, due to the quantisation carried out by a camera. This quantisation leads to a stepped contour of objects in images, which lowers the their smoothness and leads to larger magnitudes in higher order Fourier Descriptors.

For increasingly lower resolutions – measured in pixels per blob – the influence of the quantisation on the smoothness increases as the steps in the contour become increasingly bigger relative to the contour.

This dependency is depicted in Figure 3.4 which shows the calculated smoothness values for a quantised ideal circle (left) and a quantised ideal square (right) for increasing pixels per blob. The edges of the square were rotated by 45° to the edges of the pixels to observe the influence of the quantisation. The four different lines in each plot represent each a different combination of the lowest three order Fourier Descriptors, which will be discussed in the next part.

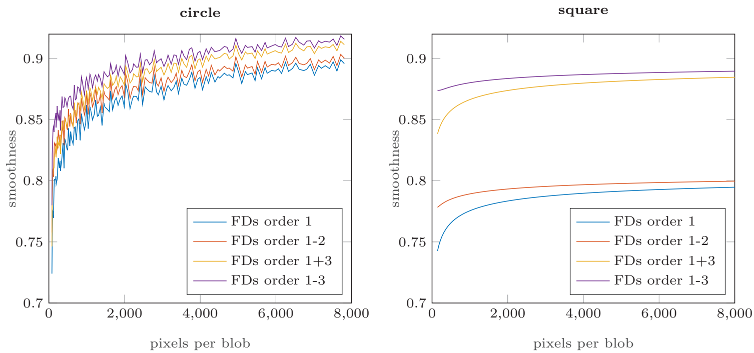

Figure 3.4: Smoothness values for circles (left) and squares (right) with different areas. The different lines represent different combinations of the three lowest order Fourier Descriptors for calculating the smoothness.

It can be observed that in the graph representing the circle, the smoothness value is comparatively low for small resolutions and increases for higher ones. The smoothness of the square on the other hand stays comparatively constant for the range of resolution, when the second order Fourier Descriptors are included. When the first and the first and third order Fourier Descriptors are used the graph shows similar properties to the circle's.

The use of different cameras, the positioning of the camera to the falling pellets and the size of the pellets have an influence on the resolution of the detected pellets images. Consequently, the influence of the resolution on the smoothness have to be taken into account when making assumptions based on the result of Equation 3.4.

Required order of Fourier Descriptors to calculate smoothness Depending on the aimed form and the needed accuracy of the detection of faulty pellets different orders of Fourier Descriptors for the nominator of Equation 3.4 will be necessary.

Considering again the graphs in Figure 3.4, it is observable for both objects, that the second order Fourier descriptors have a relatively limited influence on the smoothness value. In both cases the addition of the third order Fourier Descriptors yields a higher change of the smoothness value, as they contain information on the rectangularity of the object. For the circle this is probably due to the quantisation with square pixels.

The above implies that generally the use of first and third order Fourier Descriptors for the calculation of the smoothness will return a high value for smooth pellets, as they will most likely result in a rectangular, circular or oval projection in the images.

If high precision for detection deviations from spherical and ellipsoidal shapes is the goal, the use of only first order Fourier Descriptors is suggested by Figure 3.4, as they contain only a low quadratic share in comparison to e.g. cylindic ones. Any information in the third order Fourier Descriptors will be considered erroneous and will lead to lower smoothness values.

4 Results

In order to evaluate the application of the smoothness value on real images of pellets, we took 30 images of 11 different samples of pellets. The images were taken with the setup in Figure 2.1. Of every detected pellet the smoothness value was calculated. Figure 4.1 shows the result of every sample for different combination of orders of Fourier Descriptors as boxplots. Each boxplot shows the median as red bar, the 16%- and 84% percentile as the edges of the blue box and the minimum and maximum value as black bars. Thus, the blue box contains 68% of the detected pellets.

Samples one to nine are roughly the same size with about 4000 pixels per blob. Samples ten and eleven have a size of around 900 pixels per blob. Samples one and two are also depicted in Figure 1.1. Samples two, six and nine are considered bad quality, as they have appendices

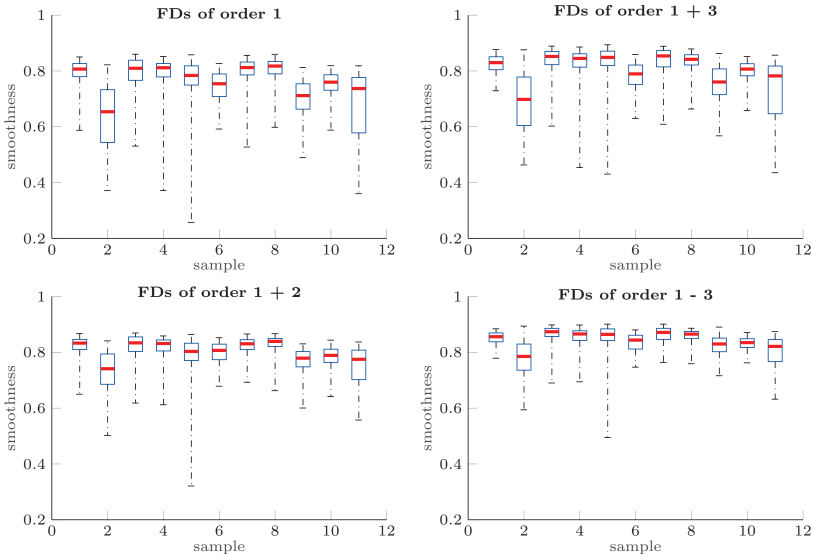

Figure 4.1: Boxplots of the smoothness values of different samples with a different combination of lower order Fourier Descriptors. The red bars show the median, the upper and lower edges of the blue boxes the 16%- and 84% percentiles and the black bars the maximum and minimum value of the smoothness values for every sample.

or show other kinds of deformations. Sample 11 contains pellets of high and low quality.

As implied by the results of the idealized forms above, the smoothness value shows the best results for the evaluation of production quality with the use of first and first and third order Fourier Descriptors. This is observable in Figure 3.3, as the 84% percentile of the low quality pellets is lower than or close to the 16% percentile of the high quality pellets in the upper two graphs. In the lower two graphs a clear distinction of samples 6 and 9 from the others is not possible.

For samples two and five the best results are obtained using first and third order Fourier Descriptors. This is due to the fact that those samples contain pellets with cylindric shapes.

The above confirms that the best results for the evaluation of a pellets quality is obtained using first or first and third order Fourier Descriptors for the calculation of the smoothness value.

5 Conclusion

Fourier Descriptors are a very useful tool to analyse the complexity of the contour of a blob. By analysing the information in the lower order Descriptors a single value can be calculated for a rough classification of the production quality. Flaws from the production process, as appendices, can easily be detected, with the proposed value for smoothness.

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