Possibilities of Industrial Data Description Using Fractal Geometry

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Abstract. The continuous growth of competitive pressure to increase the quality of products necessitates the requirement for objective measurement and control methods for materials, processes and productions. However, many structures (e.g. defects, surfaces, cracks, time series from dynamic processes) can hardly be described by conventional methods because they are complex and irregular. A new approach is the application of fractal geometry that is successfully used in science. Even though applications in industry are only sporadic and experimental, fractal geometry in connection with statistics can be used as a useful and powerful tool for an explicit, objective and automatic description of production process data (laboratory, off-line and potentially on-line). Despite the fact that this research focuses on data from the glass industry, the methodology and principles for data evaluation from industry can be applied to industry generally.

1 Introduction

Off-line and automatic on-line quality monitoring and control are a standard part of production lines. The choice of how to monitor is dependent on the analyses used and should correspond with the character of obtained data. In all industrial areas the character of data set obtained from production processes or from products can be highly structured. For this kind of data set a powerful tool for analysis of complexity – fractal geometry (especially a fractal dimension) should be used [1, 2, 3]. The fractal dimension (FD) with a combination of statistic tools is experimentally used and is an interesting and powerful tool for complex data quantification, for poor quality source searching, production optimalization and non-stability of production process subsystems searching in industrial applications. The application of FD to the industry is generally experimental [4], but application to production is possible and brings benefits. Currently, there are tools to monitor three basic data format types: digitalized photos (evaluation of 2D pictures of surface defects), time series (analysis for control systems) and topological one dimensional dividing lines (application for the corrugation test of windows glass shields and surface roughness - iron aluminides in comparison with the carbide-nickel steel in contact with glass melt) [5].

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2 Fractal Dimension Used for Industrial Data Description

The fractal dimension (also named the Hausdorff-Besicovitch dimension) is closely connected to fractals that were defined by Benoit Mandelbrot [1], though scientists found some geometric problems with specific objects before him (e.g. the measurement of coast lines per different length of rulers by Richardson). A potentially powerful property of the FD is describing complexity by using a single number that defines and quantifies structures. The number is mostly a no integer value and the FD is higher than the topological dimension. For example, the Koch curve (one of the most famous mathematical deterministic fractal) has the topological dimension $D_T = 1$, but the FD $D_F = 1.2619$. A smooth curve as a line has the topological dimension $D_T = 1$ and the FD $D_F = 1$. The FD can be computed for set of points, curves, surfaces, topological 3D objects, etc. and if the FD is higher than the topological dimension, we name the objects fractals.

A comparison of statistical tools and the FD is possible, but should be done with care. The FD gives added information about the character of describing data sets and to say that the FD is better than statistics and vice versa is impossible. Furthermore, the FD should not be used separately because the dimension does not give all the information about data set captures. Using added parameters (statistics, topology, spectral analysis, etc.) together with the dimension brings benefits and is recommended. A decisive number (a testing number) for production control or quality monitoring (for example) can be computed from obtained parameters (including the FD) by weight coefficients. This text shows methods that use the "cooperation" between the FD and statistics and gives examples of their application."

3 Description of Time Series

A lot of production processes have dynamic subsystems, which have an influence on the production. The production process can be influenced by the unpredictable of the subsystems and measured data (time series) from production sensors containing this dynamic influence. The time series are structured and typical statistic data evaluations are not often sufficient. Good quality products are the reason of accurate settings of a production process and sensors, which often produce time series in time monitors. Our research target is to develop software tools which quickly and accurately describe time series from production processes sensors using fractal geometry and statistic analyses. Fractal geometry uses the FD which describes the character (complexity) of time series with one number. To analyses time series we use statistical methods, power spectral analysis and an estimate of the FD. The estimation of the FD is calculating using the rescaled range method, the aggregated variance method and the box counting method from an "iso-set" [6].

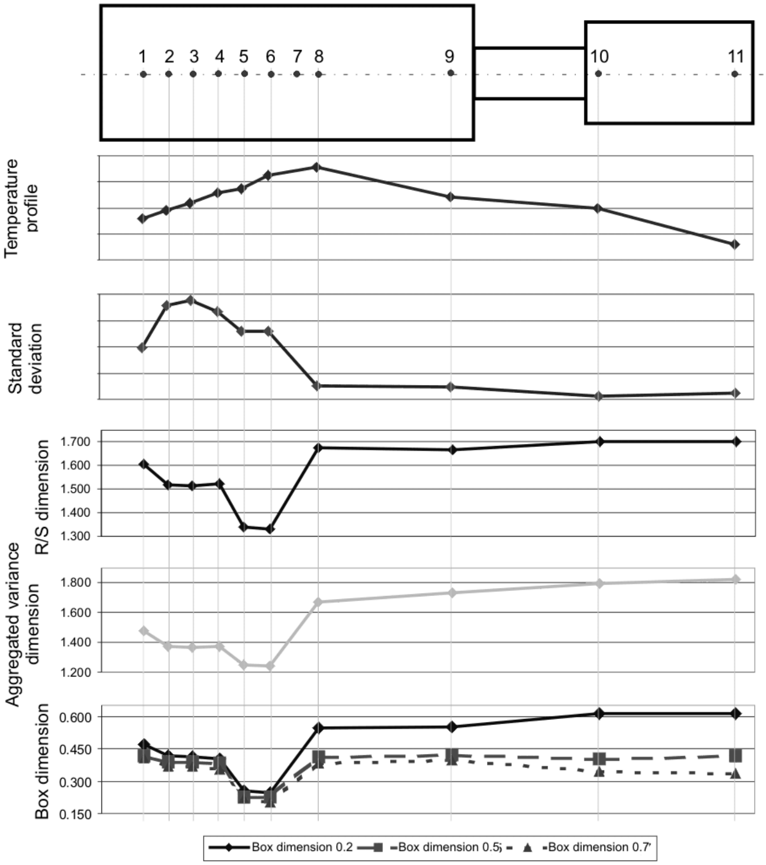


Fig. 1 Results of a tank furnace siege time series analysis

The application possibilities of a fast and accurate description of time series from production process sensors using fractal geometry and statistic analyses are numerous. Fig. 1 shows the results of a tank furnace siege time series analysis, where the standard deviation, the R/S dimension, the aggregated variance dimension and the box dimension were used. The average temperature indicates a temperature profile of the siege and an implicit temperature profile of glass melt during the siege. The FD result is a relatively large decrease from positions 5 and 6 and a subsequent ascension between positions 6 and 8. The large decrease indicates simple time series and the higher dimension represents complex time series. The decrease is in position, where a change of longitudinal currents is expected. The complex time series represent changes in temperature and the movement of melt causes the changes. It appears that fractal analysis can be used for the detection of glass melt currents [5, 7].

4 Evaluation of 2D Pictures and Defects

The explicit, objective and automatic description of image complexity can be made by different methods, both statistic and the FD. Only some of the possibilities are presented below.

In practice, the process of description has five steps:

- Preparation of samples – the structure must be visible, costume jewellery is cut, fig. 2, A.
- Taking photographs. For example photos of the hole cracks in costume jewellery are from an electron microscope, fig. 2.
- Software preparation of the digital photographs, fig. 2, C (cutting of the photographs, because only some parts of the photos are important for analysis).
- Analyses of the images.
- Evaluation of analyses results.

A digital image is a matrix (or matrixes) of pixels (rectangular array of points, fig. 2, D). Pixels can reach different numbers which depend on the format used for digital images. The pixels have numbers between 0 (black) and 255 (white) for the grey 8-bit palette bitmap and the bitmap has only one matrix. Fig. 2, C shows two typical poor quality surfaces of costume jewellery holes. The cutting C-1 has deep cracks and C-2 has a thin structure.

Software Matlab and HarFa [8] were used for these experimental evaluations. A methodology for analyses of the pictures was developed based on: histogram evaluation, percentage of black pixels, percentage of large defects, the FD, ... Only the last two analyses are suitable for describing these kinds of structures.

The grey images in fig. 2 must be transformed to binary before the analyses of the percentage of large defects and the FD. The technique for this transformation is based on what is called "thresholding"; the binary image can be determined from a grey 8-bit palette bitmap, where all the black pixels fulfil conditions e.g. $0 \leq \text{black} \leq 100$ and all the other pixels become white ($100 < \text{white} \leq 255$). We used the threshold 35.

The percentage of large defects is suitable for the detection of single, relatively large cracks and defects. This method computes the percentage of pixels with neighbouring pixels of the same value. The analysis searches for black pixels in binary images, which have five or more neighbouring black pixels. Large defects contain black pixels with five or more neighbouring black pixels that represent defects, structures, cracks, etc (in fig. 3).

The FD must be estimated for natural fractals and, of course, for data from production processes or products. For this reason many analyses can be used but the most suitable for these kinds of data and structures is the box counting method (in fig. 4). The estimated FD is named the box dimension [3] and for research the dimension was multiplied by 1000 [9].

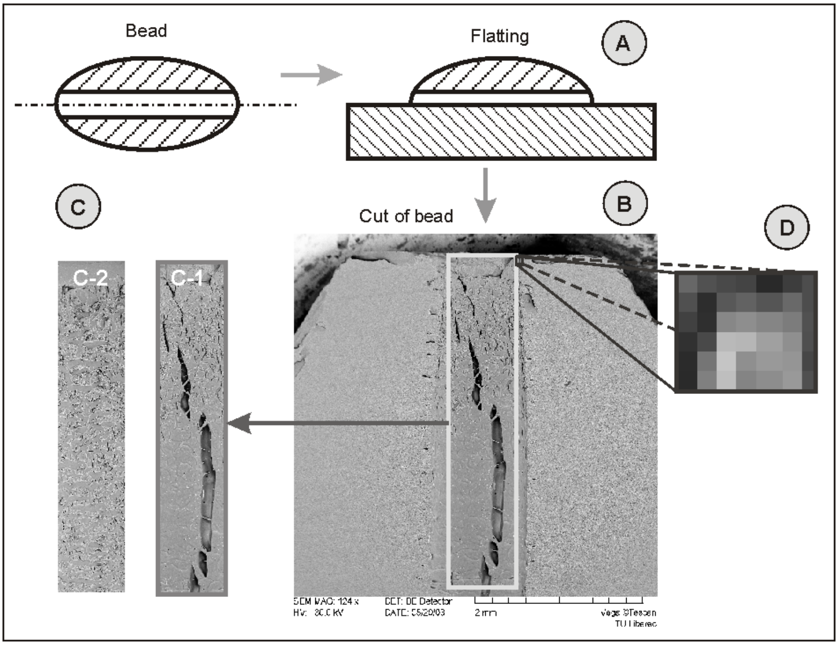


Fig. 2 Preparation of samples, taking photographs, software preparation

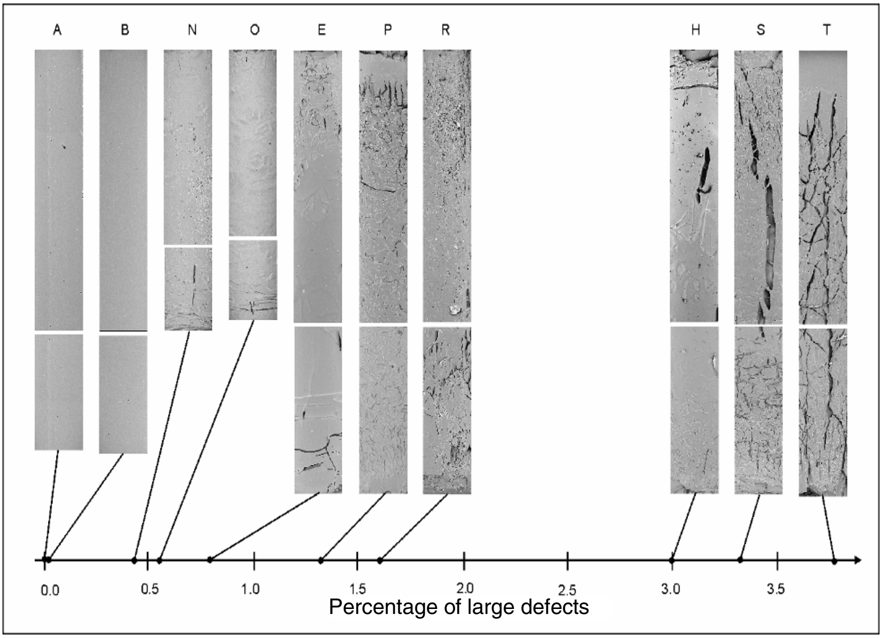


Fig. 3 Computation of the percentage of pixels with neighboring pixels of the same value - percentage of large defects

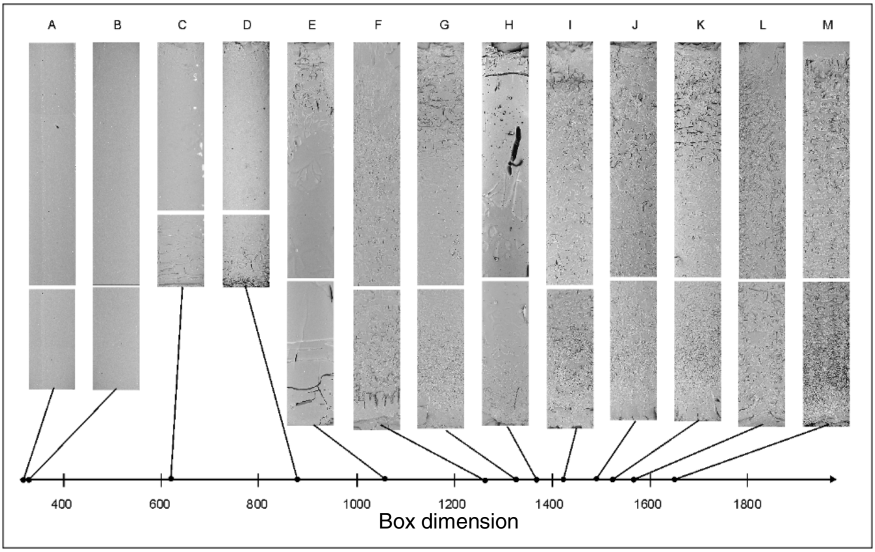


Fig. 4 Computation of box dimension

5 Classification of Topological One-Dimensional Dividing Lines

The research is intended on application of the methodology for a quantification of metal surface changes and on an objectification corrugation test of windows glass shields.

5.1 Surface Roughness Changes after Corrosion Tests

The methodology was used for quantification of metal surface changes. Relatively new materials: iron aluminides [10] are compared with currently used chrome-nickel steels in contact with a glass melt. The samples roughness is changed after interaction with molten glass during the corrosion tests. For a quantification of metal surfaces the roughness was evaluated by fractal geometry and statistic tools.

Firstly, a digital camera takes a photograph of a metal surface profile from a microscoped metallographic sample (5 photographs from one sample). Secondly, a dividing line is generated from the digital photography by a software tool that exactly defines the curve between material alloys and a surrounding. A generated dividing curve is described by FD (a compass dimension multiplied 1000, $D_{C\,1000}$) that expresses the complexity degree of the interface between alloy and glass by means of a single number. Average standard deviation all the curves (STD) and average maximum roughness all the curves (R) describe them per statistic [11, 12]. The parameters results are showed in fig. 5.

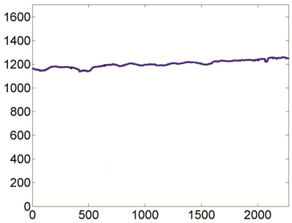
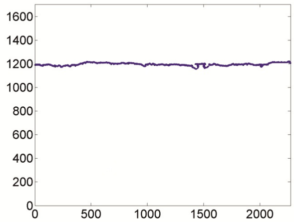
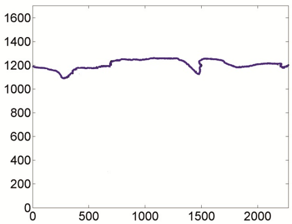
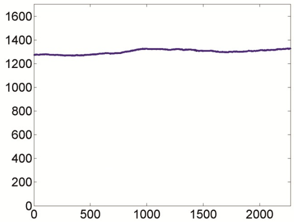
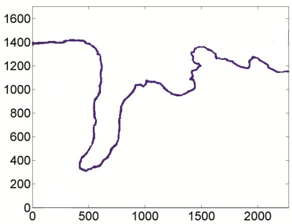
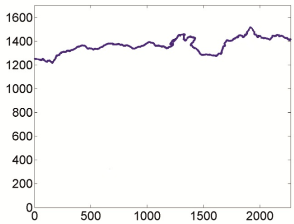
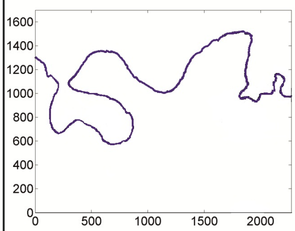
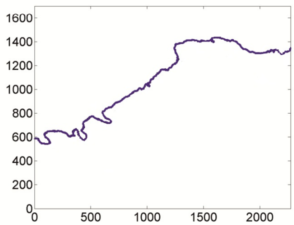
	Chrome-nickel steel EN 10095 (AISI 310) Dividing line - roughness profile (size in pixels)	R [mm] s [mm] $D_{o\,1000}$ [-]		FA - iron aluminide on base Fe3Al Dividing line - roughness profile (size in pixels)
Ground state		3.07 0.79 1029.2	1.56 0.29 1055.8	
1100OC, 24 hour		4.28 1.01 1056.4	1.54 0.47 1012.0	
1250OC, 96 hour		28.11 8.59 1121.6	5.52 1.39 1100.3	
1350OC, 96 hour		24.08 6.09 1185.4	22.64 8.09 1124.0	

Fig. 5 Examples of dividing lines chrome-nickel steel material and iron aluminide, after static glass melt effects in different temperatures and results of analyses

5.2 Corrugation Test

The optical measurement using a zebra plate is one of many important and widely used measurements for mass production and it is used in a wide range of situations: by manufacturers of float glass as a production control; by glass processors as a quality control on the glass they buy and as a production control of products (laminated glass, thermal treated glass, etc.); and as a production control, by the final customer as a quality control on the glass they buy.

The Corrugation Test is based on the reflection of light off a glass sample sheet from a skew striped plate. The test is focused on the reflection while another type of tests are specialized on passage of light though the glass. The zebra plate is 1 x 2 m with 25 mm wide black strips at an angle of 45 degrees and it is 4 m from the sheet. An observer is 4 m from the table with the sheet and the quality of the sheet is subjectively evaluated on the basis of comparison with etalons. The quality of the sheet is classified using a rate from 1.5 to 3.5. The evaluation is conducted in a dark-room and it is performed off-line. Samples of flat glass are obtained from an on-line production process and they are cut from the whole width. Fig. 6 shows good and poor quality of a glass sheet during the corrugation test. The relatively extreme "distortion" is caused by using a small angle of observation.

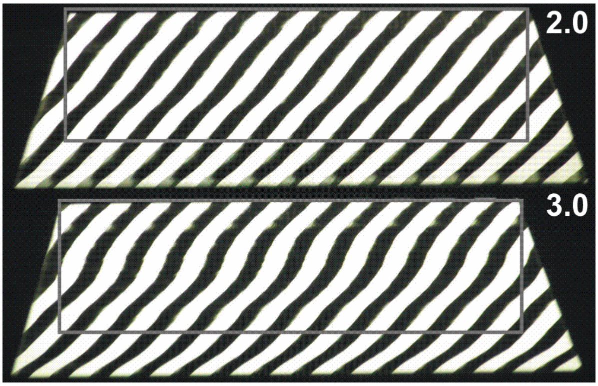


Fig. 6 Good and poor quality of glass sheets with a specification of measured parts

On the basis of our experiments a measuring system, which consists of both hardware and software, has been developed. A digital camera connected to PC replaces the operator. For the corrugation analysis a unique software for data acquisition and analysis was designed and developed using the development software Matlab, based on image analysis [13, 14]. The code is compiled as an independent program named Corrugation. An observer (an operator) lays a sheet to be tested on the table in the defined place, fills in a form in the Corrugation software and starts the evaluation by pressing a button. This initiates the communication with the camera and the image is taken on request from the software.

After downloading the image from the camera to the computer, the image analysis starts. The analysis uses the developed method and its principle is based on the detection of boundary curves between the light and the dark areas of the sheet in the image (using standard image analysis). The obtained curves are evaluated by a statistical approach, a measurement of curve length and an estimation of its FD (the compass dimension mentioned above) [1, 3]. After 30 to 60 seconds the operator can read an evaluated quality on the screen of the computer.

The tests have proved, that one parameter only cannot describe all types of the corrugation. For the assessments of a flat glass quality the following three parameters of curves generated from the reflected image are important: first complexity (smoothness) of separated curves from contours (using the FD), second the range of waviness from an ideal line (using range) and third the rate of deformation (using a length of curves). All parameters are measured in pixels. The above mentioned measurements were chosen after an extensive analysis and they reached the best conformity between a subjective evaluation done by an experienced operator and the evaluated quality using computed parameters.

The system has been successfully tested for two years on the production line with the accuracy of 0.1 – 0.3 in last version and the system has been enhanced with new features. During this test, the same image format and methodology has been used. The results of over a thousand of measurements from the real production process show good potential for the application of this methodology on-line [15].

6 Conclusion

The FD is widely used in science, but industrial applications have been rather rare. Image analysis using the FD has a great potential in combination with statistical and other measurements in industry. This methodology has been used in our research for monitoring three basic data format types: digitalized photos (e.g. digital, classical photographs, images from electron microscopes), time series (e.g. analyses for monitoring and control systems) and topological one dimensional dividing lines (e.g. profiles, roughness and the dividing line of light and shadow). Modified methods using common findings of the fractal geometry are applied to each data type.

Despite of the text focusing on data from glass industry an accent was put on possibilities of using of obtained knowledge, the methodology and principles for data evaluation from industry and products in industry generally.

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