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Enhancing Materials Science through Computer Image Analysis and IQA Approaches

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Abstract. Computer image analysis allows for various object detection and classification as well as conducting measurements on microscope images. Technological development, including the application of artificial intelligence solutions, speeds up the classification of large data sets. In the context of image analysis, an essential issue is image quality assessment (IQA). Applying the tools of image analysis, or artificial intelligence, linked with the appropriate IQA approach reveals the opportunity to develop materials with better functional and technological properties more sustainably and effectively.

Introduction

Quality is a universal and significant topic of current decades. It concerns every area of our lives. Daily, we make our decisions based on certain variables, which help us to make the right decision. The process of human analysis begins with creating images using our eyesight, then, the received data are analysed by our brains. The classification is a process that appears during this analysis. Based on classification we select what is right or wrong. This applies to every aspect of our lives, e.g., shopping (choosing the best possible fruit, products, electronic devices or books). The constant development of technology can positively influence all aspects of human life, e.g., the computer became an indispensable assistant at work, which, thanks to its components, allows for improving the work of algorithms in numerous and diverse tasks, permitting to make them efficiently and, usually, correctly (omitting the human factor). Every product, process or system shall represent proper quality, which means that it shall meet the standards of a user. To obtain that, at the stage of preparing the concept, the process shall be divided into components followed by their deep analysis. The quality of the product is verified at the stage of tests, during which extracting as much information as possible shall be required.

The tests and experiments should be planned in detail to get reliable results. In this context, the design of experiment (DoE, *Design of Experiment*) methodology is a valuable approach to planning the work sustainably and effectively [1,2]. It is necessary to establish the goals and select appropriate methods used in the experiment for the verification of results. This allows for obtaining results which can be decisive in the research with the simultaneous minimization of random errors. DoE methodology can be used to analyse the effects of various factors on the product as well as the interaction of input parameters (changing one parameter can influence the value of another). Commonly, it is used to estimate the influence of process input parameters on process output. Applying this methodology, we can determine how strong the influence of individual parameters is on the output, or, we can state that the parameters are interdependent. Also, the DoE provides the tools dedicated to solving the problems caused by multiple factors acting simultaneously. DoE

is not a new term in science, and it has been widely reviewed in scientific publications [3-6]. The application of DoE methodology in image analysis has great potential for the exploration of the material's properties, as well as the development of materials with better properties, in materials science. This work aims to show some aspects of applying the microstructure image analysis to get a deeper insight into possible solutions in this area. Image analysis made on scanning electron microscopy photos can be one step in planning a robust experiment, e.g., optimization of ceramic material of better properties, as SEM analysis is one of the fundamental methods in designing ceramic materials.

Selected Aspects in a Current Image Analysis

The use of image analysis is becoming an increasingly popular tool today. It is used, among others, in materials engineering [7-9], medical engineering [10], security [11], or quality assurance [12]. The application of image analysis gives added value in every field mentioned.

Classical image analysis comprises the relevant sequence of operations. The first stage is image acquisition. Here, problems may arise like noise, shadow or image quality problems during image acquisition. The second stage is image pre-processing. At this point, we can make the image "corrected" and fit it for further work. The next process is the detection of objects in the image and their measurement (quantitative analysis). If everything is done correctly, conclusions can be drawn.

Algorithms developed by humans require much more experience in preparation but allow for better control of factors affecting the final result. Automated image analysis is today a standard method in the quality control of metallic materials, especially in the evaluation of grain size, graphite shape and non-metallic content [13]. Automatically generated solutions based on machine learning (ML) are efficient and fairly accurate classifiers. Machine learning methods belong to the field of artificial intelligence (AI). ML algorithms have been improving the learning and processing of data. It can be compared to the natural human process of learning by experience. These algorithms create a mathematical model based on collected data, called a “training dataset”, which produces predictive or decision-making results without directly programming each step of data processing (as typical for convection algorithms). Comparing the application of ML with classical methods, the working model relates a several steps: collection of training data, characteristic feature extraction, development of model and test data [14].

Neural networks are the most important tool in machine learning. They produce versatile and scalable mathematical models which process the information. Neural networks can be applied to large and complex tasks such as image analysis. They vary greatly depending on the network architecture, learning method and activation function. An example of a neural network suitable for image analysis is a group of convolutional networks (CNN, *Convolutional Neural Network*). Their results exceed the human abilities to interpret images, owing to ever-increasing computing power and a large amount of used training data [13].

Image analysis can be defined as a set of methods to facilitate the extraction of information from images. Arranging the functions in the right sequence allows the creation of an algorithm that will be an effective tool. Three main groups of image analysis processing can be distinguished: filtration, morphological operation and binarization. Each of them has its specific tasks [15-17].

The important fact is that every sector of industry uses different types of dedicated software, based on different programming languages. Creating applications can take place at any time as well as any place on earth. We only need an appropriate compiler dedicated to the language in which we create the code. An example of a language that is often used for research, didactics as well as in business solutions is *Python* [18].

The advantage of *Python* is its easy construction which makes it user-friendly and universal. The syntax is very intuitive and, therefore, the code is easy to understand. Considering this fact, writing commands forces the user to use habits, such as making indentations in the code. Finally,

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it makes the code readable and clear. Thanks to that, we can quickly create an application, make any corrections and presents a readable code to another researcher, which greatly facilitates the work. Moreover, a large number of libraries can be utilized, presented in Table 1, supporting many existing programmes. *Python* is widely used in areas such as data science, big data or machine learning.

One of the libraries for image processing is *OpenCV* (*Open-Source Computer Vision Library*). It is a free open-source library for commercial and educational use without the need of sharing projects. One of the main goals of the *OpenCV* library is to provide a tool that allows people at different levels of programming and imaging to create both simple programs and advanced projects. *OpenCV* functions include motion analysis and tracking, image processing (filtering, edge detection, corner detection, histograms), face detection system, motion detection, image glueing (creation of views or panorama), machine learning (ML algorithms supporting the above functions are: k-means, deep neural networks, artificial neural networks, decision trees, Bayesian classifier).

Table 1. *List of selected Python language libraries, and their description.*

Name	Description
NumPy	A set of basic tools that allow for advanced mathematical calculations with matrices and sets/vectors
SciPy	A set of tools that allows for many mathematical operations and, most importantly, many numerical methods such as integration, numerical differentiation, algorithms for solving differential equations, linear algebraic algorithms, Fourier transformation and signal processing
Pandas	Toolkit for relational data analysis
Matplotlib	Graphing module
SciKit-Learn	An open-source library of ML algorithms for specific applications, such as image processing, classification, clustering or pattern mining
TensorFlow	A library for machine learning that features high performance and scalability

Image Quality Assessment (IQA) can be classified into three categories, namely the Full Reference method (FR or FR-IQA), Reduced Reference method (RR or RR-IQA) and No Reference method (NR or NR-IQA). Each of them has characteristics and is dedicated to a separate-aim use. The main division is based on the information content of the original image. The requirement of full or partial information is related to FR and RR methods, while the NR method does not require any information. The NR method is the most practical out of the three methods because, in most cases, it is not possible to refer to the pristine original image of the distorted image [19].

NR-IQA helped to create VPMI (*Visual Parameter Measurement Index*) [20]. First of all, in [20] five basic visual parameters were analysed which the human eye uses to assess the quality of the image. In this method, only low-level features that affect the image quality can be examined. The measured parameters included average information entropy, average chromatic level factor, average gradient, average luminance and average bandwidth factor. VPMI is based on the integration of these visual metrics to assess image quality. It is established that the maximum VPMI corresponds to the best quality of the colour image. The obtained results suggest that the proposed method is universal and can be used to evaluate not only the original image but also the distorted image.

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Challenges in the Quality of Images

Exploring the properties of the new material is a time-consuming process, utilizing the application of numerous experimental techniques. Image analysis is becoming a powerful tool in this area of research. But, poor image quality, noise or shadow in the analysed image disturb in performing reliable object detection.

Image quality plays a key role during image analysis, and, can be disrupted by multiple problems. In most cases, the original image shall be initially subjected to image processing, before its analysis, to get better object detection and conduct more reliable measurements. Noise is one of the problems, commonly encountered during image analysis. This can be solved by applying dedicated and combined filtering and binarization functions, as shown in Fig.1.

The use of appropriate operations in image processing enables further work on the image free from distortions (which can significantly affect the detection of objects). If we analysed the images from the point of view of how many objects are in the photograph, we would intuitively count only large objects. As shown in Fig.1b, performing measurements on the image with noise produces 5309 detected objects, while analysis conducted on the image after applying an appropriate filter shows only 15 objects, as presented in Fig.1d. So, the image with noise contained almost 354 times more elements than the image after filtration. Thus, the method for image quality assessment is essential during image analysis.

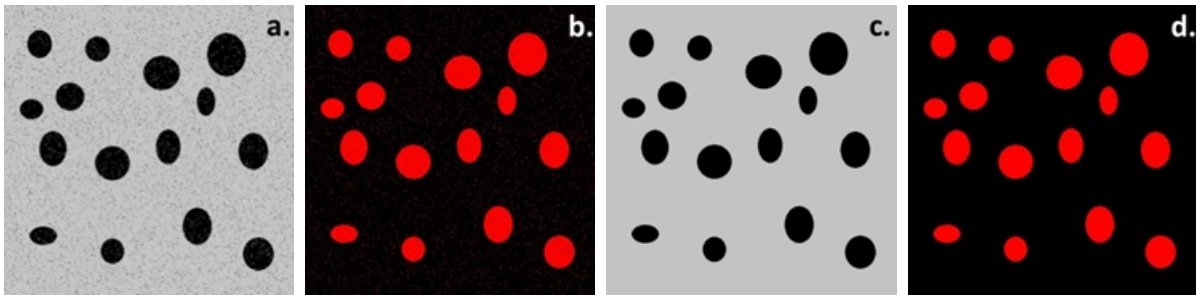

Fig. 1. *Comparison of a. an image with noise, with b. its binary image, c. image after applying the median filter (free from the noise), and d. its binary image.*

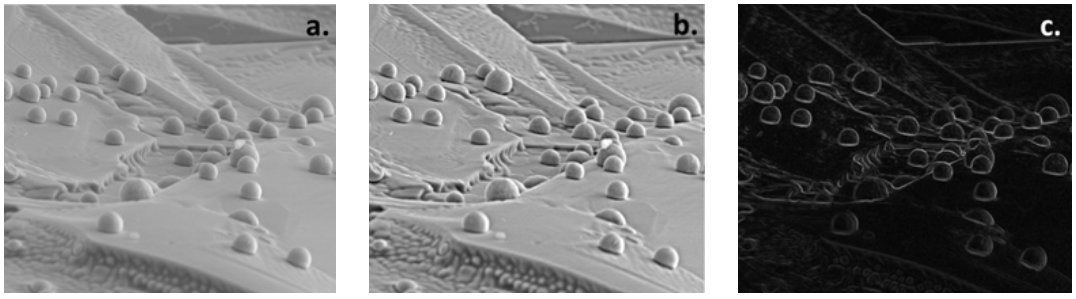

Fig. 2. *Comparison of a. an image with b. image sharpened and c. object edges detected.*

The filtering process is used to extract the information needed for image analysis. An example of such an analysis was attached in Fig.2, which aimed to detect spherical metallic droplets on the surface spinel-structure materials obtained by the arc-plasma melting technique [21,22]. Contrary to point operations, filters are contextual operations. The task of filters is noise reduction, image sharpening or edge detection [17]. The edge detection can be further used to recognize and quantify the metallic doplets on the surface of spinel material.

Following the trends of artificial intelligence applications in the development of image analysis, machine vision will greatly improve the efficiency, quality and reliability of fault finding. Visually

excellent optical illumination platforms and appropriate imaging techniques are prerequisites for high-quality images. Image processing and analysis are a tool to get information from images and deep learning is having a significant impact on the field of image analysis. The use of deep learning will play an increasingly important role in the further development of visual inspection fields [23].

Conclusions

To understand the application of image analysis it is necessary and recommended to get familiar with the methods that have been used for years, and then start experimenting with machine learning (ML) or neural networks (CNN).

Quality control is a very important issue in R&D activities. The Design of the Experiment (DoE) methodology can facilitate the research work, making it more effective and sustainable.

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