Real Time Quality Assurance and Defect Detection in Industry 4.0

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Abstract

Defect detection and quality assurance are traditionally crucial in the manufacturing sector, since it has the potential to reduce scrap rates, production time, energy consumption, and thus increase efficiency. Nowadays, automated image-based systems follow the aim to minimize reject rates and achieve quality standards within highly automated processes. The resulting cost reduction contributes to the overall objective of maximizing added value. Thereby, it is of significant importance that the underlying image mining and computer vision processes run with low overall latency. In order to analyze the relevance of a real time execution of such systems in the current scientific discussion, a literature review was conducted and is described in this paper. Besides techniques and methods, which are discussed, fields and industries could be identified. Thus, the state-of-the-art within the scientific discussion could be collected and presented.

Keywords

Defect Detection; Quality Assurance; Real Time Analytics; Image Mining; Computer Vision; Industry 4.0; Smart Factory;

1. Motivation

The widespread term industry 4.0 outlined the next generation of manufacturing, which aims to increase the automation of production processes [1]. Besides, the constant networking of all devices and machines, the basis is formed by the data collected within the production process by a large number of sensors [2]. Automated defect detection and real time quality assurance systems have the potential to reduce scrap rates, production time, energy consumption, and thus increase efficiency. To achieve these objectives, images of the production process are used as input for analytical processing. The acquisition of the necessary image data is simple to add to the production system and inexpensively to maintain. In addition, the concepts of computer vision and image mining use these collected images subsequently for analytical processing. The underlying purpose of these applications is to generate knowledge concerning product quality. The targeted reduction of production costs can be a contribution to maximize the value creation of an organization [3]. The detection of errors must be realized with a minimum of latency. Otherwise, the results obtained might become useless for the further production process. Thus, it is necessary to analyze the role of real time processing of such systems within the scientific discussion in the area of defect detection and quality assurance. This paper aims to incorporate the insights gained through a structured literature review. The focus is on the identification and deployment of techniques and methods that allow increasing the prediction accuracy of the employed supervised learning techniques while minimizing the latency of the application. In the context of serial

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production, the concepts of computer vision and image mining can already be used reliably. In this paper, we investigate the following research questions in the presented tension:

What is the role of real time processing within the scope of quality assurance systems via image mining and computer vision in the production environment?

1. *Concerning the used techniques and methods?*
2. *Concerning the application areas?*

To address the research questions posed, this paper is divided into six sections. First, the basic concepts are outlined. This is followed by the description of the applied scientific methodology in section three and the presentation and discussion of the obtained results in sections four and five. The paper closes with a conclusion and outlook.

2. Basic Concepts

Within this section, the basics of considered concepts and methods are described. This contains the concepts of computer vision and image mining, which generate knowledge based on image data by using image processing and analytical techniques. Moreover, this section contains the basics of defect detection and quality assurance systems.

2.1. Defect Detection and Quality Assurance

Undetected defects or products which does not meet the defined quality requirement result in rejects or, in a worse case, even defects in the production unit. Image-based defect detection and quality assurance systems follow the aim to avoid such value-reducing scenarios. Automated systems replaced traditional manual human inspection processes over the last decades [4]. Thereby, it is not only considered whether defect exist but also the quality of the product is evaluated, one comes into the area of quality control and assurance. Quality control focuses on the fulfillment of quality requirements. It consists of techniques and activities carried out as part of the quality assurance process to verify that the quality requirements for the product have been met [5]. If defects or not fulfilled quality requirements are detected in real time, less product time and material are lost. But also, possible repair costs for machines and equipment can be reduced. Implementation as a real time analytics application (RTA) can therefore have a positive impact on organizations' value creation. Regardless of the domain or application area, RTA is characterized simply by the execution of an analytical task in real time. Therefore, it is critical to minimize the latency between the triggering event and the final result delivery. The total latency of an analytical application can be divided into data latency, analysis latency, and decision latency [6]. To ensure that the data collected by the imaging sensor directly at the production unit is available as quickly as possible, it must first be transmitted to the place of analysis. To minimize the necessary transmission times, appropriate suitable network architectures like edge computing can be used for decentralized data processing. Edge computing describes an extension of cloud computing. In contrast to this, however, data is stored decentral at the corner of the network - the edge [7].

2.2. Computer Vision and Image Mining

The concepts of computer vision and also image mining use techniques and methods from the areas of image processing and data analytics. Both follow the aim to generate knowledge based on image data. In the scientific literature, the concepts are partly differentiated in detail, but also sometimes used synonymously. Hence, it is first important to differentiate between these two concepts. Computer vision contains various methods for acquisition, processing, and analyzing images [8]. A computer vision system usually consists of an imaging sensor, an interface to transmit the image, and a computing unit for processing the analysis [9]. The approach follows the purpose to generate knowledge related to a single image or an object within an image [10]. In this process, computer vision also uses techniques to derive an understanding of a single image from a set of images [11]. Figure 1 depicts the process steps of the computer vision approach, which is used in manufacturing in assembly, sorting, monitoring, quality control, as well as defect detection, among others [8].

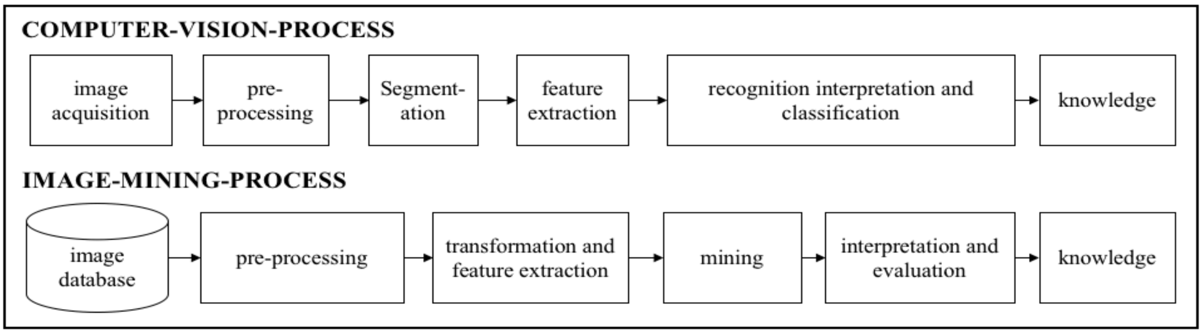

Fig. 1. Computer Vision [12] and Image Mining Process [13]

Furthermore, the figure also depicts the image mining process. These concepts differ from computer vision and other image processing techniques because the focus of image mining is on extracting patterns from a huge collection of images, whereas the focus of computer vision is on understanding and/or extracting specific features from a single image [10]. Image mining combines data mining and image processing technologies that enable the identification of patterns and relationships in image collections to gain knowledge [14]. The focus is on detecting patterns or other relationships that are not visible at first glance and thus not recognizable [15]. The process of image mining, which consists of the steps of preprocessing, transformation and feature extraction, application of the algorithms from the field of data mining, and interpretation and evaluation. All in all, it follows the aim of uncovering implicit knowledge. This can then be applied to a single image, enabling inference and interpretation [13]. In contrast to computer vision, the image mining process does not involve image acquisition methods. Thus, the entire process of defect detection cannot be covered via image mining.

3. Research Method

Considering the research questions formulated, a structured literature review was chosen. According to Cooper [16], a structured literature review includes the following five steps: 1) problem development, 2) data collection, 3) data evaluation, 4) data analysis and interpretation, and 5) presentation of results. Figure 2 depicts the process of the literature review conducted. In the first step of the literature review, the problem was first developed and identified based on existing basic articles. This was followed by data collection, after which 135 publications were identified, and subsequently analyzed. Duplicates, thematically irrelevant papers, and irrelevant publication types were removed. The remaining 92 papers were subdivided to classify the economic sectors based on the classification of the Federal Office of Economics and Export Control [17].

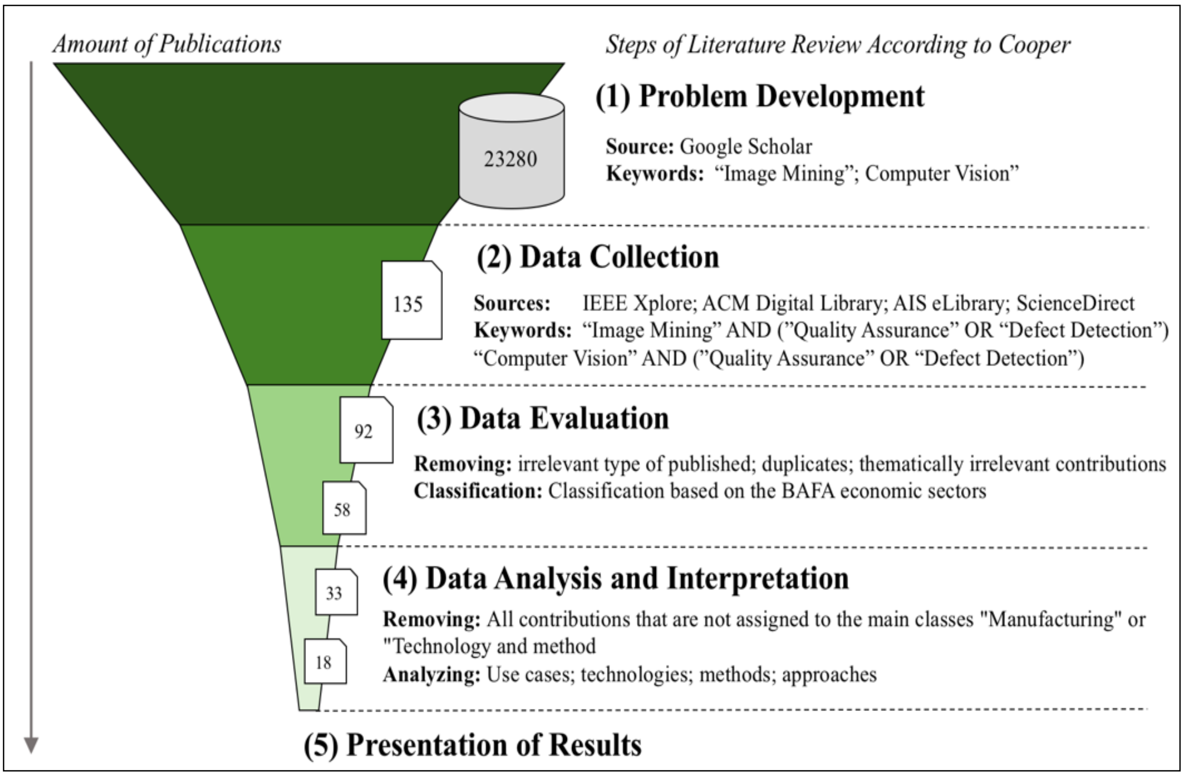

Fig. 2. Process of the literature review according to Cooper [16]

Subsequently, only those contributions that could be assigned to the manufacturing industry and focused on the technical and methodological aspects were considered. This further reduced the number of relevant contributions. The focus was placed on the 35 application-oriented publications. Two of these publications did not show relevance upon closer consideration and were therefore sorted out. In the end, 33 publications were included in the analysis. Eighteen of these papers contained a real time reference.

4. Defect Detection and Quality Assurance in Real Time

The done literature review followed the purpose to analyze the role of real time processing within the scope of defect detection and quality assurance systems. Real time execution of a defect detection or quality assurance system requires minimizing the time between image acquisition and response.

4.1. Techniques and Methods

In order to analyze the object of interest in more detail, it is necessary to consider the techniques and methods which are used in the considered systems. Thus, the process steps of image acquisition, data preprocessing and transformation, and the used algorithms are described in this section.

4.1.1. Image acquisition

A first step to automatically identify defects or insufficient qualities in production is image acquisition. This requires imaging sensors. These convert optical energy into electrical energy, making it storable and processable. In this process, the speed of the manufacturing line is crucial. The faster the production runs, the faster the sensors have to focus, capture and store the image. Thus, it depends on the production of how many images per second are captured and what resolution the images must have [8]. Furthermore, it is crucial to configure the right distance between the camera sensor and the product to be focused [18]. To obtain a holistic image of the product, the use of multiple imaging sensors is also possible. If more than one sensor is used for image acquisition, coupling or synchronization of the images is necessary in order to process them together [19]. Once the image has been captured, it is then important to transfer it with low latency to the processing unit. Network architectures such as those of edge computing, which support decentralized data processing and can thus minimize the latency of data transfer, are suitable for this purpose [20].

4.1.2. Data pre-processing and transformation

After the acquired images have been transferred from the production environment to the computing unit where the processing is to take place, the pre-processing starts. To increase the accuracy of the predictions made and to minimize the overall latency of the execution, appropriate pre-processing steps are necessary. It is crucial that the possible defects and quality levels can be predicted as easily and precisely as possible afterward and with a minimum of time. Various approaches are used and discussed in the publications examined. These preprocessing techniques can be classified into the areas of transformation, segmentation, and feature extraction. Examples of transformation are resizing, gray scaling [21], and hough-transformation [20]. Furthermore, exemplary for the segmentation area, edge Detection, and object detection [11] can be named. Considering the feature extraction, weibull distribution and local-binary-pattern can be named as representatives [20]. All in all, it can be stated that each of these steps requires a certain latency and that their number should therefore be kept as low as possible. However, some of these steps also reduce the latency of the subsequent steps. For example, reducing the image size can have a positive effect on the processing time through the algorithms.

4.1.3. Algorithmic processing

In the literature examined, supervised learning methods from the areas of classification account for the largest share of identified methods. A wide range of algorithms is applied in this area. A somewhat smaller portion of the publications discusses clustering approaches from the unsupervised learning sector. Since the potentially occurring defects in the various production facilities are mostly known in advance, in many cases an assignment of the image captured during production to an already defined class is made. In the simplest case of defect detection, this can be the classes "defect" and "no defect". However, to classify the quality of the product in production, several quality classes are also used [22]. Therefore, support vector machine is applied in the steel industry [23], but also in the context of textile [24] or porcelain manufacturing [21]. Decision tree and random forest algorithms are also applied in these sectors [21, 24]. Neuronal Networks are used in the detection of surface defects in vehicle body parts [25]. Moreover, convolutional neural networks for defect and quality classification exist in the scientific literature. For example for defect detection in the stress field of pharmaceuticals [19], detection of assembly defects of atomizers [26], in the textile industry [24], or in the field of porcelain production [21] for defect classification. In contrast, in clustering, no defect or quality classes are known to which a captured image from production can be automatically assigned. Because of that, clustering algorithms form the possibility to detect and recognize unknown error sources. An application example is the inspection of bottle caps in beverage production. Loose caps, scratches, or broken caps can be identified by the use of the K-Means algorithm [11]. Furthermore, Clustering approach are also discussed within the semiconductor manufacturing process. Thereby distance-based and hierarchical agglomerative clustering methods are considered [27]. However, it is also discussed in steel manufacturing to identify defects through similarities in texture structure [20].

4.2. Areas of Application

To obtain a better overview of the defect detection and quality assurance systems, the areas of applications and industries were considered. Figure 3 depicts the industries and areas that are addressed in the publications.

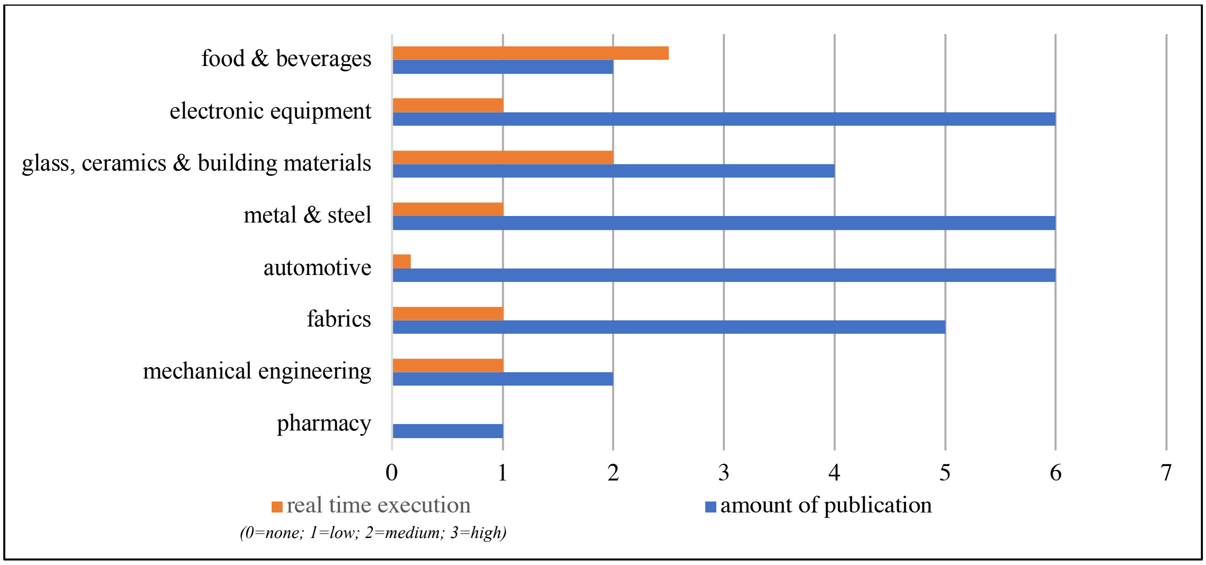

Fig. 3. Discussed application fields within the current scientific discussion

The applications are classified by the corresponding sectors according to the specifications of the German Federal Office of Economics and Export Control [17]. Figure 3 depicts also how strongly the reference to processing in real time is addressed within these publications. Image-based defect detection and quality assurance systems are used and discussed within the production of food and beverage packaging and containers. Examples are in the area of bottle cap inspection [11] or food container product quality inspection [28]. Also, defect detection systems for porcelain manufacturing are discussed [21]. This allows the complete process to be executed in real time. A robotic computer vision architecture is used for this system. Besides high-speed image processing, an autonomous self-learning system is used. Its response with minimal latency [21]. A computer vision system for defect detection in ceramic tile manufacturing is also designed to run in real time. The authors state that defects can be detected by this system with an overall latency of less than 900ms and an accuracy of 98% [29]. Similarly, a system for defect detection in light emitting diodes surfaces has an overall latency of about one second. Also, within the defect detection during the production process of liquid crystal displays, the considered systems are discussed [30]. Another example contains a computer vision system for the detection of defects in ceramic tiles in real time. In the manufacturing process, tiles with edge, corner, or surface defects were classified as defective, while tiles without defects were classified as correct. As a result, a defect detection efficiency of 98% and a maximum execution time of less than 900ms [29]. Furthermore, nearly twenty percent of the identified publications discuss use cases from fabrics industry. Within this scope, Divyadevi and Kumar [31] published a review of automated fabric inspection systems. Computer vision-based systems are playing an important role in this sector. This is due to the minimization of latency as well as the overcoming of errors in manual monitoring by employees. In particular, errors that suffer from boredom, fatigue, and low error detection rates in human quality inspection can be prevented by computer vision and image mining approaches. The authors consider common fabric defects such as stitches, skew, grease spots, skipped stitches, or knots [31]. Publications could also be identified in the literature study, which application areas can be identified from the field of pharmacy [19] or mechanical engineering [32, 33].

In summary, there could be no limitations about the application area identified by the literature study. It was not able to identify any barriers that indicate that defect detection and quality assurance systems cannot be transferred to arbitrary production scenarios and generate added value there.

5. Discussion

Further to the description of the findings in Section 4, it is required to discuss them. This is carried out in this section based on the research question posed:

What is the role of real time processing within the scope of quality assurance systems via image mining and computer vision in the production environment?

1. *Concerning the used techniques and methods?*

The findings of the literature review are the relevant and widely used techniques and methods in the considered field of interest. Thereby, image acquisition of the product is the initial point of the process. It already has a decisive impact on the prediction accuracy of a possible classification. Especially the distance between the imaging sensor and the object is an important configuration element. However, only a few generalized points could be identified. Rather, the image acquisition, the selection of techniques and methods, and the algorithms must be configured individually for each production line. For real time execution, the acquisition of the images is hardly a challenge. More critical is the transmission latency from the imaging sensor to the processing unit. In the area of pre-processing, techniques for segmentation take on a high priority, as they can narrow down the area of investigation and thus also exclude potential sources of interference prior to model training. In the case of algorithms, the focus is mostly on supervised learning methods, since the potentially occurring defects and qualities are usually known in advance. When executing the algorithms, execution with minimal latency is also possible. In this case, minimizing the latency is usually increases the accuracy. In contrast, measures to improve the accuracy hurt the latency.

2. *Concerning the application areas?*

Scientific publications about quality assurance and defect detection in production environments are identified in a large number of different industries and fields. However, restrictions to specific areas or industries could not be found out. It could be seen that most of the publications are in the fields of fabrics, metal and steel, and automotive industries, as well as in the production of printed circuits and semiconductor boards. In these areas, defect detection and quality assurance have corresponding importance and also far-reaching tradition due to the high quantities in production. In many cases, defect detection was previously carried out manually by employees in the past. Therefore, it can be assumed that the purpose of increasing the quality of defect detection as well as the reduction of employee costs are the drivers for the development of computer vision and image mining systems. The latency of the entire process plays a crucial role in image-based defect detection and quality assurance. In about half of the publications considered, the topic of real time processing was addressed. However, only in a few publications was there a penetrating discussion. As a result, two assumptions can be made. On the one hand, it could be assumed that real time processing in defect detection and quality assurance systems only plays a special role in some cases and is only of minor relevance for the other part. On the other hand, it cannot be ruled out that real time execution is already taken for granted and is therefore not addressed in a more specified way.

6. Conclusion

The done research aimed to identify the role of real time processing of image-based defect detection and quality assurance systems. Through the literature review, it was possible to identify in which industries and fields image mining and computer vision are used for quality control and discussed in the scientific community and where real time processing is relevant. It was found that quality assurance systems are used in a wide variety of industries. Most publications were found in the fabrics, metal and steel, and automotive industries, as well as in the manufacture of printed circuit boards and semiconductors. Also, the widespread techniques and methods, as well as the connection to real time execution, could be identified. It was also found that real time processing assumes importance.

The carried-out research is limited by the inputs and limitations within the literature analysis. Thus, the question of the transferability of the results into the practice cannot be answered completely herewith. However, the obtained findings have relevance for further research in this field and it is also relevant for practitioners. The gained findings have the potential to support the development of image-based defect detection and quality assurance systems.

7. References

[1] Dao, N. N., Lee, Y., Cho, S., Kim, E. , Chung, K. S. , Keum, C: Multi-tier multi-access edge computing: The role for the fourth industrial revolution. In: Information and Communication Technology Convergence (ICTC), 2017 International Conf (2017).

[2] Dais, S.: Industrie 4.0–Anstoß, Vision, Vorgehen. In: Handbuch Industrie 4.0, vol. 4, Springer, 261-277 (2017).

[3] Trinks, S, Felden, C.: Image Mining for Real Time Fault Detection within the Smart Factory. In: 2019 IEEE 21st Conference on Business Informatics (CBI), Moscow (2019).

[4] Ngan, H. Y. T., Pang, G. K. H, Yung, N. H. C.: Automated fabric defect detection—A review. In: Image and Vision Computing 29(7), 442–458 (2011).

[5] Manghani, K.: Quality assurance: Importance of systems and standard operating procedures. In: Perspectives in clinical research 2(1), 34 (2011).

[6] Trinks, S, Felden, C.: Real time analytics — State of the art: Potentials and limitations in the smart factory. In: 2017 IEEE International Conference on Big Data (Big Data), Boston, MA, USA (2017).

[7] Trinks, S, Felden, C.: Edge Computing architectures to support Real Time Analytic applications – A State of the art within the application area of Smart Factory and Industry 4.0. In: IEEE International Conference on Big Data, Seattle, USA (2018).

[8] Priese, L.: Computer Vision - Einführung in die Verarbeitung und Analyse digitale Bilder, Berling, Heidelberg: Springer Vieweg (2015).

[9] Nixon, M., Aguado, A.: Feature extraction and image processing for computer vision. In: Academic press (2019).

[10] Shukla, V. S., Vala, J. A. : Umfrage über Image Mining, seine Techniken und Anwendung. In: Internationale Zeitschrift für Computeranwendungen, 12-15 (2016.)

[11] Kulkarni, R., Kulkarni, S., Dabhane, S., Lele, N., Paswan, R. S.: An Automated Computer Vision Based System for Bottle Cap Fitting Inspection. In: 2019 Twelfth International Conference on Contemporary Computing (IC3). IEEE. (2019).

[12] Sanghadiya, F., Mistry, D.: Surface defect detection in a tile using digital image processing: Analysis and evaluation. In: International Journal of Computer Applications (2015).

[13] Ennouni, A., Filali, Y., Sabri, M. A., Aarab, A.: A review on image mining. In: Intelligent Systems and Computer Vision (ISCV). IEEE. 1-7 (2017).

[14] Parihar, V. R., Nage, R. S., Dahane, A. S.: Image Analysis and Image Mining Techniques: A Review. In: Journal of Image Processing and Artificial Intelligence, 3(2) (2017).

[15] Syed, K., Srinivasu, S. V. N.: A Review of Web Image Mining Tools, Techniques and Applications. In: International Journal of Computer Trends and Technology (IJCTT), 49(1), 36-43 (2017).

[16] Cooper, H. M.: Organizing knowledge syntheses: A taxonomy of literature reviews. In: Knowledge in society, 1(1), 104 (1988).

[17] BAFA,https://www.bafa.de/SharedDocs/Downloads/DE/Wirtschafts_Mittelstandsfoerderung/unb_kurzanleitung_wirtschaftszweigklassifikation.pdf, last accessed 2020/12/06.

[18] Ma, J.: Defect detection and recognition of bare PCB based on computer vision. In: 2017 36th Chinese Control Conference (CCC). IEEE. (2017).

[19] C. Tsay und Z. Li, „Automating Visual Inspection of Lyophilized Drug Products With Multi-Input Deep Neural Networks," in 2019 IEEE 15th International Conference on Automation Science and Engineering (CASE). IEEE. (2019).

[20] Q. Luo, X. Fang, L. Liu, C. Yang und Y. Sun, „Automated Visual Defect Detection for Flat Steel Surface: A Survey.," IEEE Transactions on Instrumentation and Measurement, (2020).

[21] A. Birlutiu, A. Burlacu, M. Kadar und D. Onita, „Defect Detection in Porcelain Industry based on Deep Learning Techniques," in 2017 19th International Symposium on Symbolic and Numeric Algorithms for Scientific Computing (SYNASC), (2017).

[22] Trinks, S, Felden, C.: Image Mining for Real Time Quality Assurance in Rapid Prototyping. In: 2019 IEEE International Conference on Big Data (Big Data). IEEE. (2019).

[23] Yan, K., Dong, Q., Sun, T., Zhang, M., Zhang, S.: Weld Defect Detection based on Completed Local Ternary Patterns. In Proceedings of the International Conference on Video and Image Processing (2017).

[24] Ouyang, W., Xu, B., Hou, J., Yuan, X.: Fabric defect detection using activation layer embedded convolutional neural network. In: IEEE Access, vol. 7, 70130-70140 (2019).

[25] Edris, M. Z. B., Jawad, M. S., Zakaria, Z.: Surface defect detection and Neural Network recognition of automotive body panels. In: 2015 IEEE International Conference on Control System, Computing and Engineering (ICCSCE). IEEE. (2015).

[26] Wang, J., Hu, H. C. L., He, C.: Assembly Defect Detection of Atomizers Based on Machine Vision. In: Proceedings of the 2019 4th International Conference on Automation, Control and Robotics Engineering (2019).

[27] Tulala, P., Mahyar, H., Ghalebi, E., Grosu, R.: Unsupervised wafermap patterns clustering via variational autoencoders. In: 2018 International Joint Conference on Neural Networks (IJCNN). IEEE. (2018).

[28] Laucka, A., Andriukaitis, D., Markevicius, V., Zilys, M.: Research of the Defects in PET Preform. In: 2016 21st International Conference on Methods and Models in Automation and Robotics (MMAR). IEEE. (2016).

[29] Hocenski, Ž., Matić, T., Vidović I.: Technology transfer of computer vision defect detection to ceramic tiles industry. In: 2016 International Conference on Smart Systems and Technologies (SST). IEEE. (2016).

[30] Ma, Z., Gong, J.: An automatic detection method of Mura defects for liquid crystal display. In: 2019 Chinese Control Conference (CCC) IEEE, 7722-7727 (2019).

[31] Divyadevi, R., Kumar, B. V.: Survey of automated fabric inspection in textile industries. In: 2019 International Conference on Computer Communication and Informatics (ICCCI), (2019).

[32] Zhou, M., Wang, G., Wang, J., Hui, C., Yang, W.: Defect detection of printing images on cans based on SSIM and chromatism. In 2017 3rd IEEE International Conference on Computer and Communications (ICCC). IEEE. 2127-2131 (2017).

[33] Han, J., Kamber, M., Pei, J.: Data preprocessing. In: Data mining: concepts and techniques, 105-130 (2020).

[34] Klinkenberg, R., Schlunder, P., Klapic, E. , Lacker, T.: „Zukunftsweisende Informations-und Kommunikations-Technologien. In: Industrie 4.0 für die Praxis, Wiesbaden, Springer Gabler, 129-146 (2018).