EAI Endorsed Transactions
on Scalable Information Systems
Research Article **EAI.EU**

Tools and Process of Defect Detection in Automated Manufacturing Systems

Hussein N. Al-Jubori[1] and Izzat Al-Darraji[1,*]

[1]Automated Manufacturing Department, Al-Khwarizmi College of Engineering, University of Baghdad, Baghdad 10070, Iraq

Abstract

INTRODUCTION: A range of tools and technologies are at disposal for the purpose of defect detection. These include but are not limited to sensors, Statistical Process Control (SPC) software, Artificial Intelligence (AI) and machine learning (ML) algorithms, X-ray systems, ultrasound systems, and eddy current systems.
OBJECTIVES: The determination of the suitable instrument or combination of instruments is contingent upon the precise production procedure and the category of flaw being identified. In certain cases, defects may necessitate real-time monitoring and analysis through the use of sensors and SPC software, whereas more comprehensive analysis may be required for other defects through the utilization of X-ray or ultrasound systems.
METHODS: The utilization of AI and ML algorithms has gained significant traction in the realm of defect detection. This is attributed to their ability to process vast amounts of data and discern patterns that may have otherwise eluded detection. The aforementioned tools have the capability to anticipate potential flaws and implement pre-emptive measures to avert their occurrence.
RESULTS: The detection of defects in automated manufacturing systems is a continuous process that necessitates meticulous observation and examination to guarantee prompt and effective identification and resolution of defects. CONCLUSION: The utilization of suitable tools and technologies is imperative for manufacturers to guarantee optimal production quality and operational success.

Keywords: Automated Defect detection, Artificial intelligence, Machine vision, Sensors, Manufacturing systems

Received on 11 July 2023, accepted on 06 September 2023, published on 27 September 2023

doi: 10.4108/eetsis.4000

1. Introduction

The identification and detection of defects or faults in a product, system, or process prior to its release or delivery to customers is commonly referred to as defect detection. The primary objective of defect detection is to guarantee the product's quality and mitigate or eliminate the likelihood of defects or malfunctions that may potentially endanger users or lead to product recalls, legal obligations, and reputational damage for the organization. Within the realm of manufacturing, there exist several approaches to identifying defects, including visual inspection, automated testing, and quality control methodologies. The process of visual inspection entails the examination of a product by proficient personnel to detect any imperfections, such as blemishes, fractures, or absent components, through manual means. Automated testing refers to the utilization of machines or software for the purpose of evaluating the performance, functionality, and other attributes of a given product. The implementation of quality control techniques entails the systematic observation and regulation of the production process to ascertain that the final product conforms to the prescribed specifications and quality benchmarks [1]. The identification of defects in automated manufacturing systems is a crucial element in guaranteeing product quality and mitigating the possibility of faulty products being delivered to consumers [2,3]. Automated manufacturing systems have the capability to detect defects with greater efficiency and accuracy compared to manual inspection processes. This leads to expedited identification and rectification of defects. Automated manufacturing

*Corresponding author. Email: izzat.a@kecbu.uobaghdad.edu.iq

systems employ a range of techniques to identify defects, such as machine vision, sensors, statistical process control (SPC) software, and Artificial Intelligence/Machine Learning (AI/ML) algorithms. The field of machine vision involves the use of computer algorithms and hardware to enable machines to interpret and understand visual information from the surrounding environment. The methodology entails the utilization of cameras and software for image processing to scrutinize commodities for any anomalies, such as the absence of parts, cracks, or scratches. Machine vision systems possess the capability to identify anomalies in a timely manner and initiate automated responses to discard or reprocess the flawed merchandise. [4, 5]. Sensors have the capability to identify defects in products through diverse parameters, including dimensions, configuration, mass, or material characteristics. As an illustration, a sensor has the capability to identify the absence of a component or a deviation from the anticipated product measurements. Consequently, it can initiate an automated response to rectify or discard the product. [6]. The utilization of SPC software entails the systematic observation and analysis of the manufacturing process in order to detect recurring trends or patterns that may serve as indicators of the existence of defects. SPC methodologies, such as the implementation of control charts, can be employed to identify anomalous fluctuations within the manufacturing process. This can facilitate the initiation of remedial measures prior to the manifestation of defects [7]. Artificial intelligence and machine learning methodologies can be employed to examine information obtained from sensors and machine vision systems in order to detect patterns or irregularities that may suggest the existence of flaws. Artificial intelligence and machine learning algorithms have the capability to acquire knowledge from historical data and enhance the precision of defect identification as time progresses [8, 9].

2. Tools

The choice of a defect detection tool is contingent upon the nature of the defect to be identified, the attributes of the product, and the specifications of the production process. The integration of multiple tools can be employed to guarantee a heightened degree of precision and dependability in detecting defects.

2.1. Machine Vision

Machine vision systems are frequently employed in automated manufacturing systems for the purpose of detecting defects. The aforementioned systems employ cameras and image processing software to conduct product inspections for the purpose of identifying defects, including but not limited to scratches, dents, cracks, or missing components [10]. The following are the procedural stages entailed in utilizing machine vision systems for the purpose of identifying defects. The initial step involves the acquisition of images, wherein the machine vision system captures product images through the utilization of one or multiple cameras. The selection of imaging angles is contingent upon the product's geometry and the specific type of defect that is being identified. The second step involves the processing of images. The machine vision system employs software to analyze images and identify defects according to predetermined criteria. The software has the capability to employ various techniques such as edge detection, blob analysis, or pattern recognition for the purpose of detecting defects. Step three involves the identification of defects. The machine vision system conducts a comparative analysis between the processed images and a reference image or a predetermined set of criteria in order to detect any potential defects. In the event that a defect is identified, the machine vision system has the capability to initiate an automated response, which may include the rejection or reworking of the product. In Step 4, the data analysis stage involves utilizing the machine vision system to scrutinize the data obtained from the defect detection process. This is done with the aim of identifying any patterns or trends that may suggest potential issues with the manufacturing process. The aforementioned data possesses the potential to enhance the efficiency of the manufacturing process and preclude the incidence of defects in subsequent operations. Machine vision systems offer several benefits for defect detection in automated manufacturing systems. Machine vision systems enable real-time defect detection and correction by inspecting products at high speeds. Machine vision systems exhibit a remarkable level of precision in detecting defects, even in intricate products that comprise numerous components. Machine vision systems offer a reliable means of detecting defects with consistent performance, thereby mitigating the potential for human error [11-13]. Machine vision systems possess the attribute of flexibility as they can be programmed to detect diverse types of defects and can adjust to varying product geometries. Notwithstanding their advantages, machine vision systems are subject to certain limitations, including the requirement for adequate illumination and the challenge of identifying flaws that are imperceptible to human perception. In automated manufacturing systems, machine vision systems play a crucial role in detecting defects, thereby enhancing the efficiency and quality of the products.

2.2 Sensors

The utilization of sensors is of the utmost significance for the identification of defects in automated manufacturing systems. Defects can be detected using diverse criteria, including but not limited to size, shape, weight, or material properties. The following are frequently utilized sensor tools for identifying defects in automated manufacturing systems. Proximity sensors are capable of detecting the existence or non-existence of an object or material. These tools have the capability to identify the absence of constituent parts or variations from the anticipated product measurements. Laser sensors have the capability to accurately measure distances and dimensions. The utilization of these tools enables the identification of variances from the anticipated product measurements or surface irregularities, such as abrasions or indentations. Weight sensors, as a type of sensor, are capable of measuring the weight of products with the purpose of verifying whether they conform to the predetermined weight specifications. These instruments have the capability to identify absent constituents or variations from the anticipated weight of the product. The fourth type of sensor, namely color sensors, is capable of detecting variations in color of products, thereby indicating the presence of defects such as stains or discoloration. Force sensors are capable of quantifying the magnitude of force exerted during the course of the manufacturing process. The utilization of these tools enables the identification of anomalies, such as fractures or distortions, within the item. Temperature sensors, classified as sensor type 6, are capable of quantifying the temperature of both products and manufacturing equipment. Thermal imaging techniques are capable of identifying anomalies such as excessive heat or fluctuations in temperature that may potentially impact the quality of the product. Vibration sensors, classified as sensor type 7, are capable of detecting vibrations or anomalous movements in manufacturing equipment. Vibration analysis techniques are capable of identifying anomalies such as slackened constituents or deteriorated bearings that may have an impact on the standard of the final product. Consequently, the integration of sensors with other defect detection tools, such as machine vision systems, can guarantee a superior level of accuracy and reliability in defect detection. The process of selecting a sensor tool is contingent upon several factors, including the nature of the defect to be identified, the attributes of the product, and the specific demands of the manufacturing procedure. In automated manufacturing systems, sensors play a crucial role in detecting defects, thereby facilitating real-time defect identification and correction. This, in turn, enhances the quality and efficiency of the final product, making sensors a valuable asset in the manufacturing industry.

2.3 SPC software

The utilization of SPC software in automated manufacturing systems is a potent mechanism for identifying defects. The utilization of SPC software enables the monitoring and analysis of data derived from the manufacturing process. This facilitates the identification of trends and detection of anomalies that may potentially indicate the presence of defects [14]. The utilization of SPC software for the purpose of identifying defects in automated manufacturing systems can be accomplished through various means. The five key components of the data analysis process are real-time monitoring, trend analysis, root cause analysis, predictive analytics, and continuous improvement. The software for SPC has the capability to monitor the manufacturing process in real-time, thereby identifying any deviations from the anticipated process parameters. In the event of process parameter deviations from anticipated values, the software has the capability to notify the operator, enabling prompt intervention to avert defects. Trend analysis is a capability of SPC software that enables the examination of manufacturing process data over a period of time. This analysis can detect patterns that may suggest the existence of defects. In the event that there is a rise in the quantity of defects over a period of time, the software has the capability to notify the operator to conduct an inquiry into the root cause and implement remedial measures. The utilization of SPC software can facilitate the identification of the fundamental cause of defects through the examination of data derived from the manufacturing process. Through the identification of the fundamental underlying factor, operators are able to implement remedial measures aimed at preventing the reoccurrence of the defect. The utilization of predictive analytics is possible through SPC software, which enables the estimation of the likelihood of potential defects that may arise in the future. This data can assist operators in implementing preemptive measures to avert the occurrence of defects. Continuous improvement can be facilitated by the utilization of SPC software, which can furnish valuable feedback to the manufacturing process. Through the analysis of manufacturing process data, operators can detect opportunities for enhancement and implement corrective measures to enhance product quality and minimize defects. In general, the utilization of SPC software is deemed as a beneficial instrument for identifying defects in automated manufacturing systems. The system enables operators to perform real-time monitoring and analysis of the manufacturing process, detect patterns and deviations, and implement remedial measures to avert defects. The utilization of SPC software can enhance the quality of products, minimize waste, and augment efficiency for manufacturers.

2.4 AI and ML Algorithms

The utilization of AI and ML algorithms has become progressively prevalent in the realm of automated manufacturing systems for the purpose of detecting defects. The algorithms possess the capability to scrutinize vast amounts of data and detect patterns and irregularities that could potentially signify the existence of flaws. The implementation of AI and ML algorithms can facilitate defect detection in automated manufacturing systems [15]. The utilization of artificial intelligence and machine learning algorithms enables the analysis of product images to identify surface defects, including scratches, cracks, and other imperfections. The algorithms possess the ability to acquire knowledge and identify regularities and deviations that could potentially signify the existence of imperfections. The analysis of sensor data can be performed through the utilization of AI and ML algorithms [16,17]. This process involves the examination of data obtained from various sensors, including proximity sensors, laser sensors, and weight sensors. The purpose of this analysis is to identify any deviations from the expected product dimensions, weight, or other characteristics that may indicate the presence of defects. The implementation of AI and ML algorithms in predictive maintenance can anticipate equipment malfunction, leading to a decrease in operational downtime and the avoidance of potential defects resulting from equipment failure. The utilization of AI and ML algorithms can facilitate the identification of the underlying cause of defects through the analysis of data derived from the manufacturing process. Through the identification of the fundamental underlying factor, operators are able to implement remedial measures aimed at averting the recurrence of the defect. The utilization of AI and ML algorithms enables real-time monitoring of the manufacturing process, facilitating the detection of any deviations from the anticipated process parameters. In the event of process parameter deviations from anticipated values, the algorithms have the capability to notify the operator, thereby enabling prompt intervention to avert defects. In general, the utilization of AI and ML algorithms has the potential to be a formidable asset in identifying defects within automated manufacturing systems. The implementation of real-time defect identification, equipment failure prediction, and root cause defect identification can enhance product quality, minimize waste, and boost efficiency. The ongoing development of AI and ML algorithms is anticipated to enhance their efficacy as defect detection mechanisms in automated manufacturing systems.

2.5 X-ray Systems

X-ray technology is extensively employed in automated manufacturing systems for the purpose of detecting defects. The aforementioned systems employ X-ray technology to permeate items, thereby enabling the identification of concealed imperfections that may not be discernible externally. The utilization of X-ray systems for defect detection in automated manufacturing systems can be accomplished through various means. The utilization of X-ray systems enables the detection of internal defects, including voids, cracks, or inclusions that may not be perceptible through external observation. The utilization of this technique can prove to be especially advantageous in identifying flaws in merchandise such as electronic parts, castings, or welding joints. The utilization of X-ray systems enables the inspection of intricate products, including assemblies or composite structures, which may pose challenges for visual inspection. The implementation of this process can aid in guaranteeing the appropriate assembly of all components and the absence of any defects that could potentially impact the performance of the product. The identification of contaminants can be achieved through the utilization of X-ray systems, which are capable of detecting the presence of foreign objects, including metal fragments, within the product. The significance of this matter is particularly noteworthy in the food and pharmaceutical sectors, where the existence of impurities can pose a significant safety hazard. Non-destructive testing is facilitated by X-ray systems, which aid in minimizing the requirement for destructive testing techniques that can potentially damage products. This approach helps in reducing waste and enhancing the overall efficiency of the testing process. Real-time inspection is facilitated by X-ray systems, which enable the detection of defects as they arise during the inspection of products. Real-time corrective action can aid operators in minimizing the production of defective products. In automated manufacturing systems, X-ray systems serve as a valuable tool for detecting defects. Non-destructive testing techniques offer various advantages, such as the ability to identify contaminants, inspect intricate products, detect internal defects, and facilitate non-destructive testing. The utilization of X-ray systems by manufacturers has the potential to enhance product quality, minimize wastage, and augment operational efficiency.

2.6 Ultrasound Systems

Ultrasound technology is frequently employed in automated manufacturing systems for the purpose of identifying defects. The aforementioned systems employ high-frequency sound waves to infiltrate substances and identify anomalies, such as fractures, empty spaces, or foreign matter. Ultrasound systems have been identified as a potential tool for defect detection in automated manufacturing systems. The utilization of ultrasound technology can aid in identifying defects in the manufacturing process. Ultrasound systems have the capability to identify internal defects present in various materials including metals, composites, and plastics. Through the analysis of reflected sound waves, the system is capable of identifying defects' location, size, and shape, thereby enabling operators to undertake remedial measures. The measurement of thickness can be accomplished through the utilization of ultrasound systems, which are capable of determining the thickness of various materials, including but not limited to metals and plastics. Accurate thickness measurements are crucial to the performance of products like pipes or containers, making this technique particularly advantageous in their manufacturing process. Ultrasound systems possess the capability to conduct real-time inspections, thereby enabling the identification of defects as they manifest. The implementation of this technology can facilitate prompt corrective measures by operators, leading to a reduction in the quantity of defective products manufactured. Ultrasound systems facilitate non-destructive testing of products, thereby mitigating waste and minimizing the necessity of destructive testing techniques that may cause harm to the products. Ultrasound systems possess the capability to examine an extensive assortment of materials, encompassing metals, composites, plastics, and ceramics. The aforementioned characteristic renders them a multifaceted instrument for identifying flaws in diverse manufacturing procedures. In automated manufacturing systems, ultrasound systems serve as a valuable tool for detecting defects. Ultrasonic testing techniques enable the detection of internal defects, measurement of thickness, real-time inspection, non-destructive testing, and exhibit versatility in their application. The utilization of ultrasound systems can enhance the quality of products, minimize wastage, and augment efficacy for manufacturers.

2.7 Eddy current Systems

Eddy current systems represent an alternative technological approach that can be employed for the purpose of detecting defects in automated manufacturing systems. Eddy current systems are predicated on the principle of electromagnetic induction and are employed for the purpose of identifying flaws in conductive materials. Their efficacy is particularly pronounced in the detection of surface or near-surface defects. Eddy current systems have been identified as a viable means of detecting defects in automated manufacturing systems. Eddy current systems have the capability to examine the surface of products or components for the presence of flaws, such as cracks, corrosion, or pitting. This process is commonly referred to as surface inspection. This technology has the potential to aid manufacturers in identifying any flaws that could potentially compromise the structural soundness of the product. The utilization of eddy current systems enables the classification of materials according to their electrical conductivity. This process can aid manufacturers in identifying materials that exhibit defects or divergent properties from the anticipated ones. The identification of irregularities in conductive materials, such as metals or alloys, can be achieved through the utilization of eddy current systems. The implementation of this technique can aid manufacturers in identifying anomalies such as inclusions, porosity, or alterations in material characteristics. Eddy current systems are a viable option for conducting quality control assessments aimed at verifying that products conform to the prescribed standards. This technology has the potential to aid manufacturers in identifying anomalies such as inadequate thermal processing or other production-related irregularities. In general, eddy current systems represent a potent instrument for identifying defects in automated manufacturing systems. The utilization of eddy current systems enables manufacturers to identify anomalies in conductive materials, thereby enhancing the dependability and excellence of their merchandise while mitigating the likelihood of product malfunctions.

3. Automated Detect Defect Process

The defect detection procedure in automated manufacturing systems generally comprises multiple stages. The following is a summary of the typical procedure:

Step 1: The initial stage involves precisely outlining the nature of the defect that requires identification. The defects in question may range from superficial imperfections to intricate internal irregularities.
Step 2: After defining the defect, one can choose the suitable tools for detecting it. Possible academic rewrite: Various technologies may be employed for quality control purposes, such as sensors, statistical process control (SPC) software, artificial intelligence (AI) and machine learning (ML) algorithms, X-ray systems, ultrasound systems, eddy current systems, or a hybrid approach that combines some of these methods.
Step 3: The tools are implemented within the automated manufacturing system once they have been selected. The process may encompass the installation of sensors or other hardware, the configuration of software or algorithms, or the establishment of X-ray or ultrasound systems.
Step 4: After the implementation of the necessary tools, the manufacturing process is subjected to defect monitoring. Possible academic rewrite: The proposed approach may encompass diverse techniques, such as sensor-based monitoring in real time, statistical process control (SPC) software or artificial intelligence/machine learning (AI/ML) algorithms for data analysis, or periodic examination relying on X-ray or ultrasound systems.
Step 5: The process of defect identification and diagnosis involves the utilization of suitable tools or a combination of tools to detect and diagnose the defect. Possible academic rewrite: The tasks may encompass diverse techniques such as sensor data analysis, X-ray or ultrasound image interpretation, or eddy current inspection for identifying irregularities in conductive substances.
Step 6: The defect is ultimately resolved through the implementation of corrective measures. Potential solutions to address the defect may include interrupting the manufacturing process to rectify the issue, implementing modifications to the production process, or undertaking a product redesign to mitigate the occurrence of the defect.

Generally, in automated manufacturing systems, the process of detecting defects is a continuous and cyclical one that involves consistent monitoring, analysis, and modification to ensure prompt and effective identification and resolution of defects. Presented below is the sequence of the tools utilized for defect detection in automated manufacturing systems:

Start: Sensors → | Statistical Process Control (SPC) Software → | Artificial Intelligence (AI) and Machine Learning (ML) Algorithms → | X-ray Systems → | Ultrasound Systems → | Eddy Current Systems → End

Consequently, the initial step involves the utilization of sensors to identify defects in automated manufacturing systems. The data generated by the sensors is subsequently channeled into statistical process control (SPC) software for the purpose of scrutinizing and overseeing the process. Subsequently, the SPC software can employ artificial intelligence (AI) and machine learning (ML) algorithms to conduct a more in-depth analysis of the data and identify any potential defects. In certain circumstances, the procedure may entail the utilization of X-ray mechanisms to facilitate a comprehensive identification of defects, succeeded by ultrasound mechanisms to identify defects on or near the surface. Eddy current systems have the capability to detect flaws in conductive materials. Ultimately, the procedure culminates in the detection and rectification of any imperfections, resulting in an enhanced caliber of the final product and a streamlined manufacturing operation. The detection of defects in automated manufacturing systems is a crucial process that plays a significant role in ensuring the production of products of superior quality. By utilizing diverse tools and technologies, manufacturers are capable of identifying and analyzing flaws in real-time, resulting in expedited issue resolution and a more streamlined manufacturing procedure. The expeditious identification of defects that may have otherwise gone unnoticed is considered a significant benefit of utilizing automated defect detection systems. In manufacturing settings with high volume production, the significance of even minor defects cannot be overstated as they can significantly affect the quality of the final product and the overall profitability of the enterprise. One additional benefit is the capacity to gather and evaluate substantial quantities of information in real-time. The aforementioned data has the potential to facilitate the identification of patterns and trends that could potentially signify underlying issues in the manufacturing process. This, in turn, enables manufacturers to adopt a proactive approach towards preventing defects from arising in the initial stages. The implementation of automated defect detection systems can be a complex undertaking that demands substantial investments in terms of time, resources, and expertise. It is imperative for manufacturers to conduct a thorough assessment of their individual requirements and make a judicious selection of tools and technologies that align with those needs. Furthermore, it should be noted that the identification of defects is not a singular occurrence. Sustained surveillance and examination are necessary to guarantee prompt detection and resolution of faults, as well as to maintain optimal operational efficiency of the production process. The detection of defects in automated manufacturing systems is a crucial aspect of guaranteeing superior product quality and a prosperous manufacturing operation. Through meticulous tool and technology selection and implementation, manufacturers can expeditiously and effectively identify and rectify defects, resulting in a manufacturing operation that is more prosperous and lucrative.

4. Conclusion

In conclusion, the utilization of defect detection tools is of utmost importance in guaranteeing the production of high-quality outputs in automated manufacturing systems. Multiple defect detection tools are at disposal, including sensors, SPC software, AI and ML algorithms, X-ray systems, ultrasound systems, and eddy current systems. The determination of the suitable instrument or amalgamation of instruments is contingent upon the nature of the flaw and the involved production procedure. Certain anomalies may necessitate immediate monitoring and analysis through the utilization of sensors and SPC software, whereas others may call for a more comprehensive analysis through the use of X-ray or ultrasound systems. The utilization of AI and ML algorithms has gained significant traction in the realm of defect detection. This is attributed to their capacity to scrutinize vast volumes of data and recognize patterns that may have otherwise been overlooked. The aforementioned technologies have the capability to anticipate possible flaws and implement preemptive measures to avert their occurrence. The detection of defects in automated manufacturing systems is a continuous process that necessitates meticulous monitoring and analysis to guarantee prompt and efficient identification and resolution of defects. The utilization of suitable tools and technologies can guarantee effective manufacturing operations and the attainment of superior production quality by manufacturers.

References

[1] Yirui Wu, Hao Cao, Guoqiang Yang, Tong Lu, and Shaohua Wan. 2022. Digital Twin of Intelligent Small Surface Defect Detection with Cyber-Manufacturing Systems. ACM Trans. Internet Technol. Just Accepted (November 2022). https://doi.org/10.1145/3571734.

[2] AlBahar, Areej & Kim, Inyoung & Yue, Xiaowei. (2021). A Robust Asymmetric Kernel Function for Bayesian

Optimization, with Application to Image Defect Detection in Manufacturing Systems.
[3] Costa, M.J.R., Gouveia, R.M., Silva, F.J.G. et al. How to solve quality problems by advanced fully-automated manufacturing systems. Int J Adv Manuf Technol 94, 3041–3063 (2018). https://doi.org/10.1007/s00170-017-0158-8.
[4] ao Zhang, Biyun Ding, Xin Zhao, Ganjun Liu, Zhibo Pang, LearningADD: Machine learning based acoustic defect detection in factory automation, Journal of Manufacturing Systems, Volume 60, 2021, Pages 48-58, ISSN 0278-6125, https://doi.org/10.1016/j.jmsy.2021.04.005.
[5] E. Deutschl, C. Gasser, A. Niel and J. Werschonig, "Defect detection on rail surfaces by a vision based system," IEEE Intelligent Vehicles Symposium, 2004, Parma, Italy, 2004, pp. 507-511, doi: 10.1109/IVS.2004.1336435.
[6] Roberto Milton Scheffel, Antônio Augusto Fröhlich & Marco Silvestri (2021) Automated fault detection for additive manufacturing using vibration sensors, International Journal of Computer Integrated Manufacturing, 34:5, 500-514, DOI: 10.1080/0951192X.2021.1901316
[7] Masoumeh Aminzadeh, Thomas Kurfess, Automatic thresholding for defect detection by background histogram mode extents, Journal of Manufacturing Systems, Volume 37, Part 1, 2015, Pages 83-92, ISSN 0278-6125, https://doi.org/10.1016/j.jmsy.2015.09.004.
[8] A. Al-Shayea, H. Kaid, A. Al-Ahmari, E. A. Nasr, A. K. Kamrani and H. A. Mahmoud, "Colored Resource-Oriented Petri Nets for Deadlock Control and Reliability Design of Automated Manufacturing Systems," in IEEE Access, vol. 9, pp. 125616-125627, 2021, doi: 10.1109/ACCESS.2021.3111575.
[9] eongsu Lee, Young Chul Lee, Jeong Tae Kim, Fault detection based on one-class deep learning for manufacturing applications limited to an imbalanced database, Journal of Manufacturing Systems, Volume 57, 2020, Pages 357-366, ISSN 0278-6125, https://doi.org/10.1016/j.jmsy.2020.10.013.
[10] F. Hardan and A. . R. J. Almusawi, “Developing an Automated Vision System for Maintaing Social Distancing to Cure the Pandemic”, alkej, vol. 18, no. 1, pp. 38–50, Mar. 2022.
[11] ABBOOD, Wisam T.; ABDULLAH, Oday I.; KHALID, Enas A. A real-time automated sorting of robotic vision system based on the interactive design approach. International Journal on Interactive Design and Manufacturing (IJIDeM), 2020, 14: 201-209.
[12] Abbood, W. T., Hussein, H. K., & Abdullah, O. I. (2019). Industrial tracking camera and product vision detection system. Journal of mechanical engineering research and developments, 42(4), 277-280.
[13] Al-Karkhi, N. K., Abbood, W. T., Khalid, E. A., Jameel Al-Tamimi, A. N., Kudhair, A. A., & Abdullah, O. I. (2022). Intelligent Robotic Welding Based on a Computer Vision Technology Approach. Computers, 11(11), 155.
[14] H. B. Matar, S. S. . Al-Zubaidi, and L. A. Al-Kindi, “Evaluation of the Main Causes of Diesel Engine Injector Failure using Fault Tree Analysis ”, alkej, vol. 17, no. 4, pp. 23–35, Dec. 2021.
[15] Najah, F. F. Mustafa, and W. S. Hacham, “Effect of Environmental Factors on the Accuracy of a Quality Inspection System Based on Transfer Learning”, alkej, vol. 17, no. 2, pp. 1–7, Jun. 2021.
[16] M. Q. Ibraheem, “Prediction of Cutting Force in Turning Process by Using Artificial Neural Network”, alkej, vol. 16, no. 2, pp. 34–46, Jun. 2020.
[17] Al-Zubaidi, S., Ghani, J.A. and Haron, C.H.C., 2012. Application of artificial neural networks in prediction tool life of PVD coated carbide when end milling of TI6aL4v alloy. International Journal of Mechanics, 6(3), pp.179-186.