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ORIGINAL PAPER

Design and modeling to identify a defective workpiece in manufacturing process: an industry 4.0 perspective

Bhaveshkumar N. Pasi[1] · Pallavi V. Dongare[2] · Suman Joshi Rawat[2] · Ankit D. Oza[3] · Harsha Padheriya[4] · Manish Gupta[5] · Sandeep Kumar[6] · Manoj Kumar[7]

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Abstract
Traditionally, the sampling process is done manually by verifying a handful of objects from a batch of several objects being produced. Based on the quality of the handful of objects verified, the whole batch may be accepted or rejected. Mistakes during manual sampling process may cause a number of defected objects to be accepted and a number of fine objects to be rejected which in turn may increase risk both at the manufacturer's and the consumer's end. Therefore, there is a need to transform manual sampling process into automatic. The purpose of this research work is to use Industry 4.0 concept and develop an image recognition-based system (IRBS) for identifying a defected workpiece to increase the accuracy of the quality inspection process. Based on recently published journals and patents, manual sampling process, Industry 4.0 concept, and Image Processing Technique are reviewed. Then, IRBS for identifying a defected workpiece is designed and developed. Next, trial is taken on developed IRBS model to investigate its performance. It is found that the use of IRBS model reduces manufacturer's risk. After implementation of the IRBS model the process accuracy is increased from 90.67 to 100%, labour productivity is increased from 5.69 to 18.4 units/min and the average time required for inspection of 05 samples is reduced from 53 to 16 s. IRBS makes sampling process automatic which results in increase in the accuracy of the quality inspection process, reduction in time required for inspection process and increase in the labor productivity.

Keywords Inspection · Industry 4.0 · Labor productivity · Process accuracy · Sampling · Quality control

Abbreviation

IRBS Image recognition based system

✉ Bhaveshkumar N. Pasi
bhavesh.pasi258@gmail.com

Pallavi V. Dongare
pallavivivekdongare@gmail.com

Suman Joshi Rawat
jsuman26@gmail.com

Ankit D. Oza
ankitoza6060@yahoo.in

Harsha Padheriya
harsha.padheriya@iar.ac.in

Manish Gupta
Gupta.manishlpu@gmail.com

Sandeep Kumar
sandeep.uietmdu@gmail.com

Manoj Kumar
mky2011@gmail.com

1 Introduction

For many years, people perform the work of inspection manually in quality control department of manufacturing

1 Department of Mechanical Engineering, Vishwaniketan's Institute of Management Entrepreneurship and Engineering Technology (ViMEET), Khalapur, India

2 Department of Civil Engineering, Vishwaniketan's Institute of Management Entrepreneurship and Engineering Technology (ViMEET), Khalapur, India

3 Department of Mechanical Engineering, Parul University, Vadodara, Gujarat 391760, India

4 Department of Computer Sciences and Engineering, Institute of Advanced Research, Gandhinagar, Gujarat, India

5 Division of Research and Development, Lovely Professional University, Phagwara, Punjab, India

6 Division of Research and Innovation, Uttranachal University, Uttarakhand, India

7 Department of Mechanical Engineering, ABES Engineering College, Ghaziabad, U.P. 201009, India

industries [1–3]. Although workers do this work well and may be performing better than machines but their working speed is less [1, 4, 5]. Also, by doing repetitive work, they start getting tired. The manual inspection process does not provide real-time inspection facility during manufacturing. Hence, this leads to increase in object rework cost and time, decrease in operation productivity, etc. [4, 6, 7]. Sometimes, the manual inspection process is dangerous and difficult in certain environment. The accuracy of the manual inspection process depends upon the skill of workers [2, 7]. To carry out the manual inspection process without an error highly skilled and experienced workers are required. Wages paid to these workers are high which lead to increase in production cost [6, 8, 9]. Therefore, many medium and large-scale manufacturing industries have adopted the automatic quality control system approach. But small-scale manufacturing industries are still not able to convert their traditional quality control system into an automated quality control system due to the various reasons such as higher cost of automatic system, requirement of skilled workforce to operate the automatic system, etc. [1, 4, 10–12]. Advances in Industry 4.0 concept and its enabling technologies can help small-scale manufacturing industries to implement automatic quality control system in their operations [13, 14]. It is found that the Industry 4.0 enabling technologies can enhance the productivity, efficiency and quality of operations of manufacturing industries [15–19]. Therefore, it is advisable to develop automatic inspection system for quality control department of small-scale manufacturing industries by using Industry 4.0 enabling technologies [4, 20, 21]. Use of Industry 4.0 enabling technologies in object inspection process will allow real-time inspection during manufacturing process that will lead to reduction in product rejection, scrap generation, product rework cost and time, etc. [2, 10, 22, 23]. Therefore, the aim of this research article is to develop cost efficient automatic inspection system for small-scale manufacturing industries by using Industry 4.0 enabling technology.

The remainder of the article is organized as follows: Sect. 2 is devoted to the materials and methods. Section 3 is dedicated to research objectives. Section 4 illustrates the IRBS model development. Section 5 is dedicated to the results and discussions. Section 6 shows conclusions. Section 7 dictates current and future developments.

2 Materials and methods

In this research article, various keywords along with their combinations (i.e. Industry 4.0; Image Processing Technique; Sampling method; Sampling method and Advantages; Sampling method and Disadvantages; Industry 4.0 and Quality inspection; Image Processing Technique and Quality inspection) are used to search the research articles and patents to carry out the detailed literature review. An electronic database such as SCOPUS, Google Scholar and Google Patents are explored for searching these keywords. Then, collected research articles and patents are evaluated based on certain criteria such as—(1) the articles and patents written only in English are considered; (2) the articles published in between January 2013 and May 2021 are considered; (3) the patents granted in last 20 years are only considered; (4) the articles and patents in which Industry 4.0 and Image Processing Technique are only mentioned as an example are excluded; (5) the articles and patents in which Industry 4.0 and Image Processing Technique are only mentioned in keywords are excluded; (6) the articles and patents in which Industry 4.0 and Image Processing Technique are only used as a tool for future scope without giving strong evidence are excluded. Figure 1 shows a research methodology flowchart. Literature review is conducted for the three different areas such as sampling process, Industry 4.0 and image processing system. Research objectives are identified after the detailed literature review. The IRBS model is designed and developed to overcome the problems associated with the manual sampling process. Performance analysis is done to check the validity of the IRBS model. Then, the IRBS model is used to solve business problem.

2.1 Overview of sampling process

In industries, when the manufactured component or product population size is exceptionally large then it is not possible to check or inspect all components of the population [6, 7, 24]. In such a scenario, a sampling inspection process is adopted [1, 6, 7, 25]. The sampling inspection process (also known as the partial enumeration inspection process) is defined as the process in which a fraction of the population is selected to represent the characteristics of the entire components being manufactured [1, 2, 26]. The sampling process has the following advantages: (a) It gives results quickly, (b) It requires low capital investment [4, 6, 27]. It is found that the sampling process is carried out manually and requires highly skilled human inspectors. As it is known that in the manual sampling process only a handful of items is selected from the population for inspection, therefore, any mistake (i.e. incorrect usage of instrument, observational error, etc.) done by the operator during the manual sampling process may lead to less reliable and accurate results [2, 4, 7, 28].

To increase the reliability and accuracy of the sampling process it is required to convert the manual sampling process into an automatic sampling process. This automatic sampling process will allow inspection of all the parameters of an object without human intervention which will help to minimize the errors introduced during the inspection process [1, 6, 7, 29]. The overall cost and time associated with the automatic sampling process are less than the manual sampling

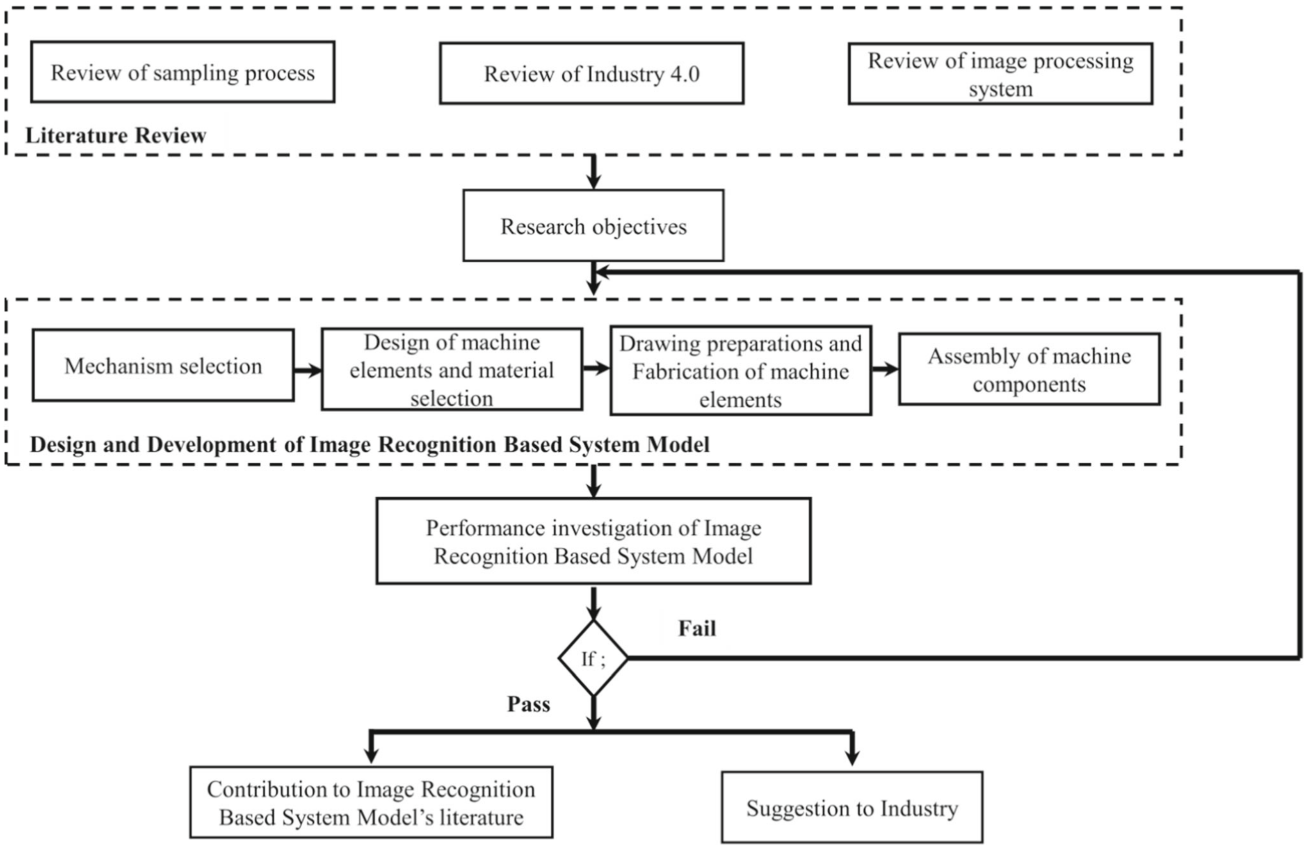

Fig. 1 Research methodology flowchart. *Source*: Author's own research

process [1, 4, 30]. It has been found that the use of Industry 4.0 concept and its enabling technologies can produce a fully automatic real-time sampling process with higher reliability and accuracy [31–33].

2.2 Industry 4.0

Few years ago, in order to integrate and extend the activities associated with the manufacturing industries, technology framework was proposed which is also called as Industry 4.0 [32, 34–36]. It includes various technologies such as Internet of Things (IoT), additive manufacturing, cloud computing, big data analytics, image processing, automated guided vehicles (AGV), artificial intelligence (AI), etc. [14, 37, 38]. Industry 4.0 concept integrates the technologies mentioned earlier and allows industrialists to develop production plant with higher efficiency [13, 39, 40]. In recent few years, industrial systems are improved due to the use of cyber physical systems and IoT [41–43]. In order to understand "4th industrial revolution" in detail, it is important to know the previous three industrial revolutions. The 1st industrial revolution deals with industrialization [19, 44]. The 2nd industrial revolution deals with mass production by using electricity which is also called as hard automation [15, 45, 46]. The 3rd industrial revolution deals with the development of flexible automation systems by using computers [47, 48]. At last, the 4th industrial revolution deals with the application of modern information and communication technology and development of integrated systems connected with each other [49, 50]. Industry 4.0 concept helps to develop smart factory by developing flexible and smarter cyber physical network [18, 21, 51]. Benefits of Industry 4.0 concept are as follows: (a) total performance improvement of the entire business [52, 53], (b) development of effective and efficient real-time production systems [54–56], (c) minimum human interventions during production activity [51, 57]. Due to various advantages of Industry 4.0 concept, in this research article, Industry 4.0 concept and its enabling technology i.e. image processing technique are used to develop automatic sampling process. Table 1 shows Industry 4.0 enabling technologies and their features.

2.3 Image processing system

Image processing system helps to increase the efficiency, quality and productivity of manufacturing systems [8, 75]. It

Table 1 Industry 4.0 enabling technologies and their features

S.No.	Technologies	Features	References
1	Autonomous robots	It is a robot that executes different activities with high degree of autonomy	[16, 32, 58]
2	Internet of Things (IoT)	It deals with connecting any device with internet. It allows communication between things to things, person to person, and person to things	[14, 38, 59]
3	Simulation	It allows imitation of real-world activities over time. It is used in testing, safety engineering, training, operating optimization, etc	[41, 45, 47, 60]
4	Cloud computing	It deals with computing services such as data storage, servers, software, networks, intelligence, and analytics. It allows effective utilization of resources, innovation at faster rate, etc	[16, 21, 22, 61]
5	Additive manufacturing	It allows layer by layer creation of 3D object in the shortest possible time	[18, 22, 41, 62]
6	Big data analytics	It deals with the use of advanced analytic techniques to analyze the large data sets	[16, 63, 64]
7	Augmented reality	It allows people to superimpose digital content over a real-world environment	[19, 41, 65]
8	Smart sensors	It deals with the execution of predefined action after sensing the input such as light, sound, heat, motion, etc	[16, 66–68]
9	Automated guided vehicles (AGV)	It allows automatic transportation of materials on the shop floor by following wires on floor. It uses vision camera	[57, 64, 69]
10	Image processing system	It deals with the extraction of useful information by analyzing images	[70–72]
11	Artificial intelligence (AI)	It deals with the development of computer or robot systems by integrating human intelligence into it to perform activities that usually done by humans	[16, 73, 74]

is an essential element of advanced manufacturing systems because it provides provision of quality control during manufacturing of objects and necessary information to robotic systems to assemble difficult products from a set of basic elements [11, 76]. Inspection by using image processing system eliminates human intervention and makes inspection process completely automatic [10, 11]. In an image processing system, one or more cameras are positioned in the vicinity of the object to be inspected. These cameras are used to capture the images of the object [8, 11, 76]. Then, features of captured images are extracted, processed and classified with the help of a central processing unit [75, 76]. In general, an image processing system consists of the following steps: (a) image acquisition, (b) image processing, (c) segmentation, (d) feature extraction, and (e) decision-making. Table 2 shows a set of operations performed in image processing technique.

Image processing system is highly recommended for visual inspection to verify the quality of products and eliminate the defective parts from the production line [10, 76]. This can be seen in a mass production system such as manufacturing lines of biscuits, beer bottles, etc. Also, image processing system is used for measurement of specific parameter of an object and use this recorded value to correct the faulty behavior of manufacturing process [8, 11, 75]. Image

Table 2 Operations performed in image processing technique

S.No.	Operations	Explanation	References
1	Point operation	This operation deals with enhancement of contrast, modification of brightness and thresholding	[10, 75]
2	Global operation	This operation deals with equalization of histogram	[8, 11]
3	Neighborhood operation	This operation deals with the smoothing of image and image sharpening	[8, 76]
4	Geometric operation	This operation deals with the adjustment of display, wrapping of image, magnification and rotation of image	[10, 11, 75]

processing system allows statistical analysis of efficiency of the production process which helps industrialists to do business planning in advance [10, 76]. Image processing system is used for various industrial applications such as food industry, automotive industry, pharmaceutical industry, steel industry, wood industry, printed circuit board manufacturing industry, etc. [10, 11, 75]. Image processing technique is used to—(a) identify the small surface defects on machined surfaces, tile surfaces and textile fabrics, (b) detect defective packaging of tins of cigarettes, and (c) carry out automatic inspection of biscuit bake color, wood, potato chips color, food products, textile fabrics, etc. [8, 10, 76].

2.3.1 Patents on image processing system used for inspection process

The cited reference [77] shows a high-resolution object inspection system consisting of three stations i.e. first station, second station and third station. The first station captures first image of an object. The first image determines the presence or absence of at least one defect on the object. If a defect is not present on the object, then object is directly transferred to third station. Otherwise, the object is transferred to the second station. The second station captures second image of an object. The second image determines the quality of defect identified in first image and decision is made whether to accept or reject the object. If quality of defect on object is accepted in second station, then object is transferred to third station. Otherwise, object is transferred to rejected bin. Third station makes a decision based on an optical property such as the object power and thickness. If optical property of object is within range, then object is sent to dispatch center. Otherwise, object is sent to rejected bin. The cited reference [78] discloses the inspection system consisting of an illuminating device. This system aims at inspection of cylindrical object. This illuminating device contains a cylindrical lighting element with a slit diaphragm placed in its core. The lighting element contains a cylindrical light source with a cylindrical diffusor arranged therein, and the slit diaphragm comprises a cylinder with axially extending slits. The slits are positioned in the cylinder in such a way that lines extending perpendicular to the axis of the cylinder converge in a point that is spaced apart from the cylinder axis in the core of the slit diaphragm through the slits. However, the cited references Vertoprakhov [77] and Yannick et al. [78] does not disclose the types of defects detected, transfer mechanism, sensors and feedback path.

3 Research objectives

Mechanical components such as gear, nut, bolt, shaft, etc. have a wide variety of use in industries. These components need to be manufactured with the accurate and required number of teeth, diameter, and so on. Also, quality assurance or inspection of different parameters of these components are to be carried out accurately and quickly. During an industrial visit it has been observed that inspection of gear, bolt, shaft, etc. is performed manually by a manufacturer by verifying a handful of objects from a batch of several objects being produced. Based on the quality of the handful of objects verified, the whole batch may be accepted or rejected. Error made by inspector during sampling process may cause a number of defected objects to be accepted and a number of fine objects to be rejected which in turn may increase risk both at the manufacturer's and the consumer's end along with decreasing the accuracy of the inspection of the objects. Therefore, it is required to develop automatic sampling processes which does not have human intervention. It has been found that these problems can be overcome by the use of Industry 4.0 enabling technology i.e. image processing technology and computers aided by some mechanical devices. Therefore, the objective of this research work is to develop image-based automatic sampling process with higher efficiency and accuracy.

4 IRBS model development

This section consists of the environment for identifying a defected workpiece, schematic block diagram, operational flow diagram and IRBS model.

4.1 Environment for identifying a defected workpiece

Figure 2 illustrates an environment 100 implementing an image recognition-based system 102 for identifying a defected workpiece 104 amongst a number of workpieces. Examples of the workpiece 104 may include, but are not limited to, a gear, a nut, a bolt, a shaft, any mechanical tool or the like. Examples of a defect may include, but are not limited to, irregularities in shape, and size, destroyed edges or the like. The image recognition-based system 102 is configured to identify one or more defects on the workpiece 104 based on a number of parameters corresponding to the workpiece 104 extracted from an image of the workpiece 104.

The image recognition-based system 102 is configured to sense presence of the workpiece 104 under conveyance, upon the workpiece entering an area within a pre-determined distance from the image-based system 102. Upon sensing the presence of the workpiece 104 within the pre-determined distance, the image recognition-based system 102 is configured to stop the workpiece 104 under conveyance and capture an image of the workpiece 104. Further, the image

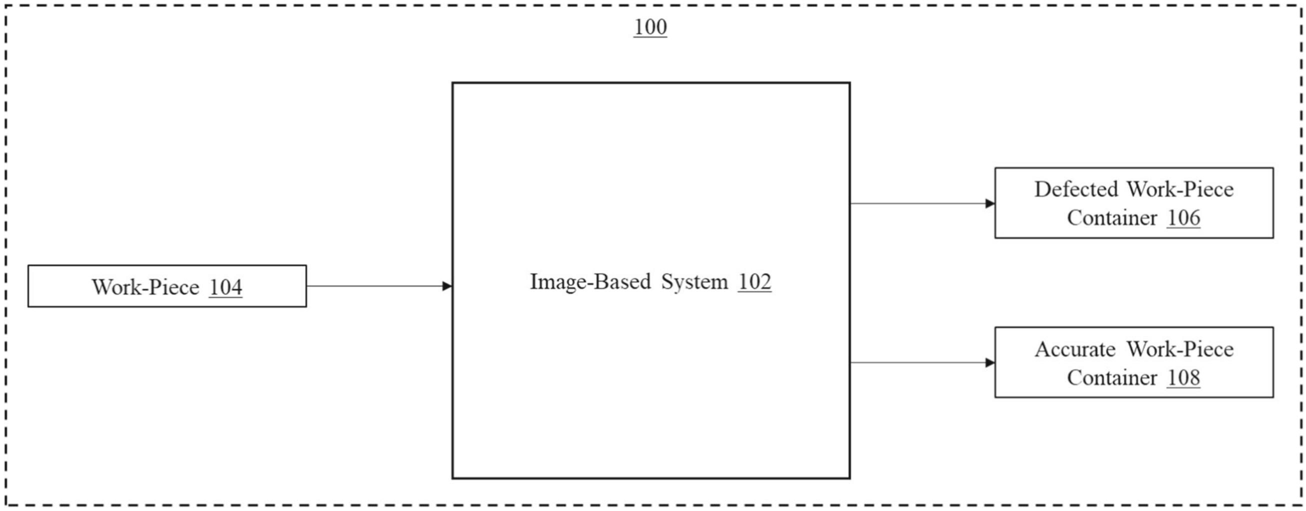

Fig. 2 Environment for identifying a defected workpiece

recognition-based system 102 is configured to extract the number of parameters corresponding to the workpiece 104 from the image of the workpiece 104. Examples of the number of parameters may include, but are not limited to, an inner diameter, an outer diameter, a pitch circle diameter, a module, a number of teeth, and height of each of the number of teeth in the workpiece 104. Subsequent to extracting the number of parameters from the image, the image recognition-based system 102 is configured to transmit the number of parameters to a server.

The server stores a number of predetermined parameters corresponding to the workpiece 104. The server is configured to run a comparing program between the number of predetermined parameters and the number of parameters received from the image recognition-based system 102. Further, the server generates and transmit a message indicating whether the number of parameters match with the number of predetermined parameters. Furthermore, the number of parameters not matching with the number of pre-determined parameters correspond to the workpiece 104 being defected. Subsequently, the image recognition-based system 102 receive the message from the server and move the workpiece 104 to any of the defected work-piece container 106 and the accurate work-piece container 108 based on the message. The image recognition-based system 102 is configured to move the workpiece 104 to the defected work-piece container 106 based on the message indicating the number of parameters not matching the number of pre-determined parameters. Also, the image recognition-based system 102 is configured to move the workpiece 104 to the accurate work-piece container 108 based on the message indicating the number of parameters match with the number of pre-determined parameters.

4.2 Schematic block diagram of IRBS

Figure 3 illustrates a schematic block diagram of the image recognition-based system 102 for identifying the defected workpiece 104 amongst a number of workpieces. The image recognition-based system 102 include a processor 202, a memory 204, data 206, module (s) 208, resource (s) 210, a conveyor belt 212, a motor 214, a controller 216, a sensor 218, an imaging device 220, and a mover 224.

The system 102 is a configurable hardware. Processor 202 is a single processing unit or a number of units, all of which could include multiple computing units. The processor 202 is implemented as one or more microprocessors, microcomputers, microcontrollers, digital signal processors, central processing units, processor cores, multi-core processors, multiprocessors, state machines, logic circuitries, application-specific integrated circuits, field-programmable gate arrays and/or any devices that manipulate signals based on operational instructions. Among other capabilities, the processor 102 is configured to fetch and/or execute computer-readable instructions and/or data stored in the memory 204.

The memory 204 include any non-transitory computer-readable medium known in the art including, for example, volatile memory, such as static random-access memory (SRAM) and/or dynamic random-access memory (DRAM), and/or non-volatile memory, such as read-only memory (ROM), erasable programmable ROM (EPROM), flash memory, hard disks, optical disks, and/or magnetic tapes. Memory 204 include the data 206. The data 208 serves, amongst other things, as a repository for storing data processed, received, and generated by one or more of the processor 202, the conveyor belt 212, the motor 214, the controller 216, the sensor 218, the imaging device 220, and the mover 224. The data 208 further include a number of parameters related to the

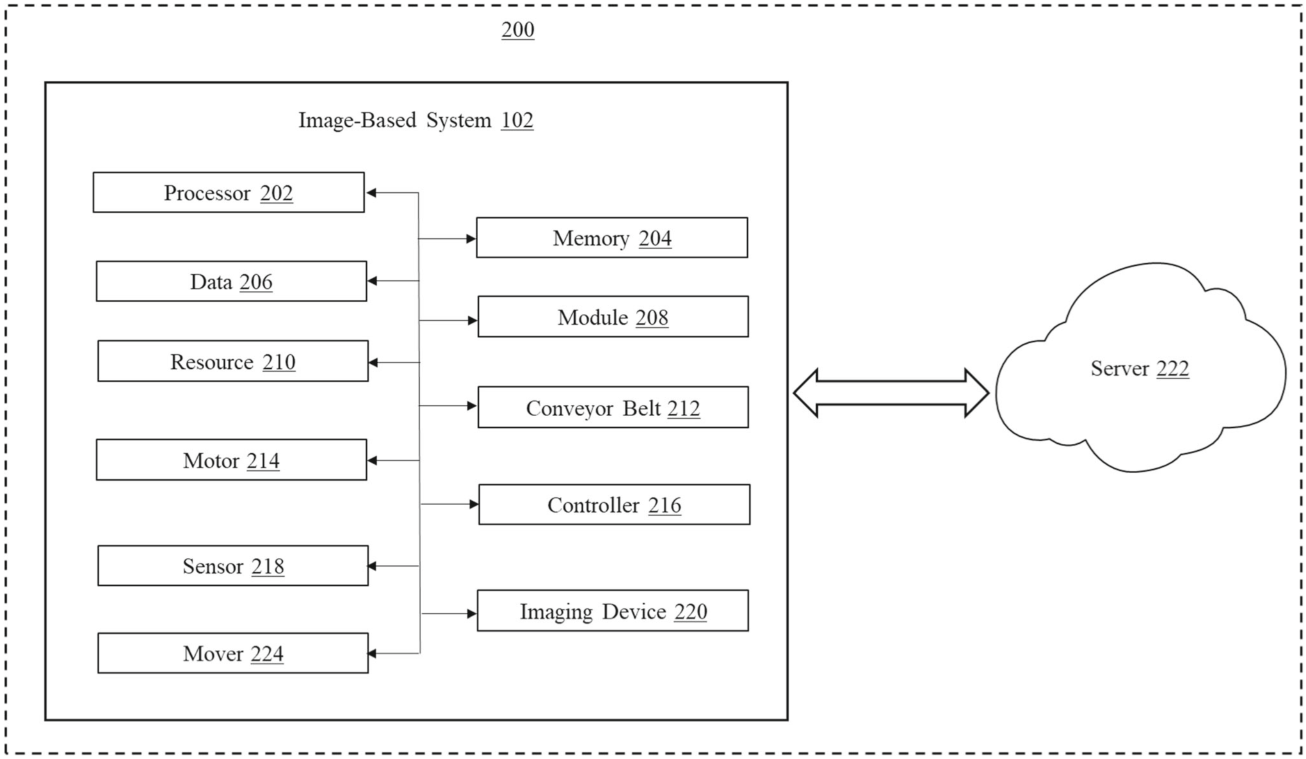

Fig. 3 Schematic block diagram of IRBS

workpiece 104. For instance, the number of parameters may include an inner diameter, an outer diameter, a pitch circle diameter, a module, a number of teeth, and height of each of the number of teeth in the workpiece 104. The resource(s) 210 is physical and/or virtual components of the system 102 that provide inherent capabilities and/or contribute towards the performance of the system 102. Examples of the resource(s) 210 may include, but are not limited to, a memory (e.g., the memory 204), a power unit (e.g. a battery), a display unit, etc. The resource(s) 210 may include a power unit/battery unit, a network unit, etc., in addition to the processor 202, and the memory 204.

The system 102 is configured to identify the defected workpiece 104 based on the number of parameters related to the workpiece 104. The number of parameters is extracted from an image of the workpiece 104 under conveyance by the image recognition-based system 104. Prior to capturing the image of the workpiece 104 under conveyance, the image recognition-based system 102 is configured to sense presence of the workpiece 104 within a pre-determined distance from the image recognition-based system 102 and stop movement of the workpiece 104 for capturing the image. For stopping the movement of the workpiece 104 under conveyance, the conveyor belt 212 may be stopped. The conveyor belt 212 is configured to transport the workpiece 104 to any of the defected work-piece container 106 and the accurate work-piece container 108. The conveyor belt 212 is permanently attached to the defected work-piece container 106 and the accurate work-piece container 108 for transporting the work-piece 104. The defected work-piece container 106 and the accurate work-piece container 108 are present in a vicinity of the conveyor belt 212 for receiving the workpiece 104.

The motor 214 is configured to power the conveyor belt 212 for moving and transporting the workpiece 104. The motor 214 is a 1000 RPM 12v dc motor. Working of the motor 214 is controlled by the controller 216 for initiating and stopping of the conveyor belt 212 transporting the workpiece 104. The controller 216 is configured to activate and de-activate the conveyor belt 212 and the mover 224 for transporting the workpiece under conveyance to any of the the defected work-piece container 106 and the accurate work-piece container 108. The controller 216 is configured to control the motor 214 connected to the conveyor belt 212 for activating and de-activating the conveyor belt 212 transporting the workpiece 104. The controller 216 is configured to communicate with the sensor 218 and receive a signal from the sensor 218 for de-activating the conveyor belt 212. The controller 216 may be an Arduino controller.

The sensor 218 is configured to sense the presence of the workpiece 104 under conveyance by the conveyor belt 212 within a pre-determined distance from the sensor 218. Examples of the sensor 218 may include, but are not limited to, a proximity sensor, an ultra-sonic sensor, a capacitive sensor, a photo-electric sensor, and an inductive sensor. The sensor

218 is present in vicinity of conveyor belt 212 for sensing presence of the workpiece 104 on the conveyor belt 212 being transported. Upon sensing the presence of the workpiece 104 within the pre-determined distance, the sensor 218 generate and transmit the signal to the controller 216. The signal is indicative of de-activating the conveyor belt 212 by controlling the working of the motor 214. Subsequent to de-activation of the conveyor belt 212 by the motor 214, in extension, by the controller 216, the imaging device 220 is configured to capture the image of the workpiece 104 and extract the number of parameters related to the workpiece 104 from the image. Examples of the imaging device 220 may include, but not limited to, a camera, a video recorder, and a closed-circuit television (CCTV). Upon extracting the number of parameters from the image, the imaging device 220 is configured to transmit the number of parameters to a server 222. The imaging device 220 is in a two-way communication with the server 222. The imaging device 222 communicate with the server 222 through any of wired and wireless standards such as Bluetooth, Wi-Fi, local area network (LAN), metropolitan area network (MAN), wide area network (WAN), Infrared, or the like.

The server 222 is configured to determine whether the workpiece 104 is defected or not. The determination is based on a comparison of the number of parameters received from the imaging device 220 with a number of pre-determined parameters. The server 222 is configured to run a comparison program for comparing the number of parameters and the number of pre-determined parameters. The number of pre-determined parameters are stored at the server 222 by a user, or an administrator of the image recognition-based system 102. The number of pre-determined parameters is derived from any state-of-the-art technology platform prior to storing at the server 222. In this research work, the computer program is MATLAB. Upon comparing the number of parameters with the pre-determined parameters, the server 222 is configured to generate a message indicating whether the workpiece 104 is defected or not. The number of parameters not matching with the number of pre-determined parameters correspond to the workpiece 104 being defected and the number of parameters matching with the number of pre-determined parameters may correspond to the workpiece 104 being not defected. Furthermore, the server 222 is configured to transmit the message to the controller 216. Upon receiving the message from the server 222, the controller 216 is configured to activate one of the conveyor belt 212 and the mover 224. The activating of one of the conveyor belt 212 and the mover 224 are based on whether the workpiece 104 is defected or not. The mover 224 is activated based on the message indicative of the workpiece 104 being defected. Upon activation, the mover 224 is configured to push the workpiece 104 into the defected work-piece container 106. The mover 224 is a pair of rack and pinion coupled to one another.

4.3 Operational flow diagram of IRBS

Figure 4 illustrates an operational flow diagram 300 for identifying the defected workpiece 104 amongst a number of workpieces. At step 302, the operational flow diagram 300 includes sensing presence of the workpiece 104 under conveyance on the conveyor belt 212 by the sensor 218 within a pre-determined distance from the sensor 218. Further, based on sensing the presence of the workpiece 104, the sensor 218 may transmit a signal to the controller 216 for de-activating the conveyor belt 212. The conveyor belt 212 is de-activated by stopping the working of the motor 214 connected to the conveyor belt 212 by the controller 216 based on receiving the signal from the sensor 218.

At step 304, the operational flow diagram 300 includes, capturing the image of the workpiece 104 under conveyance on the conveyor belt 212 within the pre-determined distance of the sensor 218. The image is captured by the imaging device 220. Upon capturing the image, the number of parameters is extracted from the image of the workpiece 104 by the imaging device 220. At step 306, the operational flow diagram 300 includes, transmitting the number of parameters extracted from the image of the workpiece 104 captured by the imaging device 220 to the server 222. The communication between the imaging device 220 and the server 222 is based on one of a wired communication standard, and wireless communication standard. Examples of the wired communication standard and the wireless communication standard may include, but are not limited to, LAN, MAN, WAN, 3G, 4G, 5G, Wi-Fi, Bluetooth, Infrared or the like.

At step 308, the operational flow diagram 300 includes, comparing the number of parameters related to the workpiece 104 received from the imaging device 220 to the number of pre-determined parameters at the server 222. The number of pre-determined parameters is derived from the state-of-the-art technology such as MATLAB prior to storing at the server 222 for comparing with the number of parameters. Furthermore, the server 222 generate a message based on the comparison between the number of parameters and the number of pre-determined parameters such that the message being indicative of whether the workpiece 104 is defected or not. The workpiece is defected when the number of parameters is not the same as the number of pre-determined parameters. When the number of parameters match with the number of pre-determined parameters, the workpiece 104 may not be defected. Upon generating the message, the server 222 communicate the message to the controller 216 of the image recognition-based system 102.

At step 310, the operational flow diagram 300 includes, determining by the controller 216 whether the workpiece 104 is defected or not. Upon determining that the workpiece 104 is not defected based on the message received from the server 222, the controller 216 at step 312, activate the conveyor

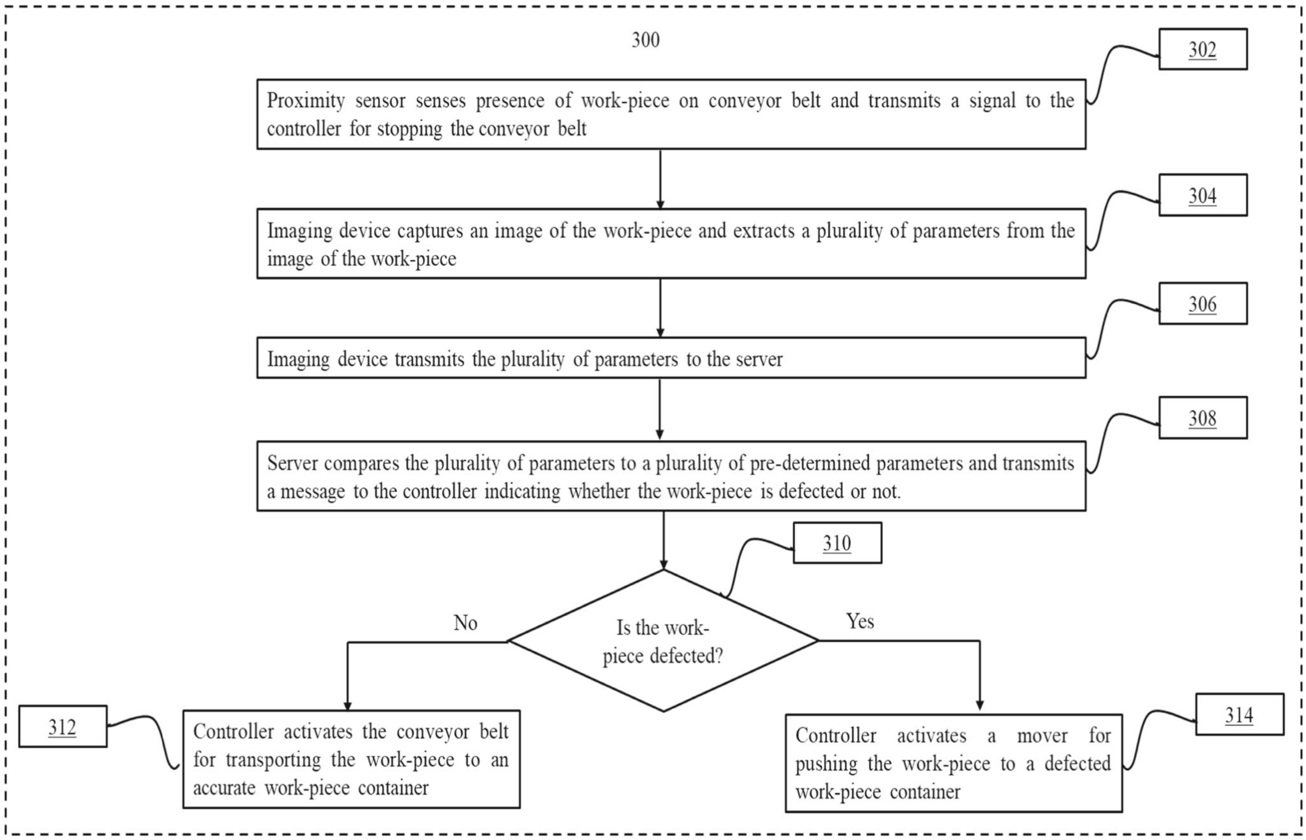

Fig. 4 Operational flow diagram of IRBS

belt 212 for transporting the workpiece under conveyance to the accurate work-piece container 108. The controller 216 activate the conveyor belt 212 by powering the motor 214 communicably coupled to the controller 216. Upon determining that the workpiece 104 is defected based on the message received from the server 222, the controller 216 at step 314, activate the mover 224 for pushing the workpiece 104 under conveyance to the defected work-piece container 106. The mover 224 includes a pair of a rack and a pinion coupled with one another for pushing the workpiece upon receiving a command from the controller 216.

4.4 IRBS model

Figure 5 shows perspective view of the IRBS model. Two rollers are mounted according to the required distance, the belt is mounted on the rollers on which the workpiece to be inspected are placed. The rollers shaft is coupled with the motor drive hence when power is supplied to the motor rollers rotate with a certain time delay according to the motor drive and the belt moves over the rollers. Thus workpiece handling is carried out. Initially belt conveyor is stationary. Workpiece is kept on conveyor belt and the workpiece image is captured by the camera which is fixed at the top. The captured image is sent to the computer. MATLAB algorithm read image and processes with the help of image processing and results are displayed on command window of MATLAB. Non-defected workpiece is collected in a separate tray and the defected workpiece is collected in another tray with the help of DC gun motor. A pushing rod is mounted in front of the DC gun motor. When the DC gun extends it pushes the plate hence the work piece in front is also pushed and collected in the tray. When the DC gun is retracted the plate also comes back to its position.

4.4.1 Features of IRBS model

Various features of IRBS model are as follows:

1. An image recognition-based method for identifying a defected work-piece, the image-based method comprising:
   - extracting, by an imaging device, a plurality of parameters associated with a work piece under conveyance from an image of the work-piece captured by the imaging device and transmitting the plurality of parameters to a server.

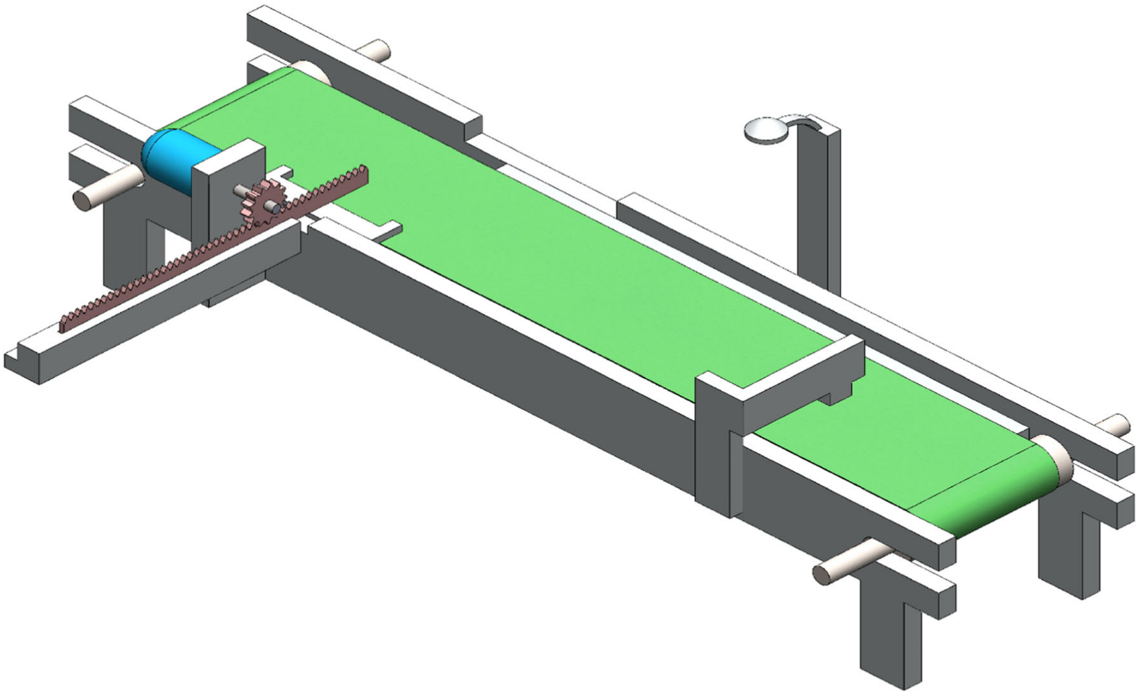

Fig. 5 Perspective view of IRBS. *Source*: Author's own research

- comparing, at the server, a plurality of parameters associated with the work-piece with a plurality of pre-determined parameters and transmitting a message to the controller; and
- activating, by the controller, a mover for moving the work-piece to a container, based on the message received at the controller from the server, wherein the message indicates the work-piece is defected based on the plurality of parameters not matching with the plurality of pre-determined parameters.

2. The method as mentioned in point 1, further comprising: stopping, by a controller, a conveyor belt transporting the work-piece based on a signal received from a sensor, wherein the signal indicates presence of the work-piece within a pre-determined distance of the sensor
3. The method as mentioned in point 1, wherein the controller activates the conveyor belt for transporting the work-piece to another container based on the message received at the controller from the server, wherein the message indicating the work-piece is not defected based on the plurality of parameters matching with the plurality of pre-determined parameters
4. The method as mentioned in point 1, wherein the plurality of parameters and the plurality of pre-determined parameters is any of an inner diameter, an outer diameter, a pitch circle diameter, and module, a number of teeth, height of each of the number of teeth in the work-piece
5. The method as mentioned in point 1, wherein the mover comprises a rack and a pinion
6. An image recognition-based system for identifying a defected work-piece, the image-based system comprising:
   - A conveyor belt, controlled by a controller, for transporting the work-piece
   - A sensor, attached to the conveyor belt, for sensing presence of the work-piece within a pre-determined distance of the sensor and transmitting a signal to controller for stopping the controller
   - An imaging device configured to: capture an image of the work-piece within the pre-determined distance of the sensor; extract a plurality of parameters associated with the work-piece under conveyance from the image; transmit the plurality of parameters to a server for comparing the plurality of parameters with a plurality of pre-determined parameters
   - A mover, controlled by the controller, for moving the work-piece to a container, based on a message received at the controller from the server, wherein the message indicating the work-piece is defected based on the plurality of parameters not matching with the plurality of pre-determined parameters
7. The system as mentioned in point 6, wherein the controller activates the conveyor belt for transporting the work-piece to another container based on the message received at the controller from the server, wherein the

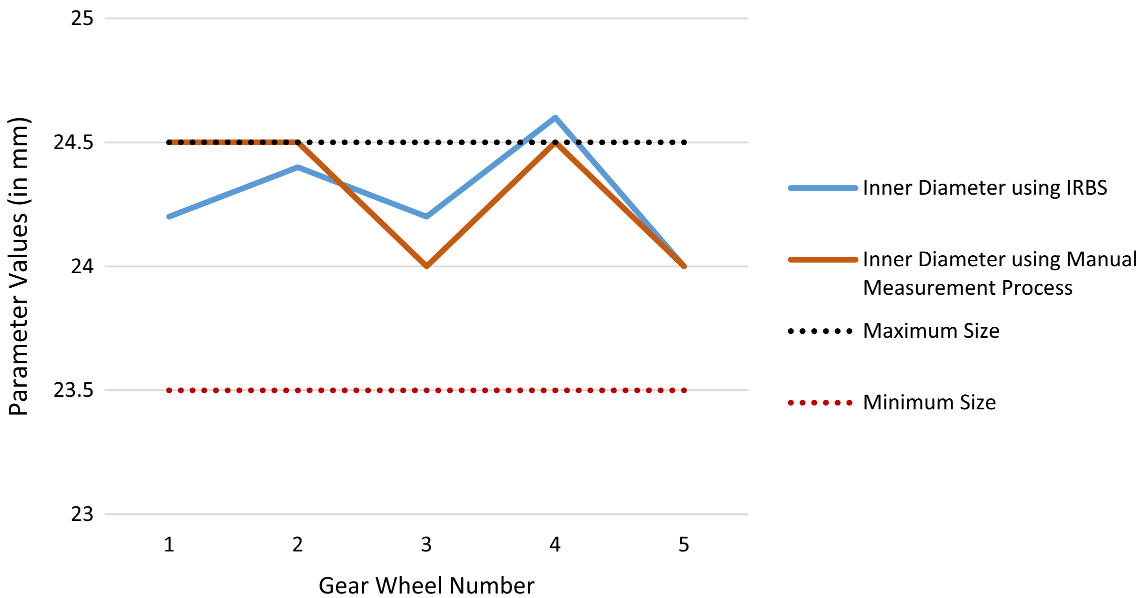

Fig. 6 Comparison of inner diameter parameter values

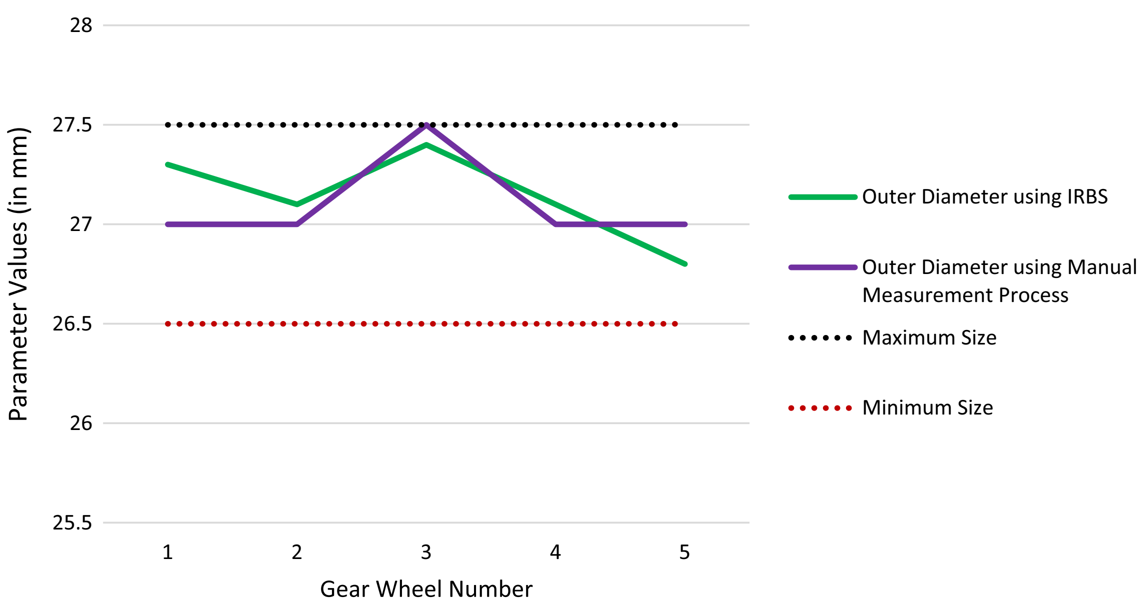

Fig. 7 Comparison of outer diameter parameter values

message indicating the work-piece is not defected based on the plurality of parameters matching with the plurality of pre-determined parameters

8. The system as mentioned in point 6, wherein the plurality of parameters and the plurality of pre-determined parameters is any of an inner diameter, an outer diameter, a pitch circle diameter, and module, a number of teeth, height of each of the number of teeth in the work-piece

5 Results and discussions

Trial is conducted on 05 gear wheels after the development of the IRBS. Various parameters such as inner diameter, outer diameter, number of teeth and tooth height of gear wheel are measured by using IRBS. During trial, parameters of master gear wheel are compared with parameters of manufactured gear wheel. Values of Master gear parameters are as follows—(a) inner diameter value $= 24 \pm 0.5$ mm, (b) outer

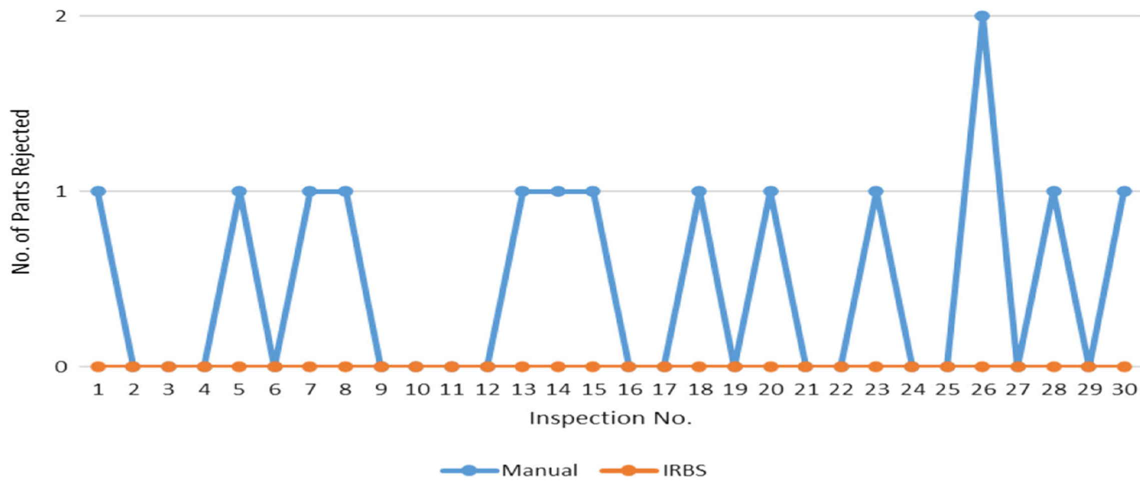

Fig. 8 Parts rejected during manual process and IRBS model

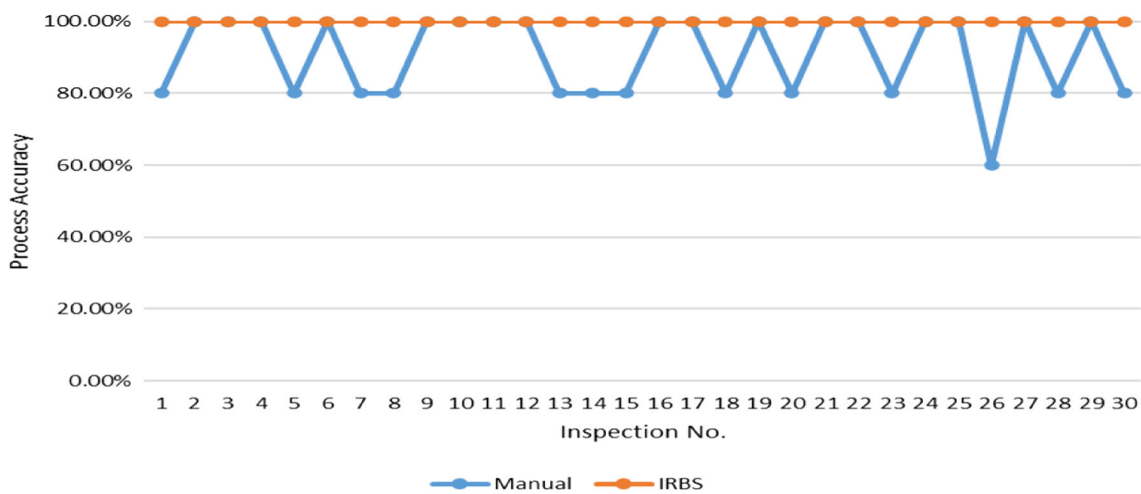

Fig. 9 Process accuracy during manual process and IRBS model

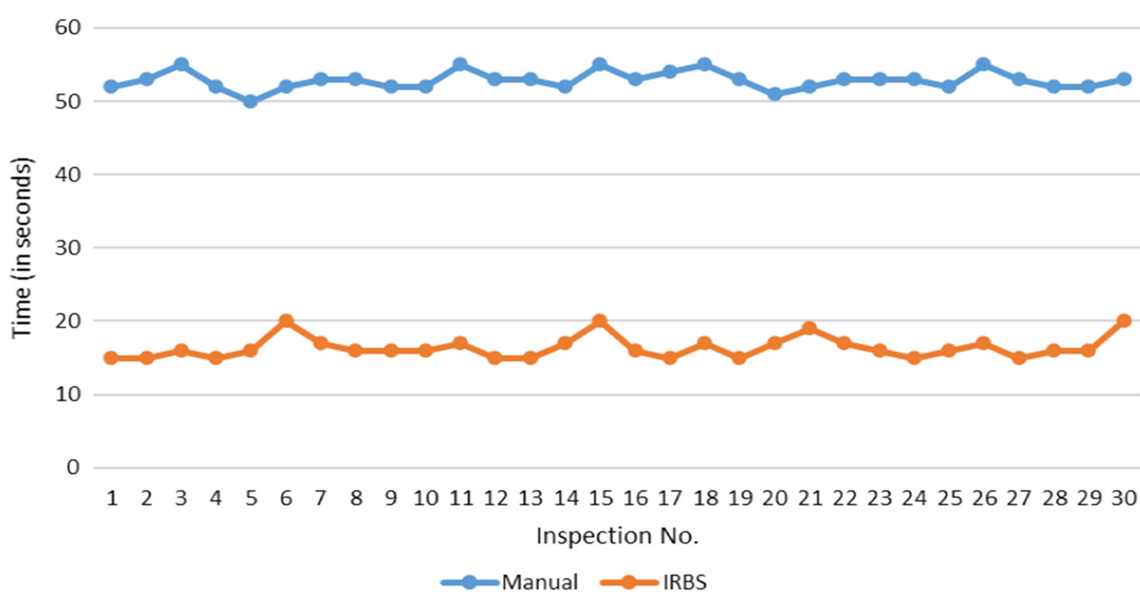

Fig. 10 Time required during manual process and IRBS model

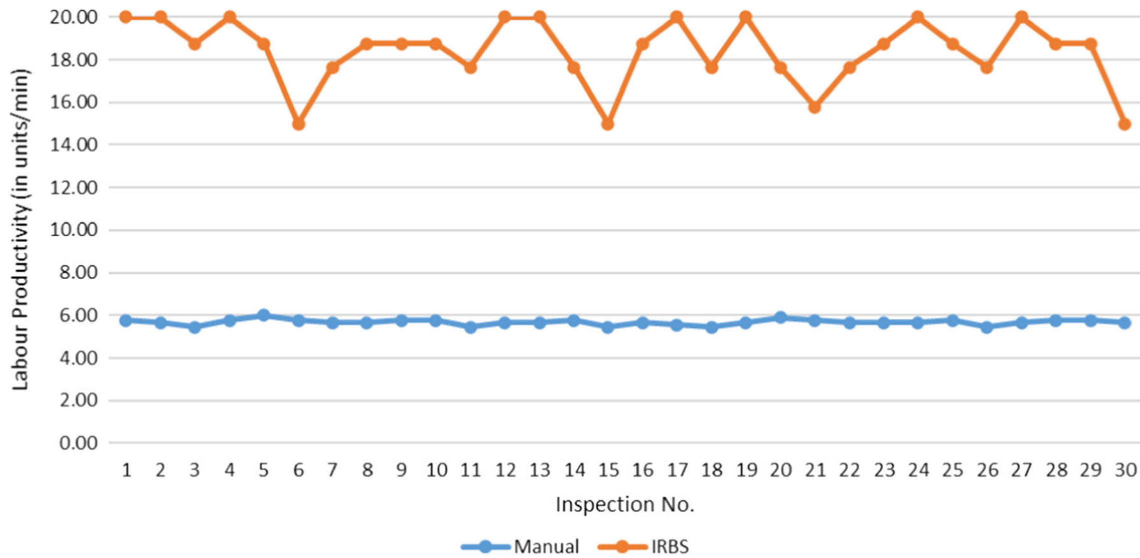

Fig. 11 Labour productivity during manual process and IRBS model

Table 3 Measurement by using IRBS versus manual measurement system

Parameters	Gear wheel number				
	01	02	03	04	05
Case 1: Measurement by using IRBS					
Inner diameter (mm)	24.2	24.4	24.2	24.6	24.0
Outer diameter (mm)	27.3	27.1	27.4	27.1	26.8
Number of teeth	12	12	12	12	12
Tooth height (mm)	1	1	1	1	1
Acceptance/rejection status	Accept	Accept	Accept	Reject	Accept
Time (per component) required for measurement	15 s to 20 s				
Case 2: Manual measurement system					
Inner diameter (mm)	24.5	24.5	24.0	24.5	24.0
Outer diameter (mm)	27.0	27.0	27.5	27.0	27
Number of teeth	12	12	12	12	12
Tooth height (mm)	1	1	1	1	1
Acceptance/rejection status	Accept	Accept	Accept	Accept	Accept
Time (per component) required for measurement	50–55 s				

diameter value = 27 ± 0.5 mm, (c) number of teeth = 12, and (d) tooth height = 1 mm. Table 3 shows measured values of parameters of manufactured gear wheels.

As shown in Table 3, it is found that the manual measurement system has given the final decision to accept the gear wheel number 04, but IRBS has recommended to reject it. To assure the reliability of the result for the gear wheel number 04, it was inspected again by using both the methods mentioned in Table 3. It was observed that values obtained for parameters of gear wheel number 04 by using a manual measurement system were different when compared to values obtained by using the same method during the first trial and recommended to reject the gear wheel number 04. But values obtained for parameters of gear wheel number 04 by using IRBS during both the trials were same. Therefore, it is concluded that results obtained by using IRBS are accurate and reliable as compared to a manual measurement system.

Also, it is observed that the time required for inspection by using IRBS is less when compared to a manual measurement system. Figures 6 and 7 shows comparison of inner diameter parameter values with maximum and minimum size, and comparison of outer diameter parameter values with maximum and minimum size, respectively.

5.1 Effects of IRBS model on performance of quality control department

IRBS model is implemented at Techno Measure Solutions, Pune, India. The said industry produces gears which are used in toys and supposed to be machined and inspected accurately. The industry uses manual sampling inspection process for gear's quality inspection. The average process accuracy of such process was found to be 90.67%. This was leading to risks at manufacturer's and customer's end. It is desired to achieve 100% process accuracy during manual sampling inspection process so that manufacturer's and customer's risks must be eliminated. Also, labour productivity of quality control department was found to be 5.69 units/min. Industry wanted to increase the labour productivity to the maximum value. Following are the reasons identified for the low process accuracy and labour productivity: (1) high instrument set up time, (2) high time for measurement, (3) complex instrument set up procedure, (4) the manual sampling inspection method, (5) the lack of standardization during inspection, (6) non-maintaining of ambient conditions as per standard norms during inspection, (7) the time of day, (8) lack of training to staff and unavailability of experienced staff.

5.1.1 Effects on parts rejection

After implementation of IRBS model number of parts rejection are reduced to zero. Hence, risk at manufacturer end is minimized. Figure 8 shows number of parts rejected during manual process and IRBS model.

5.1.2 Effects on process accuracy

It is observed that the process accuracy is increased due to the IRBS model as it is having minimum handling and processing by human. The average process accuracy is increased from 90.67 to 100%. Figure 9 shows process accuracy during manual process and IRBS model.

5.1.3 Effects on time required for inspection

Time required for inspection process is reduced significantly. The average time required for inspection of 05 samples is reduced from 53 to 16 s. Figure 10 shows time required during manual process and IRBS model.

5.1.4 Effects on labour productivity

It is observed that the average labour productivity is increased from 5.69 to 18.4 units/min. Figure 11 shows labour productivity during manual process and IRBS model.

6 Conclusions

In this research article, an image recognition-based method of identifying a defected work-piece is developed. The method includes extracting, by an imaging device, a plurality of parameters associated with a work piece under conveyance from an image of the work-piece captured by the imaging device and transmitting the plurality of parameters to a server. The method includes comparing, at the server, a plurality of parameters associated with the work-piece with a plurality of pre-determined parameters and transmitting a message to the controller. The method includes activating, by the controller, a mover for moving the work-piece to a container, based on the message received at the controller from the server, wherein the message indicates the work-piece is defected based on the plurality of parameters not matching with the plurality of pre-determined parameters. Trials are conducted on the developed IRBS model. Values of different parameters (such as inner diameter, outer diameter, number of teeth and tooth height) of gears are obtained. These results are compared with the manual measurement system. It has been found that results obtained using IRBS model are accurate and reliable. Therefore, the IRBS model has capability to minimize the consumer's and producer's risks. Also, time taken by IRBS model for inspection process is less in comparison with manual measurement system. The IRBS model eliminates the use of mechanical instrument systems which enhances the overall user experience during inspection process.

7 Current and future developments

IRBS model involves complex MATLAB programming. Therefore, skilled programmer is required to develop codes for the IRBS model. Also, different MATLAB programs are to be developed for different shapes and sizes. Performance of the IRBS model is fully dependent on light conditions and height of camera while inspection. Therefore, it is required to provide standard light conditions while inspection and provisions should be made to avoid unnecessary shadow on conveyor system. In the present research work, objects are placed manually on conveyor system of IRBS model. Future activities will focus on the development of the IRBS model with automatic placing mechanism.

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Declarations

Conflict of interest The authors declare no conflict of interest, financial or otherwise.

References

1. Bouslah, B., Gharbi, A., Pellerin, R.: Integrated production, sampling quality control and maintenance of deteriorating production systems with AOQL constraint. Omega **61**, 110–126 (2016). https://doi.org/10.1016/j.omega.2015.07.012
2. Safa, M., Soltani-Mohammadi, S., Kurdi, M.: Optimal design of additional sampling pattern for drinking-water quality control. Environ. Dev. Sustain. **19**(4), 1265–1278 (2017). https://doi.org/10.1007/s10668-016-9794-7
3. Sonawane, C., Alrubaie, A.J., Panchal, H., Chamkha, A.J., Jaber, M.M., Oza, A.D., Zahmatkesh, S., Burduhos-Nergis, D.D., Burduhos-Nergis, D.P.: Investigation on the impact of different absorber materials in solar still using CFD simulation—economic and environmental analysis. Water **14**(19), 3031 (2022). https://doi.org/10.3390/w14193031
4. Carmo, M., Infante, P., Mendes, J.: A different and simple approach for comparing sampling methods in quality control. Int. J. Qual. Reliab. Manag. **31**(5), 478–499 (2014). https://doi.org/10.1108/IJQRM-02-2012-0023
5. Oza, A.D., Kumar, A., Badheka, V., Arora, A., Kumar, M., Pruncu, C.I., Singh, T.: Improvement of the machining performance of the TW-ECDM process using magnetohydrodynamics (MHD) on quartz material. Materials **14**(9), 2377 (2021). https://doi.org/10.3390/ma14092377
6. Rusina, T.P., Carlsson, P., Vrana, B., Smedes, F.: Equilibrium passive sampling of POP in lipid-rich and lean fish tissue: quality control using performance reference compounds. Environ. Sci. Technol. **51**(19), 11250–11257 (2017). https://doi.org/10.1021/acs.est.7b03113
7. Tambe, P.P., Kulkarni, M.S.: A novel approach for production scheduling of a high pressure die casting machine subjected to selective maintenance and a sampling procedure for quality control. Int. J. Syst. Assur. Eng. Manag. **5**(3), 407–426 (2014). https://doi.org/10.1007/s13198-013-0183-4
8. Wang, D., Zhang, Y., Pan, Y., Peng, B., Liu, H., Ma, R.: An automated inspection method for the steel box girder bottom of long-span bridges based on deep learning. IEEE Access **8**, 94010–94023 (2020). https://doi.org/10.1109/ACCESS.2020.2994275
9. Kale, B.S., Bhole, K.S., Dhongadi, H., Oak, S., Deshmukh, P., Oza, A., Ramesh, R.: Effect of polygonal surfaces on development of viscous fingering in lifting plate Hele-Shaw cell. Int. J. Interact. Design Manuf. (2022). https://doi.org/10.1007/s12008-022-01030-9
10. Attard, L., Debono, C.J., Valentino, G., di Castro, M.: Tunnel inspection using photogrammetric techniques and image processing: A review. ISPRS J. Photogramm. Remote Sens. **144**, 180–188 (2018). https://doi.org/10.1016/j.isprsjprs.2018.07.010
11. Kim, H., Lin, Y., Tseng, T.L.B.: A review on quality control in additive manufacturing. Rapid Prototyp. J. **24**(3), 645–669 (2018). https://doi.org/10.1108/RPJ-03-2017-0048
12. Oza, A.D., Kumar, A., Badheka, V.: Improving quartz micromachining performance by magnetohydrodynamic and zinc-coated assisted traveling wire-electrochemical discharge machining process. Mater. Today Proc. **28**, 970–976 (2020)
13. Ammar, M., Haleem, A., Javaid, M., Walia, R., Bahl, S.: Improving material quality management and manufacturing organizations system through Industry 4.0 technologies. Mater. Today Proc. **45**, 5089–5096 (2021). https://doi.org/10.1016/j.matpr.2021.01.585
14. Pedone, G., Mezgár, I.: Model similarity evidence and interoperability affinity in cloud-ready Industry 4.0 technologies. Comput. Ind. **100**, 278–286 (2018). https://doi.org/10.1016/j.compind.2018.05.003
15. Liu, B., De Giovanni, P.: Green process innovation through Industry 4.0 technologies and supply chain coordination. Ann. Op. Res. (2019). https://doi.org/10.1007/s10479-019-03498-3
16. Pasi, B.N., Mahajan, S.K., Rane, S.B.: The current sustainability scenario of industry 4.0 enabling technologies in Indian manufacturing industries. Int. J. Prod. Perform. Manag. **70**(5), 1017–1048 (2020c). https://doi.org/10.1108/IJPPM-04-2020-0196
17. Pasi, B.N., Mahajan, S.K., Rane, S.B.: Strategies for risk management in adopting Industry 4.0 concept in manufacturing industries. J. Sci. Technol. Policy Manag. (2022). https://doi.org/10.1108/JSTPM-04-2021-0057
18. Pasi, B. N., Mahajan, S. K., Rane, S. B.: Enabling technologies and current research scenario of industry 4.0: A systematic review. In: Lecture notes in mechanical engineering, 265–273. (2020d) https://doi.org/10.1007/978-981-15-4485-9_28
19. Pires, F., Cachada, A., Barbosa, J., Moreira, A. P., Leitão, P.: Digital twin in industry 4.0: technologies, applications and challenges (2019)
20. Cimini, C., Pezzotta, G., Pinto, R., Cavalieri, S.: Industry 4.0 technologies impacts in the manufacturing and supply chain landscape: an overview. Stud. Comput. Intell. **803**, 109–120 (2019). https://doi.org/10.1007/978-3-030-03003-2_8
21. Sepasgozar, S.M.: Digital technology utilisation decisions for facilitating the implementation of Industry 4.0 technologies. Constr. Innov. **21**(3), 476–489 (2020). https://doi.org/10.1108/CI-02-2020-0020
22. Mubarak, M.F., Petraite, M.: Industry 4.0 technologies, digital trust and technological orientation: what matters in open innovation? Technol. Forecast. Soc. Change (2020). https://doi.org/10.1016/j.techfore.2020.120332
23. Surani, K., Patel, S., Alrubaie, A.J., Oza, A., Panchal, H., Kumar, S., Zahmatkesh, S.: Performance comparison of powder mixed EDM and traditional EDM on TZM-molybdenum super alloy using response surface methodology. Int. J. Interact. Design Manuf. (2022). https://doi.org/10.1007/s12008-022-01088-5
24. Vaishya, R., Sharma, V., Gupta, A., Pathania, J., Oza, A., Dixit, A.K., Bhole, K.S., Makwana, M., Patel, A.: Finite element modeling of quartz material for analyzing material removal rate in ECDM process. Int. J. Interact. Design Manuf. (2022). https://doi.org/10.1007/s12008-022-01037-2
25. Patel, V., Joshi, U., Joshi, A., Oza, A.D., Prakash, C., Linul, E., Campilho, R.D.S.G., Kumar, S., Saxena, K.K.: Strength evaluation of functionalized MWCNT-reinforced polymer nanocomposites synthesized using a 3D mixing approach. Materials **15**(20), 7263 (2022)
26. Gautam, N., Goyal, A., Sharma, S.S., Oza, A.D., Kumar, R.: Study of various optimization techniques for electric discharge machining and electrochemical machining processes. Mater. Today Proc. **57**, 615–621 (2022)
27. Oza, A.D., Kumar, A., Badheka, V., Arora, A.: Traveling wire electrochemical discharge machining (TW-ECDM) of quartz using zinc coated brass wire: investigations on material removal rate and kerf width characteristics. SILICON **11**, 2873–2884 (2019)

28. Kumar, M., Vaishya, R.O., Oza, A.D., Suri, N.M.: Experimental investigation of wire-electrochemical discharge machining (WECDM) performance characteristics for quartz material. SILICON **12**, 2211–2220 (2020)
29. Mahto, D.G., Singh, N.: Experimental study of process parameters through dissimilar form of electrodes in EDM machining. SSRN Electron. J. **1**, 31 (2017)
30. Singh, S., Singh, G., Prakash, C., Ramakrishna, S.: Current status and future directions of fused filament fabrication. J. Manuf. Process. **55**, 288–306 (2020)
31. Adamson, G., Wang, L., Holm, M., Moore, P.: Cloud manufacturing–a critical review of recent development and future trends. Int. J. Comput. Integr. Manuf. **30**(4–5), 347–380 (2017). https://doi.org/10.1080/0951192X.2015.1031704
32. Laskurain-Iturbe, I., Arana-Landín, G., Landeta-Manzano, B., Uriarte-Gallastegi, N.: Exploring the influence of industry 4.0 technologies on the circular economy. J. Cleaner Prod. (2021). https://doi.org/10.1016/j.jclepro.2021.128944
33. Singh, S., Prakash, C., Ramakrishna, S.: 3D printing of polyether-ether-ketone for biomedical applications. Eur. Polymer J. **114**, 234–248 (2019)
34. Bányai, T., Tamás, P., Illés, B., Stankevičiūtė, Ž, Bányai, Á.: Optimization of municipal waste collection routing: Impact of industry 4.0 technologies on environmental awareness and sustainability. Int. J. Environ. Res. Public Health (2019). https://doi.org/10.3390/ijerph16040634
35. Huang, C.J., Chicoma, E.D.T., Huang, Y.H.: Evaluating the factors that are affecting the implementation of industry 4.0 technologies in manufacturing MSMEs, the case of Peru. Processes (2019). https://doi.org/10.3390/PR7030161
36. Singh, G., Vasudev, H., Arora, H.: A short note on the processing of materials through microwave route. In Advances in materials processing: select proceedings of ICFMMP 2019 pp. 101–111. Springer, Singapore (2020b).
37. Balland, P.A., Boschma, R.: Mapping the potentials of regions in Europe to contribute to new knowledge production in Industry 4.0 technologies. Reg. Stud. **55**(10–11), 1652–1666 (2021). https://doi.org/10.1080/00343404.2021.1900557
38. Hopkins, J.L.: An investigation into emerging industry 40 technologies as drivers of supply chain innovation in Australia. Comput. Ind. (2021). https://doi.org/10.1016/j.compind.2020.103323
39. Pasi, B.N., Mahajan, S.K., Rane, S.B.: Redesigning of smart manufacturing system based on IoT: perspective of disruptive innovations of industry 4.0 paradigm. Int. J. Mech. Prod. Eng. Res. Dev. **10**(3), 727–746 (2020a)
40. Pasi, B.N., Mahajan, S.K., Rane, S.B.: Smart supply chain management: a perspective of industry 4.0. Int. J. Adv. Sci. Technol. **29**(5), 3016–3030 (2020b)
41. Dalmarco, G., & Barros, A. C.: Adoption of industry 4.0 technologies in supply chains. In: Contributions to management science (pp. 303–319). Springer. (2018). https://doi.org/10.1007/978-3-319-74304-2_14
42. Maghazei, O., Netland, T.: Implementation of industry 4.0 technologies: what can we learn from the past? IFIP Adv. Inform. Commun. Technol. **513**, 135–142 (2017). https://doi.org/10.1007/978-3-319-66923-6_16
43. Prakash, C., Kansal, H.K., Pabla, B.S., Puri, S.: Multi-objective optimization of powder mixed electric discharge machining parameters for fabrication of biocompatible layer on β-Ti alloy using NSGA-II coupled with Taguchi based response surface methodology. J. Mech. Sci. Technol. **30**, 4195–4204 (2016)
44. Gaub, H.: Customization of mass-produced parts by combining injection molding and additive manufacturing with Industry 4.0 technologies. Reinf. Plast. **60**(6), 401–404 (2016). https://doi.org/10.1016/j.repl.2015.09.004
45. Bosman, L., Hartman, N., Sutherland, J.: How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies. J. Manuf. Technol. Manag. **31**(5), 1117–1141 (2020). https://doi.org/10.1108/JMTM-09-2018-0283
46. Prakash, C., Singh, S., Pabla, B.S., Uddin, M.S.: Synthesis, characterization, corrosion and bioactivity investigation of nano-HA coating deposited on biodegradable Mg–Zn–Mn alloy. Surf. Coat. Technol. **346**, 9–18 (2018)
47. Dachs, B., Kinkel, S., Jäger, A.: Bringing it all back home? Backshoring of manufacturing activities and the adoption of Industry 4.0 technologies. J. World Bus. (2019). https://doi.org/10.1016/j.jwb.2019.101017
48. Margherita, E.G., Braccini, A.M.: Industry 4.0 technologies in flexible manufacturing for sustainable organizational value: reflections from a multiple case study of Italian manufacturers. Inform. Syst. Front. (2020). https://doi.org/10.1007/s10796-020-10047-y
49. Pasi, B.N., Mahajan, S.K., Rane, S.B.: A method for performing forging operation: a perspective of industry 4.0. Recent Pat. Mech. Eng. **14**(3), 423–435 (2021b). https://doi.org/10.2174/2212797614666210120110548
50. Shahin, M., Chen, F.F., Bouzary, H., Krishnaiyer, K.: Integration of Lean practices and Industry 4.0 technologies: smart manufacturing for next-generation enterprises. Int. J. Adv. Manuf. Technol. **107**(5–6), 2927–2936 (2020). https://doi.org/10.1007/s00170-020-05124-0
51. Pasi, B.N., Mahajan, S.K., Rane, S.B.: Development of innovation ecosystem framework for successful adoption of industry 4.0 enabling technologies in Indian manufacturing industries. J. Sci. Technol. Policy Manag. (2021a). https://doi.org/10.1108/JSTPM-10-2020-0148
52. Chiarvesio, M., Romanello, R.: Industry 4.0 technologies and internationalization: insights from Italian companies. Progress Int. Bus. Res. **13**, 357–378 (2018). https://doi.org/10.1108/S1745-886220180000013015
53. Ślusarczyk, B., Tvaronavičienė, M., Ul Haque, A., Oláh, J.: Predictors of industry 4.0 technologies affecting logistic enterprises' performance: International perspective from economic lens. Technol. Econ. Dev. Econ. **26**(6), 1263–1283 (2020). https://doi.org/10.3846/tede.2020.13376
54. da Costa, M.B., dos Santos, L.M.A.L., Schaefer, J.L., Baierle, I.C., Nara, E.O.B.: Industry 4.0 technologies basic network identification. Scientometrics **121**(2), 977–994 (2019). https://doi.org/10.1007/s11192-019-03216-7
55. Sishi, M., Telukdarie, A.: Implementation of industry 4.0 technologies in the mining industry-a case study. Int. J. Min. Miner. Eng. **11**(1), 1–22 (2020)
56. Prakash, C., Kansal, H.K., Pabla, B.S., Puri, S.: Processing and characterization of novel biomimetic nanoporous bioceramic surface on β-Ti implant by powder mixed electric discharge machining. J. Mater. Eng. Perform. **24**, 3622–3633 (2015)
57. Kerin, M., Pham, D.T.: A review of emerging industry 4.0 technologies in remanufacturing. J. Cleaner Prod. (2019). https://doi.org/10.1016/j.jclepro.2019.117805
58. Aliyu, A.A.A., Abdul-Rani, A.M., Ginta, T.L., Prakash, C., Axinte, E., Razak, M.A., Ali, S.: A review of additive mixed-electric discharge machining: current status and future perspectives for surface modification of biomedical implants. Adv. Mater. Sci. Eng. (2017). https://doi.org/10.1155/2017/8723239
59. Pradhan, S., Singh, S., Prakash, C., Królczyk, G., Pramanik, A., Pruncu, C.I.: Investigation of machining characteristics of hard-to-machine Ti-6Al-4V-ELI alloy for biomedical applications. J. Market. Res. **8**(5), 4849–4862 (2019)
60. Prakash, C., Kansal, H.K., Pabla, B.S., Puri, S.: Powder mixed electric discharge machining: an innovative surface modification technique to enhance fatigue performance and bioactivity of β-Ti

implant for orthopedics application. J. Comput. Inform. Sci. Eng. **16**(4), 041006 (2016)
61. de Giovanni, P., Cariola, A.: Process innovation through industry 4.0 technologies, lean practices and green supply chains. Res. Transp. Econ. (2020). https://doi.org/10.1016/j.retrec.2020.100869
62. Singh, G., Mehta, A., Bansal, A.: Electrochemical behaviour and biocompatibility of claddings developed using microwave route: review paper. J. Electrochem. Sci. Eng. **13**(1), 173–192 (2022). https://doi.org/10.5599/jese.1604
63. Silvestri, L., Forcina, A., Introna, V., Santolamazza, A., Cesarotti, V.: Maintenance transformation through Industry 4.0 technologies: a systematic literature review. Comput. Ind. (2020). https://doi.org/10.1016/j.compind.2020.103335
64. Zheng, T., Ardolino, M., Bacchetti, A., Perona, M.: The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. Int. J. Prod. Res. **59**(6), 1922–1954 (2021). https://doi.org/10.1080/00207543.2020.1824085
65. Singh, G., Singh, R., Gul, J.: Machinability behavior of human implant materials: original scientific paper. J. Electrochem. Sci. Eng. **13**(1), 99–114 (2022). https://doi.org/10.5599/jese.1514
66. Fettermann, D.C., Cavalcante, C.G.S., de Almeida, T.D., Tortorella, G.L.: How does Industry 4.0 contribute to operations management? J. Ind. Prod. Eng. **35**(4), 255–268 (2018). https://doi.org/10.1080/21681015.2018.1462863
67. da Xu, L., Xu, E.L., Li, L.: Industry 4.0: state of the art and future trends. Int. J. Prod. Res. **56**(8), 2941–2962 (2018). https://doi.org/10.1080/00207543.2018.1444806
68. Mehta, A., Singh, G.: Consequences of hydroxyapatite doping using plasma spray to implant biomaterials: review paper. J. Electrochem. Sci. Eng. **13**(1), 5–23 (2023). https://doi.org/10.5599/jese.1614
69. Vasudev, H., Singh, G., Bansal, A., Vardhan, S., Thakur, L.: Microwave heating and its applications in surface engineering: a review. Mater. Res. Express **6**(10), 102001 (2019)
70. Oesterreich, T.D., Teuteberg, F.: Understanding the implications of digitisation and automation in the context of Industry 4.0: a triangulation approach and elements of a research agenda for the construction industry. Comput. Ind. **83**, 121–139 (2016). https://doi.org/10.1016/j.compind.2016.09.006
71. Wu, D., Rosen, D.W., Schaefer, D.: Scalability planning for cloud-based manufacturing systems. J. Manuf. Sci. Eng. Trans. ASME (2015). https://doi.org/10.1115/1.4030266
72. Singh, G., Vasudev, H., Bansal, A., Vardhan, S.: Microwave cladding of Inconel-625 on mild steel substrate for corrosion protection. Mater. Res. Express **7**(2), 026512 (2020)
73. Liao, Y., Deschamps, F., Loures, E.D.F.R., Ramos, L.F.P.: Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. Int. J. Prod. Res. **55**(12), 3609–3629 (2017). https://doi.org/10.1080/00207543.2017.1308576
74. Singh, S., Prakash, C., Singh, R. (eds.): 3D printing in biomedical engineering. Springer, Berlin, Heidelberg (2020b)
75. Méndez, G.M., Montes Dorantes, P.N., Mexicano Santoyo, A.: Interval type-2 fuzzy logic systems optimized by central composite design to create a simplified fuzzy rule base in image processing for quality control application. Int. J. Adv. Manuf. Technol. **102**(9–12), 3757–3766 (2019). https://doi.org/10.1007/s00170-019-03354-5
76. Miao, Y., Jeon, J.Y., Park, G.: An image processing-based crack detection technique for pressed panel products. J. Manuf. Syst. **57**, 287–297 (2020). https://doi.org/10.1016/j.jmsy.2020.10.004
77. Vertoprakhov, V., Yew, T.P.: Object inspection system. USOO9140545B2 (2015).
78. Yannick, C., Klaus, S., Robert, C.: Illuminating device for cylindrical objects, surface inspection method implemented therewith and computer program product. US 20090290781A1 (2009).

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