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Machine Vision: An Important Pillar of Industry4.0

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ABSTRACT

This article focuses on machine vision system which is one of the most important pillars of the industry 4.0. It demonstrates the locations and role of basic elements that are: used in machine vision system and their applications. The paper presents basic structure of the machine vision system with functions of the elements. It gives sequence of general flow processes. The paper explains different types and applications of machine vision systems that are used in an industry 4.0.The paper also explains the evolution of industry from 1.0 to 4.0 and basic components involved in the evolution. Important pillars of the industry 4.0 with their meanings are presented in brief. The basic challenges in implementations of machine vision system are outlined.

Keywords: *Machine vision, Vision processing, Industry 4.0, Cyber physical systems, Internet of things.*

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1. INTRODUCTION

In this era, where the trade and technology have made the world into a more connected and interdependent place, where there has been interaction and integration among people, companies, and governments worldwide; industrial organizations are under immense pressure to introduce, establish, and upgrade their performance in this global market. To do this, the most powerful weapon used is digital technology; as it helps them enhance dynamically, make knowledge-oriented processes those are also cost specific, rationalize their business, increase automation, i.e. we can say that utilizing it to the maximum possible level. As a result, there are many industrial organizations that are investing on large scale in the digitization looking forward with the Moto of digital evolution. In this scenario, the term 'Industry 4.0' has been introduced. This introduction has signalized the "official" start of the fourth industrial revolution, which is based on the deployment and use of Cyber-Physical Systems (CPS) in industrial plants, as means of fostering the digitization, automation and intelligence of industrial processes. CPS systems facilitate the connection between the physical world of machines, industrial automation devices and operational technology (OT), with the world of computers, machine vision, cloud data canters and Information Technology (IT) [1,2].

Machine vision is the eye of the industrial automation. It is the technology and methods used to provide imaging-based automatic inspection and analysis for such applications as automatic inspection, process control, and robot guidance, usually in industry [3]. It also includes computer vision i.e. a field of artificial intelligence that trains computers to interpret and understand the visual world. With speedy expansion in many different fields including imaging techniques; CMOS sensors; embedded vision; machine and deep learning; robot interfaces; data transmission standards and image processing capabilities, vision technology can benefit the manufacturing industry at many different levels. New imaging techniques have provided new application opportunities. For example, application of MRI and Doppler ultrasound to this group of patients has revealed important insights into disease processes in rheumatoid arthritis, identifying previously concealed processes that cannot be viewed with conventional imaging. Other developments in machine vision technology lead to enhanced performance, integration, and automation in the manufacturing industry. The degree of integration can range from manual assembly assistance through to complete integration into OEM equipment and on the demanding requirements of Industry 4.0.

2. EVOLUTION OF INDUSTRY FROM 1.0 TO 4.0

Not of a sudden, but Industry 4.0 has evolved from the three of its previous industrial revolutions since 17th century that the world has experienced and even does now and thus it came into existence. So, let's first acknowledge step-by-step how it came into being. S.I. Tay et al., given different definitions and explained various characteristics of industry 4.0 [4]. Andreja Rojko has explained origin and production system of industry 4.0 [5].

2.1 The First Industrial Revolution

The first industrial revolution happened between the late 1700s and early 1800s. It is the process of change from handicraft thrift to industry and machine manufacturing. This evolved from manual and animal labour replaced by the usage of basic materials, chiefly iron and steel; energy sources, including both fuels and motive power; invention of new machines, such as the spinning jenny and the power loom; important developments in transportation and communication, including the steam locomotive, and the increasing application of science to industry. These technological changes made it possible to tremendously increase the use of natural resources with the mass production of manufactured goods.

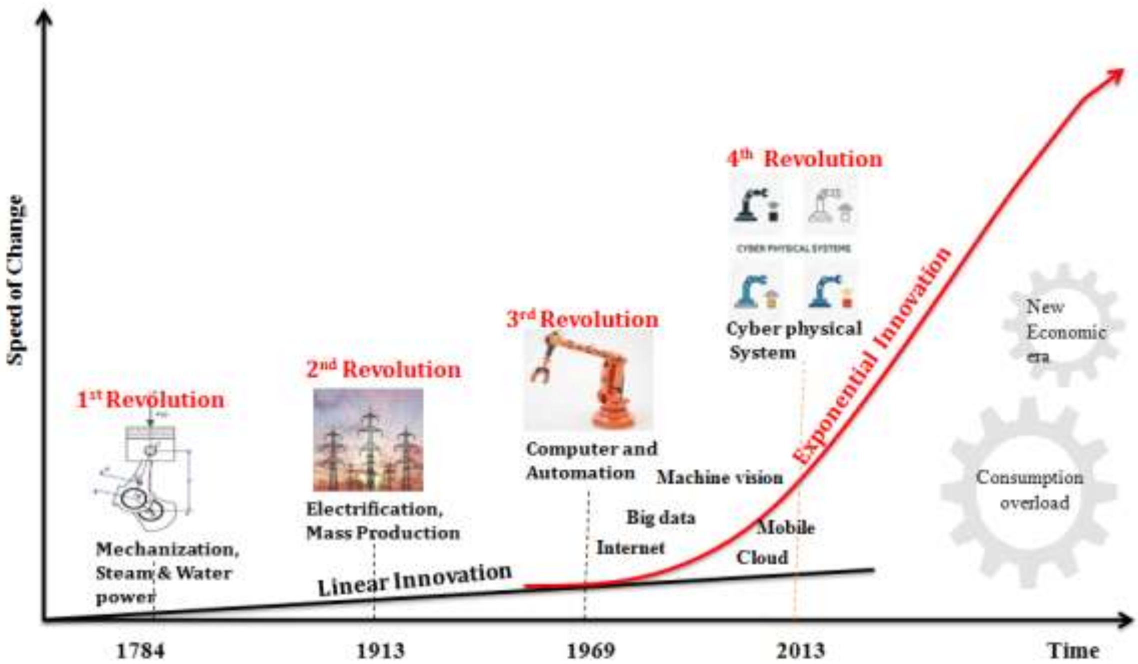

Figure 1: Display Speed of evolution of industry from 1.0 to 4.0

2.2 The Second Industrial Revolution

The second industrial revolution happened between the late 1900s and early 2000s.It was this period in which new technological systems were introduced, most significantly electrical power and telephones. It also was the period during which modern organizational methods for operating large scale businesses over vast areas came into use. This era also emerged with the birth of modern ship as different technologies came together. Thus, this was the phase of rapid standardization. Figure 1, shows the nature and major components involved in the evolution of industry from 1.0 to 4.0. We can see that the speed of change of evolution is slightly increasing till the end of 3nd revolution and it increases exponentially after that.

2.3 The Third Industrial Revolution

The third industrial revolution took place in the beginning of 1950s. It was the period when digital technologies replaced the things that were analog. This digital revolution brought semiconductors, mainframe computing, personal

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computing, and the Internet. Electronics and information technology began to automate production and take supply chains global.

2.4 The Fourth Industrial Revolution

From recent few decades, Industry 4.0 i.e. the fourth industrial revolution started. It is so characterized that it is blurring the lines between the physical, digital, and biological spheres by a fusion of technologies. This revolution emerges the fields such as artificial intelligence, robotics, the Internet of Things, autonomous vehicles, 3-D printing, materials science, energy storage, and quantum computing because of which it is possible that the of billions of people will be connected by mobile devices, with unprecedented processing power, storage capacity, and access to knowledge, and that will be unlimited. Thus, we can say that this is the era in which these new technological innovations, with its applications and progress is instantaneously going to bring drastic changes all over the globe Before digging too much deeper into the what, why, and how of Industry 4.0, it's beneficial to first understand how exactly manufacturing has evolved since the 1800s. There are four distinct industrial revolutions that the world either has experienced or continues to experience today.

2. IMPORTANT PILLARS OF INDUSTRY 4.0

To create faster, more flexible and efficient processes, the fourth Industrial revolution promotes the union of physical and digital resources, connecting machines, systems and assets as a way to produce higher quality items at reduced costs.

Following are the important pillars of Industry 4.0 and their relevance to industrial activity:

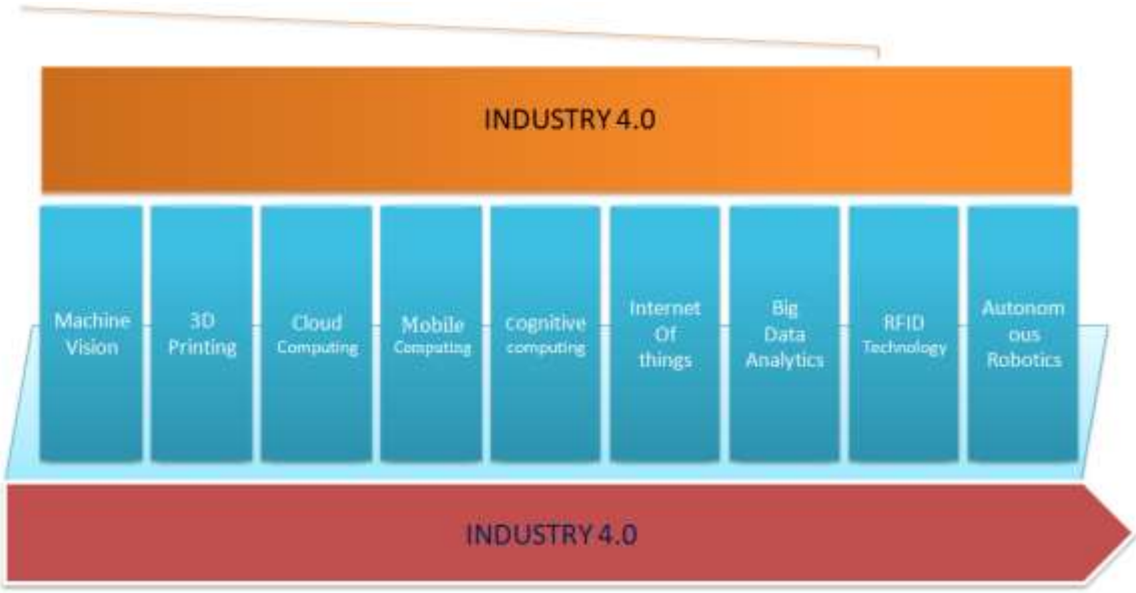

Figure 2 : Display of important pillars of industry 4.0

- **Machine Vision:** encompasses all industrial and non-industrial applications in which a combination of hardware and software provide operational guidance to devices in the execution of their functions based on the capture and processing of images.
- **3D Printing:** these technologies are already playing an important role in key areas as design, prototyping and low-volume production.
- **Cloud Computing:** provides scalable storage and increased computing power, improves data accessibility and integrity, helping to eliminate data silos.
- **Mobile Computing:** technology that allows transmission of data, voice and video via a computer or any other wireless enabled device without having to be connected to a fixed physical link.
- **Cognitive Computing:** the use of computerized models to simulate the human thought process in complex situations...
- **The Internet of Things:** refers to the networking and connectivity of smart devices.

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- **Big Data Analytics:** common theme among all of these pillars and new technologies is data collection and analysis.
- **Radio-frequency identification (RFID):** the use of radio waves to read and capture information stored on a tag attached to an object.
- **Autonomous Robot:** have the ability to gain information about their environments, and work for an extended period of time without human intervention

3. MACHINE VISION ELEMENTS

Machine vision systems consist of several elements. Although each of these elements serves its own individual function and can be found in many other systems, when working together they each have a distinct role in a machine vision system. Machine vision systems can be comprised of discrete elements or may be integrated together into one unit such as a smart camera that combines the functions of the individual elements into a single package. Some of the important elements of the machine vision system are explained in following paragraphs. Tushar Jain et al., presented overview of machine vision system and its applications [6]. Vlastimil Hotar explained the fundamentals of machine vision system processing [7].

3.1 Lighting

The selection of lighting for use in a machine vision system should be made with the goal of maximizing the contrast for whatever features are of interest to be measured or observed while minimizing the contrast of all other features of the part. Achieving this goal may require varying the amount of light used (intensity), the style of lighting and the placement of the light source relative to the part and the optical system or camera. Altering these basic parameters can markedly improve a machine vision system's ability to consistently identify and measure the part feature(s) being monitored. Lighting options include light emitting diode i.e. LED lighting and strobe lights for capturing images with fast shutter speeds.

3.2 Optical System

The optical elements in a machine vision system are typically a lens or a camera, which integrates the lens with other elements such as the sensor. The lens selection will establish the field of view, which is the two-dimensional area over which observations can be made. The lens also will determine the depth of focus and the focal point, both of which will relate to the ability to observe features on the parts being processed by the system. Lenses may be interchangeable or may be fixed as part of some designs that use a smart camera for the optical system. Lenses that have a longer focal length will provide higher magnification of the image but will reduce the field of view. The selection of the lens or optical system for use is dependent on the specific function being performed by the machine vision system and by the dimensions of the feature under observation. Colour recognition capability is another characteristic of the optical system element.

3.3 Sensor

Sensors used in machine vision systems serve to capture the light from the optical system and convert that into a digital image. Sensors use Complementary Metal Oxide Semiconductor (CMOS) or charged-coupled device (CCD) technology to capture the light and convert that to a set of pixels that show the presence of light in the different areas of the original part being observed. Sensors are measured by their resolution, which is an indication of the number of pixels available in the digital image. Sensors that have higher resolution can produce images with more pixels, which generally translate to more image quality and a greater ability to resolve details. The resolution of the sensor is related to the sizes of the parts being observed, the dimensions of the measurements being made, the tolerances of those measurements, and other application parameters. Higher resolutions will increase the accuracy of measurements made by the machine vision system.

3.4 Vision Processing

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The vision processing element of the machine vision system takes the data from the digital image and uses software to perform specific functions that are then used to evaluate the part under observation. These evaluations are pre-programmed conditions that define the acceptance and rejection criteria for the part being observed. The steps performed by the vision processing system include: acquiring the digital image from the sensor; pre-processing the image as needed to optimize it for measurements; analysing the image to locate the specific features of the part that need to be measured or observed; collecting measurements of the needed features and comparing those values against the defined dimensional criteria for that feature and establishing a result, usually as a pass-fail or go/no-go condition for that part.

3.5 Communications

Once the vision processing element has completed its steps, the last element in the machine vision system involves the communications protocol. The purpose of this element is to provide a usable output in a standardized format that can provide a usable signal to drive other components in the production process based upon the output from the vision processing system. Standardized outputs include discrete I/O signals or serial data such as RS-232 or Ethernet sent to a logging device or other system that will make use of the data. A discrete I/O signal may be fed to a PLC that will use that to light a stack light, or power solenoid driven actuator to move a rejected part out of the main production pathway. A serial RS-232 data feed might be fed to the human machine interface i.e. HMI screen to display information to an operator overseeing the production process. System integrators can assist with the process of embedding communication signals between machine vision systems and other machines in the production cell [8]. Figure 3, presents the general processes with sequence of information flow that are used in machine vision system.

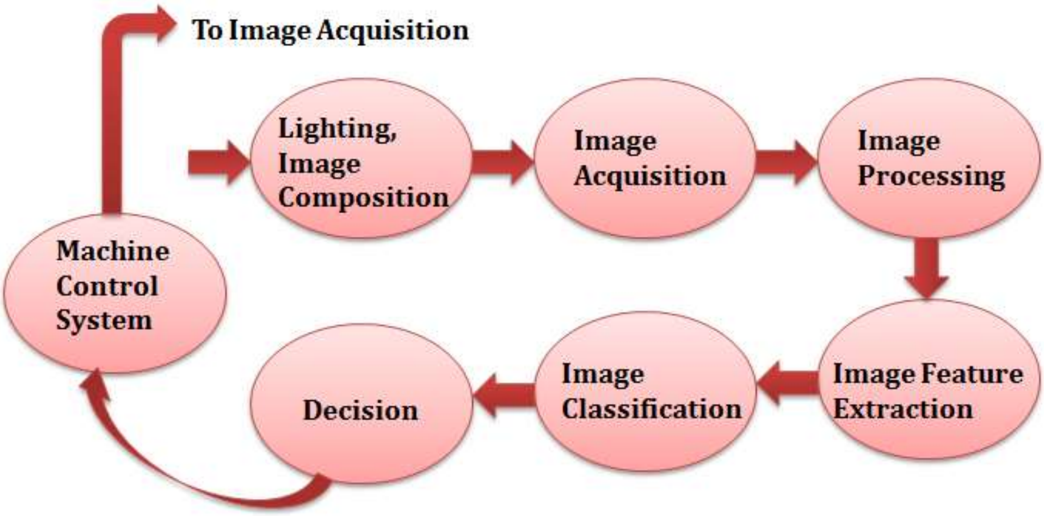

Figure 3: General process flow of machine vision system

4. MACHINE VISION WORKING

Figure 4, shows a general block diagram of a vision system. A machine vision system enables a computer to identify access and evaluate still or moving images. It is a field in computer vision that provides automatic image capturing, evaluation and processing capabilities. It basically consists of digital cameras and back-end image processing hardware and software. Depending on the design and the necessity of the machine vision system, the captured images are either stored or processed. Now, for implementing the vision system lighting and presentation of the object to be evaluated is very important task. It has great impact on system repeatability, reliability, and accuracy. Lighting source and projection should be chosen such that it accentuates the key features of the object, and gives sharp contrast and detail of the image. The specular reflections by small angle lighting and other techniques which provide diffused reflection should be avoided. Image sensor usually comprises of a TV camera, which may be camera which has greater resolution and low in cost, or it may be solid state camera CCD or charge injection device (CID). The solid state cameras have greater geometric accuracies, no image lag, and longer life. Image digitizer is usually a six to eight bit analog to digital A/D converter which is designed to keep up with the flow of video information from camera and store the digitized image in memory

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For simple processing, analog comparator and a computer controller threshold to convert the video information to a binary image is used. The binary images (having only two values for each pixel) are much simpler and facilitate high speed processing. However grey scale images contain a great deal more picture information and must be used for complex images with subtle variation of grey level across the image. Feature extractor/data compactor employs a high speed array processor to provide very high speed processing of the input image data. To generate a relatively simple feature data set, pattern recognition algorithms need to be implemented. System control computer communicates with the operator and makes decisions about the part being inspected.

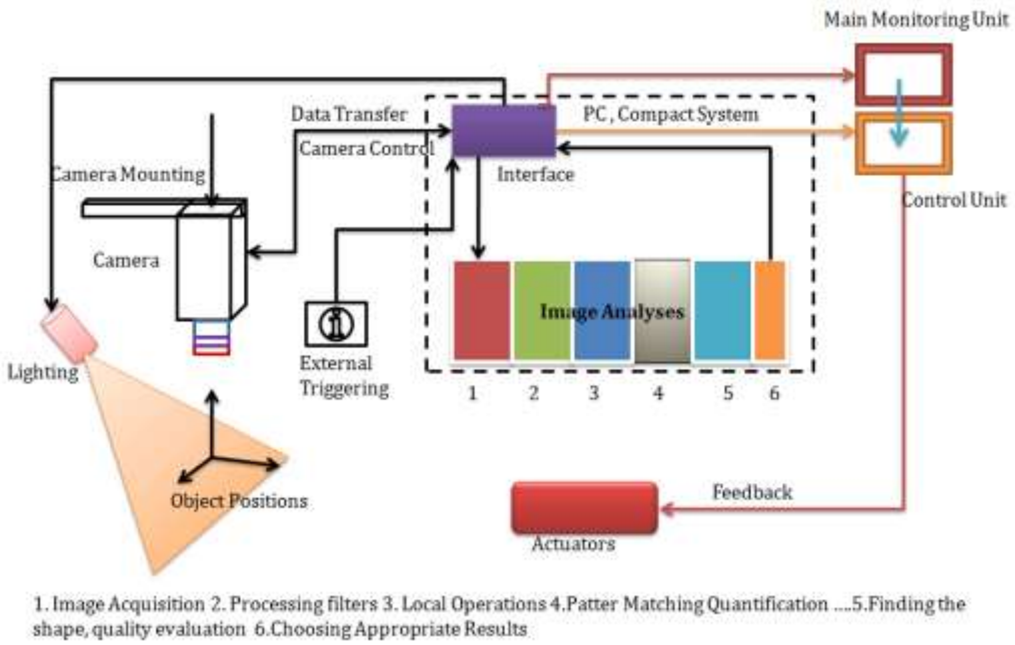

Figure 4: General layout of Machine vision system

These decisions are usually based on some simple operations applied to the feature data set representing the original image. The output and peripheral devices operate under the control of the system control computer. The output enables the vision system to either control a process or provide position and orientation information two a robot, etc.

5. MACHINE VISION TYPES

5.1 1D Machine Vision

1D vision analyses a digital signal one line at a time instead of looking at a whole picture at once, such as assessing the variance between the most recent group of ten acquired lines and an earlier group [9]. This technique commonly detects and classifies defects on materials manufactured in a continuous process, such as paper, metals, plastics, and other non-woven sheet or roll goods.

5.2 2D Machine Vision

In the case of a pure 2D machine vision system, the target object image acquired for processing is effectively a flat, two-dimensional plan view. The 2D image does not provide any height information at all. There is only X and Y data, but no Z-axis depth of field data. In 2D imaging, the analysable scene is captured either by area camera or by scanning using a line scan camera. The image produced is either in intensity values (monochrome) or colour (RGB values). Lighting is one of the most important factors in capturing this images. 2D vision is perfect for applications with high contrast, or when the texture or colour of the object is the key to the solution.

As a result, 2D (either area scanning or line scanning) machine vision systems are used extensively throughout the industry in a wide range of tasks. These include: verification of features and position, dimension checking, barcode reading, character recognition, label verification, quality inspection, surveillance and object tracking, etc.

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5.3 3D Machine Vision

3 D machine vision provides efficient, cost-effective solutions where 2D machine vision cannot. 3D machine vision systems typically comprise multiple cameras or one or more laser displacement sensors. There are several varieties of 3D machine vision systems. In stereo systems capture 3D information by using two cameras displaced horizontally from one another. Each camera images slightly different projections of the object being viewed. It is then possible to match a set of points in one image with the same set of points in the second image – a task known as the correspondence problem. By comparing these two images, relative depth information can then be computed and represented in the form of a disparity map. In this map, objects that are closer to the stereo camera system will have a larger disparity than those that are further away. Before such 3D depth information can be accurately obtained it is necessary to calibrate the stereo imaging system.

As a result of this much-extended capability, 3D machine vision is being applied to a broad spectrum of tasks where 2D capability falls short, including amongst many: Thickness, height and volume measurement; dimensioning and space management; measuring shapes, holes, angles, and curves, detection of surface or assembly defects; quality control and verification against 3D CAD models, robot guidance and surface tracking, bin picking for placing, packing or assembly; object scanning and digitization, etc.

6 MACHINE VISION *INDUSTRIAL APPLICATIONS AND CHALLENGES*

6.1 Industrial Applications

The applications for machine vision systems are widespread and cross many types of industries. Table 1, shows general examples of applications of machine vision system in different industrial settings to provide a sense of the diverse nature of the system.

Table 1: General application areas of machine vision

Type	*Industry*	*Machine vision application areas*
A	*Automotive Manufacturing*	▪ *Guiding assembly or welding robots* ▪ *Verifying orientation of parts* ▪ *Counting the number of welds* ▪ *Checking for surface defects prior to painting*
B	*Electronics*	▪ *Verifying the shape and position of connector pins Parts selection and orientation for robotic pick & place Systems* ▪ *Checking for solder connection issues or other conditions on PCBs* ▪ *General inspection of manufactured components such as LEDs*
C	*Food and Packaging*	▪ *Verifying the seal integrity on bottles* ▪ *Validating labelling, packaging and lot numbers* ▪ *Checking the fill levels on a product* ▪ *Detecting the presence of tamper-proof safety seals*
D	*General Manufacturing*	▪ *Verifying the correct part orientation for automated assembly operations* ▪ *Establishing the integrity of an adhesive bead or gasketing material* ▪ *Monitoring of plastic injection moulding processes*
E	*Semiconductors*	▪ *Inspecting wafers and masks using deep ultraviolet wavelength light (DUV.*

Machine Vision can also be applied in manufacturing industries as:

Machine vision and artificial intelligence blend together the benefits of business as they are penetrating almost every sector over the globe be it is processing social media traffic or trying to surface actionable insights or targeting

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consumers based on past purchases. Predictive maintenance, package inspection, reading barcodes, product and components assembly, defect reduction, 3d vision inspection, improving safety all of these are some of its examples.

Predictive maintenance is the technique used to determine the actual condition of the working equipment's so as to know whether their maintenance is required or not. It is the process of using machine learning and IoT devices to monitor data on machinery and components, often using sensors, to collect data points and identify signals or take corrective actions before assets or components break down. Just one minute of downtime in an automotive factory can cost very high. It challenges like machine vision can help business keep on top of, for example, a software program called ZDT (Zero Down Time), developed by FANUC, collects images from cameras attached to robots, these images and accompanying metadata are then sent to the cloud for processing and helps to identify potential problems before they arise.

A solution that involves using computer vision to check for broken or partially formed tablets is found out for the problems faced by pharmaceutical companies to count tablets or capsules before placing them into containers. The PC based Vision Inspection system is also implemented to a PC that performs the counting function and if a tablet is deemed as defective, this information is logged which then sends a signal to the counting functioning, and by the time the bottle of containers reaches the end of production line, containers that have defective tablets are then rejected, thereby removing the possibility of shipping defective medical tablets.

For any company or businessman it is the main goal to achieve defect free products. Thus Machine Vision can also be used to solve this problem of defect reduction. A firm named Shelton has a surface inspection system called Web spector that identifies defects and stores images and accompanying metadata related to the image. As items fall through the production line, defects get classified according to their type and are assigned an accompanying grade.

It also has a huge role in machine vision inspection. These inspection machines are well equipped with cameras that are used to know, verify whether the parts are in correct position or not. Vision systems can also assist robotic systems to obtain the positioning of parts to further automate and streamline the manufacturing process. A machine vision inspection system that contains a Dalsa Genie Nano camera is being used in a production line to take over the tasks that maybe difficult for humans. In this use case, the system uses high-resolution images to build up a full 3d model of components and their connector pins.

For improving safety, German firm ISW has found out a solution for the problem of tracking, tracing and verification of products from the production line to the end patient. For the packages to be tracked world-wide cartons can be printed with some details; also a globally unique identifier, oftenly, called a GTIN (Global Trade Item Number) is used. Manufacturing systems can auto generate these identifiers in a master database which are then used later in the production process and sprayed onto containers and the next step of the production process can be performed, which often is the verification of the information that was just sprayed onto the carton on the packaging. Here comes the solution for this verification that involves, high-tech cameras that can read data from labels – as well as perform optical character recognition (OCR) to read the printed text. When the printed text has been read, the system can check against the master database and validate if the system printing labelling matches the data stored in the master database. If any printed codes are unreadable or don't match existing codes in the master database, then packages or cartons can be rejected [10-13].

6.2 Challenges

With time; overcoming the problems, solutions are becoming easy but still they are few challenges faced by machine vision and those are as follows:

Placement of camera is one of the issues. If camera is not placed correctly one will have to face lightening and background issues, i.e. imaging sensors are not as sensitive as the human eye so it becomes difficult to take a digital photo in low light. Background of an image highly influences its easy detectivity. The perfect background should be black, the colour and brightness of the background should also be different from that of object. If these two things are improper the vision sensor won't be able to detect object appropriately. It also gives rise to another issue of Occlusion

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i.e. it may happen that a part of object is missing rather cannot be detected by the vision sensor and is missing in the image.

Detection of the position and orientation of object is also one of the challenges faced by the robot machine vision. Its detection is easy only if the object is completely viewed within the camera. Further if the object is not in its desired shape because of deformation or if moving joints changes the outline of object keeping its individual links same because of articulation, it becomes difficult for some robotic vision techniques. As the digital imaging sensors capture the image over a short period of time, they do not capture the whole image instantaneously. If an object is moving too quickly during the capture, it will result in a blurry image. Our eyes may not notice the blur in the video, but the algorithm will. Robot vision works best when there is a clear, static image. Thus movement matters [14].

7 CONCLUSIONS

This paper has been written with the aim to give the information about stages of evolution in industry and the role of machine vision as one of the important pillars in industry 4.0.The machine vision is called as the eye of the digital industries. Machine vision systems are a set of integrated components that are designed to use information extracted from digital images to automatically guide manufacturing and production operations. The paper shows the basic elements needed to structure the machine vision system and their locations in the structure. It shows the sequence elements and flow of information within the system. The paper gives information about the types of machine vision system and their applications in industries. There are certain limitations and also challenges for the implementation of the system. However, initially by setting up the proper environment and selecting the appropriate system elements, the full proof machine vision system can be designed and implemented with minimal cost and that is the strong feature of the system. The machine vision system can be implemented in all types of industries including core manufacturing to sales, services, marketing, securities, etc. Considering the scope and widespread applications of machine vision system, it becomes as an important pillar of the industry 4.0.

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