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The Basics and Significance of Industrial Robots in Manufacturing: A Review

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Abstract: *The aim of the review is to present easily readable and understandable integrated basic information on industrial robots for ready availability and consultation by concerned students, researchers, manufacturers, careerists, and potential users who lack basic knowledge of the robots and need resources to better the knowledge. The review covers applications, advantages, challenges, structural components, types, and leading manufacturers of industrial robots. The review importantly shows that industrial robots are made in various types that can be exploited to reliably improve productivity, quality, safety, and flexibility in manufacturing processing which cannot be realized with the conventional fixed automation structure. The review also shows that industrial robots have far more advantages than disadvantages and they are increasingly used in many industries such as automotive, electrical and electronics, and metals and machinery to replace manual labor in typical manufacturing processes such as packaging and labeling, soldering, welding, painting and spraying, picking and placing, assembling, disassembling, inspection and testing, dispensing, palletizing, etc. One important finding from the review is that, usage extents of industrial robots in different industries and countries are highly correlated to industrial and national productivity output levels across the globe and there is remarkable difference in industrial productivities and economies of developing countries especially African countries where the robots are hardly used and their counterparts where the robots are used considerably in industries. The paper contributes to knowledge about industrial robots, as state-of-art automation structural systems that are crucial for manufacturing in any industry or economy that wants much greater advantages and global competitiveness in our today's era of complex industrial processing.*

Keywords: *Manufacturing, Robotic technology, Applications, Advantages, Implementation, Challenges, Knowledge*

INTRODUCTION

An industrial robot is a programmable and reprogrammable technological structural system with either fixed or mobile capabilities in three or more axes for use in industrial automation to effectuate various manufacturing processes with much greater efficiency, speed, consistency, and reliability than human labor (Hägele *et al*, 2007; IFR, 2020; Gopinath, 2019). There are many categories of robots for application in different specialist areas of human activities. The common categories of robots include military robots, domestic robots, space exploration robots, industrial robots, fishing robots, medical robots, and entertainment robots. Robots used in industries are today by far the largest commercial application of all the robot categories (Langa, 2018). Industrial use of robots dates back over five decades ago and is presently the most advanced way of automating manufacturing processes (Banerjee, 2017; Thomasnet, 2021). Robots are used in many types of industries such as automotive, electrical and electronics, rubber, plastics, metals and machinery, precision engineering and optics, material handling, food and beverages, pharmaceuticals and cosmetics, foundry, ceramics and stones, paper and printing, and wood; to perform different manufacturing tasks. The usual manufacturing tasks that robots perform in industries include packaging and labeling, soldering, welding, painting and spraying, picking and placing for printed circuit boards, assembling, disassembling, inspection and testing, dispensing, palletizing, machine tending, surface finishing, and material handling (Stevens, 2019; Sanneman *et al*, 2020; Guma, and Akporhuarho, 2021).

Robots used in industrial processing are of various types or classes. They are increasingly used for the purposes of maximizing manufacturing output, minimizing idle time and product cost, improving product consistency and quality and delivery, and eliminating labor-intensiveness; and physical strain or injury to workers in industrial activities. The greater use of robots for industrial processing stems from their abilities to repetitively carry out manufacturing tasks with consistent accuracy, high endurance and durability, speed, and reliability (Banerjee, 2017; PAT, 2021). Another reason for increasing usage of industrial robots is their programmability, and re-programmability to adapt them to new desired manufacturing tasks and flexibility or smartness by computer control to deal favorably with many strange situations in their dedicated tasks. These make robots based industrial automation better and more preferable in many manufacturing tasks today than the conventional hard automation structures. This could be the main reason why many manufacturing outfits are nowadays using the technological option of employing industrial robots for manufacturing processing in preference to the conventional hard industrial automation systems (Atkinson, 2019; Guma, 2021). Although robotic and other automation technologies fill the need for greater precision, reliability, flexibility, and production output in our increasingly competitive and complex manufacturing industry environment; a greater number of industries or manufacturers still stick to exploiting conventional industrial technologies without venturing into or exploring the automation technologies due either to implementation costs, and/or lack of awareness on benefits and other dimensions of the automation technologies (Banerjee, 2017; Atkinson, 2019; Guma, 2021).

The applications extents of robotic and other automation technologies vary in different industries and countries, and are highly correlated to variation in industrial and national productivity output levels across the globe. The general global average level of industrial automation is presently still low (Atkinson, 2019; IFR, 2020a). There is also remarkable difference in the economies of developing countries especially African countries where industrial robots are hardly applied and their counterparts where robots are greatly applied in industries. Countries such as China, United States, Japan, United Kingdom, South Korea, and Germany are known leaders in manufacturing activities because of their greater use of automation technologies especially robotics in manufacturing activities compared to other nations.

It has been reported that less than 1% of manufactured industrial robots in the world have been sold to the African markets with no specifications of the buyer countries, in the market annals of the robots; while the percentage number sold to even one of the most productive nations in the world such as China even in a year is several times much higher than the percentage sold to all African countries in the market annals (Atkinson, 2019., De Backer, 2018). The bulk of countries with low industrialization levels and where industries face more challenges in transitioning to application of automation technologies are in developing countries especially in Africa. Nigeria is the largest economy in Africa but the country's industrial base and development has remained very low over the years of her nationhood. The stagnant growth rate of the Nigerian manufacturing sector and those of other developing economies is a sign that they need to radically upgrade their existent industrial infrastructures to modern standards to be able fit into the present global manufacturing competitiveness (Aririguzo and Agbaraji, 2016; Atkinson, 2019; Guma, and Akporhuarho, 2021). The aim of this paper is to present reviewed basic literatures covering aspects of applications, advantages, challenges, structural components, types, and leading manufacturers of industrial robots as integrated information for ready availability and consultation by concerned students, researchers, careerists, manufacturers, and potential users particularly in developing countries who lack basic knowledge on the subject but need the information to better the knowledge towards applications.

METHODOLOGY

2. Review

Information presented in the review was gotten from various literary sources as it concerns industrial robots within the scope of the study with attempt to fine-tune and combine facts from the sources in a simpler way for easy reading and understanding. Three installed industrial robots at Nigerian Breweries Plc factory in Kaduna metropolis were also surveyed while in service operations at the factory (Guma, and Akporhuarho, 2021), to practically witness some the issues from the literatures for their fine-tuning.

2.1 Components of Industrial Robot

Industrial robots are designed and constructed to possess certain anthropomorphic characteristics and capability to automatically adapt to changes during operation to perform various industrial tasks with decision-making, communication ability with other machines, and response to sensory inputs. For such functioning; the robots are designed and constructed of five main components which are the controller, sensors, arm, end effectors, and drive.
The robot controller is a dedicated digital computer that is connected to the robot and serves as its brain. The controller is an essential component of the robot without which it cannot operate. The controller component is essential for instructing the robot on how to operate through a program. Robotic programs are inputted into the controller through the use of a teach pendant. Once the program is inputted to the controller, it sends the program information to the robot's central processing unit (CPU). The CPU is a small chip located within the robot that allows the robot to process and run the program (Banerjee, 2017., MHI, 2020; Thomasnet, 2021).

The purpose of the sensors component is to acquire data relating to the internal status of the mechanical system as well as the external status of the work environment and provide the robot with feedback about their workspace to allow the robot to dynamically adapt to its work environment by sending signals to its CPU for requisite control action. The common types of sensors used in industrial robots include vision systems and microphones to act as eyes and ears of the robots.

Through the sensors; an industrial robot interacts with the physical world by measuring physical parameters like temperature, pressure, heat, infra red waves, radio waves, etc and provides feedbacks from the real world to the embedded electronics digital world which are processed for the robot to act accordingly (Thomasnet, 2021). The arm which is also called the manipulator is an essential component of majority of industrial robots. The arm is used in positioning the robots' end effectors. The structures of robot arms vary in terms of how far they can reach and the payloads they can handle. Robot arms are designed in various sizes and shapes to mimic the human arm with shoulder, elbow, and wrist like parts. The shoulder is linked to the mainframe of the industrial robot. The robot arm elbow flexes as it moves and the wrist performs the actual task. The arm is a component the robot uses to position its end effectors correctly in order to perform an application. Most industrial robots have 6 axes for a range of motion that is similar to a human's arm and each part of the robot arm serves as an individual degree of freedom or axis (Thomasnet, 2021). End effectors are the components that can be attached to the end of a robot arm to give the arm more dexterity and make it better suited for specific tasks in functioning as the robot's hand. Robotic end effectors are also referred to as end of arm tooling (EOAT) and vary in design and functional capability depending on the application type.

While some robots are fitted with the two-fingered grippers for pick and place tasks of manipulating parts to assemble objects, some robots are fitted with multiple and complex sensors that can be automatically changed with the use of a tool changer to allow such robots to complete several different complex types of applications such as robotic inspections. Different end effectors are operated in slightly different manners because they use different communication protocols, different programming interfaces, and require different levels of skill to get them up and running (Thomasnet, 2021). The function of robot drives is to provide motive power to robots. Various transmitting electric, hydraulic and pneumatic prime movers as well as their various levels of combinations are used to drive the mechanical links of robots to desired positions and orientations in the working envelopes of the robots. Hydraulic and pneumatic drives are both used for high speed and/or high-load-carrying capabilities but the major disadvantages associated with them are the possibility of oil leaking, and inherent flexibility due to bulk modulus of oil in the case of hydraulic drives; and control difficulty due to compressibility of air in the case of pneumatic systems. The commonly used electric drives for industrial robots are either electric DC servomotor or stepper motors because they are clean and relatively easy to control. In most cases, electric drives tend to be relatively less powerful to hydraulic and pneumatic drives. Smaller robots normally utilize pneumatic drives, but hydraulic drives can provide increased power and speed to the robots (Banerjee, 2017; Thomasnet, 2021).

2.2 Materials for Making Industrial Robots

The raw materials used for making the robots are mostly polymers, metals and ceramics. Common materials like steel, cast iron, and aluminum are most often used for the arms and bases of robots. Mobile parts of the robots are however usually equipped with rubber tires for quiet operations and positive grips on the floor. Industrial robots also contain appreciable amount of electronics and wiring. Some of the robots are radio or laser controlled. The motion-generating mechanisms of industrial robots such as the cylinders contain hydraulic oil or pressurized air. Hoses of silicone, rubber, and braided stainless steel are used for connecting these mechanisms to their control valves. Some exposed areas of the robots are often covered with flexible neoprene shields and collapsible bellows to protect them from the environment. Electric motors and controllers of industrial robots are housed in steel electrical cabinets located near the robots' work areas or carried on board the robots themselves (Thomasnet, 2021).

2.3 Classification of Industrial Robots

Industrial robots are designed and produced in many types or classes that are based on their: applications, structures, degrees of freedom in movement, the medium of instructions or programming given to them, speeds of operation, environments of operation, paths of travel, controller capability, payloads, involvement with humans, and involvement with hazardous material.

This shows that not all the robots are equal in size, shape, working principle, functionality, and meeting requirement for various applications (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018). One common classification of the robots is based on their mechanical structures or configurations and manipulator workspaces (Banerjee, 2017; Langa, 2018). The main robots by this classification are further discussed. Knowledge of distinctive features of robots and their classifications is crucial for suitably selecting them for various manufacturing tasks (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018).

A. Articulated Robots

Articulated forms of industrial robots are quite simple and consist of three axes of control, situated at right angles to each other. These styles of industrial robots are perfect when facility space is short because they can be installed overhead rather than on the floor. Articulated robots are classified by the number of points of rotation or axes they possess. The most common is the 6-axis articulated robot. There are also 4 and 7-axis units on the market. Properties such as flexibility, dexterity, and reach make articulated robots ideally suited for tasks that span non-parallel planes. Articulated robots can also easily reach into a machine tool compartment and under obstructions to gain access to a work-piece or even around obstructions in the case of the 7-axis style. Stand-alone articulated robots are well suited for applications like automotive assembly, palletizing, packaging, welding, steel bridge manufacturing, glass handling, steel cutting, foundry molding, forging, and machine tending, etc. However, these robots require dedicated robot controllers, complicated programming, and complicated kinematics (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018).

B. Selective Compliance Articulated Robot Arm (SCARA) Robots

SCARA robot arms are designed after human arm with an elbow, shoulder, and wrist to have three axes; the Z-axis as a rigid axis and the X and Y-axes as flexible ones. These types of robots are ideal for fast repetitive tasks and exact point to point movements and actions. SCARA robots are good and cost-effective choices for performing operations between two parallel planes such as transferring parts from a tray to a conveyor. These robots excel at vertical assembly tasks such as inserting pins without binding due to their vertical rigidity. The robots are lightweight and have small footprints, making them ideal for applications in crowded spaces. They also have very high speed with excellent repeatability and large workspace. Due to their fixed swing arm design; they are good and advantageous in assembly, inspection, and packaging, palletizing, machine loading, and semiconductor wafers handling applications, etc. However, SCARA robots face limitations when it comes to tasks that require working around or reaching inside objects such as fixtures, jigs, or machine tools within a work cell. They are therefore limited to planar surfaces. They also require dedicated robot controllers and are hard to program offline (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018).

C. *Stand-alone Delta Robots*

A stand-alone delta industrial robot is the type of robot that is connected to a central base that is connected with three arms. This type of robot is most commonly used within packaging, medical, and pharmaceutical industries; for tasks that need high degree of precision and accuracy. Stand-alone Delta robots usually possess three motors fixed to a rigid frame to control the robot arms and in positioning the end effectors. A common style of these robots is the 3-axis units, but the 4 and 6-axis units are also available (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018; IFR, 2020). By designs, the heavy motors are fixed on rigid frames and the robot arm's usually made light to enable them to be effective for high speed applications. Applications of these robots include pick and place, inspection and assembly in food and pharmaceutical and electronic industries, flight simulators, automobile simulators, and optical fiber alignment (Langa, 2018; IFR, 2020).

D. Cartesian Robots

Cartesian robot is an industrial robot whose three principal axes of control are linear and at right angles to each other. In other words, they move in a straight line rather than rotate. They have three sliding joints that correspond to moving the wrist up-down, in-out, and back-forth. This mechanical arrangement simplifies the robot control arm solution among other advantages (Banerjee, 2017; Langa,2018; Technavio Blog, 2018; IFR, 2020). Cartesian robots have high reliability and precision when operating in three-dimensional space. As a robot coordinate system, it is also effective for horizontal travel and for stacking bins. These robots typically consist of three or more linear actuators assembled to fit a particular application. Positioned above a workspace, Cartesian robots can be elevated to maximize floor space and accommodate a wide range of work-piece sizes. Higher capacity units can also be integrated with other robot types such as articulated robots as end-effectors to increase system capabilities. This custom nature of Cartesian robots can however make design, specification, and programming challenging or out of reach for smaller manufacturer's intent on approach to robotics implementation (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018; IFR, 2020). Cartesian robots are used in most industrial applications as they offer flexibility in their configuration which makes them suitable for specific application needs.

The advantages of Cartesian robots are provision of high positional accuracy, ease of programming offline, ability to handle heavy loads, high customizability, simplicity of operation, and less cost. On the side of demerits, Cartesian robots are limited to movement in one direction at a time. They also require large operational and installation area and complex assembly. The application areas of Cartesian robots include pick and place operations, material handling, adhesive applications, loading and unloading, assembly and sub-assembly, and nuclear material handling (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018; IFR, 2020).

E. Collaborative Robots

Collaborative robots are industrial robots that are designed to function in harmonious physical interaction with humans in shared workspaces that both robots and humans need to perform work tasks into. The robots are of great help in assisting humans in manufacturing tasks (Banerjee, 2017; Langa, 2018; IFR, 2020). Advances in edge computing have made collaborative robots more flexible and easier than ever to implement.

The robots are generally equipped with machine learning capabilities and little to no programming is often required to install these types of robot, so reducing their integration costs. Increasing flexibility of collaborative robots can open up a wide range of new tasks and applications that they can effectively automate (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018; IFR, 2020; Lindsay Sanneman *et al*, 2020).

F. AGVs and AMRs or Service Industrial Robots

Automated Guided Vehicle robots (AGVs) and Autonomous Mobile robots (AMRs) are not designed around a fixed installation, but are types that can move and transport goods. These robots are commonly installed within distribution and logistics industries, yet they have a lot of potential within manufacturing industries. Navigation for these robots is most either internally such as advanced software or externally such as tape or a magnetic line (Langa, 2018; PSI, 2018; IFR, 2020). AGVs have been moving things around through by the means of wires, magnets, and beacons on behalf of humans for over 60 years. They are presently familiar fixtures in factories, warehouses, and anywhere there is need for repetitive material delivery. The effectiveness of the robots, is however being challenged by a more technologically sophisticated approach. The past few years have seen the introduction of a new kind of internal logistics system called AMRs that are now taking over from AGVs in terms of fastness, smartness to recognize and react to obstacles and understand operating environment, efficiency, cost, and general sophistication (Langa, 2018; PSI, 2018; IFR, 2020).

G. Spherical Robots

Spherical robots are also called polar robots. These robots have centrally pivoting shafts and extendable rotating arms as well as spherical work envelopes with their axes forming polar co-ordinate systems. Spherical robots also have twisting joints which connect their arms with their bases and combinations of two rotary joints and one linear joint connecting their links. The gun turret configuration of polar robot sweep large volumes of space, but the accesses of its arms are restricted within its workspace. By advantage; polar robots can reach all around and above or below obstacles, require less floor space, and have large work volumes. Their disadvantages include inability to reach above themselves, low accuracy and repeatability in direction of rotary motion, short vertical reach, fallen out of favor and not common in new designs, and sophisticated control system requirement. The application areas of spherical robots include glass handling, die casting, injection molding, stacking and un-stacking, material handling, forging, and welding (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018; IFR, 2020).

H. Cylindrical Robots

Cylindrical robots have cylindrical workspaces with pivoting shafts and extendable arms which move vertically and by sliding, so offering vertical and horizontal linear movements along with rotary movement about their vertical axes. These robots have at least one rotary joint at their bases and at least one prismatic joint connecting their links. The ends of the arms of the robots are compactly designed to allow them reach tight work envelopes without any loss of speed and repeatability. Cylindrical robots are mostly used in simple applications where materials are picked up, rotated, and placed. The robots are commonly used in coating applications, assembly applications, die casting, foundry and forging applications, machine loading, and transport of liquid-crystal display (LCD) panels. The robots have advantages of less floor space requirement, simple operation and installation, ability to reach all around themselves, minimal assembly, and ability to carry large payloads.

On the side of disadvantages; the robots cannot reach around obstacles, have low accuracy in direction of rotary motion, and have fallen out of favor and not common in new designs (Banerjee, 2017; Langa, 2018; Technavio Blog, 2018; IFR, 2020d; IFR, 2020).

2.4 Typical Applications of Industrial Robots

The applications of industrial robots in manufacturing industries are rapidly increasing as; managements of industries, researchers, and engineers are constantly looking out for ways to cut down expenses, deliver quality jobs, perform jobs that are seemingly dangerous for humans to do, and reduce idle time to the bare minimum. Industrial robots are capable of satisfactorily doing the same job over and over, for days and years without complaints even under conditions that are hazardous to humans. Not only that; robots perform dedicated tasks the same way every time, and this helps manufacturers to improve production output and product quality and consistency. Applications of industrial robots in the manufacturing industry are many but the notable applications include welding, painting, machining, assembling, picking and placing, packing, palletizing, packaging and labeling, product inspection, laser measuring and verification of part assembly, and mobile services (Langa, 2018; Ji and Wang, 2019). Some of these applications are further discussed to enable better appreciation of their importance.

A. Welding

Welding is one of the most popular applications of industrial robots in manufacturing activities worldwide. It is estimated that about 25% of all in-service industrial robots are employed for welding operations. Automotive manufacturing has been the most active industry sector in terms of robotic welding adoption. The sector utilizes about 40% of total global robot supply, followed by the electrical and electronics industry with utilization of about 20% of the total global robot supply. The use of industrial robot to welding applications is most productive when completing high-volume, and repetitive welding tasks. There are several different types welding processes that can be accomplished by robotic automation technology each with its benefits and types of applications.

The most common welding processes that are done by robotic automation technology are arc welding, resistance welding, spot welding, tungsten inert gas (TIG) welding, metal inert gas (MIG) welding, laser welding, friction welding, and plasma welding (Banerjee, 2017; ATI, 2021). Robotic welding achieves flawless welding with minimum of stress. Robotic welding is very effective as it increases the safety of workers by shielding them from burns and inhaling of fumes from the welding process. However, the technology requires: choosing the right robot and programming interface, calibrating the interface, and programming the robot. Robotic welding also requires selection of the right consumables like shielding gas and electrodes, etc. Fig. 1 shows an instance of robotic welding (ATI, 2021).

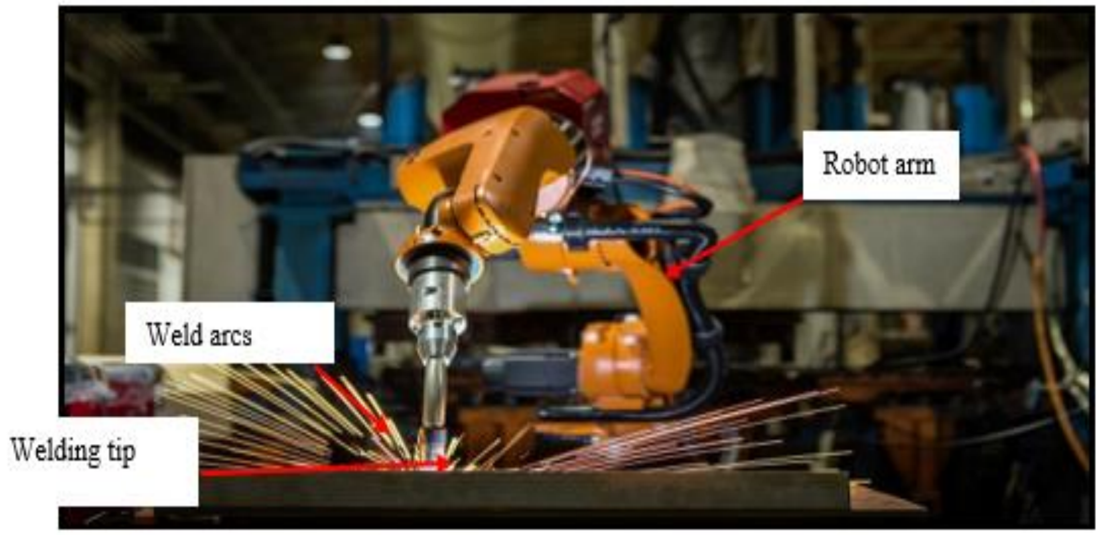

Fig. 1. An instance of robotic welding (ATI, 2021)

B. Painting

Another common and notable use of industrial robots is for spray painting. Industrial robots are used for spray painting applications in automobile and other industries to ensure paint quality and consistency of products. Robot painters were first introduced in 1969 by a Norwegian company named Trallfa. They were used for spraying bumpers and other plastics in automobile industries (Jim Montague, 2007). High painting precision with long normal run time and less paint consumption and very high productivity and quality are achieved with robotic painting. Robotic painting can be carried out continuously for 24 hours or even endlessly with quick and even speed and capability of automatically adjusting the painting height, direction, and angle position to meet needs for the parts being painted. Robotic painting provides very high safety to humans. In robotic spray painting, it is immaterial whether the work or part being sprayed is irregular or not, it can be sprayed perfectly. The robotic program can even be used to set different sizes, different colors, and special working planes to carry out automatic spraying work and small-scale production. Moreover, robotic spray painting can produce products of different shapes on the same production line, and this effectively improves the production efficiency of the assembly line and makes the production process more automated. Fig. 2 depicts instance images of some painting robots in an automobile industry (Jim Montague, 2007; Tedarobotics, 2021).

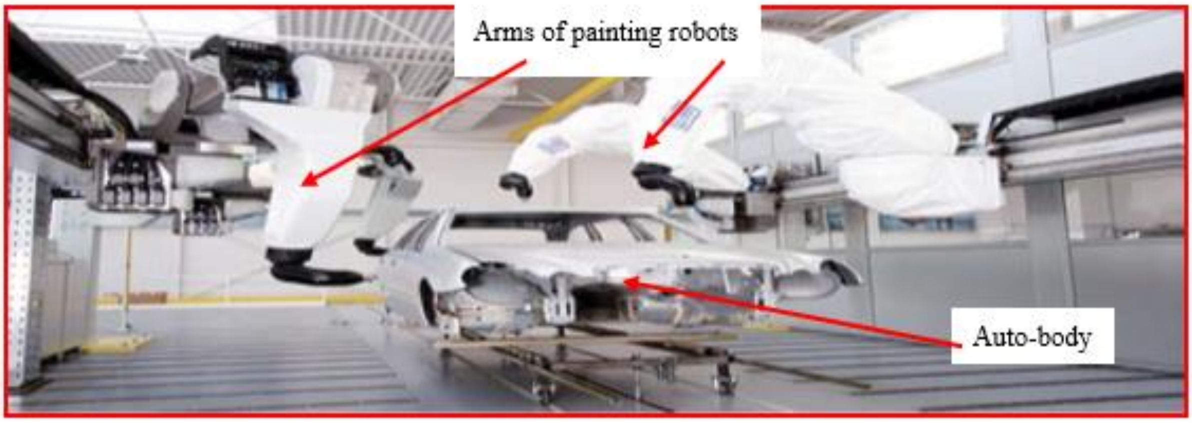

Fig. 2 Instance images of painting robots in an automobile industry (Jim Montague, 2007)

C. Machining

Suitable industrial robots can be used to automatically perform machining operation such as turning, cutting, milling, grinding, drilling, deburring, polishing, and forming; all of which are traditionally conducted through manual inputs on machine tools. Machining robots symbolize a cost-saving and flexible alternative compared to conventional CNC machines which have restricted working area and product shape limitations. Robotic machining is however endowed with ability to move along more complex paths than most CNC machines since CNC machines tend to have only 3 or 4 degrees of freedom. Machining robots produce accurate results in quick time. Robotic machining is accomplished alongside automation for machine tending which is the process of loading and unloading raw materials onto machine tool for machining processing and overseeing the machine tool while it does a job (Ver *et al*, 2019). Robotic machining requires high-work-piece clamping rigidity to achieve machining accuracy since cutting forces can be very great and work-piece deflections and vibrations can be very high to impair the required accuracy. Fig. 3 shows an image of a robot used for milling operation in which the work-piece was clamped on the worktable and the robot held the cutter (CNCTIMES, 2018)

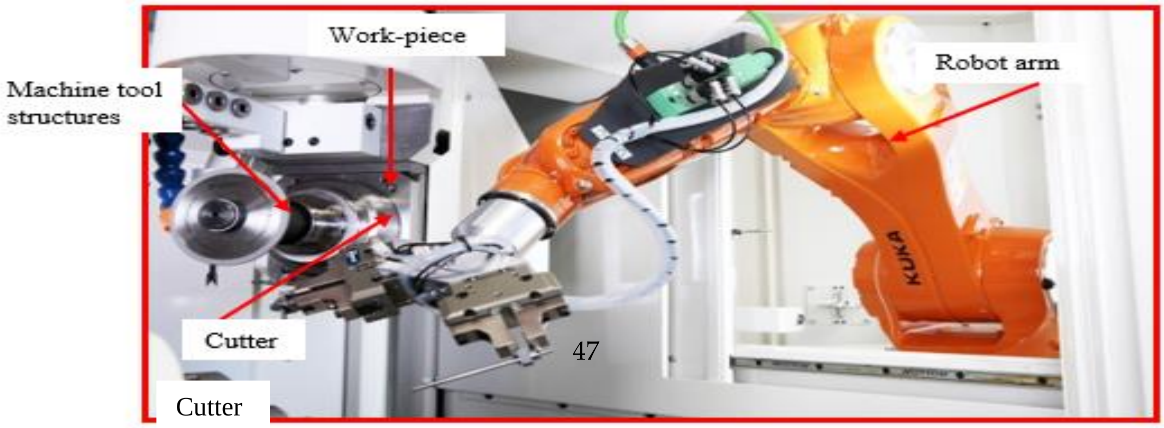

Fig. 3 An image of a machining robot (CNCTIMES, 2018)

D. Assembly

Assembling is also a top and commonly known application of industrial robots. Industrial robots are often and regularly used to assemble products in tedious and tiresome tasks. Robotic assembly typically includes automotive components like, pumps, wheels, windshields, doors, cooling and transmission hoses, engines, motors, and gear boxes. Other typical areas of robotic assembly are computers and consumer electronics, medical devices, and household appliances. Using robots increases output and reduces operational costs in assembling with boost of quality and capacity. Robotic assembling is also ideal for tasks demanding speed and precision like applying sealants and adhesives. It is especially good in applications where cleanliness is paramount, like pharmaceuticals and medical device assemblies; since robots used are not prone to debilitating injuries like carpal tunnel syndrome that comes with repetitive work to human workers. Robotic assembling can put together parts that are even too small or intricate for human workers to achieve. Not only that, assembly robots can work quickly and accurately without tiring or making mistake in assembly.

Other benefits of robotic assembly are due to activities like: handling and positioning of metal sheets, spot welding, and transport of the body frames in the case of car body assembly which are either hazardous and/or physically demanding to human workers or difficult to realize on fixed automation lines due to variety of car body configurations to be assembled on the one production line. Typically, robots used for assembling are in four configurations types. These are the six-axis articulated arms, four-axis SCARA robots, the modern Delta, and the collaborative configuration types (ACIETA, 2021). Fig. 4 depicts images of robots at work on car assembly line (Lila Shroff, 2019).

Fig .4 Images of car assembly robots at work (Lila Shroff, 2019)

E. Picking and Placing, and Palletizing

Picking of parts up and placing them in new locations and/or palletizing them are also among the popular industrial activities that industrial robots are employed to speed up processing to increase production rates and consistency. By the robotic automation; picking and placing and/or palletizing processes can be customized to fit specific production requirements in industries.

The use of industrial robots makes it an easy task to automate in the factory line the moving of large, small, heavy, or hard-to-handle products. The use of industrial robots for picking and placing requires installation of robotic cells for the automation application. The use of robots for picking and placing and/or palletizing has become a common activity in factories that have repeated job duties. Industrial robots have been used to replace humans in tiresome, cumbersome, and hazardous picking and placing and/or palletizing activities in manufacturing industries. Robots used in the processes also work faster and are far more accurate than human workers and reprogrammable to adapt to new required picking and placing, or palletizing tasks. Pick and place, and/ or palletizing robots could be of small, medium, and large size types depending on the product size and weight and the distance through which picking and placing, or palletizing is to be done. The common types of robots used for picking and placing are; the 5 or 6-axis pick and place, the Cartesian, Delta, Fast pick, and collaborative robots. Fig 5 shows a view palletizing robot with pallet assembly (Raymond, 2021).

Fig. 5 Image of a palletizing robot with pallet assembly (Raymond, 2021)

2.5 Advantages of Industrial Robots in Manufacturing

When deciding to introduce robots in manufacturing, it is needful that both the pros and cons of the robots be thoroughly studied in order to profit from this technological venture. The advantages of using industrial robots are many, and include (Industry Trends, 2018., IFR, 2020):

i. Programmability and re-programmability to meet new specific manufacturing requirements and ability to work continuously for even years, consistently meeting high manufacturing quality standards.
ii. Faster and more efficient achievement of certain manufacturing tasks than humans as they are designed and developed to perform these tasks with higher accuracy. Their uses optimize production efficiency parameters such as time and resources as they do not undergo human limitations such as sickness, tiredness, and low morale (Industry Trends, 2018; Stevens, 2019; IFR, 2020).
iii. Production of very-high quality products because of their higher accuracy levels which also results in reduction of time and cost required for quality control and ensures that standards of quality are adhered to (Industry Trends, 2018; Stevens, 2019., IFR, 2020).
iv. Performance of tasks deemed dangerous or laborious and repetitive for humans to carry, so vastly improving working conditions as well as safety within factories and production plants (Industry Trends, 2018; Stevens, 2019; IFR, 2020).

v. Increased profitability levels with lower cost per product due to increase in efficiency of the manufacturing process coupled with reduction of resources and time required to complete the process whilst also achieving higher quality products and money saving in the long run (Industry Trends, 2018; Stevens, 2019; IFR, 2020**).**
vi. Elimination of human drudgery whilst maximizing efficiency since they can work 24 hours every day for weeks or months at 100% efficiency; whereas humans have limitations such as tiredness, distraction, and sickness so can only work for very much lower duration even in a day. On average a 40% increase in the output of a production line occurs when one key person is replaced by a robot that operates the same working hours. Moreover, robots don't take holidays or have unexpected absences (Aririguzo and Agbaraji, 2016).
vii. Greater productivity with flexibility to quickly adapt production and respond to changes in demand and smaller batch sizes (Industry Trends, 2018; Stevens, 2019; IFR, 2020**).**
viii. Saving of workspace in high value manufacturing areas.
ix. Much greater overall benefits at the end over installation and operating costs (Industry Trends, 2018; IFR, 2020**).**
x. High economic life span of approximately 12 to 16 years (IFR, 2020**).**

2.6 Difficulties in Implementing Industrial Robots

There many issues that impede implementation of industrial robots in manufacturing. For example, the orientation and speed of parts presented to the robots must be carefully calculated to ensure maximum productivity without producing too much for existing systems to handle (Industry Trends, 2018., Mark Stevens, 2019).

A. Capital Intensiveness

Implementing robotic technology in manufacturing can incur high initial and ongoing costs. It is therefore needful for management boards to consider critically before implementing the technology so as to run business profitably (Industry Trends, 2018., Mark Stevens, 2019., Statista, 2021).

B. Social Implication

Implementing robots also comes with social barriers. The biggest barrier to implementing robots is the fear of replacing human capacity and creating unemployment. Different studies have been done on this by governments, researchers, labor unions, and individuals. In 1980, it was predicted that as many as 100, 000 jobs would be lost to robots. Presently robots are made for applications in medicine, engineering, and logistics, etc. Many jobs are at risk with more advancements and implementations of industrial robots (Industry Trends, 2018; Mark Stevens, 2019).

C. Costs of Acquiring Industrial Robots

The costs of acquiring robots vary greatly depending on the type of robot or whether they are new or fairly used. New industrial robots with complete controllers and teach pendants cost from about $50,000 to $80,000, but anywhere from $100,000 to $150,000 with the addition of any application-specific peripherals to the system. Used robots are less expensive and can cost only half as much as new robots. Typically, used robots cost between estimations of $25,000 and $40,000, and those of them with application components cost in the range of $50,000 to $75,000. The price of robot is directly related to the application that is to be performed. To choose the right robot model; the company has to consider work space requirements, reach and payload limits, as well as product needs. Application determines end of arm tooling, peripherals, safety components, etc., all of which impact the total cost appreciably.

According to Statista (2021), the average cost of industrial robots in selected years from 2005 to 2017 with forecast for 2025 in US Dollars were 68,659; 46,150; 31,776; 27,074; and10,856 in 2005, 2010, 2014, 2017, and 2025 respectively (Statista, 2021).

2.7 World's Top Manufacturers of Industrial Robots

There are many robot-manufacturing industries or corporations across the globe. However, the leading industrial robot manufacturers in the world include ABB, Yaskawa, KUKA, Fanuc, Kawasaki Robotics, Stäubli, and Nachi Fujikoshi Corporation (Banerjee, 2017; MRR, 2021; Technavio Blog, 2021). Industrial robots from all these manufacturers usually come with full warranty, and training and technical supports. Awareness on robot-manufacturing profiles of these industries or corporations is important for knowing where to get various robot types and their parts at affordable prices, and installation or maintenance services from the industries or corporation and their agents when needful. ABB is a leading industrial robotic manufacturer with its bases in Shanghai China, Auburn Michigan in United State, and Vasteras in Sweden.

The company is a top supplier of robotic software, equipment, and completes application solutions. ABB has reportedly installed more than 400,000 robots in various industries in its annals of existence. The company is supported by the broadest service network and offering in industry. The company also has customers in more than 53 countries (Banerjee, 2017; MRR, 2021; PAT, 2021). Yaskawa Electric Corporation is a Japanese robot manufacturer that provides robots such as handling, arc and spot welding, painting, palletizing, sealing, cutting and laser machining, biomedical, assembling, collaborative, and semiconductor wafer transfer robots (Banerjee, 2017; PAT, 2021; Technavio Blog, 2021). KUKA is a German based manufacturer of industrial robots. The company offers a broad range of highly modular robots that cover payload capabilities from 3 kg to 1000 kg. More than two thirds of the company's robots that are installed in the field use the company's open architecture PC-based controller, and make KUKA the number one PC-controlled robot manufacturer in the world (Banerjee, 2017; MRR, 2021; Technavio Blog, 2021).

Fanuc Corporation is an American manufacturer of industrial robots. The company has capacity to produce 5,000 robots every month. The types of robots produced by the company include painting, collaborative, SCARA, palletizing, Genkotsu, Delta, and arc welding robots of small and medium and large sizes with payloads that range from 0.5 to 2300Kg. Application software are also provided by the company (MRR, 2021; PAT, 2021; Technavio Blog, 2021). Kawasaki Robotics Inc is also an American robots manufacturer based in Michigan. The company is a leading supplier of industrial robots and robotic automation systems with broad product portfolio capable of servicing a wide range of applications all around the world. Kawasaki robots are essentially of medical and pharmaceutical, dual arm SCARA, cleaning, extra-large payloads, large payloads, and small-medium payloads applications. The company has provided robotic solutions to many industries such as automotive, medical, aerospace, foundry, machinery, food and beverages. electronics, semiconductor, plastic and rubber, and metal manufacturing (MRR, 2021; PAT, 2021; Technavio Blog, 2021). Stäubli is a Swiss industrial robot manufacturer which provides a wide range of robots that meet needs of all industries and applications. The company produces SCARA and 6-axis robots for industrial automation; as well as robot controllers, robot arms, and robot software (MRR, 2021; PAT, 2021; Technavio Blog, 2021). Nachi Fujikoshi Corporation is a Japanese company that is a world leader in the production of robotics. The company is headquartered in Novi, Michigan, with sales and service centers throughout the world. The company manufactures many robot types and supplies successful turnkey solutions for robotic applications. Types of robot manufactured by the company include arc welding, material removal and handling, spot welding, forging, machine tending, foundry, palletizing, collaborative, dispensing, and packaging and assembly robots. Nachi-manufactured robots can handle load capacities ranging from 1kg to 1000kg (MRR, 2021; Technavio Blog, 2021).

CONTRIBUTION TO KNOWLEDGE

The review contributes to knowledge about industrial robots as technological systems that are crucial for the state-of-art automation of manufacturing processes in industries or economies that are aspiring for much greater advantages and global competitiveness in our today's era of complex industrial processing activities.

CONCLUSION

The basics and significance of industrial robots in engineering manufacturing have been reviewed in terms of structural components, classes, uses, advantages and disadvantages, and manufacturers of the robots. The review has shown that robotic technology is a cutting-edge industrial automation technology whose application level is crucial to productivity and profitability or economic profile and competitiveness of any industry or nation in our increasingly complex manufacturing industry environment. It has been reiterated that there are many types of industrial robots in terms of working principles, functionality, capability, and areas of application which users and learners need to know in order to correctly choose them for various desired manufacturing tasks. The overall advantages and disadvantages of using the robots in manufacturing have been emphasized. It is clear from the paper that there are many advantages of using industrial robots. The only notable disadvantages in using them are the installation and running costs and need of specialist personnel for manning them. However, the benefits of the technological option of using industrial robots in today's manufacturing are seen to; far outweigh the disadvantages.

RECOMMENDATION

The review is recommended as useful information about benefits and other dimensions of applying industrial robotic technology for awareness, educative interest, application motivation, and benefits of manufacturing stake holders who lack knowledge and/or resources on the technology and stick to exploiting conventional technologies without venturing into or exploring any industrial automation technology.

CONFLICT OF INTEREST

The authors have declared that, this article is their original research work; which has not been published or under consideration for publication elsewhere.

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