TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 68, Issue I, March, 2025

CONTEMPORARY FORAYS ON THE PATHS OF INNOVATION: PERSPECTIVES ON THE EVOLUTION AND DEPLOYMENT OF SERIAL-MODULAR INDUSTRIAL ROBOTS IN FLEXIBLE MANUFACTURING CELLS

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Abstract: *The integration and deployment of industrial robots within flexible manufacturing cells has had a marked effect on industry and the transformation of production processes within many areas of industrial manufacturing. This paper analyzes the evolution and development of the use of industrial robots of serial-modular construction in flexible manufacturing cells, based on a thorough reading and analysis of the studies and research available in the literature. The paper highlights in detail the various types of technologies used for manufacturing processes, emphasizing the key moments that have shaped this area of multidisciplinary interest. It also discusses how advanced technologies have been adopted to respond promptly and concisely to the diverse requirements and needs of the robotic industry, providing a pertinent detailed insight into the impact of the use of industrial robots in flexible manufacturing cells.*

Key words: *industrial robots, seriality, modular interchangeability, flexible cells, technological humanism, human-artificial partnership.*

1. INTRODUCTON

Over the years, the robotic industry has experienced an accelerated expansion due to the emergence of new technologies in the technical field. The 21st century has seen a major change in robotic technology due to the level of automation created today and artificial intelligence. Production systems need to be flexible and versatile to meet the demands of rapidly changing markets [1]. Flexible manufacturing cells are an integral part of modern production systems. The incorporation of robotic systems in manufacturing provides the flexibility to perform increasingly complex production tasks [2]. In this paper, the evolution of industrial robots is outlined, with a focus on serial-modular robots that can be deployed in flexible manufacturing cells, taking into account the transition from the early stages of production process automation to recent innovative advances in robotics and smart manufacturing industries. The evolution and impact of emerging technologies on efficiency and flexibility in manufacturing will be analyzed, taking into account both technical innovations and changes in the requirements of modern industry. The scientific approach is intended to confirm what the scientific researcher Luigi Caprioglio has stated: *This is our application. Where is your robot?*

2. THE EVOLUTION OF INDUSTRIAL ROBOTS OVER TIME

2.1 The beginnings of robotics

The word "robot" was first introduced by the Czech prose writer Karel Capek in his short story "Opilec" in 1917, and later the term was used in the famous play "Rossum's Universal Robots" which premiered in 1923. By using the term "robota", he meant to depict the forced or unpleasant labor performed by human-like laborers/ serfs raised in reservoirs [3]. The early pioneers of industrial engineering were Geroge Devol and Joe Engelberger, recognized scientists who founded a company called "Unimation" in 1956. Inspired by science fiction writer Isaac Asimov, they designed and

Received: 29.01.25; **Similarities**: 05.03.25: **Reviewed**: 24.02./25.02.25: **Accepted**:24.03.25.

programmed and patented the first industrial robotic arm (fig. 1) [4].

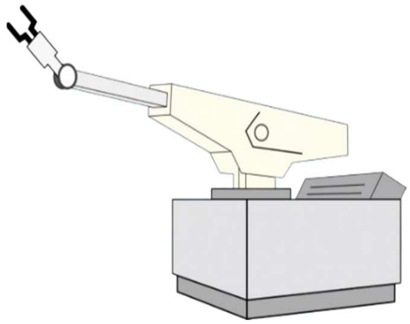

Fig. 1. The first industrial robotic arm [5]

A defining phrase of the term "industrial robot" is highlighted by the International Organization for Standardization: "An industrial robot is an automatic, servo-controlled, freely programmable, multi-purpose, intended for the manipulation of workpieces, tools or special devices. The variably programmable operations (n.a. of the robot) allow a variety of tasks to be performed."

2.2 Classification of industrial robots

Robots can be classified according to many criteria such as: the number of degrees of freedom, the number of joints they have, their payload, their kinematic configuration or the type of drive, i.e. electric, pneumatic, hydraulic or hybrid (usually electric and pneumatic).

Fig. 2. SCARA robot [7]

The first example is the SCARA robot which has a structure with 3 rotation joints and a prismatic joint resulting in 4 degrees of freedom (fig. 2). this robot is ideal for applications requiring high precision, such as assembling parts, manipulating objects and performing repetitive operations [6].

The spherical robot has 3 rotating joints, giving it 3 degrees of freedom. This means it can perform complex movements and move in a wide range of directions (fig. 3) [6].

Fig. 3. KUKA spherical robot [8]

A Cartesian robot model that possesses 3 prismatic joints, 3 degrees of freedom and its motions are rectilinear along the axes is shown in figure 4 [6].

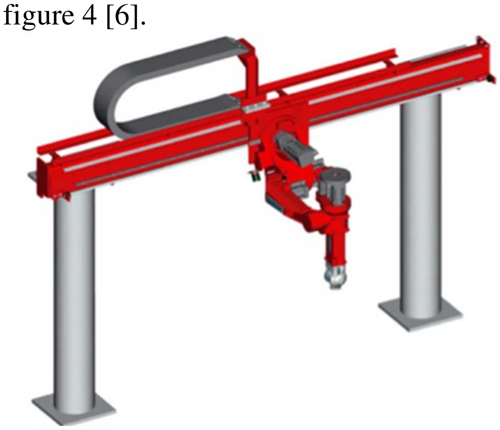

Fig. 4. Cartesian robot [8]

2.3 Industrial robots of serial-modular construction

The concept of serial-modular construction robots originated as early as the 1970-1980s [9].

These robots have a modular design, making them flexible and versatile. Thanks to this structure, components can be easily replaced, upgraded, or customized, and the robot can be quickly adapted for different tasks and operations in various environments. This allows easier maintenance and customization of the robot to specific application requirements. An illustrative example is shown in figure 5 which represents a patent for such a modular robot configuration and functionality [10].

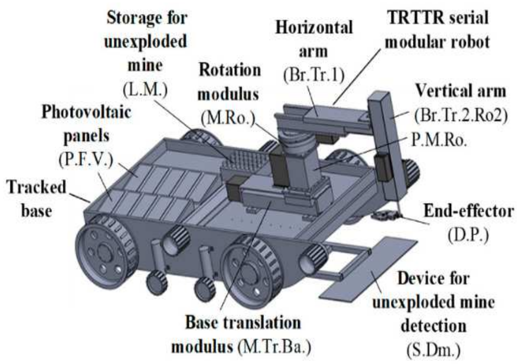

Fig. 5 Modular humanitarian demining robot [10]

2.3.1 Advantages

The serial-modular robots are easy to integrate into systems and offer flexibility, adaptability and pragmatism to the different operations they have to perform. The modular functional design offers a wide range of applications in which they can be used, from handling, sorting, packing, to surveillance, inspection or testing operations. Serial-modular robots offer precision in repetitive tasks and modular interchangeability helps optimize processes. At the same time, serial-modular robots can reduce costs by quickly replacing faulty modules, avoiding production delays.

3. FLEXIBLE CELLS

A manufacturing cell in which handling, loading and unloading operations are performed by robots is called a robot cell (fig. 6) [11].

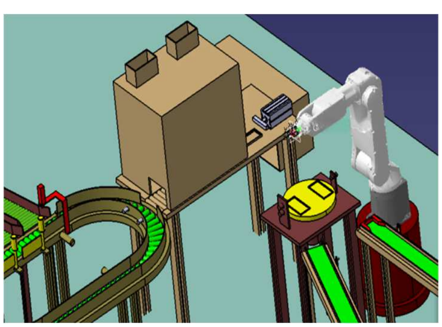

Fig. 6 Robot packaging cell [12]

They use a technological itinerary, so that parts pass through several stages in the flexible cell until they reach a finished part. The process of moving parts within the cell can be done by conveyor belts and by industrial robots for handling, storing or sorting. In addition to handling and transportation operations, flexible manufacturing cells equipped with industrial robots are also used in other areas, such as painting, welding, woodworking or even textile sewing processes.

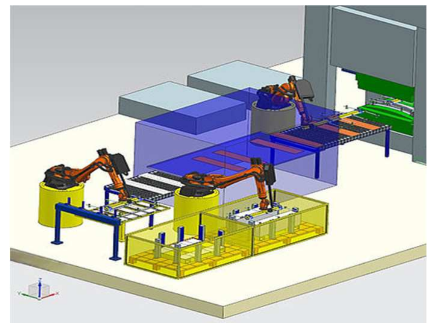

Fig. 7 Press cell, hot forming [13]

As shown in Figure 7, flexible manufacturing cells are also used in operations involving risks to human factor health, in areas where pressing, cutting, high temperatures, hazardous substances or other processes that may cause injury to the human factor are involved.

3.1 Advantages

Flexibility in production is ensured by manufacturing cells with industrial robots because they can be easily adapted to the operations required for each product. At the same time, they help to reduce costs because there is no need for a human factor at each operation, so quality is also improved because robots can perform repetitive tasks without errors. Flexible manufacturing cells with industrial robots increase productivity by reducing production time by automating the process [14].

4. STRUCTURE OF ROBOTS

A typical industrial robot is composed of three main parts: the execution parts which comprise the robot chassis, the robot arms and the gripper which is the robot's hand and is designed for handling operations. It has a movable wrist to ensure flexibility and precise arm orientation. The arm is used for positioning and the chassis is the base and support for the entire system [15]. The second category of components is highlighted by the drive mechanisms, which in turn fall into 4 categories: hydraulic, pneumatic, electrical and mechanical. Hydraulics are characterized by their simple design, compact dimensions, low weight and very high actuating force. Pneumatic systems are used in operations and processes where less actuating force is required, while electric mechanisms offer very high precision and finer control. Mechanical actuators rely on toothed gear systems and transmissions to generate motion.

The third category of components in the structure of industrial robots are the control agents that coordinate the robot's motions, which in turn are divided into point-to-point control agents based on the sequence of predefined positions and continuous control agents that allow a more fluid motion and thus greater flexibility and adaptability to environmental changes [15].

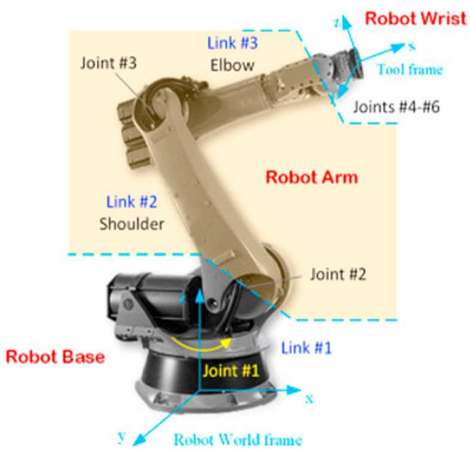

Fig. 8 Common robotic arm manipulator [16]

The most common robotic arm manipulators consist, as shown in figure 8, of the robot base, 3 joints, the robot arm, the robot shoulder, elbow and wrist [16]. The mechanical structure of the manipulator is complex and can include sensors, joints, gears and actuators. The electrical system of industrial robots consists of motors, computers, graphical communication interfaces, power supplies, and sensors, all of which provide the load capacity, speed of motion, accuracy, and all other properties of a functional system [17].

5. MODELING OF ROBOTS

By modeling industrial robots, control parameters can be identified and robots can be monitored, thus aiding production processes and operations. The goal of industrial robot modeling and simulation is to create a mathematical or computer representation of the robot's behavior in order to analyze its performance under various working conditions, optimize its design and control, and develop effective monitoring strategies for detecting and maintaining possible failures. Geometric and kinematic models of industrial robots primarily focus on its motion, describing the position, velocity and acceleration of its joints as a function of time [18]. Dynamic models also take into account the forces and moments acting on the robot, including the fundamental forces: inertia, gravity and friction [18].

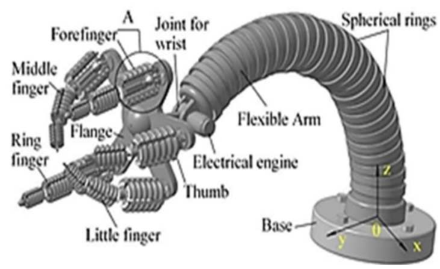

Fig. 9 Flexible robot anthropomorphic arm [19]

The design and modeling of industrial robots is an evolving field that aims to create increasingly versatile and efficient robotic systems and one of the promising directions in this field is anthropomorphic structures (fig. 9), which aim to attribute human features to non-human objects, i.e. robots [19]. The innovative flexible arm uses structural anthropomorphism as the robot's design and functionality mimics the structure and movements of the human arm.

6. OPTIMIZATION OF ROBOTS

Trajectory optimization of industrial robots is an important area of research in robotics, with direct applications for streamlining production processes and improving the overall performance of industrial robots [20]. The need to optimize the trajectory of industrial robots arises from the need to improve their performance in various aspects such as: minimizing execution time to increase productivity, minimizing energy consumption and component wear, ensuring linear and precise movements in conjunction with vibration reduction [20]. The first method is to plan the trajectory with minimum time so that the robot's work cycles are as short as possible, thus increasing productivity. The second method is trajectory optimization with minimal energy consumption, as it is essential both economically and for specific applications, such as space or underwater exploration [20]. The third is emphasized by trajectory planning with minimal shock, which refers to the third-order derivative of the position over time and indicates how rapidly the forces in the robot joints vary. This ensures smoother motion, high accuracy and reduced wear of the organological components of the trajectory-generating moving assembly [20].

In addition to these three methods, there are also hybrid criteria, which aim to combine two or more criteria to find an optimal balance between performance and equilibrium, such as time and energy minimization or time and shock minimization [19]. Thus, robot trajectory optimization is crucial for manufacturing processes to maximize the benefits of using robots in various industries and processes with maximized performance, efficiency and sustainability [19].

7. CONCLUSIONS

In conclusion, the deployment of industrial robots, and in particular of serial-modular robots in flexible manufacturing cells, has been a milestone in industrial technologies and processes. From the study and analysis of the literature and the papers highlighted in this scientific dissemination, it is recorded that both in the past when they appeared and now in modern and intelligent technologies, industrial robots in flexible manufacturing cells have brought versatility, increased flexibility and thus increased production. Flexible cells are applicable in a very wide range of industries, including automotive, aerospace, food, electronics and many others, bringing multiple benefits not only in purely engineering areas of manufacturing, but also in related fields. While flexible manufacturing cells with industrial robots provide an effective solution for modernizing and automating production processes, they also present a number of challenges as they require high upfront costs and specialized manpower to manage and optimize these systems. Overall, flexible manufacturing cells with industrial robots remain at the forefront of innovation in manufacturing and beyond, with the potential to revolutionize the way manufacturing processes and applications are carried out.

However, the ultimate success of their deployment depends on addressing the challenges of technology integration, how these technologies are effectively exploited, and the continuous training of a skilled workforce to adapt to evolving needs.

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INCURSIUNI CONTEMPORANE PE CĂRAREA INOVĂRII – PERSPECTIVE PRIVIND EVOLUȚIA ȘI IMPLEMENTAREA ROBOȚILOR INDUSTRIALI SERIALI-MODULARI ÎN CADRUL CELULELOR FLEXIBILE DE FABRICAȚIE

Abstract: *Integrarea şi implementarea roboţilor industriali în cadrul celulelor flexibile de fabricaţie a avut un efect marcant asupra industriei şi a transformării proceselor de producţie din cadrul multor domenii de fabricaţie industrială. În această lucrare se analizează evoluţia şi dezvoltarea utilizării roboţilor industriali de construcţie serial-modulară în cadrul celulelor flexibile de fabricaţie, pe baza lecturării şi analizei amănunţite a studiilor şi cercetărilor disponibile în literatura de specialitate. Lucrarea reliefează în detaliu diversele tipuri de tehnologii folosite pentru procesele de producţie, punând accent pe momentele-cheie care au modelat acest domeniu de interes multidisciplinar. De asemenea, se discută despre modul în care tehnologiile avansate au fost adoptate pentru a răspunde promt şi concis la cerinţele şi nevoile diverse ale industriei robotizate, oferind o pertinentă privire detaliată asupra impactului utilizării roboţilor industriali în cadrul celulelor flexibile de fabricaţie.*
Cuvinte cheie: roboţi industriali, serialitate, interschimbabilitate modulară, celule flexibile, umanism tehnologic, parteneriat om-artificial.

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