Robotic Design Configurations and Platforms for Manufacturing Industry

Samuel Mbakara John

MSc Robotics and Autonomous Systems, Aston University, Birmingham, United Kingdom

Abstract

Industrial robots play a vital role in modern manufacturing by improving precision, consistency, and productivity. Selecting an appropriate robot configuration is critical, as it directly influences workspace reach, accuracy, speed, payload capacity, and overall system performance. This paper presents a review and comparative analysis of common industrial robotic design configurations, including articulated, SCARA, Cartesian, cylindrical, spherical, and parallel kinematic robots. The structural characteristics, advantages, limitations, and work envelope properties of each configuration are examined. Articulated robots provide versatile spherical workspaces for a wide range of tasks, SCARA robots are well suited for high speed planar assembly, and Cartesian systems deliver rigid and accurate motion for handling heavy loads. Cylindrical and spherical robots support specialised applications, while parallel robots offer high stiffness and precision. Key considerations such as workspace constraints, industrial challenges, and emerging trends in collaborative operation and adaptability are discussed. This review supports informed robot selection and system integration for efficient and flexible manufacturing systems.

Keywords: Industrial robotics; Robot configurations; Manufacturing automation; Work envelope analysis; Articulated robots; SCARA robots; Parallel robots

1. Introduction

Industrial robots have become essential in modern factories because they improve precision, consistency, and overall productivity. ISO 8373 defines them as programmable machines with three or more axes for industrial use. Choosing the right configuration is vital, as it influences workspace reach, accuracy, speed, cost, and system performance. This report evaluates robot configurations, comparing their design features, advantages, limitations, and work envelope characteristics in the context of advanced manufacturing practice.

2. Robotic Configurations

2.1. Articulated Configuration

Articulated robots remain the most common choice in manufacturing because their rotary joint structure gives them a wide and flexible work envelope similar to parts of a sphere (Niku, 2020). With six axes, they control both position and orientation, which helps them work around obstacles and operate reliably in demanding environments such as welding cells and paint booths. They support a broad range of tasks, including assembly, material handling, and surface finishing. The main challenges include complex forward and inverse kinematic modelling based on Denavit-Hartenberg parameters and reduced rigidity at long reach distances (Niku, 2020). Even so, they remain the preferred industrial solution.

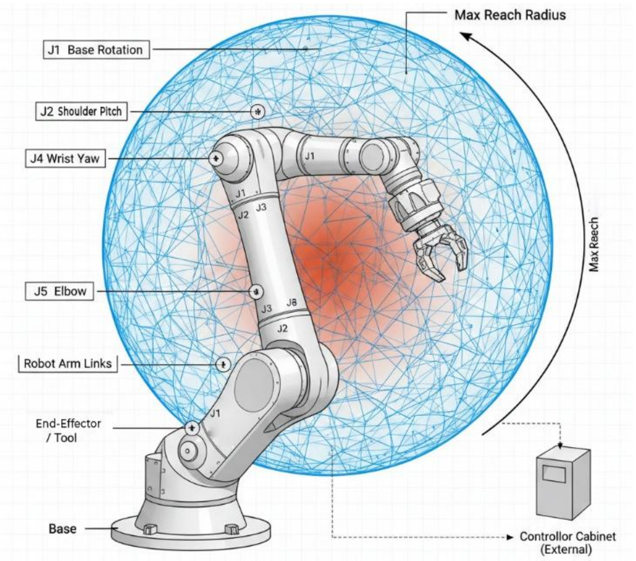

Figure 1: Schematic of a 6-axis articulated robot showing work envelope

2.2. SCARA Configuration

The Selective Compliance Assembly Robot Arm is designed for high-speed assembly and material placement tasks. SCARA robots provide compliance in the horizontal plane while remaining stiff vertically, allowing rapid insertion of delicate components (Niku, 2020). Their simplified joint structure reduces control complexity and supports short cycle times. They are widely used in electronics assembly and packaging, offering accuracy within a few hundredths of a millimetre for precision tasks (Arawade, 2021). Their main limitation is a restricted workspace and limited orientation control, yet they remain highly effective for fast, repetitive planar operations.

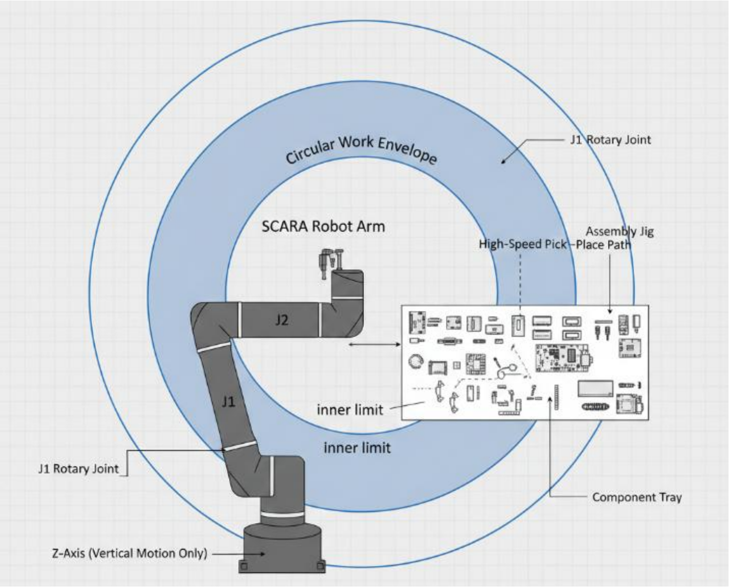

Figure 2: Top view of SCARA workspace for assembly tasks

2.3. Cartesian or Gantry Configuration

Cartesian robots use three prismatic joints arranged along orthogonal axes to deliver linear motion within a rectangular work envelope. Their straightforward geometry and intuitive coordinate system make programming simple, while the rigid structure minimises deflection during heavy payload handling (Groover, 2020). Gantry versions provide strong overhead stability for large or bulky components. Their main limitation is the significant space required, since only part of the footprint is effectively used. Although their fixed architecture limits layout flexibility, Cartesian robots remain preferred for high accuracy, long travel, and heavy-duty pick and place tasks in industrial settings.

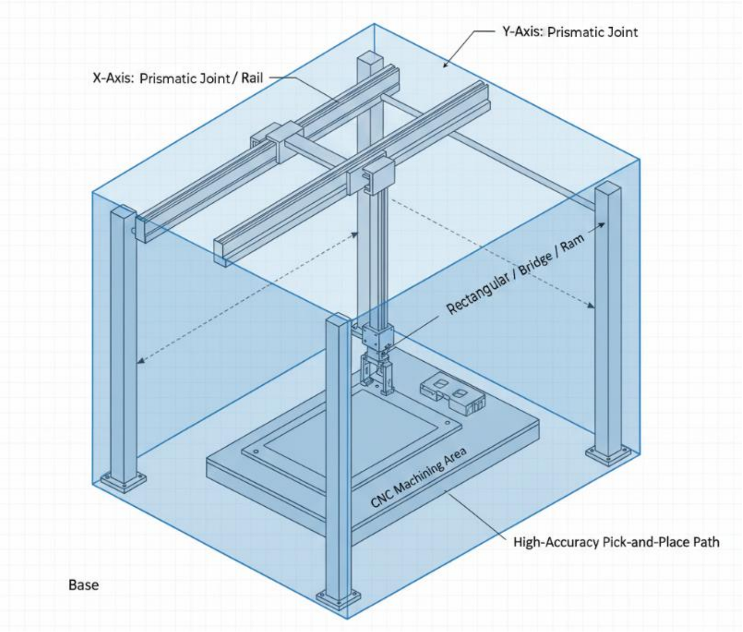

Figure 3: Cartesian robot with gantry design illustrating work envelope

2.4. Cylindrical and Spherical Configurations

Cylindrical robots use one rotary joint and prismatic joints to create a cylindrical workspace that is easy to visualise and control. They are effective for reaching into cavities or enclosed spaces and, when equipped with hydraulic drives, can generate significant force for heavy material handling in foundries and machining environments (Niku, 2020). Spherical robots use two rotary joints and one prismatic joint to form a large spherical envelope. Although both types have declined in popularity due to advances in articulated and SCARA systems, they remain useful in legacy installations and specialised applications where their geometry offers distinct advantages.

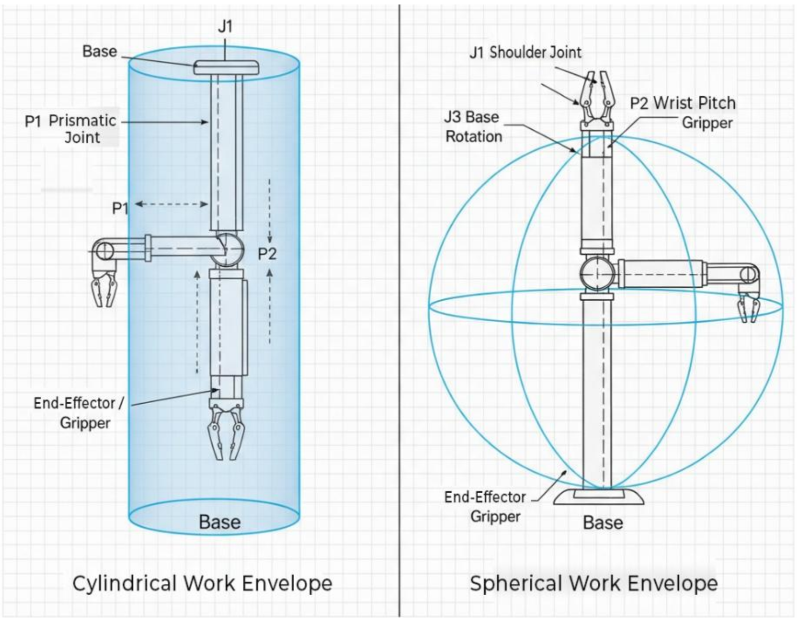

Figure 4: *Cylindrical and spherical work envelopes*

2.5. Parallel Kinematic Configuration

Parallel robots, such as the Tricept series, use multiple arms connected to a shared platform to form a closed kinematic chain. This arrangement distributes loads across several limbs, giving the robot exceptional stiffness, accuracy, and dynamic performance under demanding conditions (Merlet, 2006). These qualities make them valuable for machining, polishing, and other high precision tasks. Their main limitations are a small workspace and mathematically complex kinematics. They are also sensitive to singularities, which require advanced trajectory planning to avoid (Angeles and Park, 2008). These challenges raise cost and restrict widespread adoption, though they remain essential where rigidity is critical.

3. Work Envelope Considerations and Industrial Challenges

The work envelope defines the three-dimensional space a robot can access and determines whether it can complete tasks safely and efficiently. Articulated robots create complex envelopes with a wide reach but require careful cell design. Cartesian robots offer simple box-shaped envelopes yet occupy large footprints, while SCARA robots operate within planar envelopes suited for fast assembly. Modern manufacturing adds new pressures, including the need for collaborative operation supported by advanced sensing and safety rated control (Malik and Bilberg, 2019). Greater product variation, cybersecurity risks, and sustainability goals further influence robot selection, favouring adaptable, energy efficient, and easily reconfigured systems.

Conclusion

Selecting the best robotic configuration requires balancing workspace, accuracy, speed, payload, cost, and integration complexity. Articulated robots offer broad versatility, SCARA robots excel in fast assembly, and Cartesian systems provide high rigidity for heavy loads. Cylindrical and spherical robots meet niche needs, while parallel robots deliver exceptional precision. As manufacturing advances, adaptable and easily integrated platforms will prove most effective. Understanding these configurations helps engineers design efficient and modern industrial systems.

References

Angeles, J. and Park, F.C. (2008) 'Performance evaluation and design criteria', in Siciliano, B. and Khatib, O. (eds.) *Springer Handbook of Robotics*. Berlin: Springer, pp. 229-244.

Arawade, S.S., 2021. State of Art Review on SCARA Robotic Arm. International Journal of Advanced Research in Science, Communication and Technology, 5(1), doi:10.48175/IJARSCT-1108

Groover, M.P. (2016) *Automation, Production Systems, and Computer-Integrated Manufacturing*. 4th edn. Harlow: Pearson Education Limited.

Malik, A.A. and Bilberg, A. (2019) 'Complexity-based task allocation in human-robot collaborative assembly', *Industrial Robot: An International Journal*, 46(4), pp. 471-480, doi: 10.1108/IR-11-2018-0231

Merlet, J.P. (2006) *Parallel Mechanisms and Robots*. In: B. Siciliano and O. Khatib, eds. Handbook of Robotics. Berlin: Springer, pp.269–285. DOI:10.1007/978-3-540-30301-5_13

Niku, S.B. (2020) *Introduction to Robotics: Analysis, Control, Applications*. 3rd edn.