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Original Article

Device-Cell Level Robotics in Manufacturing. A Case Study in Mercedes Benz an Automotive Industry in South Africa

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Abstract *- The growing demand for fast, quality, and affordable production has indeed brought about the extensive usage of industrial robots in manufacturing setups. This report discusses the use and functional capabilities of industrial robots at the device-cell level, with a focus on their use in both processing and assembly tasks. This paper also presents an examination of the various robot types, discusses the actual integration with complementary automation elements, such as Programmable Logic Controllers (PLCs), sensors, and actuators, and analyses their integration across the various manufacturing cells. Indeed, the specific focus is on their contributions to improving operational efficiency, repeatability, accuracy, and workplace safety. A detailed study of the robot applications in the different processes, such as welding, painting, pick-and-place operations, and part insertion, is given to illustrate their functions. The study also entails a case study comprising an application at the Mercedes-Benz factory in East London, South Africa, that demonstrates the quantitative improvements in the production outcomes following the introduction of robotics. The research also discusses possible trends, such as artificial intelligence, collaborative robotics, and adaptive systems, that are influencing the future of automated manufacturing. Considering the positive impact of robots on improving precision and efficiency within device cells, the study indeed reveals gaps in the integration of advanced automation technologies. Further research into the application of artificial intelligence to enable real-time decision-making and to enhance the adaptability of assembly processes is really needed. More studies are also required to study how robots can collaborate effectively with humans in flexible manufacturing environments. In a nutshell, the review identifies the key opportunities, such as improved efficiency, precision, and safety in the device-cell operations, along with the potential for enhanced flexibility through AI and automation. However, the limitations include high implementation costs, limited adaptability to task changes, and challenges in achieving seamless integration with human workers and existing systems.*

Keywords *- Device cell, Industrial robots, Automotive, Mercedes-Benz.*

1. Introduction

The industrial robots are computer-controlled and programmable mechanical devices that are capable of executing different complex tasks with high precision, speed, and reliability [2, 16]. Their use is now an integral component of the present-day industrial activities, particularly in the manufacturing sectors that are demanding high throughput, standardization, and reduced operational risk [1, 7]. The robots are typically created to mimic human actions in repetitive or dangerous tasks and possess a certain level of mobility, which allows them to achieve sophisticated movements and tasks [3, 15]. Although the industrial robots have been very widely studied in the global automotive manufacturing industries [1, 5, 16], there is still a limited amount of research that properly explains and shows the real performance impact at the device-cell level in the African automotive plants [9]. Many of the existing studies mostly give the general and sometimes repetitive descriptions of the robotic technologies [3, 15, 20], but they do not provide enough clear measurable improvements in productivity, accuracy, and workplace safety after the introduction of automation [7, 12, 17]. It becomes a challenge for many people in the manufacturing sector to fully understand how these robots are actually changing the day-to-day operations on the shop floor [13, 18]. Therefore, there is still the strong need for the more evidence-based evaluation that is carefully showing how the robotic integration is truly enhancing the manufacturing outcomes in the developing and emerging industrial economies, such as the one in South Africa [8, 9], where automation is still growing and facing many different practical limitations [4, 14, 19].

The industrial robots were generally placed into the various types, although the distinctions in the different categories were at times given with inconsistent clarity in the literature [16, 20]. The articulated robots were described as machines with rotary joints, providing a high degree of dexterity, even though the exact nature of the movements was not always evident in the uniform explanations [16]. The SCARA robots were often identified as suitable for horizontal motions and assembly operations, mostly operating within the restricted planes described in various studies [5, 16]. The delta robots were frequently noted in the research for high-speed pick-and-place tasks, especially in environments where very rapid, repetitive actions were required [1, 16].

In the broader field of industrial automation, the robots were positioned at the device-cell level, which was viewed as the stage where the actual physical execution of the tasks was taking place [3, 21]. This level involved interactions with the machines, sensors, and actuators, usually coordinated by control systems such as programmable logic controllers (PLCs) [19, 21]. The device-cell level acted as the foundational platform upon which the upper-level systems, including the Supervisory Control and Data Acquisition (SCADA) and the Manufacturing Execution Systems (MES), were built [21]. Through the operations carried out at this stage, the industrial robots translated the digital commands into the physical actions, although the exact connection between the levels was not always presented with consistent explanations across the various sources [3, 7]. This literature review paves the way for a further detailed discussion of the use of such robots in manufacturing cells for both process and assembly operations [1, 3]. It also draws attention to their significance in the framework of Industry 4.0, where flexibility, smartness, and connectivity increasingly become key parameters for the establishment of manufacturing competitive edges [9, 10, 14]. The perspective on how they operate at the device-cell level provides the required insight into the developing production system and the changing competencies needed by design engineers [7, 18].

This study provided a different view about the device–cell level in the industrial automation systems, especially inside an automotive manufacturing plant in South Africa, where technology adoption was still not always complete in every section [9]. Many earlier studies mainly discussed the general advanced robot controls or the very high-level smart systems in factories [1, 7], but they did not always explain clearly how the robots, the sensors, the PLCs, and the HMIs were actually working together in real production time [3, 19]. This research used real performance data from actual machines to show small but important improvements in cycle time, safety response, and communication between the equipment [12, 17]. The use of the ISA-95 structure [21] helped demonstrate how the device–cell level could better connect with higher systems, even when challenges such as skill limitations and older machines [11] arose. Because of this, the case study provided useful evidence for people who planned or designed robotic manufacturing cells in similar, rapidly growing industrial environments [9, 25].

2. Device-Cell Level Overview

The device-cell level was regarded as a core stratum in industrial automation systems, where robot systems interact with manufacturing devices to perform physical tasks. This level was described as the place where the machinery executed processes in real time, based on input signals from the various control and feedback systems. In many discussions, the stratum was typified by the immediacy of process execution, reliance on hardware–software integration, and its role in supporting accuracy, efficiency, and responsiveness within production systems (Baptista & Henriques, 2025).

Industrial automation is moving toward more intelligent and flexible systems, where the robots are controlled with smart devices and advanced software that allows more adaptation inside factories [1, 14]. Concepts such as cognitive manufacturing and digital twins supported factories to become more flexible and adjustable when changes occurred [6, 7]. Some newer robot designs also took inspiration from nature, making them more capable of performing complicated motions [15, 18].

Industrial robots in automotive assembly lines have been discussed by many researchers, who stated that robots improved part quality and made the work faster and more accurate [3, 13, 16]. The balancing of automotive robot assembly lines remained a challenge because the robots needed to be organized so that none remained idle for too long while keeping nearby workers safe [5, 12]. However, in many of those studies, the explanations of how devices actually communicated inside the robot cell were not always detailed [17, 20].

Some works examined robot control systems and communication networks, such as PLCs with Profibus for motor control and accurate signal transmission [19]. Studies on the energy efficiency of robots showed that difficulties still existed in improving motion without reducing operational time [17]. Safety improvements were also a major concern, with several studies focusing on combining multiple safety systems to reduce errors and protect workers near the robots [8].

In the South African automotive sector, discussions were mostly about the employment effects and the economic impacts of the Fourth Industrial Revolution technologies [9, 10, 11]. Companies continued to announce progress in automation programs and support for engineering talent development [23-25]. However, the actual measurement of how robots changed the performance of a single working cell was not well recorded, especially in body-work lines [13, 20].

The industrial robots acted as the main actuators within this stage, converting the programmed instructions into mechanical motions. Through coordination with peripheral devices, the industrial robots ensured the execution of tasks involving movement, alignment, fastening, and material handling, although the descriptions of these interactions were sometimes presented with varying levels of clarity (Saleheen et al., 2024). The components that were commonly combined at the device-cell stage are presented in Table 1: Components at the Device-Cell Level (Paterson & Vargis, 2024).

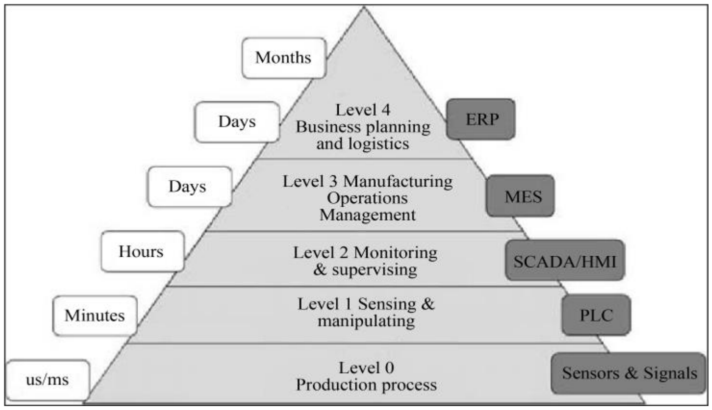

Fig. 1 Automation pyramid highlighting the device-cell level

Source: International Society of Automation (ISA), 2005. ANSI/ISA 95 Enterprise Control System Integration. ISA Standards.

Figure 1 shows the hierarchical structure of industrial automation, placing the emphasis on the device-cell level where the robots have direct interactions with the machinery and the control systems. It shows how the device–cell level could better connect with higher systems, even when there were challenges such as skill limitations and older machines [11]. Because of this, the case study provided useful evidence for people who planned or designed robotic manufacturing cells in similar, rapidly growing industrial environments [9, 25]. The device–cell level was regarded as an important layer for achieving flexibility in the production systems [21]. At this stage, the device–cell level provided the physical structure that enabled flexible manufacturing, acceptable quality, and more efficient operations, although the explanations of how these elements worked together were not consistently presented across sources [20].

Table 1. Key components at the device-cell level (Paterson & Vargis, 2024)

Components	Functions	Examples in Use
Sensor	Detects environmental variables such as pressure, proximity, or temperature	Proximity sensor in robotic welding to detect component position
Actuator	Converts control signals into mechanical movement	Pneumatic cylinder controlling robot gripper
PLC	Executes logic and coordinates hardware operations	Siemens S7 managing multiple robots in a welding cell
HMI	Provides a user interface for monitoring and manual inputs	Touchscreen panel displaying system diagnostics

The device–cell level aided machines in decision-making independently while operating, and also oversaw information by collecting data. The information added value to analysis and processes at higher levels [1, 7]. Additionally, the device–cell level was an important interface between field operations and sophisticated control systems like the Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP) systems [21]. Data generated in this level could be fed back to provide better overall production plans for enabling predictive maintenance, inventory control, and adaptive scheduling [6, 7]. Knowledge of how the device and cell worked was required for engineers who designed or optimized robotic manufacturing cells, as it enabled proper system integration, real-time control processes, and evolution toward improved performance in modern industrial settings [3, 19]. Earlier studies and reviews already showed the benefits that industrial robots could bring, and they also explained some of the new tools for robot programming and control [22, 10, 20]. However, most of them did not show a real comparison before and after a robotic upgrade inside an actual African automotive production line. Because of this, the literature clearly identified a research gap in the measurement of robot influence at the device–cell level in South African plants [9].

3. Robotic Operations in Processing and Assembly

Industrial robots have transformed how products are produced in most manufacturing fields. The robots are designed to perform repetitive, complex, or dangerous tasks with high accuracy, thereby ensuring products are of high quality, work is efficient, and production is faster. Their operations can be mainly divided into two general categories: processing operations and assembly operations (Soori et al., 2023).

3.1. Processing Operations

The processing activities were described in the literature as the operations in which industrial robots carried out various processes that changed the shape, form, or general structure of materials, and discussions often presented these activities with varying clarity [15, 18]. The welding applications were repeatedly noted as the most widespread use of industrial robots, where six-axis articulated robots were employed within the automotive and heavy-machinery sectors for spot-welding and arc-welding tasks [3, 16]. These robots were said to provide more uniform weld quality, controlled heat-input management, and reduced post-weld rework [3, 13], and examples such as the FANUC Arc Mate and the KUKA KR series appeared frequently in descriptions of this work.

In the case of machining activities, although CNC machines normally control the major machining operations, industrial robots were increasingly adopted for high-speed and light-machining processes such as deburring, polishing, and drilling [1, 2]. The versatility of robots was explained as allowing processing of multiple surfaces without the need for re-fixturing, especially in the aerospace and special-tooling sectors, although the explanations of these advantages varied across sources [16].

The painting and coating operations were also described, where spray guns mounted on robots dispensed paint with more consistent thickness and even coverage, even when working with complex geometries [3]. This improvement was linked to better aesthetic quality, reduced paint wastage, and lower worker exposure to toxic chemicals. These systems were reported as operating inside explosion-proof enclosures and, in many cases, were integrated with vision systems to adjust to different orientations of components [7, 12].

The literature also discussed laser and plasma cutting processes, where robotic cutting tools were fitted onto robots for intricate cutting work in the metal-processing and shipbuilding sectors. The advantage commonly highlighted was that robots maintained constant cutting angles and stable cutting depths with minimal supervisory intervention, although the degree to which these benefits were achieved varied depending on the specific applications described [15, 18].

3.2. Assembly Operations

The assembly-line robots were described as machines designed to handle parts with a very high level of precision and a really impressive speed, especially in operations that required very close tolerances or very fine forms of manipulation. Although the explanations about how these performances were really achieved were not always presented in a fully consistent way in the different sources, they indeed emphasized the advanced control and the careful coordination of the systems [16, 20].

Some examples described in the literature included pick-and-place operations, which were very common in automated factories. In these cases, the delta robots and SCARA robots tended to dominate the work, particularly in the electronics industry and the packaging sector, such as handling small circuit components and lightweight consumer goods [16]. These robots were said to perform thousands of cycles per hour, moving parts from the conveyors to precise positions with minimal deviation. However, although the reported figures were very impressive, the exact performance numbers were not always really consistent across the different sources [1, 5].

The fastening and screwing activities were also discussed in the literature as very important assembly tasks. In these operations, the robots equipped with torque-controlled screwdrivers actually assembled automotive components and electronic equipment, ensuring very consistent torque application and reducing the damage that could be caused by over-tightening. Indeed, this kind of automation was considered very beneficial in the high-volume production lines [5, 12].

The fitting and insertion tasks were likewise mentioned very frequently in discussions of complex assemblies, such as printed circuit boards or engine blocks. In these cases, the robots achieved a very high level of repeatability and alignment accuracy. The use of the force sensors and the vision systems also allowed an adaptive alignment and a real-time quality inspection during the insertion processes, which was actually very important for the prevention of the defects [3, 7]. In press-fit operations, the robots applied a carefully controlled force to press the components into the housings or fixtures, ensuring structural soundness and proper seating of the parts. This type of work was indeed widespread in motor-assembly lines and the medical-device manufacturing industry [13].

Compared with processing robots, assembly robots were generally positioned in areas that required greater sensitivity, more delicate handling, and real-time feedback systems. Although both types of robots were essential, the assembly robots were more focused on detailed, precise interactions with the parts [12, 20]. The collaborative robots, also known as the cobots, were increasingly used in these situations to operate safely with the human personnel, especially in applications that involved low payloads or variable part configurations. These cobots were very useful because they could adapt to changing tasks and work closely with operators without the large safety barriers [12].

The robotic processing and assembly operations were associated with several very important benefits, such as increased throughput, improved workplace safety, and reduced long-term operational costs. Indeed, the use of the robotic systems also contributed to a more consistent product quality and a very stable production environment, although the initial investment costs were sometimes relatively high [13, 17].

Their use also enabled traceability and quality control when integrated with data-collection systems and machine-vision applications [3]. As production continued moving toward mass customization and flexible manufacturing, the role of these robots was expected to continue increasing, supported by advances in sensor integration, artificial intelligence, and adaptive-control algorithms [1, 7, 14].

4. System Integration and Configuration

Industrial robots were incorporated into manufacturing plants in various configurations, depending on the complexity of production tasks, the level of automation, and the nature of human–robot interaction [12]. At the device–cell level, proper integration was required so that the robotic systems interacted appropriately with the control systems, sensors, and actuators to execute repeatable, accurate operations [3, 19]. This section elaborates on standard robotic-cell configurations and the interfaces used to manage and coordinate robotic activities [21].

4.1. Robotic Cell Configurations

There were three main configurations of the robotic cells that were widely applied in industrial environments [20, 17]. The stand-alone robotic cells were composed of a single robot that carried out a specific task independently, and these systems were typically used for low-volume processes or in situations where the integration requirements were limited [20]. Robotic painting or laser-cutting operations were often given as examples in which one robot completed the entire task inside a predefined work cell [3, 17].

The collaborative robotic cells, or cobots, were described as actually designed to operate very safely alongside human workers without the need for safety cages. These cobots were typically equipped with sensors that detected the human presence and adjusted the robot’s movement accordingly [12]. They were considered especially useful in assembly lines that required flexibility and human judgment, such as the insertion of delicate parts or the performance of quality-checking activities [12, 13].

The multi-robot cells were used mainly in high-volume production settings, where several robots worked within a single cell, either sequentially or concurrently [5, 16]. For example, in automotive welding lines, one robot positioned the car body while the others performed welding at different points [3, 16]. These arrangements required advanced coordination and synchronization using the centralized control systems [19, 21].

4.2. Interfacing with Control Systems

The effectiveness of the robot system at the device–cell level depended greatly on how well it was actually interfaced with the larger control and communication systems, although the integration itself was also really dependent on the configuration of the overall architecture [19, 21]. The Programmable Logic Controllers (PLCs) were indeed presented as the main control units of the robotic cells.

The PLCs received input from the sensors, performed the logic functions, and sent the output signals to the robots and actuators repeatedly during the operation cycles [19]. In a robotic welding cell, for example, a PLC such as the Siemens S7 actually and very precisely coordinated the robot-motion timing and the welding-current control [3].

The Human-Machine Interfaces (HMIs) provided real-time feedback on the health of the robotic cell, including diagnostics, fault alerts, and performance metrics, which were indeed very important for monitoring [12]. These HMIs also allowed for the manual overrides and the operational adjustments when really necessary, and the touchscreen HMIs were usually and very conveniently positioned on the robot-control panels for accessibility and ease of use [12, 21]

The Manufacturing Execution Systems (MES) were also described as providing a link between the factory floor and upper enterprise systems such as ERP, enabling the integration of production information, error logs, and process outcomes for real-time tracking, traceability, and optimization [21]. The industrial communication protocols, including PROFINET and other field-bus technologies, enabled device-to-device communication and supported real-time synchronization and very fast data exchange among the robots, PLCs, sensors, and other cell equipment [19].

Figure 2 shows the typical components found within a robotic cell, highlighting the integration of robots with sensors, input devices, and control applications, based on the high-level programming perspective presented in industrial robotic system studies [22].

This schematic illustrates the communication pathways between the components of a robotic cell, including the robots, sensors, actuators, and control systems, which are crucial for overall coordination.

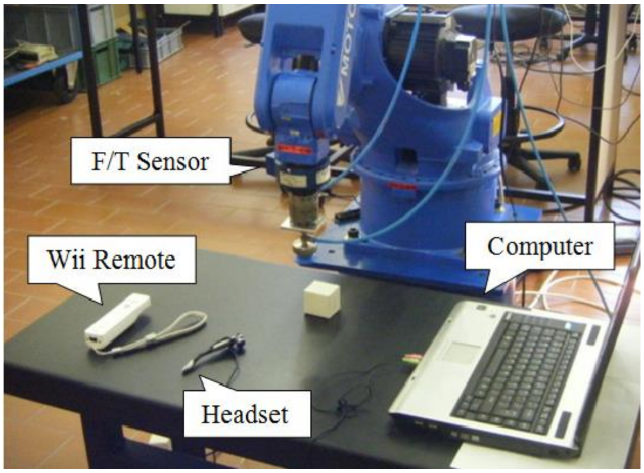

Fig. 2 Typical Industrial Robotic Cell Configuration [22]

4.3. Safety and Sensor Integration

Safety was a very critical aspect of system integration. Robot cells were typically guarded by safety fences with interlocks, light curtains, or area scanners that halted operation if a human breached the safety zone [8]. In collaborative cells, force sensors and vision systems also enabled safe interaction by detecting proximity or contact and slowing or halting robot motion appropriately [12]. Sensors such as vision cameras, proximity sensors, and force/torque sensors enhanced the robot's ability to make real-time corrections [3]. For example, in a robot pick-and-place cell, vision systems recognized the position of parts on a conveyor belt and guided the robot arm accordingly [3, 8].

4.4. Benefits and Limitations

The application of industrial robots at the device-cell level provides numerous benefits in modern manufacturing, but also presents some constraints that organisations should know about before large-scale adoption. It is actually very necessary to learn about these considerations so that fully informed decisions can be made in automation strategies, especially in cost-limited or Small-to-Medium Enterprise (SME) environments [13].

4.5. Benefits of Industrial Robots

Table 2 actually outlines the key benefits associated with the use of industrial robots in manufacturing environments, particularly at the device-cell level. These benefits span across the operational, economic, and safety dimensions. Each entry is indeed supported by the recent academic literature, emphasizing the very important role of robotics in enhancing precision, productivity, workplace safety, and adaptability in modern production systems.

These advantages are especially pronounced in industries that demand high-volume, precision-driven production, such as the automotive, electronics, and aerospace sectors.

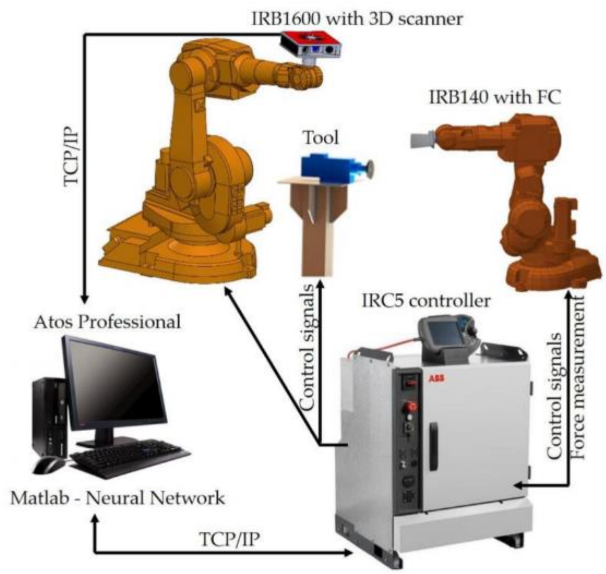

Fig. 3 Schematic of Communication Between Robotic Cell Devices

Table 2. Key Benefits of Industrial Robots in Device-Cell Manufacturing Environments

Benefits	Descriptions
Precision and Repeatability	Robots performed tasks with high precision and repeated operations thousands of times with minimal deviation, ensuring uniform product quality [1, 16].
Increased Productivity	Robots operated continuously without fatigue, leading to significant improvements in output and shorter cycle times [16, 17].
Improved Workplace Safety	Robots were deployed in hazardous environments such as welding and chemical exposure, reducing the risk of injury to human workers [8, 12].
Cost Efficiency Over Time	Although the initial investment was high, long-term cost savings were achieved through reduced labour needs, fewer errors, and lower scrap rates [1, 13].
Flexibility in Operations	Modern robots could be reprogrammed to support rapid task changes in flexible manufacturing environments [14, 16].
Data and Quality Control	Robots integrated with vision systems and sensors provided real-time data for monitoring, traceability, and quality assurance [3, 8].

4.6. Limitations of Industrial Robots

Table 3 highlights the primary limitations faced when implementing industrial robots in manufacturing environments. These challenges include financial, technical, operational, and security concerns that can affect the adoption and effectiveness of robotic systems, especially in Small and Medium-sized Enterprises (SMEs). Each limitation is supported by recent research to provide a comprehensive understanding of the barriers to robotics integration.

Table 3. Key Limitations of industrial robots in device-cell manufacturing environments

Limitations	Descriptions
High Initial Investment	The cost of robotic systems, including installation, programming, and operator training, could be prohibitive for SMEs [13].
Complex Programming Requirements	Integrating robots with existing systems and developing application-specific programs required highly skilled personnel and significant time [2, 22].
Lack of Human Judgment	Robots could not easily handle unexpected variations or intuitive decisions, especially in flexible manufacturing environments [12].
Maintenance and Downtime	Although robots reduced manual labor, they still required routine maintenance and could cause production delays if faults occurred [1, 17].
Space Constraints	Installing robotic cells often required modifying the facility layout, which could be difficult in older or space-limited plants [20].
Cybersecurity Risks	As robots became more connected through MES or digital-automation platforms, cybersecurity vulnerabilities increased if systems were not properly secured [6, 7].

While these limitations deter some organisations, they can be mitigated through proper planning, workforce training, and even phased integration strategies.

5. Case Study: Robotic Integration at Mercedes-Benz Manufacturing Plant, East London (South Africa)

The case study presented in this chapter was used to show how industrial robots operated at the device-cell level inside a real manufacturing environment, focusing on the Mercedes-Benz South Africa plant located in East London, Eastern Cape. The facility was described as being known for the use of advanced automation methods and served as one of the suppliers of Mercedes-Benz C-Class vehicles for export markets [9].

5.1. Background

The MBSA plant underwent an upgrade as part of a global investment plan by Daimler AG to modernize manufacturing activities. The production areas inside the facility were fitted with robotic systems equipped with advanced automation technologies to support improvements in efficiency, product quality, and operational safety [9]. These automation upgrades formed a large portion of the modernization initiative and created a greater need for structured coordination and integration across the production line [24, 25].

5.2. Robotic System Setup (Lorenz & Kraemer-Mbula, 2021)

The robotic arrangement in the plant involved multi-robot cells located in the main production areas. These cells operated mainly in the body-in-white welding zones, where articulated robots carried out welding functions in coordinated sequences [3, 16]. The robots used in the facility came mainly from the KUKA and FANUC product lines, equipped with welding and handling tools required for the production tasks [3, 16].

The control structure for the robotic equipment involved the integration of Siemens PLCs, touchscreen HMIs, and a central manufacturing-execution system. This configuration created an environment where operations were coordinated in real time and production events were monitored on the control platforms [19, 21]. The plant also deployed vision systems and proximity sensors that assisted with alignment of components, weld checking, and product-quality assurance [3, 12].

5.3. Operations Performed (Moshikaro-Amani and Mahlangu, 2024)

The activities carried out by the robotic systems involved spot-welding tasks, in which the robots applied weld points to the vehicle body structures with the required precision [3, 16]. The systems also handled the movement of large body parts from one workstation to the next, reducing the physical-handling demands on workers and helping maintain safe conditions around the production lines [11, 12].

In the paint and finishing areas, the robots applied sealant materials along seams and joints, creating a uniform layer that supported structural tightness and production consistency as observed in automated automotive facilities [3, 13].

6. Outcomes and Improvements

Table 4. Outcomes and areas of improvement

Areas	Improvements
Product Quality	A significant reduction in weld defects and improved dimensional accuracy was reported after robotic integration [3, 13].
Production Time	Cycle times were reduced by more than 20%, contributing to higher vehicle output per shift.
Safety	Reduced human participation in hazardous welding and handling environments resulted in fewer workplace incidents [8, 12].
Data Traceability	Integration with MES and sensor systems enabled full traceability of each production step for monitoring, compliance, and quality assurance [1, 21].

6.1. Site Visit

Pictures of the site visit are shown in Figure 1. During the visit to the Mercedes-Benz South Africa plant, the authors had an opportunity to operate an industrial robot under the supervision of a production senior cell technician. They actually gained firsthand experience with robot control techniques and observed the maintenance procedures implemented to ensure the system's reliability and reduce downtime. This hands-on exposure indeed offered valuable insights into practical robotic operations and the critical importance of safety in an industrial setting.

Fig. 4 Site visit (view 1)

Fig. 5 Site visit (view 2)

As Mercedes-Benz South Africa expanded and modernized its manufacturing operations through a major investment program, the integration of industrial robots remained indeed a central part of the overall production strategy [9]. The introduction of robotics brought several changes to the work environment, which were also observed during the site visit. One identified issue involved the very high electrical power consumption, since the robotic systems demanded a significant amount of energy during operation. MBSA investigated strategies to reduce energy usage, as improved efficiency also supported operational cost reductions and sustainability objectives [18].

Another issue observed at the plant involved maintenance challenges and unplanned system downtime. Although the robots performed the programmed tasks very effectively, technical failures occasionally led to production interruptions. To address this issue, MBSA introduced predictive-maintenance approaches to detect early fault indicators, allowing the equipment to maintain steadier operation [1, 7].

For the robotic systems to operate at the expected performance level, effective alignment with the PLCs, sensors, and MES platforms was required. Handling these systems also demanded advanced technical competencies in programming, troubleshooting, and automation maintenance. A skill gap still existed in the areas involving the higher-level automation technologies. MBSA attempted to reduce this gap through intensive training programs facilitated by the Mercedes-Benz Learning Academy as part of its long-term workforce development plan [25].

6.2. Women in Robotics and Technical Roles at Mercedes-Benz South Africa

The company demonstrated a strong record of supporting women in engineering and automation roles. One example was Nyameka Tshangana, who began her career at MBSA in 2004 as an electrical apprentice and later indeed became the first female Specialist Electrical Technical Instructor at the training academy. Under her leadership, the academy also trained approximately 400 women in technical occupations such as millwrights, motor mechanics, and auto-electricians [25].

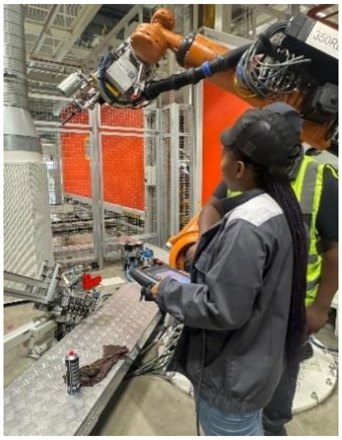

Fig. 6 Site visit (view 3)

The workplace initiatives also promoted a more inclusive environment, indeed. The Pretoria Women's Forum organized the events during Women's Month to support the professional participation of women within the industrial workforce [24].

Additionally, Mercedes-Benz Financial Services partnered with the Commercial Transport Academy in the Women Inspiring Women in Transport (WiWiT) Programme, which offered mentorship and business-skill support to women operating in the transport sector [23].

6.3. Future Trends in Robotic Cells

The progress in industrial automation actually brought about a broad movement toward robotic cells that incorporated digitally enabled capabilities, indeed. Future developments in this area also relied on technologies such as artificial intelligence, the Internet of Things, and advanced human–robot cooperation. These technologies indeed guided the formation of the robotic systems that actually adjusted to the changing production tasks again [7, 14].

6.4. Artificial Intelligence and Machine Learning

The artificial intelligence actually influenced how the robots processed the information and reacted to the dynamic conditions inside the production system, indeed. The machine-learning methods also allowed the robotic cells to adapt to part variations, manage tasks autonomously, and detect irregular events without explicit programming [6, 7]. These capabilities indeed supported the custom manufacturing and the high product-mix environments very effectively.

6.5. Collaborative Robots (Cobots)

The use of collaborative robots actually enabled the work zones where the human workers and robots operated simultaneously, indeed. These cobots also included sensors, force-feedback systems, and built-in safety functions, which significantly reduced the need for protective cages [12]. They indeed supported the expansion of automation in small and medium enterprises, given their spatial limitations and processes that require human judgment [13].

6.6. Adaptive Manufacturing Systems

The robotic cells were actually increasingly connected to the adaptive manufacturing systems that used the real-time information from the sensors and the enterprise data platforms to adjust the production processes indeed [7]. This type of configuration also aligned with Industry 4.0 concepts and again reduced manual adjustments during product-change scenarios [6].

6.7. Cloud Robotics and Edge Computing

As the volume of factory-floor data increased, the robotic systems continued shifting toward distributed processing through edge computing and cloud support. The cloud resources enabled high-level functions such as vision-based data analytics, while the edge devices also handled motion control to maintain timing accuracy very effectively [6, 7].

6.8. Digital Twins and Simulation

The digital twin models actually served as virtual representations of the robotic cells and were used to evaluate cell performance before physical deployment, indeed. When connected to IoT devices and MES platforms, these models also assisted with predictive maintenance and really reduced configuration errors during system installation [6].

6.9. Sustainability and Energy Efficiency

The environmental demands actually encouraged the design of the robotic cells, which reduced energy use and associated production waste, indeed. These improvements also included controlled-power drives and energy-saving operational modes, which were implemented very effectively [17]. Such approaches indeed aligned with the future sustainability goals in the manufacturing industry again [7].

6.10. General Discussion

This article actually discussed industrial robot operations at the device–cell level and explained how robotic systems indeed supported processing and assembly tasks. The findings indicated that the robots improved accuracy, performance consistency, and product quality very effectively [3, 13]. Additionally, the robots reduced human exposure to hazardous tasks while maintaining a steady workflow and production throughput [12]. The case study of the Mercedes-Benz South Africa plant showed that the robotic implementation enhanced body-in-white operations, reduced cycle-time interruptions, and promoted workforce development initiatives [9]. However, the challenges remained, including energy consumption, limited advanced-automation skills, and financial constraints affecting large-scale adoption [13, 17]. The research also identified several gaps: the robots still struggled with unstructured tasks; the long-term operational costs in SMEs were not well documented; and the adaptation through learning required further development, indeed. The increased connectivity also introduced concerns relating to cybersecurity and digital-system vulnerability again [7].

7. Conclusion

The industrial robots at the device–cell level have indeed transformed modern manufacturing by improving precision, repeatability, flexibility, and operational efficiency in production tasks [1]. Together with the sensors, actuators, PLCs, and HMIs, the robots formed the central automation infrastructure for processes such as welding, painting, and component assembly, operating very effectively [3, 19]. The Mercedes-Benz South Africa case also confirmed measurable improvements in quality monitoring, safety performance, and production throughput through the deployment of a multi-robot cell.

As manufacturing continued to shift toward intelligent and adaptive operations, technologies such as artificial intelligence, collaborative robotics, and digital-twin models also guided future progress [6, 7, 14]. These innovations indeed supported customized production, sustainability objectives, and improved system resilience very effectively.

In a nutshell, industrial robots were regarded not only as automation equipment but also as strategic investments that promoted competitiveness and innovation in manufacturing environments. This development also created the need for future engineering professionals to acquire multidisciplinary skills in mechanical, electrical, and software domains to support system integration in advanced robotic production environments [22].

Data Availability

The data used to support the findings of this study are included in the article.

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