Smart Factories Individual Assignment: Collaborative Robots (Cobots) and Industry 4.0

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Abstract. The rise of Industry 4.0 has reshaped the manufacturing landscape, blending cutting-edge technology with automation. Collaborative robots, more commonly referred to as cobots, have emerged as critical game-changers in this new industrial era. This research paper aims to delve deep into the world of cobots, exploring their advanced mechanics, sensor-rich capabilities, and adaptive control systems to examine their pivotal role in human-robot teamwork. This automation technology is of paramount importance in showcasing how humans and machines can collaborate seamlessly to achieve greater operational flexibility, heightened productivity, and the ability to adapt resources dynamically in smart factories. Thus, cobots act as a cornerstone in realizing Industry 4.0 goals, bridging the gap between human creativity and technological advancement.

Keywords: *Collaborative Robots · Cobots · Industry 4.0 · Automation · Smart Factories · Mechatronics · Technology · Safety · Performance · Human-Robot Interaction· Manufacturing*

1 Introduction

Industry 4.0 is a transformative approach that shifts manufacturing from the traditional machine-dominated processes to digital manufacturing with automation thoroughly implemented in all operations. To successfully implement it, a comprehensive understanding of its standards and goals is essential to ensure awareness and commitment [1].

The ongoing evolution of Industry 4.0 concepts and applications suggests that a systematic approach for assessments and evaluations is needed to expedite its adoption and whose responsibility falls on the research community to build the necessary technological infrastructure, encompassing physical systems, management models, business models, and well-defined scenarios, to facilitate its implementation [2].

Experts predict that this shift encourages manufacturing industries to adapt to the ever-changing customer demand for customisation and maintain a competitive edge. This helps promote emerging technologies like collaborative robots, Industrial Internet of Things (IIoT), autonomous decision-making systems, augmented reality, and machine learning to elevate the KPI's.

2 Literature review and Background

Cobots are a relatively new technology in the contemporary industrial automation space, but they have already been making a notable impact on the manufacturing and production industries. The concept was first introduced in 1996 by J. Edward Colgate and Michael Peshkin with a US patent in 1997. At this time the cobots still had no internal source of motor power which only became available in 2004. In the early 2010s this technology started to become mainstream and now it's a driving growth, albeit facing some challenges in terms of acceptance and security [3].

In contrast to conventional robotic systems, collaborative robots show the distinguishing capacity to engage in co-occupational tasks alongside human workers, which allows for a new and more engaging workplace design. This contrasts with the autonomous robots which are hard-coded to repeatedly perform one task, work independently and stay stationary. The human-robot collaborative work cell is conceptualized as a hybrid workspace wherein the cobot is programmed to dynamically adapt its behaviour to align with the motion of the human operator when performing any given task resulting in an optimized performance by promoting communication between both parties to ensure safety and quality [4].

Cobots can have multiple applications across all industries and its sectors, namely assembly, dispensing, material handling, finishing, machine tending, palletizing, dispensing, welding, material removal and quality inspections [5].

As per data from the International Federation of Robotics, the automotive industry stands as the primary sector investing in industrial robots and cobots, constituting 28% of the total installations. It leads ahead of the electrical/electronics sector (24%), followed by metal and machinery (12%), plastics and chemical products (5%), and food and beverages (3%) [6]. These numbers are according to expectations as most operations in vehicle production are highly repetitive and can be performed with ease through automation.

3 Architecture and Technology Overview

Collaborative robot models are projected to be mobile multitaskers since they're usually small, ergonomic, and lightweight, thus able to be easily moved around the manufacturing floor or facility. Additionally, many models can be programmed for new operations by hand guiding the arm through steps at the point of need for increased flexibility. This added value is helpful for small and medium-size manufacturers, especially those in high-mix/low-volume and just-in-time (JIT) settings. The technology's hardware design is complex and carefully thought of to incorporate sensors and actuators, video and information processing, planning as well as technologies that ensure safety, predictability and security of the solution.

Cobots come in a range of sizes, payload capabilities, maximum reach distances, and operating speeds. Though compactness is highly favoured, the larger models can mount to the floor (or ceiling, or wall, depending on the wanted application) which can be advantageous. Payload limits are generally between about 3 and 16 kg, though a model has already been developed to lift at most 35 kg. The common values for reach range from 500 mm to 900 mm. Operating speed is usually set to 1 m/s or even less depending on the proximity to the worker, but the maximum is about 1.5 m/s. Many use six-axis motion, allowing for a more sophisticated movement around and between other equipment [7].

Even now, the industrial development of cobots is still ongoing and of high value (due to the numerous benefits that cobots provide in the manufacturing landscape), made possible by collecting highly granulated data over multiple companies and multiple industry sectors to optimize further research on reaction times, exact movement patterns and even capabilities to imitate humans as they work harmoniously in sync. However, a focus on how to overcome some of the advantages inherent in the usage of cobots is needed as well, due to some of the limitations of the technology. These limitations are fundamentally related to safety protocols, cost evaluation and some KPI´s, like productivity, utilization, cycle time and wait time.

Based on all the information provided, key attributes for this realm of engineering include mobility, adaptability, connectivity, actuation, consistency, and safety. Mobility enables cobots to navigate without rigid safety barriers, while adaptability relies on sensors for task-specific adjustments. Connectivity facilitates communication with operators and other robots through efficient and fast Human-Machine Interfaces. Actuation ensures safe and efficient motion trajectories. Cobots are generally reliable, but the integration of sensors introduces an unavoidable (potential) risk for system failure. Safety is crucial, and must be achieved through features like force monitoring, passive compliance, and overwork detection, fostering a healthy and productive human-robot cooperation [8].

4 State-of-the-art

In scientific writing, the term "state-of-the art" refers to our current understanding of a specific topic. This understanding is built by analysing existing research and related studies, articles, and theses to give us a broad view of the topics that have been already widely explored and the research gaps and challenges that should be fulfilled in the future.

Human factors seek to understand interactions within systems and optimize both human well-being and system performance. Past research shows human factors significantly affect productivity and automation success. Neglecting human factors leads to failed implementations and operator frustration, while focusing on them improves efficiency.
The fourth industrial revolution must prioritize human-centered work environments, fostering human-automation symbiosis [8].

Recent literature reviews [9] have addressed collaborative applications. However, they often overlook the complex interplay between human operators and cobots, failing to explore how this interaction impacts Industry 4.0 technologies. Previous reviews primarily focus on cobot technologies, safety features, and algorithmic influences, though the crucial concept of human factors in the context of modern production systems and cobots remains unexplored with notable potential for a breakthrough. An interesting research prospect is to investigate these interactions as researchers and practitioners seek to create collaborative systems that align with the increasingly competitive demands of modern production systems [8].

In 2018, the dominant players in the Collaborative Robotics market were Universal Robots, with headquarters in Odense, Denmark, and Rethink Robotics, founded by Rodney Brooks from the Massachusetts Institute of Technology (MIT). However, these new robot models, despite their rapid growth, still represent a relatively smaller segment compared to traditional industrial robots facing some barriers in their widespread adoption in industry.

Today, the market offers a range of collaborative robot solutions from various manufacturers, each with its unique design and structure. Their effectiveness in production environments relies on their capacity to integrate technology for process and system enhancements, favouring systems that facilitate interaction between robots and humans for collaborative roles within their production lines [10].

A thorough analysis of multiple articles and research projects shows that the market for cobots in manufacturing is expanding, and academic research on the topic has grown rapidly in recent years. Cobots have been studied in five key manufacturing strategies: safety, product/system design, workplace layout, task scheduling, productivity, and ergonomics. These findings indicate that cobots effectively combine human and machine skills, making them pivotal in the future of human-robot interaction, especially within the context of Industry 4.0.

To conclude, as technology advances, cobots are expected to incorporate more AI capabilities, allowing them to perceive and collaborate intelligently, almost as humans. Trends for the future include modularization and structural imitation, enhancing their adaptability and security in complex service scenarios. Cobots are likely to find applications in surgery, rehabilitation, and various business domains, offering maximum utility. This continued development promises significant economic, commercial, and technological advantages and this constitutes the new paradigm [11, 12].

5 Market and Commercial Offer

After exploring in detail the background that lead to the emergence of Cobots and its development as a key factor in reaching the goals set by Industry 4.0, it is important to review the market and its dimension. Firstly, a brief summary will be presented followed by a more in-depth evaluation of relevant topics, such as Applications, Industry analysis, Regional analysis, and Applications. Most growth rates were forecasted by Grand View Research.

According to Interact Analysis' 'Global Collaborative Robot Market – 2023' report (Figure 1), market revenue grew considerably by 17.2% in 2022, accompanied by an increase of shipments of 21.9% (which corresponds to 37,780 units). Due to the COVID-19 pandemic, revenue dropped in 2020 but the following year was quite promising with the highest year-on-year growth reported (43.1%). Unfortunately, this maximum dropped by almost 20% and growth is predicted to remain steady but still optimistic in a medium to long-term forecast. An important parameter to interpret is the CAGR (compound annual growth rate) which is anticipated to be 27% over the next five years, varying slightly with the geographical location [13]. It should be noted that the forecast varies between sources, but with little relative error.

In regard to Payload Capacity Insights, it's important to start discriminating the data into 3 groups: up to 5kg, range between 5 and 10kg and more than 10kg. According to the data in Figure 2, the lighter cobots dominate the market with up to 44% share in 2022, with a promising growth throughout the forecasted years. At the same time, the segment with a payload capacity above 10kg is predicted to have a growth rate of approximately 33.0% over the forecast period. These heavier robots are capable of handling larger and more precise tasks, which could justify its driving growth [14].

Attending to the general cobot characteristics it is easy to justify that the Assembly, the Material Handling and the Pick & Place segments will be the most used applications across the time horizon, due to the repetitive nature of the tasks at hand. Though, other areas are expected to grow, namely Quality Inspection and Painting.

Focusing on the Regional Analysis (Figure 3), the data suggests that Europe registers the most extensive use of cobots (30%). However, it is anticipated that Asia Pacific will exhibit a remarkable CAGR of over 34% through 2030 and emerge as a major competitor. Leading the charge in this transformation will be countries such as the United States, Mexico, Germany, China, Brazil, India, Japan, Canada, and the United Kingdom [14].

Finally, the focus is on Industry Analysis (Figure 4) and, as expected, the automotive industry is leading, making up about 24% of the market, and it's likely to stay competitive in the following years. Additionally, the electronics and electrical industry is also expected to grow, and other sectors like food and drink, retail, metals and machining, and rubber and plastics will be holding a significant share of the cobot market too [14].

The data highlights some driving factors for growth (rising demand for automation and significant return on investment), as well as restraining factors (lack of skilled workforce and high capital expenditure, or even government regulations) that hamper the implementation and success of this technology. In response to this, the key industry players of this sector are doing their best to maintain their competitive edge by investing on innovation and diversity. Some of the most renowned leading players are listed below:

- Universal Robots (Denmark);
- ABB (Switzerland);
- AUBO Robotics (U.S.A.);
- K2 Kinetics (U.S.A.);
- Rethink Robotics (U.S.A.);
- FrankEmika (Germany);

- Fanuc Corporation (Japan);
- Neura Robotics (Germany).

As the level of automation grows, the need for a more diverse range of options for cobot customisation arises leading to an increase in the number of suppliers and available products in the market. To better understand the current market, an example of a cobot from a renowned cobot producer (UFACTORY) will be presented, with a detailed overview of its 3D design, hardware specifications and most suitable control box settings (Figures 5 to 7, respectively).

Additionally, this commercial Cobot is prepared to be equipped with extra components depending on the operation, namely a Gripper, a Vacuum Gripper, a BIO Gripper, a 6 Axis Force Torque Sensor, and a Linear motor. In terms of software, it was projected to work seamlessly with the UFACTORY Studio software with a user-friendly interface, and it's a certified reliable product including a 1-year warranty against manufacturer defects [15].

Some notable recent developments include a partnership announced in May 2023 between Universal Robots A/S (Denmark) and Denali Advanced Integration with the aim of propelling the cobot technology to major businesses all around the world offering end-to-end integration and service support. Another recent strategic partnership (October 2022) is between ABB (Switzerland) and a startup Scalable Robotics to provide more user-friendly systems without any coding, particularly for welding [16]. Other recent major investments made in July 2023 cover 30M USD to develop and deploy novel cobots by Collaborative Robotics, and Neura Robotics who raised 55M USD to fund cognitive robotics [17].

6 Conclusions

Summarising, this paper has shed light on the pivotal role of collaborative robots (cobots) in the context of Industry 4.0 and Smart Factories. This is a technology with extreme potential and multiple applications across areas like safety, design, scheduling, and ergonomics, all of which contribute to the optimization of human-robot collaboration, reduction of cycle time and reduced costs long-term due to the high return on investment.

Cobots have been undergoing a steady evolution ever since their first introduction and now they can even adapt to the changing needs of the market and offer intelligent collaboration possibilities. This progress places them at the forefront of modern industry.

Therefore, this technology plays a key role in the transformation of the manufacturing processes, and, in general, the whole industry sector, transitioning to the era of highly automated and smart processes capable of cooperating with human workers.

Annexes

Figure 1 - Interact Analysis' 'Global Collaborative Robot Market – 2023'

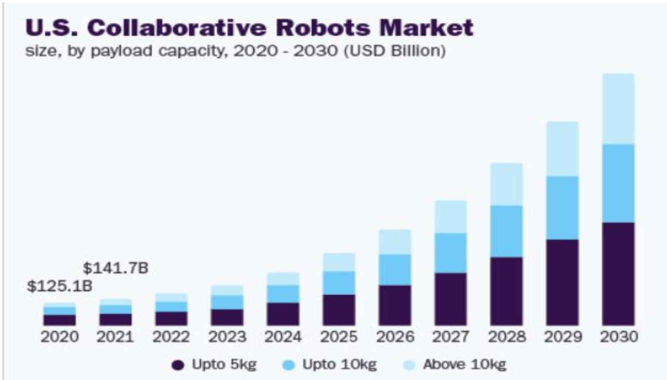

Figure 2 - Collaborative Robots Market, by payload capacity

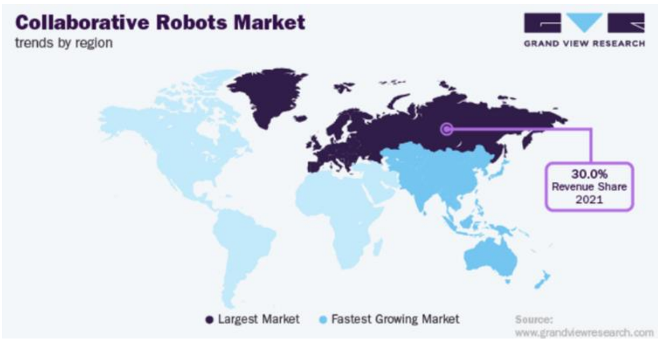

Figure 3 - Collaborative Robots Market, trends by region

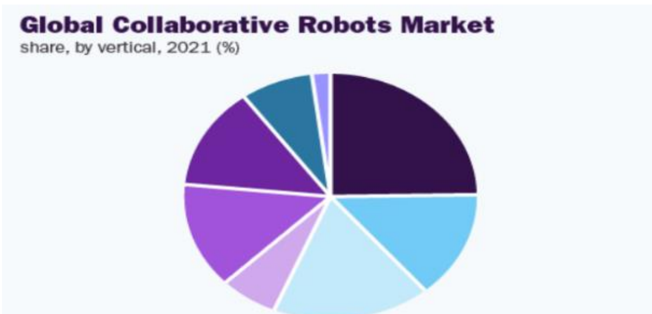

Figure 4 - Global Collaborative Robots Market, by Industry

Figure 5 - Example of a commercial cobot by UFACTORY.

XARM	ROBOT SPECS
*Ambient Temperature Range	0-50℃
Power Consumption	Min 8.4 W, Typical 200 W, Max 400 W
Input Power Supply	24V DC， 16.5A
Footprint	Ø 126 mm
Materials	Aluminum, Carbon Fiber
Base Connector Type	M5*5
ISO Class Cleanroom	5
Robot Mounting	Any
End Effector Communication Protocol	Modbus RTU(rs485)
End Effector I/O	2*DI/2*DO/2*AI/1*RS485
Communication Mode	Ethernet

Figure 6 - Cobot SPECS.

	AC CONTROL BOX	DC CONTROL BOX
Input	100-240VAC 50/60Hz	24VDC
Output	24VDC 20.8A	24VDC 672Wmax
Weight	3.9kg	2.6kg
Dimension(L*W*H)	285*135*101mm	262*160*76mm
Control Box IO	16*DI/16*DO/2*AI/2*AO	16*DI/16*DO/2*AI/2*AO
Communication	Ethernet, RS485 Master*1, RS485 Slaver*1	Ethernet, RS485 Master*1, RS485 Slaver*1

Figure 7 - AC/DC Control Box settings

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