INDUSTRIAL SOCIAL ROBOTS (SOBOTS) TO ENHANCE SMART PRODUCTION SYSTEMS

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Abstract: This paper explores the potential use of social robots in smart manufacturing industries, presenting several use cases where such robots could bring benefits. The design considerations for developing social robots that can effectively operate in industrial production environments are also discussed, using the TRIZ methodology. Furthermore, the paper highlights the advantages of using social robots together with traditional robots in some use cases. The aim is to provide insights on how social robots can be designed and utilized to improve efficiency, safety, and worker satisfaction in smart industrial production systems.
Keywords: social robots, smart manufacturing, TRIZ, design considerations, implementation cases.

1. Introduction

Most of us imagine that social robots are used in tasks that are only outside industrial production. In principle, this has happened till now, but it is time for new innovations! We have to be creative and search for new areas of applications of social robots. To overcome mental barriers, we have to see a social robot as the 3rd generation of robots, also called robots for humans, and coined as cobiots [1].

Any robot that has collaborative capacities, cognition, the capacity to display emotion, the possibility to connect in various ways with other technologies and with humans, extended perception of the environment, and a high versatility can be categorized as being a cobiot. A classical industrial robot arm that comprises such capabilities falls into the category of social robots, too. Though, social robots do not necessarily have to look like a human.

The social dimension of machinery in industrial production is a promising field that has gained increasing attention in recent years [2], [3]. Social robots, with their ability to interact with humans and their surroundings, can bring new levels of flexibility and adaptability to some industrial operations. However, designing social robots for industrial production presents unique challenges that must be addressed to ensure safe, efficient operation, and cost-effectiveness. This paper presents a comprehensive review of the potential use cases of social robots in manufacturing industry and identifies the key design considerations for developing effective social robots. The paper also explores how traditional industrial robots can be complemented by social robots to enhance their capabilities and performance. The paper proposes the use of TRIZ as a design methodology [4] to address the complex challenges associated with developing social robots for industrial production. It ends with conclusions and future researches. Note: Images in this paper are original, being created with AI-based stable diffusion algorithms.

2. Methodology

The core research question of this paper is: How can social robots be effectively designed and integrated into manufacturing industry, and what are the potential benefits of using social robots in conjunction with traditional robots?

To answer to this research question, this paper proposes a methodology in five steps, as follow:

- Literature review: Conducting a comprehensive review of existing literature on social robots and see their potential use in the manufacturing industry.
- Expert interviews: Conducting interviews with experts in robotics and manufacturing to gain insights into the potential use cases and benefits of using social robots in conjunction with traditional robots and the design considerations for such integration.
- Use cases: Studying existing examples of social robots in industrial settings, brainstorming, and user-centered design to identify potential uses cases of social robots in industrial production and analyzing the design features and benefits of these robots.
- Design thinking methods: Using design thinking methods such as TRIZ to generate ideas and solutions for effectively designing and integrating social robots in the manufacturing industry.
- Evaluation and analysis: Analyzing the advantages and disadvantages of integrating social robots with traditional robots in manufacturing, and drawing conclusions and recommendations based on the findings.

The proposed methodology aims to provide a better understanding of the potential benefits and drawbacks of using social robots in conjunction with traditional robots in the manufacturing industry, while also offering recommendations for effective design and integration of social robots in this context.

3. Literature Review

We conducted a comprehensive literature review by searching Clarivate Analytics and SCOPUS databases using keywords such as "social robots in industrial production", "social robots in manufacturing", and "social robotics in industry". The returns with these keywords clearly indicate that integration of social robots in manufacturing processes was not yet been studied. However, there are two publications that report researches about the consideration of social robots as companions and co-workers for human workers with disabilities [5], [6], and one publication that investigates the social implications of robot co-workers in industrial settings [7].

It is evident that there is limited research on the integration of social robots in manufacturing processes. Further research is needed to explore the potential benefits and drawbacks of integrating industrial social robots, and to develop best practices for their implementation.

4. Expert Interview

In order to gain insight into the perspectives of professionals in the manufacturing industry regarding the potential use of social robots in industrial production, an online survey was conducted with 230 engineers and managers. The survey aimed to investigate their perceptions on the use of social robots in manufacturing, as well as the benefits and concerns associated with their implementation.

The results indicated that 76% of the respondents believed social robots could enhance productivity and efficiency in various areas of the manufacturing enterprise. This improvement is not limited to the production floor but also extended to other primary and secondary processes of the value chain. In addition, 64% of respondents felt that social robots could reduce the risk of workplace accidents, and 53% believed that social robots could free up workers to perform more complex tasks. However, 42% of respondents expressed concern about potential technical and organizational challenges in relation to social robot implementation.

The expert interviews revealed that there are several potential use cases for social robots in manufacturing and subsequent processes, including assembly, inspection, packaging, material handling, employee training, etc. They will be highlighted in the next section of the paper. Experts also emphasized the importance of designing social robots with safety in mind, as they will be working alongside human workers in many cases. There was consensus among experts that social robots have the potential to bring some benefits, but they should be integrated strategically to avoid disruption to existing workflows. Experts also pointed out that there are several technical issues to consider when designing industrial social robots, such as easy programming, flexibility, adaptability, scalability, and affordability.

5. Use Cases

This section provides a summary of the use cases identified in the survey. To accommodate space limitations, some more familiar use cases are presented succinctly, while others are discussed in greater detail. It is important to approach this with an open mind and consider the potential benefits that social robots can bring to industrial production. As smart platforms with unique mechanical and control designs, social robots offer novel solutions to longstanding challenges in manufacturing. Thus, it is useful to explore and envision the practical implementation of these use cases. The next part of this section presents new ways to utilize social robots in manufacturing enterprises, as they have been imagined by interviewees.

- *Quality control*: Social robots can be used to assist with quality control and monitoring the production line, and performing inspections to ensure that products are manufactured to the required standards.
- *Maintenance and repair*: Social robots can be used to perform routine maintenance and repairs, reducing the need for human technicians, and improving the efficiency of the maintenance process.
- *Collaborative working*: Social robots can be used to facilitate collaboration between employees, helping to improve communication and teamwork. For example, they can be used to provide real-time updates on the status of projects and assist with team meetings.
- *Safety and security*: Social robots can be used to monitor and secure the workplace, alerting employees to potential hazards and helping to prevent accidents and incidents.
- *Inventory management*: Social robots can be used to assist with inventory management, tracking the movement of goods and materials within the factory, and ensuring that supplies are properly restocked.
- *Logistics and supply chain management*: Social robots can be used to help manage the logistics of getting goods and materials to and from the factory, reducing the risk of delays and ensuring that everything is delivered on time.
- *Employee wellness and morale*: Social robots can be used to promote employee wellness and boost morale, for example by organizing games and activities during breaks, or by providing a friendly and supportive companion for employees.
- *Employee engagement and feedback*: Social robots can be used to gather feedback from employees,

helping to identify areas for improvement and encouraging open communication between management and workers.

- *Employee training and onboarding*: Social robots can be used to train and onboard new employees, providing them with a safe and controlled environment to learn about the company and its procedures.
- *Customer service and engagement*: Social robots can be used to interact with customers and provide information about the company and its products, helping to build brand awareness and customer loyalty.
- *Customer service*: Social robots can be used to provide customer service, assisting customers with product information, orders, and technical support. They can also be used to provide a unique and innovative customer experience, helping to differentiate the company from its competitors.
- *Market research and data collection*: Social robots can be used to collect data about customer preferences, behaviors, and opinions, providing valuable insights for the company.
- *Events and tradeshows*: Social robots can be used to interact with attendees at events and trade shows, providing them with information and demonstrating the company's products and services.

As one can observe, managers and engineers do not see yet the implementation of social robots in hard manufacturing operations, where collaborative robots or traditional industrial robots do a great job and are more cost-effective. However, the survey revealed areas in manufacturing enterprises where social robots can do very good jobs, alone or assisting human personnel.

5.1. Highlights on Inventory Management

Industrial social robots can play a vital role in inventory management by providing companies with real-time tracking of goods and materials movement within the factory. Inspirational images for this use case are shown in Fig. 1.

Fig. 1. Social robots in inventory management.

These robots are equipped with cameras and sensors to monitor supplies and raw materials and alert managers to potential shortages or discrepancies. They can also keep track of inventory levels and ensure that supplies are properly restocked. Automating the inventory management process with social robots increases efficiency, accuracy, and reduces the risk of stockouts, thereby improving productivity and saving time and resources. Moreover, industrial social robots can interact with workers and stakeholders, gathering feedback and data to optimize the supply chain and improve decision-making for seamless and efficient factory operations.

5.2. Highlights on Logistics

Industrial social robots have potential applications in logistics and supply chain management to manage the movement of goods and materials. They can be equipped with cameras, sensors, and GPS technology to track shipments, monitor delivery times, and ensure on-time delivery. Social robots can also interact with workers and stakeholders to provide information and help resolve issues. By providing real-time data and feedback, social robots can enhance the overall supply chain management process, providing valuable insights on suppliers, shipments, and delivery times that can optimize the supply chain and reduce costs. Fig. 2 could inspire for the use of social robots in logistics.

Fig. 2. Social robots in logistics.

5.3. Highlights on data collection

Social robots can be used in market research and data collection for manufacturing enterprises to gather information about customer preferences, behaviors, and opinions. These robots are equipped with speech recognition and natural language processing technology that enable them to interact with customers and collect data about their needs and preferences. By analyzing this data, companies can inform product design, marketing strategies, and customer service initiatives.

Fig. 3. Social robots in data collection.

Social robots can also be used to monitor customer interactions with products and services in real time, providing insights for business decisions and innovation. They are connected with human staff to provide real-time feedback. Furthermore, these robots can engage with customers in retail settings, providing product demonstrations and answering questions to increase brand awareness and customer engagement.

5.4. Highlights on Employee Training

Social robots have the potential to transform employee training and onboarding by providing a safe and interactive learning environment. With interactive interfaces and natural language processing technology, social robots can deliver training programs that are engaging and allow new employees to learn about company policies, procedures, and products. By using social robots for training and onboarding, companies can improve the overall experience for new employees, making it easier for them to assimilate into the company culture and learn about their roles. Social robots can also provide ongoing support to employees by delivering training programs and providing feedback on performance, helping employees to develop new skills and advance in their careers. Fig. 4 illustrates some use cases from employee training with social robots.

Fig. 4. Social robots in employee training.

5.5. Highlights on maintenance and repair

Social robots equipped with sensors, cameras, and AI algorithms can be used for maintenance and repairing tasks, such as routine checks and cleaning, to reduce the need for human technicians, improve efficiency and reduce costs. The robot can inspect machinery and identify signs of wear or damage, generate maintenance requests, and alert human technicians to perform repairs. They can also perform routine cleaning tasks, such as wiping down machinery, reducing the risk of contamination, and improving overall hygiene. Social robots can provide real-time updates on the status of machinery, helping to identify potential problems before they become more serious and lead to costly downtime. In Fig. 5 one can see several examples of social robots involved in maintenance and repairing.

Fig. 5. Social robots in maintenance and repairing.

5.6. Highlights on Quality Control

Social robots can be implemented in quality control by using cameras, sensors, and AI algorithms to monitor the production line and perform inspections. These robots can detect defects and inconsistencies, alerting human technicians to perform necessary adjustments or repairs. Social robots can also perform sophisticated tasks, such as measuring the size and weight of products, checking proper packaging, and labeling, and ensuring that products meet specific standards and regulations. By automating routine tasks, human technicians can focus on problem-solving and quality improvement. Fig. 6 shows examples of social robots in potential use cases for quality control.

Fig. 6. Social robots in quality control.

5.7. Highlights on Customer Service

Social robots are useful in customer service to offer information, support, and assistance. They can handle different tasks like answering frequently asked questions, providing product details, and taking orders. Equipped with AI algorithms and natural language processing, social robots can interact with customers, understand their requests, and respond human-like. These robots can also provide unique and innovative customer experiences, such as performing demonstrations, giving interactive tours, or entertaining customers with games. By automating routine tasks, human customer service reps can focus on complex and valuable tasks like resolving complaints and offering personalized support. It is important to note that social robots should be used in combination with human representatives to provide personalized and empathetic support when required. Suggestive cases are presented in Fig. 7.

Fig. 7. Social robots in customer service.

5.8. Highlights on Communication

Social robots can facilitate collaboration and communication between employees by providing real-time project updates and serving as a platform for remote meetings. They can also promote teamwork and build team morale through interactive activities and games. However, social robots should be used in conjunction with other collaboration tools and not be seen as a replacement. Other collaboration tools like video conferencing software, online project management tools, and instant messaging platforms should still be utilized. The use of social robots can complement other communication tools and enhance the overall collaboration experience. Some illustrative examples are shown in Fig. 8.

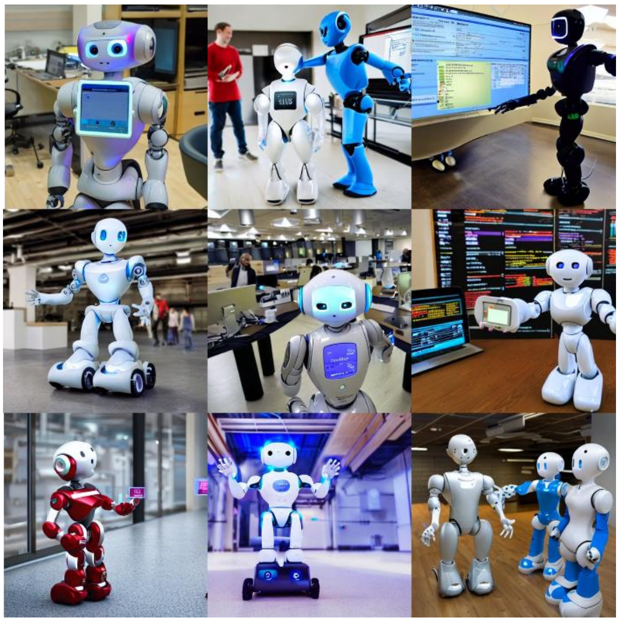

Fig. 8. Social robots in communication.

5.9. Highlights on Monitoring

Social robots can assist in monitoring the factory floor and ensure health and safety regulations are followed. They can check if employees are wearing protective equipment, if equipment is being used safely, and if fire exits are accessible. They can also aid in emergency response by detecting potential safety hazards, alerting personnel, and assisting with investigations. During safety drills and emergencies, social robots can provide instructions, assist with evacuation, and provide real-time updates. By using social robots, companies can reduce the risk of accidents and liability, improving employee morale and safety. Social robots should be used with other safety measures such as employee training, safety drills, and alarms. Fig. 9 visualizes some use cases.

Fig. 9. Social robots in monitoring.

6. Adoption of Social Robots in Industry

To reveal a perspective about the adoption of social robots in industrial production, a design thinking tool called "TRIZ 9 windows" is further considered [8]. It analyzes adoption from nine angles, as follows:

Time: Social robots are a relatively new technology, and their adoption in industrial production is still in the early stages. However, there has been significant progress in the development of social robots over the past few years, with improvements in areas such as AI, sensing and control technologies, and human-robot interaction. These advances may help to accelerate adoption in the future in industry.

Space: Social robots are being used in industrial production primarily in developed countries, such as Japan, the US, and Germany. However, there is potential for expansion in other regions, particularly in emerging economies where labor costs are high, and there is a need for automation.

Matter: Social robots used in industrial production must be made of lightweight materials such as aluminum and plastic, which make them easier to move around and reduce the risk of injury to workers. Advances in material science could potentially lead to the development of even lighter and stronger materials, making social robots more efficient and safer.

Energy: Social robots used in industrial production typically require electricity to operate but advances in energy storage and management could potentially reduce the energy requirements and improve the efficiency of these robots.

Information: Social robots in industrial production require a significant amount of data and information to operate effectively. Advances in data analytics and AI could potentially improve the accuracy and efficiency of social robots, making them more useful and reliable.

Structure: The physical structures and designs of social robots that might be used in industrial production are constantly evolving, with advances in areas such as mobility, sensing, and manipulation capabilities. These improvements could potentially make social robots more versatile and effective in a wider range of industrial applications.

Time-space: The timing and location of social robot deployment could impact adoption in industrial production. For example, social robots may be more useful in certain industries or locations than others, and the timing of deployment may need to be carefully planned to avoid disrupting existing workflows.

Non-material: There may be legal, regulatory, and ethical considerations that need to be considered when adopting social robots in industrial production. For example, there may be safety regulations that need to be followed, or ethical concerns about the use of robots to replace human workers.

Interactions: The human-robot interactions involved in the use of social robots in industrial production may impact adoption. For example, workers may be hesitant to work alongside robots or may require specialized training to use them effectively. Ensuring safe and positive human-robot interactions will be crucial for the successful adoption of social robots in industrial production.

This analysis suggests that there are relevant opportunities for the adoption of social robots in industrial production, but that there are also a number of challenges that need to be addressed. Companies that are considering adopting this technology will need to carefully consider the factors identified in this analysis and develop strategies to overcome any potential barriers.

7. Designing for Industry of Social Robots

The same method from the previous section can be applied to indicate basic technical requirements for social robots that might be deployed into industrial production. Thus, one can analyze the following insights:

Time: Social robots should be designed to be easily upgradeable and scalable, with features such as modularity, standardized interfaces, and compatibility with different hardware and software systems. They should also be designed with open-source software to facilitate customization and development of new features.

Space: Social robots should be designed to be compact and agile, with features such as small footprints, high mobility, and obstacle detection and avoidance capabilities. They should also be designed to operate in a variety of environments, including extreme temperatures, dust, and humidity.

Matter: Social robots should be made of lightweight and durable materials, such as carbon fiber, titanium, and composites, to minimize weight and increase durability. They should also be designed with features such as shock absorption, impact resistance, and waterproofing to reduce the risk of damage and injury.

Energy: Social robots should be designed to operate efficiently, with features such as low power consumption, energy recovery systems, and renewable energy sources. They should also be designed with features such as fast charging and hot-swappable batteries to minimize downtime.

Information: Social robots should be designed to process and analyze large amounts of data quickly and accurately, with features such as AI algorithms, computer vision, and machine learning. They should also be designed with features such as wireless communication and real-time data transmission to enable coordination with other robots and machines.

Structure: Social robots should be designed to be highly mobile and flexible, with features such as multi-axis movement, omnidirectional wheels, and manipulator arms. They should also be designed with features such as force sensing, tactile feedback, and high-resolution cameras to enable precise manipulation and assembly tasks.

Time-space: Social robots should be designed with features of dynamic task scheduling, adaptive motion planning, and autonomous navigation to adapt to changing production needs and schedules.

Non-material: Social robots should comply with all relevant regulations and safety standards, with features such as collision detection, emergency stop buttons, and safety certifications. They should also be designed with features such as privacy protection, data encryption, and transparent governance to ensure ethical and responsible use.

Interactions: Social robots should be designed to work safely and collaboratively alongside human workers, with features such as natural language processing, gesture recognition, and facial expression analysis. They should also be designed with features such as interactive touch screens, voice assistants, and augmented reality displays to facilitate training and interaction with human workers.

There are several contradictions in designing cost-effective and reliable social robots for industrial environments. They are tackled with "TRIZ contradiction matrix" in order to generate solutions that surpass these contradictions [9].

Contradiction: Increased flexibility vs. Increased stability. *Innovative solution*: Use modular designs and standardized interfaces to increase flexibility while also ensuring stability and compatibility with existing systems.

Contradiction: Increased functionality vs. Simplification. *Innovative solution*: Use AI and machine learning algorithms to enable advanced functionality while also simplifying the user interface and reducing the need for complex programming.

Contradiction: Increased accuracy vs. Increased speed. *Innovative solution*: Use advanced sensors and computer vision algorithms to enable precise manipulation and assembly tasks while also optimizing motion planning and reducing cycle time.

Contradiction: Increased safety vs. Increased efficiency. *Innovative solution*: Use collision detection and emergency stop features to ensure safety while also optimizing production efficiency through dynamic task scheduling and motion planning.

Contradiction: Increased autonomy vs. Human control. *Innovative solution*: Use natural language processing and gesture recognition to enable human-robot interaction and control, while also increasing autonomy through autonomous navigation and dynamic task scheduling.

Contradiction: Increased customization vs. Standardization. *Innovative solution*: Use open-source software and modular designs to enable customization and flexibility, while also ensuring compatibility and standardization with existing systems.

Contradiction: Increased functionality vs. Cost reduction. *Innovative solution*: Use open-source software and modular designs to reduce costs while also enabling advanced functionality through AI and machine learning algorithms.

Contradiction: Increased accuracy vs. Cost reduction. *Innovative solution*: Use low-cost sensors and computer vision algorithms to enable precise manipulation and assembly tasks while also reducing costs.

Contradiction: Increased safety vs. Cost reduction. *Innovative solution*: Use low-cost safety features such as collision detection and emergency stop buttons to ensure safety while also reducing costs. Implementing safety measures can ultimately lead to a reduction in costs associated with workplace accidents and injuries.

Contradiction: Increased customization vs. Cost reduction. *Innovative solution*: Use modular designs and standardized interfaces to enable customization and flexibility, while also reducing costs by streamlining production and assembly processes.

Based on these design recommendations, one can imagine how social robots would look like for industrial applications. Some insights are given in Fig. 10.

Fig. 10. Possible designs of social robots for industry.

As Fig. 10 shows, the physical appearance of social robots that might be used in industry can vary widely depending on their intended use and application. Some social robots are designed to look like humans, with a head, torso, arms, and legs that are similar in shape and size to a human body. Others may have a more abstract or stylized appearance, with a simplified body shape or unique design elements.

Social robots may be equipped with a variety of physical features and components, including cameras, microphones, speakers, touchscreens, and sensors for detecting movement, temperature, or other environmental factors. They may also have specialized tools or end-effectors for performing specific tasks, such as gripping or manipulating objects. Thus, the physical appearance and features of social robots are designed to facilitate their ability to interact with humans in a natural and intuitive way, allowing them to be more effective in social and emotional contexts from the industrial settings.

8. The Economics of Industrial Social Robots

To provide an economic relevance for adopting social robots in production activities, this section starts by introducing two illustrative examples. The first one is about the deployment of a social robot on a mass customization-based assembly line as co-worker with human operators (e.g., assembling personalized toys for kids). It actually performs quality control and placement of the product in boxes according to a personalized scheme. Products come in a random position, orientation, and class. The robot also interacts with the human operators to collaborate and optimize the assembly line process. The robot communicates with the operators to inform them of any issues or defects it detects in the products, and work together with them to find solutions. The robot also provides real-time feedback and suggestions to the operators on how to improve the efficiency and quality of the assembly line. Furthermore, the robot learns from the human operators and adapts to their work patterns and preferences, creating a more personalized and efficient working environment. To achieve these functions, the social robot has to incorporate a high-precision robotic arm capable of manipulating and grasping parts, computer vision algorithms and sensors for identifying and recognizing different parts and components, AI and machine learning algorithms for detecting and responding to errors or defects in the production process, modular designs and standardized interfaces for customization and flexibility.

In this use case, the initial investment in the social robot is $50,000. Labor cost savings per year in a developed country is $40,000. Maintenance and repair costs per year are $10,000. The estimated increase in productivity is 20%, the estimated increase in product quality is 10% by avoiding scrap and rework, and the expected lifespan of the social robot is 5 years. The annual cost savings are $30,000 (i.e., $40,000 – $10,000), which leads to $150,000 over 5 years. With the increase in productivity, the company produces 20,000 more units per year (which means an additional $20,000 per year for a cost of the product of $1), and by reducing scrap and rework costs the company saves about $10,000 per year. Over 5 years this leads to $150,000 additional benefits. Thus, the return on investment (ROI) is [($300,000 – $50,000)/$50,000]×100 = 500%.

The second example is from material handling operations, more specifically from a distribution center of the manufacturing enterprise where a special designed social robot assists human workers in picking and packing orders, sorting, and organizing inventory, and transporting goods between different areas of the facility. The social robot is equipped with sensors and cameras to navigate the warehouse and identify items that need to be moved, as well as the ability to interact with human workers to receive instructions and coordinate tasks. Additionally, the robot helps to reduce the risk of injury to human workers by lifting and moving heavy objects, and by handling repetitive tasks that can lead to physical strain over time. To achieve these functions, the social robot must embed autonomous navigation and obstacle avoidance capabilities, computer vision algorithms and sensors for detecting and recognizing materials and products, a high-capacity robotic arm or conveyor system for transporting materials and products, safety features such as collision detection and emergency stop buttons to ensure safe operation.

In this case, the initial investment in the social robot is $75,000, labor cost savings per year are $50,000, maintenance and repair costs per year are $15,000, estimated increase in productivity is 30%, and expected lifespan of the social robot is 7 years. The annual cost savings are $50,000 – $15,000 = $35,000, resulting in total cost savings over 7 years of $245,000. Increased productivity of 30% of current output leads to an additional $40,000 benefits per year. The total benefits over the lifespan are ($50,000×7 + $40,000×7) + $245,000 = $875,000. Total operating costs are $15,000×7 = $105,000. Thus, the ROI is [($875,000 – $105,000 – $75,000)/$75,000] × 100 = 927%.

The cost of a social robot can vary widely depending on factors such as the robot's capabilities, the complexity of the application, and the level of customization required. Still, social robots can be relatively expensive compared to traditional industrial robots or other automation solutions. Social robots are typically designed with more advanced AI and machine learning capabilities than traditional industrial robots, which can drive up the cost of development and production. Additionally, social robots often require more sophisticated sensors and hardware to enable natural and intuitive human-robot interaction, which can also add to the cost. Nevertheless, it is important to keep in mind that the cost of a social robot should be evaluated in the context of the potential benefits and ROI that the robot can provide. While social robots may be more expensive up front, they can also offer significant long-term cost savings and productivity gains through improved efficiency, quality control, and reduced labor costs. It is important to carefully consider the specific needs and requirements of each application to determine whether a social robot is the best solution and whether the potential benefits compensate for the initial cost.

9. Discussions

There are several reasons why social robots may be preferred over traditional industrial robots in certain industrial use cases. One reason is that social robots are designed to interact with humans in a more natural and intuitive way, which can be beneficial in applications where human-robot collaboration is required. For example, in assembly line use cases, social robots can work alongside human workers to complete tasks that require human dexterity or judgment, while also taking over repetitive or physically demanding tasks. Another reason is that social robots are often more flexible and adaptable than traditional industrial robots in tasks with high variability, which are often designed for specific tasks and require extensive reprogramming and customization to perform new tasks. Traditional industrial robots are typically designed to perform repetitive tasks in a highly structured environment. They can be programmed to perform a specific task with a high degree of accuracy and consistency, but they lack the flexibility and adaptability to respond to changing conditions or unexpected events. This can make them less effective in dynamic and unpredictable environments. Social robots, on the other hand, can be reconfigured or trained to perform new tasks relatively easily, thanks to their modular designs and advanced AI and machine learning algorithms. A third reason is that social robots are often designed with safety and ergonomics in mind, which can be beneficial in applications where human workers are present. Social robots are typically designed to work safely alongside human workers, with features such as collision detection and emergency stop buttons to ensure safe operation. In addition, social robots can be designed to reduce physical strain on human workers by taking over repetitive or physically demanding tasks. They can also interact with humans in a pleasant and fun way, which might contribute to the quality of the working atmosphere.

An important remark is that using social robots in industrial production can make sense in certain applications, but not in any application. Social robots can offer a number of advantages over traditional industrial robots or human labor, in cases where there is a need for:

- Improved efficiency in haphazard working environments: Social robots can work alongside human workers to help perform tasks more efficiently, increasing overall productivity and reducing cycle times.
- Increased accuracy at affordable costs in unplanned working environments: Social robots can use advanced sensing and vision technologies to perform tasks with a higher degree of accuracy than human workers, reducing errors and improving quality.
- Enhanced safety: Social robots can be used to perform tasks that are too dangerous or difficult for human workers, reducing the risk of workplace injuries.
- Flexibility and adaptability: Social robots can be programmed to adapt to changing conditions or unexpected events, making them well-suited for tasks that require a high degree of flexibility or adaptability.
- Increased control: Social robots can be used in some tasks where there is no clear trust in the quality and ethics of the jobs done by workers.

It is also important to not confuse the social robots that are dedicated to industrial settings with the social robots used in other areas, such as entertainment, health, education, etc. As was highlighted in section 7 of this paper, industrial social robots must have a special design to face industrial requirements.

For example, a social robot designed to work in assembly operations in a production setting would need to have a number of specific features and capabilities in order to perform its tasks effectively, as follows:

Physical Appearance:

- A humanoid design with a torso, arms, and a head to enable the robot to move and manipulate objects in a manner similar to human workers.
- The robot's body should be made of durable materials to withstand harsh production environments.
- The robot's arms should be able to move in multiple directions and have grippers or end-effectors that can pick up and manipulate parts, to face with specified payload capacity, and to be endurant to higher speeds and persistent repetitive movements.

Sensors and Perception:

- The robot should be equipped with cameras, sensors, and other perception technologies to detect and recognize parts and their locations.
- The robot should be able to distinguish between different parts and understand how they fit together.

Navigation and Movement:

- The robot should be able to navigate autonomously through the production environment, avoiding obstacles and moving around other workers and equipment.
- The robot should be able to move its arms and torso in precise and coordinated movements to pick up and manipulate parts.

Interaction and Communication:

- The robot should be able to communicate with human workers and other robots in the production environment using natural language, gestures, or other forms of communication (e.g., I-IoT, wireless).
- The robot should be able to collaborate with human workers on assembly tasks, adjusting its movements and actions based on the worker's input.

In Fig. 11 there are imagined various physical appearance concepts of social robots dedicated to this example.

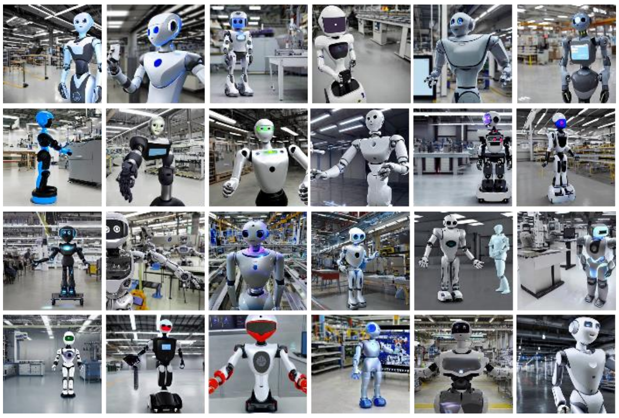

Fig. 11. Social robots for assembly operations.

In the factory of the future, the traditional industrial robots (tibots), collaborative industrial robots (cobots), and industrial social robots (sobots) will work together with human workers to achieve maximum productivity and efficiency. Traditional industrial robots are designed to automate repetitive and dangerous tasks that were previously performed by human workers, such as welding, painting, and material handling. They are often located in cages or behind barriers to ensure the safety of human workers. Collaborative industrial robots are designed to work alongside human workers in a shared workspace. They are equipped with sensors and software that allow them to detect and respond to human presence and movements. This makes them ideal for tasks that require close collaboration between human workers and robots, such as assembly, pick and place, and inspection. Industrial social robots represent a relatively new addition to the factory floor. Unlike traditional industrial robots and collaborative industrial robots, they are designed to interact and communicate with human workers. They are equipped with advanced sensors and software that enable them to perceive and interpret human emotions, gestures, and expressions. This makes them ideal for tasks that require high levels of social interaction and communication, such as quality control, maintenance, repair, monitoring, and training, but not only.

In the factory of the future, these different types of robots will work together seamlessly with human workers being interconnected through the Industrial Internet of Things (I-IoT); thus, enabling them to share data and communicate with each other in real-time. This will facilitate the factory in responding quickly to changing market demands and optimizing production processes. Industry 5.0 [10], the next phase of industrial development, will build upon the principles of Industry 4.0 [11] and will focus on creating a more human-centered approach to manufacturing. This means that robots and humans will work together even more closely, with robots taking on increasingly complex tasks while human workers focus on tasks that require creativity, problem-solving, and social interaction. The super-smart factory of the future will be a truly collaborative workspace, where robots and humans work together to create products that are of the highest quality and value.

Collaborative industrial robots (cobots) and industrial social robots (sobots) can also work together in a variety of ways to improve the efficiency and productivity of manufacturing operations while also enhancing the safety and well-being of human workers. Cobots can perform repetitive, dangerous, or strenuous tasks, while sobots can provide additional capabilities such as social interaction and adaptability. For example, a cobot can lift and move heavier objects, while a sobot can identify and sort those objects based on their visual or other sensory features. Sobots can also provide guidance and assistance to human workers in real-time. They can help to train workers, monitor their performance, and provide feedback and advice to improve their skills and efficiency. In addition, sobots can communicate with workers and other robots, enabling seamless coordination and collaboration among different teams and processes. In a smart factory of the future, cobots and sobots will work in concert with human workers, leveraging advanced technologies such as AI, IoT, and machine learning to optimize production processes and improve product quality. The result will be a highly efficient and responsive manufacturing system that can adapt quickly to changing market demands while also supporting workers.

Also, in the factory of the future, both traditional industrial robots (tibots) and industrial social robots (sobots) are likely to coexist and work together with human workers. One possible scenario is that traditional industrial robots can handle heavy lifting, welding, or other tasks that require high precision, while industrial social robots can work on tasks that require more dexterity and interaction with human workers, such as material handling, quality control, or assembly tasks. For example, an industrial social robot could receive instructions from a human worker, pick up a component from a bin, and place it in the appropriate location for the traditional industrial robot to perform the next step in the manufacturing process. In this scenario, industrial social robots could act as "smart assistants" to human workers, providing guidance, assistance, and collaboration. They could also perform tasks that are not feasible or cost-effective for traditional industrial robots, such as inspection, maintenance, or customization tasks. Thus, the collaboration between traditional industrial robots and industrial social robots could result in a more efficient, flexible, and adaptable manufacturing process, while also improving the quality of work for human operators.

10. Highlights on Contributions

This paper introduces a new perspective of integrating social robots into industrial settings. In order to achieve this research objective, the author has proposed a methodology of investigation. First, the author conducted a comprehensive literature review to identify existing studies on the application of social robots in manufacturing. This step revealed that the topic is under-researched, emphasizing the novelty of our study. He also led a comprehensive survey with 230 professionals in the manufacturing industry, revealing a generally positive perception of social robots' potential to enhance productivity and safety, while also highlighting concerns over technical and organizational challenges. Based on the insights gathered during the expert interviews, the author identified several use cases for social robots in manufacturing processes. The potential applications span various aspects of the manufacturing process, including quality control, maintenance and repair, collaborative working, safety and security, inventory management, logistics and supply chain management, employee wellness and morale, customer service, market research and data collection, and events and tradeshows. Further, the application of TRIZ in this research has generated a range of innovative ideas and potential solutions for the integration of social robots in the manufacturing industry. The generated solutions were then evaluated and analyzed to understand their feasibility and potential impact. Also, the author delves into the design aspects of industrial social robots. Based on the TRIZ tool, the author proposes solutions to overcome potential contradictions faced in designing these robots, such as balancing flexibility with stability, functionality with simplification, and accuracy with speed, among others. The paper also explores the potential return on investment (ROI) in the context of two industrial scenarios: a mass customization-based assembly line and a material handling operation in a distribution center. In both cases, despite the high upfront costs, social robots demonstrate high potential for ROI when considering long-term cost savings, increased productivity, and improved quality control. These examples help to frame the economic relevance of social robots in industrial settings.

11. Conclusions

The introduction of social robots in industrial production settings is a promising area for future research and industrial innovations. While there is currently limited literature on the topic, this paper has provided various use cases and design requirements for such robots, as well as economic considerations for their implementation. The paper has also discussed the potential benefits of social robots working alongside traditional industrial robots and human workers in the factories of the future.

It is evident from this research that social robots can bring significant benefits in situations such as material handling, quality control, monitoring, customer service, training, maintenance, assembly line operations, etc. These robots can work collaboratively with human workers and other industrial robots, ultimately enhancing the efficiency and productivity of manufacturing processes. However, it is important to acknowledge the limitations of current research and continue investigating the potential of social robots in different industrial settings.

The findings of this research suggest that industrial social robots have the potential to improve productivity, quality control, and safety in manufacturing operations. Additionally, our analysis of design requirements and economic considerations highlights the importance of carefully selecting and designing social robots to ensure their successful integration into existing workflows. However, while this research provides valuable insights into the potential uses and benefits of social robots in the manufacturing industry, it is important to acknowledge its limitations. The lack of existing literature in this field made it challenging to draw definitive conclusions or generalize about the effectiveness of social robots in different settings. Additionally, this research focused on a limited number of use cases and did not account for all possible factors that may impact the successful integration and deployment of social robots in manufacturing.

Future research should focus on addressing the challenges of designing industrial social robots that can work efficiently and effectively in dynamic, unpredictable environments while ensuring safety and ease of use for human workers. Additionally, it is important to study the impact of industrial social robots on the work environment and employee well-being. Moreover, future research should focus on the development of algorithms that would allow industrial social robots to recognize emotions and interact with workers on a more human level.

At the end, we can outline that the introduction of social robots in industrial production settings has the potential to revolutionize manufacturing operations and bring significant benefits to businesses and workers alike. With continued exploration and innovation, social robots have the potential to become an integral part of the factory of the future, working collaboratively with traditional robots and human workers to create safer, more efficient, and more productive manufacturing environments. Still, it is important to acknowledge that the integration of social robots is not a one-size-fits-all solution, and that further research is needed to identify the most effective ways to implement social robots in various industrial settings.

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Personal Notes

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