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Advancements in Robotic Systems and Human Robot Interaction for Industry 4.0

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Abstract – Robotic systems are software and algorithms used to mechanize iterative human processes. Robotic Process Automation (RPA) operates based on simple principles and business logic, enabling it to engage with various information systems by using pre-existing graphical user interfaces. The process is the use of non-invasive software robots, often referred to as "bots," to automate actions that are repetitive in nature and governed by predefined rules. The integration of data analytics, artificial intelligence (AI), process mining, and cognitive computing is now being used to expand the capabilities of RPA, enabling it to do more intricate jobs. This study investigates the progress made in robotic systems and the interaction between humans and robots in Industry 4.0 context. The paper examines the use of RPA, the incorporation of AI into robotic systems, and the advancement of autonomous driving and mobile robots. The study also emphasizes the significance of efficient human-robot interaction strategies and the possible influence of artificial intelligence (AI) on the prospective progress of intelligent and independent service robots. Furthermore, this study delves into the obstacles and forecasts pertaining to the development of sophisticated machine intelligence.

Keywords – Robotic Systems, Robotic Process Automation, Artificial Intelligence, Human-Robot Perception, Human-Robot Interaction, Vehicle-To-Vehicle Communication.

I. INTRODUCTION

According to an Der Aalst, Bichler, and Heinzl [1], Robotic Process Automation (RPA) is characterized as the use of certain techniques and technologies that rely on algorithms and software with the objective of automating repetitive activities typically performed by humans. The system primarily operates based on straightforward rules and business logic as it interacts with various data systems using pre-existing graphical user interfaces. The features of this system include the automation of actions that are repeated and based on rules, achieved via the use of a non-invasive software robot, sometimes referred to as a "bot" [2]. In recent times, there has been an expansion in the concept of RPA to include its integration with data analytics, AI, process mining, and cognitive computing. The implementation of sophisticated digital technology has facilitated the reassignment of RPA from mundane and error-prone jobs in corporate processes to more intricate and knowledge-intensive activities that provide value. To evaluating the condition of the RPA market, Huang and Vasarhelyi [3] has selected twelve RPA suppliers that provide comprehensive, enterprise-level solutions capable of meeting the demands of a "shared service" or an RPA utility deployed across an entire organization. While several suppliers of RPA provide solutions tailored to certain industries, Enríquez, Ramirez, Mayo, and Garcia-Garcia [4] argue that the fundamental principle of RPA is not limited to any one industry.

However, the collaboration between RPA vendors and prominent AI providers has facilitated the integration of conventional RPA capabilities with novel emerging technologies. These technologies encompass self-learning through natural language generation, process discovery, AI-based screen recognition, robot training and automated documentation generation for processes. According to a survey conducted by Dhatterwal, Kaswan, and Bainsla [5], a significant proportion of the 400 organizations included in the study have begun their journey in implementing RPA, while an additional 25% of the companies intend to embark on this journey over the next two years. Additionally, it has been reported that the payback timeframes for these initiatives are now averaging around one year. Furthermore, the anticipated benefits in terms of enhanced compliance, cost reduction, timeliness, accuracy, and flexibility have been consistently reached or even surpassed. According to Coury, Léo, and Kumar [6], it is projected that by the year 2021, the number of robots engaged in the automation of repetitive operations would exceed 4 million. However, there will be a shift in emphasis towards integrating artificial intelligence (AI) and enhancing analytics for RPA. In a similar vein, Cempini, De Rossi, Lenzi, Vitiello, and

Carrozza [7] highlights that although a significant proportion of consumers express high levels of satisfaction with RPA solutions, there is a need for the augmentation of analytics and cognitive functionalities.

In spite of the considerable advantages associated with RPA, an only 5% of organizations examined by Ribeiro, Lima, Eckhardt, and Paiva [8] have successfully integrated over 50 robots into their operational processes. The success of RPA initiatives heavily relies on two key factors: organizational competence and a comprehensive grasp of business objectives. The primary problems associated with the automation of processes are highlighted as a deficiency in comprehending the concept of RPA and its potential applications, insufficient support from management, and employee concerns around potential job displacement. The implementation of a strategy of change management, together with a transformation of the company culture and a shift in attitude, may serve as effective measures to address the disconnect between the perception of RPA as only an IT tool and its potential impact on the business aspects. In contrast, the survey conducted by Zhong, Xu, Klotz, and Newman [9] revealed that participants placed significant importance on factors such as effective customer support, comprehensive education and training resources, reliable RPA services of maintenance, and a robust vendor ecosystem for complementing technologies. These factors were identified as key drivers for the adoption of RPA. Moreover, the advent of novel technology raises inquiries about the administration, central control, and governance of robots.

The use of robotic systems has been widespread within the production industry owing to its notable attributes such as repeatability, strength, accuracy, speed, precision, agility, and absence of tiredness. The disproportionate emphasis on manufacturing as the predominant field for robotics has led to the use of rigid actuation and inflexible materials in traditional mechanical system designs. The design architecture used in this context posed inherent safety risks to human-robot interaction, leading to the adoption of a prevalent practice in industrial settings to physically separate the workstations of humans and robots. With the increasing need for human-robot interaction (HRI) in many applications outside the industrial sector, the development of soft robotics has gained momentum. Oral and İder [10] identified the constraints of traditional mechanical design approaches for robots when applied to scenarios that include intricate unstructured environments and considerable human-robot interaction. The field of soft robotics emerged as a result of drawing inspiration from natural sources, specifically: (1) the inherent flexibility observed in the soft tissues of plants and animals, and (2) the concept of morphological computation or embodied intelligence, which refers to the ability of living organisms to physically integrate intelligence within their bodies and utilize it for controlling their motion.

This article investigates the progress made in robotic systems and the engagement between robots and humans within the context of Industry 4.0. The paper examines the use of RPA technology, the incorporation of artificial intelligence (AI) into robotic systems, and the advancement of autonomous driving and mobile robots. The study also emphasizes the significance of efficient Human-Robot Interaction (HRI) strategies and the possible influence of AI on the forthcoming advancements of intelligent and autonomous service robots. Furthermore, this study delves into the obstacles and forecasts pertaining to the development of advanced machine intelligence. The remainder of the article has been arranged as follows: Section II presents a discussion the human-robot perception, and the robotic systems. Section III provides an extensive analysis of the future potential of robotic systems. In this section a discussion of the commencement of the breakthrough in HRI is discussed. Section IV provides a conclusion to the research on advancements in robotic systems and human-robot interaction for industry 4.0.

II. HUMAN-ROBOT PERCEPTION AND ROBOTIC SYSTEMS

This section examines various types of systems of robots that are frequently employed in industrial settings, namely mobile manipulators, robot cars, and mobile robots. The objective is to demonstrate how these systems respond and perceive to the stationary obstacles in industrial scenarios or presence of human operators, particularly in collaborative and cooperative applications.

Robot Car

The process of automating cars is now progressing rapidly. Advanced Driver Assistance Systems (ADAS) provide assistance to drivers; however, they do not now enable complete automation of traffic driving. The use of driver assistance systems is seeing significant advancement, driven by active engagement from business, research institutes, and governmental entities.

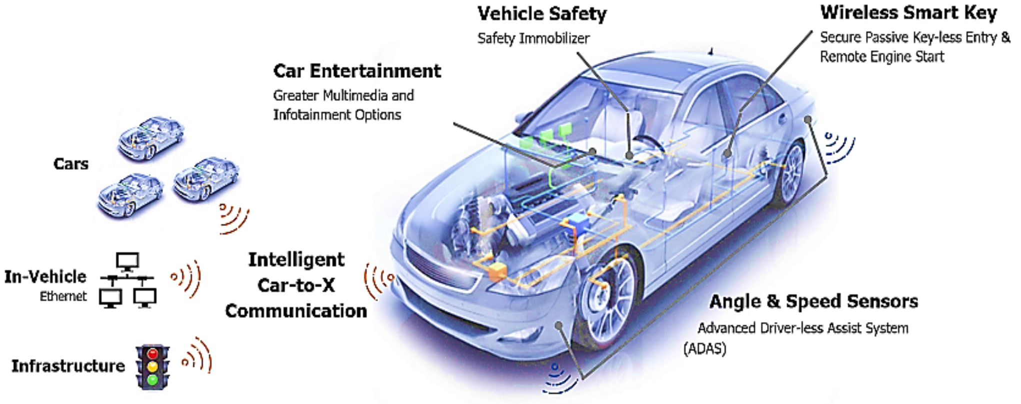

Fig 1. Application of Chips to Create Different Technologies for Robotic Cars.

These systems are subject to significant safety demands. The already accessible driver assistance technologies likely serve as precursors to a significant advancement that will facilitate the gradual automation of the driving work. The current phenomenon is presently observable. The current development of systems that were initially designed to provide advice or warnings, such as unintentional veering off the roadway or alerting the driver about speeding, is progressing towards systems that actively intervene. Furthermore, automobile makers engage in intense competition, particularly in the domains of comfort and safety, since there exists limited scope for further enhancements in the overall quality of vehicles. Consequently, intelligence emerges as the distinctive feature that sets apart a novel automobile. **Fig 1** illustrates the potential of chip integration in the automotive sector, mostly in the context of converting conventional cars into Smart cars. This integration offers several advantages, including enhanced safety measures, heightened security features, and improved connectivity capabilities.

Science also indicates the possibility of systems of cooperation, in combination with management of traffic, that function via networked navigation. Currently, a significant amount of research is being conducted, with a considerable portion of these research endeavors being financially supported by the European Union (EU). Examples of such projects include Safespot (2006–2010) [11], COOPERS (CO-OPerative systEms for Road Safety) 2006–2010 [12], CVIS (Cooperative Vehicle-Infrastructure Systems) 2006–2010) [13], and SATRE (Safe Road Trains for the Environment) 2009–2013 [14]. The pilot project have been successfully implemented, and it is anticipated that the implementation of these collaborative systems would result in reduced traffic congestion and improved efficiency in using the road infrastructure.

The European Commission [15] intends to provide a set of concise technical requirements that are necessary for the interchange of information and data between vehicles (V2V) and between infrastructure and vehicles (V2I). The proposed standardization is expected to drive the increased adoption and use of these technologies. The concept of “train driving,” which involves vehicles closely following one another and sharing data on their speed, position, and acceleration, necessitates the establishment of a standardized cooperative driving electronics framework. This framework would enable vehicles from various manufacturers to seamlessly integrate into a unified “train” system. Despite the anticipated favorable impact of cooperative systems, as opposed to driver assistance systems, there exists a dearth of study pertaining to the safety and potential adverse consequences associated with cooperative systems. The implementation of V2V and V2I communication in cooperative driving will need a considerable amount of time to ensure its safety and reliability.

The advancement of cooperative systems is projected to be vital in facilitating the widespread adoption of autonomous driving technology. The implementation of autonomous driving systems may be required specifically on motorways, using cooperative ACC technology, which will need the application of Vehicle-to-Vehicle (V2V) communications. The existing infrastructure requires little modifications since drivers can readily get comprehensive data on roadworks, traffic congestion, local traffic rules, and related updates via their in-car navigation systems or other sources of in-vehicle information. The potential implementation of roadside devices for the purpose of facilitating autonomous driving, particularly in the context of highway slip lanes, is worth considering. Semi-autonomous driving enables the autonomous operation of a vehicle on certain roadways characterized by less intricate traffic conditions, such as highways, while excluding locations with more intricate traffic scenarios, such as urban environments.

According to Weiskircher, Wang, and Ayalew [16], it is anticipated that this feasibility will be achieved approximately by the year 2030. The anticipated outcome of implementing semi-autonomous driving technology encompasses many benefits, including enhanced fuel efficiency of vehicles, improved highway safety, and partial alleviation of traffic congestion, particularly in instances of shock wave congestion of traffic. During the operation of autonomous vehicles, the driver is given the opportunity to engage in activities such as reading literature, accessing online resources, or consuming a morning meal, among other possibilities.

The concept of an autonomous automobile was first proposed in by Bel Geddes in 1939 as a segment of the Futurama display, he curated for General Motors at the World Fair in New York. In the television series Futurama, Geddes engaged in speculation over the potential characteristics of future societies [17]. In his publication titled “Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability?”, Kalra and Paddock [18] asserts that the vehicles of 1960, together with the corresponding road networks, would have mechanisms designed to rectify the deficiencies shown by human drivers. The implementation of this measure will serve to mitigate the occurrence of mistakes on the part of the driver. In the year 1958, engineers employed by General Motors successfully showcased the first prototype of an 'autonomous vehicle'. The vehicle in question was operated in an autonomous manner along a section of highway by using magnets affixed to the automobile and wire embedded inside the roadway, sometimes referred to as 'automatic highways'.

General Motors issued a press statement whereby it expressed its satisfaction with the outcome. Today at the General Motors Technical Center, a self-driving vehicle navigated a one-mile test track with the assistance of an electric wire located under the surface of concrete. This event was the first exhibition of its kind using a passenger vehicle of standard dimensions, hence suggesting the potential for an integrated navigation system for future road networks. The vehicle traversed the two-lane roadway and successfully maneuvered the inclined turning loops at both terminations, all while the driver abstained from manual control of the steering mechanism.

According to Naranjo, González, Garcia, and De Pedro [19], it was anticipated that the development of autonomous roads will materialize during the timeframe of 2000 to 2020. The year 2010 saw the announcement of Google's intention to engage in research pertaining to autonomous cars. In the meanwhile, the organization has conducted extensive testing of autonomous vehicles, including six Toyota Prius models and one Audi TT, covering a significant distance on public roads in California. The implementation of a preventive measure included the placement of the drivers' hands in close proximity to the steering wheel, poised to respond promptly in the event of any issues. In the beginning of 2011, Google initiated a lobbying effort in the state of Nevada with the aim of advocating for modifications to road traffic rules. Google asserts that there is a need for the legalization of autonomously driven vehicles, as well as the removal of the prohibition on text messaging while operating such vehicles in motion. In the present time, Florida, Nevada, and the states of California are in the process of establishing regulations and guidelines pertaining to the use of autonomous vehicles on public roadways. As per the findings presented by study head Sebastian Thrun, Google aspires for the progress of this development to finally provide improvements in flow of traffic and a decrease in the occurrence of accidents.

According to Bansal and Kockelman [20], it is projected that the global yearly count of 1.2 million injuries might potentially be reduced by 50% with the use of autonomous vehicle technology. Since 2011, an autonomous car, referred to as "Made in Germany", has been in service in Berlin. The present vehicle functions as the direct variant of the "Berlin Spirit", a former participant in the DARPA Urban Challenge held in 2007. The customized Volkswagen Passat, serving as a vehicle, is the result of the Nomos automotive program. This initiative received financial backing from the German administration and was carried out by the AI Assembly at the Free Berlin University. The designers have obtained a license to conduct automotive testing on public roads inside the territories of Brandenburg and Berlin. The subsequent objective of the creators is to successfully navigate the automobile across the continent of Europe. One noteworthy advancement of this initiative is the ability to place a vehicle order using a smartphone device. The creators have a distinct and well-defined perspective on the future. The proposition posits that automobiles need to disappear from the roadway during periods of non-operation.

According to Kim et al. [21], it is recommended that forthcoming automobiles be stored inside centralized parking facilities until a specific request for their use is initiated. Upon receiving the call, the driverless taxi promptly starts its journey towards the client's designated location. Subsequently, it proceeds to collect the passenger and transports them to a place of their choosing, as stated via their smartphone. During the course of the journey, the car's system has the capability to make determinations on the inclusion of additional passengers it sees along the planned route, provided that their intended destinations align with those of the existing passengers. Based on the findings of the researchers, it is suggested that in urban areas such as Berlin, the integration of private automobiles with the existing public transportation system might result in effective transportation with a significantly reduced number of cars, estimated to be as low as 10% of the current daily car use in the city. Therefore, the researchers see this advancement as indicative of a growing inclination for environmentally friendly vehicles.

Mobile Robots

The significance of mobile robots is steadily growing in the industrial domain. Industrial Mobile Robots (IMRs) are widely recognized as crucial components within contemporary and prospective production line and logistical environments. Autonomous Mobile Robots (AMRs) provide more flexibility in the working environment by eliminating the route limitations associated with traditional Automated Guided Vehicles (AGVs). The enhancement of productivity and reduction of downtime in production facilities may be achieved via the use of spatial and temporal flexibility. This is particularly evident in situations when alterations to the production sequence configuration are necessary. The present and future design of production lines are necessarily influenced by flexibility needs, which are driven by the market's desire for customized goods.

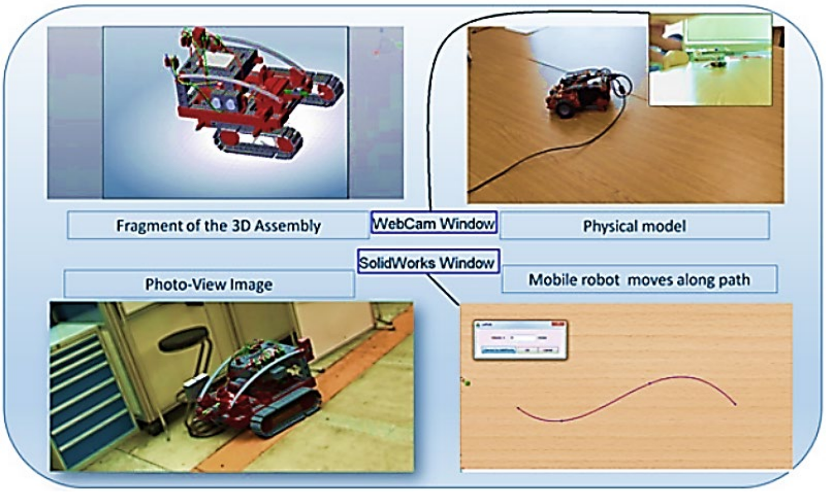

Fig 2. Integrated Model for Mobile Robot

Hähnel, Burgard, and Thrun [22] review mobile robots, defining their physical characteristics and the use of 3D modeling techniques. The objective is stated as follows: to create a mobile robot that is responsible for traversing a predetermined course inside a given area. Previously, a three-dimensional representation of the robot's surroundings was constructed as a component of a shared assembly. The findings from the first phase of the research are shown in **Fig 2,** which showcases the Fischertech-nik building kit in its assembled form. This representation was generated using 2Dvia Composer and includes a physical model as well as a photo-view picture. The trajectory may be defined as a spline curve or as a region of unobstructed space with a tunnel for the motion inside the shared 3D model, including both the environment and the robot. In this particular instance, the preferred trajectory is represented by the spline, which is defined inside the desktop model.

The importance of optimizing processes cannot be overstated in terms of enhancing the entire efficiency of a working arrangement, including factors such as productivity and energy usage. The sensing of its surroundings by the IMR becomes significant in order to achieve optimum integration with other components of Cyber-Physical Systems (CPS), beyond its fundamental function of platform localization during navigation. The introduction of autonomous navigation for autonomous mobile robots (AMRs) has created a heightened need for efficient HRI strategies. In the context of cooperative operations, the efficacy of such endeavors may be compromised due to the subjective perspective that human operators have about the mobility and actions of autonomous agents. On the other hand, the efficiency of mobile base task execution may be impeded by inadequately controlled human perception.

The AGV motion pre-definition pathways ensure predictability, in contrast to the frequently challenging interpretation of AMR movements by human operators. The perception systems of conventional Automated Guided Vehicles (AGVs) have experienced significant modifications in order to attain navigation autonomy and enhanced perception capabilities in industrial settings. This has led to an increased focus on real-time techniques, as they enable the examination of the environment and people in a more sophisticated manner. Furthermore, the increasing and widespread use of stationary collaborative robots in the manufacturing process has generated significant interest in the adoption of secure collaborative operations including Intelligent Mobile Robots (IMRs). Industrial mobility platforms must transition from a purely informational approach to a semantic understanding of the robot's environment.

The issue of improved perception in humans is gaining attention in the industrial environment. However, it has previously been extensively studied and used in several other sectors. These include assistive service robotics and agriculture, where robots play a crucial part in the whole process chain. The authors find it pertinent and engaging to include in this review a discussion on various methodologies used in the domains mentioned, since it is plausible that the FoF may adopt similar or equivalent strategies in the context of intelligent IMRs. Kruse, Pandey, Alami, and Kirsch [23] propose a non-intrusive approach to navigation of robot-aware. This approach allows the robot's actions in a home workspace, divided into virtual regions, to be determined by human preferences. In [24], there exists a collaborative task between a human and a mobile robot. The robot is run remotely by an operator who has access to a comprehensive 360-degree visual scene. This scene is enhanced with interactive elements that direct attention towards areas with abundant information. To achieve this, a 360-degree camera is utilized, and the captured frames are subjected to processing using the YOLO (You Only Look Once) CNN model, as described by Nguyen, Nguyen, Kim, and Lee [25]. In this particular scenario, the attainment of the objective is prevalent, and there exists a mutual reinforcement between the robot`s perception and the human operator's perception.

Furthermore, the implementation of teleoperation is discussed in [26], where a hybrid shared control method is used for human-robot collaboration (HRC). The operator utilizes an EMG (electromyography) signal sensor to transmit orders to a distant mobile robot, which is indicative of muscle activity. The human participant is issued with haptic devices, which are capable of detecting force feedback, hence providing information regarding the existence of barriers. The research outlined in [27] centers on the investigation of intricate natural engagement between mobile robots and cohort of human participants within measured laboratory habitat. The study provides evidence that individuals have a tendency to follow smoother and more regular trajectories when engaging with an autonomous navigation system, as opposed to a tele-functioned robot. The experimentations were carried out on automated mobile robots, social momentum, teleoperation, and utilizing optimal reciprocal collision elimination as a navigation method.

In [28], Siva and Zhang provide a novel technique known as Robot Perceptual Adaptation (ROPA). The algorithm outlined in this research aims to obtain a flexible integration of data from multiple sensory modalities. The organism possesses the ability to adjust and accommodate to alterations in its surrounding conditions, whether they be of a temporary or prolonged kind. The method is designed with a specific emphasis on the task of human detection. It leverages a range of data gathered from color and depth sensors that are integrated into a mobile robot. The primary objective is to facilitate the robot's ability to effectively monitor and pursue a human collaborator for a prolonged duration.

The utilization of a structured light camera enables the collection of color-depth information, whereas a digital luminosity sensor is utilized for the capture of luminosity data. In a study conducted by Bengio, Courville, and Vincent [29], a methodology for representation learning was developed with the objective of getting a scalable long-term representation model that is specifically tailored for scene matching. The procedure entails the acquisition of knowledge pertaining to different scene templates and the utilization of this knowledge to dynamically select the subset of templates that possess the most distinctive characteristics. The subset is subsequently utilized to develop the representation model, which effectively captures the attributes of the existing surrounding habitat. The latter method is implemented with the aim of establishing a continuous dissemination of data in collaborative Human Resource Planning (HRP) applications, utilizing the advantages of Augmented Reality (AR). Furthermore, detailed research in the agricultural field reveals a significant focus on prioritizing safety and ensuring the comfort of individuals in collaborative interactions between humans and robots. The planning model introduced in [30] suggests the use of Recurrent Neural Networks (RNNs) and picture quality evaluation to enhance the mobility of mobile robots inside crowded environments. The acquired pictures undergo pre-processing using OpenCV calibration tools, followed using a customized RNN-based visual quality assessment to filter out background noise.

Furthermore, in the context of assistance robotics service, the dual nature of perception is prominently observed. It is crucial for the robot to be perceived by users in a manner that is as natural as possible. Simultaneously, the robot must possess the ability to recognize intentions to effectively assist the human counterpart, such as in the case of Sit-To-Stand support. Additionally, the SMOOTH program of robot, as described in [31], serves as a sample of the adaptive sensory fusion attained by a neuron system that is singular multi-sensory that incorporates learning mechanisms. This integration aims to enhance the perceptive capacities of a welfare robot to mimic those of a human. The robot is outfitted with a forward-facing two cameras and safety laser scanner, one positioned towards the front and the other towards the rear. The study conducted in

[32] underscores the significance of data fusion in augmenting the perceptual capacity of mobile robots. The literature evaluated in this study examines the use of data collected from various sensors, including LIDAR, stereo cameras, and RGB cameras that are monocular. The objective is to get the most suitable data for autonomous tasks of navigation, such as localization, mapping, avoidance, and obstacle identification.

Considering the aforementioned methodologies, it is conceivable to anticipate the significant influence they may have on the nascent study on Human-Robot Interaction (HRI) inside the industrial domain. Numerous algorithms are now being developed with the objective of achieving optimal applicability across various contexts involving human-robot interactions. Mead and Matarić [33] emphasize the need of having a cohesive framework for facilitating Social-Aware Navigation (SAN). In their work, they provide a new method for autonomously perceiving the context of interactions and generating and following trajectories that are conducive to human interaction. Multiple contexts are taken into consideration and an intent detection function is included at the local layer of planning.

In the realm of firm logistics, Boschetti, Faccio, Milanese, and Minto [34] put up a proposal for a system using range finders to establish a collaborative assembly line. This system places particular importance on ensuring comfort between humans and robots, considering the proxemics principles. A cost function is allocated to both assembly systems and operators to influence the cost map for the navigation of the mobile robot. Martins, Pereira, Ferreira, Sá, and Silva [35] present a framework for human-aware navigation specifically designed for use in warehouses of logistics. The mobile robot in question is fitted with a laser scanner and an RGB-D camera, which serve the purpose of detecting individuals and estimating their stance. This enables the robot to classify humans as a distinct category of obstacles and take appropriate measures to avoid them. The suggested approach consists of a two-step process. Firstly, depth information is used to cluster and identify three-dimensional boxes that are probable to include human barriers. Secondly, human presence confidence index is computed based on the data of RGB.

On the other hand, the methodologies put out in [36] strive to showcase the incorporation of augmented reality (AR) as a facilitator for improved perception-driven interactions inside assembly Manufacturing Execution Systems (MES). The authors provide a proposition for the use of mixed reality smartglasses in the implementation of augmented reality (AR) for collaborative purposes using a cobot. Additionally, they suggest a route visualization application for individuals working with automated guided vehicles (AGVs), employing an augmented reality computing platform. Another study presents a potential resolution to human-robot interaction (HRI) by using eye tracking and gesture control technologies to enable the robot to comprehend intentions of human. Additionally, a pocket beamer is used to enhance the interpretability of robot information for the operator of human.

In their study, Yang, Zeng, Liang, Li, Li, and Su [37] introduce a novel human-robot (HR) skill transfer system. This system involves the use of a mobile robot that is provided with instructions to replicate a trajectory that has been previously shown by a human teacher. In order to precisely collect and transmit trajectory information to the robot, the human teacher use a device of capturing motion known as an IMU. The Kinect sensor is employed for the acquisition of trajectory data, which is subsequently employed for the modeling of a nonlinear system referred to as a Dynamic Motion Primitive. Following this, the posture human undergoes a correction operation through the utilization of multi-modal sensor fusion techniques. Furthermore, this study presents a novel way to motion control through the utilization of a distinctive nonlinear model predictive control technique.

Mobile Manipulators

The Mobile Manipulator (MM) is a system that involves the integration of a robotic manipulator onto the mobile system. While the popularity of mobile manipulators has just emerged lately, the individual components that comprise these systems, namely the robot manipulator and mobile system, have enjoyed widespread popularity for a considerable period. Since the introduction of the first firm robot, Unimate #001, in 1959 [38], there has been substantial advancement in the domain of robot manipulators, resulting in a wide array of capabilities. The advancement of mobile base robots has made significant progress since the introduction of the first AGV in the 1950s, created by Northbrook's Barrett-Cravens, Illinois (now known as Savant Automations Inc., located in USA, MI, Walker).

Bennett and Hollerbach [39] examined a mobile manipulator with six degrees of freedom (D.O.F.), as depicted in **Fig 3.** The joint angles of the robot manipulator, namely θ2, θ3, θ4, and θ5, were taken into consideration. Additionally, θ1 represented the directions of the truck in the reference coordinate framework, while ϕ1, ϕ2, ϕ3, and ϕ4 denoted the rotation angles of the mobile manipulator wheels. The coordinates (xT, yT) corresponded to the mass center of the truck, which was positioned at the contact point between the truck and its manipulator. The chosen configuration entails the use of a differential drive mechanism for the front wheels. Put simply, the orientation of the truck is determined by the disparity in velocities between the left and right wheels. It is worth noting that each wheel is equipped with its own actuator, denoted as τL and τR respectively.

In essence, mobile manipulators (MMs) are comprised of one or more robotic arms affixed to the upper portion of a mobile system. The system is embedded with tools, sensors, and actuators that enable the MM to navigate its environment autonomously and securely. Additionally, the system allows the MM to execute certain tasks by using the appropriate tool embedded to the end-effector of its arm. Mobile manipulators (MM) have the potential to exhibit unique functions via the customization of their tools, size, payload, shape, mobility, and other inherent properties. These devices are specifically engineered to operate inside distinct habitats, which may include terrestrial settings (both indoor and outdoor, accommodating either smooth or turbulent routes), airborne conditions, or aquatic surroundings. These mechanisms may be engineered to facilitate the transportation of both delicate and massive things, hence serving various purposes such as the handling of tiny, sensitive items or the execution of large-scale building projects. Mobile platforms may exhibit either legged or wheeled configurations.

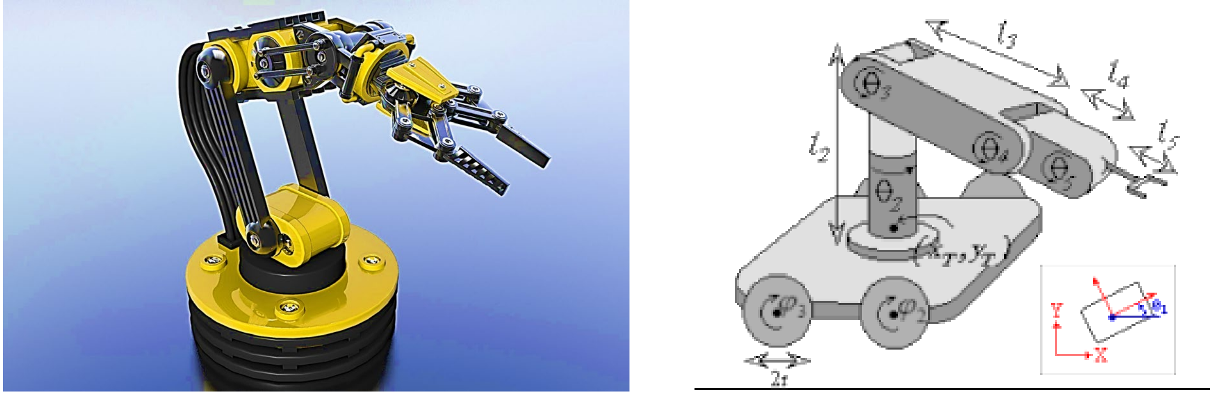

Fig 3. The Mobile Manipulator Considered by [40]

The term "wheeled" is more often used in academic discourse, including several types of wheel configurations, including omnidirectional, holonomic, and nonholonomic designs. Microbots, also known as MMs, have progressively solidified their prominence throughout a wide array of domains, including agricultural, military operations, nuclear facilities, space exploration, mining operations, assistive and healthcare technologies, domestic applications, rescue, and search operations, as well as industrial settings. The main emphasis of this article is on the firm applications. Nevertheless, several initiatives covered below have also tackled solutions in other domains. In their work [41] presented a comprehensive survey of the many multimedia messaging (MM) systems that have been developed, starting with the first prototype known as MORO in 1984 and extending up to the year 2010. However, it is worth noting that the foundations of MM innovation may be traced back to the Institute of Stanford Research. Specifically, the development of SHAKEY, a pioneering mobile manipulator, took place between 1966 and 1972.

The trajectory of MMs has undergone a series of developmental phases, with the body of literature serving as markers for each significant period of transformation. The introduction of mobile manipulators (MMs) in manufacturing lines was largely intended to enhance navigation, control, and perception, which has been extensively examined and debated in the context of RoboCup competitions. With the integration of serial manipulator arms into mobile platforms, the capabilities of these systems expanded to include more than nine degrees of freedom. This development opened up new possibilities for applications outside the traditional firm sector, such as rehabilitation and service.

Nevertheless, the expansion of the operational area of these manipulators presented significant obstacles in terms of mechatronic and control design. The collaborative method has emerged as a viable route in industrial applications, with MMs being conceptualized as collaborative entities. The Collaborative Mobile Industrial Manipulator, referred to as CMIM, demonstrated a sophisticated integration of several hardware components, including end-effectors and sensors, together with software that included planners and controllers. The adaptability of these entities has attracted attention across several industries, including logistics and manufacturing. Ongoing research efforts aim to further enhance their interaction autonomous and dynamics control capabilities.

Another significant development was the integration of UAVs with MMs, indicating potential advancements in dynamic logistics and cooperative assembly. However, the synergistic capabilities of UAVs and mobile robotic manipulators (MRMs) are still in their early stages of development, underscoring the need for more targeted research. Although the aforementioned evaluations provide valuable insights into many areas of MMs, such as UAV-MM integration, system design, hardware-software architecture, and collaborative aspects, it is evident that some parts of MMs have not been well addressed. Given the context, this review endeavors to provide a novel viewpoint on the previously unexamined or inadequately addressed aspects, so facilitating a comprehensive comprehension of the multimedia domain.

The fourth industrial revolution, aims to enhance the efficiency, adaptability, and responsiveness of production processes by integrating advanced technologies like the robots, IoT, advanced sensors, and AI. The rise of robotic technology in recent decades has been significantly influenced by the advent of I4.0, which has played a crucial role in shaping the modern industrial landscape. To meet the evolving demands of the future factory in the framework of Industry 4.0, it is anticipated that the next iteration of robots and their associated technologies would assume a significant role. The proper use of the newest sensor technologies is a critical component of recent development in the sector of robotics. The use of modern sensors serves to augment the robots' comprehension of their environment, while also playing a crucial role in facilitating secure and effective communication between people and robots. This particular sector is recognized as one of the foremost regions propelling advancements in the realm of systems of robots.

When introducing a novel product for implementation in Industry 4.0 settings, it is imperative to take into account the essential prerequisites of the 4.0 paradigm. Industry 4.0, via the proposition of a decentralized architecture as opposed to the conventional computer-integrated manufacturing (CIM) structure, and the introduction of Cyber-Physical Systems (CPSs), facilitates seamless communication and real-time data interchange across all constituent elements. Consequently, an essential necessity is the device's capacity to communicate effectively in both physical and cyber spaces. Conversely, the ability to perceive and deduce the surroundings, facilitated by a range of sensors and perhaps enhanced by artificial intelligence methodologies, is vital in achieving a versatile robotic system like MMs that can adeptly adjust to evolving and dynamic circumstances. Hence, developers of mixed reality (MM) are actively advancing their research efforts to adequately equip themselves for the integration of MM technologies into real-world settings, aligning with the present requirements of various businesses. The Technology Readiness Level (TRL) is a methodology used to assess the level of preparedness of a notion for practical application in real-world settings. Examining MMs through the lens of Technology Readiness Level (TRL) will facilitate the assessment of their appropriateness for integration into Industry 4.0 production systems.

III. THE FUTURE POTENTIAL OF ROBOTIC SYSTEMS

Numerous studies have projected a substantial surge in the quantity of robots in forthcoming years, as shown by notable papers such as [42], [43], and [44]. Industrial robots are expected to dominate the workforce in the near future. Nevertheless, it is anticipated that robots and autonomous systems will increasingly be used in many domains of society in the forthcoming years. This includes the integration of self-driving automobiles and the deployment of service robots in both professional and domestic settings. The issue that poses a significant challenge is the speed at which we might anticipate seeing a substantial transition. The technologies that encompass our environment exhibit many forms and varying degrees of technological advancement, exerting distinct influences on our daily existence. One possible method of categorizing robots as shown in **Table 1.**

Table 1. Categorization of Robotic Systems

Industrial robots	Industrial robots have been in existence for a considerable period of time and have had a significant influence on the industrial sector. The robots are primarily programmed by a human teacher and are comprised of a robotic arm composed of multiple degrees of freedom.
Service robots	According to the International Federation of Robotics, service robots are defined as robots that possess the capability to function either semi-autonomously or completely autonomously in order to carry out beneficial activities for people or equipment. It is imperative to acknowledge that this definition explicitly omits any applications pertaining to industrial automation. At now, these technologies are being used in certain contexts, including intra-hospital transportation, lawn maintenance, and household vacuuming.
Artificial intelligence	AI is a type of software that facilitates the ability of technology to demonstrate adaptive behavior through learning. The primary goal of AI is to enable systems to effectively observe, reason, and execute activities in an optimal manner. In recent times, there has been a notable increase in the utilization of AI across several industries, including decision-making and customer service assistance.

The shift from firm robots to service robots signifies a progression towards more customized systems that possess a higher level of autonomy. This statement suggests the existence of adaptable robots that possess the capability to execute tasks inside an unbounded, human-centric setting. The influence of firm robots has been evident for a considerable duration, but the effects of service robots in both professional and domestic settings are still to be seen and evaluated. The advancement of artificial intelligence research is anticipated to have a significant influence on the expeditious development of intelligent and autonomous service robots.

Commencement of the Breakthrough

Anticipating the precise time and location of technological breakthroughs is a formidable challenge. Frequently, such occurrences happen in a haphazard manner, devoid of any discernible connection to significant endeavors or undertakings. Objects or phenomena that may first seem dull or inconsequential have the potential to possess considerable value or importance. Certain individuals may recall their experiences with early graphical web browsers, like Mosaic, which emerged in 1993. Mosaic was created at the NCSA (National Center for Supercomputing Applications) Illinois Urbana-Champaign at the University of Illinois in the United States. The development of the web and the Internet during this period was characterized by a relatively modest pace, leading to a lack of immediate recognition about their potential for significant growth and widespread integration in contemporary society. Over time, there has been a progressive improvement in Internet speed and increased accessibility, accompanied by the development of more user-friendly web browsers. The surge in popularity of this technology may likely be attributed to its user-friendly interface, efficient retrieval of global information, and facilitation of unrestricted connection with individuals throughout the globe. The fundamental basis of the Internet is a scalable technology that enables the accommodation of continuously growing levels of network traffic.

According to Burke [45], the limited availability of advanced technology capable of effectively managing intricate settings has been a significant obstacle for artificial intelligence (AI). As the level of intricacy in our challenges escalates, the task of developing an automated system to effectively address them will correspondingly grow more arduous. The divide-and-conquer approach provides minimal assistance. The task at hand is deciphering the mechanisms behind the processes of growth and scaling in the natural world. This pertains to the advancement of individual agents as well as the interplay of several agents. In contemporary times, there exists a substantial amount of computational capacity at our disposal. However, the efficacy of this computing power remains constrained due to our incomplete understanding of optimal program design methodologies. Numerous rules governing the behavior of natural events within the realm of physics have been uncovered; nonetheless, a comprehensive comprehension of the mechanisms behind the emergence of complexity in the natural world remains elusive. The potential ramifications of advancements in research within this domain are expected to significantly influence the field of artificial intelligence. One example of advancement in the field is the training of artificial neural networks with several layers, often referred to as deep learning. This development signifies a positive step towards improvement.

In conjunction with computational intelligence, it is important for robots to possess mechanical bodies. The bodily components are now in a stationary state subsequent to their production and implementation. The integration of 3D-printing and fast prototyping has presented a new opportunity for mechanical reconfiguration and adaption in several fields. There are two distinct cohorts of researchers who actively contribute to the progression of artificial intelligence. One cohort is dedicated to the examination of medical or biological occurrences and trying to construct models that most accurately replicate them. In this manner, the authors attempt to illustrate the feasibility of computer simulations in replicating biological systems. This phenomenon has significant use, particularly in the realm of advancing the development of enhanced pharmaceuticals and therapeutic interventions for various ailments and impairments. Numerous scholars in the field of medicine engage in collaborative endeavors with computer scientists in the pursuit of this particular area of study. An illustration can be seen in the advancements made in cochlear implants, which have been made possible via a deeper comprehension of the auditory system. These implants have the capacity to provide individuals with hearing impairments the sensation of sound and the ability to approximate a typical auditory experience.

Merkert, Harjunkoski, Isaksson, Säynevirta, Saarela, and Sand [46] primarily directs their attention on the resolution of industrial challenges and the optimization of engineering systems for enhanced reliability. In this context, it is intriguing to explore the potential of biology as a source of inspiration for the development of more efficacious methodologies beyond those already used. Typically, this cohort of scientists operates at a more elevated degree of abstraction compared to the preceding cohort, which endeavors to ascertain the optimal approach for modeling biological systems. However, both groups get reciprocal benefits from each other's findings. One illustrative instance pertains to the advent of the aircraft, which materialized as a result of the Wright brothers' comprehension of the principles of air pressure and wing configuration, ascertained via their meticulous examination of wind tunnel experiments. Early attempts at developing flexible wings like those seen in birds proved to be ineffective. Therefore, it became imperative to use a more abstract approach, detached from biological principles, in order to design aircraft that were both durable and efficient.

In light of the many cautionary messages surrounding artificial intelligence (AI), Adadi and Berrada [47] conducted a comprehensive survey of perspectives from prominent scholars in the area, including those with large citation counts, in order to ascertain their outlook on forthcoming developments. A total of 170 answers were obtained from the 549 invitations that were sent. According to Ghazi, Anwar, Mumtaz, Saleem, and Tahir [48], the median estimate suggests a 50% likelihood of achieving high-level machine intelligence that refers to the capacity of machines to do various human occupations at least as proficiently as an average person, between the years 2040 and 2050. Furthermore, the probability of attaining this level of machine intelligence is projected to increase to 90% by the year 2075. According to these scholars, it is anticipated that during the following three decades, systems will progress towards achieving superintelligence, which is defined as possessing cognitive abilities that surpass those of humans in almost all areas of interest. Moreover, it is estimated that there is a probability of around one in three that this advancement would have negative consequences, categorized as either "detrimental" or "highly detrimental," for the whole of humankind. Nevertheless, it is important to approach this assertion with caution, since forecasting future events is a challenging task. Extensive analysis of expert predictions has shown a consistent pattern of inaccuracy in their projections.

IV. CONCLUSIONS

This article examines the progress of Augmented Reality (AR) in collaborative Human-Robot Proximity (HRP) applications, with a specific emphasis on ensuring safety and enhancing comfort during interactions between people and robots. This underscores the significance of data fusion in augmenting the perceptual capacity of mobile robots by incorporating data from many sensors. In addition, this paper discusses the necessity of establishing a unified structure that presents a novel approach for autonomously identifying interaction environments. This article delves deeper into the context of industrial logistics and puts up a proposition for implementing a collaborative assembly line system that utilizes a Sensor Area Network (SAN) based on range finder technology. This research investigates the use of augmented reality (AR) in order to improve perception-driven interactions inside assembly Manufacturing Execution Systems (MES). This article presents a thorough examination of mobile manipulators (MMs), which are comprised of robotic arms affixed to a mobile platform, and their wide-ranging applications in multiple sectors such as industry, agriculture, defense, search and rescue missions, nuclear facilities, household settings, space exploration, assistive technology, medical care, and mining. This article primarily examines the industrial applications, while also considering prospective solutions in several other sectors. The evolution of Mobile Manipulators (MMs) has progressed through many phases, commencing with the first prototype in 1984 as the pioneering variant. The collaborative method has emerged as a viable route in industrial applications, with MMs being conceptualized as collaborative entities. The integration of UAV with mobile manipulators (MMs) indicates the potential for collaborative assembly and efficient logistics in the next years. The perception of I4.0, aims to facilitate the creation of smart manufacturing facilities that exhibit exceptional efficiency, adaptability, and responsiveness to fluctuations in market conditions. The next cohort of robots and its associated technologies are poised to assume a significant role in meeting the ever-changing demands of the future industry, situated within the framework of Industry 4.0. The prospective advancements of robotic systems include industrial robots, service robots, and artificial intelligence. The shift from firm robots to service robots signifies a progression towards more individualized systems characterized by a growing level of self-governance. This implies the development of adaptable robots capable of executing tasks within a human-centric environment without limitations.

Breakthroughs in technology often manifest in an unexpected manner, devoid of any direct connection with significant undertakings. The popularity of the internet and its widespread adoption may be attributed to its user-friendly interface, rapid information retrieval capabilities, and cost-free communication features. As the level of intricacy in issues escalates, the task of developing automated solutions to effectively address them gets progressively challenging. The elucidation of the mechanisms behind the emergence of complexity in natural systems will have a significant impact on the field of artificial intelligence. The advancement in the training of artificial neural networks with several layers, often known as deep learning, exemplifies a promising trajectory towards growth. Researchers provide valuable contributions to the progress of artificial intelligence (AI) via their investigation of biological or medical phenomena, as well as their emphasis on addressing industrial challenges in problem-solving. The probability of achieving high-level machine intelligence is estimated to be 50%.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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