Advances In Industrial Process Automation Using Microcontrollers – A Review

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Abstract - This article reviews the recent advances in industrial process automation using microcontrollers. It examines the various microcontrollers available on the market, their programming techniques, and the programming languages they use. Additionally, the article discusses the benefits of using microcontrollers in industrial automation processes and the potential limitations. In modern industrial settings, microcontrollers have become increasingly important components in automation processes. They allow for precise control of various processes, from temperature and pressure regulation to motion control. The most popular microcontrollers available today are the Arduino, PIC, and MSP430. Each of these microcontrollers has its own unique programming techniques, ranging from C and C++ to assembly language. Depending on the application, various programming languages may be used, such as Python, JavaScript, and MATLAB. The article discusses the advantages of using microcontrollers in industrial processing. These include increased accuracy, reduced cost, and improved safety. The article also mentions the potential drawbacks, such as the need for specialized programming skills and the possibility of data loss. Overall, microcontrollers offer a great potential for industrial automation processes. This review article provides a comprehensive overview of the current state of microcontrollers in industry and the potential benefits they offer. With the right programming techniques and languages, microcontrollers can be used to greatly improve industrial efficiency and safety.

Keywords - Microcontroller, Industrial Process Automation, Programming, Arduino, PIC, MSP430, C, C++, Assembly Language, Python, JavaScript, MATLAB.

I. INTRODUCTION

The development of industrial automation processes has been rapidly advancing in recent years thanks to the increasing availability of advanced microcontrollers. Microcontrollers are small, programmable computers that offer high precision and accuracy in controlling a wide variety of industrial processes [1]. They are becoming increasingly popular for industrial automation due to their low cost, high performance, and ease of programming. This review article aims to provide an overview of the current state of microcontrollers in industrial automation, the programming techniques and languages used, and the potential benefits and limitations of using them. Microcontrollers are available in a wide range of models, from the widely popular Arduino, PIC, and MSP430 to more specialized models [2]. They come in various sizes and configurations, depending on the specific application. The most widely used microcontrollers use either the C or C++ programming language, which are relatively easy to learn and use. Additionally, more advanced programming languages such as Python, JavaScript, and MATLAB are becoming increasingly popular for microcontrollers as they offer more flexibility in programming. In terms of industrial automation, microcontrollers offer a number of advantages [3]. They offer greater precision and accuracy in controlling various processes, from temperature and pressure regulation to motion control. Additionally, they are relatively low cost compared to other automation solutions, and their programming is relatively simple. However, there are also some potential drawbacks to using microcontrollers in industrial automation. For example, programming them requires specialized skills, and there is always the risk of data loss due to improper programming. Additionally, microcontrollers require regular maintenance to ensure smooth operation, as any malfunction can cause disruption in the process [4-10]. Overall, microcontrollers offer a great potential for industrial automation processes. This review article provides a comprehensive overview of the current state of microcontrollers in industry and the potential benefits they offer. With the right programming techniques and languages, microcontrollers can be used to greatly improve industrial efficiency and safety. Furthermore, microcontrollers can be used to reduce costs, as well as for more specialized applications such as robotics. As technology continues to advance, microcontrollers will become more and more important components in industrial automation processes [11].

II. TYPES OF MICROCONTROLLERS

Industrial automation is a rapidly developing field that is being implemented in various industries, from manufacturing and energy to healthcare. Automation processes allow for increased efficiency, safety, and accuracy, reducing costs and improving productivity. Microcontrollers are essential components of automation processes, providing the basis for precise control of various processes. This review article examines the recent advances in industrial process automation using microcontrollers, discussing their features, programming techniques, and potential benefits and drawbacks [12].

Types of Microcontrollers

Microcontrollers are small computers that are embedded in electronic devices. They are designed to carry out specific tasks and can be programmed to control various processes. There are a variety of microcontrollers available on the market, each with its own unique features. Popular microcontrollers include the Arduino, PIC, and MSP430.The Arduino is an open-source microcontroller platform that is designed to be easy to use and program. It is the most popular microcontroller for hobbyists and is used in a wide variety of projects [13-15]. The Arduino can be programmed using the Arduino IDE, which supports a variety of languages including C, C++, and Python.The PIC (Peripheral Interface Controller) is a family of microcontrollers from Microchip Technology. It is popular for industrial applications due to its low cost and powerful features. The PIC can be programmed using Assembly language or C.The MSP430 (Mixed Signal Processor) is a family of microcontrollers from Texas Instruments. It is designed for low-power applications and is used in a variety of products, including medical devices and sensors. The MSP430 can be programmed using C, C++, and Assembly language [16-21].

Programming Techniques and Languages

Programming microcontrollers involves writing code in a programming language that the microcontroller can understand. The most popular programming languages for microcontrollers are C, C++, and Assembly. However, depending on the application, other languages such as Python, JavaScript, and MATLAB may be used.C and C++ are the most commonly used programming languages for microcontrollers. They are powerful and versatile, allowing for complex programming tasks. Assembly language is another popular language for microcontrollers, as it is more efficient and can be used to take advantage of the microcontroller's features [22].

Benefits of Microcontrollers in Industrial Automation

Microcontrollers offer many benefits in industrial automation processes. They allow for precise control of various processes, from temperature and pressure regulation to motion control. Additionally, they can be used to reduce costs, increase safety, and improve accuracy.

The use of microcontrollers in industrial processes can reduce costs by eliminating the need for expensive components or systems. Additionally, they can help improve safety by monitoring and controlling hazardous processes. Finally, they can improve accuracy by providing precise, consistent control of various processes.

Potential Limitations

Although microcontrollers offer many benefits in industrial automation processes, there are some potential drawbacks. For example, using microcontrollers requires specialized programming skills, which may not be available to all users. Additionally, there is always a risk of data loss due to power outages or system malfunctions.Ina nutshell, microcontrollers offer a great potential for industrial automation processes. This review article provides a comprehensive overview of the current state of microcontrollers in industry and the potential benefits they offer. With the right programming techniques and languages, microcontrollers can be used to greatly improve industrial efficiency and safety.

III. PROGRAMMING TECHNIQUES

Industrial process automation is the use of computers, robots, and other machines to control and monitor industrial processes. It is a rapidly growing field that offers a number of benefits to industry, including increased efficiency, improved safety, and decreased costs. Microcontrollers are a key component in industrial process automation, providing the necessary computing power to allow for the automation of complex processes. This paper reviews the advances in industrial process automation using microcontrollers, outlining the various technologies that are being used and the benefits they offer.Industrial process automation has been used for many years to reduce the costs associated with manual labor and to improve the quality and efficiency of industrial processes. The use of microcontrollers in industrial process automation has been particularly advantageous, as they provide the necessary computing power to automate complex processes. Microcontrollers are small, integrated circuits that are used to control and monitor hardware, such as motors, sensors, and actuators. They are programmed using a high-level programming language, such as C or assembly language, and can be used to control a variety of industrial processes.Industrial process automation has been greatly enhanced by the use of microcontrollers. There are several different types of microcontroller technologies that are used in industrial process automation, each offering its own advantages and disadvantages [23].

Programmable Logic Controllers
Programmable logic controllers (PLCs) are a type of microcontroller that is used to control industrial processes. PLCs are programmed using a specialized form of assembly language and can be used to control a variety of industrial processes, from simple on/off signals to complex tasks such as sequential control and motor control. PLCs are particularly advantageous for industrial process automation due to their reliability, flexibility, and cost-effectiveness [24].

Robotic Process Automation
Robotic process automation (RPA) is a type of technology that is used to automate a variety of tasks in industrial processes. RPA technology is used to automate repetitive tasks, such as filling out forms or entering data into a database. It can also be used to control robotic arms and other machines in order to perform complex tasks. RPA technology is advantageous for industrial process automation due to its ability to automate complex tasks and reduce the amount of time and effort required to complete them [25].

Industrial Internet of Things
The industrial Internet of Things (IIoT) is a type of technology that is used to connect industrial machines and devices to the internet. IIoT technology is used to collect data from machines, analyze it, and then take action based on the results. IIoT technology is advantageous for industrial process automation as it can be used to remotely monitor and control industrial processes [26].

Industrial Automation Software
Industrial automation software is a type of software that is used to control and monitor industrial processes. Industrial automation software is typically used to automate complex tasks, such as sequencing and motor control. It is advantageous for industrial process automation as it can automate complex processes and reduce the amount of time and effort required to complete them [27].

Benefits
The use of microcontrollers in industrial process automation offers a number of benefits. The automation of complex processes can reduce the amount of time and effort required to complete them, resulting in increased efficiency and decreased costs. Furthermore, the use of microcontrollers can improve the accuracy and reliability of the processes, leading to improved safety. Finally, microcontrollers can be programmed to monitor and adjust processes in real-time, providing greater flexibility and control [28].

In a nutshell, microcontrollers are a key component of industrial process automation, providing the necessary computing power to automate complex processes. There are several different types of microcontroller technologies that are used in industrial process automation, each offering its own advantages and disadvantages. The use of microcontrollers in industrial process automation offers a number of benefits, including increased efficiency, improved safety, and decreased costs. The advances in microcontroller-based industrial process automation will continue to have a major impact on the industry in the coming years [29].

IV. PROGRAMMING LANGUAGES

Industrial process automation using microcontrollers has been a rapidly growing field in recent years. It is a technology that has been used to improve the efficiency and productivity of industrial processes, as well as to reduce labor costs and improve quality. This review will cover the advances in industrial process automation using microcontrollers and highlight some of the benefits of this technology.Microcontrollers are small, single-chip computers that are used to control various processes within an industrial system. They are often used as the primary control device for machines such as robots, conveyor belts, and other automated systems. They are also used in various types of communication systems, such as RFID and GSM. Microcontrollers are extremely versatile and can be used in a variety of applications [30].

Benefits of Automation Using Microcontrollers
The use of microcontrollers in industrial process automation has many advantages. The use of microcontrollers allows for a more efficient and precise control of industrial processes, saving time and money. Microcontrollers can be programmed to perform routine tasks, such as monitoring temperatures, controlling motors and other devices, and managing data. They can also be used to control complex processes, such as production lines and equipment.Microcontrollers are easy to use and are relatively inexpensive compared to other automation technologies. They are also highly reliable and require minimal maintenance. Additionally, microcontrollers can be programmed to handle multiple tasks, allowing for more efficient use of the system.In addition to the advantages of automation, microcontrollers are also capable of providing feedback to the user. This feedback can be used to improve the efficiency of the system and to monitor the performance of the process. This feedback can also be used to troubleshoot any problems that may arise during the process [31].

Microcontrollers for Automation

The most common type of microcontroller used for industrial process automation is the 8-bit microcontroller. This type of microcontroller is capable of performing a variety of tasks and is relatively inexpensive. These microcontrollers are typically programmed using a language such as C++, which is widely used and easy to learn.The use of 16-bit microcontrollers is also becoming increasingly popular in industrial automation applications. These microcontrollers are more powerful than 8-bit microcontrollers and are often used for more complex applications. They are also more expensive than 8-bit microcontrollers, but can provide greater flexibility and control [32-35].Microcontroller-based automation systems are usually connected to a network and can be easily monitored and managed remotely. This allows for greater flexibility and scalability in the system. Additionally, these systems can be configured to send data back to the user, providing real-time feedback on the system's performance [36].

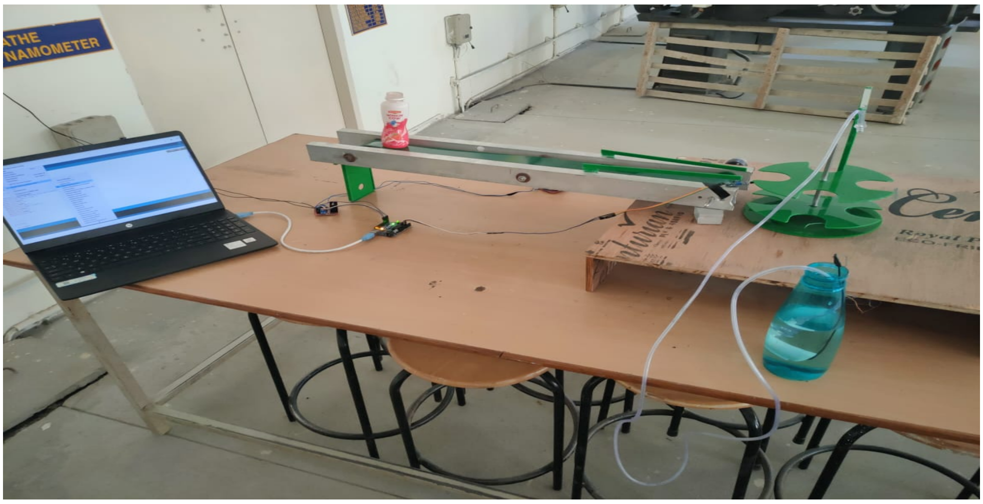

Fig 1. A Typical Bottle Filling Automation Using Arduino Micro Controller

Industrial process automation using microcontrollers has been a rapidly growing field in recent years. Microcontrollers are small, single-chip computers that are used to control various processes within an industrial system. The use of microcontrollers in industrial process automation has many advantages, including the ability to perform a variety of tasks, the ability to provide feedback to the user, and the ability to easily monitor and manage the system remotely. 8-bit and 16-bit microcontrollers are the most common types used, and both offer different levels of control and flexibility. The use of microcontrollers has allowed industrial processes to become more efficient and productive, and has also reduced labor costs and improved quality [37]. A Typical Bottle filling using Arduino Micro controller is exhibited in **Fig 1**.

V. BENEFITS OF MICROCONTROLLER AUTOMATION

Microcontroller automation has revolutionized the way businesses and industries operate in today's world. By utilizing microcontroller-based automation systems, businesses can save time, money, and effort while increasing efficiency and accuracy. This article will review the benefits of microcontroller automation and demonstrate why it is becoming increasingly popular in a variety of industries. The most obvious benefit of microcontroller automation is the ability to reduce costs. By automating processes, businesses can save on labor costs, increase production efficiency, and eliminate errors [38]. With automated processes, businesses can eliminate the need for manual labor and reduce the need for costly human resources. Moreover, automated processes can help reduce the cost of materials by eliminating the need for expensive components or materials. Additionally, automated processes can reduce downtime and improve production cycle times, leading to more efficient production and cost savings. In addition to cost savings, microcontroller automation can also help improve accuracy and quality. By automating processes, businesses can ensure that tasks are completed accurately and efficiently. Automated systems can reduce the chances of human error and ensure that tasks are completed according to specifications. Furthermore, automated systems can help reduce the risk of errors or defects by providing real-time feedback to operators and improving the quality of processes. Another benefit of microcontroller automation is the ability to increase data security. By using automated systems, businesses can ensure that sensitive data is stored securely and accessed only by authorized personnel. Automated systems can also help reduce the risk of data breaches by providing secure data storage and access protocols. Additionally, automated systems can help businesses ensure the safety of their networks by providing real-time monitoring and alerting capabilities [38]. Finally, microcontroller automation can help increase productivity. Automated processes can reduce the need for manual labor and help businesses complete tasks more quickly. Automated processes can also help businesses streamline their operations by eliminating redundant tasks and increasing efficiency. Furthermore, automated processes can help businesses reduce cycle times and increase the accuracy of their operations, leading to greater productivity and cost savings. In conclusion, microcontroller automation has numerous benefits for businesses and industries. By utilizing automated systems, businesses can reduce costs, improve accuracy and quality, increase data security, and increase productivity. With the numerous benefits of microcontroller automation, it is no wonder that this technology is becoming increasingly popular in a variety of industries [39].

VI. POTENTIAL DRAWBACKS

One potential drawback of using microcontrollers in industrial process automation is that it can be difficult to implement. Microcontrollers are complex systems and require a significant amount of programming and hardware expertise to get them up and running. If a system is not properly configured, the results can be unreliable and potentially hazardous. Additionally, the cost of the hardware and software needed to implement the system can be high. Another potential issue with using microcontrollers in industrial process automation is that they can be prone to errors. Microcontrollers are typically programmed using a specialized set of instructions, and if the instructions are not followed correctly, the system can malfunction. This can result in inaccurate data or even dangerous situations. Additionally, as the complexity of the system increases, the chances of errors increase as well [40]. A third potential drawback of using microcontrollers in industrial process automation is that the system can be vulnerable to cyber-attacks. As the system becomes more complex and integrated, there is a greater risk of malicious actors attempting to gain access to the system, potentially compromising its security. Additionally, the system can be vulnerable to viruses and other forms of malware, resulting in data loss or corruption. Finally, the use of microcontrollers in industrial process automation can lead to a lack of flexibility. As the system becomes more complex, it can become difficult to make changes or adapt to new conditions. This can be a significant issue in industries where the environment is constantly changing, such as in the manufacturing sector. Despite these potential drawbacks, there are a number of methods that can be used to mitigate the issues associated with industrial process automation using microcontrollers. First, it is important to ensure that the system is properly installed and configured. This can involve using a qualified technician to ensure that the system is correctly set up, or using a software package that offers automated installation and configuration. Additionally, it is important to ensure that the system is regularly updated and maintained, as this can help to reduce the risk of errors or malicious attacks. Second, it is important to ensure that the system is adequately secured. This can involve using firewalls to protect the system from external threats, as well as implementing encryption and authentication protocols to ensure that only authorized personnel can access the system. Additionally, it is important to regularly monitor the system for potential issues, and to have a response plan in place in case of a security breach. Finally, it is important to ensure that the system is designed with flexibility in mind. This can involve using modular components that can be easily replaced or updated, as well as using software packages that allow for easy customization or integration with other systems. Additionally, it is important to ensure that the system is designed to accommodate future changes, such as new technologies or new regulations. In conclusion, the advances in industrial process automation using microcontrollers have the potential to revolutionize the way in which industrial processes are carried out. However, there are potential drawbacks that should be considered when implementing this technology. By taking the necessary steps to mitigate the risks associated with using microcontrollers in industrial process automation, organizations can ensure that the system is reliable and secure, and that it is able to accommodate changes in the environment [41-42].

VII. CONCLUSION

In conclusion, advances in industrial process automation using microcontrollers have been impressive and successful. By leveraging the power of digital signal processing, microcontrollers have been able to provide improved efficiency, accuracy and cost-effectiveness. This has enabled process automation to become a viable alternative to manual labor and manual control systems. The development of process automation systems based on microcontrollers has also been instrumental in reducing operational costs and improving the quality of the processes they are used to control. This has been achieved by improving the accuracy, reliability and speed of the processes that are automated. The use of microcontrollers in process automation has also enabled the development of more advanced technologies such as artificial intelligence and machine learning. These technologies have enabled process automation to become more adaptive to changes in the environment and to identify and optimize the best strategies for operation. The use of microcontrollers in process automation has also made it possible to develop solutions that are more scalable and adapted to different types of industrial applications. This has enabled process automation to become more efficient and flexible and to better meet the needs of the industry. Finally, the use of microcontrollers in process automation has also helped in reducing the environmental impact of industrial processes. By improving the efficiency of the processes, the amount of energy consumed and the emissions produced by these processes can be reduced. Overall, advances in industrial process automation using microcontrollers have been significant and have enabled the industry to become more efficient, cost-effective and environmentally friendly. With the continued development of microcontrollers and other technologies, process automation is expected to become even more advanced and efficient in the future.

VIII. FUTURE PROSPECTS

Industrial process automation has been a topic of immense interest for researchers and practitioners since the advent of microcontrollers. Microcontrollers have enabled a wide range of automation solutions, ranging from simple process control to sophisticated robotics applications. With the rapid advancement of technology, microcontrollers are now being utilized in various industries and applications, with substantial improvements in their capabilities. This research review article will discuss the advances in industrial process automation using microcontrollers. The development of microcontrollers has been a major factor in the advancement of industrial automation. Microcontrollers provide a cost-effective solution to automate a wide range of industrial processes. Microcontrollers are capable of performing complex tasks with minimal programming and can be easily integrated into existing systems. Furthermore, they are small in size and require minimal power consumption, which makes them ideal for use in applications with limited space and limited power supply. One of the most significant advances in industrial process automation using microcontrollers is the development of real-time systems. Real-time systems allow for the automation of processes with fast response times and improved accuracy. This has enabled the automation of processes such as chemical processing, manufacturing, and even medical diagnostics. Furthermore, real-time systems can be used to monitor and control multiple processes simultaneously, thereby reducing the manual labour and increasing efficiency. The development of wireless communication technologies has also enabled the automation of industrial processes. By using wireless communication, it is possible to transmit data between multiple devices without the need for physical wiring. This has enabled the automation of processes in hazardous and remote environments, such as in the mining industry. Furthermore, wireless communication technologies are also used to remotely control and monitor industrial processes to improve efficiency and reduce manual labour. The development of the Internet of Things (IoT) has also revolutionized the field of industrial process automation. IoT enables the connection of multiple devices over a network, allowing for the automation of processes. This has enabled the automation of processes such as inventory management, process control, and predictive maintenance. Furthermore, IoT has enabled the development of predictive analytics, which can be used to analyse large amounts of data to predict future trends and outcomes. The development of artificial intelligence (AI) and machine learning (ML) has also been a major advancement in industrial process automation. AI and ML can be used to automate complex tasks, such as those related to predictive maintenance and process control. Furthermore, AI and ML can be used to develop sophisticated algorithms that can autonomously monitor and control industrial processes. This has enabled the automation of processes such as production scheduling and resource allocation [50]. Finally, the development of cloud computing has enabled the automation of industrial processes from anywhere in the world. By using cloud computing, it is possible to access data from multiple sources and analyse it in real-time. This has enabled the automation of processes such as inventory management, logistics, and supply chain management. Furthermore, cloud computing has enabled the development of sophisticated analytics solutions that can generate insightful reports and provide predictive analytics. In conclusion, the advances in industrial process automation using microcontrollers have been incredible. Microcontrollers provide a cost-effective solution to automate a wide range of industrial processes. Furthermore, the development of real-time systems, wireless communication technologies, IoT, AI and ML, and cloud computing have enabled the automation of complex processes and the development of predictive analytics solutions. These advances have enabled automation in various industries and have significantly improved efficiency, accuracy, and safety.

References

[1]. V. Popov, S. Ahmed, N. Shakev, and A. Topalov, “Gesture-based Interface for Real-time Control of a Mitsubishi SCARA Robot Manipulator,” IFAC-PapersOnLine, vol. 52, no. 25, pp. 180–185, 2019, doi: 10.1016/j.ifacol.2019.12.469.

[2]. M. Benoussaad, A. D. L. Rangel, G. I. Perez-Soto, K. A. Camarillo-Gómez, and M. Rakotondrabe, “Force-position modeling and control of a two robots based platform for automated pick-and-place task using H∞ technique,” IFAC-PapersOnLine, vol. 55, no. 12, pp. 641–646, 2022, doi: 10.1016/j.ifacol.2022.07.384.

[3]. B. Tipary and G. Erdős, “Generic development methodology for flexible robotic pick-and-place workcells based on Digital Twin,” Robotics and Computer-Integrated Manufacturing, vol. 71, p. 102140, Oct. 2021, doi: 10.1016/j.rcim.2021.102140.

[4]. Y. Li, T. Huang, and D. G. Chetwynd, “An approach for smooth trajectory planning of high-speed pick-and-place parallel robots using quintic B-splines,” Mechanism and Machine Theory, vol. 126, pp. 479–490, Aug. 2018, doi: 10.1016/j.mechmachtheory.2018.04.026.

[5]. V. Krasniqi, S. Buza, A. Pajaziti, and F. Krasniqi, “Control Algorithm of a pick & place three dimensional robots,” IFAC Proceedings Volumes, vol. 46, no. 16, pp. 440–443, 2013, doi: 10.3182/20130825-4-us-2038.00029.

[6]. E. Hortal, E. Iáñez, A. Úbeda, C. Perez-Vidal, and J. M. Azorín, “Combining a Brain–Machine Interface and an Electrooculography Interface to perform pick and place tasks with a robotic arm,” Robotics and Autonomous Systems, vol. 72, pp. 181–188, Oct. 2015, doi: 10.1016/j.robot.2015.05.010.

[7]. M. Moghaddam and S. Y. Nof, “Parallelism of Pick-and-Place operations by multi-gripper robotic arms,” Robotics and Computer-Integrated Manufacturing, vol. 42, pp. 135–146, Dec. 2016, doi: 10.1016/j.rcim.2016.06.004.

[8]. Y. Huang, R. Chiba, T. Arai, T. Ueyama, and J. Ota, “Robust multi-robot coordination in pick-and-place tasks based on part-dispatching rules,” Robotics and Autonomous Systems, vol. 64, pp. 70–83, Feb. 2015, doi: 10.1016/j.robot.2014.10.018.

[9]. N. W. Gosim, T. Faisal, H. M. A. A. Al-Assadi, and M. Iwan, “Pick and Place ABB Working with a Liner Follower Robot,” Procedia Engineering, vol. 41, pp. 1336–1342, 2012, doi: 10.1016/j.proeng.2012.07.319.

[10]. K. Harada, T. Tsuji, K. Nagata, N. Yamanobe, and H. Onda, “Validating an object placement planner for robotic pick-and-place tasks,” Robotics and Autonomous Systems, vol. 62, no. 10, pp. 1463–1477, Oct. 2014, doi: 10.1016/j.robot.2014.05.014.

[11]. M. Pellicciari, G. Berselli, F. Leali, and A. Vergnano, “A method for reducing the energy consumption of pick-and-place industrial robots,” Mechatronics, vol. 23, no. 3, pp. 326–334, Apr. 2013, doi: 10.1016/j.mechatronics.2013.01.013.

[12]. J. Park, M. B. G. Jun, and H. Yun, “Development of robotic bin picking platform with cluttered objects using human guidance and convolutional neural network (CNN),” Journal of Manufacturing Systems, vol. 63, pp. 539–549, Apr. 2022, doi: 10.1016/j.jmsy.2022.05.011.

[13]. L. Bu, C. Chen, G. Hu, A. Sugirbay, H. Sun, and J. Chen, “Design and evaluation of a robotic apple harvester using optimized picking patterns,” Computers and Electronics in Agriculture, vol. 198, p. 107092, Jul. 2022, doi: 10.1016/j.compag.2022.107092.

[14]. P. Bencak, D. Hercog, and T. Lerher, “Evaluating robot bin-picking performance based on Box and Blocks Test,” IFAC-PapersOnLine, vol. 55, no. 10, pp. 502–507, 2022, doi: 10.1016/j.ifacol.2022.09.443.

[15]. B. P. Mathew, F. Devasia, A. Asok, P. R. Jayadevu, and R. Baby, “Implementation of an origami inspired gripper robot for picking objects of variable geometry,” Materials Today: Proceedings, vol. 58, pp. 176–183, 2022, doi: 10.1016/j.matpr.2022.01.255.

[16]. K. Wang, T. Hu, Z. Wang, Y. Xiang, J. Shao, and X. Xiang, “Performance evaluation of a robotic mobile fulfillment system with multiple picking stations under zoning policy,” Computers & Industrial Engineering, vol. 169, p. 108229, Jul. 2022, doi: 10.1016/j.cie.2022.108229.

[17]. M. Huang, L. He, D. Choi, J. Pecchia, and Y. Li, “Picking dynamic analysis for robotic harvesting of Agaricus bisporus mushrooms,” Computers and Electronics in Agriculture, vol. 185, p. 106145, Jun. 2021, doi: 10.1016/j.compag.2021.106145.

[18]. P. Fager, R. Hanson, Å. Fasth-Berglund, and S. Ekered, “Supervised and unsupervised learning in vision-guided robotic bin picking applications for mixed-model assembly,” Procedia CIRP, vol. 104, pp. 1304–1309, 2021, doi: 10.1016/j.procir.2021.11.219.

[19]. K. L. Keung, C. K. M. Lee, and P. Ji, “Industrial internet of things-driven storage location assignment and order picking in a resource synchronization and sharing-based robotic mobile fulfillment system,” Advanced Engineering Informatics, vol. 52, p. 101540, Apr. 2022, doi: 10.1016/j.aei.2022.101540.

[20]. F. Sgarbossa, A. Romsdal, F. H. Johannson, and T. Krogen, “Robot picker solution in order picking systems: an ergo-zoning approach,” IFAC-PapersOnLine, vol. 53, no. 2, pp. 10597–10602, 2020, doi: 10.1016/j.ifacol.2020.12.2813.

[21]. A. S. Olesen, B. B. Gergaly, E. A. Ryberg, M. R. Thomsen, and D. Chrysostomou, “A Collaborative Robot Cell for Random Bin-picking based on Deep Learning Policies and a Multi-gripper Switching Strategy,” Procedia Manufacturing, vol. 51, pp. 3–10, 2020, doi: 10.1016/j.promfg.2020.10.002.

[22]. Y. Zhuang, Y. Zhou, Y. Yuan, X. Hu, and E. Hassini, “Order picking optimization with rack-moving mobile robots and multiple workstations,” European Journal of Operational Research, vol. 300, no. 2, pp. 527–544, Jul. 2022, doi: 10.1016/j.ejor.2021.08.003.

[23]. Y. Li, Q. Zhang, H. Xu, E. Lim, and J. Sun, “Virtual monitoring system for a robotic manufacturing station in intelligent manufacturing based on Unity 3D and ROS,” Materials Today: Proceedings, vol. 70, pp. 24–30, 2022, doi: 10.1016/j.matpr.2022.08.486.

[24]. Y. Xiong, Y. Ge, and P. J. From, “An obstacle separation method for robotic picking of fruits in clusters,” Computers and Electronics in Agriculture, vol. 175, p. 105397, Aug. 2020, doi: 10.1016/j.compag.2020.105397.

[25]. Y. Xiong, Y. Ge, and P. J. From, “An obstacle separation method for robotic picking of fruits in clusters,” Computers and Electronics in Agriculture, vol. 175, p. 105397, Aug. 2020, doi: 10.1016/j.compag.2020.105397.

[26]. Z. Hou, Z. Li, T. Fadiji, and J. Fu, “Soft grasping mechanism of human fingers for tomato-picking bionic robots,” Computers and Electronics in Agriculture, vol. 182, p. 106010, Mar. 2021, doi: 10.1016/j.compag.2021.106010.

[27]. R. Higashinaka, T. Minato, K. Sakai, T. Funayama, H. Nishizaki, and T. Nagai, “Dialogue Robot Competition for the Development of an Android Robot with Hospitality,” 2022 IEEE 11th Global Conference on Consumer Electronics (GCCE), Oct. 2022, doi: 10.1109/gcce56475.2022.10014410.

[28]. S. Macenski, T. Foote, B. Gerkey, C. Lalancette, and W. Woodall, “Robot Operating System 2: Design, architecture, and uses in the wild,” Science Robotics, vol. 7, no. 66, May 2022, doi: 10.1126/scirobotics.abm6074.

[29]. K. Charalampous, I. Kostavelis, and A. Gasteratos, “Recent trends in social aware robot navigation: A survey,” Robotics and Autonomous Systems, vol. 93, pp. 85–104, Jul. 2017, doi: 10.1016/j.robot.2017.03.002.

[30]. X. Ke et al., “Review on robot-assisted polishing: Status and future trends,” Robotics and Computer-Integrated Manufacturing, vol. 80, p. 102482, Apr. 2023, doi: 10.1016/j.rcim.2022.102482.

[31]. B. Xiao, C. Chen, and X. Yin, “Recent advancements of robotics in construction,” Automation in Construction, vol. 144, p. 104591, Dec. 2022, doi: 10.1016/j.autcon.2022.104591.

[32]. Y. Tian, C. Chen, K. Sagoe-Crentsil, J. Zhang, and W. Duan, “Intelligent robotic systems for structural health monitoring: Applications and future trends,” Automation in Construction, vol. 139, p. 104273, Jul. 2022, doi: 10.1016/j.autcon.2022.104273.

[33]. L. Wang, Y. Lu, Y. Zhang, W. Chen, X. Zhao, and F. Gao, “Design and soft-landing control of underwater legged robot for active buffer landing on seabed,” Ocean Engineering, vol. 266, p. 112764, Dec. 2022, doi: 10.1016/j.oceaneng.2022.112764.

[34]. A. Martini et al., “Salvage Robot-assisted Renal Surgery for Local Recurrence After Surgical Resection or Renal Mass Ablation: Classification, Techniques, and Clinical Outcomes,” European Urology, vol. 80, no. 6, pp. 730–737, Dec. 2021, doi: 10.1016/j.eururo.2021.04.003.

[35]. W. Chen, B. Zhou, H. Huang, Y. Lu, S. Li, and F. Gao, “Design, modeling and performance analysis of a deployable WEC for ocean robots,” Applied Energy, vol. 327, p. 119993, Dec. 2022, doi: 10.1016/j.apenergy.2022.119993.

[36]. C. Zhao, Q. Cao, X. Sun, X. Wu, G. Zhu, and Y. Wang, “Intelligent robot-assisted minimally invasive reduction system for reduction of unstable pelvic fractures,” Injury, vol. 54, no. 2, pp. 604–614, Feb. 2023, doi: 10.1016/j.injury.2022.11.001.

[37]. X. Sun, S. Deng, B. Tong, S. Wang, C. Zhang, and Y. Jiang, “Hierarchical framework for mobile robots to effectively and autonomously explore unknown environments,” ISA Transactions, vol. 134, pp. 1–15, Mar. 2023, doi: 10.1016/j.isatra.2022.09.005.

[38]. S. M. Shafaei and H. Mousazadeh, “Experimental comparison of locomotion system performance of ground mobile robots in agricultural drawbar works,” Smart Agricultural Technology, vol. 3, p. 100131, Feb. 2023, doi: 10.1016/j.atech.2022.100131.

[39]. J. (Justin) Li, M. A. Bonn, and B. H. Ye, “Hotel employee’s artificial intelligence and robotics awareness and its impact on turnover intention: The moderating roles of perceived organizational support and competitive psychological climate,” Tourism Management, vol. 73, pp. 172–181, Aug. 2019, doi: 10.1016/j.tourman.2019.02.006.

[40]. Y. Liu, H. Xu, D. Liu, and L. Wang, “A digital twin-based sim-to-real transfer for deep reinforcement learning-enabled industrial robot grasping,” Robotics and Computer-Integrated Manufacturing, vol. 78, p. 102365, Dec. 2022, doi: 10.1016/j.rcim.2022.102365.

[41]. B. Wang et al., “Small-Scale Robotics with Tailored Wettability,” Advanced Materials, vol. 35, no. 18, Mar. 2023, doi: 10.1002/adma.202205732.