Robotics arm implementation in Industry 4.0 Environment

Submitted as Research Report in SIT723

SUBMISSION DATE
T1-2022

Pravindu Lokuarumage
STUDENT ID 218665646
COURSE - Master of Software Engineering Honours (S464)

Supervised by: Imali Dias, Thuong Hoang

Abstract

Purpose of Review - This paper provides an overview of Industry 4.0 and how it functions with the use of edge computing and machine learning and the how one would implement a new automated system into this environment. Further it looks into other technologies that are used when implementing an automated system which helps the system to achieve the industry standards required such as low latency and real time communication which are the most important in this industry for automation.
Summary - This paper first gives the steps taken in the installation of UR3e robotics arm as the experimental set up followed by an overview of the industry 4.0. Concluded by the future prospect of implementing the UR3e robotics system in a industry 4.0 surrounding.

Contents

List of Figures

1 Introduction

The aim of this research report is to review the literature on Industry 4.0 and how this industry currently integrates its robotics components into its environment. This report will be reviewing the advantages and disadvantages of the industry 4.0 and how it uses other technologies such as edge computing and machine learning to complement and improve the integration of automated robotics into the workspace. Additionally, I will be setting up an experimental set up using the UR3e robotics arms.

This project is the research for the implementation of UR3e in an industry 4.0 environment for the application of material detection by the use of tactical sensors of the gripper. The first section of this report will be reporting on the steps taken in setting up and installation of the UR3e robot.

In the following section of the report, a detailed literature review on the chosen topic is presented to analyse how the industry 4.0 functions, the process of resource allocation, the usage of machine learning and multi-edge computing in industry 4.0. The literature review further aims to an analysis of the advantages and disadvantages of this technology in ensuring better resource allocation and improving work efficiency. In this literature review, only the journal articles that were published after the year 2016 are chosen to ensure that an up-to-date data is used in the literature review.

Finally, the proposal of this research paper will be stated by outling in which ways we intend to implement the UR3e robotic arm in an industry 4.0 environment and methods of implementation that is being planned and looked at currently.

2 UR3e Installation

For this project we will be proposing to implement the UR3e robotics arm in an industry 4.0 environment. By following the user manual of the UR3e robotics arm i started the installation of the arm. For the mount of the UR3e the Easy work ER5 so that the arm can be installed in a mobile state. The UR3e was secured onto the ER5 using 4 8.8 strength M6 bolts and the arm was connected to the control box which was installed inside the ER5.

The cables of the arm and control box are isolated in the ER5 trolley and is protected from contact with liquids and solid object larger than 1mm such as a wire. When setting up the robotics arm the IP ratings of the parts were taken into consideration. the control box having a IP rating of IP44 was installed isolated from the environment as mentioned above and both the robot arm and teach pendent with a IP rating of IP54 were installed on the ER5 exposed to the environment the laboratory environment was made sure that it has minimum dust and not jets of water were available in its vicinity. An area free of objects was allocated to the robot arm to be situated when in function to avoid and physical harm to users or the product by accidentally knocking on object in its vicinity. To access the arm the teach pendent will be used outside of the area so that the users safety is ensured.

The control box has 3 connections one to the robotic arm another to the teach pendent and the other the main power source. The control box act as the brains of the robotic arm giving it the power and the instructions through the teach pendent. An emergency stop for the robot was inbuilt on the teach pendent with the use of an emergency stop button. With some wiring of the control box we can implement other emergency stop buttons and this will be taken into consideration when the implementation of the arm is done.

The connection to the arm and control box is done through the base flange cable. The robot cable connector on the control box was turned to the right for easy of installation of the cable to comply with the spacial restraints on the inside of the ER5. The cable was twisted twice to ensure its properly locked into the robot cable connector and the connector on the arm. The cable was then passed through the inside of the ER5 mounting column to protect the cables from the environment and prevent tripping hazards.

The gripper tool was then attached to the tool flange on the arm a connector on the tool flange was used to connect the arm with the gripper and the gripper was fitted on to the arm mechanically through a hook mechanism which allows easy unmounting and mounting of the tool though a press of a button.

3 UR3e System setup

Before starting to use the robot we first need to register the robot by getting its license certificate. By singing up in the www.universal-robots.com/activate website and giving the relevant information of the robot and downloading the generated registration file. This file is then uploaded onto the teach pendent and the registration is confirmed.

next step will be to setup the safety password in the teach pendent with this password created we can lock and unlock the robot for safety.

After registration and setting safety passwords we will have access to the free drive system of the robot which allows the user to manually move the robot into any desired position/configuration. when using this operational mode we need to be cautious of several risks such as pinch points and robot drift this is mitigated as the robot will automatically stop when it reaches a singularity scenario which means a scenario where the robots joints cannot move any further within the given safety confinements. These safety confinements are created by the robot taking into consideration the center of gravity and the TCP location of the robot these locations are to be calibrated by the user.

The center of gravity was calibrated by moving the arm into 4 different positions the teach pendent will show a green light next to the saved position if these positions are distinct enough from the others given to it. Then the 4 positions are considered in the calculation of the center of gravity. the TCP (tool center position) is calculated by having the tool in this case the gripper positioned on to one single point on 3 different configurations. After these 2 calibrations are done properly the arm will be able to accurately move through the space without having difficulties. If the calibration is not done properly the arm would not be able move in the desired way and will get into singularity scenarios in unexpected ways and can lead to harming the arm itself in extreme cases where the robotic arm hit itself due to poor calibrating.

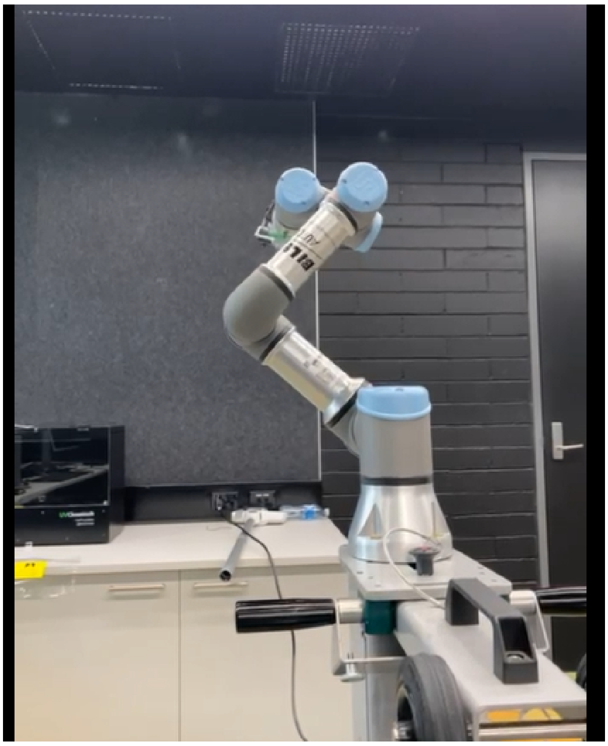

Figure 1 - UR3e Setup

4 Literature review

The aim of this literature review report is to identify and analyse the previously published literature, research papers and journals related to the chosen topic of the fourth industrial revolution of industry 4.0. The chosen topic conceptualises a rapid change in the technology, industries and social patterns due to increasing inter connectivity and smart automation. The chosen topic is important to analyse as it is revolutionising the way in which different companies or business organisations, manufacture, improve or distribute their products. In order to ensure better operational output, The manufacturers are integrating newer technologies such as the Internet of Things, Artificial Intelligence, Machine Learning and cloud computing in their daily business operations. Therefore, it can be said that industry 4.0 represents a fundamental change in the way people work. It is important for increasing work efficiency [20].

4.1 Industry 4.0

According to Xu, David and Kim [13], Industry 4.0 or the fourth industrial revolution, can be indicated as the current trend in automation and data exchange in the manufacturing technologies, which include cyber-physical systems, internet of things, cloud computing and cognitive computing, in order to create a smart factory. In this context, Philbeck and Davis [17] indicated that Industry 4.0 is changing the way companies operate by bringing in better efficiency in their work processes. The manufacturers are integrating different technologies such as edge computing, machine learning, cloud computing, AI and others to improve the efficiency of their production facilities. The use of digital technology increases works efficiency through automation. The fourth industrial revolution represents a new stage and process in the organisation and control of the value chain. It is defined as a name for current trends and data exchange in the field of manufacturing technologies, including the IoT, cloud computing, cognitive computing and smart factory. The 4IR indicates even more automation than in the third industrial revolution, thus bridging the gap between the physical and digital world. Therefore, the primary goal of 4IR is to enable an autonomous decision-making process, ensure proper resource monitoring in real-time and increase other operational efficiencies. The 4IR is therefore considered as a vision, policy or concept in motion, with reference through architectures, standardisation and flux.

Davis [6] describes industry 4.0 as the intensive information transformation of manufacturing, especially in a connected environment, of big data, people, processes, services, systems, and IoT enabled industrial assets. Hence, in simple terms, 4IR can be outlined as a broad vision with clear frameworks and references architecture, which is primarily characterised by bridging the gap between the industrial assets and digital technologies in cyber physical systems [18]. The technologies of IoT, cloud computing, edge computing, AI and other advanced technologies play a critical role in all the operations related to industry 4.0.

4.1.1 Functions

According to Penprase [8], industry 4.0 provides an emphasis on digital technologies from the recent decades to a whole new level. This has been possible because of the inter connectivity through IoT, access to real time data and the introduction of cyber-physical systems. The fourth industrial revolution has made it possible to create and develop smart factories. Industry 4.0 aims at transforming the manufacturing and engineering sectors by introducing the concept of smart factories. In smart factories, the business processes are automated, and the business communication process is mainly executed with the help of technology such as IoT, which contributes to assisting people in executing the tasks within the shortest possible time (Liao et al. 2018). Therefore, it can be said that all the functions associated with 4IR are mainly executed with the help of modern technology and processes, which makes it effective to execute even the complex tasks in the shortest possible time. This would not have been otherwise possible.

4.1.2 Advantages

According to Butler-Adam [2], the advantages related to 4IR are evident in terms of the increased effectiveness in the work processes, enhancing the quality and improving the competitiveness. The technology of 4IR is associated with smart factories, and the ability to offer smart factories is a major advantage associated with this technology. A detailed analysis of the advantages offered by the industry 4.0 is presented as follows-

- Improved Productivity: One of the primary advantages of industry 4.0 is an increase in productivity as the technologies related to 4.0 enable one to do more with less input. The use of technology enhances the production lines, thereby ensuring appropriate resource allocation, appropriate time management and better execution of the critical work processes [16]. All these aspects help in increasing productivity.
- Improved Efficiency: Technology 4.0 has critically improved the overall work efficiency by increasing the efficiency of the production line. An increase in efficiency includes faster batch changeovers, automatic tracking and automated reporting.
- Increased Knowledge Sharing: Knowledge sharing is important for better management of work processes. Traditional manufacturing plants operate in silos where knowledge sharing is a foreign concept [19]. However, industry 4.0 prioritises the process of knowledge sharing to improve the overall operations. Increased knowledge sharing contributes to making an improvement across multiple production lines, thereby increasing the overall work efficiency.

- Collaborative working: One of the primary advantages of industry 4.0 is an increase in collaborative work working. Through the use of technology, certain complex work processes can be executed with ease, thereby enhancing the operational output. Collaborative working is possible as the industry 4.0 associated technologies have the capability of easier communication among the different work processes [22]. The increase in efficiency in work automation and communication helps in enhancing the overall process of collaborative working.

- Flexibility and Agility: The benefits of industry 4.0 are further extended to increase flexibility and agility. This is possible as this technology contributes to easier scaling of the production in smart factories [23]. With the help of technology, it is possible to introduce new products to the production line along with the creation of opportunities [4]. The benefit of flexibility and agility contributes to the creation of opportunities such as one-off manufacturing runs and high-mix manufacturing.

- Better Customer Experience: Adoption of 4IR is advantageous as it contributes to improving the services offered and, in turn, enhancing the customers' experiences.

- Better Compliance: The manufacturing industries are keen on adopting the industry 4.0 technologies, as it makes it possible to automate compliance, including track and trace, automated quality inspections, data logging and others

- Cost Reduction: Cost reduction is one of the primary advantages offered by the 4th industrial revolution. This is primarily because a smart factory can automate several time-consuming work processes, including manufacturing and report generation [10]. The increase in automation helps in the reduction of the overall operational cost, which is a major advantage. Modern technologies further contribute to faster manufacturing, use of lesser resources, and lower overall operational costs.

- Innovation Opportunities: Industry 4.0 contributes to greater knowledge and manufacturing processes, management of supply chain, management of the distribution chains, increase in efficiency and business performance, along with the creation of opportunities to innovate [12]. The innovation opportunities and the ability to innovate further provide a competitive advantage to the organisation.

- Higher Revenues: As discussed earlier, industry 4.0 increases the efficiency of business management, increases production and also provides an opportunity to innovate, which in turn helps in increasing the revenues. This is the primary reason why the adoption of technologies that come under industry 4.0 is expected to increase in future.

- Increased Profitability: Industry 4.0 enables higher productivity, increase in efficiency and higher revenue, which enhances the overall profitability of the organisation.
- Effective ROI: Industry 4.0 is transforming manufacturing facilities across the globe. The primary reason behind its increase in adoption is an effective ROI.

4.1.3 Disadvantages

Although there are several advantages linked with industry 4.0, there are certain disadvantages as well, which are necessary to be addressed. The primary disadvantage associated with this technology is the cybersecurity risk. Since in 4IR, everything is interconnected and is associated with the use of the internet, the risks and issues related to cybersecurity increase. The interconnectedness challenges the very nature of identity and privacy [23]. Another major disadvantage associated with the use of this technology is the associated ethical concern, which arises because of the use of technology such as AI, increased automation and genetic engineering. Although there is a rapid increase in the use of AI, the issues related to core industry disruptions prove to be another major concern linked with 4IR [14]. For example, the business of Uber has made the traditional taxis heavily compete with the technology.

4.1.4 Resource Allocation

Human resource allocation is a major challenge in industry 4.0 as it has led to an entirely fresh approach to production, growth of labour and management of productivity and competitiveness. The 4IR is mainly driven by technology, and hence there is a requirement for high-skilled labourers to manage and execute the manufacturing process. However, in the majority of the cases, there could be seen as a major lack of skilled labourers as the existing staff may not be ready to upskill themselves [9]. Furthermore, the majority of the time consuming and repetitive tasks can easily be automated with the help of the technologies such as Artificial intelligence

Algorithm	Network set up	Latency	Bandwidth
ES SAE CEC	wired/wireless	500 – 2500ms	10 – 30 Mbps
CSC	wired/wireless	500 - 2500ms	10 - 30 Mbps
OEC	wired/wireless		
EECCT	wired/wireless		
ARES	wired/wireless		
AOCL	wired/wireless		

and machine learning. Hence, industry 4.0 results in certain major ethical concerns linked with the use and adoption of industry 4.0 in the manufacturing process.

According to Genkin et al. [7], if the majority of the work processes are automated, there will be a lesser demand for human resources, thus reducing the need for recruitment. Therefore, an increase in the adoption of industry 4.0 in different organisations might result in facing major ethical issues in terms of human resource allocation.

Although the concern related to human resource management is genuine in the case of industry4.0, the allocation of other resources in the management of the work processes becomes easy in 4IR. This is because of the efficiency in decision-making and the use of technology to allocate resources based on the requirements of each task. Hence, in industry 4.0, the efficiency of resource allocation is significantly increased.

For this research i have looked at several resource allocation algorithms and compared their usage cases and performance to decide the best fit for this project.

4.2 Usage of multi-access edge computing in industry 4.0

According to Dao et al. [5], multi-access edge computing forms an integral part of industry 4.0. The multi-access edge computing or MEC is a technology that moves the computing traffic and services from a centralised cloud to the edge of a network to present it closer to the customer. The MEC is a major aspect of 4IR, as this technology, instead of sending all data to the cloud for processing, the MEC analyses, processes and stores data. The collection and processing of data closer to the customer reduce latency, which in turn brings out real-time performance to high-bandwidth applications. MEC is widely used in industry 4.0, primarily because of the benefits it offers. The primary benefits are real time data analytics with lower latency. The use of this technology further reduces cloud data storage and transport cost. With the use of this technology, it is possible to strengthen security and compliance [11]. The key drivers behind the technology of MEC are the IoT, 4G network and 5G network. The adoption of MEC in 4IR is essential mainly because this technology contributes to bringing flexibility and agility of the cloud closer to the needs and requirements of the customers [1]. As outlined an ultra-low latency and reliable working conditions is a must for a smart manufacturing system to achieve the precision of controls from the commands received by the application to the industry standards. However, since the robots and machinery within the factory has limited computing prowess the data generated by the machinery should be offloaded to the network for processing and storage. An improved MEC that has been presented in recent years has been the multi-tier MEC (mMEC) which consists of 3 tiers:

- Edge Devices: The edge devices act as switches and access points which have small computing capability. Its purpose is to reduce the redundancy of the IIoT data, and the errors caused due to transmissions and protocols.
- Edge Gateway: The edge gateways act as routers which have much greater computing capability, and its purpose is to perform pre-processing of the raw data such as decoding and compressing and forwarding it to the appropriate edge server.
- Edge Servers: The edge servers have the highest computing capabilities and storage capacities these are used to analyse the data and provide the required return responses to the IIoT devices based on the decision-making policies or machine learning algorithms/AI that is used.

Therefore, in simple terms, it can be indicated that the use of MEC in industry 4.0 is prioritised mainly because it brings technology closer to the end users. In 4IR, the use of technology is significantly essential, and this is the reason why MEC is widely used in 4IR.

4.3 Usage of machine learning in industry 4.0

According to Candanedo et al.[21], machine learning can be described as a major aspect of AI, which allows the software applications to become more accurate at predicting the outcome of an action or a decision. Industry 4.0 is largely based on the concepts and different aspects of machine learning. The automation of the complex tasks and work processes that are offered by the 4IR is possible only because of the use of the technology of machine learning. Davis [6], in this context, indicated that machine learning is one of the most powerful technologies that is allowing the business processes to gain a foothold in the businesses, industries and in the factory floor. This proves that machine learning is one of the most important requirements associated with the operation of industry 4.0. Machine learning is a form of AI that allows computer systems and their associated algorithms to improve automatically based on experience. With the help of machine learning, there has been massive progress in the manufacturing space in terms of optimisation. This is primarily because the possibility of developing a smart factory can only be possible through the use of the technology of machine learning.

Çınar et al. [24] indicated that machine learning is widely used in 4IR primarily because of the capability of machine learning to increase the efficiency of the work processes without bringing any major changes in the existing resources. For example, the use of machine learning technologies significantly contributes to easier error detection. Therefore, with the utilisation of smart technologies such as IoT and smart devices, it is necessary to incorporate machine learning to enhance the operational output. Additionally, the use of machine learning can also provide certain insight, which allows the factories to transform from the reactionary environment to the ones that help in stopping the error from occurring [15]. Therefore, it can be indicated that the technology of machine learning forms an important part of industry 4.0, and its application in 4IR enhances its overall operations [3]. It enables an organisation to deliver value through predictive maintenance and learning from past experience.

4.4 Summary

The report presents a detailed understanding of the technology of 4IR and its functions. The findings from the literature review indicate that many manufacturing and business organisations have already adopted the technology of 4IR. The 4IR represents an era of economic and knowledge growth, which in turn contributes to the mitigation of the various operational risks. For example, the use of machine learning technology in 4IR helps in error reduction. The review presents a detailed analysis of the advantages and disadvantages of 4IR. Based on the findings, it can be indicated that 4IR is the next big thing in terms of management and revolutionising industrial operations.

5 Project Proposal

Taking into consideration the gathered literature and the preliminary setup for the project I will be proposing the project plan for the implementation of the robotic arm.

For the robotic arm to be integrated into a industry 4.0 environment we will first need to implement the remote access capabilities to the arm as this is one of the most important features of the industry 4.0. for this implementation I suggest the usage of UR RTDE . Real time data exchange (RTDE) can be easily implemented onto the UR3e through a python script. to achieve this the robot will first need to be connected to an local network or the internet using an Ethernet connection through the control box. after this connections is setup within the teach pendent by confirming the IP address and DNS of the network we will be able to upload and access the robot through the network. Thereby giving us access to integrate python scripts to the robot program through the network. Using this connection and the inbuilt script integration of the program in teach pendent we can have real time updates to the python script that we are uploading through the network.

This allows us the opportunity to have a flexible code on the robot by creating a skeleton program on the teach pendent with integration of python scripts we can create a remote real time access to the robot.

Another advantage of using RTDE is that we are able to use this same library to have access to the output parameters of the robotics arm so that any analysis that need to be done on the data is easily accessible to the network.

As we have to consider the latency of the system we will also need to implement a working multi access edge computing system to handle the analysis of the data created by the robot. A good consideration for a edge computing system is the Microsoft azure edge. This platform can be used to generate the data analysis to give us information about the position of each joint and also data from the tactile sensors of the gripping tool.

The position data of the arm can be used to generate a digital twin simulation of the robotics arm and this can be used to remotely monitor the system in action. A further improvement on this can be to implement remote access control through the manipulation of the digital twin simulation. As we can remotely access the python scripts injected to the robot program we can use the position data of the simulation to make movements through the use of the python scripts. For this functionality to be implemented the system will need to be able to switch between automatic and manual control modes to avoid any unintended behaviour. And with a manual control mode we can use this to remotely assess the state of the system or give corrections to the system manually.

The tactile data from the force sensors on the gripper can be used for material detection as this is the function we are trying to achieve in this system. Machine learning algorithms can be used on the edge to identify and differentiate the different gripping force signatures of different materials and categorise them accordingly. A proposed usage for this functions in an industry application can be to sort different materials into a few categories such as picking and separating screws and rubber washer.

This can be achieved first using the gripping data and sending it through a ML prediction algorithm that was trained to categorise different materials and finding what kind of material it is. Then once we have confirmed what category it belongs to we can send a movement command to the arm through the python scripts using the network and this movement can be to move to the left or right depending on the category we have confirmed.

6 Data Simulation

In this experiment, the data was simulated to mimic the real-world conditions of the gripping process. The size of the balls was simulated by generating random numbers between 30 to 100 mm, which represents the width range of the gripper claw. To introduce uncertainty in the gripper measurements, a noise component was added to the simulated sizes. The noise values ranged from -1 mm to 1 mm and were rounded to the first decimal place to match the precision of the RG2 gripper width measurement.

The grip force was simulated with the assumption of the gripper alignment in the y-axis. The force calculation was based on the equation for the slipping point of the ball, which is force = mass * 9.81 * coefficient of friction. The mass of the ball was calculated using the density of the material and the simulated size of the ball obtained earlier.

The simulation process was repeated 300 times for each type of material. The types of materials used in the simulation were 'rubber', 'steel', 'plastic', 'wood', 'glass', and 'aluminum'. By running the simulation multiple times, it allowed for variability and statistical analysis of the generated data.

Overall, the simulated data allowed for the creation of a diverse dataset that captured the variability and uncertainty present in real-world gripping scenarios. This dataset was then used to train and evaluate machine learning models for material detection and classification.

7 Challenges and Improvments

During the course of this research, several challenges were encountered, particularly in the calculation of material deformation and the determination of the gripping force. These challenges highlighted the importance of accurately simulating and measuring the relevant parameters for effective material detection. In this section, we discuss these challenges in detail and outline the improvements that were made to address them.

Deformation Calculation: One major challenge was the incorrect calculation of material deformation. The initial calculation used the wrong units for Young's modulus, resulting in vastly exaggerated deformation values. This oversight became apparent upon closer examination of the data and the realization that the calculated deformations were impractically large. To rectify this issue, the correct unit for Young's modulus was applied, leading to significantly smaller deformation values that were more in line with realistic expectations.

Gripping Force Determination: Another challenge was the selection of an appropriate gripping force for material detection. Initially, a constant grip force was used, which did not accurately reflect real-world scenarios as not all objects could be lifted using the same constant force additionally if a constant force is used it would not give any further information on the material. It was realized that the grip force should vary based on the slipping point of the object, i.e., the minimum force required to lift the ball without it slipping from the gripper. This change in approach allowed for a more realistic simulation of the gripping process. However, it introduced the challenge of determining the slipping point, which can be time-consuming and impractical in practical applications.

To address these challenges and improve the research methodology, the following enhancements were made:

Accuracy in Parameter Measurement: To ensure accurate results, a thorough review of the calculation formulas and units was conducted. By rectifying the error in the units used for Young's modulus, the calculations for material deformation were corrected. Additionally, rigorous quality control measures were implemented to verify the accuracy of all measurement parameters, such as size, density, and coefficient of friction. This ensured that the simulated data more closely reflected the real-world conditions.

Consideration of Practical Limitations: While the calculation of material deformation was initially included in the research, it was recognized that the level of deformation expected in the gripped objects would be negligible for the equipment used in the experiment. Therefore, this calculation was reevaluated, and it was decided to focus on grip force and size as the primary input parameters for material detection. This adjustment allowed for a more practical and efficient approach, as the slipping point of the object could be determined more quickly without the need for extensive deformation calculations.

Exploration of Alternative Techniques: In light of the challenges associated with determining the slipping point, alternative techniques were explored to improve the efficiency of the material detection process. One potential approach is to use machine learning algorithms that can analyze the force data at various grip forces and sizes to identify patterns indicative of different materials. This would eliminate the need for explicitly determining the slipping point and provide faster and more reliable material classification.

In summary, the challenges faced during this research project highlighted the importance of accurate parameter measurement and the need to consider practical limitations. By addressing these challenges and making the necessary improvements, the research methodology was refined to enhance the accuracy and efficiency of material detection. Additionally, the exploration of alternative techniques, such as machine learning, offers promising avenues for future research in this field.

References

[1] D. Borsatti, G. Davoli, W. Cerroni, and C. Raffaelli, Enabling industrial iot as a service with multi-access edge computing, IEEE Communications Magazine, 59 (2021), pp. 21–27.

[2] J. Butler-Adam, The Fourth Industrial Revolution and education, South African Journal of Science, 114 (2018), pp. 1 – 1.

[3] J. Carvajal Soto, F. Tavakolizadeh, and D. Gyulai, An online machine learning framework for early detection of product failures in an industry 4.0 context, International Journal of Computer Integrated Manufacturing, 32 (2019), pp. 1–14.

[4] A. W. Colombo, S. Karnouskos, O. Kaynak, Y. Shi, and S. Yin, Industrial cyberphysical systems: A backbone of the fourth industrial revolution, IEEE Industrial Electronics Magazine, 11 (2017), pp. 6–16.

[5] N.-N. Dao, Y. Lee, S. Cho, E. Kim, K.-S. Chung, and C. Keum, Multi-tier multi-access edge computing: The role for the fourth industrial revolution, in 2017 International Conference on Information and Communication Technology Convergence (ICTC), 2017, pp. 1280–1282.

[6] N. Davis, What is the fourth industrial revolution., 01 2016.

[7] E. Genkin, S. Filin, V. Velikorossov, Z. Kydyrova, and K. Anufriyev, The fourth industrial revolution: personnel, business and state, E3S Web of Conferences, 159 (2020), p. 04012.

[8] N. W. Gleason, Higher Education in the Era of the Fourth Industrial Revolution, Palgrave Macmillan Singapore, 2018.

[9] P. HA., Are we ready for the fourth industrial revolution?, Yearbook of medical informatics, (2016).

[10] A. Hirschi, The fourth industrial revolution: Issues and implications for career research and practice, The Career development quarterly, in press (2017).

[11] A. Islam, A. Debnath, M. Ghose, and S. Chakraborty, A survey on task offloading in multi-access edge computing, Journal of Systems Architecture, 118 (2021), p. 102225.

[12] G. Li, Y. Hou, and A. Wu, Fourth industrial revolution: technological drivers, impacts and coping methods, Chinese Geographical Science, 27 (2017), pp. 626–637.

[13] S. H. K. Min Xu, Jeanne M. David, The fourth industrial revolution: Opportunities and challenges, International journal of financial research, (2018).

[14] R. Morrar and H. Arman, The fourth industrial revolution (industry 4.0): A social innovation perspective, Technology Innovation Management Review, 7 (2017), pp. 12–20.

[15] M. Paolanti, L. Romeo, A. Felicetti, A. Mancini, E. Frontoni, and J. Loncarski, Machine learning approach for predictive maintenance in industry 4.0, in 2018 14th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA), 2018, pp. 1–6.

[16] A. Petrillo, F. De Felice, R. Cioffi, and F. Zomparelli, Fourth Industrial Revolution: Current Practices, Challenges, and Opportunities, 02 2018.

[17] D. N. Philbeck T., The fourth industrial revolution., Journal of International Affairs, (2018).

[18] P. Prisecaru, Challenges of the fourth industrial revolution, Knowledge Horizons - Economics, 8 (2016), pp. 57–62.

[19] K. Schwab, The fourth industrial revolution: What it means, how to respond., (2016).

[20] K. Schwab, The Fourth Industrial Revolution, Penguin Books Limited, 2017.

[21] I. Sittón-Candanedo, E. Hernández Nieves, S. Rodríguez, T. Santos-Martín, and A. González Briones, Machine Learning Predictive Model for Industry 4.0: 13th International Conference, KMO 2018, Žilina, Slovakia, August 6–10, 2018, Proceedings, 07 2018, pp. 501–510.

[22] A. STĂNCIOIU, The fourth industrial revolution „industry 4.0", (2017).

[23] E. Sutherland, The fourth industrial revolution – the case of south africa, Politikon, 47 (2020), pp. 233–252.

[24] Z. M. Çınar, A. Abdussalam Nuhu, Q. Zeeshan, O. Korhan, M. Asmael, and B. Safaei, Machine learning in predictive maintenance towards sustainable smart manufacturing in industry 4.0, Sustainability, 12 (2020).