TOWARDS REMOTE CONTROL OF MANUFACTURING MACHINES THROUGH ROBOT VISION SENSORS

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ABSTRACT

The remote management of equipment is part of the functionalities granted by the design principles of Industry 4.0. However, some critical operations are managed by operators, machine setup and initialization serve as a significant illustration. Since the initialization is a repetitive task, industrial robots with a smart vision system can undertake these duties, enhancing the autonomy and flexibility of the manufacturing process. The smart vision system is considered essential for the implementation of several characteristics of Industry 4.0. This paper introduces a novel solution for controlling manufacturing machines using an embedded camera on the robot. This implementation requires the development of an interactive interface, designed in accordance with the supervision system known as Manufacturing Execution System. The framework is implemented inside a manufacturing cell, demonstrating a quick response time and an improvement between the cameras.

Keywords: Design engineering, Design for Additive Manufacturing (DfAM), Design process, Industrial robots, Smart vision sensors

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1 INTRODUCTION

Industry 4.0, which is related directly to the Internet of Things (IoT), Cyber-Physical Systems (CPS), and Information and Communication Technologies, has been lately an important target for most industrial companies. Industry 4.0 has imposed new requirements such as short development periods, individualization on demand, decentralization, and resource efficiency (Lasi *et al.*, 2014). For this purpose, some fundamental concepts were introduced: digitalization, control and insight, and automation (El Hamdi, Abouabdellah and Oudani, 2019). It is intended to introduce sensors and embedded systems and transfer data from the production line in real-time in human-centered digitalization. Manufacturing machines have evolved to communicate with control systems and real-time relay data. The MES is a crucial control system that is supposed to function similarly to a manufacturing flight deck, providing real-time data flow from various industry divisions (Mantravadi and Møller, 2019). In addition, a smart vision system is implemented to monitor and track manufacturing as well as to perform quality control over production.

Smart vision systems enable robots to perceive, assess, and adapt to their surroundings and have recently played a key role in enhancing autonomy and flexibility in a robot-based factory. The continuous advancement of industrial cameras has made this technology useful for a variety of functions inside an industrial setting. Some of the prior essential duties included robotic navigation and control, process control, part identification, and automated visual inspection (AVI) (Golnabi and Asadpour, 2007). To accomplish these duties with smart vision cameras, they must have a specific level of technology and be adaptable in their use. One of the important technologies that improved the performance of industrial cameras is providing a 3D position of workpieces (Oh and Lee, 2007) rather than just showing a 2D model of the studied product, and the efficiency of industrial cameras have increased.

Integrating these technologies is crucial to achieving a high level of digitalization and reliability, thereby transforming the sector into an industry 4.0. Our integration is based on the development of the manufacturing machines indirect interaction with the operator through the smart vision system embedded on an industrial robot and an HMI (Human Machine Interface) design created on the MES. Currently, a lot of manufacturing machines have limited functionalities. They do not give feedback report on the state of the machine. In addition, the initialization task of the machines, after sudden emergency stop, is done by operators which takes several hours depending on the geographical distribution of machines. This check operation is time-consuming and should be automated as part of the industrial revolution. This paper discusses the described scenario in detail and the importance of our designed approach.

Section 2 explains the problematic through a brief literature review. Section 3 shows the framework and its integration to check the efficiency and benefits of this method. The results are presented in section 4. Section 5 sums up the whole study.

2 STUDY OF VISION SYSTEMS

Some research employs smart vision systems, such as camera or lidar, in advanced applications, like tracking and user identification. These applications need the mining of sensor data for hidden information. Sensor inputs add the ability to understand the behavior of the systems and boost the digitalization of industrial production lines over the past 10 years. When machine visual interpretation is used, it raises system intelligence. Although the perception of machine data hold the most potential for advancement, it also poses a challenge, especially when used in real-world scenarios (Sergiyenko *et al.*, 2018).

Manufacturing industries are hit with the industry 4.0 transformation. The production and supply chain inventory management need to be approached differently with more intelligence, making it possible for machines to see, communicate, and perform tasks just autonomously with high accuracy and superior results. Numerous potentials arise when giving machines the ability to understand information from the physical world and support people in difficult tasks. In their manufacturing

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facilities, many businesses are either using computer vision or considering it (*Computer Vision and Industry 4.0: Value, tools, examples of use*, no date). Liu *et al.* (2022) gives a review about the importance of getting robots smarter by adding sensors, making robots free from archaic constraints and hard-programmed situations, and exploring options to be used in more adaptable and human-centered jobs (Wang, 2019). As an illustration, a smart vision system has been a useful tool for machine inspection and condition assessment. It also plays a significant role in analyzing the quality of manufactured parts under real-world conditions and determines whether a part is accepted, which is important for smart manufacturing (el Helou *et al.*, 2022).

Smart vision system is a technology that enhanced the performance in an industrial environment, as it is used in different topics. Some applications are state estimation of the tool through a variety of in-cycle vision sensors that deploys a variety of image processing algorithms (Kurada and Bradley, 1997). Real-time production/assembly, process monitoring, and repetition are possible by a contactless monitoring framework with machine vision (Lou *et al.*, 2022). Material identification utilizes machine learning and vision technologies to improve the cognitive capabilities of machine tools (Penumuru, Muthuswamy and Karumbu, 2020). Assembly of small part materials used for the 3C's industries (computer, communication and consumer electronics) thanks to a dual robot arm and smart cameras (Ge, Chi and Li, 2014). Smart vision systems are also used for monitoring of the tasks for example picking and hooking task (D'Avella, Avizzano and Tripicchio, 2023).

Vision systems and CNC machines are used in a simultaneous way to achieve the improvements needed. The performance of CNC machining is improved using an online vision-based monitoring and control system. A system is suggested and created to address a number of identified problems that impede the integration of computer vision with CNC machines (Al-Kindi and Zughaer, 2012a). Image data processing is used to examine tool imprints left on the machined surface in order to determine the quality of the machining surface and the cutting tool status (Al-Kindi and Zughaer, 2012b), which shows the importance of integrating vision systems with CNC machines.

Moreover, the deployment of robot vision sensors is part of the production control system because the interpretation of the visualization results changes the scheduling of operations. Thus, it is important to have a monitoring system and a control system in an industrial platform such as the MES. The scope of MES has also expanded to incorporate manufacturing enterprise supply, design, and business processes. The realization of next-generation MES tools should be compliant with the real-time manufacturing environment. Recent technology breakthroughs and the demand for highly tailored products forces manufacturing businesses to adapt and create new solutions addressing the shift in markets. The MES is an important system especially in the phase of scheduling and real-time monitoring of the machines actions (Shakeri and Benfriha, 2022). It is critical to understand its significance for Industry 4.0 (Kaczmarczyk et al., 2022). Recently, MES has taken on a significant role in industrial platforms by being utilized in a way that optimizes and controls the manufacturing process. (Benfriha *et al.*, 2021). Monitoring systems are helpful in different fields and this can be an essential part when transferring towards a digitalized and automated industry (Mühlbauer et al., 2022).

3 PLATFORM 4.0

The study was held in platform 4.0 which is an industrial lab created to develop different technologies from control systems, predictive maintenance, mobile manipulator, and digital twin adding to that the different CNC machines and industrial robots (Kuka). All these integrate creates a flexible production line, with several Ph.D. students to reach the industry 4.0 features. Figure 1 presents the platform in a 3D view.

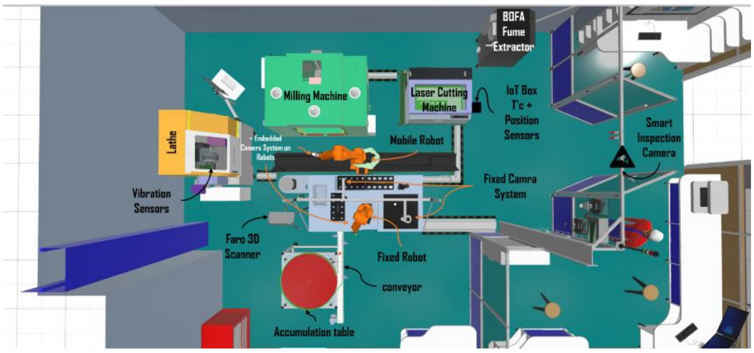

Figure 1. Top 3D view of the platform

The main technologies integrated in achieving this research are the smart camera (SensoPart Visor) which is an industrial camera that has a special software visor vision system where the camera can be calibrated, and pictures are studied through the different detectors found such as the "barcode", "datacode", "pattern matching", and other detectors. The camera is embedded in a mobile robot. The CNC milling machine is going to be inspected by the camera through its LEDs on the control box, like the red LED for emergency stop, and monitoring through the user interface (UI) screen, referred to PathPilot. The machine interface, visualized on an LCD touchscreen, is used to achieve the interaction between the robot and the machine. Figure 2 shows the UI and the control box of the machine. After understanding the interaction environment, the monitoring comes with the adaption of the actions of the robot based on the outputs of the camera. This goal is achieved using a designed pen holder adapted to the gripper of the robot, so it will be able to select on the UI and control box easily.

Figure 2. UI and the control box

As previously mentioned, an important technology also used in this study is the system MES used to control the operations. To this end, it has access to the camera outputs and can so react according to the situations that arise. The MES controls most inputs and outputs of the systems found in the platform. For that, it was used to notify the operator by the errors that may occur while launching the CNC milling machine. This achievement is due to a special communication methodology and protocol between these systems, as shown in figure 3.

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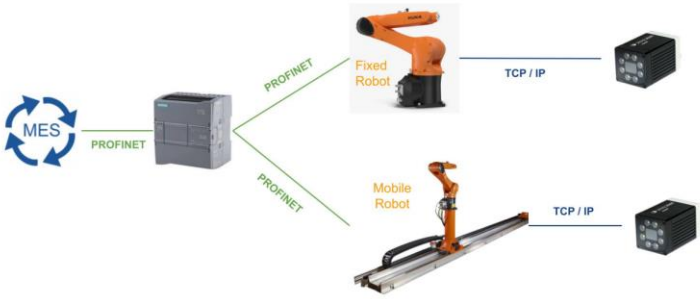

Figure 3. Communication protocol (Zouhal et al., 2021)

4 FRAMEWORK

Industry 4.0 presents some functionalities to be maintained during production. The main ones are decentralization, flexibility, prediction, and the robustness of the systems. These goals are achieved through several research topics in the industry 4.0, mostly with the development of interactive technologies. These innovations allow making the production line more intelligent and more efficient which allows it to gain autonomy and to propose actions based on the quality of final product or an external unscheduled event.

The functionalities of Industry 4.0 are maintained by the integration of external sensor that allows studying new aspects through the usage of the smart vision system, in addition to similar topics like object detection and quality control of products. The integration of smart embedded vision cameras on industrial robots being able to analyze the UI of the CNC machines found by notifying the MES with the outcomes until launching the G-code required for the production.

The framework followed to apply the study was to analyze the different functionalities of the camera and choose what suits this automation step. Following the communication protocols between the different systems integrated in this study, two different loops must be achieved. The first is between the camera and the industrial robots that occurs through the TCP/IP protocol and by that the robot can adapt to actions in accordance with the outputs of the camera. The second one is the communication protocol "PROFINET" that is present between the camera and MES through the PLC. Which allows the camera to notify the operator through the MES by any error that may occur and keep the operator updated of the flow of the task. The flow chart of the framework followed in this experimentation is presented in figure 4.

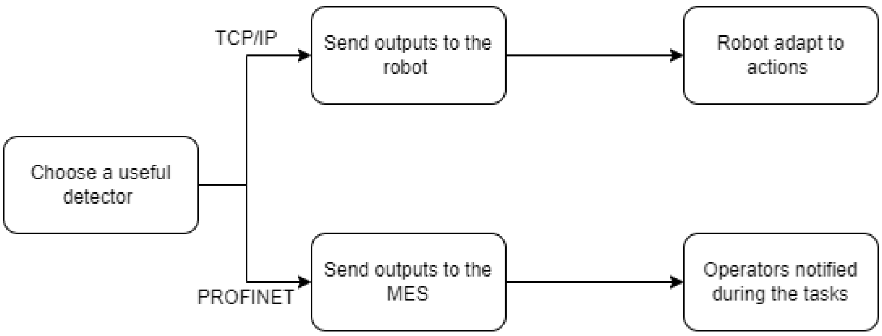

Figure 4. Framework flow chart

5 EXPERIMENTATION

The important part of this experimentation and why it is important to follow this framework is the lack of ability to access the internal software of the machine, and the inaccessibility to control it directly by the user except from the machine directly. And the following experimentation is so helpful in such cases, as most of the factories have the same model of these machines.

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The experimentation uses the mobile robot of the manufacturing cell having an embedded camera, like the SensoPart VISOR, that analyzes the UI and control box of the CNC milling machine (see figure 5). Then, the MES displays the state of the machine and possible errors

Figure 5. View of the mobile robot and the CNC machine

The analyzing process is repetitive and assure a successful/alert. The process starts by analyzing the state of the machine at the beginning of the task by taking a picture of the UI using the “contour”, “brightness”, and “OCR (Optical Character Recognition)” detectors of the SensoPart camera. After analyzing the screen by using one of these detectors, it finishes the task in one case if the machine is already launched. At this point, the MES is notified by an error and continues the process by checking the emergency stop on the control box. If the red light is turned on, the CNC machine is in an emergency stop state; so, the robot is going to press the reset button by the pen held by the gripper. The next phase is where the robot should reset the UI and check the machine if it is referenced by pressing the reset button and reference buttons which moves the machine to an initial position. Then a picture is taken verifying that the machine is referenced and ready to launch the code and not blocked by the limit. The limit switch active state means that the machine is in a position that can’t allow to the tool or component to move in each direction. In this case the operator should adjust the positioning of the machine manually and the references are not activated. Then comes the phase of choosing the G-code and start the cycle.

The operator needs to be informed about the progress of the task, so it is important to integrate the MES by creating an HMI system that will notify the operator in which state the robot is. Creating a code and designing it uses the graphic toolbox this happens by having an output created between the Kuka robot, the PLC, and the MES, and the connection happens between them through the coding and creating a SensoPart output. Based on this output the MEs will display the different stages of the machine.

A flow chart of the experimentation is presented in Figure 6 for a clear view of the process.

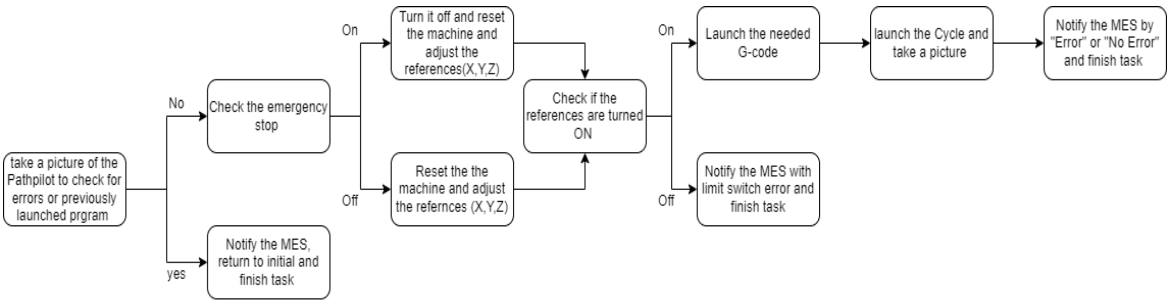

Figure 6. Flow chart of the experimentation

6 RESULTS

The challenges in this research are based on the camera capability in studying the steps needed to launch the CNC machine, to communicate with the robot and to notify the operator through the MES.

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The camera showed a high level of accuracy in the brightness and contour detectors used but it was hard for the OCR detectors as the size of the writings where small and the light affection from the screen did not help in giving the best conditions for the camera to be able to recognize different G-codes. The substitute was to use the contour detector to recognize the difference between the beginning stage of the machine and the stage where the machine is launched by a code.

Figure 7 shows the difference between the beginning stage of the machine and the end state, detected by the camera using the contour detector.

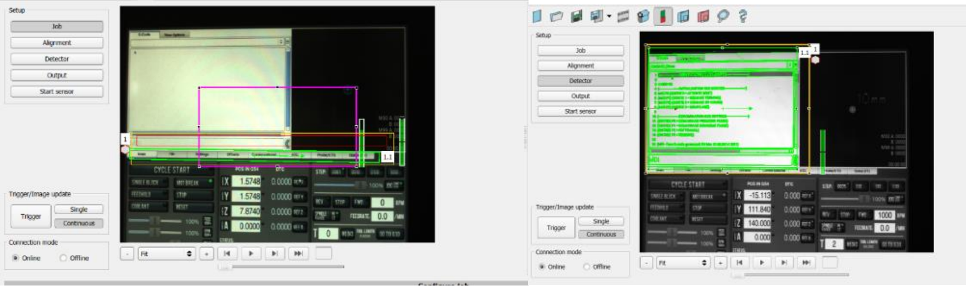

Figure 7. Detection of the state of the CNC machine

The camera was more flexible in the brightness detector where it showed great efficiency, and the errors were almost 0.9 % in the tests done. Figure 8 it shows the detection of the emergency stop and the references.

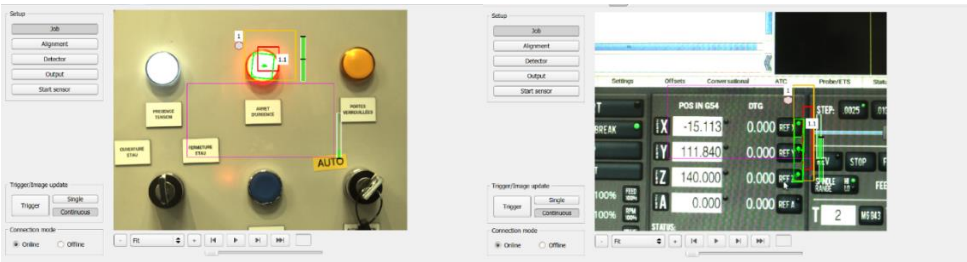

Figure 8. Detection using the brightness detector

Finally, the flow of data from the camera to the MES to achieve full control over this task was achieved in a very efficient way and provided real time tracking of the overall process and provided the proper alerts when needed, figure 9 presents the design of the HMI done for this task.

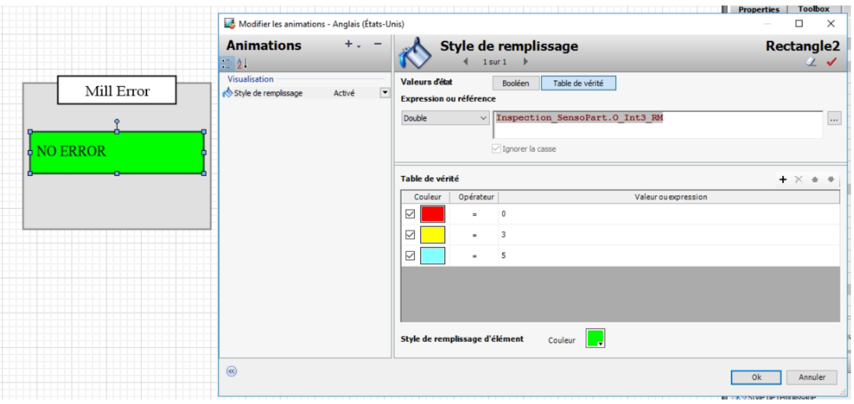

Figure 9. MES design

As a result of the whole experiment, the objective is successfully achieved. The CNC machine now is launched in an automatic way through an indirect interaction with the operator by sending the errors that occurs while undergoing this process to the control system, known as MES. The camera acquired an important role in allowing the robot to interact with the machine, not just following a predefined pattern on the screen but rather having the ability to decide its next step.

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The results showed great efficiency of the framework that have been followed. As for the nest step of this experimentation s to be to configure the different g-codes on different CNC machines directly by the camera.

7 CONCLUSION

This article has brought a new method of experimenting smart vision systems with the help of the industrial robot to monitor and interact with a CNC machine, being able to have a full control in initializing them and monitoring the process through the MES. The automation and robustness of the system have been increased as well as the performance of the robot by being able to adapt to its surrounding and cooperate with it.

This article provides a review of past research on the use of smart vision, an introduction to the workspace where this experiment took place, a brief description of the suggested technique in the framework and experimentation, and a recap of the results.

Concerning the execution of the work and the camera used, some approaches are challenging despite their successful implementation and testing. The production engineer must manually instruct the camera on how a contour should appear for each new product Lighting is an additional restriction when dealing with image processing algorithms. It would therefore be interesting to apply artificial intelligence on the camera or employ neural networks to overcome illumination issues, allowing the camera to adjust to any given situation.

The prospects for this work are very promising, especially for advanced production systems. The smart camera embedded on a high-performance robot will allow for less operator intervention, greater fluidity of operations, and finally for the manufacturers, they will have a technology adapted to their current production means.

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