Design of an AI driven Architecture with Cobots for Digital Transformation to Enhance Quality Control in the Food Industry

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ABSTRACT

In recent years, the rapid evolution of smart technologies has spurred enterprises to undergo digital transformations, revolutionizing their business processes and operations. This shift, known as Digital Transformation, has permeated diverse sectors, particularly impacting production systems. Notably, Artificial Intelligence (AI) and robotic automation have emerged as pivotal drivers in this transformation, promising enhanced efficiency and innovation in industrial digitization. This paper presents a novel architecture designed to facilitate digital transformation within enterprises, harnessing the capabilities of advanced collaborative robots (cobots) and cutting-edge image segmentation techniques. Focused on a practical scenario within a food production environment, our proposed architecture aims to seamlessly integrate a cobot and a camera in an automatic system for efficient cardboard disposal. Specifically, our attention is drawn to the challenge of differentiating sections of food packaging suitable for disposal from those contaminated with stains or organic residues, a task with significant implications for waste management efficiency. By leveraging a cloud-based architecture and deploying AI algorithms for image segmentation, localization, and robot guidance, our study showcases the tangible benefits and practical applicability of these methodologies in real-world settings. This research not only highlights the potential of AI-driven solutions in addressing specific industrial challenges but also underscores the broader impact of digital transformation on optimizing operational processes and driving innovation across sectors.

KEYWORDS

Digital Transformation, Cobot, Image Segmentation, Artificial Intelligence

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1 INTRODUCTION

In today's fast-paced digital landscape, the concept of digital transformation [5] has transcended mere technological upgrades. It is now a holistic strategy centered around enhancing human experiences, both internally and externally [2]. For small and medium enterprises (SMEs), embracing digital transformation is not just about adopting new tools; it is about reimagining processes, relationships, and values with a human touch at its core [12].

A human-centered approach to digital transformation starts from within the organization. By providing employees with user-friendly digital tools and fostering a culture of continuous learning and innovation, SMEs can empower their workforce to thrive in the digital age. User-centric design principles ensure that digital solutions align with employees' needs and preferences, enhancing their efficiency, satisfaction, and overall well-being [10].

Digital technologies have the power to break down barriers and facilitate meaningful connections within and beyond the organization. SMEs can harness collaboration platforms, project management tools, and virtual communication channels to foster teamwork, creativity, and inclusivity. By prioritizing human interactions and relationships, businesses can cultivate a sense of belonging among employees, driving collective success and innovation [8].

True digital transformation is not just about digitizing existing processes; it is about reimagining possibilities and creating value in entirely new ways. SMEs can embrace human-centered innovation by encouraging experimentation with diverse stakeholders. By soliciting feedback, and fostering a culture of empathy and curiosity, businesses can uncover latent needs and opportunities, driving breakthrough innovations that positively impact people's lives.

To stay ahead in the digital age and preserve growth, profitability, and the long-term viability of businesses from the challenges of outdated processes, inefficient workflows, rising customer expectations, and intensifying competition, companies must embrace new technologies as a strategic imperative [14]. By leveraging innovative digital solutions such as automation, artificial intelligence (AI), data analytics, cloud computing, and robotics, companies can streamline operations, enhance customer experiences, drive innovation, and gain a competitive edge in the marketplace. Failure to adapt to the transformative power of new technologies risks stagnation and irrelevance in an increasingly digital world.

Following this trend, this paper presents an architecture tailored to facilitate digital transformation within enterprises, focusing on a practical scenario in the food production sector. Our proposed architecture is designed to seamlessly integrate a cobot with a camera system to enhance the efficiency of cardboard disposal. Our primary focus is on addressing the challenge of distinguishing between sections of food packaging suitable for disposal and those contaminated with stains or organic residues, a critical aspect of optimizing waste management processes. Through the utilization of a cloud-based architecture and the implementation of AI algorithms for tasks such as image segmentation, localization, and robot guidance, our research demonstrates the tangible advantages and real-world applicability of these methodologies.

2 STATE OF THE ART

2.1 Digital Transformation for Enhancing Quality Control in the Food Industry

The continuous advancements in the digital domain open a wide range of optimization opportunities in several sectors of the food production industry, starting from agriculture and dairy enterprises. The works of [3] and [4] explore the role of the internet-of-things (IoT) and AI in the monitoring of several physical parameters - such as temperature and humidity - impacting the quality of agricultural and milk production, through a network of connected sensors and AI-based processing, considering also the color and overall appearance of the products.

Computer vision techniques can also improve the efficiency of error-prone tasks such as product counting during the production, packaging, and transportation phases, allowing real-time monitoring of the production numbers, and therefore production optimization and material waste reduction [1]. Moreover, an important part of digital transformation is represented by robotic automation, involved in several tasks of the production process such as picking and placing, slicing, packaging and loading, reducing labor, while improving efficiency and minimizing contamination and hygiene concerns [7].

2.2 Architectures for Waste Management Efficiency

Waste management is a crucial topic for industry sustainability, whose efficiency in SMEs often relies on human resources, with great benefits resulting from access to computer vision and automation. In [11], a neural network model for waste sorting is exploited to distinguish between cardboard, plastic, and wood waste materials, with up to 100 accuracy. The work of [6] presents an Easy-to-Hard Instance Segmentation Network, based on a Convolutional Neural Network (CNN), for the recognition of different waste categories based on X-ray images, achieving 46.85 average precision. Image segmentation and object detection techniques enable garbage detection automation through specialized robots, such as in the approach described in [13] for the collection of plastic bottles in touristic areas. The proposed system exploits autonomously moving robots, able to detect and avoid obstacles in order to reach the waste material to be retrieved and collected for correct disposal, with a 93.3 success rate.

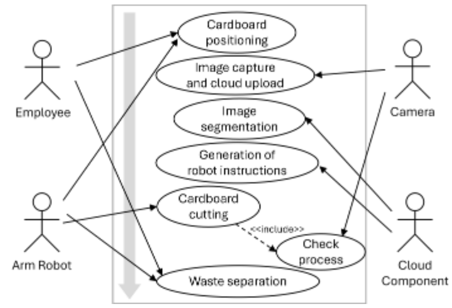


Figure 1: Food cardboard disposal diagram.

Compared to the works of [11] and [6], which target the recognition of the material for the correct identification of the waste category, in this work, we focus on waste materials deriving from food packaging, particularly on the distinction between the clean section of the packaging, and the portions presenting organic residue and thus destined to the general waste. Similarly, the solution described in [13] focuses on plastic recognition for garbage collection, not on the fine-grained distinction between the material suitable or not suitable to be recycled correctly. Furthermore, the architecture proposed in this work combines computer vision through neural network models with automation enabled by robotic elements. Unlike [13], we consider cobots to be included in SMEs, where they can assist the employees in waste management.

3 THE TASK ADDRESSED

This paper presents a cloud architecture designed to facilitate digital transformation in local businesses, focusing on the food production sector. Specifically, it proposes to enhance the waste management efficiency in an SME, i.e., restaurants, with an emphasis on the disposal and recycling of food cardboard. In the standard waste disposal process, the used food boxes are collected to be transported to recycling centers, where they are cleaned, purified, and ultimately recycled and reintroduced into commerce as packaging material or for other uses involving recycled paper. Commonly, no distinction is made between clean and soiled boxes in the SME, and all procedures are left to waste centers, leading to a visible waste of resources, both from a logistical point of view and within the centers themselves. With a focus on improving waste management efficiency, this paper proposes an enhancement to the standard flow in food box management through a cloud-based architecture responsible for recognizing and separating dirty box sections. The removed dirty cardboard is then sent to the recycling centres, while the clean paper can be recycled on-site, e.g., ground and transformed into packaging material.

In this sense, Figure 1 illustrates a food cardboard disposal diagram, where the main actors are represented by the SME employee in charge of waste, the robot, the camera, and the cloud component, where all the intelligent algorithms are deployed. Initially, both the

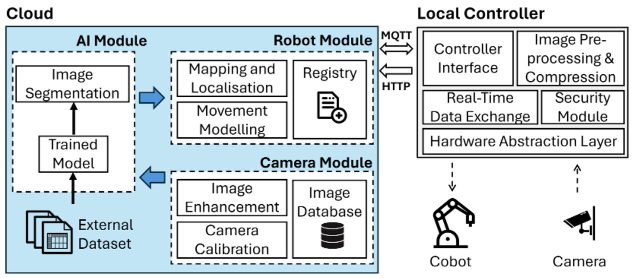


Figure 2: The Proposed Architecture for Waste Efficiency.

employee and the robot are responsible for positioning the cardboard on the workbench; the employee places stacks of used boxes, and the robot positions them one at a time for recognition. For each box, the camera is responsible for capturing an image and sending it to the cloud, where image segmentation for the recognition of areas to be removed, their mapping and localization, and the generation of instructions for the robot is performed. The robot can thus begin the cutting phases and the sectioning of the cardboard into clean and dirty parts; these are arranged with the help of the employee, once all the boxes initially positioned have been completed.

4 THE PROPOSED ARCHITECTURE FOR WASTE EFFICIENCY

According to the diagram described in Section 3, we propose an architecture to improve waste efficiency through the recognition and separation of soiled cardboard. Specifically, the architecture enables the management of cobots, exploited for positioning and sectioning the boxes, and the connection of cameras, allowing the cardboard to be analyzed and the entire robot process to be controlled. The architecture leverages the computational power of the cloud for artificial intelligence algorithms of image segmentation without burdening the devices. Moreover, the cloud is utilized to enhance scalability and allow the updating of algorithms tailored to more specific use cases; meanwhile, critical factors such as security and the robot's real-time operations are delegated to the local controller. The following two subsections detail all the modules of the architecture and the devices and algorithms used in the created instance.

4.1 Architecture Modules

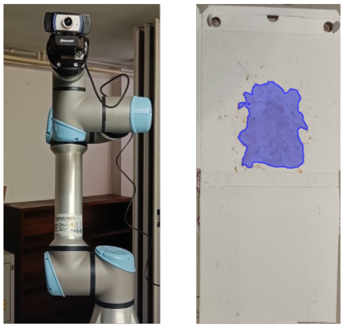
Figure 2 illustrates the complete architecture, which consists of a local controller for the physical management of the devices, i.e., the cobot and the camera, and a cloud component where all the algorithms for the devices' management and recognition of the cardboard sections are handled.

The local controller is responsible for managing the cobot and the camera, communicating with the devices through the hardware abstraction layer, in which the drivers for their connection and all the interfaces for communication are managed. Moreover, the local controller includes modules responsible for managing the Real-Time Data Exchange protocol, which allows real-time communication with the robot, the image preprocessing and compression module, which is responsible for the preparation of the images that should be sent to the cloud, and the security module, responsible for the safety of the robot and blocking or limiting the robot's actions in the event of errors or malfunctions. Finally, the local controller provides interfaces for communication with the Cloud. Specifically, it uses two protocols to communicate with the cloud modules: MQTT for exchanging information with the robot module to allow fast message exchange and HTTP for sending the images that should be recognized.

All the algorithms for image segmentation, localization, and robot guidance reside in the cloud component of the architecture, where the amount of resources can be adjustable based on the current use case. Specifically, three modules reside in the cloud: the robot module, the camera module, and the AI module. The camera module is responsible for the camera configuration and includes functionalities for adjusting and calibrating the camera, such as calculating the focal distance and other parameters necessary for 3D mapping. Moreover, this module includes functions necessary for image enhancement and decompression, as well as a database in which the images that should be classified are saved. On the other hand, the robot module contains all the functionalities and algorithms for managing the robot. In this sense, a registry is provided to describe the environment in which the robot works and the configurations of the specific robot. It also includes a component for mapping and localization, which extracts the coordinates of the sections identified by the AI module and performs the robot mapping in the real environment. Furthermore, a movement modeling component translates the coordinates into robot language and writes the necessary instructions for positioning and cutting. Lastly, the AI module is responsible for image segmentation and recognition of areas to be removed. The model, trained from an external dataset, takes images from the camera module as input and communicates the sections to be removed to the robot module. This module represents the core of the intelligent decision-making process, enabling the system to identify and act upon the areas of interest in an efficient and automated manner.

4.2 An Implementation of the Proposed Architecture

In this section, the implementation of the proposed architecture, mentioned in Section 4.1, is described. As an cobot, we utilized the 6-axis UR5 robot from the Universal Robot [9], with two installed tools for positioning the cardboard on the workbench and for cutting the dirty sections, respectively. Moreover, in our implementation, we utilized a high-resolution camera. This camera, along with the UR5 robot, are both connected to a Raspberry Pi 4, which serves as the local controller. The local controller is responsible for managing the devices at the local level and handling real-time safety features. It also performs initial processing of the images captured by the high-resolution camera. This setup allows for efficient and effective control of the devices, ensuring smooth operation and real-time response to various situations. Regarding cloud management, the various modules are managed as web services deployed on a cloud service provider; specifically, we utilized Microsoft Azure. Finally, for the segmentation task, we employed the Fast Segment Anything (FastSAM) model [15], which represents a real-time CNN-based solution. The FastSAM model, is based on the YOLOv8-seg topology



a) b)

Figure 3: UR5 Robot and camera used for the implementation a and example of cardboard segmentation with FastSam b .

and exploits 68M parameters. It was trained on 2 of the SA-1B dataset, showing results comparable to the original SAM network, but it can be exploited as a tool for zero-shot segmentation, thus applied to different data to produce masks corresponding to the different objects on the image, demonstrating adaptability in different scenarios. Due to this reason, it was considered in our implementation. The output of the network is a set of masks representing the detected residues. The information on the position of the objects corresponding to each mask can be extracted with the marching squares algorithm.

In Figure 3, two images are presented, depicting a preliminary implementation of the architecture, which is still in the process of completion. Specifically, Figure 3 a) illustrates the UR5 robot and the camera used; both are connected to the local controller that communicates with the Cloud. Meanwhile, Figure 3 b) demonstrates an example of FastSam's operation, which is capable of recognizing the stain from the cardboard and tracing the contours; the coordinates are thus translated and sent to the robot, which is responsible for cutting the section.

5 CONCLUSIONS AND FUTURE WORKS

In conclusion, this paper has presented a comprehensive architecture designed to enhance waste management efficiency in the food production sector, particularly within SMEs. By leveraging AI algorithms, robotic automation, and cloud-based solutions, our proposed architecture aims to revolutionize the traditional approach to waste disposal, with a specific focus on managing food box waste in SMEs such as restaurants.

The proposed architecture outlines an approach to recognizing and separating soiled cardboard sections from clean ones, thus streamlining the recycling process and minimizing resource wastage. Through the integration of advanced image segmentation techniques and cobot technology, our solution not only addresses the immediate challenge of optimizing waste management but also sets the stage for broader digital transformation within SMEs. As of the current state, significant progress has been made in the development and implementation of various architecture modules. The local controller, responsible for managing the cobot and camera operations, is actually in the testing phase. Additionally, cloud-based components housing AI algorithms for image processing and robot guidance have been established, showcasing good results in preliminary testing phases.

Looking ahead, our focus shifts towards completing the integration of all architecture modules and conducting comprehensive testing in laboratory settings. In parallel, efforts will be directed toward the practical deployment of the proposed solution in real-world use cases. Collaborating closely with the SME, we aim to conduct field trials to assess the architecture's performance in actual production environments.

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