Transforming Bakery Production Lines in Finnish SMEs through Modeling, Simulation and Co-Robotization for Efficient Use of Energy Resources

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***Abstract* - The practical modeling and simulation use of a collaborative robot in the food production business is covered in this study. This paper's major goal is to show how modeling and simulation may be used to automate a production line. The pilot was run at a bakery manufacturing facility in Finland. Consideration was given to the current facility design and equipment when modeling and simulating the deployment of collaborative robots. The goal was to create a solution specifically for the factory. An industrial bakery production line's typical process was modeled, simulated, and robotized: 1) Filling empty trays with batter, 2) loading them into oven-ready trolleys, and 3) removing the baked cakes from the trays for the subsequent topping decoration stage and 4) final step was to palletize the packed cakes. The automation of the food production sector decreased monotonous work and idle time and increased output. As a result, the industry of food production benefits from the efficient use of heavy machinery and energy resources as a result of robotization. This paper was written based on the food industry cobot prototype being developed under Kesytek project (EU ERDF fund - A 310156).**

Keywords - Automation, Collaborative Robotics, Food Industry, Modelling, Simulation

I. INTRODUCTION

In recent years, the application of modeling, simulation, and co-robotization has gained significant attention in various industrial sectors to enhance production efficiency, reduce costs, and improve product quality. One area where this technology has been applied is in the food industry, particularly in bakery production lines. The use of collaborative robots (cobots) in bakery production lines has the potential to improve production efficiency, reduce idle time, and increase output, leading to more efficient use of heavy machinery and energy resources. Several studies have been conducted to explore the practical use of cobots in food production lines, particularly in bakery facilities.

However, the implementation of robotics in food production is not without its challenges. One major issue is the need for specialized programming skills to develop and maintain the robotic systems. Additionally, concerns have been raised about the potential for job displacement and the impact on the overall quality of the final product.

To address these challenges, this paper explores the use of modeling, simulation, and co-robotization in transforming bakery production lines in Finnish SMEs. The goal of this study was to show how these technologies can be used to automate a production line while also taking into account the specific needs and constraints of the factory.

The pilot study was conducted at a bakery manufacturing facility in Finland, where an industrial bakery production line's typical process was modeled, simulated, and robotized. Specifically, the process included filling empty trays with batter, loading them into oven-ready trolleys, removing the baked cakes from the trays for subsequent topping decoration, and palletizing the packed cakes. The results showed that automation decreased monotonous work and idle time while increasing output, leading to more efficient use of heavy machinery and energy resources.

This study builds on previous research in the field of robotics and automation in food production. For example, research has shown that robotics can improve productivity, reduce waste, and improve product quality (Ismail et al., 2021; Li et al., 2018; Naeem et al., 2020). However, challenges remain, particularly in regard to programming and integration with existing production processes (Kim et al., 2020). By using modeling and simulation, this study seeks to address some of these challenges by allowing for more accurate and efficient planning of the automation process.

In addition, previous studies have also highlighted the potential benefits of co-robotization, or the collaboration between humans and robots in the workplace (Janssen et al., 2019; Zhou et al., 2018). Co-robotization has been shown to improve productivity, reduce injuries, and enhance worker satisfaction, among other benefits.

One example of such a study is the work conducted by Ehsan et al. (2020), where modeling and simulation were used to automate a bakery production line. The study was carried out at a bakery manufacturing facility in Finland, where the current facility design and equipment were considered when modeling and simulating the deployment of cobots. The researchers modeled, simulated, and robotized an industrial bakery production line's typical process, including filling empty trays with batter, loading them into oven-ready trolleys, removing the baked cakes from the trays for the subsequent topping decoration stage, and palletizing the packed cakes. The results showed that the automation of the food production sector decreased monotonous work and idle time and increased output.

Furthermore, research has also highlighted the importance of energy efficiency in the food production industry, particularly in light of increasing energy costs and environmental concerns (Choudhury et al., 2021; Kolios et al., 2017). The use of robotics and automation can contribute to more efficient use of energy resources, reducing the industry's overall environmental footprint.

Similarly, Madsen et al. (2019) explored the use of industrial robots in high-speed bread production. The study focused on automating the bread-making process, including dough handling, shaping, proofing, and baking. The results showed that the use of robots improved the production efficiency and reduced the production cost.

Simulation-based optimization of the baking process for energy conservation was explored by Park et al. (2017). The study focused on the optimization of the baking process using a simulation model. The results showed that the proposed optimization method reduced energy consumption by 10.3%.

A review of recent research on the application of robotic and automation technologies in the food industry, including bakery production lines, was conducted by Tewolde and Nokes (2020). The review highlighted the benefits of using robotics and automation technologies, including increased efficiency, reduced costs, improved product quality, and reduced food waste.

In summary, this paper presents a novel approach to the automation of bakery production lines in Finnish SMEs, using modeling, simulation, and co-robotization. The results of the pilot study demonstrate the potential benefits of this approach, including more efficient use of resources and increased productivity. The remainder of this paper will provide more details on the methodology used in the pilot simulation study and discuss the implications of these findings for the food production industry as a whole.

II. PROTOTYPE SETUP

The project was targeted at the digitalization rate increase in small and medium enterprises. It was planned to bring more flexibility and comprehensive control over the productivity of the line by devising a customer-centric solution. Besides, the management of the factory is brought to a new level by implementing an automated process to monitor the production quantity.

The main goal of this project was to create a digital model and simulate the food production line in order to estimate the benefits that include increased output and energy efficiency and decreased monotonous work and idle time.

This paper covers the simulation of the food production process which includes four steps that were automated:

1. Filling empty trays with batter.
2. Loading them into oven-ready trolleys.
3. Removing the baked cakes from the trays for the subsequent topping decoration stage.
4. Palletizing the packed cakes for transportation.

The bakery preparation setup was based on Universal Robot UR10e robotic arm, Onrobot Lift100 robot lift and own design gripper. All devices were chosen and designed to meet the safety requirements of the food factory where the working space is shared between human workers and robots. UR10e was chosen as it meets the requirements for the payload. Position of the robot station is in the processing area of the factory.

The dimensions of the bakery facility were measured and used in the digital model. The model also includes a conveyor where the empty trays are filled with batter. This conveyor equipped with the automatic filling machine was built by the factory to decrease the labor load for human workers. Now a major part of the process can be substituted with the cobot.

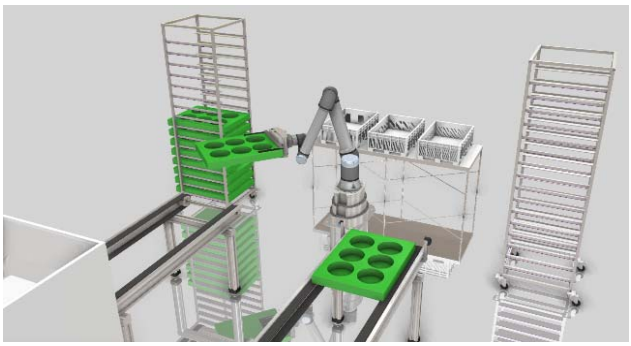

Figure 1. Digital model of the processing area: filling empty trays

Figure 1 shows the digital model of the processing space where the robot firstly places the empty trays on the conveyor with the filling machine. And Figure 2 presents the removal of the baked cakes into a plastic crate.

Another part of the bakery production that was simulated is palletizing performed by another UR10e cobot equipped with a suction gripper. The robot station is also based on Onrobot Lift100. For the palletizing application, the robot setup was located in the packaging area, from where the bakery was transported to the customer. For the palletizing sequence, a Euro pallet of 900x1200 mm was chosen to be filled with 5 layers of packed cakes. **Error! Reference source**

not found. presents the packaging space model. The cobot fills two pallets from two sides with square carton boxes with cakes.

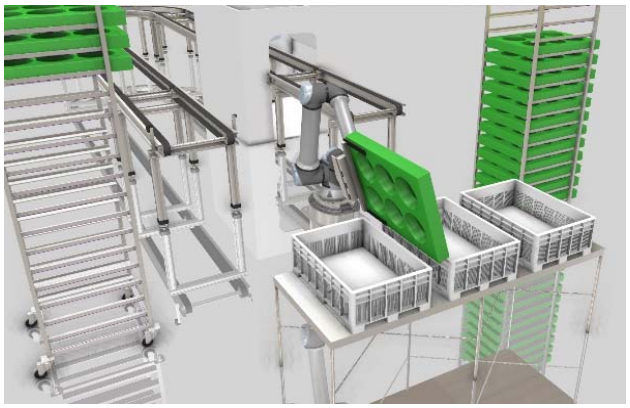

Figure 2. Digital model of the processing area: removing the baked cakes from the trays

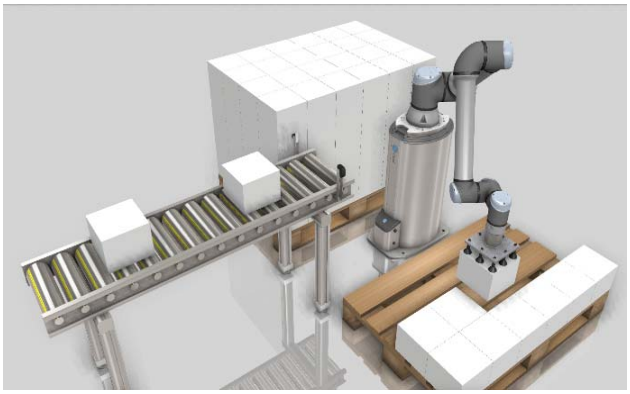

Figure 3. Palletizing space digital model

III. METHOD

In summary, we studied how modelling and simulation can be used to automate a production line. A simulated digital twin was run in the created virtual bakery facility. The following factors were considered:

- Current facility design.
- Current equipment for bakery (trolleys, trays, ovens, etc).
- Shared workspace between people and cobots.
- Hygiene requirements in food production.

The gripper concept was provided to the bakery factory. It was designed in the virtual environment to carry the heavy trays with the batter of a weight of 6 kg. The gripper model can be 3D printed. The whole process was simulated in Visual Components 4.6 software. The speed and acceleration of the robot are set to maximum values when there are no workers around. To make it safer for people working in the factory, a sensor system was designed to detect humans and reduce speed and acceleration by 50%. The conveyor was set to move at the speed of 200 mm/s which corresponds to the real facility parameters. The total space takes approximately 9 square meters. The trolley height is 2000 mm. To increase the working space of the robot it was decided to put it on a lift that is able to move the robot up and down by 400 mm. This setup allows the cobot to reach all trays in the trolley.

The oven is located outside of the robot's working space, so the trolleys with trays are driven into and from the oven by human workers. However, this does not hamper the systematic arrangement of the facility since the trolley and oven always remain in the same location.

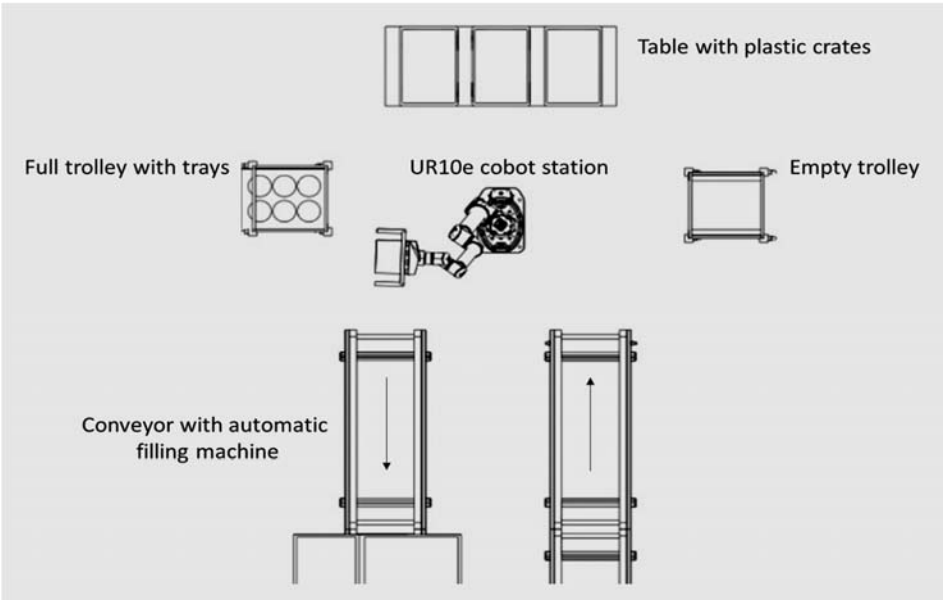

Figure 3. Working area in the processing stage

IV. RESULTS

The results of this preliminary study have shown certain benefits. As was already mentioned, robotization can save more than 10% of used energy by reducing the waste of products due to its precision and repetitiveness. We cannot omit that the robot relieves the bottleneck since the filling machine is adjusted to the cobot performance. Besides, the cobot station was designed to fit the current environment with high trolleys, so the human workers are not to lift the trays. Moreover, automated data collection on productivity excludes the need for the constant watch of human workers. Consequently, this diminishes the kinetic energy waste in the facility. Such a systematized and organized arrangement leads the current production chain to a lean process. Finally, lean production contributes to the achievement of the smallest possible storage area what facilitates the efficient use of resources.

V. ANALYSIS OF RESULTS

The concept of cobot application was designed for the most promising manual activities in a bakery manufacturing facility. Automating these tasks with cobots can eliminate different kinds of waste in the manufacturing process. For instance, idle time would decrease significantly compared to manual work. The potential of injury caused by heavy load tasks to the laborers would disappear. The errors in the production process would minimalize and record completely to the working history of the cobots. With the data from cobots, managers could estimate the quantity of products made in a day, a week or even a month, or a year. The maintenance of the cobots is a must to keep their work more stable, but it is easy to make a plan for this activity with the data collected during the working time. Benefits from the deployment of the cobot application could come in different ways. From the side of management, by knowing the number of products made, the manufacturing plans could be created beyond. The quality and hygiene of products are controlled fully by the automated system. Time saved from the manufacturing process can benefit in terms of more products. Less waste material means more efficiency in using energy resources.

VI. DISCUSSION AND CONCLUSIONS

This project brings the capacity for predictable production adjusted to the customer's needs, since the factory is able to lift the data concerning productivity. Our future plan is to develop the data analysis for the production chain.

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