Automation and Safety in Croissant Production: Designing an Efficient and Secure Manufacturing System

ME 262: Introduction to Microprocessors and Digital Logic

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1.0 Introduction

Automation has revolutionized various industries, allowing many businesses to reduce their reliance on labour while optimizing production. In the baking industry, automation ensures precision and consistent quality for every batch of baked goods, highlighting how important it is for maintaining steady business [1]. Crescent, a local croissant factory, supplies their baked goods to Astro Brews, a worldwide coffee chain. To expedite their production, the factory wished to automate their dough sheeting process using SCARA robots, stepper motors, conveyor belts, sensors, and programmable logic controllers. Therefore, this report will provide a comprehensive overview of the necessary background knowledge, identify the constraints, and demonstrate how the final design was implemented for the factory to use.

2.0 Background Knowledge and Definitions

2.1 Automation and Control Systems

The term automation comes from the Greek words “auto” which means self, and “matos” which means moving [2]. Thus, automation is the ability for a system to move by itself. In all applications, automation helps reduce manufacturing costs by eliminating labour to allow for quicker and more efficacious production [3]. Control systems are an integral part of automation, handling the management of a set of devices based on inputs. Control systems can be closed loop (constantly checking the state of the system and making changes) or open loop (operating more autonomously) [4].

2.2 Quality Control

For any business, quality control is essential to maintain profitability. It ensures that products meet predefined standards and specifications while maintaining consistency [5]. For the croissant production line, implementing quality control eliminated any outliers (bad croissants) as much as possible. The best way to accomplish that, within the context, was to use workers that will stay vigilant at the end of the production line. Through visual inspection, the croissants are scrutinized to ensure they meet the factory’s standards. Due to the complex nature of quality control, human judgement was needed.

2.3 Safety Protocols and Measures

Safety protocols are essential in production lines to protect workers and equipment [6]. For the croissant production line, conveyor belt safety measures that were implemented into the design include guard rails protecting workers, accessible emergency stop buttons, a start-up alarm, preventative maintenance routines, as well as sensors and alarms to detect malfunctions [7]. As for sharp tools, all the safety measures from the conveyor were also implemented, in addition to guard rails and cages around the machines to keep fingers out, and light curtains that automatically stop the machines if movement is detected.

2.4 End of Arm Tooling

End of Arm Tooling (EOAT) refers to the tools that are placed at the end of robotic arms that interact with the environment to complete tasks [8]. They were designed in such a way that each tool is easily replaceable according to the needs of the production line such as the size and shape of croissants. The implemented EOAT that was attached to the SCARA robots included cutting tools for slicing the dough into the required shape and scraping tools to roll the croissants.

2.5 Scalability

Scalability refers to a production line's ability to increase its output without compromising on things like efficiency and quality [9]. Scalable production lines allow businesses to quickly adapt to rising and falling market demands, thereby increasing profitability. Within the context of the croissant production line, if the factory needs to ship out a higher volume of baked goods, it can implement multiple conveyor belts and simply repeat the design that was implemented.

2.6 Flexibility

Flexibility is somewhat related to scalability, and it refers to a business's ability to adapt to demands of customer [10]. Within automation systems, this allows for adjustments and changes to the production process without significant downtime or reconfiguration. For example, if market demands favoured donuts over croissants, a flexible production line could adapt. Luckily, this is already implemented into the design with the use of EOAT. By switching out one set of tools for another, Cresent can quickly pivot its output to another baked good. The same concept would apply for an order for different sized croissants.

3.0 Solution Design

3.1 Assumptions

For the design of the automated croissant production system, several key assumptions were made to ensure the feasibility and efficiency of the process. Firstly, it was assumed that the dough entering the sheeting process was already rolled flat to a consistent thickness. Moreover, the conveyor belts and all EOAT, were assumed to be coated with a non-stick material which prevented the dough from adhering to the surfaces. Lastly, it was assumed that the dough is always cut into equilateral triangles and that there was always a gap left between.

3.2 Implemented Design

After the assumptions were ascertained, the automated croissant production line, as shown in Figure 1, below, was designed through a series of stages.

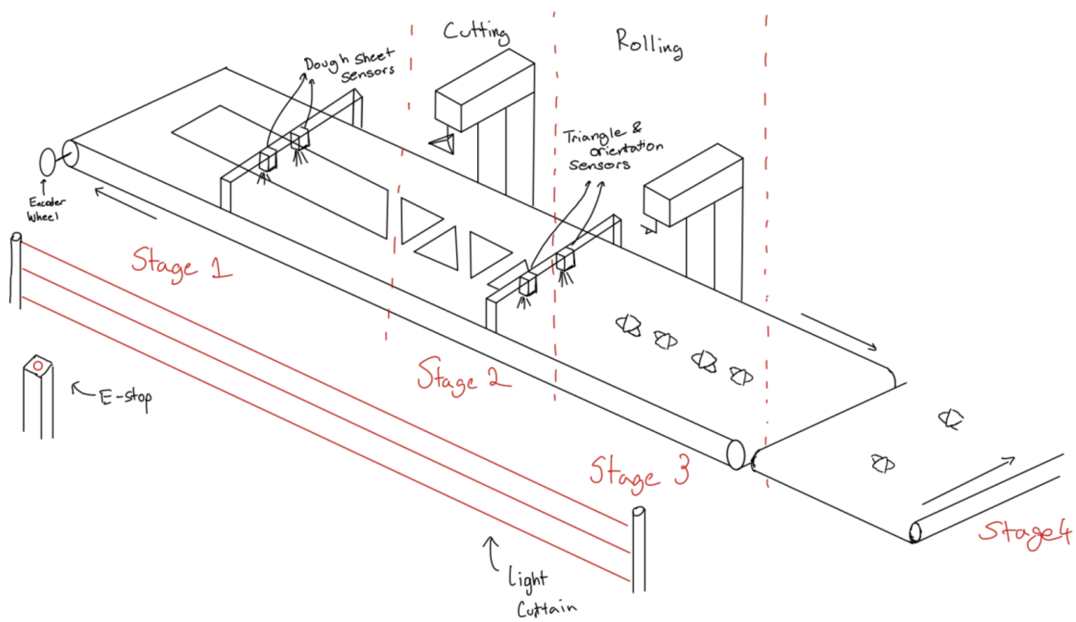

Figure 1: Schematic Design of the Croissant Production Line

At all stages, an E-stop input is present, which stops the conveyor belt speed (an output) whenever triggered. The list of all stages is shown below, as well as its function, inputs, and outputs.

Stage 1: Roll of dough comes in on conveyor.

> *Function*: The incoming dough sheet is checked to ensure that it is in a rectangular shape and is fed into stage 2.

Inputs: Proximity sensor to detect incoming dough

Outputs: Conveyor belt speed should be set to 0 if no dough is detected.

Stage 2: Dough is cut into triangles.

Function: The robot stamps the incoming dough sheet with a triangular stamp at a constant distance interval, creating equally sized croissants.

Inputs: Incremental encoder to detect how much the conveyor has moved since the last stamp

Outputs: Whether or not the robot arm stamps the dough with the EOAT.

Stage 3: Triangles are rolled into croissants.

Function: Incoming triangular pieces of dough are detected along with their orientation and the robot rolls the triangles into croissants. The triangles are then transported to a secondary conveyor.

Inputs: Proximity sensors to detect presence and orientation of dough triangles

Outputs: Whether or not the robot arm rolls the triangles into croissants.

Stage 4: Croissants are transported to human checking station on a different production line.

Function: A secondary conveyor transports croissants to a human checking station.

Inputs: None

Outputs: None

3.3 Constraints and Requirements

For each input and output, the constraints and requirements were be defined to further understand how the system worked, as shown in Table 1, below.

Input/Output	**Constraints**	**Requirements**
Proximity Sensor (Input)	±0.5 mm accuracy	Food-safe
Incremental Encoder (Input)	±0.5 mm accuracy	Spin with the pulley
Conveyor Speed (Output)	±2 mm/s accuracy	Can stop from full speed within 1 second
E-Stop (Input)	Stop machine within 0.5 secs	Easily accessible,
Robot arm position (Output)	0.5 mm accuracy	Cover the conveyor’s width

Table 1: Constraints and Requirements of each Input and Output Outlined in the Stages

3.4 Sensors Required and Real-World Considerations

To select the best sensors for each of the inputs, various options were considered and chosen based on their requirements and constraints.

<u>Proximity Sensor: Detecting the presence of dough on the conveyor belt</u>

Proximity sensors were chosen to detect dough because they are the most reliable option. Color sensors were also considered but not chosen as they are prone to failure due to light interference. Proximity sensors tend to be very compact and are relatively cheap [11].

Proximity sensors are used in stage 1 and stage 2 of the production line. In stage 1, two proximity sensors are used to detect if the dough sheeting spans the expected width in order for stage 2 to create triangles. In stage 3, two more proximity sensors are used to detect the orientation of incoming dough triangles based on which sensor is triggered first. This is a trade-off in terms of size as using two sensors will occupy more space, however it is a necessity for the production line to function properly.

Some real-world considerations that were made when choosing proximity sensors is their tendency to bounce between on and off values. This can be fixed in the PLC software by debouncing the value. The distance of the proximity sensors also affects their accuracy, and to ensure optimal operation they should be placed at most 15mm above the conveyor belt. With croissant dough being about 3-5mm thick on average, the precision of theses sensors also matters greatly, and choosing 0.5mm precision sensors will allow for fewer false positives. Additionally, these sensors need to be food-safe, which is addressed by purchasing IP69K food grade sensors [12].

<u>Encoder: Detecting distance the conveyor has moved</u>

In stage 2 there is a need to detect how far the conveyor has moved to correctly determine when the robot should stamp the dough. To do this, an incremental rotary encoder was chosen as it can be directly attached to the conveyor belt shaft. By using a counter function in the PLC program, the robot arm's cutting tool can be activated at set distance intervals. There are no real size trade-offs to using encoders, and they can be purchased for very low costs. However, this cost could be eliminated entirely by avoiding the use of an encoder. In that case, the robot would be programmed to stamp the dough at set time intervals. In the interest of maintaining consistency, it is unrealistic to assume that the conveyor always operates at a constant velocity. Therefore, an encoder is required so that the cuts are evenly spaced.

Real-world considerations for encoders include food safety once again, which is addressed by purchasing encoders which are made with stainless-steel casings and are rated to a minimum IP67 water resistance rating [13].

E-stop: Stops all machinery immediately

For emergency-stopping, there are two inputs. The first is a manually triggered input for which a simple button can be used, as they are cheap, reliable, and easily replaceable with no trade-offs. The second input is triggered whenever an object enters a zone around the cutting robot to ensure safety. For this, a light curtain sensor was chosen as they function very quickly. While these sensors tend to be very expensive, they are essential for ensuring safety within the production line. A trade-off considered when using light curtains was that they may cause unwanted stoppage of the production line, and could be triggered by accident, which may be a problem. However, these cases are rare, and it is more important to prioritize the workers' safety above the function of the production line.

3.5 Control Systems Used

For this system, a programmable logic controller (PLC) can be used as all the inputs being used are binary, and all outputs operate in a repetitive manner. Additionally, PLCs allow for multiple inputs and outputs and are generally suited for industrial use, making them scalable and reliable as well.

3.6 Safety measures

As with any manufacturing line involving moving machinery, safety is the top priority. Primarily, there are sufficient safety measures to keep humans out of harms way. First, physical barriers and guards are implemented along the edge of all conveyors and surrounding their motors and pullies. This keeps workers away from dangerous areas. A light curtain is also installed along the length of the system and works as an emergency stop button would. When an object penetrates the curtain, it immediately brings the machinery to a halt [14]. Additionally, physical emergency stop buttons are installed at multiple locations along the conveyor for easy access during an emergency. While these fixtures exist, regular preventative maintenance routines and worker training are important to ensure the smooth operation of the machines.

3.7 Velocity Considerations

In this application, it is important to consider the rate at which the conveyor accelerates as the rolling and cutting processes are highly dependent on the fact that the dough is not displaced relative to the conveyor while the conveyor is moving. This is because the cutting arm operates using the encoder to identify where the dough is, and if inaccurate can cause malfunction of the cutting stage and all later stages. In addition, fast acceleration or velocity may cause the rolled croissants to roll on the conveyor, which can cause interference with other stages of the process. As a result, a slow acceleration, slow velocity conveyor system is ideal as it reduces the chances for failure on the production line, making the process much more efficient.

4.0 Conclusion

The design and implementation of an automated croissant production line involves the integration of automation, safety, and quality control. By equipping SCARA robots with end-of-arm-tooling, PLCs, and various sensors, the system ensures effective and efficient production practices. The robot's repetitive motions are controlled by inputs received from various sensors along the conveyor belt. Additionally, top-of-the-line safety protocols including light curtains and physical barriers prioritize worker safety while maintaining consistent production numbers. The scalability and flexibility of the design allows for production to adapt to changing market demands. Ultimately, the design highlights the innerworkings of automated production lines that consistently produce high quality products.

5.0 References

[1] J. Dummer, "Automation advances in the baking industry," Food In Canada, 23 March 2023. [Online]. Available: https://www.foodincanada.com/features/automation-advances-in-the-baking-industry/. [Accessed 30 July 2024].

[2] Z. Khalil, "Learning Industrial Automation," LinkedIn Learning, 22 August 2023. [Online]. Available: https://www.linkedin.com/learning/learning-industrial-automation/basics-of-industrial-automation-14444217?resume=false&u=55034593. [Accessed 30 July 2024].

[3] O. Munro, "Automation in Manufacturing: Uses, Examples, & Trends," Unleashed, 15 February 2023. [Online]. Available: https://www.unleashedsoftware.com/blog/automation-in-manufacturing#:~:text=Automation%20in%20manufacturing%20refers%20to,the%20risk%20of%20human%20error. [Accessed 30 July 2024].

[4] P. Kirvan, "What is a control system?," TechTarget, 30 March 2023. [Online]. Available: https://www.techtarget.com/whatis/definition/control-system#:~:text=A%20control%20system%20is%20a,big%20role%20in%20these%20systems. [Accessed 30 July 2024].

[5] A. Hayes, "Quality Control: What It Is, How It Works, and QC Careers," Investopedia, 23 June 2024. [Online]. Available: https://www.investopedia.com/terms/q/quality-control.asp. [Accessed 30 July 2024].

[6] I. Nesterenko, "Safety Protocols: Definition and Tips for Effective Writing," Fluix, 27 February 2024. [Online]. Available: https://fluix.io/blog/safety-protocols. [Accessed 30 July 2024].

[7] West River Conveyors, "Top 7 Safety Features Your Conveyor Should Have," 10 January 2024. [Online]. Available: https://www.westriverconveyors.com/blog/top-conveyor-safety-features/#:~:text=Proper%20conveyor%20guarding%20prevents%20access,risk%20of%20accidents%20and%20injuries. [Accessed 30 July 2024].

[8] Association for Advancing Automation, "EOAT in Robots: A Basic Overview," 19 September 2017. [Online]. Available: https://www.automate.org/robotics/blogs/eoat-in-robots-a-basic-overview#:~:text=End%20of%20arm%20tooling%20(EOAT)%20is%20a%20crucial%20aspect%20of,on%20a%20robotic%20welding%20system.. [Accessed 30 July 2024].

[9] J. Hurley, "How to Maximize Scalability in Manufacturing," SmartFile, 19 April 2023. [Online]. Available: https://www.smartfile.com/blog/maximize-scalability-manufacturing. [Accessed 30 July 2024].

[10] Upwork, "The Importance of Flexibility in Business," 31 March 2023. [Online]. Available: https://www.upwork.com/resources/flexibility-in-business. [Accessed 30 July 2024].

[11] Newark, "Proximity Sensors," [Online]. Available: https://canada.newark.com/c/sensors-transducers/sensors/proximity-sensors-proximity-switches. [Accessed 30 July 2024].

[12] HTM Sensors, [Online]. Available: https://www.htmsensors.com/ip69k-food-grade/. [Accessed 30 July 2024].

[13] Lika, [Online]. Available: https://www.likausa.com/news/stainless-steel-encoders-for-the-food-industry/. [Accessed 30 July 2024].

[14] Sick Sensor Intelligence, "What exactly is a safety light curtain?," 8 December 2020. [Online]. Available: https://www.sick.com/ca/en/what-exactly-is-a-safety-light-curtain/w/blog-definition-safety-light-curtain/. [Accessed 30 July 2024].