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3D Simulation of a Yogurt Filling Machine Using GRAFCET Studio and Factory IO: Realization of Industry 4.0

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3D SIMULATION OF A YOGURT FILLING MACHINE USING GRAFCET STUDIO AND FACTORY IO: REALIZATION OF INDUSTRY 4.0

Summary

Manufacturing systems, enterprises and academic institutions worldwide are implementing Industry 4.0 (IR4.0). By integrating the services and equipment, IR4.0 develops autonomous systems that manage industrial operations and exchange real-time data in real time. This study includes a simulation of an existing production system using the GRAFCET Studio software. To realize the concept of a 3D smart factory, the GRAFCET programming language was used and connected to the Factory IO software. The simulation can accurately replicate the filling, scanning and removing processes in an actual yogurt filling system. A virtual factory was designed and developed using the IO Factory software to clarify the workflow and simplify the modification of the production line. This virtual factory better enables the identification of areas for optimization, improving also efficiency and productivity. A comparison between the simulated and the actual system results shows that the simulated results are approximately 90% accurate. In addition, some improvements are proposed to enhance the existing system's efficiency. The improvements involved the testing of the system under different conditions to identify shortcomings and modify the design accordingly.

Key words: *GRAFCET Studio; Factory IO; 3D factory; simulation; Industry 4.0*

1. Introduction

Over the past few years, the need for global markets has become increasingly specialized. Due to this reason, producers create extremely customized manufacturing systems with highly dynamic behaviour and, thus, higher variability [1-3]. The implementation of the Industry 4.0 concept should be the primary goal of every company, depending on the type of industry and its current characteristics [4]. Several manufacturers rushed to adopt Industry 4.0 as this offers superior advantages which upgrade manufacturing systems with the most recent technological advancements in information and communication systems, such as the Internet of Things (IoT), cyber-physical systems (CPS), big data analytics (BDA), cloud computing, and etc. [5–6]. As a result of the Industry 4.0 implementation, the current industrial structure can be replaced or upgraded by cutting-edge digital devices so that all elements can collaborate, communicate and share data continuously [7-9]. From this perspective, Industry 4.0 focuses on the digital integration of equipment, products and systems that create intelligent networks through the entire production chain [10].

Industry 4.0 can effectively control and coordinate intelligent factories, increasing their responsiveness to the continuously changing market demands [11–15]. The performance of manufacturing companies can be enhanced by several smart Industry 4.0 capabilities, including real-time tracking, monitoring, visibility, dynamicity and adaptability, autonomy, decentralization, intelligent production planning, control, and scheduling. According to Waschneck et al. [16], Industry 4.0 offers manufacturers a new and practical means of improving their production systems by developing real-time production scheduling.

The present study was conducted at King Saud University (KSU), Saudi Arabia, with the aim of transforming an existing yogurt filling system into an automated one based on Industry 4.0 fundamental ideas, which would automatically fill yogurt and add various flavours following the client's requests [17]. The KSU's automatic yogurt filling system was presented in later studies showing consistent results. For instance, the accuracy of robotic arms and conveyor belts was demonstrated to increase production sustainability in Industry 4.0 in the virtual reality (VR) based engineering education [18]. Real-time scheduling and dispatching of lean production settings based on Industry 4.0 explained the yogurt filling technique fully [19]. At the request of a client, Salah et al. [20] studied a yogurt filling device that can add three different flavours to yogurt. According to Industry 4.0 concepts, Salah et al. [21] introduced a second phase control architecture for the yogurt filling machine, which incorporated a platform for near-field communication to enhance customer satisfaction.

This study proposes a design and development of a three-dimensional factory model that simulates a yogurt filling setup using the Industry 4.0 concepts. Therefore, the primary objective of the current study is the incorporation of mass production and customization. Hence, the production rate is a key performance indicator of the current customized mass yogurt filling system. Additionally, this article validates the results of the previous studies by using the same yogurt filling system in a simulation environment. Figure 1 shows the layout of the existing lab-scale setup.

Fig. 1 Layout of the existing yogurt production system

On the basis of the previous study by Salah et al., the scope of the study was limited to introducing three sizes of bottles and adding assorted flavours to satisfy customer requests [22]. The current system needed some machines that were essential for implementing the Industry 4.0 concept. Therefore, two machines were added: a sealing machine to seal the bottle, and a storage station to store the products afterwards. The system does not have a virtual version that helps in testing the system and discovering defects in the stations, so a virtual factory is developed by means of the Factory IO program to clarify the factory's workflow and ease of modification on the production line.

The process layout is presented in Figure 2, which starts with an empty yogurt bottle entering the system and coming out with a required volume of yogurt mixed with a desired flavour. The filled bottle is then sent to the storage unit.

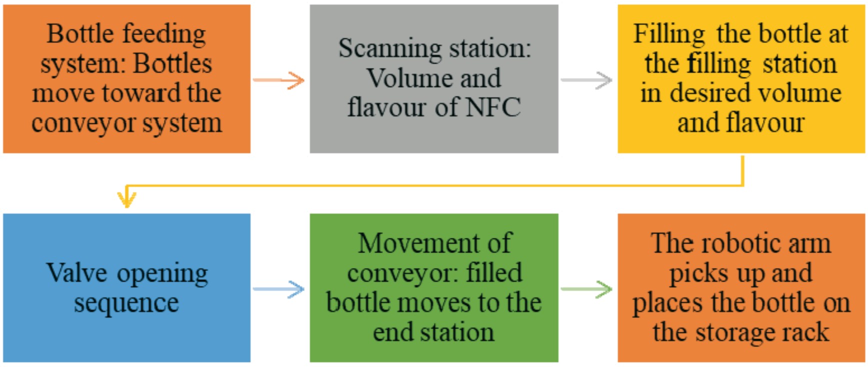


Fig. 2 Flow chart of the existing process

1.1 Research gap, contributions and objectives

In the context of Industry 4.0, there is a need for more information and research that would describe how to combine services and instruments to create autonomous systems, manage industry operations and communicate real-time data. This study tries to fill this gap. To make the concept of a 3D smart factory a reality, the Factory IO software and the GRAFCET programming language are coupled. The simulation mimics the filling, scanning and removing processes employed in an actual yogurt filling machine by mimicking these steps. With the help of this virtual factory, it is simpler to identify areas that may be improved to increase output and efficiency. A comparison with the real system data shows that the simulated system's conclusions are about 90% accurate. In relation to the efficiency of the present system, several changes are also suggested. To make the changes, it was necessary to evaluate the system under various circumstances to identify problems and change the design. Additionally, this evaluation established the accuracy and dependability of the simulation findings, making testing more effective and precise. The study shows that the machine sequence can be changed by adding or eliminating control stages, and the production cycle time influences customer delivery timings. The results can be used to develop a concept of a digital twin model in future studies.

2. Literature review

2.1 Overview of Industry 4.0

According to recent research studies, several technological pillars or technologies make up the fourth industrial revolution. Each technology pillar has importance for various sectors and services implementing Industry 4.0. Using the IoT, automation system interoperability and integrability issues can be addressed. The IoT is at the centre of the fourth industrial revolution and is considered as the first technological pillar for its implementation. It connects all commercial and technological components through the internet. The IoT is a network of several physical objects connected over the internet to exchange data and interact [23]. These gadgets are called intelligent devices and come in various forms and functions. The industrial Internet of Things (IIoT) gathers data in real time and provides feedback on the health of systems and machines [24]. It is intended to be used to assess and improve industrial processes. Most devices currently on the market contain sensors that the manufacturers put in. The sensors are used to monitor the operation so that suspect components can be replaced before they cause any damage. Due to accurate performance feedback, these sensors can be employed to create efficient supply networks. Several successful case studies have enabled smart production, a crucial step towards Industry 4.0.

With the development and standardization of cyber technologies, there is a need for information and data protection, making cyber security one of the Industry 4.0 pillars. Cyber security is considered the second pillar of Industry 4.0 as it helps ensure that hardware, software, and electronic data are protected against theft or damage [25]. The goal of Industry 4.0 is also to create a cyber-physical environment through the integration of information technology and operational technology.

Safe networking makes sharing data securely across devices feasible, and cyber security is essential to this effort. Data sharing between various value-adding chains (for instance, material sourcing, production operations and recycling processes) is feasible through horizontal and vertical integration and is considered as the third pillar of Industry 4.0. To gain agility, a company can use vertical integration to integrate many systems [26]. Conversely, horizontal integration refers to the connections between various partners. Cloud computing is crucial for seamless data sharing across many systems, gadgets and operational tasks. Digital supply chains and logistical methods are also crucial to satisfy customer expectations and increase overall profit. Big data and analytics are regarded as the fourth technological pillar in the conceptualization of Industry 4.0 [27, 28]. Big data analytics became possible as massive data sets appeared in several industries.

The fifth technological pillar of Industry 4.0 is simulation and augmented reality (AR). AR brings to the Industry 4.0 environment the benefits of automated inspection, time savings, accuracy improvement, and non-destructive defect detection [29, 30]. AR provides best practices to maximize quality, options for training for the use of complex equipment without thick paper manuals, and it easily enables an understanding of complex technologies. AR is becoming more prevalent in art, craft and architecture to speed up the production of 3D CAD-enabled images and improve productivity. For Industry 4.0, artificial intelligence (AI) is used in complex robotic systems to make them autonomous in difficult situations. By means of advanced machine learning algorithms, robots may learn from their errors and steadily enhance their performance in an Industry 4.0 environment. In practice, social robots (cobots) are replacing basic robots. Being the sixth pillar, robots can complete complex and delicate tasks, unlike everyday robots, which are integrated with advanced software and sensors [31, 32]. Today, additive manufacturing (AM) and 3D printing technologies are essential to the fast manufacturing of prototypes. Customized, complex and lightweight designs can be achieved with advanced 3D printing techniques [33, 34]. AM is the seventh pillar of Industry 4.0. The main goals are improving equipment and services, maximizing production quality and energy conversion [35, 36]. As shown in Figure 3, data is transferred by devices, machines, and systems such as enterprise resource planning (ERP) and manufacturing execution system (MES) to automate the entire system successfully.

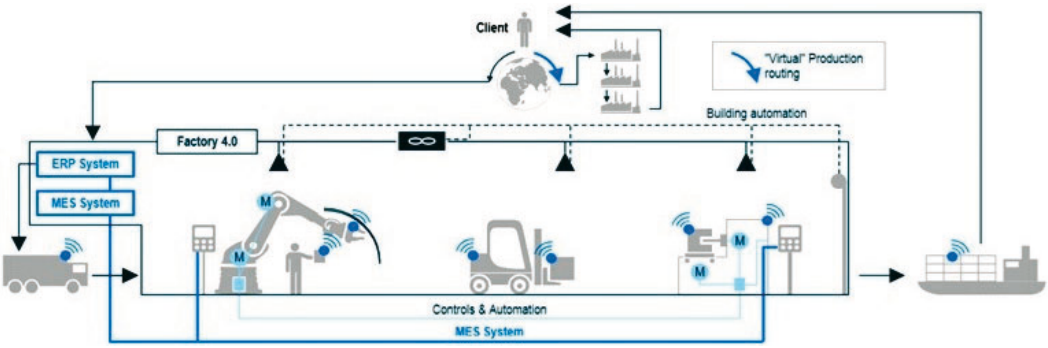


Fig. 3 Data exchange within Industry 4.0 system (adapted from [21])

2.2 Intelligent scheduling in Industry 4.0

Recent studies have explored the advantages of Industry 4.0 for production scheduling and control in an intelligent manufacturing environment [37-39]. For instance, Parente et al. concluded that since Industry 4.0 systems collect real-time data during the physical interaction between production units and build an ideal production schedule [40-44], they may immediately and effectively support the scheduling process of the production operations. The innovative views of job-shop scheduling in Industry 4.0 were investigated by Zhang et al. [45]. New methods for creating models and frameworks for job-shop scheduling under Industry 4.0 were also presented. Rossit et al. [46] explained how the Industry 4.0 paradigm would positively affect production scheduling and performance.

2.3 Smart factory and the role of digital twin

In the context of Industry 4.0, digital twins are also getting growing attention in mimicking a real-world product or process online. The entire industry can be displayed digitally through real-time simulation to help companies understand their processes better, conduct an analysis and optimize their systems. For instance, Chen et al. [47] proposed a hierarchical design for a smart factory considering the physical resource layer, the network layer and the data applications. The authors discussed typical characteristics of an intelligent factory using a laboratory prototype platform as an example. They studied the manufacturing line for packing candies using the prototype platform from the laboratory. Biesinger et al. [48] focused on various cyber-physical system data sources and information needed for digital twins. The study tested significant components of the idea in an actual body-in-white manufacturing system. Using a digital twin of a cutting tool as a virtual representation of a physical tool, Botkina et al. [49] investigated the data format, architecture, flow of information and data management of the tool for manufacturing performance. It was reported that the digital twin saved, improved and transmitted flexibility in the design of an efficient machining solution. Iris et al. [50] developed a digital twin for several duties at an assembly station to demonstrate the effects of integrating humans into production and production control systems.

GRAFCET is a functional modelling language used for the specification of controllers in discrete event systems. It enables the definition of a control program to be organized hierarchically depending on the elements encapsulating steps, partial-GRAFCET and driving commands. For designing a system, the GRAFCET Studio provides two aspects of a control system, the actions (commands) and the sequence of execution [51]. GRAFCET comprises three essential elements, steps, actions and transitions, and these can be utilized in almost the same way pneumatic or electrical components operate. Steps are active or inactive and follow the transitions from a subsequent step. The transitions are used to describe the sequence of a control system. Another tool used in this study is Factory IO, a 3D factory simulation for learning automation technologies. It is very easy to use it and it allows the user to quickly construct a virtual factory using various common industrial components. The Factory IO features closely resemble factory operations [52].

3. Methodology and approach

3.1 System architecture

The production cycle starts by transferring empty bottles to the bottle feeding system; once the sensor detects a bottle, a signal is sent to the controller to move the plate. In the next station, the near-field communication (NFC) module reads the tag and stores the information about the customer's order (amount and flavour). Next, the information from the NFC module is sent to the controller allowing the plate to move to the filling station. When the sensor of the filling station detects the tag of the bottle, the plate stops, and the manipulator in the station adjusts itself to fill the bottle depending on the information received from the NFC module. After the filling process, the plate moves to the end of the production system, enabling the rest sensor, and stops at the end station, where the robot takes the final product and puts it in a temporary storage area. The current system layout and components are presented in Figure 4. The different components in the system, their number and purpose, are given in Table 1.

Table 1 Component details and description

Part	Qty	Description
Piston	5	One for a bottle-feeding system, one for the NFC station, one for the filling station, and two for the start and end stations
Automated bottle-feeding system	1	Supplying empty bottles
Photoelectric proximity sensor	5	One for a bottle-feeding system, one for the NFC station, one for the filling station, and two for the start and end stations
Proximity sensors	1	Notifying when the process finishes
Solenoid valve	4	Three for flavour and one for yogurt
Diaphragm pump	4	For each solenoid valve
Solid state relay	4	Switching of load by WAGO PFC
WAGO PFC	1	Managing the system
NFC module	1	For reading tags
Raspberry Pi	1	Controlling the signal from NFC
5.5” OLED touchscreen	1	Displaying the function of Raspberry Pi
FTDI-chipped board	1	Supplying the power to the NFC module
Switched-mode power supply	1	The switch power source of the WAGO controller (only 0.5 A)
Switched-mode power supply	1	The switch power source of the diaphragm pump (only 2 A)
Stack light	1	Providing visual status of the system
Control panel	1	Protecting electrical and electronic parts
Air filter regulator	1	Filtering the air laboratory source
Tank	4	Three for flavour and one for yogurt

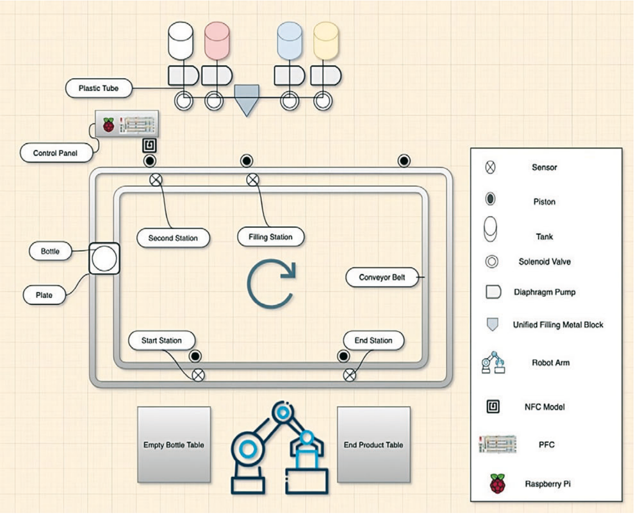


Fig. 4 Model of the current production system

3.2 System modelling and simulation analysis

A 3D factory was simulated by employing commercial simulation software to study the process parameters of the newly designed system. The simulation of the system is composed of two parts that run in two different software programs, one for programming in the GRAFCET Studio and the other for visualizing in 3D in the Factory IO. The GRAFCET tool describes each step sequentially and runs the complete system simulation. The GRAFCET Studio program defines the input and output of each step with unique addresses. This helped develop a 3D virtual factory by integrating all addresses of the GRAFCET software. In GRAFCET, a chart was created to represent the sequential steps of each phase in the yogurt filling system, which facilitated the implementation of each step and the procedure in the other software. Using the GRAFCET Studio, the GRAFCET chart was exported for further testing. Finally, the Factory IO software was used to build a virtual 3D model and show the simulation of the yogurt filling system. The abbreviations used in the layout diagrams for different modules include BFPC (bottle fixture plate cylinder), BFC (bottle feeding cylinder), BSC (bottle scanning cylinder), FSC (filling station cylinder), FSV (filling solenoid valve), and ESC (end station cylinder). The addresses of the sensors and actuators are depicted in Figure 5.

SENSORS

1B1
1B2
2B1
2B2
3B1
3B2
4B1
4B2
5B1
5B2
B
FACTORY I/O (Paused)
FACTORY I/O (Reset)
FACTORY I/O (Running)
FACTORY I/O (Time Scale)
G
M
Machining Center 0 (Opened)
Machining Center 0 (Is Busy)
Machining Center 0 (Progress)
Machining Center 0 (Has Error)
mov
P0
P1
P4
PV1
PV2
PV3
S
Stacker Crane 0 Moving-Z
Stacker Crane 0 Left Limit

Start Button 0	I0.0	Q0.0	BFPC Extended
1B1	I0.1	Q0.1	BFPC Retracted
1B2	I0.2	Q0.2	BFC Extended
2B1	I0.3	Q0.3	BFC Retracted
2B2	I0.4	Q0.4	BSC Extended
3B1	I0.5	Q0.5	BSC Retracted
3B2	I0.6	Q0.6	FSC Extended
4B1	I0.7	Q0.7	FSC Retracted
4B2	I1.0	Q1.0	ESC Extended
5B1	I1.1	Q1.1	ESC Retracted
5B2	I1.2	Q1.2	FSV1
P1	I1.3	Q1.3	Green
PV1	I1.4	Q1.4	Start
PV2	I1.5	Q1.5	Belt
PV3	I1.6	Q1.6	FSV2
P4	I1.7	Q1.7	FSV3
G	I2.0	Q2.0	
B	I2.1	Q2.1	SORTE
M	I2.2	Q2.2	TAPIS
P0	I2.3	Q2.3	UP
S	I2.4	QW256	Stacker Crane 0 Target Position
mov	I2.5	QW258	
	IW100	QW260	
	IW102	QW262	
	IW104	QW264	
	IW106	QW266	
	IW108	QW268	
	IW110	QW270	
	IW112		
	IW114		

ACTUATORS

Belt
Belt Conveyor (2m) 9
Belt Conveyor (2m) 0 (V)
Belt Conveyor (2m) 1 (V)
Belt Conveyor (2m) 5 (V)
Belt Conveyor (4m) 0 (V)
Belt Conveyor (4m) 1 (V)
BFC Extended
BFC Retracted
BFPC Extended
BFPC Retracted
BSC Extended
BSC Retracted
Chain Transfer 0 (-)
Chain Transfer 0 (Left)
Chain Transfer 0 (Right)
Emitter 1 (Emit)
Emitter 2 (Emit)
ESC Extended
ESC Retracted
FACTORY I/O (Camera Position)
FACTORY I/O (Pause)
FACTORY I/O (Reset)
FACTORY I/O (Run)
FSC Extended
FSC Retracted
FSV1
FSV2
FSV3
Green
Machining Center 0 (Stop)

Fig. 5 Addresses of sensors and actuators

3.3 Steps of coding and simulation model of the yogurt filling system

First, all cylinders are retracted by the system once the start signal is activated. In the next step, the BFPC ensures that the system is in position (indicator green set) for all steps, as shown in Figure 6(a). Figure 6(b) shows that the BFC is extended as the plate is detected. Once the bottle is placed on the plate, the BFC retracts first, followed by the BFPC, as seen in Figure 6(b).

(a) (b)

Fig. 6 (a) BFC is extended (b) BFC is retracted

Now, the plate can move to the scanning station of the system. Once the bottle reaches the scanning station, the sensor reads the NFC code and indicates the volume requested by the customer. There are three different volumes, i.e., 300 ml, 600 ml and 900 ml. After the volume is determined, the system detects the flavour selected for mixing with the base yogurt. Therefore, the steps are conditional, i.e., the base yogurt with no flavour, yogurt with mango flavour, yogurt with blueberry flavour and yogurt with both flavours. Step 9 for the base yogurt with mango flavour is shown in Figure 7 as an example. After the volumes of yogurt and the flavour are detected, the piston of the BSC is retracted and the bottle moves to the next station. The process is shown in Figure 7.

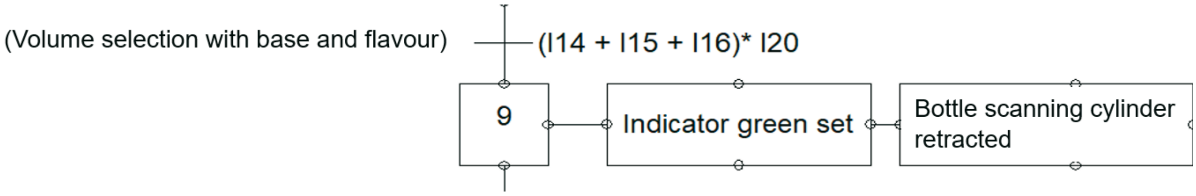
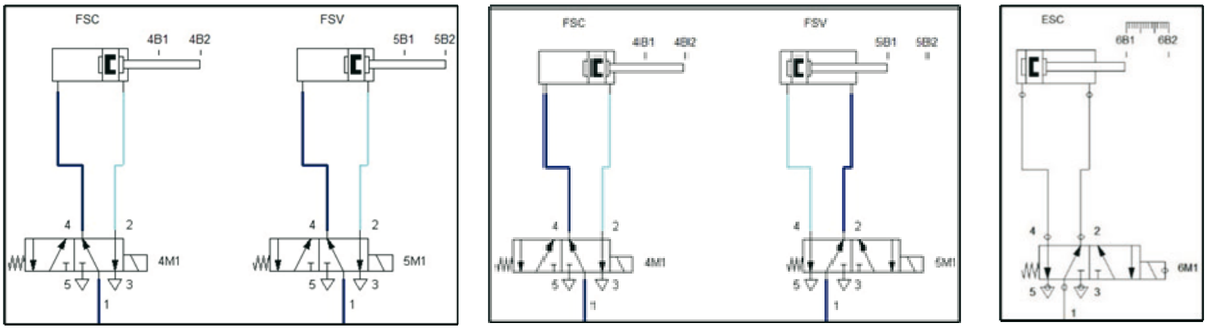


Fig. 7 Selection of flavour and moving the bottle to the next station (base yogurt with mango flavour)

As seen in Figure 8(a), to fill the bottle with a desired volume and flavour, an FSV must be opened when the bottle is at the filling station. During this step, the empty bottle is transported to the filling station and the sensor detects the bottle, extending the FSC. As the bottle is filled, the FSV is closed, as shown in Figure 8(b), while the FSC is extended to ensure that the valve is completely closed and will not leak. After that, the filled bottle moves to the final station, where the FSC retracts.



(a) (b) (c)

Fig. 8 (a) FSC and FSV extend to fill yogurt and flavour (b) FSC is extended and FSV is retracted
(c) ESC is extended

To ensure that the filled bottle leaves the system, the bottle goes to the end station, where the sensor detects the filled bottle, allowing the ESC to be extended. As shown in Figure 8(c), after leaving the robotic arm, the filled bottle moves to the table (temporary storage), and the ESC retracts so that the empty plate can be returned to the first station for the next cycle.

3.4 GRAFCET Studio and Factory IO synchronization

The GRAFCET Studio and Factory IO are synchronized by connecting to the addresses. First, all variables are created and fixed in the GRAFCET Studio; then, Factory IO is selected through the MHJ driver to connect the addresses.

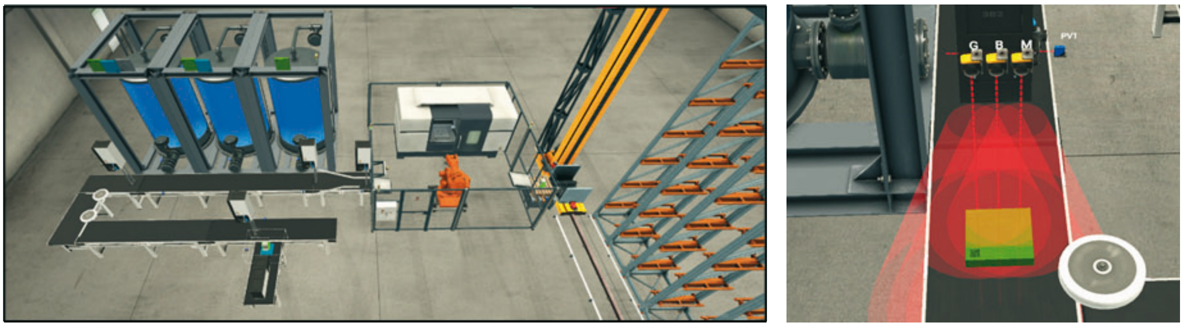


Fig. 9 Steps 6, 10 and 14 in IO Factory

The code was written in the GRAFCET language and comprises 25 steps and transitions. For explanation purposes, only the scan NFC code station is described here, which is used for detecting the type of flavour and the bottle order sequence. Once the bottle reaches the scanning station, the sensor reads the NFC code, as shown in Figure 10. The NFC code indicates the volume ordered by the customer; there are three different volumes, i.e., 300 ml, 600 ml, and 900 ml. As depicted in Figure 10, three types of bottles represent different flavours in the simulation: green, blue, and gray. When the bottle type is detected, the BSC is retracted, allowing the bottle to pass through the filling station. The code for the first filling station to fill the bottle with the base yogurt can be seen in Figure 10, where an FSV opens when the bottle is at the filling station. The bottle arrives at the first filling station, and a sensor detects its presence, then the FSV remains open until the sensor detects the bottle size. Once the bottle is filled, the FSV is closed, and the FSC is retracted to ensure all valves are completely closed and no leakage occurs, as shown in Figure 11. To ensure that the filled bottle leaves the system, the bottle goes to the end station, where a sensor detects the filled bottle (P4), allowing the ESC to retract.

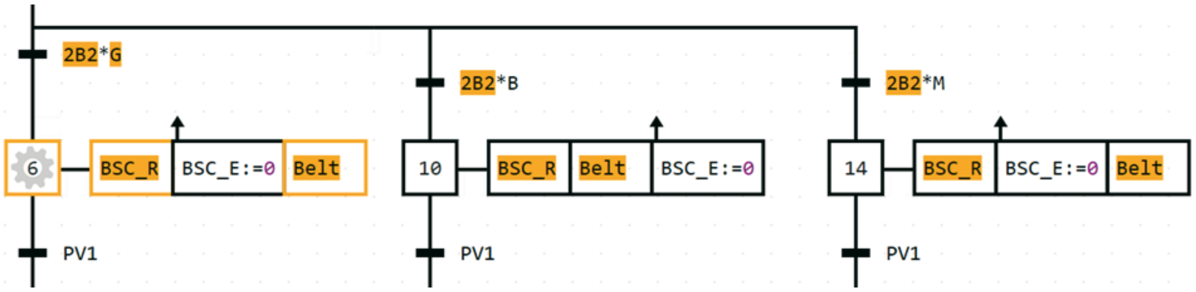


Fig. 10 Steps 6,10 and 14 in GRAFCET Studio (NFC code station)

In the end station, after the sensor detects the filled bottle, the robot places the bottle into the yogurt sealing machine, which subsequently seals the bottle, and the robot places the sealed bottle in the storage station. When there is a bottle in the storage station, the conveyer of the station activates and transports the bottle to the storage machine. The counter of the stock position is updated for a new position.

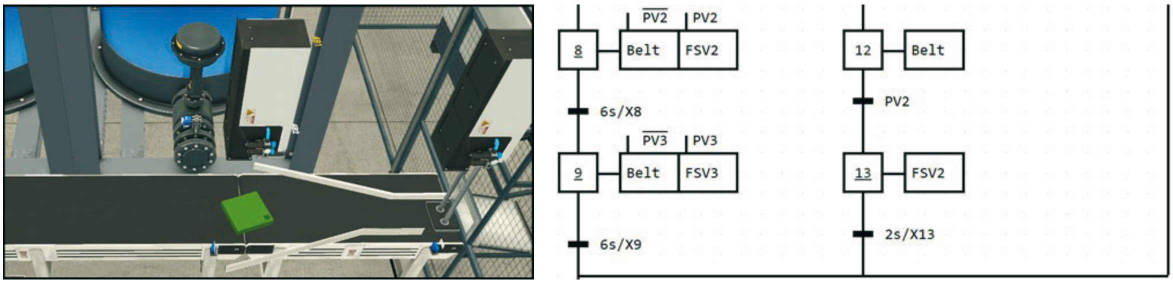


Fig. 11 Steps 8, 9, 12 and 13 in GRAFCET Studio

Steps 21 to 23 are the stock machine movements. Steps 21 and 22 are the UP movements, while step 23 is the movement in open space where the product is placed in a specific position.

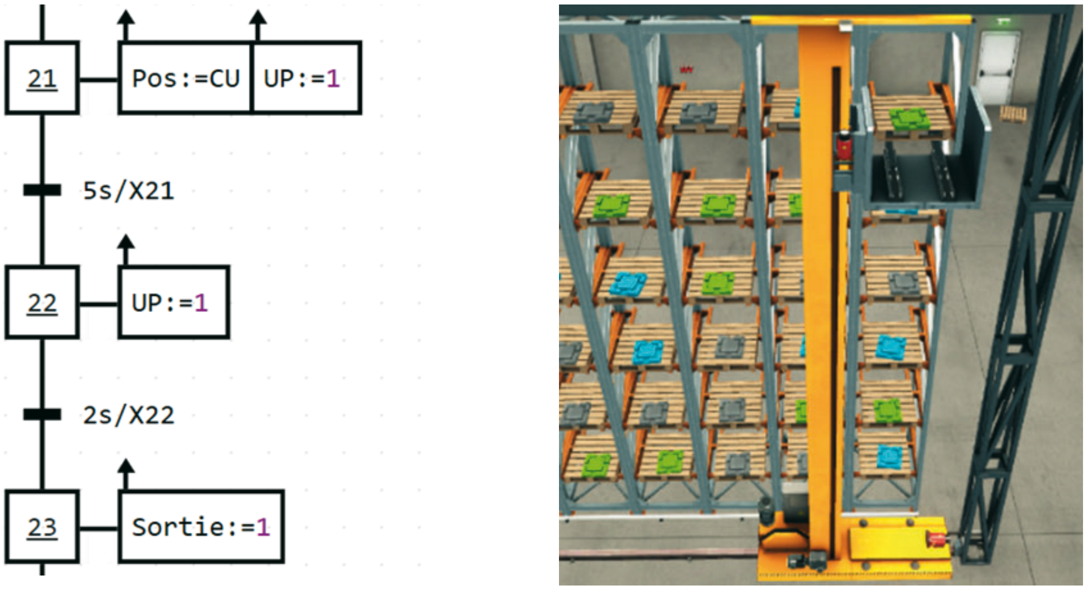


Fig. 12 Steps 21, 22 and 23 in GRAFCET Studio (storage system)

4. Results and discussion

The primary objective of Industry 4.0 is to incorporate mass production and customization. So, the production rate is the key performance indicator in the current customized mass yogurt filling system. As there are three types of bottle sizes (300, 600, and 900 ml), the cycle time and production rate for each size can be calculated based on the following three different conditions.

i. Base yogurt
ii. Base yogurt with one flavour (strawberry)
iii. Base yogurt with two flavours (strawberry and mango)

$$T_c = T_r + Max\, T_0 \qquad (4.1)$$

where,

Tc: Cycle time
Tr: Transfer time
To: Max filling time

Production rate Rc = 60/Tc… (4.2)

Based on the Factory IO simulation processes, transfer and cycle times were observed and all minimum measurements were calculated for the 300 ml size as a case analysis. Furthermore, transfer, sealing and scanning times are the same in all conditions. For instance, in the case of 300 ml, 30 seconds refer to 5 seconds for the scanning station, 20 seconds for the filling station and 5 seconds for the sealing machine. Eq. 1 can be used to calculate Tc, and the bottleneck station was selected as the filling station. It is observed that the cycle time varies when volume changes. The results are presented in Table 2.

Table 2 Production rate of yogurt filling system

Volume (ml)	300	600	900
Transfer time Tr (sec)	30	30	30
Max filling time: Max To (filling station) (sec)	20	40	60
Total cycle time (sec)	50	70	90
Production rate (Pc/hr)	72	51.4	40

The analysis of the simulation shows that the highest production rate of 72 bottles per hour was observed in the case of the bottles of 300 ml filled with base yogurt (no flavour); however, the lowest production rate of 40 bottles per hour was observed in the case of the bottles of 900 ml filled with both flavours when the simulation and software applications were used, i.e. GRAFCET Studio and Factory IO. By integrating IR4.0 enabler technologies such as simulation-based modelling compared to a physical model, potential improvements can be identified before the physical implementation. Another potential improvement is the earliest possible identification of stations affected by a breakdown. This is one of the potential improvements related to maintenance. For instance, using the GRAFCET sequence steps, the maintenance engineer can easily identify where the machine sequence hangs by observing the graphs presented on an available monitor.

As a result, all variables in the GRAFCET network and Factory IO were defined to ensure synchronization between the two programs. A three-dimensional production line model was developed within the Factory IO program to make supervision easier, hence, finished products can be tracked and malfunctions can be noted. Two more machines were added to IO Factory to make the system more comprehensive and integrated. These are sealing machines to seal the bottles and storage machines to store the filled bottles. A set of conditions was implemented to ensure that the yogurt filling system is a custom filling machine. Depending on the requirements of the customer, a variety of flavours as well as different bottle sizes were made available. A clear image of the final 3D simulated factory is shown in Figure 13. As can be seen, the two software programs are synchronized and the system functions correctly.

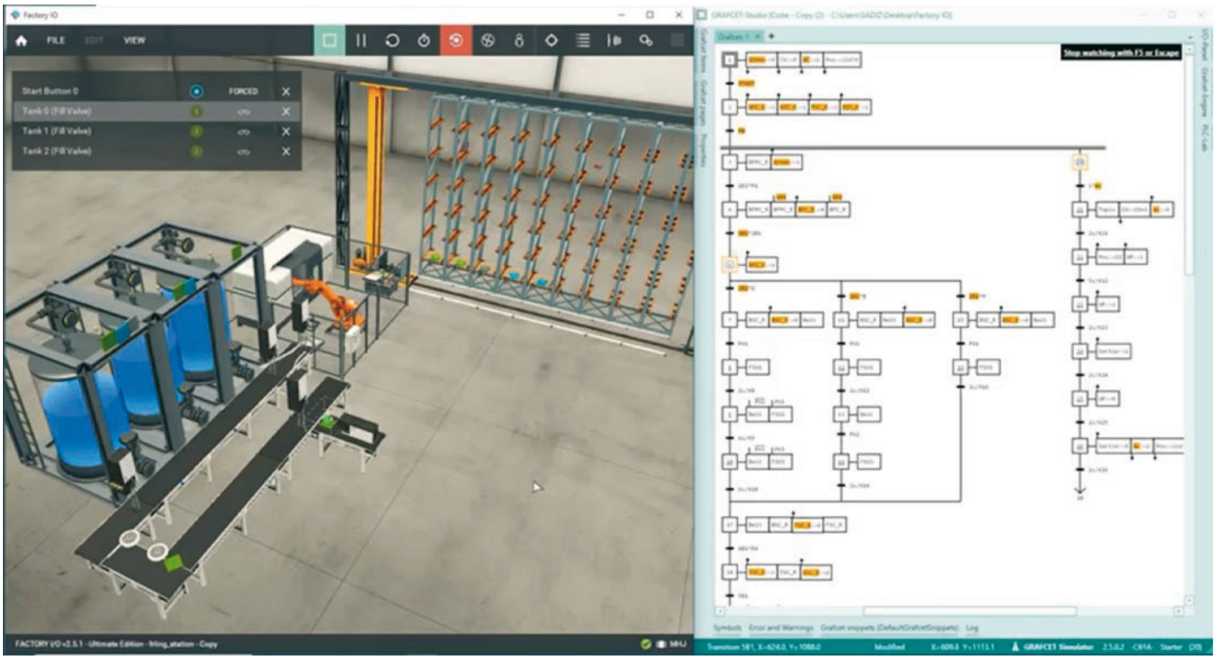


Fig. 13 The final system (synchronization)

In this study, it was decided to experimentally monitor the transfer, scanning and filling time on the physical model. The results are given in Table A-1 for a 300 ml bottle. Data was collected for ten bottles, and the average time for each process was calculated. The physical model was used to simulate the production line to measure the time needed to complete each process. The data was collected to understand how long it took to transfer, scan and fill the bottles of different volumes. This data was then used to calculate the average time for each process for the ten bottles of 300 ml. The simulation results are compared with the experimental results. Table 3 provides average values of the experimental observations. According to the simulation, the average transfer time is 30 seconds, whereas the physical model takes 28.9 seconds. Therefore, the simulation is 96% accurate compared to the physical model. In the case of the filling time, the accuracy is around 90%.

Table 3 Production rate of the yogurt filling system

Reported processing observation	Transfer time Tr (sec)	Filling time (sec)
Observation 1	28	21
Observation 2	27	23
Observation 3	31	24
Observation 4	32	22
Observation 5	30	23
Observation 6	26	21
Observation 7	29	24
Observation 8	28	23
Observation 9	29	21
Observation 10	30	21
Average (sec)	28.9	22.3

5. Conclusion

Internal logistics activities of every manufacturing company, such as ensuring the availability of materials and preparing delivery to customers, have a major influence on the incurred costs and the revenue the company generates [53]. As part of this study, a 3D factory simulation was developed that mimics a current manufacturing system in order to implement the concepts of Industry 4.0. Furthermore, a fully automated yogurt filling system was successfully implemented and a virtual machine was incorporated into the system.

GRAFCET combined with Factory IO was used to compute and simulate possible outcomes of the designed yogurt filling machine. The sequential flowchart was expected to track and anticipate malfunctions. Based on the simulation results, an interactive mode was provided for checking the operation flow step-by-step. Thus, the physical model of the current yogurt filling machine is used as a validation tool for the simulation results of GRAFCET combined with Factory IO.

Synchronizing the two software systems allows for better prediction, identification of system failures and pinpointing their location. Also, through the software's capability of visualizing the plant layout simulation, the performance and configuration of the system can be analysed more easily and rapidly based on customer variations.

According to the experimental results compared with the simulation results, the simulation results are about 90% accurate, demonstrating the effectiveness and accuracy of the digital twin modelling. It also proves the reliability of the simulation results, allowing for more efficient and accurate experimentation. Furthermore, by performing an analysis of the digital twin model, it is possible to modify the machine sequence by adding or removing control steps and predicting the production cycle time, which affects customer delivery times. There are plans to add a diagnostic control model to predict the performance of the yogurt filling system. For instance, the proposed simulation system predicted faults such as decreasing the base yogurt's volume in the storage tanks. In addition, it is necessary to predict the overload of the actuators of the entire system as it may impact the overall operation of the system.

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