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Performance analysis and realization of the design for the use of social areas of ındustrial liquid filling systems

Endüstriyel sıvı dolum sistemlerinin sosyal alanlarda kullanımına yönelik tasarımının gerçekleştirilmesi ve performans analizi

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Performance Analysis and Realization of the Design for the Use of Social Areas of Industrial Liquid Filling Systems

Highlights

- *Adaptation of industrial production facilities to private sector use*
- *End-user and fully automated system integration*
- *Optimization of precision and speed in special (personal) production*
- *Reducing operating costs in social areas*

Graphical Abstract

In the study, a fruit juice filling system that produces fruit juice in the ratio and amount desired by the user using four different juices is proposed. In the system, juice filling, cap cover, marking, and fruit juicing processes are carried out according to certain steps.

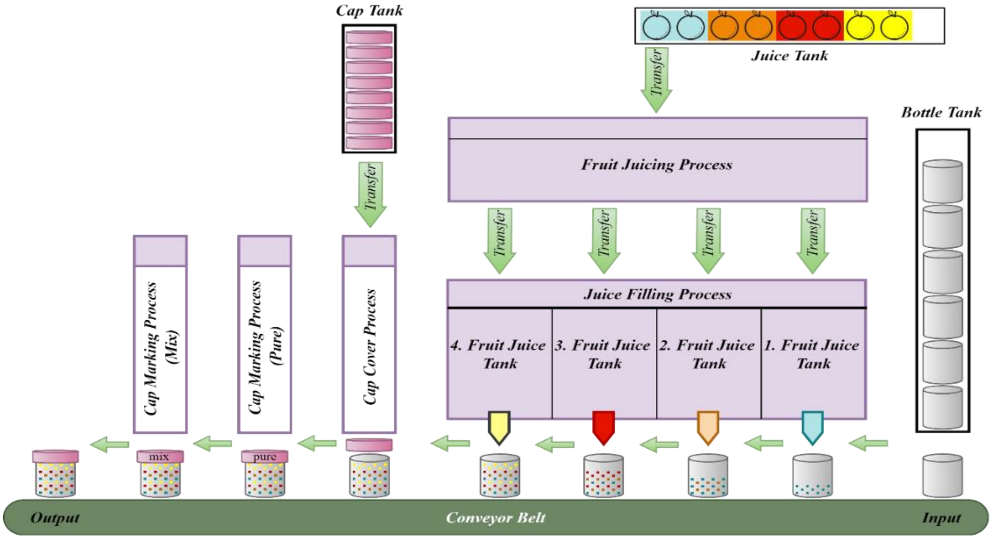

Figure. Structural architecture of juice filling system

Aim

In order to solve the problems that arise in the application of industrial systems to private areas, a special liquid filling system is realized that both meets the needs of people at a high level and includes the features of the production systems used in the industry.

Design & Methodology

In the study, a fruit juice filling system that produces fruit juice in the ratio and amount desired by the user using four different juices is proposed. In the system, juice filling, cap cover, marking, and fruit juicing processes are carried out according to certain steps.

Originality

Mechanical and automation design for the use of industrial liquid filling systems in social areas.

Findings

It is observed that the effect of the cycle time on the unit production time is reduced in the mass production method used in the system, while the cycle time is directly equal to the production time in the private production method. In addition, when the mass production method is used, it is observed that increasing the selection of different fruit juices reduces the production time, as it distributes the filling time to more than one station.

Conclusion

It is thought that when the study done by reducing the need for space with a compact design and increasing the production speed with station-based processes is applied to the private sector, both operating costs are reduced and end-user demands are met to the desired extent.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Performance Analysis and Realization of the Design for the Use of Social Areas of Industrial Liquid Filling Systems

Araştırma Makalesi / Research Article

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ABSTRACT

Today, the insufficient of speed, quality, and precision in the service provided with the increasing density in the enterprises located in social areas, and the fact that standard products are made rather than optional products are observed as a disadvantageous situation in terms of people's demands. Although liquid filling systems used in industrial production facilities include features that are important for production such as speed, quality, and efficiency, they arise problems in social areas in terms of design, size, economy, and personalized production. In solving the problems, it is realized a special liquid filling system that both meets the needs of people to highly and includes the features of the production systems used in the industry. In the study, a fruit juice filling system that produces fruit juice in the ratio and amount desired by the user using four different juices is proposed. It is thought that when the study done by reducing the need for space with a compact design and increasing the production speed with station-based processes is applied to the private sector, both operating costs are reduced, and end-user demands are met to the desired extent. It is observed that the effect of the cycle time on the unit production time is reduced in the mass production method used in the system, while the cycle time is directly equal to the production time in the private production method. In addition, when the mass production method is used, it is observed that increasing the selection of different fruit juices reduces the production time, as it distributes the filling time to more than one station.

Keywords: Liquid filling, machine design, industrial automation, PLC, SCADA.

Endüstriyel Sıvı Dolum Sistemlerinin Sosyal Alanlarda Kullanımına Yönelik Tasarımının Gerçekleştirilmesi ve Performans Analizi

ÖZ

Günümüzde sosyal alanlarda yer alan işletmelerde artan yoğunluk ile verilen hizmette hız, kalite ve hassasiyetin yetersiz olması, isteğe bağlı ürünler yerine standart ürünlerin yapılması kişilerin talepleri açısından dezavantajlı bir durum olarak görülmektedir. Endüstriyel üretim tesislerinde kullanılan sıvı dolum sistemleri hız, kalite, verimlilik gibi üretim için önemli olan özellikleri içermekle birlikte tasarım, boyut, ekonomiklik ve kişiye özel üretim açısından sosyal alanlarda sorunlar ortaya çıkarmaktadır. Problemlerin çözümünde hem insanların ihtiyaçlarını yüksek düzeyde karşılayan hem de endüstride kullanılan üretim sistemlerinin özelliklerini içeren özel bir sıvı dolum sistemi gerçekleştirilmektedir. Çalışmada, dört farklı meyve suyu kullanılarak kullanıcının istediği oran ve miktarda meyve suyu üreten bir meyve suyu dolum sistemi önerilmiştir. Kompakt bir tasarımla alan ihtiyacı azaltılmış ve istasyon bazlı süreçlerle üretim hızı artırılarak yapılan çalışma özel sektöre uygulandığında hem işletme maliyetlerinin düştüğü hem de son kullanıcı taleplerinin istenilen şekilde karşılandığı düşünülmektedir. Sistemde kullanılan seri üretim yönteminde çevrim süresinin birim üretim süresine etkisinin azaldığı, özel üretim yönteminde ise çevrim süresinin üretim süresine doğrudan eşit olduğu görülmektedir. Ayrıca seri üretim yöntemi kullanıldığında, farklı meyve sularının seçiminin arttırılmasının dolum süresini birden fazla istasyona dağıttığı için üretim süresini azalttığı gözlemlenmiştir.

Anahtar Kelimeler: Sıvı dolum, makine tasarımı, endüstriyel otomasyon, PLC, SCADA.

1. INTRODUCTION

It is very important to have high efficiency and product quality in industrial production. Efficiency in production is directly related to the cost of the product produced per unit. Raw materials, equipment and personnel requirements used for production are the main factors the cost of products. Automatic machines and systems are used in sections where manpower is required but not suitable for production [1,2]. One of the main goals is to minimize the manpower need in mass production facilities. To achieve this goal, the transition to fully automatic mechanization in production is accelerated, especially with industry 4.0 [3,4].

Liquid filling systems used in industrial production facilities include features that are important for production such as speed, quality, and efficiency. Industrial liquid filling facilities are frequently encountered in mass production systems such as food, paint, chemical, and pharmaceutical industries. Today, people's spending time in social areas (shopping centers - restaurants – cafes, and bistros – entertainment, and

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playgrounds) reveals their demands for food, beverage, and service in the environment they are in [5]. The insufficient of speed, quality, and precision in the service provided with the increasing density in the enterprises located in social areas, and the fact that standard products are made rather than optional products are observed as a disadvantageous situation in terms of people's demands [6]. In addition, the increase in the number of workers employed with the increasing density and demand in the enterprises and the increase in the costs of the workers employed accordingly is a disadvantageous situation for the enterprise. Although the use of industrial systems in these areas solves problems such as speed, quality, and precision, some problems come along with it.

Since the working structure of liquid filling units used in industry is designed to be suitable for mass production, it limits personalized production. In addition, it does not seem possible for industrial systems to be in social areas in terms of design, size, and economy. Even though the currently operating automat machines eliminate these disadvantages of industrial systems, they meet the standard product needs because they do not produce according to the product features demanded by people [7]. In solving these problems that arise in these areas, it is aimed to develop a special liquid filling system that will both meet the needs of people highly and include the features of the production systems used in the industry.

Shaukat at al. [8] in the study proposed a fully automatic liquid filling system controlled by a programmable logic controller (PLC). It is emphasized that with the study, the production is increased, and the resulting errors are reduced, thus economic gain is achieved. Shankar [9] in the study, it is aimed to transform a manual system used to keep the temperature constant in the boiler into a fully automatic system. PLC is used to control the system, supervisory control and data acquisition (SCADA) is used for monitoring, and level, pressure, and flow sensors are used for data collection. By setting the boiler temperature on the SCADA screen, the economizer and heater are activated, and the temperature is adjusted to the desired level. Das et al. [10] proposed a system for controlling the liquid tank level using PLC and SCADA. Three different sensors are used for the data of the liquid level and a pump is used to adjust the liquid level. It is stated that it is important to use a float sensor to prevent the disruption of the liquid level due to vibration. Dhiman and Kumar [11] in their study, proposed a hybrid method for automatic filling of bottles using PLC and SCADA systems and visualization of processes on the SCADA panel. In this method, some liquids are mixed in desired proportions. With the remote control and monitoring of the application, the system is easily accessible and warns the operator in case of any malfunction. In the study, it is emphasized that the automation system provides low cost, low power consumption, accuracy, and flexibility. They also stated that the processing time is reduced, and the correct liquid volume is provided in liquid filling.

Chakraborty et al. [12] in their study, proposed to perform the filling and cap cover operations in the bottling plant using PLC and SCADA. The empty bottle is transferred to the filling section and then to the cap cover section with the help of a conveyor belt. By using an automatic system, the production time is reduced, and filling and cap cover operations could be performed. By following the production process entirely, a system that is easy to control and flexible is designed. Altinkaya et al. [13] proposed a system for the classification of plastic bottle caps in their study. The importance of automation systems is emphasized by separating the covers according to their size and color with an image processing-based system. PLC and SCADA are used in the control of the system, and a conveyor belt, robotic arm, and camera are used in its application. In addition, it is thought that the developed system could be used in laboratories as educational material. Farrukh et al. [14] in their work collect the level in the liquid tanks by means of sensors and provide control with PLC. The liquids in the tanks are subjected to separation by distillation. The temperature application for the distillation process is carried out by the control of the pump, thermocouple, heater, and solenoid valve with the help of a console panel. It is observed that 90% of methanol is separated by condensation from the mixture content of methanol and water.

Baladhandabany et al. [15] performed a liquid filling process on a conveyor belt in their studies. PLC is used as the controller for filling multiple bottles at the same time and the filling amount is entered by the user. It is stated that the use of an automation system reduces costs, saves time, and creates flexibility and ease of use. Saleh et al. [16] in their study designed a system that automatically fills bottles of different sizes. Thanks to the system controlled by PLC, time savings, power consumption, and operational costs are reduced. A conveyor belt is used for the transfer system, solenoid valve, and sensors are used for liquid flow control. Sreejeth et al. [17] in their studies transformed the liquid mixing systems, which are carried out manually, into the automatic liquid filling and mixing systems using PLC. In this way, human intervention is reduced, production time is decreased, and errors are minimized. There are two tanks for the mixing system, and the bottles are filled by mixing at preferred rates. Gadhe et al. [18] designed an automation system that provides low operating cost, low power consumption, accuracy, and flexibility in their work, as well as saving the operation time and bringing the bottle to the correct liquid volume level. This system is realized as a laboratory prototype of an automatic liquid mixing and bottle filling system with PLC-based control. They emphasized that the proposed system works effectively by preventing unnecessary liquid pour or waste and can also be adapted for use in industrial applications due to its automatic control method.

Kiangala et al. [19] in their studies, proposed the development of issues such as production tracking, reduction of manual control by applying the basic requirements of the concept of industry 4.0. They implemented the study on an industrial system that performs bottling, using SCADA and PLC. Manual adjustment steps of the parameters used for the production time in the bottling process are reduced and system monitoring is provided via the human-machine interface (HMI) panel. It is observed that the production time is decreased by reducing the manual parameters. Win and Nwe [20] in their study, proposed a PLC-based system for bottle filling and cap cover processes. It is stated that with the developed prototype, operational costs, power consumption, and maintenance costs are reduced, and accuracy, precision, and performance are increased. A conveyor belt is used to transfer the bottles and sensors are used to understand the filling amount. Ahmed et al. [21] in their study realized an automatic bottle filling system by using a PLC control system. In the design, a conveyor belt is used for the transfer, a pump and a sensor are used to adjust the liquid level. In the study, it is stated that the use of a liquid filling system in coffee, juice, and other beverage places is appropriate. Abubakar et al. [22] in their studies designed an automatic liquid filling system and used Arduino for control. A conveyor belt for transport, a robotic arm for transfer, and sensors for measurements are used in the system. It is emphasized that the prototype made is suitable for small-scale industries and works successfully.

When the literature is examined, it is seen that the most important functions in liquid filling systems are filling precision and speed. In the study, it is aimed to ensure the use of fruit juice filling systems used in the industry to produce the needs of people in social areas in a short time and to increase the quality and standards of the product produced. It has been thought to keep the sensitivity and quality of the products high, to make mixtures that appeal to people's taste, to mix products according to personal demand (for example, products obtained by squeezing solid fruits and mixing them in certain proportions). The realization of these processes by the fruit juice filling system, which is suitable for use in social areas, produces high accuracy, fast, high quality, and personalized products, which both satisfy people and reduce personnel expenses in operating costs.

2. MATERIAL AND METHODOLOGY

In the study, the mechanical design and the main components used in the mechanical design and the automation software and main components are examined in two parts. Features and design parameters of the elements used in mechanical design, PLC and SCADA systems in automation software, main components used for electronic control are given. The mechanical and software designs are carried out systematically to complement each other.

2.1. Mechanical Design and Main Components of Juice Filling System

The mechanical design of the fruit juice filling system and the components used in the design are applied by examining the industrial systems where the liquid filling is performed. The functionality, compactness, applicability to private sector use and precision of the mechanical design are its advantages over other liquid filling systems. The mechanical design and properties made in the study are examined together with their applications.

2.1.1. System architecture of mechanical design

It is revealed different methods in expressing the systems created with the use of physical products in wide scopes in designs. System architecture, which is one of these methods, is used to determine the integrated design or the working structure of the system. The architectural structure of the general design for the juice filling system is shown in Fig. 1.

2.1.2. Pneumatic elements used in mechanical design

Pneumatic actuators are elements that convert air pressure into mechanical motion. Pneumatic elements are included in the system with connection equipment, and they perform the required movement. Pneumatic elements used in the juice filling system as actuators are given in Table 1.

Pneumatic cylinders are actuators that convert compressed air into linear pushing and pulling motion by controlling it with the help of valves. 32x160 and 32x50 mm double-acting, 40x500 mm rodless cylinders are used in the juice filling system. Pneumatic cylinders are used to make bottle and cap movements in the system. A pneumatic reciprocating valve is used to control the liquid flow during the juice filling. It basically consists of a single-acting cylinder and a brass material valve. Vacuum generators are elements that generate reverse pressure vacuum using pneumatic pressure. Vacuum is obtained by increasing the velocity of the air passing through a certain channel by narrowing the cross-sectional area. In the system, it is used together with pneumatic cylinders to carry out the movement of the bottle and cap by gripping it. Solenoid valves are used to control the pneumatic actuators used in the system. Solenoid valves provide the desired movement by controlling the airflow according to the information received from the control mechanism.

2.1.3. Main processes and features in the juice filling system

It includes many main processes and auxiliary process steps in the juice filling system. Within the juice filling system, there are main processes such as bottle starting, transport, juice filling, cap cover, cap marking, and fruit juicing. There are both mechanical and electronic connections between the processes running to complete the processes. The transport between all the main

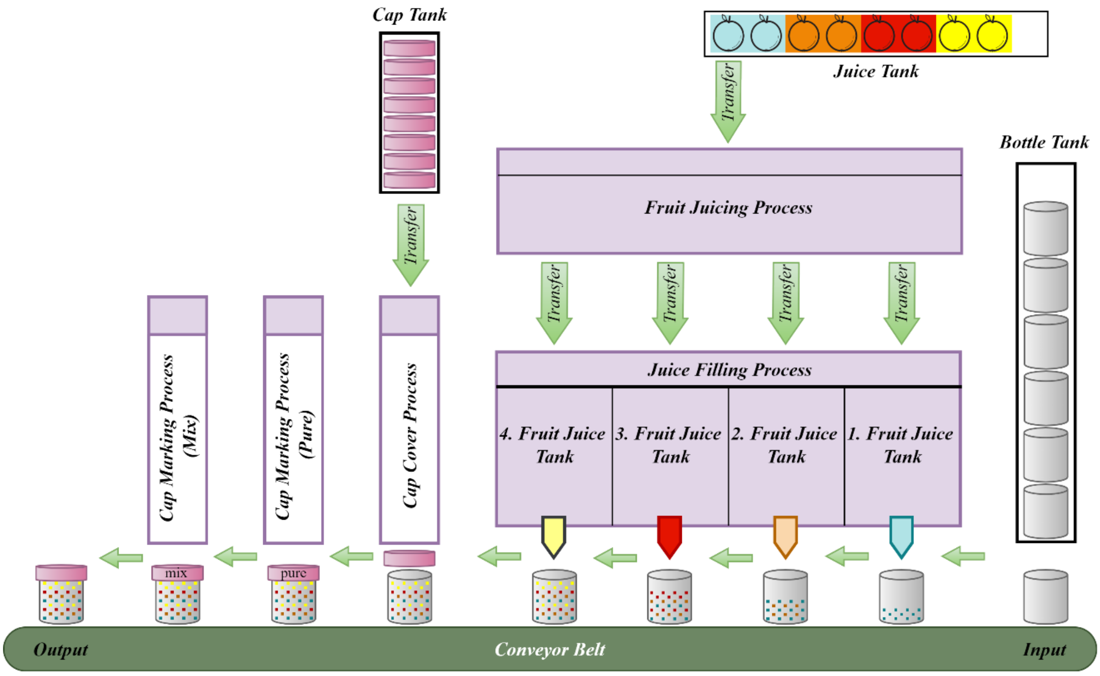


Fig. 1. Structural architecture of juice filling system

Table 1. Pneumatic actuators used in juice filling system

Main Elements (Mechanical)	Features	Number
Pneumatic Cylinder	Ø32 mm Diameter 50-160 mm Stroke	11
Rodless Cylinder	Ø40 mm Diameter 500 mm Stroke	1
Reciprocating Valve	Flow Control 10 mm Stroke	4
Vacuum Generator	63 l/min Flow Rate	5
Solenoid Valve	24 V Trigger - 5/2 Direction Control	21

processes designed is done according to a certain algorithmic flow. For mass production, the transition length between the main processes is kept equal, allowing different processes to work at the same time.

After the mixes to be produced in the juice filling system are determined, the first carried out process is the bottle starting process. In the bottle starting process, bottles from the tank where the bottles are located are pushed onto the conveyor belt. The pushing process is carried out by the pneumatic cylinder whose stroke length is selected according to the design. Optic sensor is also used to control the number of bottles in the bottle tank. Sigma profiles are used to bring the bottles to the height of the conveyor belt and the connections of the sigma profiles to the bottle tank, and the pneumatic cylinder is achieved by means of fasteners. In addition, 10 mm thick plexiglass pieces are also used as interconnect elements.

After completing any of the main processes working in the juice filling system, the transport process is used to move on to the next process. The transport process is done by a step motor driven flat belt conveyor to ensure precision. The drive drum is used to provide the connection between the conveyor belt and the step motor. With the encoder sensor located on the tension drum, the step precision in the rotation of the step motor is provided. The design and components of the bottle starting and transport processes are given in Fig. 2.

When the bottle starting process is completed in the juice filling system, the transport process is carried out. When the transport process carries out, the bottles come to the juice filling process where the juice filling is made. The juice filling process is completed in four steps, and in each step, different juices are filled according to the amount requested by the user. The fruit juice tanks used for fruit juice filling contain about 20 liters of fruit juice and the amount of juice in the tanks is controlled by the pressure sensor. In order to fill the juice, each bottle must be pushed into the filling section. When the pneumatic cylinder conveyor belt stops, it moves forward and pushes the bottle to the weight measurement section which is the filling section. When the bottle comes to this section, the filling process starts with the opening of the reciprocating valve and the loadcell sensor information is checked and the reciprocating valve is closed automatically when the filling is completed. In order to bring the bottle, which has been filled with juice, back to

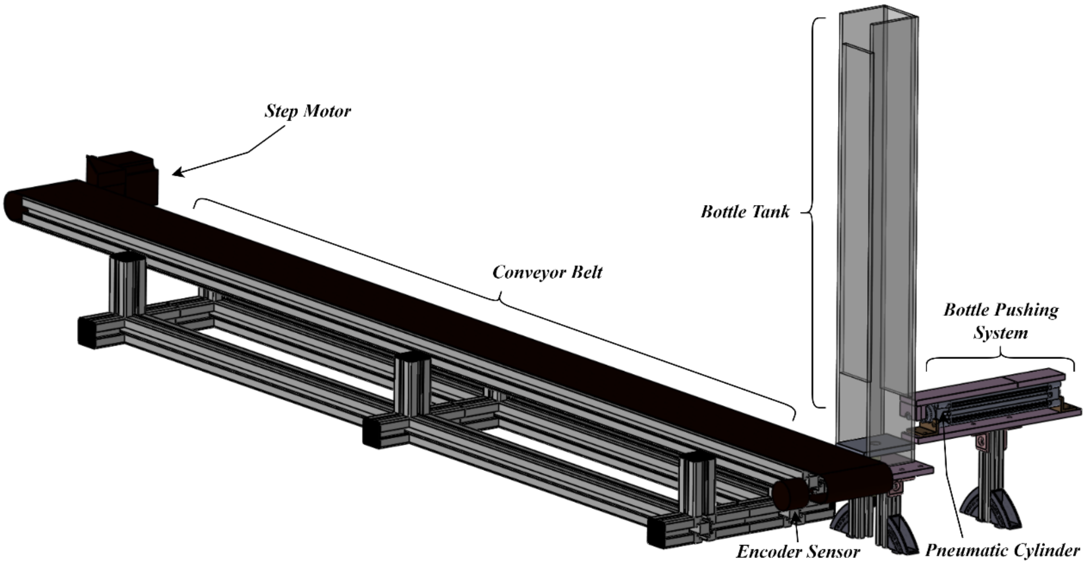


Fig. 2. Design and components of bottle starting and transport processes

the conveyor belt, the vacuuming process is started with the vacuum apparatus at the end of the cylinder and the bottle is brought back. The design and components of the juice filling process are given in Fig. 3.

After the juice filling main process is completed, the section where the caps of the bottles are attached is expressed cap cover process. The filled bottle is brought to the process of cap cover with a conveyor belt. The cap cover process is carried out by taking the cap pushed from the cap tank and closing it on the bottle. The process of pushing the cap from the cap tank to the place where it is transferred is carried out by the pneumatic cylinder. Since the long transfer distance of the cover negatively affects the use of double-acting cylinders in the cap cover process, a rodless cylinder is used for precision and safe transfer. In the process of cap cover, the rodless cylinder moves horizontally between the cap tank and the bottle. A vertically moving pneumatic cylinder was used for cap cover, and a vacuuming apparatus is attached to the end. This pneumatic cylinder, which is mounted on the moving part of the rodless cylinder, is used for taking and covering the cap in the vertical direction. In addition, an optic sensor is used to control the number of caps in the cap tank.

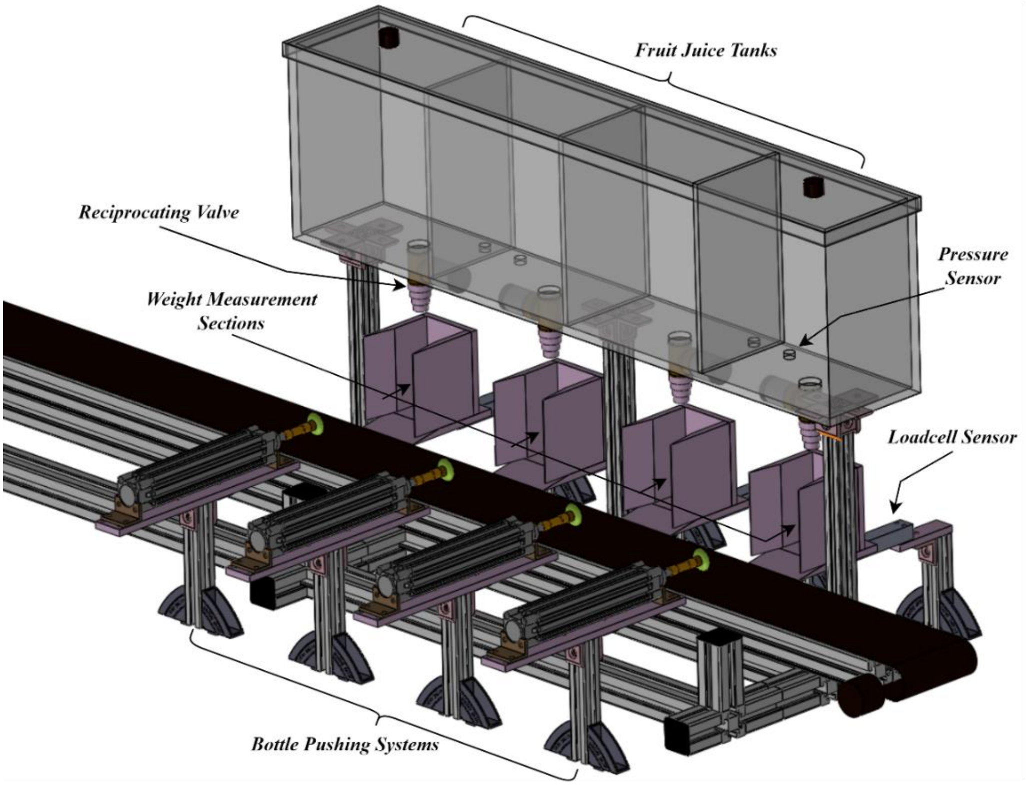


Fig. 3. Design and components of juice filling process

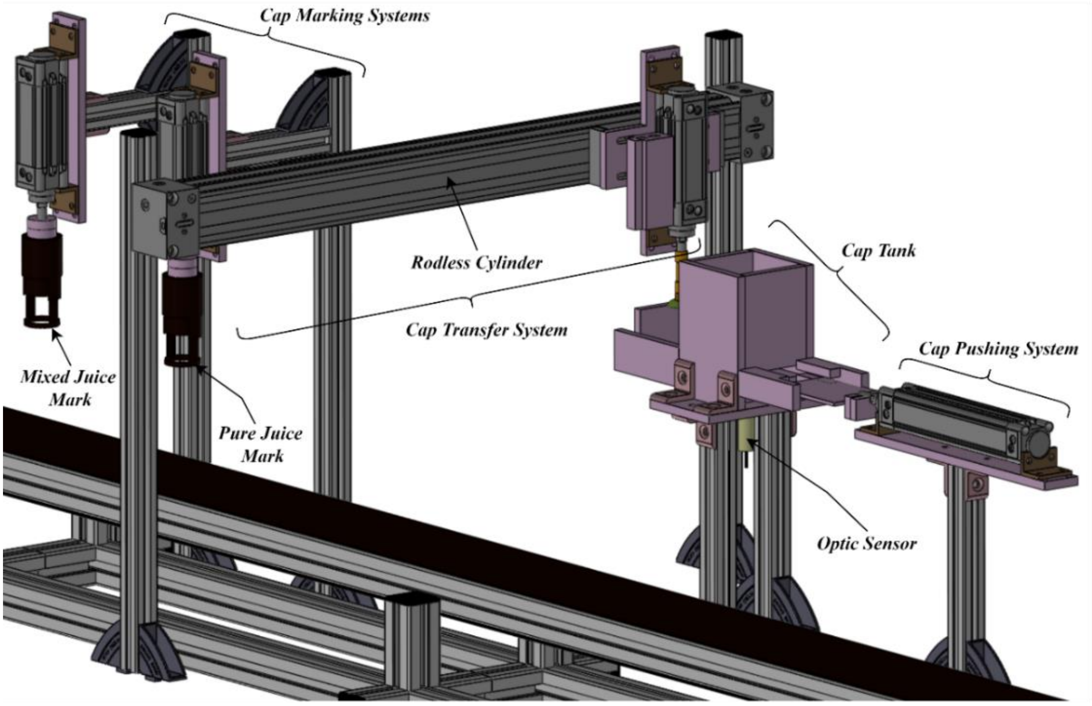


Fig. 4. Design and components of cap cover and cap marking processes

When the cap cover process is completed, the bottle with the cap covered comes to the marking process with the transport process. The marking process is completed in two steps and includes pure or mixed marking according to the product mixture and feature desired by the user in the process. Mark printing is printed to the central area of the cap. Mark printing is carried out by a 32x50 mm pneumatic cylinder with pushing-pull movement. The design and components of the cap cover and cap marking processes are given in Fig. 4.

The fruit juicing process consists of sequential steps and has no relation with the process steps and times of other main processes. When there is a decrease in the fruit juice tanks, the starting signal is sent to the fruit juicing process. The fruit juicing process consists of two main parts: pushing fruit from the fruit tank to the juicing machine and juicing the fruit. The pushing of the fruits to the juicing place is carried out by the pneumatic cylinder, and when the process is completed, the pneumatic cylinder returns to its original position. By pushing the fruit from the fruit tank, the fruit falls into the juicing machine and the juicing process begins. The same processes are repeated until the amount of fruit juice desired is obtained. In order to speed up the juicing process, vertical pressure is created with the help of a pneumatic cylinder with an apparatus attached to the end. The juiced fruit juice is first transferred to a tank and the accumulated fruit juice is transferred to the fruit juice tanks with the juice transfer pump. In addition, an optic sensor is used to control the number of fruits in the fruit tank. The design and components of the fruit juicing process are given in Fig. 5. The study basically includes the functions of the main processes and the auxiliary processes in the main processes. The main processes carry out interdependently and the distance between them is equal. In the mechanical design made in the study, the main processes are fixed on the aluminum plate in precision dimensions. The design has a length of 2350 mm, a width of 1350 mm, and a height of 885 mm. According to the information entered by the user from the HMI control section, the fruit juice filling is carried out and the finished product is taken from the output unit (bottle barrier).

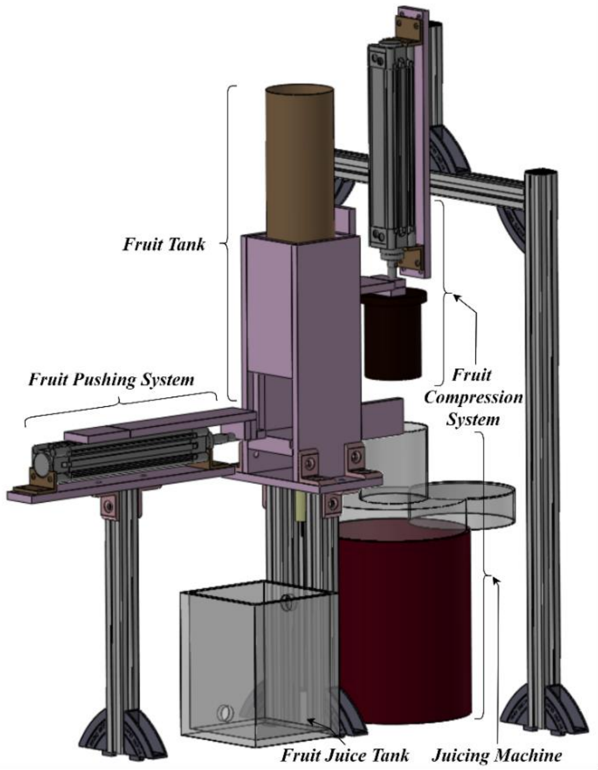
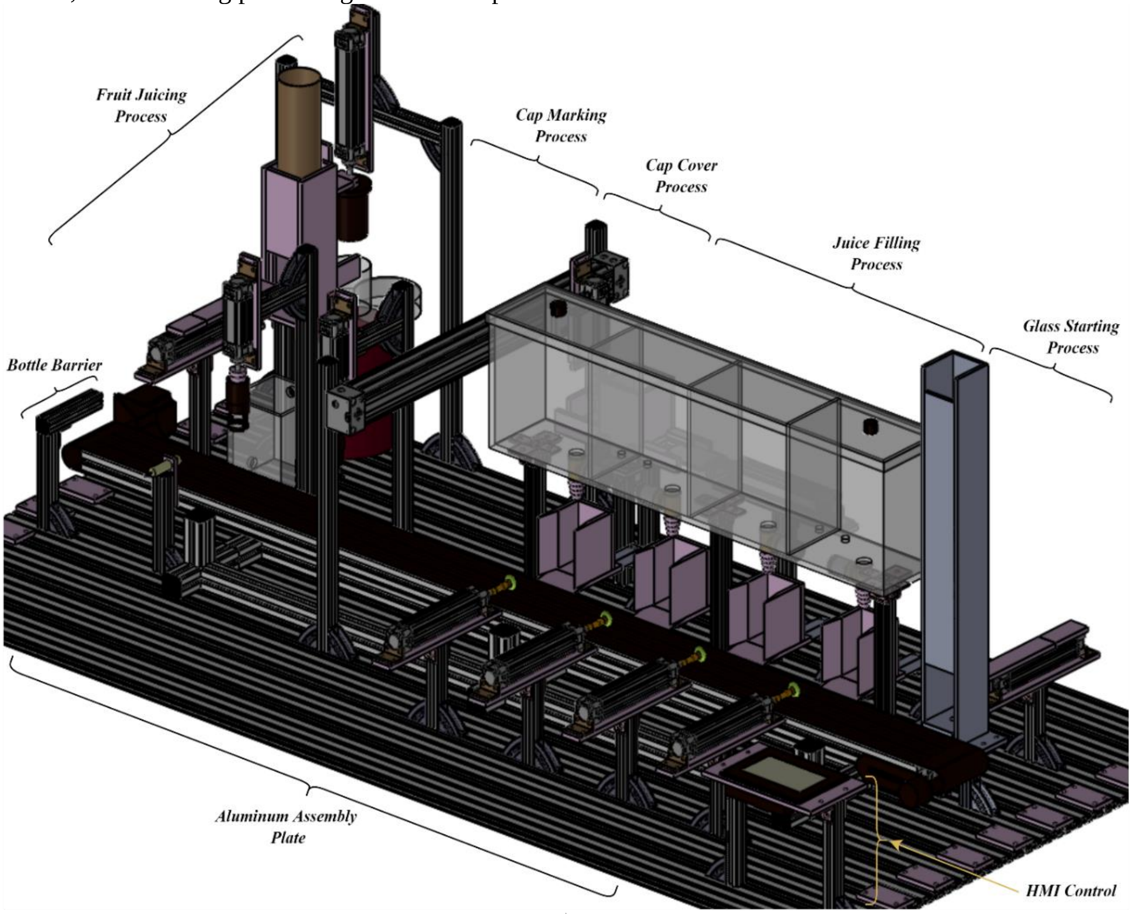
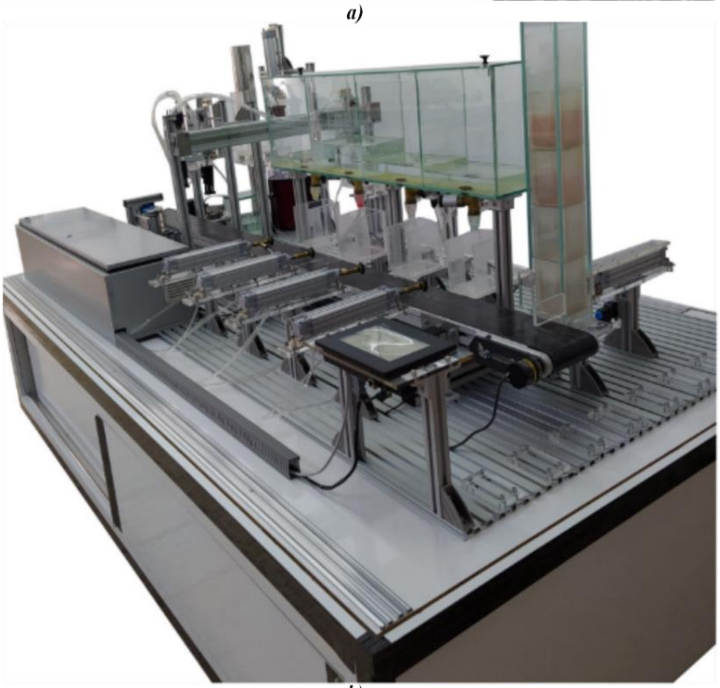


Fig. 5. Design and components of fruit juicing process

The mechanical design and components of the juice filling system are given in Fig. 6 a. The prototype of the juice filling system is created by assembling the main and auxiliary materials, mechanical and electronic components, and mounting parts designed in a computer environment. The assembling of all the materials used in the system is carried out with precision equipment and measures. The prototype design of the juice filling system is given in Fig. 6 b.



a)



b)

Fig. 6. a) Mechanical design and components of the juice filling system **b)** Prototype implementation of the juice filling system

2.2. Automation Software and Main Components of Juice Filling System

Automation software and electronic components are used to carry out the mechanical design of the juice filling system. PLC for the realization of automation software, SCADA systems for data acquisition and control, and stepper motor and sensors for precise operation and evaluation of the application are used. The control software for the PLC and SCADA system is developed.

2.2.1. PLC and SCADA automation software

PLCs contain many input and output modules, and communication between modules is carried out according to certain protocols. PLCs have a microcontroller to process the information, a temporary memory to hold the data used during the process, and permanent memory to hold the general programs in the PLC. In the juice filling system, permanent memory units are used to record the last status of the operation in case of power cuts. The software languages used for programming the PLC have different structures and one of the most used is the ladder diagram [23,24]. The programming of the system is carried out with the ladder diagram method.

The juice filling system includes the method of filling by weight measurement. A load cell (LC) expansion module is used to convert the measurement values with the loadcell sensor used for weight detection. The LC module is designed to detect two sensor data, and four sensor data are transferred into the PLC program by using two LC modules in the system. An analog pressure sensor is used to measure the amount of juice in the tanks during the juice filling process. Since the PLC inputs have the feature of detecting digital signals, the analog data coming from the sensor is detected by the analog-digital converter (ADC) module and converted into a digital signal so that the main PLC can use it. Since there are four juice tanks, four pressure sensors are used and the number of channels of the ADC module is four [25].

SCADA systems are devices that collect data continuously and in real time from various electronic devices such as PLC, loop controllers, distributed control systems, input-output systems, and smart sensors. In the system, SCADA is used to enable the graphical observation and control of the end devices used in production from the central control device. Communication protocols mostly used in SCADA systems are Modbus, transmission control protocol-internet protocol (TCP/IP), Profinet, and distributed network protocol (DNP3). Three main units are used in the design of the SCADA system: master terminal unit (MTU), communication system, and remote terminal unit (RTU) [26,27]. In the SCADA of the system, PLC, HMI, and TCP/IP are used for MTU, RTU, and communication protocol, respectively. The architecture of the SCADA system used in the juice filling system is given in Fig. 7.

In the fruit juice filling system, the necessary information for the production of fruit juice at the rates desired by the

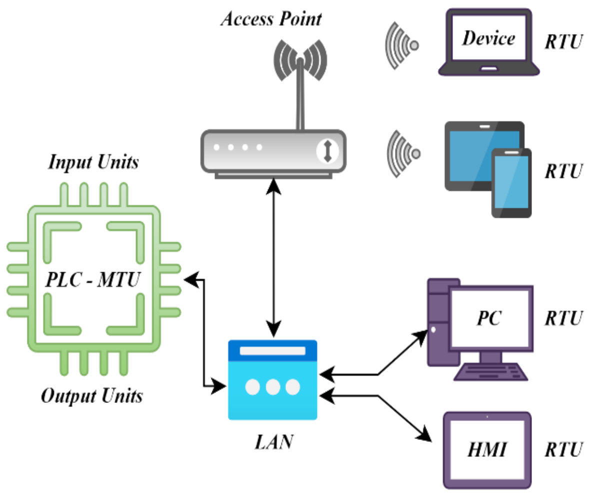


Fig. 7. Architecture of the SCADA system

users are entered through the HMI panel. The HMI panel is designed in a way that all users who need the product can operate and use it [28]. In HMI, there is the start page that the user will encounter for juice production, the page for determining the production method according to the production amount, and the admin page for adding bottle-cap-fruit. In addition, there are pages in the HMI for the selection and control of three types of production methods (see Fig. 8 a): mass production (mixed), mass production (pure), and special production (personal).

For mass production (mixed), it is necessary to select the products, fill quantities, and numbers from the page. The juice filling amount is entered in ml in the section opposite each fruit. In fruit juice filling, the upper limit is determined as 300 ml, which is the maximum filling amount of the bottle, and the lower limit is 50 ml, which is the minimum filling amount with the highest filling precision in the process steps. This process is written as a macro code in the mass production mixed sheet. In order to change the filling quantities entered on the HMI page, new quantities can be entered by pressing the "Weight Change" button. After the necessary data is entered, controls are provided on the page and the main production processes are started by pressing the "Start" button. When all the main processes are completed, the production is completed, and the start page is returned to ensure that the products are received at the output station (see Fig. 8 b). For mass production (pure) product production, fruit selection is made and the amount in ml. is entered. After determining the attribute of the product, the number of products to be produced is entered in the number section and the main production processes are started by pressing the "Start" button. Since there is only one product selection in this production method, the amount of information is taken from the user as a single entry (see Fig. 8 c).

If the amount of product to be produced is one, the "Special Production" button is selected on the production method selection page. With the "Special Production" button selection, personalized production of the juice filling system is provided. Personalized production is carried out to ensure the use of the fruit juice filling system outside the industry. The working structure of the special production method works in an algorithmic structure similar to mass production. In order to make production on the special production page, the selection of the products and the filling quantities must be entered. On the special production page, both mixed and pure production can be made. Unlike mass production pages, since a single product will be produced, there is no number of selection entries. Also, this page design shows the juice amounts in the fruit juice tanks (see Fig. 8 d). Buttons are used to provide controls on the HMI pages and the functions of these are given in Table 2.

2.2.2 Electronic main components used in the juice filling system

In the fruit juice filling system, the transport process is used to transfer the bottles that are completed in the main processes to other main processes. The transport process is carried out with a conveyor belt and a step motor is used in the drive system for precision positioning. It is an electromechanical device that converts the electrical energy applied to the step motor input into rotational movement energy. The most important advantages of step motors compared to other motor types are that they can provide very precise position and speed control. The disadvantage of step motors is that they do not have a feedback mechanism due to open-loop control.

Fig. 8. HMI page designs **a)** production method selection **b)** mass production (mixed) **c)** mass production (pure) **d)** special production (personal) [25]

Table 2. Buttons and functions used in HMI pages

Buttons	Functions	Page Position
Start	initiation the processes	right-left corners
Stop	terminates the processes	middle
Hand	stop processes momentarily	lower left corner
Electricity	power cut information	lower right corner
Back	return to previous page	lower left corner
Start Page	return to first page	upper right corner

Table 3. Electronic components and features of juice filling system

Main Elements (Electronic)	Features	Number
Main Processor(PLC and Modules)	16k Step16 Input - 32 Output ADC - LC - SP	7
HMI	7" - 800x600 Pixel Ethernet - RS232	1
Step Motor	1.4 Nm - 4 A	1
Encoder Sensor	1024 Pulses 100 kHz Response	1
Loadcell Sensor	2 mV/V Output 0 - 6 kg Range 0.1 g Sensitivity	4
Pressure Sensor	4-20 mA Output 0-250 mBar Range 0.5 mBar Sensitivity	4
Optic Sensor	60 cm Sensitivity 24 ms Response	4

The disadvantage of step motors is that they do not have a feedback mechanism due to open-loop control. The absence of a feedback mechanism leads to failure to detect errors such as motor locking, belt breakage, jamming, and step misses. This problem, which emerged in the study, is solved by connecting the encoder sensor to the rotation axis of the conveyor tension drum and creating a feedback mechanism. Encoders are used to calculate the angle, rotational speed, direction of rotation, and length of rotating objects. When step motors are wanted to be operated in the desired position, speed, and direction, signal pulses are applied to the motor windings in a certain order. The control of the step motor is carried out by drivers called electronic switches.

In the PLC, which provides control within the juice filling system, sensors are used to perform the operations that require control, measurement, and adjustment in the programming steps. Sensors are modules, devices, elements, or systems that determine the events or situations in the working environment and transmit the obtained data to electronic devices working as controllers. While the fruit juice is being filled, the control of whether the weight of the bottle reaches the desired level during filling is determined by the loadcell sensor. In the system, an optic sensor is used to control the presence of the bottle in the bottle tank, the cap in the cap tank, the fruit in the fruit tank and to determine the completion of the processes according to the number of bottles coming out of the last station. In addition, pressure transmitters are used to determine the level of fruit juice in the fruit juice tanks and to make the necessary warnings and actions according to the level status. The electronic components used in the juice filling system and their properties are given in Table 3.

2.2.3. Juice filling main process control program

A command is expected from the PLC to carry out the main processes running in the juice filling system. For the PLC to send the run command to the main processes, it must receive an information signal that the previous main process has finished. The flow charts of the main processes working in the fruit juice filling system are designed and the main process of fruit juice filling is examined as an example.

The main process of fruit juice filling is divided into auxiliary processes in the form of stations that can perform four different fillings. In the main process of juice filling, fruit juice filling works in the same algorithmic flow with each other in four stations. When the previous main process is completed and the "Start" signal is received by the PLC, firstly, whether there is sufficient juice in the first tank is checked with a pressure transmitter. As a result of the control of the juice tank, if there is no juice, a warning is given and a "Start" signal is sent to the fruit juicing main process. After the juice in the first tank is completed, the bottle on the conveyor belt is pushed to the first filling station. The desired amount of filling is carried out by opening the reciprocating valve during the filling process into the pushed bottle. The accuracy of the desired amount of filling is made by measuring the loadcell sensor. When the juice is filled, the bottle is brought back to the conveyor belt from the filling station with the vacuuming apparatus attached to the pneumatic cylinder end. When the bottle is on the conveyor belt, the vacuum system is stopped, and the command is sent to the PLC at the first filling station. The existence of four filling stations in the juice filling system required the control structure to be in the form of a loop. The flow chart of the main process of juice filling is given in Fig. 9.

3. RESULTS AND DISCUSSION

The most important feature of industrial liquid filling systems is to reduce the unit product cost by reducing the production time. However, the design in industrial systems is seen as very disadvantageous for private sector use in terms of size and cost. In the study, mechanical and automation software designs are made for the use of fruit juice filling systems used in the industry in social areas to produce the product requested by the user and to increase the quality and standards of the product produced. With its high accuracy, fast, high quality, and personalized product production, the fruit juice filling system will both satisfy the user and become suitable for the private sector in terms of design. In the study, 3 types of production methods are carried out: special production (personal), mass production (mixed), and mass production (pure). With the production methods, 16 different types of mixtures can be created with 4 different fruit juices in total. The fruit juice used, the mixtures obtained according to the production method, cycle times

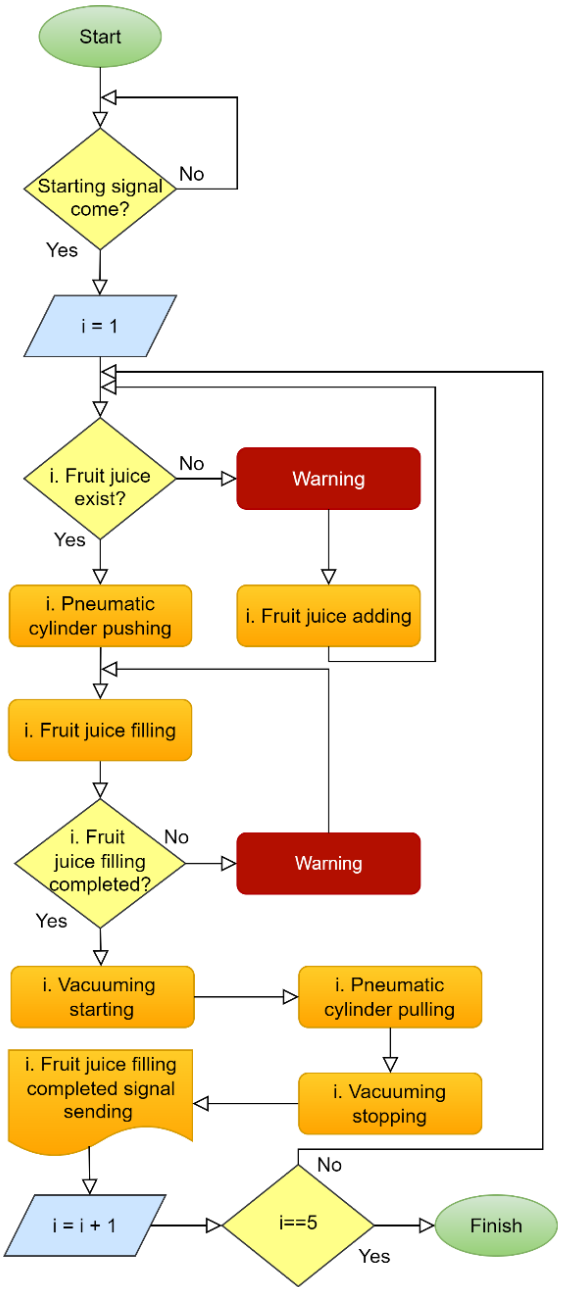


Fig. 9. Flow chart of the juice filling main process

and production times according to filling quantities, unit production times according to production amount are given in Table 4. In addition, the best operating performance of the designed system and the main process-based processing times are as follows:

- The maximum capacity of the bottle used for filling is 300 ml.
- In order to use a fruit juice filling unit, at least 50 ml. amount of fruit juice must be selected.
- Each 50 ml fruit juice filling takes about 1 second.
- Bottle starting and transport processes: 3 seconds.
- Fruit juice filling process: minimum 9, maximum 14 seconds.
- Cap cover process: 10 seconds.
- Cap marking process: 3 seconds.

In Table 4, the filling quantities are calculated over 1/3, 2/3, and 3/3 of the maximum capacity of the bottle. Fruit juice combinations refer to mixtures that can be made with fruit juice varieties. While the cycle time in the table expresses the time taken for the first product production in both special production (personal) and mass production methods, the production time shows the production time of 1 product in the production whose cycle time has been completed. In addition, in the table, the change in the number of productions in the mass production method and the unit production time including the cycle time is given.

When Table 4 is examined, it is seen that the cycle time is the same as the production time, since there is 1 personalized product production in the special production method. In the special production (personal) method, 100 ml. (about 33%) fruit juice filling is carried out in about 50 seconds in one fruit juice selection. If two fruit juice are selected, an additional 8 seconds is added as one more juice filling station running. Similarly, for 200 ml. (about 66%) fruit juice filling, it is measured to be about 52 seconds for fruit juice selection, 60 seconds for two fruit juice selections, and 68 seconds for three fruit juice selections. For 300 ml. (100%) fruit juice filling, it is measured as 54 seconds for one fruit juice selection, 62 seconds for two fruit juice selections, 70 seconds for three fruit juice selections, and 78 seconds for four fruit juice selections.

When Table 4 is examined, it is seen that there is a great difference between the cycle time and the production time in the mass production mixed and pure filling method. Since there is more than one production, the cycle time occurs once during the whole production. In the mass production (mixed) method, it is seen that need a minimum of 13 (cap cover and transport processes) and a maximum of 17 seconds (maximum juice filling and transport process) according to the processing time of the longest process among the main processes. Considering the filling quantities, it has been observed that choosing one fruit juice or two fruit juice in 100 ml. (about 33%) filling does not make a difference in the production time and 13 seconds are required. For 200 ml. (about 66%) filling, 15 seconds are needed for one fruit juice selection, 14 seconds for two fruit juice selections, and 13 seconds for three fruit juice selections. Similarly, in the mixed method of mass production, 17 seconds are needed for 300 ml. (100%) filling, while selecting one fruit juice requires 16 seconds for selecting two fruit juice, 15 seconds for selecting three fruit juice, and 14 seconds for selecting four fruit juice.

When the cycle time, production time, number of productions, and unit production time are analyzed according to the reference production method, filling amount, and fruit juice combination, the following results are obtained:

Table 4. Working times of the fruit juice filling system

Production Method	Filling Amount *(ml.)*	Juice Combination	Cycle Time *(sec.)*	Production Time *(sec.)*	Number of Productions	Unit Production Time *(sec.)*
Special Production (Custom)	100	one fruit juice	50	50	1	50
		two fruit juice mixing	58	58	1	58
	200	one fruit juice	52	52	1	52
		two fruit juice mixing	60	60	1	60
		three fruit juice mixing	68	68	1	68
	300	one fruit juice	54	54	1	54
		two fruit juice mixing	62	62	1	62
		three fruit juice mixing	70	70	1	70
		four fruit juice mixing	78	78	1	78
Mass Production (Mixed)	100	two fruit juice mixing	58	13	2	42
					10	18.80
					30	14.93
					100	13.58
	200	two fruit juice mixing	60	14	2	44
					10	20
					30	16
					100	14.60
		three fruit juice mixing	68	13	2	47
					10	19.80
					30	15.27
					100	13.68
	300	two fruit juice mixing	62	16	2	47
					10	22.20
					30	18.07
					100	16.62
		three fruit juice mixing	70	15	2	50
					10	22
					30	17.33
					100	15.70
		four fruit juice mixing	78	14	2	53
					10	21.80
					30	16.60
					100	14.78
Mass Production (Pure)	100	one fruit juice	50	13	2	38
					10	18
					30	14.67
					100	13.50
	200	one fruit juice	52	15	2	41
					10	20.20
					30	16.73
					100	15.52
	300	one fruit juice	54	17	2	44
					10	22.40
					30	18.80
					100	17.54

- When the fruit juice filling system is operated with a special production (personal) method, it is observed that the processing times of the main processes are directly added to the production time.
- The main process, which has the longest operation among the main processes working in mass production, determines the production time. For this reason, the fact that the production times of the main processes operating in the fruit juice filling system are close to each other shows that the optimum production time emerges.
- Mass production methods provide a large number of productions infrastructures, and it is seen that the effect of cycle time on unit production time is reduced.
- It is seen that in the mass production (mixed) method, the selection of a few numbers of fruit juice in the production with high filling quantities ensures that the selected fruit juice is spent more time at the filling station. Increasing the selection of different kinds of fruit juice when a large amount of filling is required reduces the production time as it distributes the filling time to more than one station.

Production methods and unit production times according to the number of productions are given as a graphical in Fig. 10. As can be seen in the graphic, in mass production (mixed - pure) methods, the unit production time decreases with the increase in the amount of fruit juice production. In the mass production (mixed) method, increasing the amount of fruit juice selected according to the filling amount increases the cycle time, but further reduces the unit production time.

4. CONCLUSION

Mechanization is required to provide features such as reducing product and production costs and decreasing the need for manpower in the private sector. Liquid filling systems used for industrial production include important features such as speed, quality, precision, and product standard. It does not seem possible in terms of design, size, and cost for the production systems used in the industry to be in social areas where people are present. It is aimed to preserve the important features of liquid filling systems used in industrial production and to make them usable in these areas where the end consumer is present. Although the current cold-hot beverage automat machines meet some features, they cannot provide the product that people really demand. In addition, since the machines used in the private sector remain at a simple level and require operators, they cannot fully provide the desired benefit. It is sufficient for production to enter the fruit juice information requested by the end-user into the device with the help of the HMI panel, regardless of any operator. It is thought that when the study done by reducing the need for space with a compact design and increasing the production speed with station-based processes is applied to the private sector, both operating costs are reduced, and end-user demands are met to the desired extent. In addition, since the fruit juice filling system in the study was developed for the use of the private sector, it is thought that it will close the gap in the private sector in meeting the needs of people in areas where industrial production cannot be applied.

In future studies, it will be important to record the information about which products and mixtures people prefer in different social areas with a fruit juice filling system in databases and to make predictions about the fruit juice filling system with artificial intelligence techniques for the future. The outputs obtained with the system developed with learning algorithms will be used by the establishment where the fruit juice filling system is located and will provide many advantages in terms of planning the necessary precautions and steps. It will be easier to evaluate many situations such as reducing the production time of the product, meeting the raw material needs, incoming demands, and price policy. In addition, presenting the mixture recommendations to the users from the information obtained will facilitate the selection process.

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS’ CONTRIBUTIONS

Hakan BUYUKPATPAT: Methodology, software, performed the experiments and analysis of the results, validation, visualization, writing-original draft preparation.

Hilmi Cenk BAYRAKCI: Methodology, analysis of the results, supervision.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] R. Kleinwort et al., “Experimental comparison of different automatically tuned control strategies for active vibration control,” ***CIRP Journal of Manufacturing Science and Technology***, 35;281–297, (2021).

[2] I. Kao and C. Gong, “Robot-based computer-integrated manufacturing as applied in manufacturing automation,” ***Robotics and Computer-Integrated Manufacturing***, 13(2);157–167, (1997).

[3] T. Czvetkó, A. Kummer, T. Ruppert, and J. Abonyi, "Data-driven business process management-based development of Industry 4.0 solutions," ***CIRP Journal of Manufacturing Science and Technology***, 36; 117–132, (2022).

[4] L. Kılıç, "Industry 4.0 and internet of things implementation at Sisecam energy management system," ***Journal of Polytechnic***, Nov. 2019, doi: 10.2339/politeknik.538279.

[5] T. O. Boucher, J. T. Luxhoj, T. Descovich, and N. Litman, "Multicriteria evaluation of automated filling systems: A case study," ***Journal of Manufacturing Systems***, 12(5);357–378, (1993).

[6] J. Pokojski, K. Oleksiński, and J. Pruszyński, "Conceptual and detailed design knowledge management in customized production – Industrial perspective," ***Journal of Computational Design and Engineering***, 6(4); 479–506, (2019).

[7] K. Joshi, S. N. Melkote, M. Anderson, and R. Chaudhari, "Investigation of cycle time behavior in the robotic grinding process," ***CIRP Journal of Manufacturing Science and Technology***, 35, 315–322, (2021).

[8] N. Shaukat, W. Naheed, B. Rawan, and Z. Uddin, "PLC based automatic liquid filling process," ***Institute of Industrial Electronics Engineering***, pp. 39–39, 2005, doi: 10.1109/inmic.2002.1310146.

[9] K. G. Shankar, "Control of boiler operation using PLC - SCADA," ***Lecture Notes in Engineering and Computer Science***, 2169(1), 1281–1286, (2008).

[10] R. Das, S. Dutta, A. Sarkar, and K. Samanta, "Automation of tank level using PLC and establishment of HMI by SCADA," ***IOSR Journal of Electrical and Electronics Engineering***, 7(2), 61–67, (2013).

[11] J. Dhiman and D. Kumar, "Hybrid method for automatically filling of the chemical liquid into bottles using PLC & SCADA," ***International Journal of Engineering Research and General Science***, 2(6); 1000–1007, (2014).

[12] K. Chakraborty, I. Roy, and P. De, "Controlling process of a bottling plant using PLC and SCADA," ***Indonesian Journal of Electrical Engineering and Informatics***, 3(1), 39–44, (2015).

[13] H. Altınkaya, A. Moftah, and A. Mohamed, "Image-based automation system for sorting plastic bottle caps using PLC and SCADA," ***4th International Symposium on Innovative Technologies in Engineering and Science***, 2016, pp. 1467–1477.

[14] M. Farrukh, I. Ahmed Halepoto, B. S. Chowdhry, H. Kazi, and B. Lal, "Design and implementation of PLC based automatic liquid distillation system," ***Indian Journal of Science and Technology***, 10(29); 1–6, (2017).

[15] D. Baladhandabany, S. Gowtham, T. Kowsikkumar, P. Gomathi, and P. Vijayasalini, "PLC based automatic liquid filling system," ***International Journal of Computer Science and Mobile Computing***, 4(3), 684–692, 2015, [Online]. Available: www.ijcsmc.com

[16] A. L. Saleh, L. F. Naeem, and M. J. Mohammed, "PLC based automatic liquid filling system for different sized bottles," ***International Research Journal of Engineering and Technology***, 04(12), 57–61, 2017, [Online]. Available: www.irjet.net

[17] M. Sreejeth and S. Chouhan, "PLC based automated liquid mixing and bottle filling system," ***1st IEEE International Conference on Power Electronics***, Intelligent Control and Energy Systems, 2017, 1–5.

[18] A. Gadhe, P. Bhojane, and K. Kawade, "Chemical mixing for process industry using PLC & SCADA," ***International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering***, 7(4), 1784–1790, (2018).

[19] K. S. Kiangala and Z. Wang, "An Industry 4.0 approach to develop auto parameter configuration of a bottling process in a small to medium scale industry using PLC and SCADA," ***Procedia Manufacturing***, 35, 725–730, (2019).

[20] Z. K. Win and T. T. Nwe, "PLC based automatic bottle filling and capping system," ***International Journal of Trend in Scientific Research and Development***, 3(6), 389–392, 2019, [Online]. Available: https://www.ijtsrd.com/engineering/electrical-engineering/28114/plc-based-automatic-bottle-filling-and-capping-system/zar-kyi-win

[21] M. Liton Ahmed, S. Kundu, and M. Rafiquzzaman, "Automatic bottle filling system using PLC based controller," ***Journal of Advancement in Mechanics***, 4(1);17–24, (2019).

[22] A. N. Abubakar, S. L. Dhar, A. A. Tijjani, and A. M. Abdullahi, "Automated liquid filling system with a robotic arm conveyor for small scale industries," ***Materials Today: Proceedings***, 49, 3270–3273, (2022).

[23] G. Gelen and M. Uzam, "The synthesis and PLC implementation of hybrid modular supervisors for real time control of an experimental manufacturing system," ***Journal of Manufacturing Systems***, 33(4), 535–550, (2014).

[24] M. Fujishima, K. Ohno, S. Nishikawa, K. Nishimura, M. Sakamoto, and K. Kawai, "Study of sensing technologies for machine tools," ***CIRP Journal of Manufacturing Science and Technology***, 14, 71–75, (2016).

[25] H. C. Bayrakci and H. Buyukpatpat, "Liquid filling automation with PLC and SCADA control methots," ***European Journal of Science and Technology***, 27, 283–291, (2021).

[26] Y. Mo, R. Chabukswar, and B. Sinopoli, "Detecting integrity attacks on SCADA systems," ***IEEE Transactions on Control Systems Technology***, 22(4), 1396–1407, (2014).

[27] O. Duymazlar and D. Engin, "Design, application and analysis of an OPC-based SCADA system," ***Journal of Polytechnic***, Mar. 2022, doi: 10.2339/politeknik.1029629.