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DATA ACQUISITION FOR DIGITISATION IN THE PARAFFIN CANDLE PRODUCTION PROCESS

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Abstract. By utilising digital technology, digitisation helps businesses streamline procedures, increase efficiency and cut costs. Moreover, it enables businesses to gather knowledge and make data-driven choices that enhance product quality, customers' satisfaction, and market competitiveness. Data acquisition, which permits the collection and analysis of real-time data from equipment and processes, is a crucial component of the digitalisation of industrial automation. Predictive maintenance may, therefore, be utilised to decrease downtime, enhance quality control, and optimise operations. The paraffin candle production process is being discussed, and its key variables are being identified for the purpose of digitisation. The study proposes data collection and processing methods from a candle production line and uses an IoT-enabled controller to collect and analyse data. The PLC software that reads, processes, and saves data in a SQL database on a remote PC is then built based on these techniques. An MSSQL database is used to store information on process variables, including temperatures, cycle times, and downtimes, for the different candle production stages, including the paraffin preparation tank, extruder, and conveyor for cutting candles. The database acts as a storage location for the gathered information, which can then be utilised to analyse and improve the manufacturing process. Python and the open-source package Streamlit were used to provide a user-friendly interface for operators. The interface allows the user to select historical data for each item of equipment by time and relevant variables, and it shows the filtered data in an understandable graphical style. This allows the operator to evaluate the production process, spot trends, and optimise it. With the use of support and assistance technologies, the data may be used for decision-making in future.

Keywords: digitisation, data acquisition, Python, Streamlit, MSSQL.

Introduction

Digitalisation is the process of incorporating digital technologies into routine tasks and activities. To increase effectiveness, productivity, and communication, it involves using computer-based systems to store, manage, and process information and data.

Business, healthcare, education, entertainment, production, and many more fields are all impacted by digitalisation. With the analysis of data, it helps firms automate manual operations, expedite workflows, and enhance decision-making.

The primary objectives of Industry 4.0 were to use digitalisation to boost automation in the manufacturing sector and enhance or optimise its production processes. However, more objectives were soon defined. They included the requirement for customised Industry 4.0 relevant business models and the investigation of new revenue streams based on process digitisation and related data. All of these were designed to achieve higher business continuity through advanced maintenance and monitoring possibilities, better products through real-time monitoring, IoT-enabled quality improvement, the introduction of robots, better working conditions and sustainability, increased product personalisation and customisation, and improved manufacturing processes. J.Milisavljevic-Sayed and others (2020) analysed the extent to which the strategy has been implemented over the last decade. Most of the first efforts were technologically oriented and targeted at developing architecture models for putting into practice cyber-physical systems for manufacturing. As this revolution gained momentum, it became obvious that additional, previously undeveloped parts would need to be created for it to realise its full potential, i.e., creating a new, digitally literate workforce, making significant expenditures in cybersecurity research and development, and creating new, disruptive business models that capitalise on the disruptive technologies.

According to the authors, companies should develop a comprehensive perspective and plan for Industry 4.0-compliant Production Engineering ecosystems to succeed in the long run rather than rush to adopt discrete point solutions for instant gratification (J.Milisavljevic-Sayed et al., 2020). New market opportunities are being created by globalisation and digitisation, especially for small factories. However, to remain competitive in future industries, logic has to be changed and integrated into strategic decisions. For this purpose, D. Paulus-Rohmer et al. (2016) suggested that an ecosystem model be transferred to the manufacturing industry.

Digitisation provides several options to improve production. The possibilities vary from individual machine condition monitoring to fully autonomously controlled production systems. Yet, investments are normally necessary to capitalise on those opportunities. Businesses frequently need to link equipment, purchase, upgrade, or extend IT systems, or carry out digital twin initiatives across several departments. Such initiatives need integrated system analysis and, consequently, expertise from a wide range of technical and scientific fields. An extra level of economic judgment necessitates further economic knowledge. R. Joppen et al. (2019) proposed a scheme for evaluating investments in digitisation. It offers a systematic review of prospective investment constraints, efforts, and potentials. As a result, the technique allows for evaluating a potential investment within the context of a workshop.

A digital factory is a manufacturing facility that uses advanced digital technologies, such as IoT, AI, cloud computing, and big data analytics, to optimise its production processes and improve efficiency, quality, and flexibility. Choosing the right technology is one of the most important aspects of digitisation. C. Siedler et al. (2019) propose a technology map that groups digitising technologies according to their intended uses and designates the many lifecycle phases in which they may be implemented. Such technologies may cover RFID, Augmented Reality (AR), the Internet of Things, Product-Service Systems 4.0, Optical Character Recognition (OCR), Digital Twins, and Edge Computing.

Many studies have been published that provide research on digitisation trends in manual assembly. The most commonly encountered are predictive maintenance, decision-making, and worker support. Augmented reality, virtual reality, cyber-physical systems, and human-robot cooperation are the specific technologies that are most frequently employed to complete a given task (Vertim et al., 2020).

Studies show how to build manufacturing and auxiliary systems in a plant considering digitisation and a changing market. One of the quickest methods to convert a traditional factory into a contemporary digital one is to use intelligent and autonomous transportation systems (M. Fusko and others, 2019).

Even partial digitisation of the production operation in SMEs (Small and Medium Enterprises) has a positive effect on the progress of the process: running TPM (Total Productive Maintenance) chart indicators helps improve the efficiency of work (Klimecka-Tatar, Ingaldi, 2022).

MTConnect, IoT devices, and open-source software are among the technologies employed to collect production and machine energy data on the factory floor and then transfer that data to a central repository, where data analytics tools generate Key Performance Indicators for display on dashboards (Doyle and Cosgrove, 2019).

The next step towards digitisation is to select the correct data to be acquired. The goals of this data vary. Thus, it is crucial to define what a company hopes to achieve through digitisation, whether it is improving efficiency, streamlining workflows, or reducing costs. This will help to determine what processes and activities need to be digitised and how to measure success. One of the key data points for acquisition could be process time in production (M. Sudhoff et al., 2020).

The basis for gathering input data and determining optimisation methods, and subsequently a fundamental element for resource conservation, is the networking of sensors and actuators. Following data preparation and appropriate process modelling, operator support and assistive technologies are used to make decisions for operators, resulting in less waste and rejections, as well as more effective material use and maintenance. As a result, support systems can help save raw materials, energy, and ecosystem services (Böhner et al., 2018).

Paraffin candle manufacturing is the method of making candles using paraffin wax, a petroleum-based wax extensively used in candle manufacture. The manufacturing process may be divided into steps, which are as follows:

1. Melting the wax: the paraffin wax is melted in a double boiler or wax melter until it reaches the desired temperature and consistency.
2. Adding fragrance and colour: using specialised dyes and perfumes, fragrance and colour may be added to the melted wax.
3. Preparing the wicks: wicks are normally composed of cotton or another natural fibre and are trimmed to the right length before being primed with wax to promote equal burning.
4. Pouring the wax: the molten wax is placed or extruded into candle moulds prepared with wicks.
5. Cooling and finishing: when the wax has set, the candles are taken from their moulds and cut to the appropriate form and size. They can also be polished or sealed to achieve a glossy appearance and(or) even applied by a coloured ornament.

Data acquisition is the process of gathering and storing data on numerous factors such as temperature, pressure, humidity, and other key process variables that impact the quality and consistency of the candles being made in the context of paraffin candle manufacture. The capacity of data gathering to offer real-time information about the manufacturing process is critical to the digitalisation of paraffin candle manufacture. It is feasible to spot deviations and irregularities in the production process as they occur by collecting and analysing data in real time. This allows operators to take corrective action quickly to preserve the quality and uniformity of the candles being made. Several sensors and measuring tools linked to a computer or programmable logic controller can automate the data-collecting process. The obtained data may be saved and examined using special software that can spot patterns and trends in the data. The production process can then be optimised to increase product quality while decreasing waste and expenses.

Because it makes it possible to gather and analyse data that can be used to identify areas for improvement in the manufacturing process, the data acquisition process is essential to the digitalisation of the paraffin candle-making process. Data gathering and analysis on a far greater scale than would be conceivable with manual data-collecting methods are made possible by digitising the production process. The effectiveness and uniformity of the candles produced can be greatly improved, and the maker may also see cost savings.

The study aims to create a data acquisition system for digitising an existing paraffin candle manufacturing process.

The following objectives have been set to achieve this goal:

1. Identify the key variables of the existing paraffin candle manufacturing process that need to be recorded for digitisation.
2. Select appropriate measurement equipment that can accurately capture the identified variables.
3. Develop and test a data acquisition system to collect and store the data from the equipment.
4. Develop a user interface allowing operators to see and evaluate the acquired data meaningfully.

Data acquisition hardware setup and methodology

Different manufacturers have designed the existing equipment for the production of paraffin candles. When employed in the same production line, equipment made by various vendors may have interoperability concerns. This is due to the possibility that the equipment uses several communication protocols or has various incompatible control systems. As a result, there may be ineffective communication between the equipment, resulting in mistakes, inefficiencies, or even equipment failure. Various performance tolerances or equipment characteristics may impact the overall performance of a manufacturing line. Hence, while building and executing a production line, it is crucial to carefully evaluate the compatibility and interoperability of various parts of equipment.

The individual devices in the production line are incompatible, i.e., they do not have a common communication line for exchanging data and a capability for transmitting data to the main control panel or remote computer. In this situation, a unified data acquisition system capable of reading the various process data is needed.

Another problem encountered is that the individual paraffin candle production equipment was not developed based on digitisation trends and technologies. It is not feasible to complete digital tasks without implementing digital technologies in the production line.

Data is gathered and processed for digitisation objectives using digital and analogue signals. To read and process these signals, a Unistream PLC with IoT functionality is selected. USC-P10-T24 controller is equipped with digital and analogue inputs, integrated Ethernet ports, a great variety of communication protocols, a Web server, and an SQL connector. These functionalities have been integrated into the data acquisition process. Fig.1 shows the structure of the created data acquisition system.

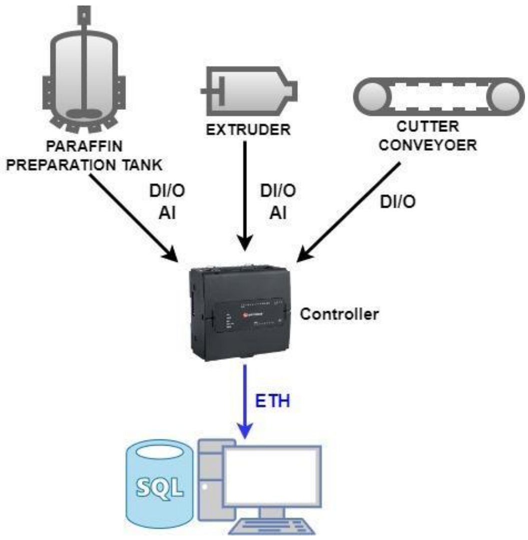

Fig. 1. Structure of data acquisition in the paraffin production line

The purpose of the paraffin preparation tank is to melt the paraffin wax and other elements required to make the candles and maintain the temperature of the mixture during the preparation. It features a local temperature controller that handles the temperature-regulating process. A Modbus interface is available on the temperature controller. The communication between the local and main controllers is established using the integrated Modbus TCP protocol in USC-P10-T24.

The main function of the extruder is to shape the melted paraffin mixture into a continuous, desired shape. The extruder consists of a hydraulic pump and cylinder, three heated zones that melt the paraffin wax mixture, and an outlet at the end of the cylinder that shapes the wax as it is extruded through the outlet. Temperature control is monitored with three different temperature controllers, ATR244-12ABC-T, that include integrated analogue outputs to output process parameters that may be configured using NFC. Analogue inputs on the local controller board are used to read the process temperature on the extruder heating zones. Statuses of the extruder are read using digital inputs, and information is interpreted in the main controller.

The cutting conveyor consists of a candle-cutting device and a conveyor for transporting candles. The status of this equipment is read via digital inputs and evaluated in the main PLC program.

The controller software reads certain process signals from each device at a preset sample rate. The signals are then analysed and categorised. The controller's SQL connection provides access to a database on a remote host computer for data monitoring and analysis. The time-stamped data is thus written to or updated in the relevant data tables.

A web server built inside a controller makes it easier to create a web-based graphical user interface (GUI) that lets users choose the desired process data and determine the sample time for data acquisition. Users may simply access this GUI because it can be accessed using a web browser. In fact, the web server and GUI simplify the data-collecting process by offering consumers an easy-to-use interface to personalise their data-collection settings.

Following the analysis of the performance of the equipment during the manufacturing of paraffin candles, it was decided that several crucial process data parameters needed to be chosen for digitisation purposes. These key parameters comprise:

1. the temperature of the paraffin wax in the preparation tank;
2. the process temperatures of the extruder in its three different heating zones, the power on, hydraulic station running time, extruding, retracting time of hydraulic cylinder, and overall downtime;
3. the cutter manual, auto cycle time, downtime, and the number of cutting cycles.

Figure 2 illustrates the data processing structure.

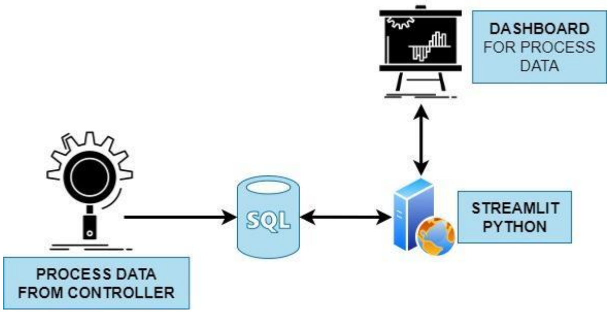

Fig. 2. Structure of data processing

Numerous data management-related tasks are carried out using the Python programming language, including reading data from a SQL database, processing that data, and creating visual representations of the information. Because of its versatility and the availability of numerous libraries and tools that allow data analysis and visualisation, Python is chosen as the language of choice. The data from the SQL database is quickly and efficiently processed using Python's capabilities, and then it is presented in a relevant way utilising graphs and charts.

Data processing for the paraffin candle manufacturing process uses Streamlit, a Python library, to create web-based applications. This open-source library is used to build a user-friendly interface that makes it easier to filter and process data. Using a friendly interface, users may access historical data in graph form and examine updated process data in a dashboard manner. This function is helpful for visualising trends and finding patterns over time, which may assist users in streamlining and enhancing the production process.

Results

Based on the developed algorithm, a PLC program was built. The PLC program is structured in three parts, where each part is responsible for reading and processing process data from the preparation tank, extruder, and cutting conveyor. The obtained data is divided into two categories. The first category consists of historical data, such as the temperature of paraffin or the temperature of the heating zones in an extruder.

The second category is made up of process data that is continually updated, such as the amount of time the extruder or cutter is down. The PLC reads both groups of process parameters using different cycle times. Cycle time is individually set for each separate device and group.

One part of the algorithm is shown in Figure 3. It starts with checking if the user selects acquisition mode for updating cutter downtime (cycle time, etc.). If the mode is chosen, the program looks for a sampling time to read process data. If the user forgets to set this parameter, the program uses the default value. Reading cutter inputs and evaluation of downtime, cycle time, and other time factors take place. The PLC then attempts to establish communication with the SQL database. If the connection is successful, an update of the process data takes place.

Using Python and the open-source Streamlit library, a web-based user interface is created. It enables using a date and time selector to read the process data of individual equipment in the paraffin candle manufacturing line. It reads the SQL database tables of appropriate equipment based on the user's selected software.

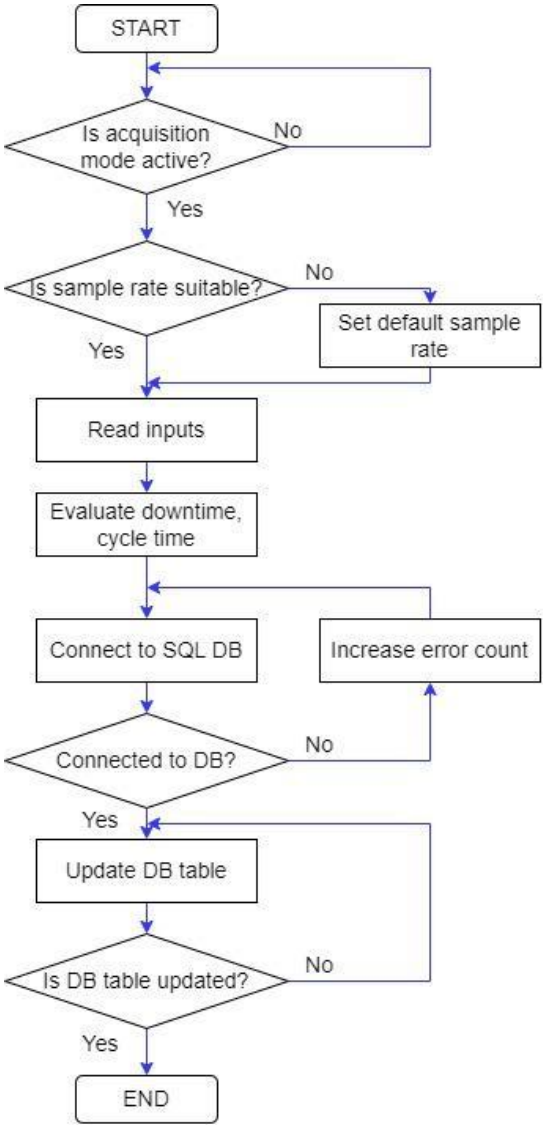

Fig. 3. Algorithm of operation of the PLC for processing and updating cutter process data in the SQL data table

Finally, the data are processed and displayed in graphical form. The displayed data is divided into historical and instant data.

Figure 4 depicts the user interface for candle-cutting process figures that have been filtered.

On the dashboard, there are several data fields which include information such as power on, autorun time, number of cycles, and the last cycle time. Additionally, there is a ratio graph that shows the most up-to-date process information.

The graphical and numerical data are refreshed after each equipment cycle. This makes it simple for the operator to acquire details on the length of the cutter's automatic cycle and the overall production time.

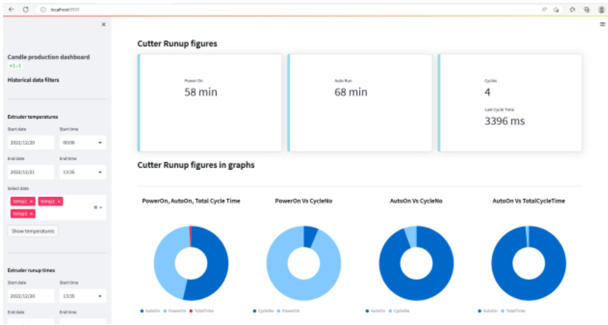

Fig. 4. Web-based GUI for filtering and visualising data

By displaying these indicators, the operator may rapidly see problems and make appropriate modifications to improve production performance.

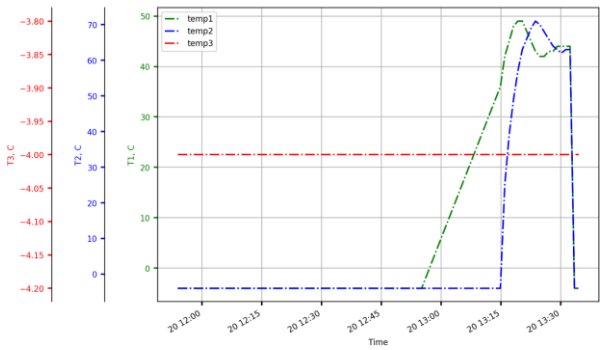

Fig. 5. Temperature of heating zones in the extruder

Figure 5 depicts the temperature data of the extruder after being filtered, demonstrating the heating process occurring in two distinct zones. The third zone exhibits consistently negative values and indicates a temperature controller malfunction.

Conclusions

1. After analysis of the paraffin candle production process, the key variables essential for digitisation were identified. The parameters to consider include the temperature of the paraffin wax in the preparation tank, the temperatures of the extruder in its three different heating zones, the power on, hydraulic station running time, extruding, retracting time of the hydraulic cylinder, overall downtime, the cutter manual, auto cycle time, downtime, and the number of cutting cycles. Tests on the production line demonstrated that the chosen parameters properly represent how the manufacturing process functions and can be used to analyse and improve it.
2. Considering the analysis of paraffin production, the line equipment IOT-based PLC was selected as the main hardware for reading and processing process data accurately from the process. With

analogue and digital inputs and various communication protocols, the SQL connector controller was found suitable for writing data to a SQL database. The test results have demonstrated that the selected hardware satisfies the criteria for data collection and transmission.
3. Using the programming language of the USC-P10-T24 PLC, an algorithm was developed for collecting data from the paraffin preparation tank, extruder, and cutting conveyor and storing it in an MSSQL database. Tests with the production line showed the functionality of the developed algorithms.
4. Finally, using Python and the Streamlit library, a user interface was developed, which presents the acquired data in a meaningful and accessible way for the operators to evaluate. The user interface is easy to use and understand, allowing operators to make informed decisions and optimise the manufacturing process. The data were gathered for 5 working days to test the system. They were analysed and provided to production engineers in graphical form using the designed user interface. The engineers found areas for productivity improvement by evaluating the offered graphical information.

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DUOMENŲ RINKIMAS PARAFINO ŽVAKIŲ GAMYBOS SKAITMENINIMUI

Santrauka

Naudojant technologijas, skaitmeninimas padeda įmonėms supaprastinti procedūras, padidinti efektyvumą ir sumažinti išlaidas. Be to, skaitmeninimas leidžia įmonėms kaupti žinias ir priimti duomenimis pagrįstus sprendimus, kurie gerina produktų kokybę, klientų pasitenkinimą ir konkurencingumą rinkoje. Duomenų rinkimas, leidžiantis rinkti ir analizuoti įrangos ir procesų duomenis realiuoju laiku, yra labai svarbi pramonės automatizavimo skaitmeninimo sudedamoji dalis. Prognozuojamoji techninė priežiūra gali būti naudojama siekiant sumažinti prastovas, pagerinti kokybės kontrolę ir optimizuoti operacijas. Straipsnyje aptariamas parafininių žvakių gamybos procesas ir nustatomi pagrindiniai jo kintamieji skaitmeninimo tikslais. Tyrimas siūlo žvakių gamybos linijos duomenų rinkimo ir apdorojimo metodus. Duomenų rinkimui ir analizei naudojamas IoT valdiklis. Remiantis pasiūlytais metodais, lokaliam valdikliui sukuriama programinė įranga, kuri nuskaito, apdoroja ir išsaugo duomenis SQL duomenų bazėje nutolusiame kompiuteryje. MSSQL duomenų bazėje saugoma informacija apie proceso kintamuosius, įskaitant temperatūrą, ciklų trukmę ir prastovas skirtinguose žvakių gamybos etapuose, įskaitant parafino paruošimo rezervuarą, ekstruderį ir žvakių pjaustymo konvejerį. Siekiant sukurti operatoriams patogią vartotojo sąsają, naudota Python programavimo kalba ir atvirojo kodo biblioteka Streamlit. Vartotojo sąsaja leidžia naudotojui filtruoti kiekvieno gamybos linijos įrenginio istorinius duomenis pagal laiką ir pasirinktus kintamuosius, o išfiltruoti duomenys pateikiami suprantamu grafiniu pavidalu. Tai suteikia operatoriui galimybę įvertinti gamybos procesą, pastebėti tendencijas ir jį optimizuoti.

Reikšminiai žodžiai: skaitmeninimas, duomenų surinkimas, Python, Streamlit, MSSQL.

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