Digital Twins: An Emerging Tool for Food Process and Product Design

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The continuous automation of conventional manufacturing and industrial procedures utilizing cutting-edge smart technologies is known as the Fourth Industrial Revolution, or Industry 4.0. Knowledge management, big data analysis, cyber-security, cyber-physical systems, robotics, computer vision, human-computer interface, and simulation are some of the components that make up the technology. Faster algorithms, more computing power, and a wealth of available data enable the modeling of real-time control and optimization of goods and production lines, thanks to the Industry 4.0 vision and the growth of big data analytics. One of the key components of the fourth industrial revolution is the digital twin (DT), or digital representation of the physical model. It is anticipated to make it possible to predict future system performance accurately and to effectively maintain process quality by facilitating simple visualization and the integration of cognitive capabilities into the actual system (Bottani *et al*., 2020).

A digital twin of a certain product is defined as a virtual representation of its real-world counterpart, which contains all essential elements, such as all geometrical components and material properties; simulates accurately and realistically all relevant processes and their kinetics throughout the product's life-cycle; and is connected to the real-world product and processes by sensor data, which is preferably continuously updated in real-time (Shrivastava *et al*., 2021). The digital twins can be classified either as a digital model, digital shadow or digital twin.

Elements of digital twin

Digital twins are there in various engineering fields and in health sector also. In order to successfully adopt the technology for food processing operations, the following elements are required.

Sensor

Sensors allow communication over wireless network, allowing to capture data, activation, programming and operation. The sensors selected are normally cheap, simple and wireless ones that exploit different parts of electromagnetic spectrum such as Nuclear magnetic resonance and other spectroscopic imaging techniques for measuring temperature, humidity, gases, light,stress, flow rate and pressure.

1) Big data

Data from the sensors are integrated and combined with data from enterprise and are communicated to digital world through integration technologies. Statistical data analysis tools including statistical process control (SPC), multivariate statistics (MVS), data mining (DM), machine learning (ML) and deep learning (DL) are used for analysis of big data and will be provided by operators including Amazon, Microsoft, IBM, GE and SAS.

Physics based model

They rely on CAD geometries of the product, material property data and initial and final boundary conditions. They require an appropriate mathematical formulation of the relevant underlying biological processes that affect quality attributes, such as biochemical reactions involved in the respiration metabolism. Physics-based models do not suffer from statistical uncertainty or biological variability in the data. Discrete event simulation (DES) is a popular tool for modelling multi product batch plants and include ProModel from ProModel Corporation, Arena and Witness from Rockwell Automation, and Simio from Simio LLC. Mathematical optimization tools include SAP APO from SAP AG (Walldorf, Germany), IBM ILOG Plant PowerOps from IBM Corporation (Armonk, NY, USA), Aspen Plant Scheduler from Aspen Technology (Burlington, MA, USA) etc…

Actuators

Should an action be warranted in the real world, the digital twin produces the action by way of actuators, subject to human intervention, which trigger the physical process.

Creating a digital twin

The creation of digital twin and getting started with a digital twin can be best understood in terms of 6 steps as follows:

1) **Create:** This step encompasses outfitting the physical process with sensor that measure critical inputs from the process and surroundings. The sensor can measure either the (a) operational parameters such as tensile strength, displacement, strength and color uniformity or (b) environmental data affecting the performance including temperature, pressure and humidity level.
2) **Communicate:** This step help in real time seamless bi-directional connectivity between the physical system and digital platform. Network communication comprises of three primary components:
   - Edge processing: The edge interface process signals and data from sensor and pass it along the digital platform.
   - Communication interface: This helps in transferring information from sensor function to integration function.
   - Edge security: New data communication techniques have developed data security issues also. The common security approaches are to use firewalls, encryptions, application keys and device certificates.
3) **Aggregate:** This step supports ingestion of data to suitable data repository.
4) **Analyze:** The data is analyzed and visualized in advanced analytic platforms.
5) **Insight:** In this step, insights from analytic step are presented through dashboards, highlighting the difference in operation between physical system and digital part and thereby indicating areas that need immediate investigation and change.
6) **Act:** In this step, actionable insights from the previous step is fed back to physical system thereby creating an impact of digital twin in physical system.

Digital twins in Product and Process Design

Digital twin to develop pasteurization system for beverages

Digital twin models are used to replicate pasteurization process of food beverages. Bottani *et al*., 2020 developed a digital twin for a pasteurization system of food beverages. The pilot plant consisted of a pulsed electric field for sterilization, a preheating system of tube in tube heat exchanger and an electric steam generator. The digital twin system consists of a simulation tool developed under LABVIEW, cloud server system to communicate with HMI (human machine interface) and user device and an anomaly prediction tool. Each variation in the controlled parameter correspond to analogous variation in system. Anomaly prediction tool analyses status of line in real time and adjust parameter thereby acting on real system by feedback control mechanism.

Digital twin to identify trade-off between drying time

The digital twins can monitor trade-off between drying time and quality during drying process. Praviranto *et al*., 2021 proposed a model that was able to predict drying time thereby preventing over drying or under drying, provide information on drying state of product and having all elements to capture relevant heat and mass transfer kinetics and quality degradation. The study was conducted in four different variations where the basic configuration was a simple solar dryer consisting of collector, glass cover, air channel, absorber plate and insulator. The second configuration incorporated a storage bed made of sand, third configuration had a dehumidifier unit and the fourth unit had an air heater to heat up the incoming air. The digital twin model first needed to be fed with weather data in order to assess variation in drying time and final quality of product. The information on dehydration state of product helps the operator to decide when to stop drying. Simulations are performed using finite element method in COSMOL Multiphysics version.

Digital twins to assess performance of e-gastronomic things

Karadeniz *et al*., 2019 proposed a digital twin model for an ice-cream machine. Gastronomy includes the process of cooking, serving, presenting and preparing food and the digital cloning of gastronomic things comes under e-gastronomy. The physical entity consisted of sensors to measure temperature, hardness, hopper condition and operation of valves.

The digital twin model was able to be accessed by the end users and technicians via virtual reality and augmented reality respectively. Virtual manual enables training to end users and technical staff to fix problems. Virtual reality explains step by step for end user indicating current status of physical pair in digital world. Augmented reality is for technicians thereby presenting instant data.

Digital twins in oil extraction perspective

Andrade *et al*., 2020 developed a digital twin model for essential oil extraction plant. The physical is a steam distillation unit. The distiller is of 10kg capacity. Before starting the process, bottom portion of distiller is filled with water. Electrical heating element is immersed in the water. Level switch make sure the amount of water. The water turns to steam and passthrough distiller. Temperature sensors are provided in the top, middle and bottom parts of distiller to prevent channelling. Flow indicator near condenser measure essential oil and hydrosol reaching the condenser. The essential oil tube is monitored by image processing done by Raspberry pi model and camera module v2. Algorithm prepared in OpenCV in python. The algorithm explains color detection and finding contours. The digital twin model is created in MATLAB which increases yield. Mathematical model is created in Simulink in MATLAB. The digital model is a hybrid model comprising of a physical model and a data driven model. The physical model is based on Fick's law for mass diffusion and Darcy's law for flow through porous media. Color of the oil, raw material present in distiller and information on undesirable change in process dynamics are given by digital twin.

Conclusion

Digital twins can combine the advancements in science together thereby providing an efficient way to monitor various operations and processes that are taking place in a food industry. For the success of a digital twin technology, food process modeler, specialists in sensor technology, ICT, programming, optimization, statistics and artificial intelligence need to work together. The success of implementing digital twin workflow with respect to ease of use and reliability, will determine whether digital twins will survive for food processing operations. The optimization capabilities, the possibility of saving resources, the production control and the data analysis are some of the reasons the digital twins must be more discussed, creating better solutions for the food industries.

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