Digital Twin of eGastronomic Things: A Case Study for Ice Cream Machines

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Abstract— **With the recent advancements in industry 4.0 new concepts like "Digital Twin" has been rising also for the gastronomy sector. Gastronomic processes like cooking, serving, presenting, and preparing food have evolved with the new trends utilizing Internet of Things (IoT), Augmented Reality (AR) and Virtual Reality (VR). This paper presents an innovative concept of digital cloning of gastronomic devices, named as eGastronomic things, to monitor their functions and simulate their operations. Here, eGastronomic things have both real physical appearances and their digital counterparts presenting them as a living 3D model augmented with its real incorporating data. Such live data can be any sensory or instant data observed while the device is working, or any catalogue data, like the model name and the owner information, stored in a database. In order to prove the concept, a case study where the digital twin of an industrial ice cream machine (as an example of an eGastronomic thing) is presented. The ice cream machine and its 3D digital twin can be visualized in a 3D virtual environment which enables interaction through AR or VR. The digital twin of the machine is secured with an electronic IoT gateway embedded in the machine and incorporated with a data acquisition board. Thus, the device is protected against unauthenticated use by realizing a secure access control mechanism.**

Keywords—digital twin, eGastronomic things, augmented reality, virtual reality, 3D interaction, Internet of Things, security

I. Introduction

A digital twin/clone is described as a pair of the physical and virtual representation of a digitally-represented asset. Digital twin enables the analysis of data and monitoring of even complex systems for the problems either before they even occur or happen actually; prevent time, money or quality losses; and forecast or even plan for their future use by simulating the diversified factors and use case scenarios. Digital twin is rather a new concept that refers to a digital counterpart of physical assets (known as the physical twin), processes, people, places, systems and devices which can be replicated digitally. This new concept has been used in very advanced areas where digital twins of cars, factories, hospitals, planes, ships and even people like patients or celebrities are presented.

Digital twins consume any historical data to model the behaviors of a physical "thing", and apply accurate measurement and observation of its current status to identify any fault during its operation or even predict its future. A digital twin provides a better knowledge of both the current context and the prediction of the future state of a physical pair. Such an approach can be used to effectively monitor, simulate, and control an asset or process, and optimize lifecycles whether it is online or offline.

This paper adapts the Digital Twin notion to gastronomy sector where any digital food device or kitchen appliance is accepted as an eGastronomic thing. Assuming that kitchens are transforming into smart kitchens, including industrial kitchens for mass production, devices like ovens, refrigerators, cookers, tea or coffee machines, food robots and other electronic kitchen appliances can be accepted as eGastronomic things. Note that in new generation smart kitchens, such eGastronomic things are becoming connected and remotely controlled in a distributed network. Thus, such things communicate with each other, requiring a secure and effective monitoring of their operations.

As these devices are getting more complex, Digital Twin concept has another usage which enables virtual manuals to train end users or technical staff to fix problems. As it facilitates interaction with AR or VR, end users can examine the 3D models enriched with its status data, how-to-do inscriptions or even error codes in a digital environment.

In line with this novel concept, digital twin of an industrial ice cream machine (eGastronomic thing in this case) is presented. Here, 3D model of the "thing" is visualized both in a VR and AR environment. VR is proposed for training of end users where a step-by-step guide is presented for personal use or monitoring the current status of the physical pair in a digital world. AR, on the other hand, is proposed for technical personnel aiming to inform them by presenting the instant status data. By enabling AR, the technicians can see how to maintain the ice cream machine in an interactive way. Instant status data is composed of sensory data measuring the power, voltage and current, temperature of the milk and powder tank, amount of ice cream ready for service or already served, etc. Such data can be visualized from anywhere connected to the cloud; one can monitor the statistical analysis of ice cream consumption and the device performance; observe faults and give alerts for the technical staff; and even update firmware remotely.

The main objective of this paper is to introduce a real case study where the digital twin concept is applied for industrial food technologies. Aligned with this objective, the paper is organized in a way that the upcoming three sections present the state-of-the-art, description of the proposed solution, and the concluding remarks, respectively. Note that the presented proof of concept can be applied to any food-related digital device and can be extended to wider and heterogeneous distributed environments.

II. State of the Art

As the Industry 4.0 is taking place in our lives, the demand for digital twin technology rises in order to develop Cyber-Physical Systems (CPS) applications for vertical and horizontal lifecycle integration [1]. This concept gathers information technologies like cloud computing, IoT, big data, mobile internet, Artificial Intelligence (AI) etc. to play role in achieving the interconnection and interoperability between physical and virtual (information) world of manufacturing with capability of intelligent operations [2].

The authors in [3] emphasize the research gaps in product lifecycle management despite the amount of various big data collected by the physical systems. The mentioned gaps are: (i) The focus on physical products rather than virtual models, (ii) Lack of convergence between physical and

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virtual space, (iii) The difficulty of keeping control to a product at customer's location and response to a demand or failure during Product Lifecycle Management (PLM).

In [4], the authors underlines the importance of digital twin for building complex, and time- and safety-critical systems where dozens of sensor data are acquired. Furthermore, the simulation of an *as-built* system, which is integrated with sensor data, provides presentation of defects and suspicious occurrences, remote assistance, action predictions etc. which can be time- and budget effectiveness to apply directly in the physical system. The digital twin paradigm is being applied in areas starting from the simplest physical systems like bicycles [3] to the most complex systems like aerospace vehicles or engines [4].

In another paper [5], the decision-making support of digital twins in asset management and PLM is discussed. Here, IoT integration allows collecting and exchanging data through network of devices which is then followed by implementing Big Data analytics and smart analytic tools to provide fast decision-making support.

On the other hand, AI and Machine Learning (ML) technologies also play a critical role in decision-making support [6], where virtual assistants are trained with historical or real-time data (acquired by IoT-enabled end nodes) and user interactions in purpose of predicting actions and giving suggestions. In addition, the proposed idea of *Virtual Friends Forever* (VFF), mentioned in [6], presents a virtual assistant that understands the user, applies the orders or commands and also suggests the optimized actions according to the observed situation.

On the gastronomy side, authors in [7] and [8] discuss the importance of automation and robotic applications in food industry. Another old study [9] reviews the benefits of statistical process control in food production. Furthermore, in [10] the virtualization of IoT-aided food supply chains is presented and the authors introduce the system as "*potential self-adaptive system in which smart objects operate, decide and learn autonomously*".

Finally, Virtual Reality (VR) and Augmented Reality (AR) technologies help end users visualizing the aforementioned concepts. As defined in [11], VR aims at substituting the perception of the world with its artificial counterpart, whereas AR is used for enriching a person's perception of the surrounding environment [12]. Thus, AR provides an interaction with the physical objects via IoT integration and receives additional context-aware information about it [13]. The authors in [14] and [15] cover a wide perspective of applying VR and AR technologies into CPSs, which in our case is the industrial ice-cream machine. Moreover, the authors in [11] and [16] emphasize the importance of training technicians to acquire new maintenance and assembly skills for a related IoT-aided product. In [16], the authors present a concept of multimodal AR-based training of maintenance and assembly skills which in our novel concept is presented as VR for step-by-step guidance for personal use and AR for interactive maintenance of the IoT-aided industrial ice-cream machine.

III. The Proposed Digital Twin Application

The focused digital twin application is based on distributed use of industrial ice cream machines whose main electromechanical components are presented in Figure 1. As seen in Figure 1, a typical ice cream machine is composed of a cylinder, hopper, radiator, compressor, agitator and agitator motor, pump and pumping motor, inverter, fan and fan motor, heating/cooling valves of hopper and cylinder and various sensors observing the hopper and cylinder temperature and the proximity of end users (optic sensor).

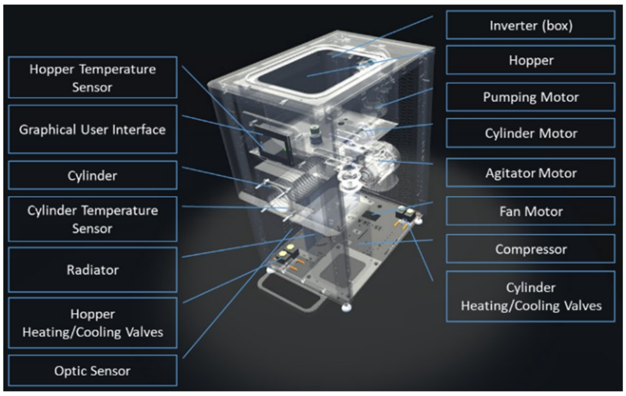

Figure 1. Main components of the ice cream machine visualized on its digital twin

Besides its electromechanical components the ice cream machine has also electronic components. As depicted in Figure 2, the presented digital twin exploits a hardware-based security layer which is embedded in the machine. Here, the mainboard of the ice cream machine is an embedded control card which gathers sensory or instant data (i.e. from the electromechanical components), makes necessary calculations and sends them to secure gateway by serial communication (RS-485 and RS-232) via the MODBUS protocol. Secure gateway is the second critical electronic card which takes data from the main board, also acting like an acquisition board, opens a secure connection with cloud, encrypts and finally sends the gathered data to cloud through a chosen interface. Here, each machine supports the foremost interfaces like Ethernet, Wi-Fi, SMS, GPRS, 3G, LTE and LoRa (through a communication layer) to communicate with other nodes using the Message Queuing Telemetry Transport (MQTT) protocol. This communication protocol distributes the data given in Table 1 over cloud.

Table 1. Critical sensor and components aligned with the proposed digital twin concept

Sensor/Component	Range
Cylinder Temperature	-100 to +650 °C
Hopper Temperature	-100 to +650 °C
Hardness	0 - 1000 (scale)
Cylinder Head	True/False
Hopper Cover	True/False
Hopper Full	True/False
Hopper Empty	True/False
Optic Sensor	True/False
Cylinder Cooling Valve	True/False
Cylinder Heating Valve	True/False
Hopper Cooling Valve	True/False
Hopper Heating Valve	True/False
Pump Motor	True/False
Agitator Motor	True/False
Fan Motor	True/False
Compressor	True/False
Cylinder Motor	True/False
Error Codes	NA

Each ice cream machine, assumed as an eGastronomic thing, is installed by considering its connection with other nodes through a distributed environment. Here, the communication layer enables secure IoT communication with a cloud that makes such eGastronomic things connect to a control center. By enabling security, ice cream machines are protected against malicious use which may cause very serious problems for human health (i.e. poisoning the content or the use of expired ingredients) or loss of money through fake reporting of consumed ingredients.

As depicted in Figure 2, the overall system has other crucial components enabling not only distributed communication but also interaction and visualization technologies like AR and VR, collection and filtering of data by applying a Database Management System (DBMS) and mobile accessibility by using PCs, tablets or smart phones.

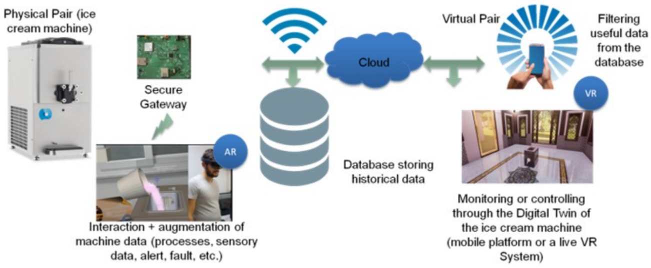

Figure 2. General Overview of the Proposed Solution

The proposed cloud infrastructure is responsible from storing data that come from secure gateways (MQTT) to DBMS. Since there might be thousands of ice cream machines installed worldwide, batch processing jobs like MapReduce or bootstrap, prediction algorithms, and other big data services are encountered. Here, one can use traditional DBMSs like MySQL, SQL Server, Oracle or PostgreSQL for relatively small distributed digital twin networks. However, when big data problems are taken into account, tools like Hadoop, MongoDB, Kafka or Virtuoso can be utilized. In this study a typical MongoDB-based DBMS is applied for the purpose of proof of concept.

A. *Visualization and Interaction*

On the other hand, AR and VR technologies play a crucial role in both visualizations of and interaction with the digital twin of an ice cream machine. VR is benefited in this study to facilitate the user interaction and used as a virtual assistant for the technical staff. By realizing the VR, 3D models of an ice cream machine are presented with either active smart glasses (like Oculus Rift or HTC Vive) or passive devices operating with smart phones (like Samsung Gear VR or Google CardBoard). Figure 3 presents the VR environment where the 3D model of the machine is displayed by using Oculus Rift. In this 3D environment a virtual assistant helps the technical staff by introducing the main components of the device which are depicted in Figure 1.

Figure 3. Visualization of and interaction with the digital twin of an ice cream machine by using active VR glasses

VR is also used for end users who are willing to prepare ice cream. In such a case, a low-cost VR application, realized by using passive VR glass branded as Samsung GearVR, is preferred as a virtual recipe (as appears in Figure 4). This recipe shows and utters the usage steps of the device resulting with the service of ice cream.

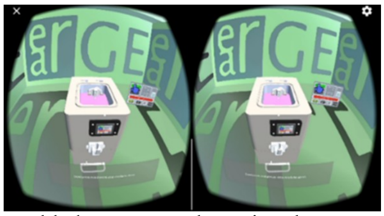

Figure 4. VR-enabled user manual uttering the preparation steps of strawberry ice cream (Samsung GearVR)

VR is not the sole way of visualization or interaction in digital twin applications. AR is also useful as this technology provides an augmented use of the device where one can see the physical pair and regarding information in the same screen. As presented in Figure 5, the digital twin of the ice-cream machine is augmented virtually on its physical pair. Here, not only the 3D digital twin but also ice cream preparation steps and instantly observed machine data are augmented. The snapshots are taken from one of the most popular AR glasses which is known as Microsoft's Hololens. By using AR, either technicians or ice cream makers can be oriented over the digital twin which is visually linked with its physical counterpart.

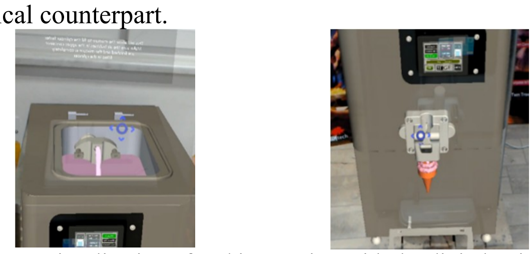

Figure 5. Visualization of and interaction with the digital twin of an ice cream machine by using active AR glasses

In VR studies Unity and Unreal Engine are used as game engines. Since it presents very professional visual quality, Unreal is used for VR with active smart glasses (Figure 3). Unity, on the hand is used for both AR and VR as it provides relatively low visual quality which is more efficient than Unreal, especially when smart phones or tablets are preferred (Figure 4). Since it has Hololens support, Unity is used for the AR application presented in Figure 5. Additionally, Solidworks is used to design the 3D model of the ice cream machine. Then, the 3D models of both ice cream machine and the physical environment are simplified and improved by 3dsMAX. 3D model of the machine is used as a marker in AR and Scale-Invariant Feature Transform (SIFT) features are used for tracking the physical model during AR interaction.

B. *Security*

Security is a crucial factor in the presented digital twin application. In order to provide secure data transmission between the virtual and physical pairs a secure gateway is developed. As depicted in Figure 6, secure gateway receives the data from the ice cream machine by RS485 protocol and the transceiver converts this data to UART on the gateway. The received data is then sent to micro-controller unit (MCU) in which a crypto-module is implemented. The crypto-module has symmetric and asymmetric cryptographic components as well as a hashing submodule. This module is the core for securing the transmitted data. Once secured the data is published to the cloud via an MQTT channel. Here, GPRS, Bluetooth and Wi-Fi are the wireless communication interfaces and the Ethernet is used for wired communication. Secure gateway enables the duplex secure communication providing bilateral data transmission between physical and virtual pairs.

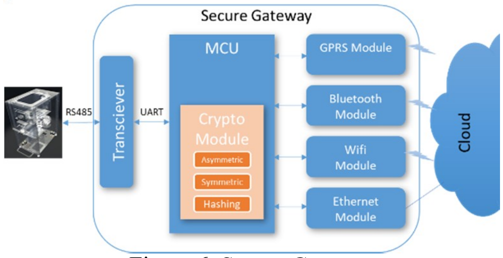

Figure 6. Secure Gateway

Crypto-module is implemented by considering the de-facto algorithms. Here, RSA (2048 bit) is used as the asymmetric cryptographic algorithm for the purpose of exchanging symmetric keys between two end nodes in coordination with the well-known Diffie-Hellman key exchange protocol. Once symmetric keys are exchanged 128-bit AES is used as the symmetric cryptographic algorithm which provides fast and secure data transmission between end nodes. Finally, SHA-256 is applied as the widely-accepted hashing algorithm. SHA-256 provides data integrity which is also crucial in mission-critical digital twin operations.

IV. Concluding Remarks

In this study, recent and famous digital twin concept is introduced by presenting a case study on ice cream machines. Ice cream machines, like other industrial or kitchen appliances, are defined as eGastronomic things as they are getting connected with each other. This paper aims to initiate a discussion on using eGastronomic things and their digital twins for better monitoring of their faults, assessment of their performances and prediction of potential usage and/or level of depreciation. The presented study focuses on main functions of a typical digital twin application such as status observation, bilateral and secure data transmission, 3D visualization and interaction with the digital or physical pair through VR or AR. Analysis of status information, sensory data analytics and prediction algorithms are left to further studies. Moreover, this study mainly focuses on digital twin of ice cream machines. However, smart kitchens themselves and all electronic appliances in these kitchens are subject to the proposed to the heterogeneous eGastronomic things approach and digital twin concept. Such an approach requires deeper research on heterogeneous and distributed networks, more sophisticated IoT security solutions and advanced AI and ML algorithms.

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