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AI in Food and Beverage Industry

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Abstract

This introductory article opens the section giving an overview of the state-of-the-art AI technologies in the food and beverage industry and the current AI development in areas such as quality optimisation and analytics and predictive maintenance. It also presents future potential and opportunities for AI in the sector, covering trends of using AI and IIoT technologies in production optimisation, safety/quality, maintenance, waste reduction, environmental sustainability, and packaging. Finally, the article introduces the five contributions to this section, providing highlights on the use of AI and IIoT in various scenarios in champagne production and soybean manufacturing processes and challenges and technological advancements.

Keywords: artificial intelligence (AI), industrial internet of things (IIoT), champagne production, soybean manufacturing, optimisation, predictive maintenance.

4.0.1 Introduction and Background

The food and beverage industry is undergoing a significant transformation to adopt new technologies, accelerate automation, increase efficiency, safety and avoid production disruption.

Artificial intelligence (AI) and the industrial internet of things (IIoT) enable digitising industries. The advancement in technology brings more intelligence at the edge that empowers IIoT devices with smarter decision-making, high performance, low power processing, and built-in security to create more intelligent and adaptive industrial applications.

The deployment of AI, IIoT and robotics solutions in the food and beverage industry has supported overcome significant issues related to production and execution by reducing the possible chance of human errors and by increasing the automation process while moving manual labour to specific tasks that are crucial for the quality of the final product.

AI and IIoT fuel change in food and beverage production and packaging to reach user expectations concerning quality and associated impact on the cost. To achieve the desired trade-off between quality and price, manufacturing stakeholders actively leverage AI and IIoT technologies' potential across various applications, like product design, quality control, maintenance, and user engagement.

4.0.2 AI Developments in Food and Beverage Industry

The integration of AI technology has transformed the productivity in the food and beverage industry, with increased efficiency, significant decreases in downtime, repair costs, and added labour requirements and costs.

Companies in the food and beverage production and manufacturing industry leverage AI's benefits by using AI methods such as neural networks (NNs), machine learning (ML) techniques, and advanced analytical tools, like speech and text analysis linked with computer vision and voice recognition technologies to optimise time and improve the overall user experience. The food manufacturing facilities use AI to automatically sort, clean, and dispose of products like fruits and vegetables. Manual labour is automated using cameras, sensors, and actuators integrated into autonomous machines. These improved monitoring abilities can reduce millions of tons of food waste. Food quality and safety are monitored using IIoT devices, supported by arrays of sensors, wireless devices, and edge technology, while AI-based food safety solutions help identify food risks in food products.

AI technologies monitor potential problems through various supply chain levels, supporting food manufacturing to become safer, healthier, and more efficient. Precise inventory management is a base of the food and beverages production and manufacturing industry, ensuring production lines

are stocked with the equipment, ingredients, and supplies necessary to run an effective and profitable business. AI helps remove the uncertainty from inventory management. Strategies like intelligent forecasting can utilise sales data, consumer behaviour, and seasonal information to predict how to keep warehouses stocked accurately.

In most food and beverage applications, AI and IIoT interpret data from sensors, detect patterns or anomalies and identify when action is needed. Sensors generate the data that is aggregated, classified, and significant data points are analysed using AI techniques. These technologies are used to detect anomalies, such as early warning signs that an asset may fail or require maintenance at food and beverage manufacturing facilities. AI technology is used to distinguish patterns, expand the knowledge base, recognise cause-and-effect relationships, use analytics insights related to likely outcomes or the next data point in the trend's curve.

Food and beverage manufacturing facilities are utilising capital-intensive machinery and improving and optimising the use of these machines; their energy consumption and efficiency are critical for staying competitive in the industry. The industry is an integrated chain of suppliers, vendors, utilities, labour, stakeholders, ancillaries and manufacturing, and the increase in efficiency in each part of the supply chain improves the overall productivity.

Predictive quality analytics and predictive maintenance are areas in the food and beverage industry where AI and IIoT are used to detect machine failures and anomalies, predict faults and abnormalities, redefine/define error classes and find factors that impede productivity.

IIoT devices and their digital twins provide benefits for predictive maintenance solutions in food and beverage processing and manufacturing combined with AI, including deep learning (DL) and NNs. Advanced and accurate detection of faults, predicting the remaining useful life of an asset given an operational context, can be simulated in an environment where accurate digital twin models of IIoT devices are used. The intelligent IIoT digital twin represent a continuously learning system that is updated automatically to mirror the changes and parameters of the physical IIoT devices. The digital twins can predict asset behaviour and deliver results within given parameters and cost constraints. The equipment is constant functioning, and the digital twins provide information about the physical processes to achieve the targeted outcome.

4.0.3 Future Trends for AI Technologies and Applications in Food and Beverage Industry

In the food and beverage market, AI has a value at USD 3.07 billion in 2020 and is foreseen to attain USD 29.94 billion by 2026 at a CAGR of over 45.77% during the period (2021 - 2026) [1][2][3]. Shifts in consumer needs by preferring fast, affordable, and easily accessible food options have led to a transformation in the food and beverage industry, with many companies leveraging advanced technologies, such as AI, ML, IIoT and robotics to scale operations and help corporations stay competitive in a dynamic market environment. The future trends indicate several areas in food of beverage that are impacted by AI, IIoT and automation, and provide opportunities for expanding AI technologies' development, increasing efficiency and profitability. The AI and IIoT technologies are focusing on addressing process optimisation, predictive maintenance, and production efficiency.

In the following paragraphs a short overview is provided covering the trends of AI, IIoT technologies and applications used in areas such as food and beverage production optimisation, safety/quality, hygiene, maintenance, waste reduction, environmental sustainability, and packaging.

Production Optimisation - AI and IIoT technologies have the most potential to optimise production and reveal manufacturing facilities' best operating points to meet and even exceed the production facility nominal performance.

The production optimisation allows to address all the productions issues related to the climate change introducing a more rigorous monitoring systems and more agile production changeovers, decreasing the amount of time needed to switch from one product to another and recognising production bottlenecks before they grow into a problem. IIoT devices, AI algorithms and actuators can be used together with AI trained models to calibrate production automatically, improving output quality and speed.

Safety and Quality - AI-based systems with the support of IIoT devices provide performant solutions for detecting safe and quality issues in production. These technologies deliver safer, more accurate production lines resulting in higher speed and more consistency than humans. AI-based detection on the factory floor has the potential to keep employees and equipment safer, identifying possible risks.

Hygiene - AI technologies have the potential for optimising the hygiene and cleaning tasks that are critical for food and beverage facilities by using self-optimising cleaning systems, where AI-based multi-sensor IIoT systems recognise food residue and microbial debris on equipment to determine the optimal length of cleaning time.

Maintenance - Food and beverage processing covers the whole value chain from planting and growing, harvesting, receiving materials to production, quality assurance and inspection, and the packing and dispatching of final products. In each step of the value chain, the processes happen in a particular environment (hot, cold, harsh, humid, etc.) that requires constant maintenance of equipment, storage, and workspaces. IIoT and AI, DL are applied to understand data, make predictions, and suggest recommended actions without explicit human guidance. Predictive maintenance brings benefits, including shortened maintenance time, streamlined equipment reconfiguration, avoid downtime, reduced failures, including maintenance costs. The AI-based maintenance in food and beverage includes production line sensors, equipment, motors, manufacturing assets and quality inspection controls to smart connections with electronic records and manufacturing execution systems (MES).

Waste Reduction - AI and IIoT are effectively used in optimisation and provide novel approaches to measuring and monitoring production input and output materials and significantly impacting waste reduction. AI analytics use IIoT real-time monitoring to identify anomalies in production outputs as soon as they occur concerning each batch or cycle and check the production quality.

Environmental Sustainability - The food and beverage process optimisation using AI and IIoT provides an indirect way of optimising energy and water consumption, creating immediate advantages for operating costs and margins while positively impacting the environment. The raw materials utilised as input to the production (e.g., fruit, grapes, vegetables, beans) differ significantly in size, shape, colour, moisture, and texture, adding a layer of complexity to the production line. Implementing AI-based computer vision and pattern recognition techniques combined with parameter measurements using sensors can easily recognise variances, removing contaminants without wasting whole batches and continually adjusting water and energy usage according to process requirements. The entire process operating 24-7,

including robotics and IIoT devices, can be fully automated using AI-based solutions across the production line.

Environment sustainability is achieved by reducing waste, pollution, carbon footprint and cutting electricity consumption using AI-based forecasting, alerts, and energy management tools using predictive ML algorithms to help facility managers to identify issues before they become problems, reducing costly downtime.

Packaging - Automation using AI-driven robotics, 3D cameras, IIoT devices is an area that is evolving fast for applications such as packing and picking demands for fast and efficient delivery. The food and beverage industry processes offer unique potential for intelligent automation by reducing complexity and automating the labour-intensive process, reducing cost, increasing efficiency, accuracy, and work at scale. AI is used in supply chain management through logistics, predictive analytics, and transparency. AI is used to analyse the supply chain data and better understand variables in the supply chain by anticipating future scenarios by reducing the time to market and establishing an agile supply chain capable of foreseeing and dealing with uncertainties.

The high cost of large-scale deployment of AI-based solutions in the food and beverage sector restricts the market growth, and the trend is to develop AI, IIoT technologies that are cost-effective, scalable, and energy-efficient and applied to several layers in the food and beverage supply chains.

Feedstock in the food processing industry can be increasingly made uniform, considering that the food storage is done with the help of AI-based automated solutions used in sorting, which can decrease the labour cost, increase speed, and improve yields.

4.0.4 AI-Based Applications

AI4DI partners are developing AI and IIoT technologies with applications in different areas of the food and beverage sector. The articles included in this section cover five demonstrators and actionable insights into how AI and IIoT are used in food and beverage applications, presenting challenges and technological advancements to accelerate the digitisation process across the industry.

The article "*Innovative Vineyards Environmental Monitoring System Using Deep Edge AI*" presents a novel environmental monitoring system, demonstrating how to connect science (AI) engineering (IIoT) and design

to improve the quality of products and increase the efficiency of their industrial processes by better tracking the production flow. IoT nodes provide real-time data related to weather, soil, crop water status and soil salinity. Connecting many sensors with different sensing technologies to each IIoT node allows for the generation of many and best-fit use cases in champagne production. Sensor data is accessed rapidly and at a relatively low cost by using LoRaWAN wireless technology. In the study, ML is deployed on IIoT nodes, and two architectural pattern solutions were investigated: one, where deep neural networks (DNNs) are executed on the end device with no AI on the cloud, and the other, where DNNs are implemented on both edge and cloud in a complementary manner. The results show that with proper hardware and automatic conversion of pre-trained NNs to fit within the limited resources, moving computation to the edge solves the business and power consumption constraints and addresses the privacy and security requirements.

The article "*AI-Driven Yield Estimation Using an Autonomous Robot for Data Acquisition*" explores automated and non-destructive methods for detection and counting grapes to overcome the drawbacks of the traditional techniques based on automated data acquisition and AI. The conventional techniques are both manual and destructive and have often been uncertain regarding the results' precision and repeatability /reproducibility. Most automated processes based mainly on the analysis of 2D images have drawbacks linked to detecting hidden grapes and estimating the number of berries. LiDAR combined with non-linear modelling can achieve better performances. The extra modelling step can determine hidden parts on the 2D images, such as grapes hidden by leaves. The LiDAR sensor installed on a vineyard robot and the image acquisition cameras used for grape detection transform the robot into a fully automated tool for yield forecasting.

The article "*AI-based Quality Control System at the Pressing Stages of the Champagne Production*" discusses computer vision algorithms/models to automatically classify grapes containers in terms of the average quality of contained grapes. The system detects grapes and unwanted elements (green or ripen grapes, leaves, stones, tools) for quality estimation before the delivery of the grapes to the press, as well as the challenges of deploying the trained models into the field, namely, on small edge devices with limited capabilities. The paper proposes using converters rather than rewriting the models in low-level languages to reduce the size and resources. Thus, trained models developed with high-end API (such as TensorFlow) can be deployed on various boards, allowing for exploring trade-offs between performances and inference time. A deep neural network with an encoder-decoder architecture

has been developed for this purpose. The architecture's performance is evaluated based on three parameters (inference time, the model's overall size, and the intersection over union score) and in three board configurations: without quantised, quantised without an accelerator, and quantised with an accelerator. The results obtained are promising, showing that it is possible to deploy the converted model in a real-time context while limiting the performance losses due to its conversion.

The article "*Optimisation of Soybean Manufacturing Process Using Real-time Artificial Intelligence of Things Technology*" presents a soybean process optimisation solution using real-time artificial intelligence of things (RT-AIoT) technology based on data collected from - and transmitted to different types of industrial IoT sensors, cameras, and actuators, using several wired and wireless protocols. Implementing intelligent vision locally on IIoT edge devices solves several issues faced by deploying it to the cloud and brings further challenges posed by deep learning on resource-constrained edge devices. Data is analysed using AI-based algorithms to improve the utilisation of the raw material, increase the yields and end-product quality, and optimise energy consumption reduction by supporting and/or replacing manual work and existing systems. The overall target is an analysis system that monitors the production line and offers information and analytics on production adjustments to preserve or increase the quality and utilisation. With multi-image sensors, IIoT devices under evaluation, the proposed production optimisation system is interfaced with the existing industrial SCADA system, processes and analyses the IIoT sensor data at different edge computing granularity levels. By applying analytics and AI-based approaches based on data, it is possible to obtain interpretive results for strategic decision making for process optimisation, cost reduction and energy-efficient process tuning.

The article "*AI and IIoT-based Predictive Maintenance System for Soybean Processing*" presents a creative and innovative approach to bringing artificial intelligence to edge devices with various levels of resources, demonstrated for an industrial soybean processing AI and IIoT-based predictive maintenance system. The system implements an architecture integrated at micro, deep and meta edge levels, based on a heterogeneous wireless sensor network that consists of sensor nodes and IIoT devices with different communication interfaces (BLE, LoRaWAN, Wi-Fi). This allows for exploring various combinations of computing power, sensing range, and AI-based processing capabilities to identify the parameter changes that occur before a failure and predict a future period in which these parameter changes

appear and thus identify when a failure might occur. The experimental results are promising, showing that it is possible to plan maintenance actions to reduce the number of production stops for single maintenance actions and thus minimise the downtime of the soybean production line.

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