# Enhancing the Smart, Digitized Food Supply Chain through Self-Learning and Self-Adaptive Systems

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***Abstract*— This work presents a concept to reduce food waste and improve food safety using adaptive systems in the food supply chain. These include smart sensors to adaptively monitor the food's condition and machine learning frameworks to predict the food's quality and shelf life. The build of a prototype is planned to evaluate the system.**

***Keywords*-food supply chain; self-learning; self-adaptation**

## I. Motivation and Challenges

A recent survey [1] showed that 70% of the more than 300 surveyed companies in the food industry consider end-to-end traceability from the origin of the goods to the customer to be an important scenario for the current decade. Various types of sensors exist to support this. Appropriate technologies for Big Data analysis and blockchain as data storage are slowly finding their way into the food industry. However, the potential is far from being exploited. In particular, there is no real-time integration of the sensors with the blockchain, and data are analyzed retrospectively "in the cloud". A real-time analysis should be used for pro-active food supply. Therefore, this PhD work will relate mainly to the following aspects resulting in self-adaptive systems [2]:

- machine learning for determination of spoilage patterns
- food adaptive choice of prediction algorithms
- adaptive monitoring to reduce the energy demand of smart sensors

## II. Contribution and Objectives

Blockchains work as decentralized data storage where the data are shared between the participants [3]. Since changes are logged and validated with hash functions, blockchain can be seen as nearly not manipulable and transparent. Therefore, central trust authorities are not needed anymore, and the operational costs can be reduced [4]. In the food supply chain, many actors participate, which is why a decentralized blockchain is beneficial.

Blockchains are already used in the food sector, but most are only used for traceability, e.g., *Carrefour S.A., France* or *DOWNSTREAM Beer by Ireland Craft Beverages LTD, Great Britain*. The consumer can access the information by scanning a unique QR code and is able to trace the production steps [4]. For instance, the production steps of a dairy product are logged from the farm (e.g., date, time, and location of collection) up to the filling in the dairy (e.g., date, time, and ingredients). The allocation over several participated actors is also an advantage in food safety issues, where authorities can faster trace those actors.

Promising blockchain applications in the food supply chain are real-time tracking and shelf life predictions [5]. Intelligent packaging can share the quality and current condition of a product with the customer [6]. Intelligent packaging consists of intelligent materials or objects, which are defined by their behavior of monitoring "the condition of packaged food or the environment surrounding the food" [7]. Therefore, sensors can be integrated into the packaging [6] to monitor, e.g., the temperature, the pH value, the humidity, the pressure on the food, or vibrations during transportation [5]. Further, gas sensors can measure the concentration of carbon dioxide or hydrosulfuric acid to allow concluding the current condition of the food [6]. Bio sensors can detect pathogens in bacteria-contaminated foods and turn a barcode into unscannable conditions [8]. Thus, current sensor technology helps to pretend consumers from buying spoiled food.

Nevertheless, the full potential of these technologies is not yet used, as data are sampled and stored but not analyzed in real-time. Due to computing capacity reasons, current approaches target central, machine learning-based analysis *in the cloud* [9]. However, new hardware enables data processing *on the edge* at the place of origin. Therefore, specialized hardware components as edge servers, GPU servers, and Field Programmable Gate Array (FPGA) are used, but these fully-fledged devices are not appropriate in mobile scenarios. Using mini-computers as Arduino, Rasperry Pi, or Jetson Nano could overcome these issues.

The main contribution of this project is to combine the technologies mentioned above and improve both food safety and the reduction of food waste. Novel sensors integrated into the packaging design support the targeted collection and storage of relevant data in the blockchain. Blockchain should be used as data storage, so the amount of paperwork is reduced, and the data sharing becomes faster, which helps

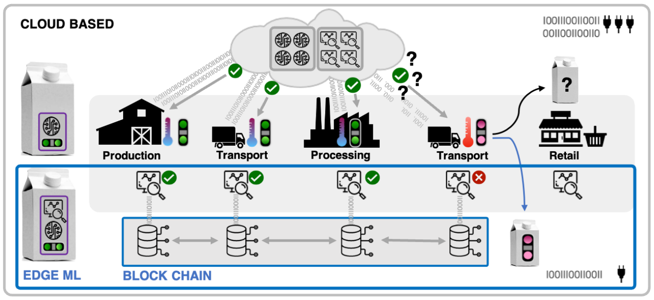


Figure 1. Technologies within the smart, digitized food supply chain

to automate the process. Additionally, the consumer can access the information depending on the blockchain design, leading to increased consumer trust and awareness of the food's origin.

By integrating current trends in machine learning (ML) *on the edge* (Edge ML), i.e., the analyses take place directly at the point of the data's origin in real-time and not retrospectively in the cloud [9]. This also allows forecasting, e.g., to predict the food's shelf life and adapt the best-before date, or to anticipate critical conditions and act adaptively instead of only identifying critical conditions afterward. The required analysis algorithm should be chosen adaptively related to the food and delivery conditions; parameters of aging models can be optimized by learning on the fly. Since these analyses require a lot of computing power, they are often energy-intensive. In this project, intelligent, adaptive monitoring techniques will reduce the amount of data in the analysis (e.g., by adjusting sensor sample rates), resulting in a reduced energy consumption and processing time. Fig. 1 shows an overview of the concept.

## III. Methodology and Preliminary Results

The primary aim of this project is to investigate the integration of the different technologies as smart sensors, blockchain, and Edge ML within an adaptive system for controlling the food supply chain. Therefore, the conception and build of a prototype are considered.

In a first step, necessary and suitable technologies concerning sensors, hardware, software, and frameworks for ML applications are identified. Afterward, the process and the components of the data sampling, data processing, and analysis, as well as the adaptive monitoring are conceptualized and implemented in a hardware-testbed consisting of an Edge-ML prototype and a comparative cloud setup.

In the following, we sketch how to use the *Multi-Level Observer/Controller architecture* [10] known from Organic Computing for the adaptive system infrastructure. In general, the productive layer (layer 0) includes influenceable parts like sensors or adaptive shelf life and delivery routes. Regarding the sensors, several structures are possible: The sensors could be included in the whole system, or it could be implemented as a separate subsystem, as the adaptation of the sampling rate may not need external information. The reactive adaptation layer (layer 1) affects layer 0 directly, representing the nearest adaptation logic. Although the analysis should be applied on the edge, the integration of a cloud is considered, where among others, new patterns and further prediction models should be learned and developed, respectively. The cloud could also serve to determine sensor faults and failures by using swarm intelligence [11]. This would represent the reflection layer (layer 2). The top layer 3 (collective layer) supports cross-company communication and transactions or (seen from a different observation level) cross-product communication. Worth mentioning is that the higher the layer becomes, the more calculation time is available for the controller to develop and validate possible adaptations [12].

The experimental evaluation of the prototype regarding the performance and accuracy of the algorithms should conclude this part. Therefore, an exemplary food product must be chosen for which intelligent packaging is reasonable [6]. These are primarily perishable foods as dairy products or meat. Further, we plan to cooperate with industrial and scientific partners for data provision to apply large scale simulations and modeling.

Another important aspect is the amount of data: If more parameters are monitored, the flexibility is increased through the larger set of parameters. Hence, the precision of the predictions can be improved by choosing the best-fitting parameters for a use case, however, it might be more complex to tune models while preserving individual, best-fitting parameters. With an increasing number of sensors, the product prize increases as well [8]. Further, the reduction and selection of the monitored data are necessary to perform the data analysis efficiently. Therefore, problem-specific, domain-specific, and generic approaches concerning adaptive monitoring or, more precisely, adaptive sampling will be considered [13]. Possible approaches regard optimizing the sensor sampling rate in case of stable conditions or removing faulty data through validity checks before the analysis.

## IV. Future Work and Research Plan

This PhD project is at an very early stage. This abstract presents a first description of the idea. A initial, rough literature review has been done. The following steps include the definition of the system's design and the choice of suitable sensors and research approaches to integrate into the testbed. Therefore, the focus will be on selecting an exemplary product and the induction of its quality parameters and the aging process. Based on that, the generating and sampling of training data will be done, followed by aging process analysis and comparison. Further, the development of prediction models and the training of machine learning models will be included in this step. Afterward, the implementation of the adaptation logic will be focused.

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