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The digitization of a food package's life cycle: Existing and emerging computer systems in the pre-logistics phase

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ABSTRACT

Traditional design and production methods for food packages become less and less suitable to rapidly respond to ever-changing requirements and regulations. Computer systems applied in discrete manufacturing (ranging from computer-aided-technologies to image analysis systems) are now also specifically developed for and gradually adopted by the food package industry to improve efficiency in terms of material usage, operational costs, and food loss, and to allow the development of more performant and sustainable food packages. In this paper, an extensive overview is provided of such systems that, when combined, offer the perspective to realize a more holistic research, design and production approach that fits within the spirit of the fourth industrial revolution. Special attention is given to the importance of information from and knowledge about the logistics and post-logistics phase of a food package's life cycle in the manufacturing process. The main purpose of this review paper is to provide, for the first time, a complete and coherent overview of the digitization of a food package's life cycle that can be used as a blueprint for future research, development and discussion in this emerging research topic.

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1. Introduction

Notwithstanding computer systems have evolved to a level where they are able to support or even completely take over certain complex industrial processess, they still fall short in replacing the commonly used trial-and-error based methods to research, design and produce a food package [1–3]. The challenge of finding an appropriate food package solution gradually evolves to a conundrum due to an increasing number of intertwined and often contradictory requirements related to the inherent complexity and increasing diversity of food products, changing consumer demands, increasingly stricter food quality requirements, increased sustainability demands and highly dynamic, multimodal food distribution networks (especially those linked to e-commerce).

As the traditional design and production methods become less and less suitable to rapidly respond to the aforementioned issues, the need for a holistic research, design and production approach arises [4]. This approach fits within the context of smart manufacturing and the ongoing fourth industrial revolution (better known as Industry 4.0) which aims at seamlessly interconnecting all the differents steps (research, design, testing, production, and quality control) and systems in a certain manufacturing process [5]. It is also strongly related to the concept of Product Lifecycle Management (PLM), a business approach encompassing all managerial and collaborative practices and technological tools for manufacturing new products [6]. PLM aims at taking into account the diverse requirements and challenges related to the each stage in a product's life cycle,[1] hereby transcending the boundaries of the factory [7–10]. A holistic research, design and production approach of food packages can be realized through the development and application of new cyber-physical systems (CPS), i.e. intelligent computer systems that establish a connection between the digital and the physical world [11] and allow data to be exchanged across different phases of a food package's life cycle. Such systems offer the perspective to support or even automate the manufacturing process of more performant, qualitative, and sustainable food packages. Here, the word sustainable should be interpreted in the broadest sense. It is not only related to the reduction of material usage, energy costs and environmental load, but also to the ongoing debate concerning food loss: a food package can also be considered sustainable if it contributes to the reduction of food loss.

This review paper provides an extensive overview of existing and emerging computer systems that already are being or possibly will or can be employed in the pre-logistics phase[2] of a food[3] package's[4] life cycle to further support research, facilitate the design, testing, and production, and/or speed up the quality control of food packages. This paper fits within a broader research effort of the authors to provide a complete overview of intelligent food packages. These can be defined

- in a narrow sense as food packages that are provided with one or more intelligent devices (sensors, RFID tags, . . .) that allow tracking and tracing, authentification, counterfeit and theft prevention, and quality and/or safety monitoring of packaged food products. An intelligent food package can thus register data about its content, its integrity, its location and/or its environment in the logistics and post-logistics phase[5] of a food package's life cycle. In a recent paper, the authors of this paper provided an overview of ongoing scientific research, recent technological breakthroughs, and emerging technologies that offer the perspective of developing a next generation of intelligent food packaging systems to sense, detect, or record changes in the product, the package or its environment [12].
- in a broad sense as food packages that are manufactured through the application of intelligent computer systems. Such systems will be the subject of discussion in this paper.

To complete the review triptych, the authors of this paper have also written a review paper about computer systems that in one way or another can interact or communicate with intelligent food packages (in the narrow sense of the definition) in the logistics and post-logistics phase of a food package's life cycle. Such systems fit within the context of PLM and the emerging Internet of Everything (IoE) [13]. They offer the perspective to feedback all the data and knowledge registered and collected in the logistics and post-logistics phase to the pre-logistics phase.

The main purpose of this review paper is to provide, for the first time, a complete and coherent overview of the digitization of a food package's life cycle that can be used as a blueprint for future research, development and discussion in this emerging research topic. Throughout the paper, data and information flows between the different identified computer systems will be discussed, together with the existing research challenges and technical issues that to a certain extent hinder or slow down the further development of more connected and holistic manufacturing processes of food packages.

2. Review methodology

The rough division of a food package's life cycle into the aforementioned phases was based on the defined phases in the product and production system lifecycles that are discussed in a report of the National Institute of Standards and Technology [14]. The authors then defined two main stages[6] in the pre-logistics phase of a food package's life cycle, each corresponding to a separate section in this paper: 1/research, design, and production, and 2/quality control and fault detection. The latter stage concerns the verification of certain predetermined quality standards in terms of shape, size, or content. The rationale behind this choice is based on the different nature of the emerging computer systems in the considered stages. Emerging computer systems in the research,

[1] The life cycle of a food package ranges from problem definition and research, through (engineering) design and production, to use or consumption and disposal, reuse or recycling.
[2] The pre-logistics phase of a food package is defined as the phase encompassing all steps in the manufacturing process of a food package, i.e. the phase before its actual application.
[3] In this review, food stands for food and beverages.
[4] In this review, the term "packaging" is used to denote packaging materials. The terms "package" or "food package" are used to denote a package as a whole.
[5] The post-logistics phase of a food package's life cycle is defined as the phase encompassing sales, consumption, reuse & recycling.
[6] In this paper, a stage is considered to be a subdivision of a phase.