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Procedia CIRP 72 (2018) 1022–1027

www.elsevier.com/locate/procedia

51st CIRP Conference on Manufacturing Systems

Smart Packaging: Opportunities and Challenges

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Abstract

The global market for smart packaging is expected to reach $26.7bn by 2024. Smart packaging refers to packaging systems with embedded sensor technology used with foods, pharmaceuticals, and many other types of products. It is used to extend shelf life, monitor freshness, display information on quality, and improve product and customer safety. In addition, smart packaging offers new business opportunities based on digitization and thus fits into the broader realm of Industry 4.0. In this paper, the authors provide an introductory overview of smart packaging and discuss its underlying base technologies. This is followed by a presentation of potential benefits and emerging opportunities in the packaging sector, contrasted by a number of challenges that first have to be overcome for smart packaging to reach its full potential. Finally, conclusions are drawn and an outlook towards the future, critical research areas to work in, and potential lessons to be learned from associated areas are presented.

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Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.

Keywords: Smart packaging; Active packaging; IIoT; Cyber-physical systems; Industry 4.0.

1. Introduction

The main purpose of packaging is to protect a product against deteriorative effects caused by exposer to and usage in the external environment. In addition, product packaging serves as an effective means of marketing to communicate with the consumer. It comes in various shapes and sizes and, as a user interface, provides consumers with both ease of use and convenience. The main functions of product packaging have been categorised as follows [1]: protection, communication, convenience, and containment. For example, packaging used in food products usually serves the following purposes [2]:

- To prevent the product from leaking or breaking, and to *protect* it against possible contaminations.
- To *communicate* important information about the contained food product and its nutritional content and to provide cooking instructions.
- To provide *convenience* such as allowing consumers to reheat the contained food in a microwave.
- To provide *containment* for ease of transportation and handling.

However, traditional packaging is no longer sufficient due to continuously increasing customer experience expectations, increasing product complexity, and, most recently, national and international initiatives towards fostering a circular economy and minimising the carbon footprint of manufactured products [3]. Innovative packaging with enhanced functionality is also required to accommodate a variety of additional consumer needs. Examples include offering foods processed with fewer preservatives, products that meet increased regulatory requirements, and packaging that allows for cradle-to-grave tracking and thus may serve as a protection against lawsuits. In addition, smart packaging serves as a means of expanding markets in the context of globalization, helps to accommodate stricter national and international food safety regulations and even serves as a protection against potential threats of food bioterrorism [4].

Over the past two decades, terms such as active packaging, intelligent packaging and smart packaging have emerged in literature and are often used interchangeably [4]. They all refer

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Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.
10.1016/j.procir.2018.03.240

to packaging systems used for foods, drinks, pharmaceuticals, cosmetics and many other perishable goods. Strictly speaking, one should actually distinguish between intelligent, smart, and active packaging.

- Kerry et al. [5] defined active packaging as "incorporation of certain additives into packaging systems with the aim of maintaining or extending product quality and shelf-life".
- Otles and Yalcin [6] defined intelligent packaging "as a packaging system that is capable of carrying out intelligent functions (such as sensing, detecting, tracing, recording and communicating) to facilitate decision-making to extend shelf life, improve quality, enhance safety, provide information, and warn about potential problems".
- Several other authors, including Otles and Yalcin [6] and Vanderroost et al. [2], defined smart packaging as "one that possesses the capabilities of both intelligent and active packaging. Smart packaging provides a total packaging solution that on the one hand monitors changes in the product or the environment (intelligent) and on the other hand acts upon these changes (active)".

In this paper, the authors discuss the background of smart/active packaging technology and provide a brief overview of its main application fields and opportunities for adding value in the global market place. They also discuss related challenges and outline steps towards future research on this topic.

2. Underlying technologies of packaging systems

Packaging base technologies vary not only in terms of hardware, but also in the amount and type of data they can generate, capture, process and distribute [7].

2.1. Active packaging

Active packaging is a first alternative to traditional packaging methods. It refers to an innovative food-packaging concept introduced in response to continuous changes in consumer demands and market trends. Active packaging technology embeds components into the packaging that are able to release or absorb substances from or into the preserved food or the surrounding environment to sustain quality and prolong shelf life [8]. Advantages of using active packaging for perishable goods include reduction of the amounts of active substances, reduction of localisation activity and migration of particles from film to food, and elimination of unnecessary industrial processes that might introduce bacteria into the product [9]. The components frequently used in active packaging systems include oxygen scavengers, ethylene scavengers, flavour and odour absorber/releaser, antimicrobial and antioxidants [10].

2.2. Intelligent packaging

According to Kerry et al. [5], intelligent packaging is mainly used 'to monitor the condition of packaged foods such as meat to capture and provide information on the quality of the packaged good during transport and storage'.

Intelligent packaging system use communication functions to facilitate decision-making aimed at preserving food quality, extending shelf life and improving overall food safety [11]. It is capable of carrying out intelligent functions such as sensing, detecting, and tracing, recording and communicating certain types of information [12]. Accordingly, intelligent packaging systems consist of hardware components such as time-temperature indicators, gas detectors, freshness and/or ripening indicators [10] and radio frequency identification (RFID) systems [5].

The required functions can be implemented and realized via indicators and sensor devices to communicate the pertinent information. Indicators inform about a detected change in a product or its environment, for example a change in temperature or pH level [4]. In food packaging, this technology is often complemented with biosensors to detect, record and transmit information related to potential biological processes and reactions occurring inside the package, for example changing oxygen and freshness levels [4, 11].

2.3. Smart packaging

According to Vanderroost et al. [2], "smart packaging provides a total packaging solution that on the one hand monitors changes in a product or its environment (intelligent) and on the other hand acts upon these changes (active)". Smart packaging utilises chemical sensors or biosensors to monitor the quality and safety of food all the way from producers to consumers [13]. As with the previously discussed technology, smart packaging utilises a variety of sensors for monitoring food quality and safety, for example by detecting and analysing freshness, pathogens, leakages, carbon dioxide, oxygen, pH-level, time or temperature.

The exact functionalities of specific smart packaging solutions vary and depend on the actual product being packaged, for example, food, beverages, pharmaceuticals, or various types of health and household products [13]. Similarly, the exact condition to be monitored, conveyed, or adjusted vary accordingly.

Smart packaging allows to track and trace a product throughout its lifecycle and to analyze and control the environment inside or outside the package to inform its manufacturer, retailer or consumer on the product's condition at any given time.

3. Application areas and market opportunities

3.1. Application areas

Based on findings by Pereira et al. [14], more than 6 million cases of foodborne diseases occur every year in the United States, potentially leading to more than 9,000 deaths. It is estimated that in Spain, there are 60 cases of foodborne disease per 100,000 inhabitants every year. Hence, it is not surprising that one of the key application areas of smart packaging technology is the development of biosensors to detect pathogens in food. Other areas of application include moisture absorbers, antimicrobial packaging solutions, carbon dioxide emitters, oxygen scavengers, and antioxidants embedded into the packaging.

In general, smart packaging technology has a wide variety of potential application fields from monitoring food safety and drug use, to tracking postal delivery of items via embedded security tags [8]. From a customer perspective, such opportunities are perceived as value-added benefits. In this day and age of people being permanently connected to the Internet, new ways of tracking and monitoring purchased goods with associated apps has turned into an important business opportunity for companies to increase customer satisfaction and loyalty. Pacquit et al. [15] identified that smart packaging may also be used to identify supply chain inefficiencies, reduce costs and errors, improve product performance and ultimately increase profit margins.

3.2. *Global market opportunity*

The global market for advanced packaging systems was at a level of $31.4 billion in 2011 and $33.3 billion in 2012, respectively. It is predicted to grow to $44.3 billion in 2017/18 [12]. The global demand for electronic smart packaging is expected to grow to over $1.45 billion over the next decade [16]. According to findings by Fuertas et al. [17], in the US this type of packaging is anticipated to keep developing with an annual growth rate of 7.4%, reaching US $3,600 million in the next decade (see Fig. 1). The second largest market is Japan reaching the equivalent of US $2,360 million, followed by Australia with the equivalent of US $1,690 million; the UK, at the equivalent of US $1,270 million; and finally Germany, at a level equivalent to US $1,400 million.

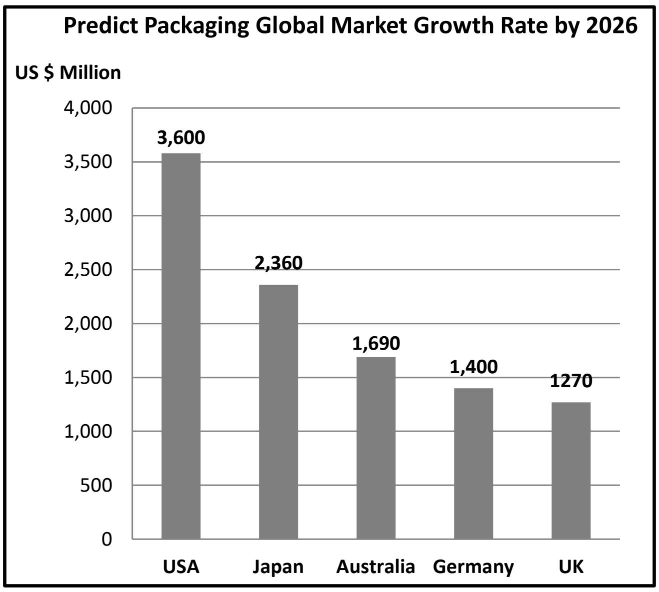

Fig 1. Predicted global market growth rate

4. Research challenges and opportunities

According to the United Nations [18], approximately one-third (over 1.3 billion metric tons) of all edible products for human consumption is lost or wasted annually. This is due to poor practices and conditions in terms of harvesting, transporting and storing of goods [19]. This massive waste of food constitutes a significant financial burden for the food industry to cope with, hence designing adequate packaging for perishable goods is of utmost importance in terms of allowing for longer transportation and storage periods and thus extended shelf-life [5]. However, the design and manufacture of adequate smart packaging technology is quite challenging from an industrial point of view, for a number of reasons (see Fig 2) and the grey area represents opportunities.

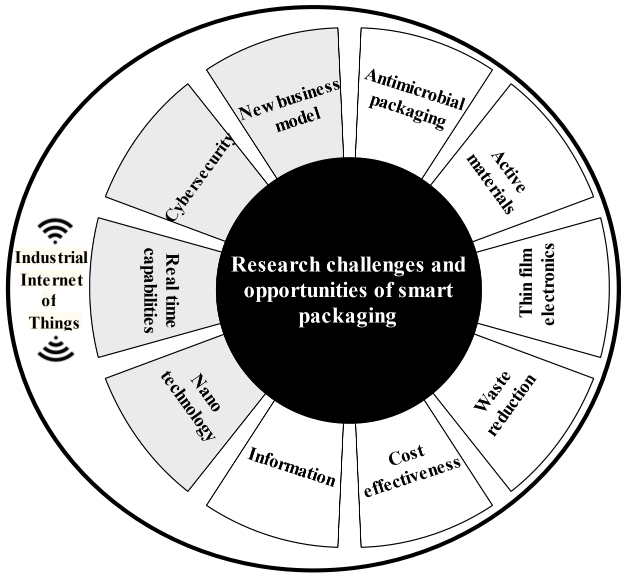

Fig. 2. Challenges and opportunities of smart packaging

4.1 *Challenges*

- ***Antimicrobial packaging*** is gaining interest from researchers and industry alike due to its potential for providing quality and safety benefits [5, 20, 21]. Future research in the area of microbial active packaging should increasingly focus on naturally-derived antimicrobial agents, bio-preservatives and bio-degradable solutions. For example, bio-degradable packaging technology with improved quality and safety has already resulted in a number of innovations in the packaging sector and contributed toward the enhancement of food quality and safety, proving the feasibility of bio-active functional components.
- Further development of so-called ***active materials*** is also important as they are able to preserve both their original mechanical and barrier properties [12]. This will further increase food safety and extend shelf life. Realini and Macros [12] concluded that ‘the use of active compounds derived from natural resources is also expected to continue growing as well as the incorporation of biodegradable packaging materials as carrier polymers’.
- Research and development of ***thin film electronics*** to integrate into packaging technologies is a challenging area. Vanderroost et al. [2] point out that the integration of thin film electronics into printed and flexible sensor systems can be used for temperature tracking to monitor

perishable goods. However, performance is still an issue to be resolved.

- It is well known that that ***waste*** generated from smart packaging is mostly unsustainable for recycling and as such poses a major challenge to industry [22]. Although government policies for the recycling and treatment of packaging waste have been in place for quite some time [23], practical experience shows that the recycling of some types of packaging waste proofs difficult [24]. Therefore, one of the main challenges in the design and manufacture of smart packaging is to advance research on the treatment and recycling of packaging waste, or, for example, to find more suitable materials that may allow for the implementation of sensor and communication functionalities that are bio-degradable.
- ***Food waste*** can occur at different points in the food supply chain [25]. As previously alluded to, as soon as food enters its supply chain its packaging starts to play an important role in keeping it safe, fresh and to its highest quality. However, further research to improve packaging along this entire lifecycle is required:
  - A common weakness in packing relates to ***unreliable sealing*** of a product, which, for example, may cause problems such as grain spillage from sacks resulting in the attraction of rodents that in turn may result in larger infestations.
  - ***Regulations*** on the selling and further distribution of perishable goods damaged during transportation.
  - ***Food that is about to reach its end-of-life point may have to be processed differently***, for example to avoid feeding it back to livestock, which might lead to the outbreak of major epidemics causing huge financial harm.
- Kuswandi et al. [13] propose that the growing need for ***information*** to be embedded in packaging is particular challenging for food-producing companies. They conclude that further research into this will drive the need for smarter packaging:
  - More and more consumers expect to be able to get easy access to information ranging from the ingredients of a product, their origin, and the conditions the product has been exposed to whilst in transport to the grocery store or their home.
  - Smart labelling and stickers are expected to be capable of communicating directly with the customer via thin film devices providing visual food safety information.
  - Visual safety and disposal instructions on pharmaceutical and health products should be provided to inform consumers on how to safely consume the product and how to dispose of it after expiration.
  - Drug delivery systems based on smart packaging technology are expected to further increase health services and patient safety by relaying pertinent information to doctors and health care providers. Along the same lines, they may help to prevent misuse and fraud.

4.2 *Opportunities*

- ***Nanotechnology*** is likely to play an important part in the near future, keeping in consideration the safety concern associated with packaging. According to Majid et al. [26], a key opportunity is the need and development of suitable and safe advanced packaging materials. These materials are to be used to control the release of active agents in conjunction with sensors embedded in the packaging system.
- ***The Industrial Internet of things (IIoT)*** is a concept aimed at providing a globally interconnected network infrastructure for connecting objects to the cyber-physical world. It allows for the tracking and control of devices equipped with sensors and actuators. For example, packaging objects equipped with RFID tags [27] can easily be tracked along their journey from manufacturer to customer. For e-commerce delivery services UPS estimated that 1% of their shipments are lost or damaged [28]. UPS deliver about 4.6 billion packages annually and this is equivalent to 4.6 million packages are either lost or damaged every year. Hence by the integration of smart packaging this could potentially reduce UPS parcel loss significantly. By 2025, not only mobile phones, tablets, laptops and personal computers will be part of the Internet of Things, other appliances such as food packages, furniture, cars, boats, and even manufacturing machines and entire factories will become part of the Industrial Internet of Things (IIoT) as well [29].
- **Real-time capabilities and CPS**. One of main areas for further advancement and improvement in packaging technologies is that of monitoring, managing and controlling the conditions of goods in real time. This capability will significantly affect food safety, consumer health and reduction of waste. A precursor for this is the existence of a reliable IIoT infrastructure and the associated Information and Communication Technologies embedded into both the packaging and the entire supply chain of a product concerned. Technically speaking, this is referred to as the creation of cyber-physical production and delivery networks at both vertical (within one company) and horizontal levels (across several companies). To further benefit from such a digitization of the cradle-to-grave lifecycle and supply chain, Artificial Intelligence can be expected to soon play a more significant role in improving machine learning, data mining and decision support systems that are able to adjust processes in real time and on the basis of big data [2].
- **Cybersecurity**. Despite the many new possibilities and emerging technologies, a major concern is that of cybersecurity [30]. Existing internet technologies are plagued by cybersecurity and data privacy issues that may present major challenges. If these challenges are not appropriately addressed, the full potential of smart packaging as one of the most exciting application domains in the context of Industry 4.0 may never be reached. The modern Internet security landscape is

characterized by attacks that are voluminous, constantly evolving, extremely fast, persistent, and highly sophisticated. These characteristics impose significant challenges on preventive security services. Consequently, methodologies that enable autonomic detection and response to cyberattacks should be employed synergistically with prevention techniques in order to achieve effective defense-in-depth strategies and robust cybersecurity systems. This is true for all cyber-physical systems in general, not just for smart packaging.

- **New Business Models**. Along with the ongoing digitization in the smart packaging sector, new business models capitalizing on the new opportunities have to be developed [31]. Customers are more and more looking for an experience of sorts, hence the industry sector is seeing a shift from products (past paradigm) towards product-service-systems (new paradigm). Traditional value chains and business models are expected to soon come under increasing pressure. Big data and digitization across the sector have already begun to challenge them. Reflecting on past disruptive technologies, it is evident that there is a strong correlation between technological and business model developments and that employing the latest technology in concert with innovative business models is a recipe for success (see Fig. 3). This can be expected to hold true for the evolving smart packaging arena as well. Given the strong interest of the manufacturing sector per se in big data analytics [32], it does not come as a surprise that idea based on data-driven business opportunities and models currently dominates the discussion.

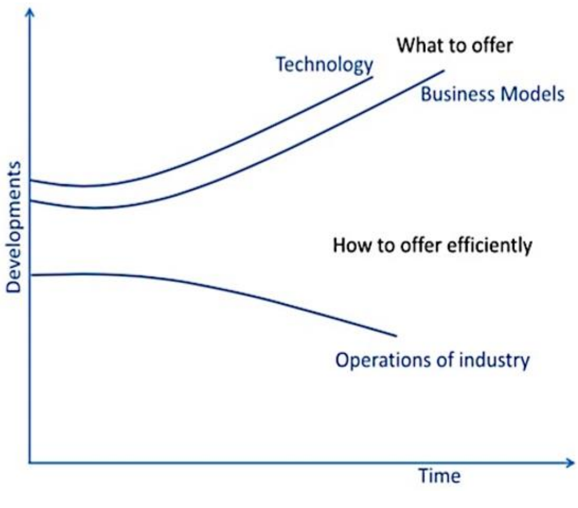

Fig. 3. Relationship of technology and business models [33]

As mentioned earlier, smart packaging provides a total packaging solution encompassing both active and intelligent capabilities. Considering the myriad of before-mentioned challenges, combining and integrating these active and intelligent packaging concepts into fully functional and reliable systems is an enormous task and expected to provide an exciting ground for both fundamental and applied research for years to come.

5. Concluding remarks

Smart packaging relies on the development of sensor technology and materials to inform its quality, safety, shelf-life and usability. Therefore, the future of smart packaging to enhance current packaging technology requires work on a number of aspects:

- Enhance sensor technology to incorporate both smart and conventional materials, adding value and benefits across the entire food packaging supply chain.
- Future senor technology will consist of thin film electronics, smart materials and Nano technologies to be integrated in the packaging. Hence, they need to be suitable for printing technology and mass production, represent only a low-cost relative to the value of the food product, easy to use, environmentally friendly as well as safe to use for the humans.
- In food products, new and advanced smart packaging must focus on advanced food safety aspects to be able to detect microbial growth, oxidation and improve tamper visibility. Furthermore, this new technology should also increase a product’s shelf-life and offer the capability of tracking, convenience and sustainability.
- Treatment of recycling packaging and food wastes can be solved by developing integrated packaging sensors. These senora may store information on, for example, the material(s) that the package is made of, food expiration date, oxygen level, temperature and pH levels etc. Such information can be communicated to food suppliers, distributors and even packaging recycling businesses via the Industrial Internet of Things.
- From an Information and Communication Technology (ICT) point of view, the actual integration of smart packaging into the growing number of horizontally and vertically integrated production networks [34] as part of the Industrial Internet of Things and Internet of Services requires the manufacturing sector to overcome a number of challenges, including a seamless integration of their internal Information Technology (IT) and Operational Technology (OT). This so-called IT/OT convergence is a precursor for enabling the distributed and largely autonomous smart manufacturing networks of the future [35]. Along the same lines, new ways of addressing cybersecurity and ensuring data security and IP protection along the entire lifecycle are of utmost importance.

This paper serves as a foundation for understanding the opportunities and challenges of smart packaging and leads into a number of research areas to be addressed. Building on this work, the authors seek to derive a 5-7 year research roadmap for the field and to further investigate suitable research directions to tackle the challenges identified.

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