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Prospects of robotics in food industry

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Abstract

Technological advancements in various domains have broadened the application horizon of robotics to an incredible extent. Highlighting a very recent application area, this paper presents a comprehensive review of robotics application in food industry. Robots essentially have the potential to transform the processes in food processing and handling, palletizing and packing and food serving. Therefore, recent years witnessed tremendously increased trend of robots deployment in food sector. Consequently, the aspects related with robot kinematics, dynamics, hygiene, economic efficiency, human-robot interaction, safety and protection and operation and maintenance are of critical importance and are discussed in the present review. A comparison of actual robots being used in the industry is also presented. The review reveals that the food serving sector is the new potential area in which ample research opportunities exist by integrating advancements from various technology domains. It is anticipated that wider dissemination of research developments in 'robo-food' will stimulate more collaborations among the research community and contribute to further developments.

Keywords: robotics in food industry; cyber physical systems; mechatronics in food handling and processing; food serving robots.

Practical Application: Automation in food processing industry.

1 Introduction

Advancements in various technological domains during the last two decades have transformed 'fiction' robots in reality (Zohaib et al., 2014). Robotics lies in the category of industrial automation (Iqbal et al., 2016). Pressing demands of enhanced productivity have necessitated deployment of robot to automate tasks (Baizid et al., 2015). Today, robots are considered as an integral part of industries. Historically, the population of industrial robots followed increasing trend with the last year setting a new sales record (International Federation of Robotics, 2015). In 2015, sale of 240,000 units marked for the first time, revealed 8% global year-on-year growth. New installations of industrial robots of about 1.3 million are speculated during 2015-2018. During this period, number of units of sale of industrial robots for Brazil are anticipated to increase by a factor of three as reported by International Federation of Robotics (International Federation of Robotics, 2015). The operational stock of industrial robots in Brazil is expected to increase from 10,300 units (in 2015) to 18,300 units (in 2018). The same pattern has been witnessed in robotics for food and beverage industry where the reported numbers of units sold during 2011-2013 were 4650, 4900 and 6200 respectively with increasing trend in recent years. In food industry, earlier use of robots was limited to packaging of food and palletizing in dairy, beverages, chocolates and food tins. In 1998, the launch of the Flex Picker robot revolutionized the food industry as it is the world's fastest pick and place robot. Potential benefits of incorporating robots in automation include improved operational efficiency, reduction in material movements and vehicle activity and reduced in-process stages.

Food manufacturing and processing factories are now using cost effective automation solutions for higher production volume as compared to conventional processes. As the reliance on manual labor is considered a classical concept now, more preference is given to robotized handling/manufacturing installation. Common examples include; picking, placing, packaging and palletizing applications. The last two applications are most common (see Figure 1) as highlighted by a detailed study conducted by German researchers (Buckenhüskes & Oppenhäuser, 2014).

Robots are being used from seeding, spraying water and harvesting to cutting, processing and packaging of food products (Sun, 2016). Various robot systems are used in meat processing and automatic quality detection of the final product of bakery items. Figure 2 illustrates two different operational scenarios of a robot working in food industry. Also, in beverages industry, bottles are cleaned, counted, filled and arranged on a conveyer belt automatically via robotic machines (Saravacos & Kostaropoulos, 2016). Additionally, modern vision systems are utilized through multiple High Definition (HD) cameras for defect identification and inspection through robot learning. A detailed review exploring the potential of computer vision to inspect and control quality of vegetables and fruits is presented in (Saldaña et al., 2013).

Food industry manufacturers have recorded an increase in productivity of +25% after employing robotics as compared to the work done by a human chain. However, the speed of execution varies in different food sectors (Gebbers & Adamchuk, 2010).

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In fact, it depends on several factors like level of automation carried out, number of robots deployed and product variation due to change in customer's demands. For example, a pasta factory in Argentina (ABB, 2015) has increased its productivity by 10% with installation of six robots. Most of the food processing industry requires product variation but without making change in processing line or fiddling with hardware. Recent trend shows that for this industry, investment in robotic automation is essential to address competitive challenges by protecting future of the business and reducing the impact on environmental degradation. Therefore, companies are looking for expert robotic solutions specific to the processing line requirement.

This paper presents a comprehensive review of the robots specifically selected or configured to match the requirements of the food processing industry. The requirements and challenges are better understood by comparing different types of services offered by the robots in food industry. A motivation behind this type of study is to see whether the increasing trend of robots use in food industry sector is sustainable or not.

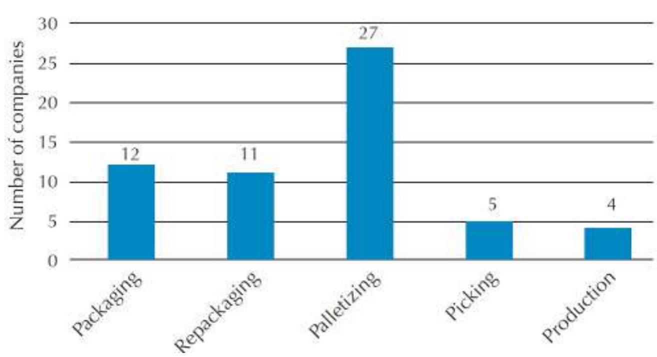


Figure 1. Applications of robots in food industry (Buckenhüskes & Oppenhäuser, 2014).

2 Requirements in food industry

A detailed analysis of requirements in food industry, being an essential prerequisite to tailor a general-purpose robot, is presented below:

2.1 Kinematics, dynamics and control

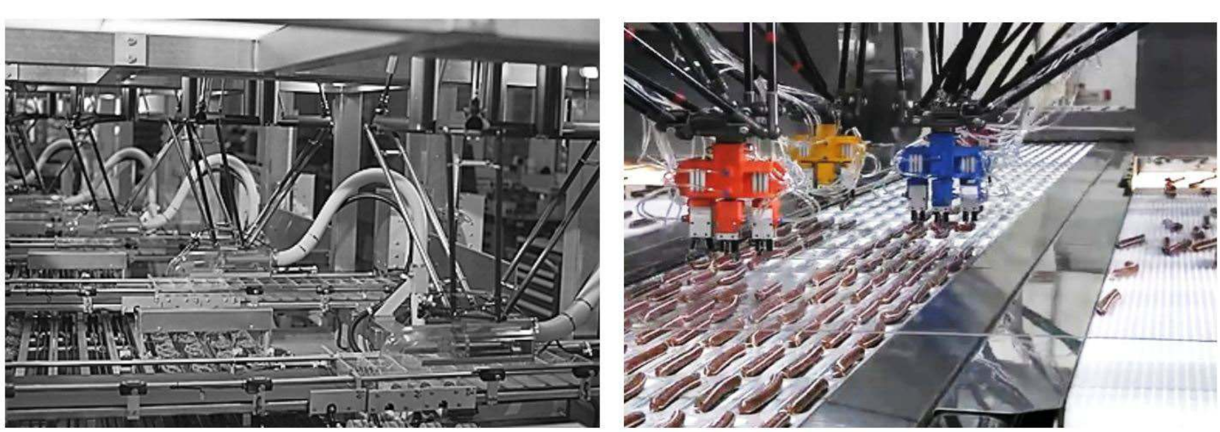
A major portion of the robotic applications in food industry is carried out by the serial robots having vertically articulated structure. The other class of robots which came later on in the food industry and is currently more common is conceptually based on parallel kinematics.

An example of serial robot is AUTonomous Articulated Robotic Educational Platform (AUTAREP) manipulator, which is a novel and pseudo-industrial multi-DOF framework. Figure 3 shows AUTAREP framework and its kinematics.

One of the first steps to develop an application for the robot is to derive its kinematic and dynamic models. Based on kinematic representation shown in Figure 3b, the forward and inverse kinematic models of AUTAREP manipulator are reported in (Iqbal et al., 2014).

In contrast to serial manipulators, the forward solution in PKM cannot be obtained analytically. Thus, computational methods have been employed and multiple solutions are common. In both serial and parallel robotic systems, the dynamic models are necessary to predict actuator forces for the end-effector tasks. Inverse dynamics is critical as it evaluates the actuator torques/forces required to generate the desired trajectory. The two most common algorithms for deriving dynamics include Euler-Lagrange and Newton-Euler.

The control and dexterity of industrial manipulators is vital to accomplish tasks requiring high precision, repeatability and reliability by mitigating the effects of disturbances (Ullah et al., 2016). Trivial control approaches have been the main workhorse



(a) (b)

Figure 2. Robots in food industry (a) Demaurex's line-placer packaging pretzels in an industrial bakery (Bonev, 2014); (b) Three ABB's FlexPicker robots sorting and placing salami of the mini pepperoni (ABB, 2016a).

of industry for decades (Ajwad et al., 2015b). However, in a highly uncertain operational environment, sophisticated control strategy is required (Iqbal et al., 2015). Figure 4 elaborates this concept where a linear control law based on Proportional Integral Derivative (PID) with Computed Torque Control (CTC) is compared with a robust control approach i.e. Sliding Mode Control (SMC). Both control strategies are subjected to bounded time varying matched disturbance so as to characterize their comparative performance in the presence of uncertainties. It is evident that SMC can track the reference signal even in the presence of disturbance. A comprehensive review of control strategies for industrial manipulators is reported in (Ajwad et al., 2014).

2.2 Hygiene

Food safety is an important issue and it is required that the food and beverage products must be untouched by humans during their processing in order to avoid transmission of germs and bacteria as shown in Figure 5. For such stringent requirements, hygienic design of robotic manipulators, vision

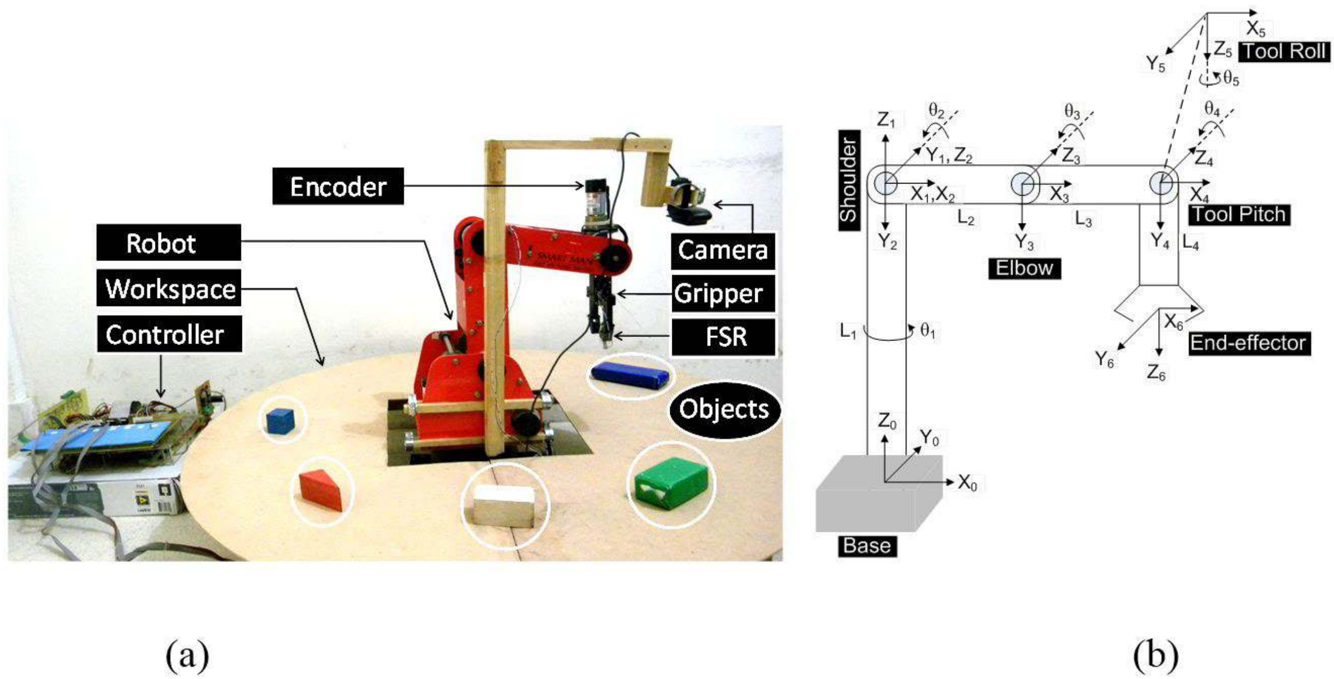


Figure 3. (a) AUTAREP – An open source pseudo-industrial framework (Ajwad et al., 2016); (b) Kinematic representation (Ajwad et al., 2015a).

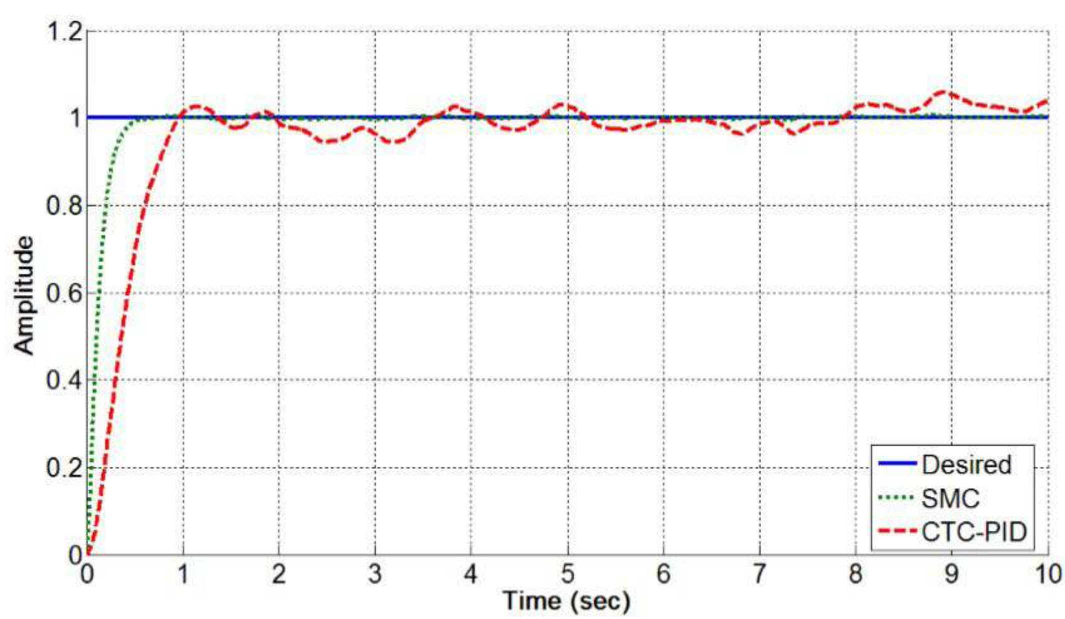


Figure 4. Non-linear control strategy exhibit better disturbance rejection capability (Islam et al., 2014).

systems and end-effectors or grippers is a necessity in food industry. The grippers of the robots used for food handling application are washed down with industrial detergents and pressurized hot water.

2.3 Productivity

The demand of productivity has been increased in the food preparation, handling and production as well as in the food serving industry (Figure 6a). The prime focus of the PKM robots is in the food preparation and handling. Fast operational pick and place speeds are possible due to highly agile robotic structures and the incorporated control schemes. The use of robots has surpassed the operator-based manual production rate.

2.4 Workers' safety

In a futuristic hybrid Human Robot Interaction (HRI) environment, there is a stringent need to standardize risk hazards (Khan et al., 2014a). The prevailing concept is to completely isolate the robot system from the human worker access as shown in Figure 6b. The robot must be able to assess the hazard situations for which the smart sensor integration is a must to be employed.

3 Classification of robots in food industry

Robots in food industry are used mainly for pick and place like food handling, packing and palletizing and for food serving applications.

3.1 Pick and place

The major trend to deploy robots in transforming traditional processes in food industry is currently happening in the food handling category (Mahalik & Nambiar, 2010). Examples of robots for this purpose include ABB IRB-660 and IRB-360. The former is a serial robot used for high demanding payload transfer while the latter is based on PKM mechanism (ABB, 2007) and is designed for high-capacity collating, picking and placing of products onto trays, cartons or feeding of other machinery.

3.2 Packing and palletizing robots

In this category, the robots and applications have been mostly standardized. The decisions are made based on the payload specifications and the range of speeds available. Palletizing of cookies, beverages, pasta, sweets and other items are now stacked using the robots (See Figure 7a). For example, a typical solution allows the production of 900 bags (of 20 Kg each) per hour and then stack them in order to minimize the freight costs.

3.3 Serving robots

Food serving industry is the newest approach of robots use in food industry (Asif et al., 2015). This is the most innovative area not tapped fully so far. As this directly deals with retail and consumers, therefore, it is seen as an exciting change in life style involving a recreational activity and thus necessitates addressing the concepts of human system integration. Sushi in

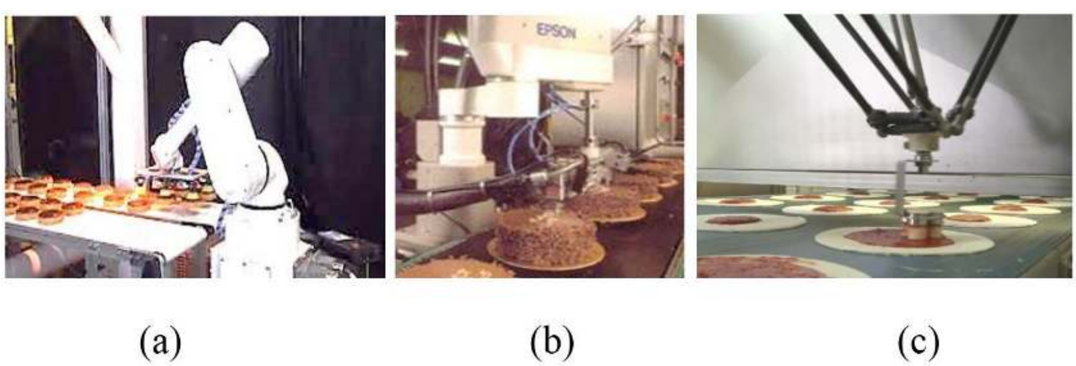


Figure 5. Food robots for: (a) Pick and Place task (RobotWorx, 2012); (b) Decorating cakes (Integrated Dispensing Systems, 2014); (c) Pizza making (ABB, 2016b).

Figure 6. Productivity and workers' safety (a) Sushi serving concept through conveyor belt (DigPlanet, 2013); (b) Robots in operation in a completely isolated and properly fenced working area (ABB, 2016b).

Japan has started the idea of automated food lines. Figure 7b illustrates one such idea in which the wheeled footed serving robot presents the food to the consumers.

4 Challenges and opportunities

The unmatched performance of robots to accomplish various tasks in food industry comes with the challenges which researchers are still striving to resolve (Mueller et al., 2014). A very recent trend is to apply the concept of Cyber Physical System (CPS) in food industry. Bridging the physical world with the virtual world, CPS is a recent multi-disciplinary research domain based on the concept of Internet of Thing (IoT) that finds potential to streamline end-to-end supply chain in food sector. CPS can play its role to achieve the highest level of certainty in food safety (Khan et al., 2014b). European commission recently identified seven key domains which have enormous potential to benefit from infrastructure and tools related with cyber-physical engineering (Henshaw & Barneveld, 2016). Food industry together with agricultural sector is listed as one of the priorities where CPS is anticipated to have significant impact in future. The short term milestones for CPS involvement include: (i) Improved food safety by sensors deployment to scan for diseases and to access product's freshness (ii) Hygienic assistance using autonomous machines (iii) Precision farming by employing drones, sensors and state-of-the-art farming machines. In the long term, the whole production and supply chain will witness communication of smart food labels so as to give in-depth insight of where exactly the food is coming from (Piramuthu & Zhou, 2016). Also, future CPS in emerging sectors like food industry will be beneficiated by cloud robotics as highlighted in (Chaâri et al., 2016).

A typical CPS-based system for food manufacturing consists of three primary elements (Lee & Seshia, 2011); production machine process, field device process and manufacturing control process. From hardware perspective, such a food manufacturing system may comprise of robots, Programmable Logic Controllers (PLC), actuators, sensors, networks and other components to realize motion control and machine vision systems. Software algorithms may rely on Artificial Intelligence (AI), neural networks, fuzzy logic and other machine learning paradigms.

CPS-based food traceability systems can minimize poor quality or unsafe products in supply chain. A recent study reported in (Chen, 2017) proposed a food traceability system realized through integration of CPS and enterprise architectures. Inspired by fog computing, the novelty of the presented solution lies in intelligent value stream-based CPS which aims to optimize events for tracing and tracking processes with the help of a collaborative mechanism. Figure 8 illustrates conceptual framework of the proposed traceable mechanism.

(a) (b)

Figure 7. Robots in food industry: (a) IRB 660 for palletizing cartons; (b) Serving robot in China (Griffiths, 2014).

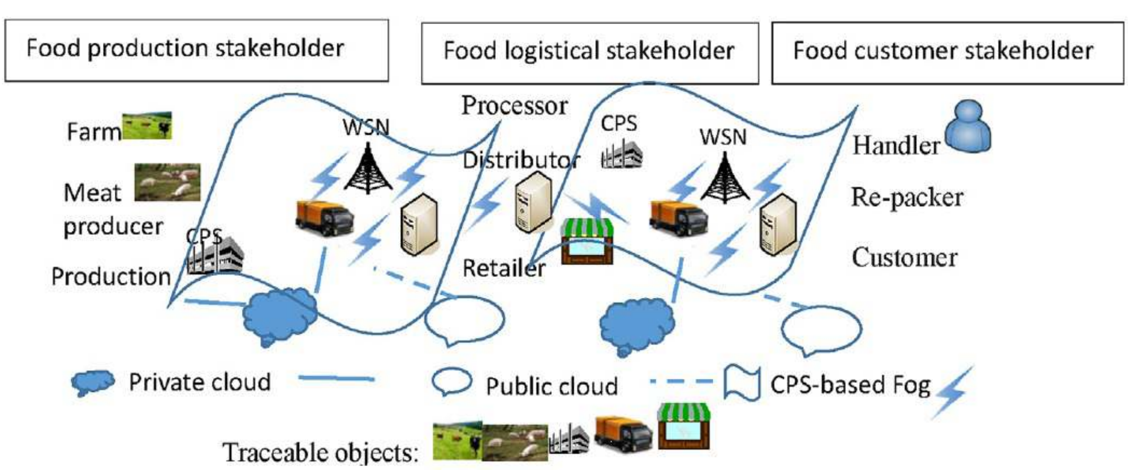


Figure 8. CPS-based food traceability system (Chen, 2017).

The concept of CPS is now being applied to address factors which indirectly influence food quality. One such example includes prevention of contaminated water for being entering into food production chain and drinking water management systems. The mutual dependence of Food, Energy and Water (FEW) systems is now well recognized in scientific community. A comprehensive study reported in (Dong et al., 2016) presents benefits offered by a real-time and autonomous water quality monitoring system in comparison with its traditional counterpart. Recent examples of CPS implementation for FEW systems includes Wolfe et al. (2016) and Hang et al. (2016).

5 Conclusion

The comprehensive state-of-the-art reveals that the domain of robotics has incredibly increased the productivity as compared to the manual production systems. It is highlighted that the food serving sector has the largest potential of research and development. Opportunities lie in sensor fusion, CPS design, HMI, robot learning and training software solutions, vision systems, robot structural re-configurability and operation of robots during maintenance. The new ideas are emerging based on the enabling technologies that were unavailable. The urgent requirement is to integrate various sorts of technology areas to realize competitive and novel solutions.

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