Available Online at www.ijcsmc.com

International Journal of Computer Science and Mobile Computing

A Monthly Journal of Computer Science and Information Technology

ISSN 2320–088X

IMPACT FACTOR: 7.056

IJCSMC, Vol. 12, Issue. 8, August 2023, pg.72 – 77

Robotics in Food Manufacturing Industry in the Industry 4.0 Era

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DOI: https://doi.org/10.47760/ijcsmc.2023.v12i08.009

Abstract— Robotics is used in food manufacturing in multiple processes. Prominent existing applications are: preparation of soil, seeding, water sprinklers, harvest controlling, cutting the harvests, food extractions, processing, packaging, loading/unloading, food warehouse operations, and food retail operations. Robots enhancements in Industry 4.0 framework have enabled cognitive and collaboration capabilities related to dynamics, kinematics, self-diagnostics, and self-control. Robots can identify and change their robotic hands as per process requirement. Robotics in food manufacturing is used to improve food quality and hygiene, increasing quality and its consistency, improving process performance, improving production rate and productivity, production reconfigurability, improving supply chain resilience and responsiveness, improving food traceability, reducing food loss and wastage, and improving workplace safety. Industry 4.0 allows robotic cyber physical systems (RCPS), HMI interfacing with robots through augmented reality thus ensuring remote real time precision monitoring and control of field robots. Robots with attached cameras with machine learning for image visualization analytics can ensure quality assurance and control of food products during all the stages of the food manufacturing logistics. The key drivers for adopting robotics in food manufacturing are cloud manufacturing, Internet of Things (attached with robotic controller cards), virtual reality simulations, augmented reality for HMI controls, additive manufacturing in food processing, integration of Industry 4.0 systems (IoT with blockchains, edge computing, big data analytics, and machine learning), and autonomous automation software. Robotics in food manufacturing using Industry 4.0 capabilities is a positive change. However, there are ethical and financial challenges. Increased usage of robotics can affect employment of food harvesting and manufacturing workers in developed as well as developing economies. Further, economics of using robotics in food manufacturing is not yet justified in developing nations given the high initial costs and prolonged time to break even. Overall, robotics in food manufacturing using Industry 4.0 has many technical and production advantages but ethical and financial viability is an ongoing research domain.

Keywords— Industry 4.0, Big Data Analytics, IoT with blockchain, edge computing, Machine Learning for Robots, Real Time Robotic Monitoring and Control

I. INTRODUCTION

Smart robots have evolved in the Industry 4.0 era. They are cognitively-aware and environmentally-conscious such that they can collaborate and can make their own decisions in an operational environment. Communications with robots have been standardized such that several robots can be monitored and controlled remotely using augmented reality human-machine interfacing (HMI). These characteristics make the robots smart. Recent literature has presented designs on employment of smart robots in food manufacturing industry, in both harvesting fields and in processing plants. The designs present several capabilities, such as interchangeable robotic hands, hygiene, reduced wastage of food products and raw materials, digitally controlled quality assurance, monitoring and control through a blockchain of agriculture robots, remote control by humans, and knowledge building through big data analytics. Robotics in agriculture appear to be promising. However, there are challenges and financial and ethical implications to be considered. This article presents a review of literature on robotic enhancements under Industry 4.0, employment of robotics in food manufacturing, and ethical and financial implications of the same. The research questions are as follows:

(a) What are the enhancements in robotics under Industry 4.0?

(b) How can robotics be employed in food manufacturing in developing countries?

(c) What are the financial and ethical implications for employing robotics in food manufacturing in developing countries?

The article explores the answers to these research questions by reviewing latest academic and professional literature.

II. ROBOTIC CYBER PHYSICAL SYSTEMS UNDER INDUSTRY 4.0

The Industry 4.0 era has shaped the human–robot interactions in a different way [1]. In the industry 3.0 era robots were supporting humans in conducting difficult tasks through robotic scheduling and control programs embedded within the built-in computers in the robot or computers at a distance wired with the robots. The robotic task programming was completely human-controlled. The Industry 4.0 era has evolved a system in which, several robots can be controlled through robotics control programs running on centralized computers connected with the robots wirelessly [1], [2]. This era has evolved the smart robots, which can communicate with each other, are cognitively aware with the help of location positioning system, and are aware of the environment in which they operate (such as avoiding collisions automatically). The robots operate in a controlled authentic contextual learning environment driven by machine learning to build appropriate reflections in the past experiences and make decisions for the future [1]. The key application areas of the smart robots are: agriculture, manufacturing, logistics, healthcare, warehousing, defense, and hospitality with kitchen applications [2]. The smart robots may be broadly categorized as machining robots, materials handling robots, pick and place robots, welding robots, and miscellaneous robots.

The smart robots are interconnected through an ad-hoc networking environment, which connects over backhaul broadband links to the cloud robotics software [3], [4]. The ad-hoc networking allows the robots to interact in a localized operating environment whereas the cloud robotics software helps the robots in database queries, data flows management, information processing, decision-making, routing, parallel communications, protocol support, filtering, preprocessing, scheduling, cognitive relating with the location positioning system, quality of services, and cost – task optimization [3]. All these (and perhaps, many more) tasks allow the robots to offload their heavy computation overheads to cloud computing servers [4], [5]. This is, however, a complex operating model because the robots need to send all their sensory data to the cloud robotics software in real time [4]. There is a very high reliance on network bandwidth, response times, and availability. The cloud resources should be very powerful and the applications should have high response times to ensure quick computation of robotics tasks and send the commands back to the robots in real time to allow them continuity in operations. The cloud robotics is designed to control human – robots interactions and mutual interactions among the robots [5], [6]. The HMI is connected to the cloud robotics software given that the robots operate as remote nodes controlled by the cloud robotics, thus making them robotic cyber physical systems (RCPS). These concepts can be visualized in the diagram presented in Figure 1.

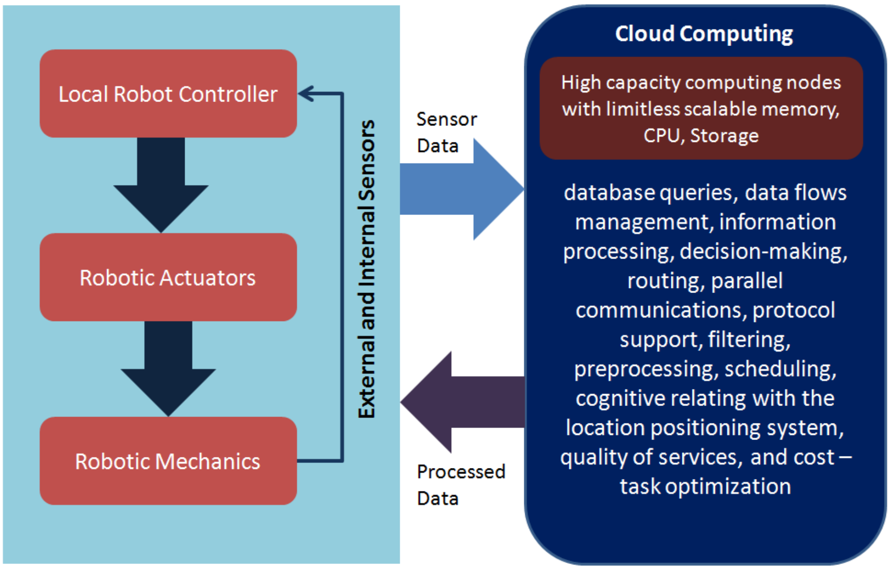

Fig. 1 Robotic cyber-physical systems in Industry 4.0 ([3], [4])

III. ROBOTICS IN FOOD MANUFACTURING INDUSTRY IN DEVELOPING NATIONS

In food manufacturing industry, the most critical challenges are food quality, food safety (hygiene), wastage of food products, food production and logistics efficiency, skills required in the food industry, and financial costs [7]. To address some or all of these challenges, robotics and autonomous systems could be introduced in the food manufacturing industry. Unlike sophisticated industries like aerospace, automotives, electrical, and electronics, food industry have not yet adopted robotics en mass in their processes. There may be several reasons for this. However, the primary reason is the types and suitability of robotics for food industry [8]. For example, robots used for food manufacturing should not have any loose parts, greases, metallic powder, etc., which may get into contact with food products. Further, the traditional processing in food manufacturing is carried out either by human hands or by machines operated by human operators.

There is significant tacit knowledge about food handling that has not yet been captured in written form to execute food handling through automation [8], [9]. For example, there are several ways of grasping food pieces for cooking, processing, and packaging that require human skills. Cooking food is an art. Hence, if robots are introduced in food manufacturing, they need multiple grasping hands, which should be closely guided and controlled by human operators. The gripper system and other robotic functions for food handling is highly complex and requires several design considerations [9], [10]. There are several challenges in using robots for food manufacturing. Bader and Rahimifard [9] identified some of them as: loss of grip on soft food products (such as, eggs, cheeses, figs, berries, and tomatoes), damage of food under excess pressure, wrong grip selected for processing (such as for peeling vegetables, cutting apricots, and preparing cheeses and pastries), and challenges in dealing with irregular surfaces and uneven sizes (includes all natural food having irregular shapes and uneven sizes).

Food manufacturing has hundreds of stereotype processes requiring different skills [9], [10]. Hence, hundreds of robotic varieties are needed under several classifiers, such as kinematics, mobility and dynamics, dexterity, control, hygiene, support and maintenance, and applications [10], [11]. Some of the main application areas in food manufacturing, logistics, and services are: agriculture field robotics, food processing robots, pick, place, palletizing, packaging and labeling robots, inspection robots, test robots, kitchen robots, and serving, cleaning, and dish washing robots [10], [11], [12]. In collaborative mode, robotics in food industry is conceptualized for precision agriculture and additive manufacturing of synthetic food products [11] and [12]. Autonomous robotic software systems are evolving in several industries, and they may soon find way into the food manufacturing at large scales. For example, they can be used for crop monitoring and robotic vision for quality assurance (using processing of images captured by robots by machine learning and artificial intelligence), for sensing data from manufacturing processes using Internet of Things (IoT; attached with the robotic controller cards) to facilitate real-time visualization, and advanced big data analytics to create reusable knowledge about best practices in agriculture and food processing [10], [11], [12], [13], and [14]. Augmented reality is emerging as the human-machine interfacing for controlling field robots or the ones used in manufacturing facilities (such as 3D printing of food products). Integration of robotics data with edge computing and blockchain can ensure tracing, monitoring, quality assurance, and food safety. Machine learning algorithms designed especially for food manufacturing industry can help in identifying quality and safety issues, and in making the right process decisions. These concepts are summarized in Figure 2.

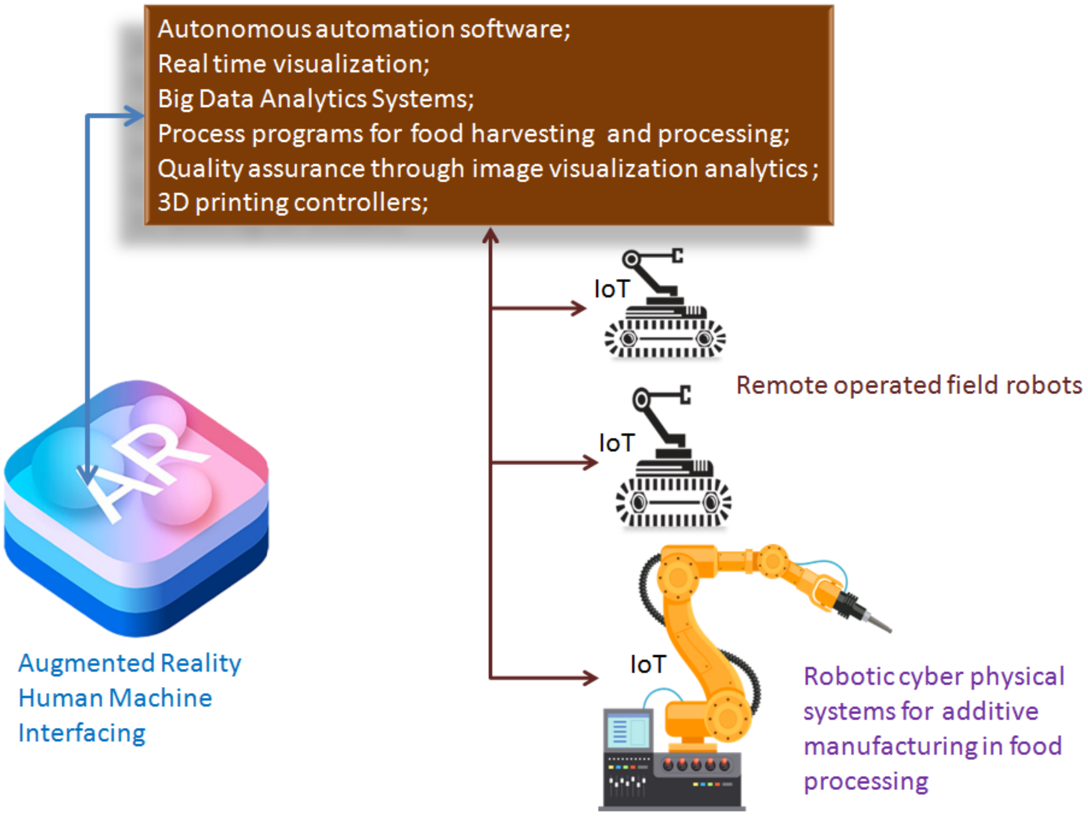

Fig. 2 Industry 4.0 Robotics in Food Manufacturing Industry (based on concepts explained by [10], [11], [12], [13], and [14])

Robots are not humans but should be bound by constraints of ethics and values. The designers of robotic hardware, robotic operations software, machine learning algorithms, and artificial intelligence applications should ensure deep focus on ethics and moral standards in robotics used for food industry (or any other industry) [15], [16], [17] and [18]. The robotic innovations in food industry should be done responsibly reflecting in all the decisions and steps taken [15]. There are several areas of responsibilities to be considered in robotics innovation for food industry: regulatory, data privacy, employment, economics, trustworthiness, health and safety, environmental and social sustainability, and socio-cultural lifestyles and well-being of farmers and consumers. Health and safety of workers while interacting with field robots are of prime importance [16]. Robots may malfunction in extreme temperatures causing industrial accidents. Typical operating range of robots is 5 to 40 degrees Celsius. Hence, robots may not be safe to operate in many Sub-Saharan countries in Africa, in the Middle East, and the hotter states in India. Further, robotics may fail in extremely dusty and windy environments. These limitations should be considered when deciding a human-robots combination for agriculture fields and food industry.

Apart from health, well-being, and safety, ethics in robotics for food industry should consider wellbeing of farmers, workers, and consumers [17], [18]. Employment, safe production of food, inflation of food products, food supplies, and food security are some of the key ethical considerations for adopting or rejecting robots for the food industry as appropriate. Relationships of robots with human society should be defined clearly. When awarding autonomy, the degree of autonomy, the tolerance of errors and mistakes, and the accountability of damages should be considered. Public perceptions about robotics in food industry and labor relationships are ethical considerations, as well. A just division of work and workspace separation between humans and robots need to be defined in government laws and regulations.

Finally, the economics of robotics in food industry needs to be considered. Robotics is expected to induce cost variability in operations when replacing human workers [19]. Human workers are not viewed from capital cost perspective [20]. Human costs are mostly in salaries and benefits that vary by economic cycles of the country and the employment levels in an economic cycle. Robotics is going to be viewed through the lens of completely different costing models [10], [19]. There will be very high initial capital costs involved in adopting robotics for food industry because the initial machines will be expensive and complex requiring additional costs in the form of setup costs, integration costs, running costs, and skills development costs. Autonomous robots will have a learning cycle for machine learning, which also will add to the costs. The costs may reduce when they take over fully from humans but the variability and uncertainties will cause difficulties in estimations and budgeting. At this stage, the economics of robotics cannot be compared with the economics of human workers definitely. Perhaps, the current consideration of adopting robotics should be based more on their capability and quality superiority over human workers as much as justifiable.

IV. CONCLUSION

In Robotics has been adopted by several industries for replacing manual processes by automating them using specialized robots designed for several jobs. However, robots are not designed to conduct multi-tasking like humans given the limited degrees of autonomy (freedom to conduct several tasks using the same hands) allowed to them. Thus, robotics adoption is limited in food manufacturing in the agriculture fields and the food processing plants. The varieties, variabilities, complexities, and delicate working required in food industry give way to limited types of robots for employment replacing human operators. Recent studies have designed some of the robotic hands, grips, dynamics, and their processes for suitable food production processes. However, they still are insufficient to match the multitasking skills of humans, and to meet the standards of varieties, variabilities, complexities, and delicate working formulated and delivered by human operators. Hence, robots have not been able to replace humans in food manufacturing industry. They have been mostly considered for tough tasks very difficult for humans to deliver using hand-operated tools. Industry 4.0-enabled smartness in robotics for food manufacturing processes may increase the scope of employment of robots, but humans will continue as the major contributors in food manufacturing in both developed and developing economies.

Robotics in developing nations may face more challenges of adoption in food manufacturing industries. Farmers may adopt robots for some hard works, like cutting crops and pulling out stables in the fields. Robotic machines for cleaning food products (such as cleaning wheat and maize) are already in action. However, food production in developing nations requires sophisticated and delicate processes, which are difficult to design for the robots. Contamination of food products by metal powders, oil, greases, etc. is a major consideration. Further, ethical standards need to be considered. Robotics in food industry can take away millions of human jobs thus affecting social well-being of people negatively. Robots may affect socio-cultural lifestyles and well being of farmers and consumers negatively. They may cause health and safety issues for their human co-workers.

Economically, they may be very expensive initially when sophisticated machines are deployed, integrated, and make operations ready using cloud computing software systems. When robots are deployed in operations, there may be additional cost such as setup costs, integration costs, running costs, and skills development costs. Robotics in healthcare may have several cost heads whereas humans only draw salaries and perks. People in developing nations are less expensive than developed nations. Hence, robotics in food manufacturing for developing countries should be considered more for enhancement of efficiencies and capabilities instead of cutting human employment costs. As a conclusion, robots may be helpful but cannot replace humans fully in food manufacturing for developing nations.

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