ROBOTICS AUTONOMOUS SYSTEMS (RAS) IN FOOD LABORATORIES ARE THE FUTURE OF FOOD PROCESSING INDUSTRIES-A REVIEW

Abstract:

The industrial robotics and mobile robotics and then expand on new trends in robotics research that focus more on the interaction between human and robot. The new trends in robotics research have been denominated service robotics because of their general goal of getting robots closer to human social needs. Laboratory automation was thought to be limited to only some extent Since the laboratory robot is computer controlled and computer driven, then consideration must be given to the operation and programming of the unit. Each laboratory procedure, no matter how complex, can be broken down into a series of discrete laboratory unit operations, and these building blocks can therefore be integrated to allow the accomplishment of the overall analysis scheme. While robotics systems have been useful tools in the laboratory for many years, most notably in the area of liquid handling, many tasks are still only automated to a small extent. At the same time a new wave of robotic devices is reaching the market from robot lawn mowers to driverless cars, as well as smarter robots in manufacturing. Future generations of scientists will need to possess both biological and engineering abilities in order to fully realize the potential of laboratory automation. Future research programmes will probably depend more and more on automation in the lab, continuing the trend of fusing scientific and engineering knowledge to address original research problems.

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Key Words: Robotics, automation, pipetting, sample handling, automation, productivity.

1.0 Introduction

Food crises lead to uneven access to nutritious food in the right amounts and quality, which is recognized as a worldwide risk in society (World Economic Forum, 2020). Food demand will rise by 59% to 98% by 2050 due to increases in the world population and personal incomes in developing nations (Elferink and Schierhorn, 2016). This necessitates concentrating on enhancing efficiency by implementing cutting-edge technology like autonomous systems and robotics (RAS) in food laboratories (Rehman *et al.,* 2019). RAS is not a novel idea; it is employed in the construction business to create high-rise structures (Cai *et al.,* 2019), in the tourism sector for goods delivery and check-in and in transportation using self-driving trucks (Sanders *et al.*, 2019). The application of RAS in food safety is a promising area to address difficulties in the food supply chain (Bouzembrak *et al.*, 2019).

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1.1 History of Robotics

The origin of the term “robot” is placed in more recent times: namely, it comes from the Czech word “robota”, meaning “heavy work” or “forced labour”. The introduction of this term is due to the Czech writer Karel Capek (1890-1938), who used it for the first time in 1920 in his novel Industrial applications of robotics gained a paramount importance in the last century. The beginning of “Industrial Robotics”, as we currently define it, can be dated back to the 1950’s, although some kinds of automatization in the industrial environment started to appear since the times of the Industrial Revolution. The evolution of industrial robots can be subdivided into four categories, as in (Zamalloa *et al.*, 2017), the first three covering the timespan from the 1950’s to the end of the 1990’s. The robots of the fourth generation (which ranges from 2000 to nowadays), that are characterized by high-level “intelligent” features such as the capability of performing advanced computations, logical reasoning, deep learning, complex strategies and collaborative behavior.

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1.2 Basic components of a robotic system:

- Power Supply
- Actuators
- Electric motors (DC/AC)
- Sensors:
- Controller

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1.3. Reasons for automating processes

It is necessary to decrease direct labor, improve quality, increase production, make it harder for workers to complete tasks manually, make it harder to consistently meet specifications, make processes more flexible, make work safer for employees, and remove a source of contamination.

2.0 ROLE OF ROBOTICS IN FOOD SAFETY:

Generally, food safety refers to the avoidance of illness resulting from the consumption of contaminated food. The issue of food safety has been increasingly discussed through products recalls, for example, the presence of salmonella in chicken. Another well-known example of food safety crisis was the discovery of horsemeat in some beef products as well as the increased detection of porcine DNA in some processed “Halal” products in the United Kingdom (Fuseini *et al.,* 2021). The growing attention towards food safety might be because of the increasingly stricter legislation and economic motivation (Akkerman *et al.,* 2010). The food safety failure or recall can be a devastating factor and often tarnishes a company’s reputation (Soon *et al.*, 2020). A wide range of standards and systems have been developed to help companies in order to manage food safety issues. For example, the Hazard Analysis Critical Control Point (HACCP) system aims to analyze and control biological, chemical, and physical hazards from the entire food supply chain (FDA, 2004). The core idea of HACCP is to offer a structured method to identify risks along the food supply chain and where possible either reduce those risks or eliminate them. The underline of HACCP systems is the traceability of products along the food supply chain. Government has enforced legislation to actively encourage the traceability during all stages of production, manufacturing, and distribution. However, the complex and interconnected nature of food supply chains limits the ability to undertake traceability in the food industry. In this context, food companies have used RAS to address the traceability within their supply chains. Kshetri (2018), high-lighted a recent success story in which Walmart used RFID technology to improve food safety on the dinner tables of Chinese consumers. In this application, information such as farm origin, storage temperatures, processing data, expiration dates, and transportation details from an ecosystem of suppliers to store shelves and end users may show potential food safety hazards.

Alternatively, Alfian *et al.* (2017) used RFID and a wireless sensor network to measure the temperature and humidity of kimchi during storage and shipping in South Korea. The proposed method assists by optimizing kimchi distribution, monitoring freshness, and increasing consumer satisfaction. However, the full benefits of RFID can only be realized if all enterprises in the food chain use the technology (Balocco *et al.,* 2011). Full application of RFID technology across the supply chain increases enterprises' risk and expenses (Kelepouris *et al.,* 2007). Because of the intricacy of the food supply network and the fact that the majority of food enterprises are small and medium-sized, these requirements pose significant challenges to RFID adoption in the food supply chain.

2.1 Role of robotics and their importance in food laboratories

Automation in food laboratories aims at reinforcing aspects that are elemental to its sustenance but underachieving. Despite the laboratory being one of the largest, greater dependence on human labor to execute repetitive functionalities has deflated its economy. The ratio of production to demand is severely short. This, at times, disrupts the demand-and-supply chain causing inflation in foodgrain prices and food shortages.

An effective answer to this crisis is the incorporation of robotics into the food laboratories. Several companies in food production have taken decisive steps in this direction. Various levels of analysis can be made efficient by constituting robotics in the food laboratories. On the other hand, the integration of robotics development services can lead to the automation of processes that are performed manually, make production cost-effective, and minimize risks and errors.

2.2 Types of some robotics used in food laboratories

2.2.1 Pickolo™ Colony-Picker

Pickolo™ is a colony-picker add-on for Tecan robots. The product enables advanced and fully automated micro-organism colony picking from agar plates, both Petri-dish and various multi-well plate formats, based on diverse criteria such as size, shape and color of the colonies. The product seamlessly installed on to the robot in just a few minutes. The software is easily integrated into regular Tecan scripts such as Freedom EVOware® software enabling colony picking downstream and upstream to other robotic tasks. The software generates automatic documentation of the picked colonies (Bodai *et al.,* 2017).

Features:

- Fast performance up to 800 colonies per hour
- Full automation with upstream and downstream applications
- Flexible selection criteria by color, size and more
- Easy to use and
- Simple to install

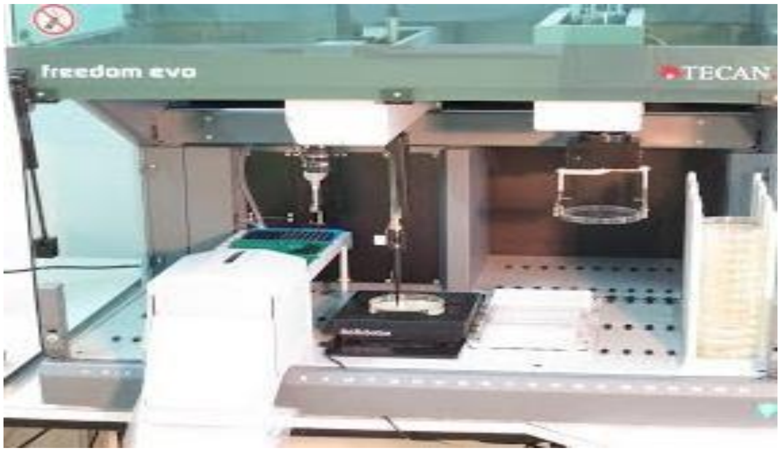


Figure 1: Pickolo™ Colony-Picker

2.2.2 PetriPlater™ Robotic Spiral Plating and Streaking

Automate dilution plating and spiral sample plating on the Freedom EVO® 75 with SciRobotics' PetriPlater add-on. This provides state-of-the-art hardware and software to automate your colony-picking experiments in an easy and cost-effective way. The Robotic Manipulator Arm™ brings the source plate to the light table, and a high-resolution camera takes a photo. The Pickolo software then analyzes the image and selects colonies for picking according to your individual criteria. The template script provided makes it simple to set up the picking process while maintaining the freedom to define a variety of different colony selection criteria, micro-organisms and agar type (Truswell *et al.,* 2021).

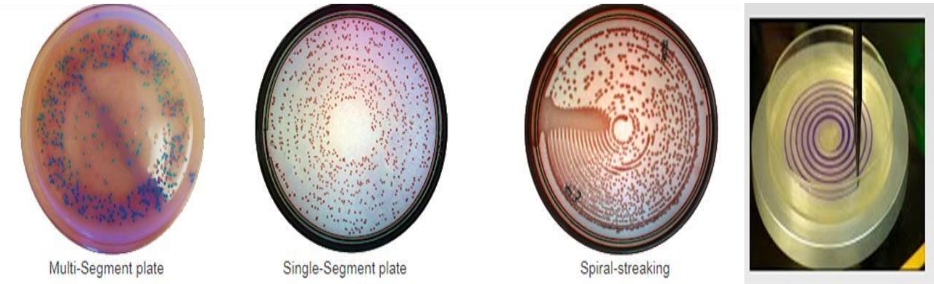
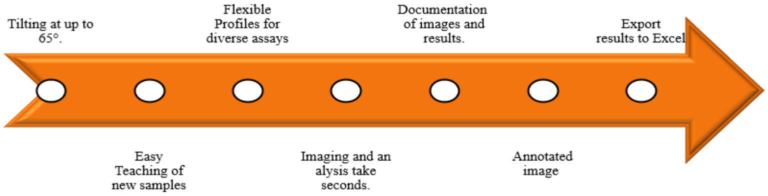

Multi-Segment plate
Single-Segment plate
Spiral-streaking

Figure 2: PetriPlater™ Robotic spiral plating and streaking

2.2.3 FluHema™ Hemagglutination Analyzer

It can image an assay microplate, interpret the results and report them in multiple ways. Plates can be tilted for imaging at up to 65°. Results are analyzed using advanced computer vision techniques to identify positive vs. negative wells. The algorithm can be easily tailored by the user to his specific assay by providing typical examples. All results are documented and can be reviewed easily by lab personnel (Wilson *et al.,* 2017).

Advantages:



2.2.4 GF Pickolo - GFP fluorescence colony picking

These robots pick the colonies with the strongest fluorescent signal or the weakest. They can use average signal or cumulative signal or even pick the colonies with the largest fluorescent signal to maximize protein secretion.

Properties	Performance
High-resolution industrial grade camera and lens (10MB)	Perform fluorescence imaging of colonies expressing GFP
Optical filter for the fluorescence imaging	Select the colonies based on sophisticated and flexible criteria combining properties from both back-light imaging and fluorescent imaging
Software controlled illumination	Screening and isolation of monoclonal mammalian cell lines such as Hybridomas, CHO cell lines microbial clones

Table 1: properties and performance of GFPickolo - GFP fluorescence colony picking

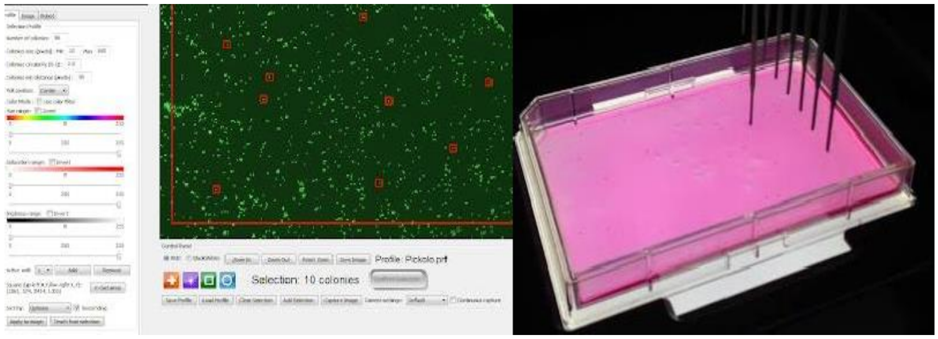


Figure 3: GFPickolo - GFP fluorescence colony picking

3.5 PickoloMI™ - for MALDI-TOF Microbial Identification

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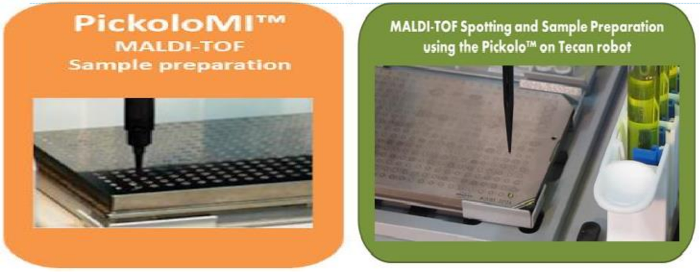

Fig 4: PickoloMI™ - for MALDI-TOF microbial identification

Advantages:

- ✓ Direct smearing: colony is smeared directly on MALDI target using disposable tip

- ✓ Smart algorithm: specifically designed for automatic colony selection for MALDI
- ✓ Sample tracking: Samples are automatically assigned to spots using a barcode reader
- ✓ Documentation: easy review of plate and colony images from previous runs
- ✓ Reports: Generate reports and sample file for Bruker's Biotype

2.2.5 PetriSel™: Petri-Dish Carousel Add-On for Tecan Robots

This robotic arm takes the petriplate directly from the carousel using special finger adapters to hold a petri dish on the robot. This automatic plate sensing enables easy operation and long walk-away time for petri-dish driven tasks. This robot allows the carousel to work with no transfer station or shuttles and greatly speeds up operation with an integrated storage solution for up to 180 petri-dish which includes 12 stackers containing up to 15 petri-dish each.

2.2.6 PickoCell™ picking stem-cell colonies on Tecan Robots

This is composed of a special dark field illumination table combined with high-resolution camera and Pickolo versatile and flexible image analysis software. The solution provides both interactive or automatic colony selection based on diverse criteria of the desired colonies. By using the robot tips, colonies covered with a thin layer of media are accurately and gently aspirated from the plate bottom and dispensed into any kind of tube or collection plate while keeping the colonies viable and intact (Ochs *et al.*, 2021).

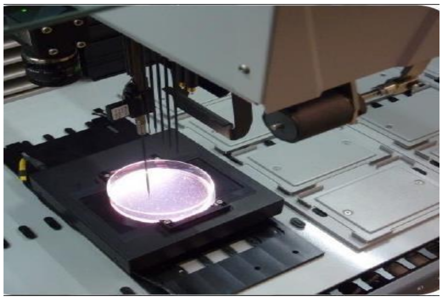

Fig 5: PickoCell™ picking stem-cell colonies on Tecan Robots

2.2.7 Sensory robotics E-nose

Consists of different polymer films, which are specially designed to conduct electricity. When a substance is absorbed into these films, the films expand slightly, and that changes how much electricity they conduct. Each electrode reacts to particular substances by changing its electrical resistance in a characteristic way (Moshayedi *et al.*, 2023).

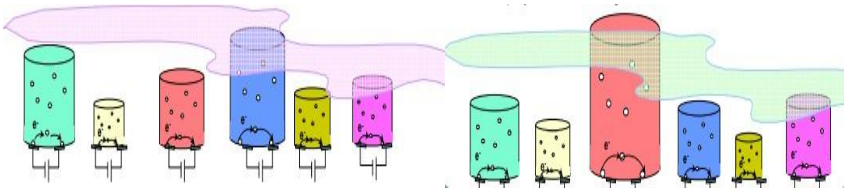

Figure 6: Baseline resistance of the E-nose smelling properties

Each polymer changes its size, -and therefore its resistance, by a different amount, making a pattern of the change. If a different compound had caused the air to change, the pattern of the polymer films' change would have been different

Biological nose	**E nose**
Inhaling	Pump
Mucus	Filter
Olfactory epthelium	Sensors
Binding with proteins	Interaction
Enzymatic proteins	Reaction
Cell membrane depolarized	signal
Nerve impulses	Neural network

Source (Tan *et al.*, 2020)

Table 2: similarities between biological nose and E nose

2.2.8 Sensory robotics E-tongue

An electronic tongue is a device made of sensors responding to some taste (soluble) of foods through the transduction of a signal or a pattern of signals thanks to a pattern-recognition software system. This is able to quantify bitterness or “spicy level” of drinks or dissolved compounds, quantify taste masking efficiency of formulations (Tan *et al.*, 2020)

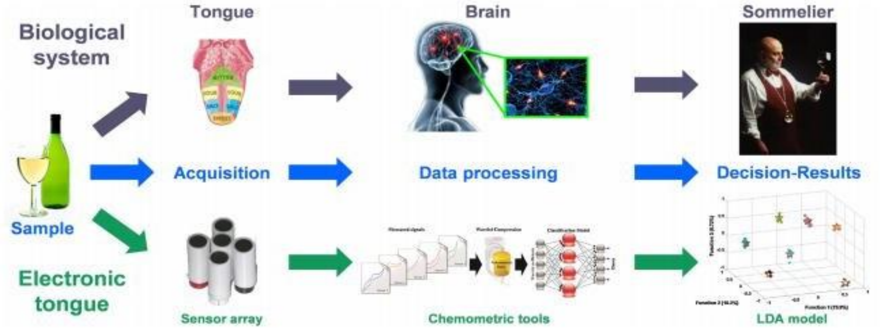

Figure 7: how actually the E-tongue works

Identify	**E nose**
Function	Identify chemical composition of liquids
Application	Wine industry
Principle	100s of microchip Sensors.
Colour change	Depends upon chemicals
Cost	20 USD
PROS	Effective qualitative results

Source (Tan *et al.*, 2020)

Table:3 Importance of E-tongue

2.2.9 Munch-o-matic- An artificial Mouth

This reproduces the result of mastication by chewing the samples and the release of saliva. The rate of food breakdown and the temperature all affect the flavor and smell of food before it’s swallowed (Panda *et al.*, 2020).

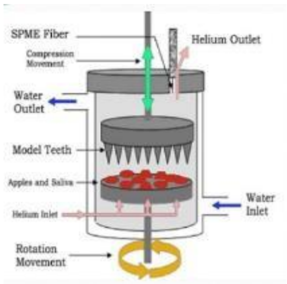

Fig 8: Munch-o-matic- An artificial Mouth

2.2.10 Two-arm MOTOMAN CSDA10F robot

Partial automation, in which the robot performs the repetitive actions of the laboratory staff, thus facilitating routines. This robot assumes handling tasks, but process control remains with lab personnel or automatic analysis system. Full automation of the testing procedure, including sample preparation, pipetting, test implementation and operation of all analytical equipment by the robot. This can independently carry out lab processes 24 hours per day with the highest precision and repeatability (Sasamata *et al.*, 2021).

Fig 9: Two-arm MOTOMAN CSDA10F robot

3.0 Robotics and worker safety

Although the number of deaths caused by robots is very low, data varies on the number of deaths or injuries caused by robots over the past few decades.

In 1942 Asimov created the Three Laws of Robotics, or also known Asimov's Laws, a set of principles robots should follow in the future towards human beings.

- A robot may not injure a human being or, through inaction, allow a human being to come to harm.
- A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
- A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

Through proper implementation of Robots in a manufacturing or production area, it can decrease musculoskeletal disorders, injuries associated with falls from higher places and other hazards that can cause harm to human beings. Robots can also reduce overexertion and repetitive, monotonous or tasks which is often associated with the food chain for example bulk vegetable cutting. Robotics is ideal to work in harsh environments for example in freezers where temperatures reach -18℃ or below. Robots can also assist with heavy lifting, for example in a bakery lifting heavy bread tins, or arranging heavy food items in a dry store (Scheel, 1993).

4.0 Challenges faced by the implementation of robotics in the food chain

The implementation of Robotics will initiate the unforeseen requirements of the policies and regulation related to the operation, usage and legalities of the business. However, the contemporary challenges of implementation of Robots in the food chain are as under.

4.1 Policies and regulations

Policies and regulations need to be in place that will guide the collaboration between humans and robots successfully. In many implementations, the policies and regulations that will guide the collaboration between humans and robotics are not in place once the implementation is completed. In case of an event where it involved a robotic, it will create a new set of issues. “While OSHA (Occupational Safety and Health Administration USA) does not have regulations specific to robots in the workplace, employers would be wise to conduct job hazard analyses and evaluate any existing or potential robotic equipment installation, to abate any hazards posed by these machines.” Companies should have regulations in place for example regulations that protect their work force from a human error involving robotics. A proper analysis should be done of the hazards that could arise from working next to a robot in certain areas. Robots and automation are complex, which leaves the business owner with many questions associated with 'human' and moral values.

5.0 Conclusion

RAS is being developed rapidly and thought to be a promising technology. The adoption of RAS in the food supply chain improves the management as well as increase the quality and efficiency. With the rising labor cost and labor shortage due to uncertain political policies and disruption events, RAS might be one of the approaches to make food affordable. Although several areas of the food manufacturing sector will benefit from robotic devices; the robotic devices specifically designed for food production will help reduce the time and cost of production could make a great contribution to the food manufacturing sector .

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