

1 **ROBOTICS AUTONOMOUS SYSTEMS (RAS) IN FOOD LABORATORIES ARE THE FUTURE**
2 **OF FOOD PROCESSING INDUSTRIES : A REVIEW**

3 **Abstract:**

4 Recent advancements in robotics have witnessed significant progress in both industrial and mobile
5 robotics, paving the way for a new era of automation. However, a paradigm shift is underway in
6 robotics research, focusing on enhancing the interaction between humans and robots, termed as
7 service robotics. This emerging field aims to cater to a wide array of human social needs by
8 bridging the gap between man and machine. Traditionally, laboratory automation has been
9 constrained by the rigid control mechanisms of computer-driven robots. Despite their utility,
10 particularly in liquid handling tasks, many laboratory procedures remain only partially automated.
11 Nonetheless, by breaking down laboratory processes into discrete unit operations and integrating
12 them, overarching analysis schemes can be accomplished. The future of laboratory automation
13 necessitates interdisciplinary skills, requiring scientists to blend biological knowledge with
14 engineering expertise to fully exploit its potential. Simultaneously, a new wave of robotic
15 innovations is permeating various sectors, from robot lawn mowers to autonomous vehicles,
16 alongside smarter robots in manufacturing environments. This progression underscores the
17 increasing reliance on automation, with future research endeavours expected to pivot towards
18 leveraging laboratory automation to tackle novel scientific challenges. This abstract underscore
19 the necessity for future scientists to acquire a comprehensive skill set that integrates both biological
20 knowledge and engineering expertise. It highlights the trend towards greater automation in
21 laboratory environments, representing the merging of scientific and engineering fields to tackle
22 new research challenges.

23 **Key Words: Robotics, automation, pipetting, sample handling, automation, productivity**

24 **1.0 Introduction**

25 “Food crises lead to uneven access to nutritious food in the right amounts and quality,
26 which is recognized as a worldwide risk in society” (22). “Food demand will rise by 59% to 98%
27 by 2050 due to increases in the world population and personal incomes in developing nations” (7).
28 “This necessitates concentrating on enhancing efficiency by implementing cutting-edge
29 technologies such as robotics autonomous systems (RAS) in food laboratories” (15). The concept

30 of robotic automation systems, is not a new one; it has been utilized across various industries. For
31 instance, in construction, RAS is employed to erect high-rise structures (6), while in the tourism
32 sector, it aids in tasks like goods delivery and check-in. Additionally, RAS plays a crucial role in
33 transportation, particularly with the use of self-driving trucks (16).

34 Promising Role of RAS in Enhancing Food Safety and Addressing Supply Chain
35 Challenges (5).

36 **1.1 History of Robotics**

37 The origin of the term “robot” is placed in more recent times: namely, it comes from the
38 Czech word “robota”, meaning “heavy work” or “forced labor”. The term "robotics" was
39 introduced by the Czech writer Karel Capek (1890-1938) in 1920 in his novel. “Industrial
40 applications of robotics have gained paramount importance in the last century. The beginning of
41 “Industrial Robotics”, as we currently define it, can be dated back to the 1950s, although some
42 kinds of automatization in the industrial environment have started to appear since the Industrial
43 Revolution. The evolution of industrial robots can be subdivided into four categories, as in, with
44 the first three covering the time span from the 1950s to the end of the 1990s. Fourth-generation
45 robots (which range from 2000 to the present), are characterized by high-level “intelligent”
46 features such as the capability of performing advanced computations, logical reasoning, deep
47 learning, complex strategies and collaborative behavior”. (23)

48 **1.2 Basic components of a robotic system:**

- 49 ✓ **Power supply:** The power supply provides electrical energy to the robotic system,
50 powering all its components. It could be a battery, mains electricity, or another power
51 source depending on the application.
- 52 ✓ **Actuators:** Actuators are devices that convert energy into mechanical motion. They are
53 responsible for the movement of the robot, such as rotating a joint, extending an arm, or
54 moving a gripper. Common types of actuators include electric motors, pneumatic cylinders,
55 and hydraulic systems.
- 56 ✓ **Electric motors (DC/AC):** Electric motors are a type of actuator that converts electrical
57 energy into rotational mechanical energy. Direct Current (DC) motors are often used in
58 robotics for their simplicity and controllability, while Alternating Current (AC) motors
59 might be used for specific applications requiring higher power or speed.

- 60 ✓ **Sensors:** Sensors are devices that detect and respond to changes in the robot's environment
61 or internal state. They provide feedback to the controller, allowing the robot to perceive
62 and interact with its surroundings. Examples of sensors used in robotics include proximity
63 sensors, cameras, lidar, accelerometers, and gyroscopes.
- 64 ✓ **Controller:** The controller is the brain of the robotic system. It processes information from
65 sensors, determines the appropriate actions based on programming or algorithms, and sends
66 commands to the actuators to execute those actions. The controller's functionality can vary
67 from simple microcontrollers for basic tasks to sophisticated computers running complex
68 algorithms for advanced robotics applications.

69 **1.3. Reasons for automating processes**

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

73 **2.0 ROLE OF ROBOTICS IN THE FOOD SAFETY:**

74 “Generally, food safety refers to the avoidance of illnesses resulting from the consumption
75 of contaminated food. The issue of food safety has been increasingly discussed through product
76 recalls; for example, the presence of Salmonella in chickens. Another well-known example of a
77 food safety crisis was the discovery of horsemeat in some beef products, as well as the increased
78 detection of porcine DNA in some processed “Halal” products in the United Kingdom” (9). “The
79 growing attention towards food safety might be due to increasingly stricter legislation and
80 economic motivation” (1). “Food safety failure or recall can be a devastating factor that often
81 tarnishes a company’s reputation” (19). “A wide range of standards and systems has been
82 developed to help companies manage food safety issues. For example, the Hazard Analysis Critical
83 Control Point (HACCP) system aims to analyze and control biological, chemical, and physical
84 hazards across the entire food supply chain” (8). “The core idea of HACCP is to offer a structured
85 method to identify risks along the food supply chain and where possible either reduce those risks
86 or eliminate them. The underlying feature of HACCP systems is the traceability of products along
87 the food supply chain. The government has enforced legislation to encourage traceability during
88 all stages of production, manufacturing, and distribution. However, the complex and

89 interconnected nature of food supply chains limits their traceability in the food industry. In this
90 context, food companies have used RAS to address traceability within their supply chains”. (11),
91 high-lighted a recent success story in which Walmart used RFID technology to improve food
92 safety on the dinner tables of Chinese consumers. In this application, information such as farm
93 origin, storage temperatures, processing data, expiration dates, and transportation details from an
94 ecosystem of suppliers to store shelves and end users may indicate potential food safety hazards.

95 Alternatively, (2) used “RFID and a wireless sensor network to measure the temperature
96 and humidity of kimchi during its storage and shipping in South Korea. The proposed method
97 assists in optimizing kimchi distribution, monitoring freshness, and improving consumer
98 satisfaction”. “However, the full benefits of RFID can only be realized if all enterprises in the food
99 chain use this technology” (3). “The full application of RFID technology across the supply chain
100 increases enterprise risks and expenses” (10). Because of the intricacy of the food supply network
101 and the fact that the majority of food enterprises are small and medium-sized, these requirements
102 pose significant challenges to RFID adoption in the food supply chain.

103 **2.1 Role of robotics and their importance in food laboratories**

104 Automation in food laboratories aims to reinforce aspects that are elemental to its sustenance are
105 underachieving. Despite the laboratory being one of the largest, the greater dependence on human
106 labor to execute repetitive functionalities has deflated its economy. The ratio of production to
107 demand was very low. At times, this disrupts the demand-and-supply chain causing inflation in
108 food grain prices and food shortages.

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

114 **2.2 Types of some robotics used in food laboratories**

115 **2.2.1 Pickolo™ Colony-Picker**

116 “Pickolo™ is a colony picker add-on for Tecan robots. The product enables advanced and
117 fully automated microorganism colony picking from agar plates, both Petri dishes, and various
118 multi-well plate formats, based on diverse criteria such as the size, shape and color of the colonies.

119 The product was seamlessly installed on the robot for a few just a few minutes. The software is
120 easily integrated into regular Tecan scripts such as Freedom EVO ware® software enabling colony
121 picking downstream and upstream to other robotic tasks. The software generates automatic
122 documentation of selected colonies” (4).

123 **Features:**

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



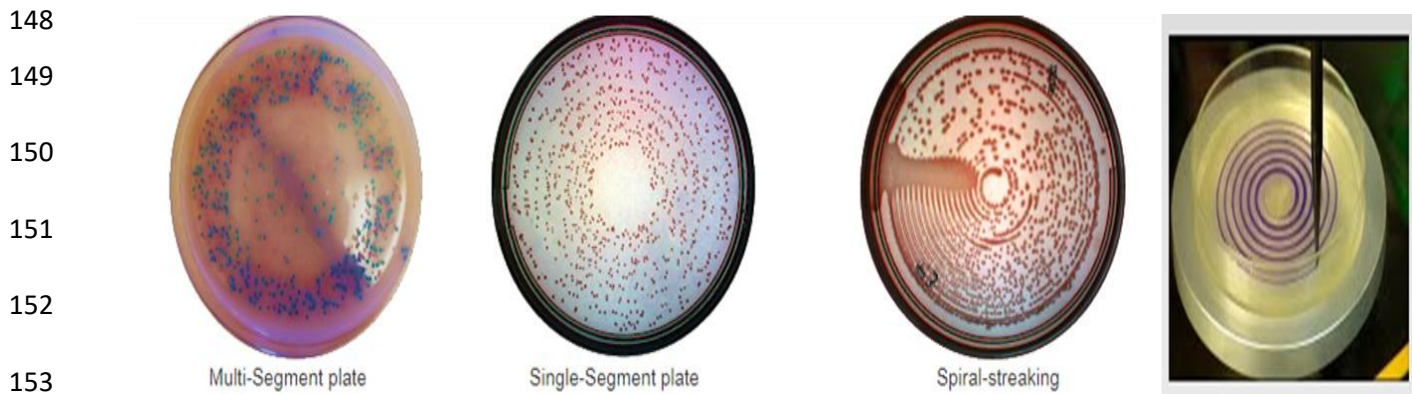
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138 **Figure 1: Pickolo™ Colony-Picker**

139 **2.2.2 PetriPlater™ Robotic Spiral Plating and Streaking**

140 “Automate dilution plating and spiral sample plating on Freedom EVO® 75 with
141 SciRobotics’ Petri Plater add-on. This provides state-of-the-art hardware and software to automate
142 colony-picking experiments in an easy and cost-effective manner. The Robotic Manipulator
143 Arm™ brings the source plate to the light table, and a high-resolution camera captures a photo.

144 The Pickolo software then analyzes the image and selects colonies for selection according to your
145 individual criteria. The template script provided makes it simple to set up the picking process while
146 maintaining the freedom to define a variety of different colony selection criteria, microorganisms
147 and agar types” (21).

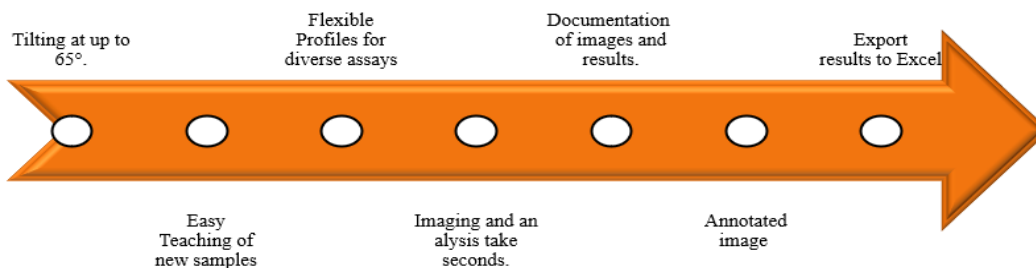


154 **Figure 2: Petri Plater™ Robotic spiral plating and streaking**

155 2.2.3 FluHema™ Hemagglutination Analyzer

156 It can image an assay microplate, interpret the results and report them in multiple ways.
157 The plates could be can be tilted for imaging at up to 65°. The results were are analyzed using
158 advanced computer vision techniques to identify the positive and negative wells. The algorithm
159 can be easily tailored by the user for a specific assay by providing typical examples. All results
160 have been documented and can be easily reviewed by lab personnel.

161 Fig 3: Advantages



163 2.2.4 GF Pickolo - GFP fluorescence colony picking

164 These robots select the colonies with the strongest fluorescent signal or weakest
 165 fluorescent signal. They can use the average cumulative signal or even pick the colonies with the
 166 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

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

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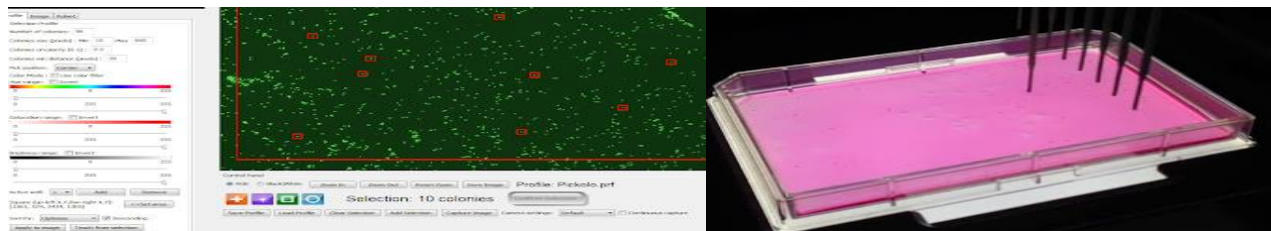
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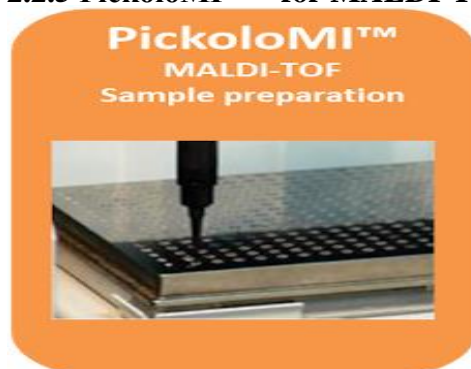
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Figure 4: GFPickolo - GFP fluorescence colony picking

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2.2.5 PickoloMI™ - for MALDI-TOF Microbial Identification

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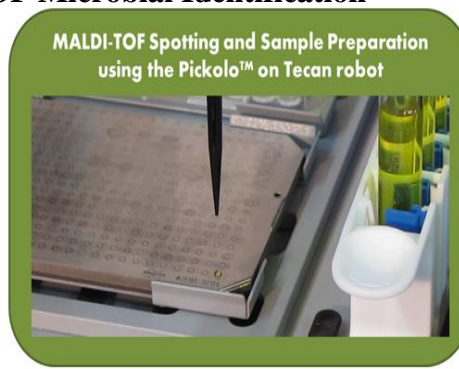


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Fig 5: PickoloMI™ - for MALDI-TOF microbial identification

Advantages:

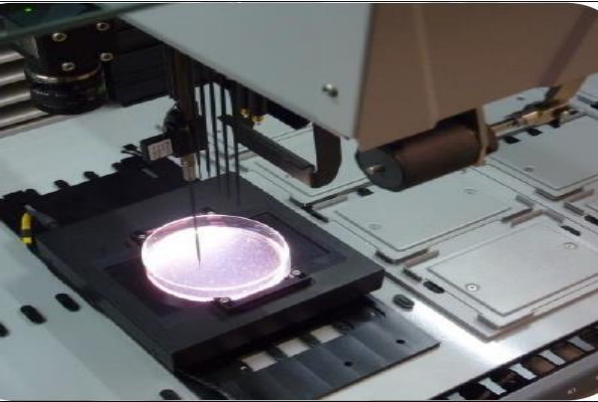
- ✓ Direct smearing: colony is smeared directly on MALDI target using disposable tip
- ✓ Smart algorithm: specifically designed for automatic colony selection for MALDI
- ✓ Sample tracking: Samples are automatically assigned to spots using a barcode reader
- ✓ Documentation: easy review of plate and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

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

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

2.2.7 PickoCell™ picking stem-cell colonies on Tecan Robots

“It is composed of a special dark field illumination table combined with a high-resolution camera and Pickolo versatile and flexible image analysis software. The solution provides both interactive and automatic colony selection based on diverse criteria for the desired colonies. By Using the robot tips, colonies covered with a thin layer of media were accurately and gently aspirated from the plate bottom and dispensed into a tube or collection plate while keeping the colonies viable and intact” (13).



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Fig 6: PickoCell™ picking stem-cell colonies on Tecan Robots

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210 2.2.8 Sensory robotics E-nose

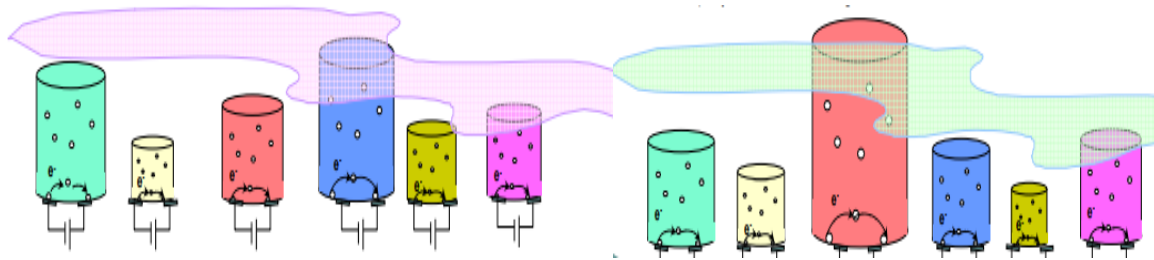
211 “It consists of different polymer films, specially designed to conduct electricity. When a substance
212 is absorbed into these films, the films expand slightly, which changes the amount of electricity that
213 they conduct. Each electrode reacts with a particular substance by changing its electrical resistance
214 in a characteristic manner” (12).

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Figure 7: Baseline resistance of the E-nose smelling properties

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

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

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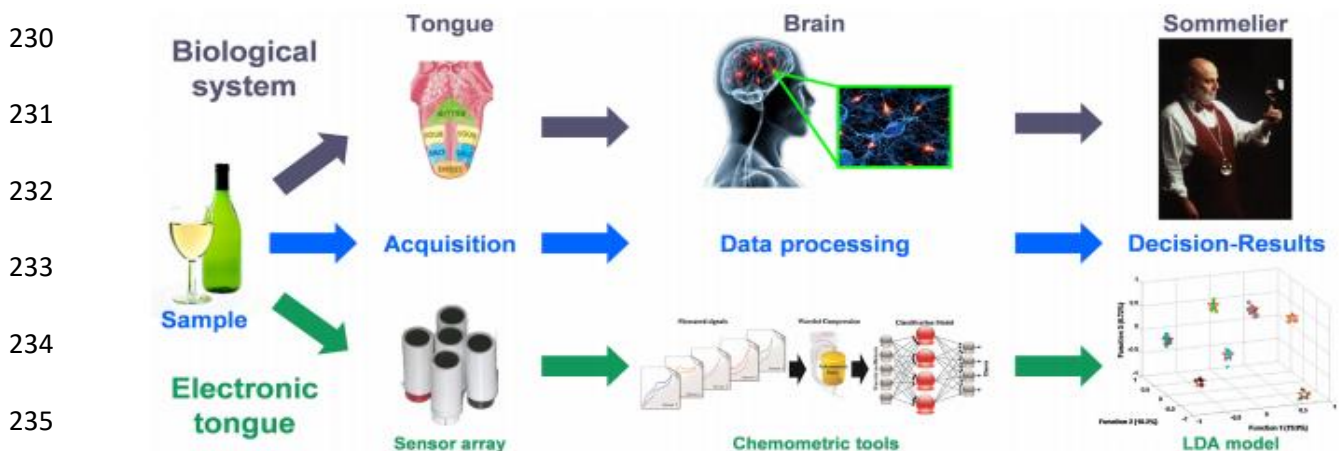
Source (20)

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Table 2: similarities between biological nose and E nose

225 **2.2.9 Sensory robotics E-tongue**

226 An electronic tongue is a device made of sensors that respond to some taste (soluble) of foods
 227 through the transduction of a signal or a pattern of signals using a pattern-recognition software
 228 system. This is able to quantify bitterness or “spicy level” of drinks or dissolved compounds,
 229 quantify taste masking efficiency of formulations (20).



236 **Figure 8: how actually the E-tongue works**

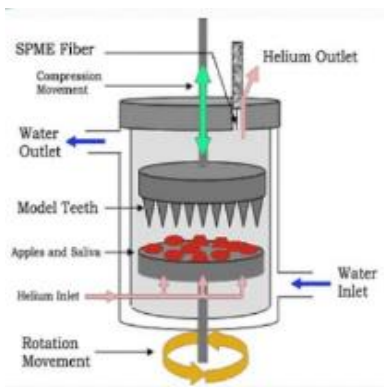
Identify	E nose
Function	Identify chemical composition of liquids
Application	Wine industry
Principle	100s of microchip Sensors.
Colour change	Depends upon chemicals
Cost	20 USD
PROS	Effective qualitative results

237 Source (20)

238 **Table:3 Importance of E-tongue**

239 **2.2.10 Munch-o-matic- An artificial Mouth**

240 “This reproduce the results of mastication by chewing the samples and the releasing saliva. The
 241 rate of food breakdown and the temperature all affect the flavor and smell of food before it is
 242 swallowed” (14).



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Fig 9: Munch-o-matic- An artificial Mouth

248 **2.2.11 Two-arm MOTOMAN CSDA10F robot**

249 “Partial automation, in which the robot performs repetitive actions by the laboratory staff,
250 thereby facilitating routines. This robot handles tasks, but process control remains with lab
251 personnel or an automatic analysis system. The testing procedure was fully automated, including
252 sample preparation, pipetting, test implementation and operation of all analytical equipment by the
253 robot. This can independently carry out laboratory processes 24 h per day with the highest
254 precision and repeatability” (17).

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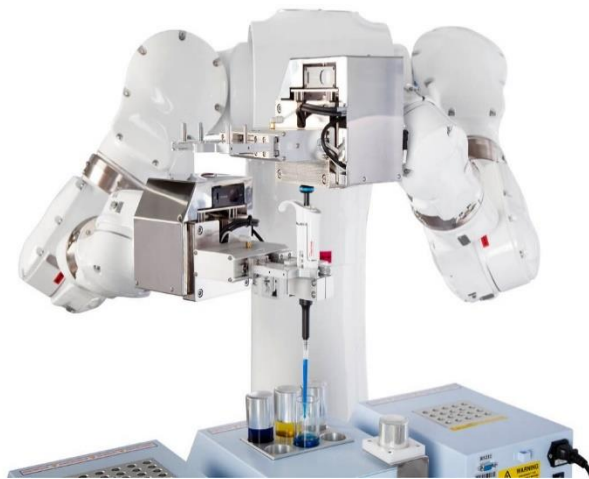
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Fig 10: Two-arm MOTOMAN CSDA10F robot

264 **3.0 Robotics and worker safety**

265 Although the number of deaths caused by robots is very low, data have varied in the number
266 of deaths or injuries caused by robots over the past few decades.

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

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

275 “Through proper implementation of Robots in manufacturing or production areas,
276 musculoskeletal disorders, injuries associated with falls from higher places and other hazards that
277 can cause harm to human beings can be decreased. Robots can also reduce overexertion and
278 repetitive, monotonous tasks which are often associated with the food chain for example, bulk
279 vegetable cutting. Robotics is ideal to work in harsh environments for example in freezers where
280 temperatures reach -18°C or below. Robots can also assist with heavy lifting, for example in a
281 bakery lifting heavy bread tins, or arranging heavy food items in a dry store” (18).

282 **4.0 Challenges faced by the implementation of robotics in the food chain**

283 The implementation of robotics will initiate the unforeseen requirements of the policies and
284 regulations related to the operation, usage and legalities of the business. However, the
285 contemporary challenges in the implementation of robots in the food chain are as follows.

286 **4.1 Policies and regulations**

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

298 **5.0 Conclusion**

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

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