

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

19 **Abstract:** It is suggest to rewrite indicating the problem, objective and results of the review.

20 The industrial robotics and mobile robotics and then expand on new trends in robotics research
21 that focus more on the interaction between human and robot. ~~The~~ ^{New} new trends in robotics research
22 have been denominated ^{as} service robotics because of their general goal of getting robots closer to
23 human social needs. Laboratory automation was thought to be limited to ~~only some extent~~ ^{certain extent because}
24 ~~Since~~ the laboratory robot is computer-controlled and computer-driven, ^{and} then consideration
25 must be given to the operation and programming of the unit. Each laboratory procedure, ~~no~~
26 ^{regardless of,} ~~matter how complex,~~ can be broken down into a series of discrete laboratory unit operations,
27 and these building blocks can therefore be integrated to allow the accomplishment of the
28 overall analysis scheme. ^{Although} While robotics systems have been useful tools in the laboratory for many
29 years, most notably in the area of liquid handling, many tasks are still only automated to a small

30 extent. At the same time, a new wave of robotic devices is reaching the market, from robot lawn
 31 mowers to driverless cars, as well as smarter robots in manufacturing. Future generations of
 32 scientists ~~will~~ need to possess both biological and engineering abilities ~~in order~~ to fully realize the
 33 potential of laboratory automation. Future research ~~programmes~~ ^{programs} will probably depend ~~more and~~
 34 ~~more~~ on automation in the lab, continuing the trend of fusing scientific and engineering knowledge
 35 ~~to~~ ^{the} address original research problems.

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

References must be cited in accordance with the journal's standards.

36 1.0 Introduction

37 Food crises lead to uneven access to nutritious food ~~in~~ ^{of the} the right amounts and quality, which
 38 is recognized as a worldwide risk in society ^[1] (World Economic Forum, 2020). Food demand will
 39 rise by 59% to 98% by 2050 due to increases in the world population and personal incomes ~~in~~
 40 developing nations (Elferink and Schierhorn, 2016). This necessitates concentrating on enhancing
 41 efficiency by implementing cutting-edge ~~technology like~~ ^{technologies such as} autonomous systems and robotics (RAS)
 42 in food laboratories (Rehman *et al.*, 2019). RAS is not a novel idea; it is employed in the
 43 construction business to create high-rise structures (Cai *et al.*, 2019), in the tourism sector for
 44 goods delivery and check-in and in transportation using self-driving trucks (Sanders *et al.*, 2019).
 45 The application of RAS in food safety is a promising area ~~to address~~ ^{for addressing the} difficulties in the food supply
 46 chain (Bouzembrak *et al.*, 2019).

47 1.1 History of Robotics

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

60 1.2 Basic components of a robotic system:

- 61 ❖ Power Supply
- 62 ❖ Actuators
- 63 ❖ Electric motors (DC/AC)
- 64 ❖ Sensors:
- 65 ❖ Controller

66 1.3. Reasons for automating processes

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

70 2.0 ROLE OF ROBOTICS IN FOOD SAFETY: ^{IN THE}

71 Generally, food safety refers to the avoidance of ^{illnesses} illness resulting from the consumption of
 72 contaminated food. The issue of food safety has been increasingly discussed through products-
 73 recalls, for example, the presence of ^{Salmonella chickens} salmonella in chicken. Another well-known example of food
 74 safety crisis was the discovery of horsemeat in some beef products ^{, as} as well as the increased
 75 detection of porcine DNA in some processed “Halal” products in the United Kingdom (Fuseini *et*
 76 *al.*, 2021). The growing attention towards food safety might be because of the increasingly stricter
 77 legislation and economic motivation (Akkerman *et al.*, 2010). ^{Food} The food safety failure or recall can
 78 be a devastating factor and often tarnishes a company’s reputation (Soon *et al.*, 2020). A wide
 79 range of standards and systems ^{has} have been developed to help companies ~~in order to~~ manage food
 80 safety issues. For example, the Hazard Analysis Critical Control Point (HACCP) system aims to
 81 analyze and control biological, chemical, and physical hazards from the entire food supply chain
 82 (FDA, 2004). The core idea of HACCP is to offer a structured method to identify risks along the
 83 food supply chain and where possible either reduce those risks or eliminate them. The ^{underlying feature} underline
 84 of HACCP systems is the traceability of products along the food supply chain. ^{The government} Government has
 85 enforced legislation to ~~actively encourage the~~ traceability during all stages of production,
 86 manufacturing, and distribution. However, the complex and interconnected nature of food supply
 87 chains limits ^{their} the ability to ~~undertake~~ traceability in the food industry. In this context, food
 88 companies have used RAS to address ~~the~~ traceability within their supply chains. Kshetri (2018),

89 high-lighted a recent success story in which Walmart used RFID technology to improve food
 90 safety on the dinner tables of Chinese consumers. In this application, information such as farm
 91 origin, storage temperatures, processing data, expiration dates, and transportation details from an
 92 ecosystem of suppliers to store shelves and end users may ^{indicate} show potential food safety hazards.

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

102 2.1 Role of robotics and their importance in food laboratories

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

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

113 2.2 Types of some robotics used in food laboratories

114 2.2.1 Pickolo™ Colony-Picker

115 Pickolo™ is a ^{colony picker} colony-picker add-on for Tecan™ robots. The product enables advanced and
 116 fully automated ^{micro-organism} micro-organism colony picking from agar plates, both ^{Petri dishes,} Petri-dish and various
 117 multi-well plate formats, based on diverse criteria such as ^{the} size, shape, and color of the colonies.
 118 The product ^{was} seamlessly installed on ^{to} the robot in just a few ^{for a few} minutes. The software is easily

119 integrated into regular Tecan scripts such as Freedom EVOware® software enabling colony
120 picking downstream and upstream to other robotic tasks. The software generates automatic
121 documentation of ~~the picked~~^{selected} colonies (Bodai *et al.*, 2017).

122 **Features:**

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

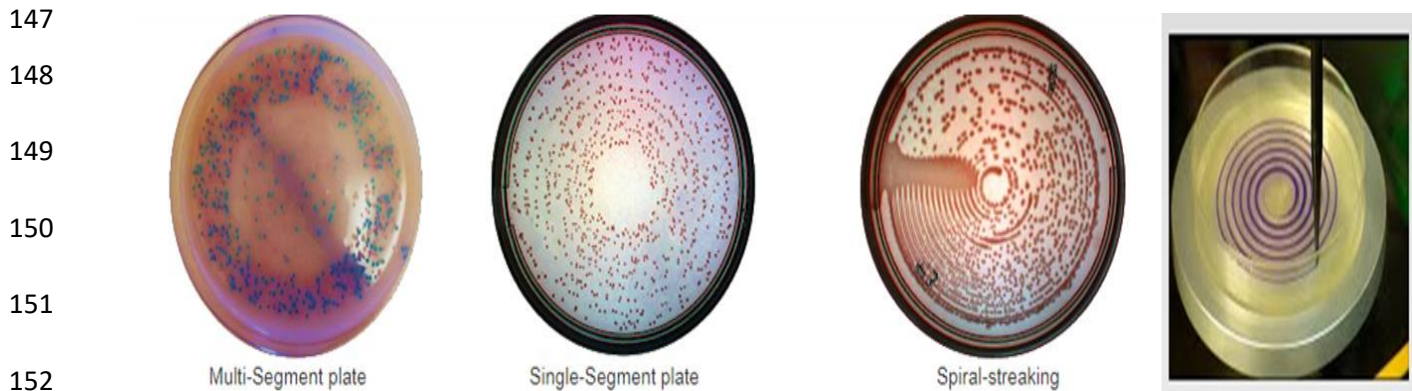


137 **Figure 1: Pickolo™ Colony-Picker**

138 **2.2.2 PetriPlater™ Robotic Spiral Plating and Streaking**

139 Automate dilution plating and spiral sample plating on ~~the~~ Freedom EVO® 75 with
140 SciRobotics' PetriPlater add-on. This provides state-of-the-art hardware and software to automate
141 ~~your~~ colony-picking experiments in an easy and cost-effective ~~way~~^{manner}. The Robotic Manipulator
142 Arm™ brings the source plate to the light table, and a high-resolution camera ~~takes~~^{captures} a photo. The
143 Pickolo software then analyzes the image and selects colonies for picking according to ~~your~~^{selection}.

144 individual criteria. The template script provided makes it simple to set up the picking process while
 145 maintaining the freedom to define a variety of different colony selection criteria, **microorganisms**
 146 and agar type (Truswell *et al.*, 2021).

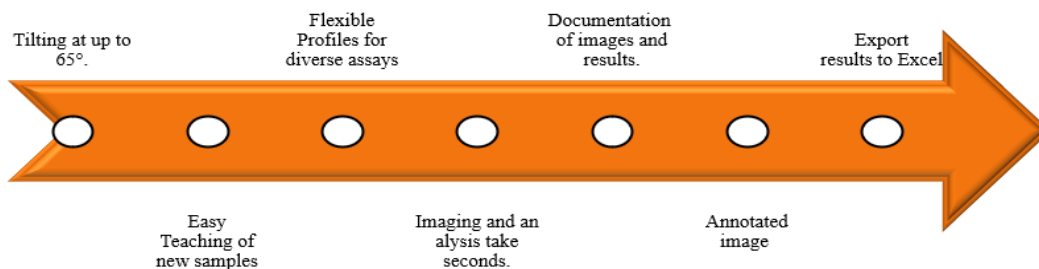


153 **Figure 2: PetriPlater™ Robotic spiral plating and streaking**

154 **2.2.3 FluHema™ Hemagglutination Analyzer**

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

160 **Advantages:**

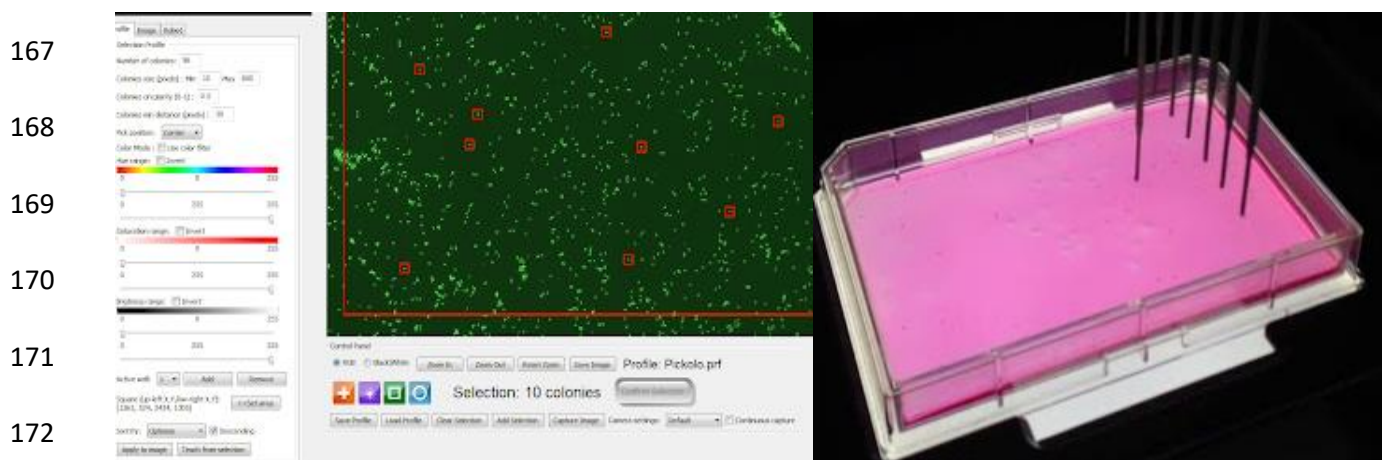


162 **2.2.4 GF Pickolo - GFP fluorescence colony picking**

163 **select the** These robots pick the colonies with the strongest fluorescent signal **or weakest fluorescent signal.**
 164 **the** can use average ~~signal~~ or cumulative signal or even pick the colonies with the largest
 165 fluorescent signal to maximize protein secretion.

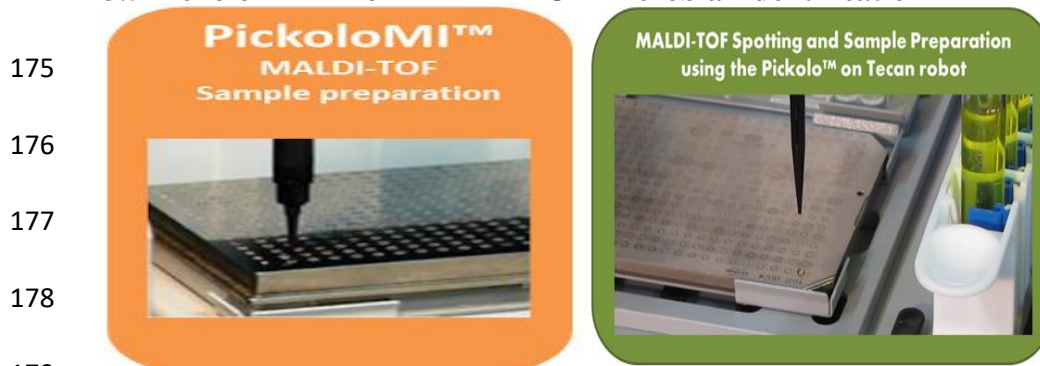
Properties	Performance
High-resolution industrial grade camera and lens (10MB)	Perform fluorescence imaging of colonies expressing GFP
Optical filter for the fluorescence imaging	Select the colonies based on sophisticated and flexible criteria combining properties from both back-light imaging and fluorescent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

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



173 **Figure 3: GFPickolo - GFP fluorescence colony picking**

174 **3.5 PickoloMI™ - for MALDI-TOF Microbial Identification**



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

181 **Advantages:**

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

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

187 **2.2.5 PetriSel™: Petri-Dish Carousel Add-On for Tecan Robots**

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

193 **2.2.6 PickoCell™ picking stem-cell colonies on Tecan Robots**

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



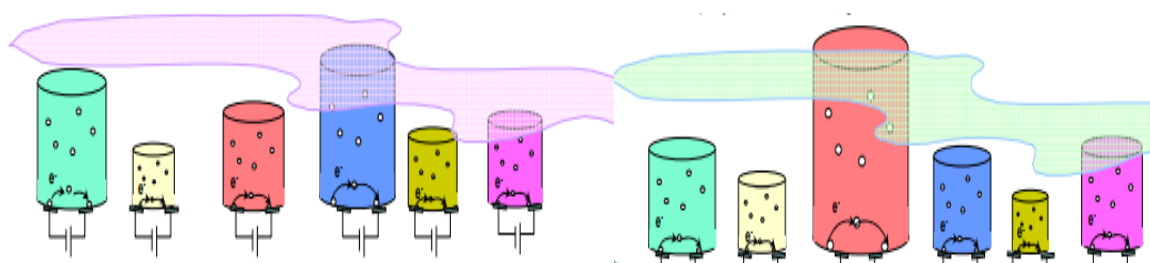
206 **Fig 5: PickoCell™ picking stem-cell colonies on Tecan Robots**

207

208

209 **2.2.7 Sensory robotics E-nose**

210 ~~In consists~~
 211 Consists of different polymer films, ~~which are~~ specially designed to conduct electricity. When a
 212 substance is absorbed into these films, the films expand slightly, ~~and that~~ ^{which} changes ^{the amount of}
 213 electricity they conduct. Each electrode reacts ^{that they} to particular substances ^{with a} by changing its electrical
 214 resistance in a characteristic way ^{manner} (Moshayedi *et al.*, 2023).



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

219 Each polymer changes its size, ~~x~~ and therefore its resistance, by a different amount, making
 220 a pattern of the change. If a different compound had caused the air to change, the pattern of the
 221 polymer 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

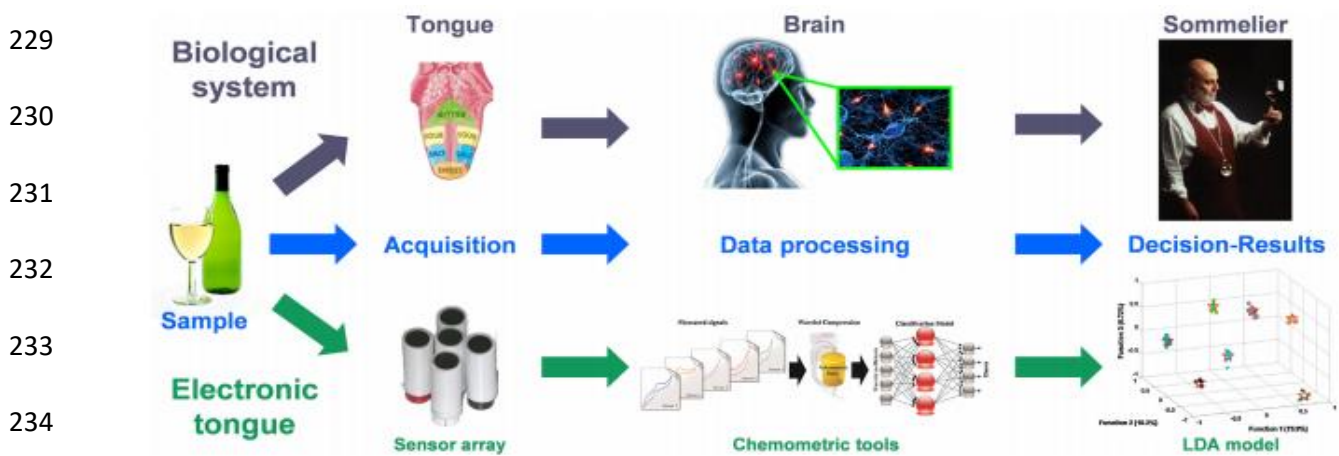
222 Source (Tan *et al.*, 2020)

223 **Table 2: similarities between biological nose and E nose**

224 **2.2.8 Sensory robotics E-tongue**

225 An electronic tongue is a device made of sensors responding to some taste (soluble) of foods
 226 through the transduction of a signal or a pattern of signals ^{that respond} ~~thanks to~~ ^{using a} pattern-recognition software

227 system. This is able to quantify bitterness or “spicy level” of drinks or dissolved compounds,
 228 quantify taste masking efficiency of formulations (Tan *et al.*, 2020)



235 **Figure 7: how actually the E-tongue works**

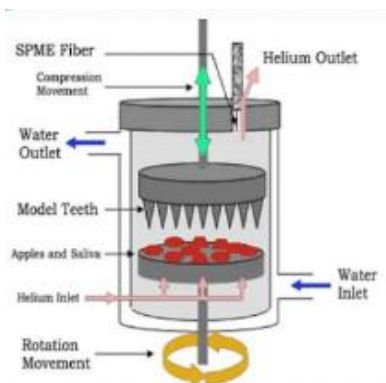
Identify	E nose
Function	Identify chemical composition of liquids
Application	Wine industry
Principle	100s of microchip Sensors.
Colour change	Depends upon chemicals
Cost	20 USD
PROS	Effective qualitative results

236 Source (Tan *et al.*, 2020)

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

238 **2.2.9 Munch-o-matic- An artificial Mouth**

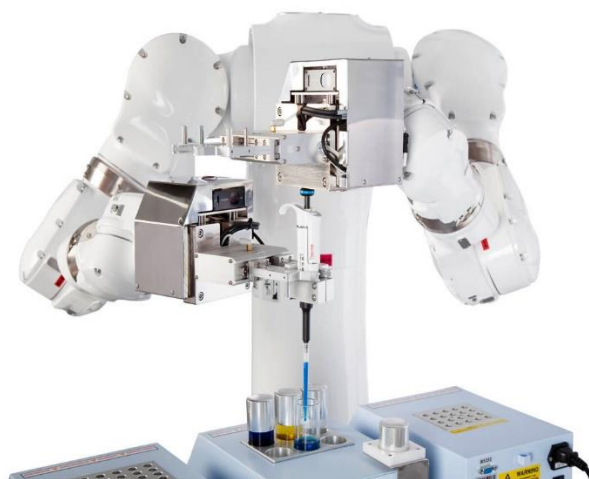
239 This reproduces the result of mastication by chewing the samples and the release of saliva. The
 240 rate of food breakdown and the temperature all affect the flavor and smell of food before it's
 241 swallowed (Panda *et al.*, 2020).



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

247 2.2.10 Two-arm MOTOMAN CSDA10F robot

248 Partial automation, in which the robot performs ~~the~~ repetitive actions ^{by} of the laboratory staff,
 249 ^{thereby} thus facilitating routines. This robot ^{handles} ~~assumes handling~~ tasks, but process control remains with lab
 250 personnel or automatic analysis system. ^{or an} ~~The testing procedure was fully automated,~~ Full automation of the testing procedure, including sample
 251 preparation, pipetting, test implementation and operation of all analytical equipment by the robot.
 252 This can independently carry out lab processes ^{laboratory} 24 h per day with the highest precision and
 253 repeatability (Sasamata *et al.*, 2021).



261 **Fig 9: Two-arm MOTOMAN CSDA10F robot**

262 3.0 Robotics and worker safety

263 Although the number of deaths caused by robots is very low, data ^{have varied in the} varies on the number of
 264 deaths or injuries caused by robots over the past few decades.

265 *In 1942, Asimov created the Three Laws of Robotics, or ^{also known as Asimov's} also known Asimov's Laws, a set of*
 266 *principles robots should follow in the future towards human beings.*

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

302 specifically designed for food production will help reduce the time and cost of production could
 303 make a great contribution to the food manufacturing sector .

References must be presented in accordance with the journal's standards.

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