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A methodology for the selection of industrial robots in food handling

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ABSTRACT

As the global population continues to rise and consumer demand for a wider variety of food products increases, food manufacturers are exploring various strategies, methods and tools to change and adapt. Furthermore, restriction in access to low-cost labour and introduction of more stringent legislation are forcing the food industry to update their production processes. Industrial robots, a pillar of Industry 4.0, promises many benefits to the food manufacturing industry, especially in responding to these new challenges. The integration of such automation into food manufacturing has been a slow process in comparison to other manufacturing sectors and has largely been limited to packaging and palletising. This research aims to improve the application of industrial robots within food manufacturing through definition of a methodology for the identification of a flexible automation solution for a specific production requirement. The paper explores the four steps within the Food Industrial Robot Methodology (FIRM), through which users define, classify and identify their foodstuff and automation solution. The application of FIRM is exemplified through an industrial case study to support food manufacturers investigating the potential benefits of utilising industrial robots within their production systems.

1. Introduction

Feeding the ever-growing population of the World with changing dietary requirements and preferences is becoming one of the leading global societal concerns. Producing enough food is no longer the only worry, the rapid growth of allergies and intolerances as well as special diets due to non-communicable diseases such as diabetes, heart and kidney conditions have added to the strain as producers' race to cater to all customers. Furthermore, globalisation of food manufacturing has resulted in more demands for diverse cuisines and products (Kodituwakku, Nobel, & Apostolidis, 2013). As the list of pressures on food producers posed by consumer demands as well as changes in the environment and legislation continues to grow, one of the key solutions to tackle these changes is the large-scale adoption of 'flexible' automation processes. This is supported by the onset of Industry 4.0 that promises growth via the Internet of Things (IoT) (Alcácer & Cruz-Machado, 2019), which is heavily supported by the use of artificial intelligence and Industrial Robots (IR) in all manufacturing systems (Demartini et al., 2018; UK-RAS Network, 2016).

For years literature has outlined the benefits that flexible automation would offer the food industry. Wallin (1997), Chua, Ilschner, and Caldwell (2003), Mueller, Kuhlenkoetter, and Nassmacher (2014), Luo (2015), Iqbal, Khan, and Khalid (2017) have all agreed that IR will specifically facilitate increased hygiene, flexibility and reconfigurability, as well as improving efficiency and productivity.

An extensive list of IR benefits and their methods of improving food manufacturing are outlined in Table 1. These benefits are widely observed by IR manufacturers who contribute with the design of customised systems as well academic researchers who have developed bespoke food IR in recent years. Many of these IR designs have been proposed for various stages of the food manufacturing, but most common applications are seen in food finishing processes such as packaging and palletising (KUKA, 2013). The applications of IR in food industry can be broadly classified into three categories of material handling, assembly, and finishing processes. Material handling refers to the transportation of materials, in part or as a whole, from one place to another. Assembly includes the manufacturing of two or more materials into one part of, or a whole congregated product. These operations typically include a series of pick and place operations along the processing line.

Despite the emergence of Industry 4.0, IR uptake remains low (Caldwell, 2013) due to a few contributing factors, including stringent hygiene requirements, complex foodstuff characteristics and organoleptic properties, the shortage of skilled operators as well as a range of economic and social barriers (Bader & Rahimifard, 2018; Iqbal et al., 2017). A list of characteristics of foodstuffs and the properties which

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Abbreviations: IR, industrial robot; FV, Foodstuff Variety; FIRM, Food Industrial Robot Methodology

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Table 1
Industrial robot capabilities and their possible benefits to manufacturers.

Industrial robot capabilities		Method of benefit
Decrease	Production cost	Reduce costs associated with manual labour and utility expenses
	Material waste	Increased efficiency allows for reduction of production material waste and less scrap from rejects
	Capital cost	
	Floor space	Compact systems with mounting versatility
	Production time	Higher speed and efficiency, fast reconfigurability
Improve	Product quality	More efficient process control, high repeatability and accurate task execution
	Product uniformity	Errors caused by human error and fatigue eliminated
	Working environment	Existing labour upgraded, removes humans from unfavourable conditions and tedious tasks
Increase	Production rates	Ability to produce 24/7 without disruptions
	Flexibility	Reconfigurable and easy to apply to a variety of tasks
	Safety compliance	Works in hazardous environments, made of hygienic materials
	Competitive advantage	Faster response to market demands, allows for product customisation and personalisation
	Efficiency	Optimised processes, increased yield

Table 2
Foodstuff characteristics and the challenges they pose to automation.

Foodstuff characteristic	Effect on automation	Example
Naturally soft or fragile	● Loss of grip probable ● Likely damaged under pressure	Tomatoes, berries, figs, cheeses, eggs
Slippery surfaces	● Loss of grip by slippage	Cut-up fruits, peeled vegetables, meat and poultry
Non-rigid or semi-rigid	● Likely damaged under pressure	Apricots, cheeses, pastries, meat and poultry
Irregular shapes and sizes	● Likely affects surface grip ● Systems will require visual systems for IR to assess each individual item and use decision making to handle it	All-natural foodstuffs are irregular in shapes and sizes
Uneven surfaces		Avocados, meat and poultry

are susceptible to damage by handling and processing are included in Table 2. Due to these characteristics, any faults imposed by handling and processing can greatly affect the organoleptic properties. Furthermore, these properties represent the aspects of foodstuffs which are associated with the consumer's senses. Sight, taste, smell and the texture of foodstuffs can vary in a negative sense if foodstuff are handled incorrectly (Mueller et al., 2014; Nayik, 2015). For example, bruising in fruits damages the structural integrity of the foodstuff, changing the texture, releasing juices and causing discolouration, therefore altering the taste, visual appeal and quality. Inadequately designed automation systems can inflict such damage to foodstuffs; however, technological advancement of sensor technologies allow for the design of IR that can manage them. There are a range of sensors being used in such automation including tactile, proximity and vision sensors, that can be used to tackle challenges posed by foodstuff requirements (Li & Liu, 2019). Other concerns include the belief that IR cannot maintain the hygienic requirements posed by the food industry, however, IR systems can be built from food-grade stainless steel and designed to withstand stringent cleaning schedules to conform to hygiene legislation. One of the other most challenging hindrances is the shortage of skilled developers and operators (Wilson, 2010) of IR systems in the food industry. This is augmented by both the workforce in the food industry not being aware of the benefits of IR or their applicability as well as the IR developers not fully understanding the specific characteristics of foodstuffs and their production requirements (Bader & Rahimifard, 2018).

2. Methodology for the selection of industrial robots for food manufacturing applications

The abovementioned challenges associated with the handling and processing of natural foodstuffs indicates that an innovative method is needed to identify and select appropriate IR for specific applications in food industry. While foodstuff processing includes highly complex operations which typically employee bespoke and specialised automation, foodstuff handling can be simplified and generalised. In this context, a Food Industrial Robots Methodology (FIRM) has been devised which analyses foodstuff characteristics and production requirements to identify the most appropriate IR physical configuration, as well as the end effector mechanisms, for a specific application. To achieve this, FIRM consists of four steps which navigate the consideration of eight different factors, which are shown in Fig. 1 and described below.

2.1. Navigating the FIRM Steps

2.1.1. Step 1: Define Food Characteristics

The first step involves defining the foodstuff and classifying their fundamentals by identifying the nature of where the ingredient originates. It is imperative that users of the FIRM are fully aware of the specifications of the foodstuff they are investigating. Three tasks within this step include identifying foodstuff type, condition and state.

2.1.1.1. Foodstuff type. Foodstuff reflects the origin of the product being handled, identifying the type lays the basis of the material's texture and their change under different forms of preparation, which further determines hand-ability requirements. The following five types of foodstuff have been identified based on most commonly used ingredients. In addition, a sixth option allows users to define the condition and state of the foodstuff if it cannot be categorised under the other five types. These types of foodstuffs are classified as:

1. *Meat and Poultry*; derivatives of animals in the form of their muscles and organs. This includes but is not limited to; red meats from cattle, sheep, pigs, as well as meats from chickens and other such poultry.
2. *Seafood*; any type of fish, shellfish and other sea creatures, prepared to be consumed in whole or sectioned, and in a raw or cooked form.
3. *Vegetables and Fruit*; various parts extracted from plants and trees. Vegetables are those that are commonly eaten as part of a main meal and fruits are generally consumed individually or as part of dessert meals.
4. *Baked Goods and Confectionary*; products that combine two or more components and are subjected to heat treatment in ovens before consumption. This category includes items such as bread, cakes and pastries, as well as confectionary items like sweets and chocolates.
5. *Dairy Derivatives*; processed products manufactured from milk. This

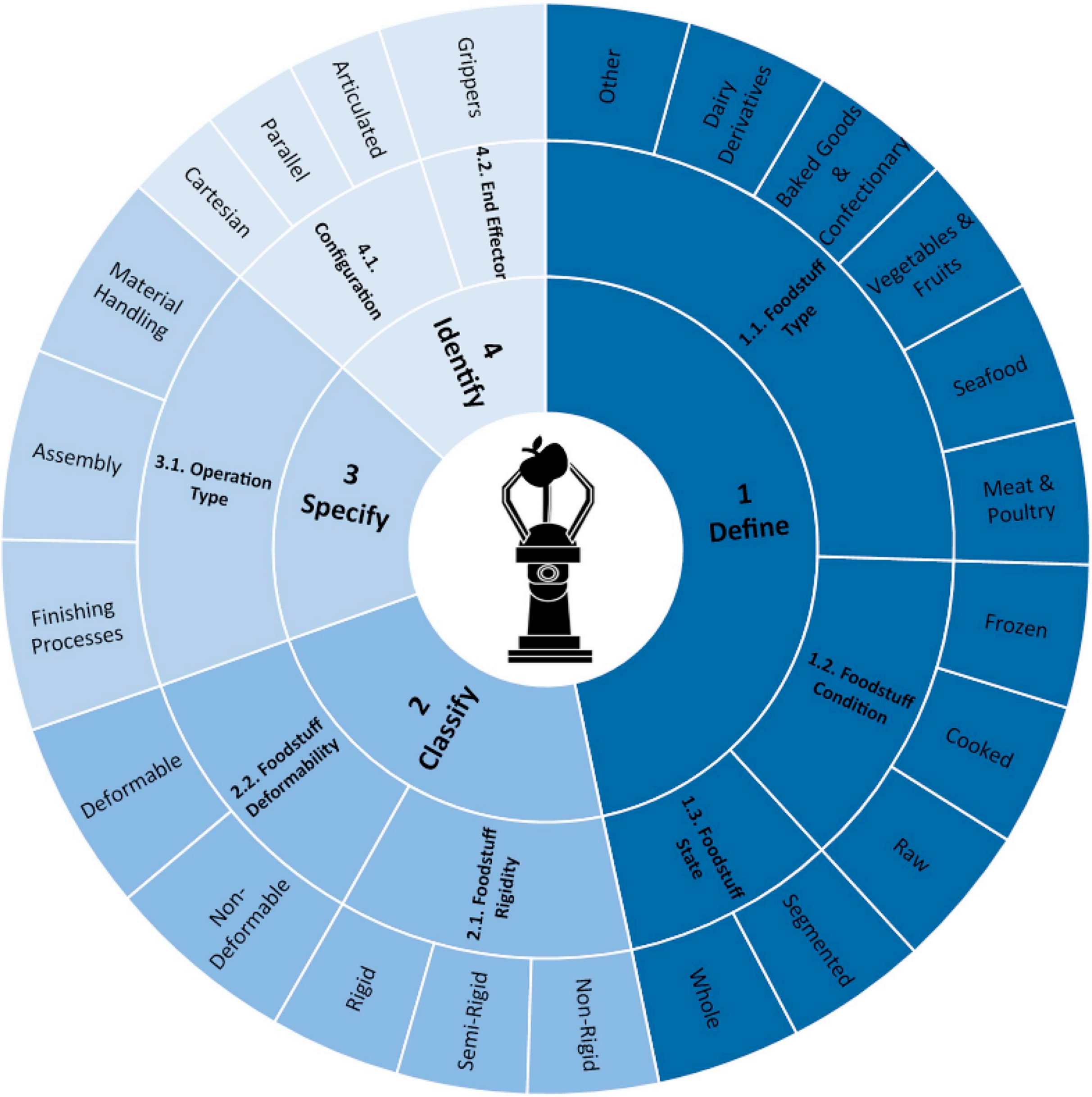


Fig. 1. The methodology for selection of industrial robots for food manufacturing applications.

Table 3
Foodstuff examples for the six FVs.

FV code	Rigidity and deformability	Foodstuff example
FV1	Non-rigid, deformable	Berries
FV2	Non-rigid, non-deformable	Cooked meats
FV3	Semi-rigid, deformable	Bananas
FV4	Semi-rigid, non-deformable	Raw meats
FV5	Rigid, deformable	Biscuits, cookies
FV6	Rigid, non-deformable	Raw apples

category addresses the processed dairy products rather than milk in its liquid form as their manufacturing processes are more suitable for application of IR which is typically ineffective for liquids.

6. *Other*; any foodstuff considered unsuitable for any of the top 5 categories can be identified as other and defined only by its condition, state, rigidity and deformability. It is important to note that the use of IR for liquid or semi-liquid food products is not feasible and that other methods of automated equipment such as tanks, pipes, fillers etc. are more appropriate, therefore, the FIRM only focuses on semi-solid and solid foodstuffs.

2.1.1.2. Foodstuff condition. Textures, wetness, hardness and the structural integrity of foodstuff are determined by its condition (Caldwell, 2013). The following three foodstuff conditions are defined which greatly affects the material handling and processing.

1. *Raw*; foodstuff presented in its natural state, unrefined and not subjected to form-altering temperatures.
2. *Cooked*; foodstuff subjected to partial or full form-altering hot temperature treatment, including boiling, baking, roasting, frying or sautéing.
3. *Frozen*; foodstuff subjected to partial or full form-altering cold temperature treatment, including blast freezing, which requires storage in cold stores typically in temperatures at or below −18 °C, but this can vary (Food Standards Agency, 2018).

For example, a raw apple can be considered solid and could handle

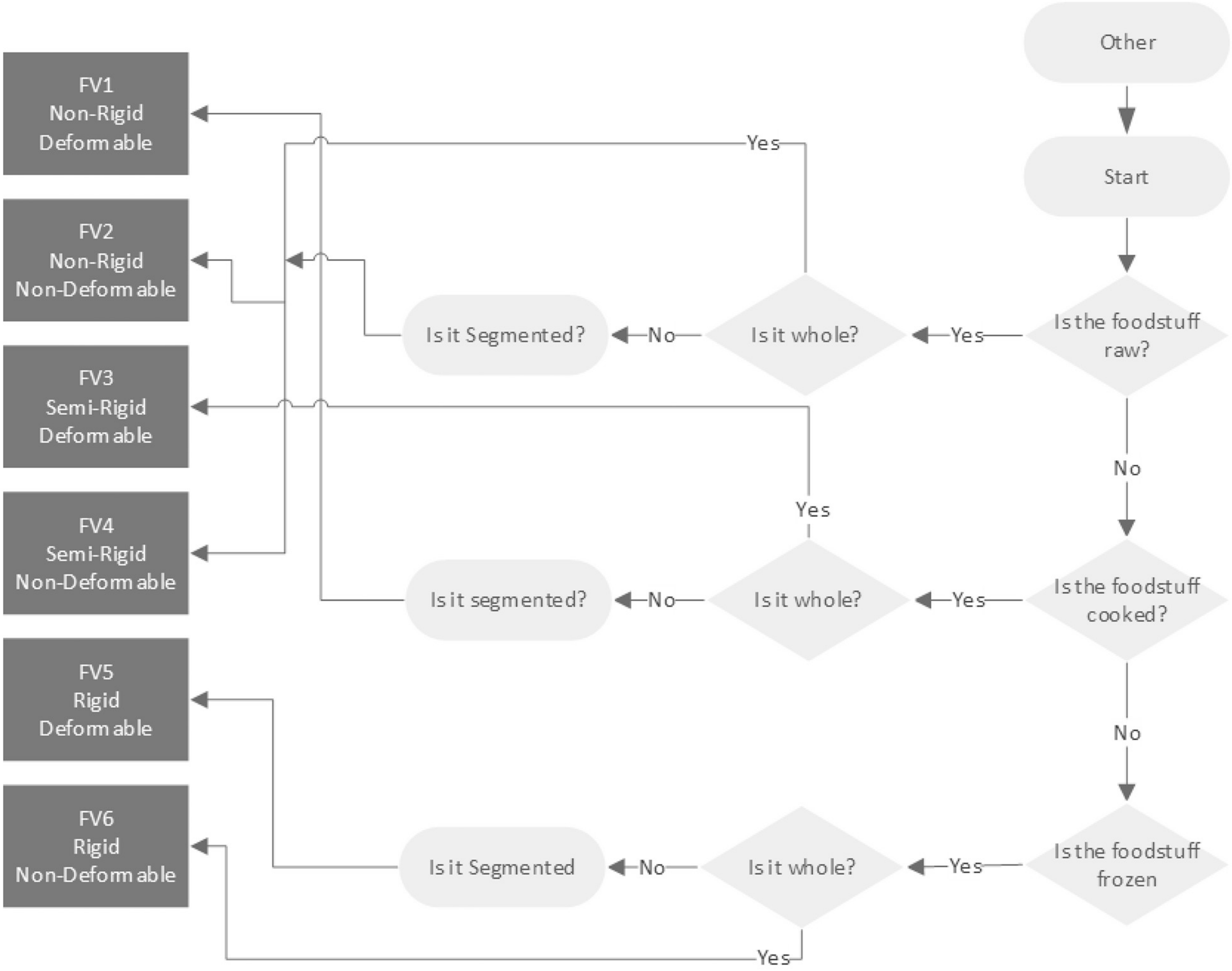


Fig. 2. Assisting general decision tree for the classification of foodstuff variety.

pressure, however, a cooked apple is considered limp and will break apart under pressure. It is important to know the condition of the foodstuff as it is a detrimental factor in the handling requirements.

2.1.1.3. Foodstuff state. Following types and conditions, the next consideration in this step of FIRM is the state of the foodstuff. This is defined based on wholesome state and their segmented state as outlined below.

1. *Whole*; foodstuff found in its full form, not having been subjected to cutting or separation.
2. *Segmented*; foodstuff found in its partial form, having been separated into two or more parts.

In the same way as foodstuff condition, the structural state of a foodstuff alters its texture, wetness, hardness and structural integrity, thereby changing the processing requirements. For example, a raw whole potato possesses different processing requirements than that of a segmented cooked potato.

2.1.2. Step 2: Classify Food Grouping

Following up from the information collected in step 1 for types, condition and status of foodstuff, the second step of FIRM is crucial to further outline the handling requirements of the foodstuff, which are the key factors that determine the IR solution. This is based on foodstuff rigidity and deformability, as outline below.

2.1.2.1. Foodstuff rigidity. This is an important consideration, in particular when designing or assigning the end-effector's mechanism and selecting the most appropriate gripper technology for the foodstuff being handled. Rigidity is divided into three levels;

1. *Rigid*; foodstuff that has no flexibility, is considered to be stiff or firm, and its structure remains intact under pressure.
2. *Semi-Rigid*; foodstuff that has slight flexibility but will retain its structure under some forms of pressure.
3. *Non-Rigid*; foodstuff defined as flexible and soft, where the application of any form of pressure will alter its structure.

2.1.2.2. Foodstuff deformability. This refers to the alteration of foodstuff's structure when being handled or manipulated. The levels of deformability differ greatly with various foods and their type, condition, state and rigidity. The quality of foodstuff produced highly depends on the processes being repeatable without deformation of the product. Any deformability that results in damage will firstly greatly decline the products visual appearance, making it undesirable to consumers. And secondly, if the damage is extensive and alters the structure of the foodstuff, it will affect the taste, smell and texture of the product. In general, FIRM refers to two forms of deformability to simplify the selection of gripper mechanisms, these are:

1. *Deformable*; foodstuffs that are easily disfigured by application of pressure, this includes semi-rigid as non-rigid foods, which may be raw or cooked, and, whole or segmented.

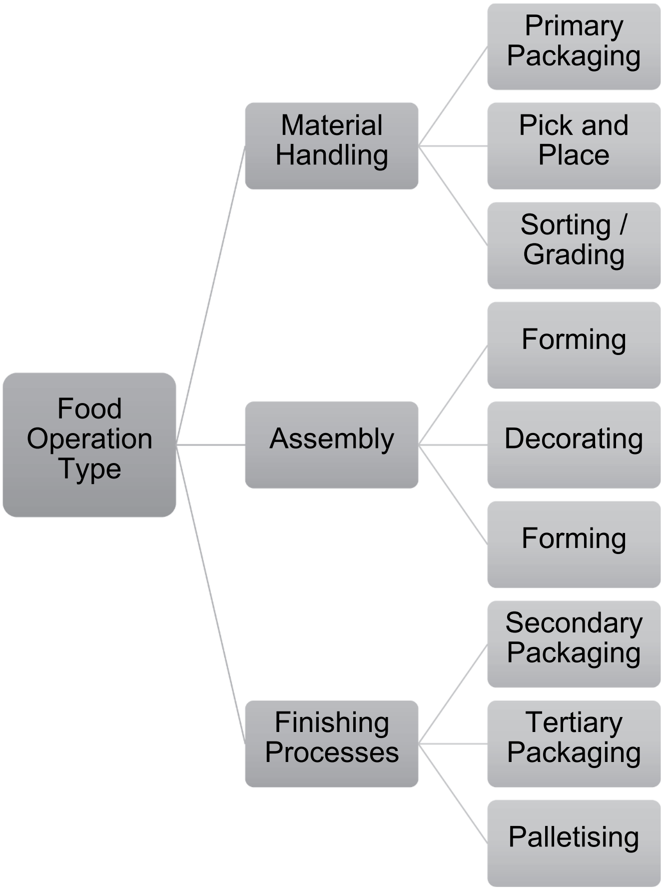


Fig. 3. Classification of foodstuff operations.

2. *Non-Deformable*; foodstuffs that can retain their structure under the application of pressure. This includes rigid foods, which may be raw, cooked or frozen, and, whole or segmented.

There are six possible combinations of these two categories, these combinations are referred to as the Foodstuff Variety (FV), as outlined in Table 3. In the cases where users are unable to determine their foodstuff's rigidity and deformability, a set of six decision trees (one for each foodstuff types) have been devised to assist them, as depicted in Fig. 2.

2.1.3. Step 3: Specify Food Operation Type

This step focuses on specifying actions that need to be performed by IR as part of the foodstuff processing. These actions can be a single action or a variety of tasks, and as outlined earlier, these operations fall under the following categories:

1. *Material Handling*; the transfer of foodstuff; whole or segmented, from point A to B within the reach of station. Foodstuffs in these operations are unpackaged and uncovered, resulting in the handling system to come in direct contact with the material. Operations that fall under material handling usually require a series of pick and place for machine loading and unloading, sorting and grading. This category includes any handling of foodstuff without any protective layer i.e. packaging, and therefore includes primary packaging operations. These tasks are simple and repetitive, so they typically employ simple to moderately complex IR technology if a large product variety is present. An example of this is the pick and place of pancakes from a cooling conveyor belt into stacks of four in preparation for packaging.
2. *Assembly*; the joining of two or more parts of whole of foodstuffs,

Table 4
Types of IR end-effector grippers applied in food handling (Blanes, Mellado, Ortiz, & Valera, 2011; Lien, 2013; Salvietti, Iqbal, Malvezzi, Eslami, & Prattichizzo, 2019).

Gripper mechanism	Pinching	Enclosing	Pinning	Pneumatic	Freezing	Levitating	Scooping
Description	Mechanical grip between two or more ‘fingers’, hold established via friction between the ‘fingers’ and the component, release achieved by opening ‘fingers’	Claw/jaw-like attachments encompass components to achieve partial or full grip, release achieved by opening of apparatus	One or more pins are injected into components, the penetration establishes a surface or deep grip, release achieved by extraction of pins	Air or pressurized gas is used to establish a grip via vacuum, release achieved by removal of pressure	Ice is formed between the gripper and the foodstuff component via instant freezing points, release achieved by instant melting of ice	Based on the Bernoulli concept, grippers lift components via differential air velocities, release by interruption of air flow	Gripper design can be flat or parabolic, allows for pick-up of foodstuff in ‘sweeping’ motion, release by tipping
Advantages	Simple, effective, reliable, non-intrusive		Strong single sided grip, precise grip, quick, hygienic	Surface grip only, compact gripper, reliable, non-intrusive	Surface single sided grip, hygienic		Portion control, simple, effective, non-intrusive, quick
Disadvantages	Possible bruising of food components, food residue may collect in grooves (dependent on design of gripper)		May cause visual quality decline, may tear tissue, can collect food residue	Loss of grip can occur, may collect food debris	May have unpredictable releasing action	May have unpredictable releasing action, most suitable for flat foodstuffs	Food residue may build up, control of material can be difficult, foods may spill during motion, may deform foods
Foodstuff component characteristics	Rigid, semi-rigid Non-deformable, deformable, Non-sticky, slippery		Rigid, semi-rigid Non-deformable, slippery	Rigid, semi-rigid Non-deformable, deformable Smooth surface Non-sticky, slippery	Rigid, non-rigid, semi-rigid None-deformable, deformable Smooth surface		Rigid, non-rigid, semi-rigid, non-deformable, slippery, Non-sticky
Example application	Pick and place of confectionary items and small decorative foodstuff	Pick and place of fruits and vegetables for sorting, packaging and palletising	Pick and place of meats and poultry, fish and seafood	Pick and place of eggs, packaging and palletising	Pick and place of meats, poultry, fish, seafood or frozen fruits and vegetables	Pick and place of soft, light foods such as pastas and baked goods	Loose foods, Sauces, powders, cooked rice, portioning ready meals

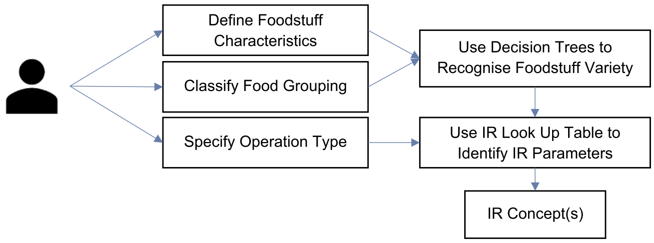


Fig. 4. The flow of Information through the steps of FIRM.

resulting in a whole or subassembly of a product. Such tasks employ flexible IR with a higher technological complexity. An example of assembly is producing a layered dish or a sandwich or forming operations such as pretzel bread shaping or customised icing on baked goods.

3. *Packaging and Palletising*; in the same way as material handling operations, packaging and palletising includes a series of pick and place operations. This includes the transfer of finished products through primary, secondary and tertiary packaging, followed by palletising for storage and distribution, i.e. the finishing processes, in which the IR system does not come into direct contact with the foodstuff. Products at this point are typically more consistent in shape and size, therefore utilises simple IR technology. Examples of this include packaging of individual olive jars into a package of 20, then stacking the packages onto a pallet.

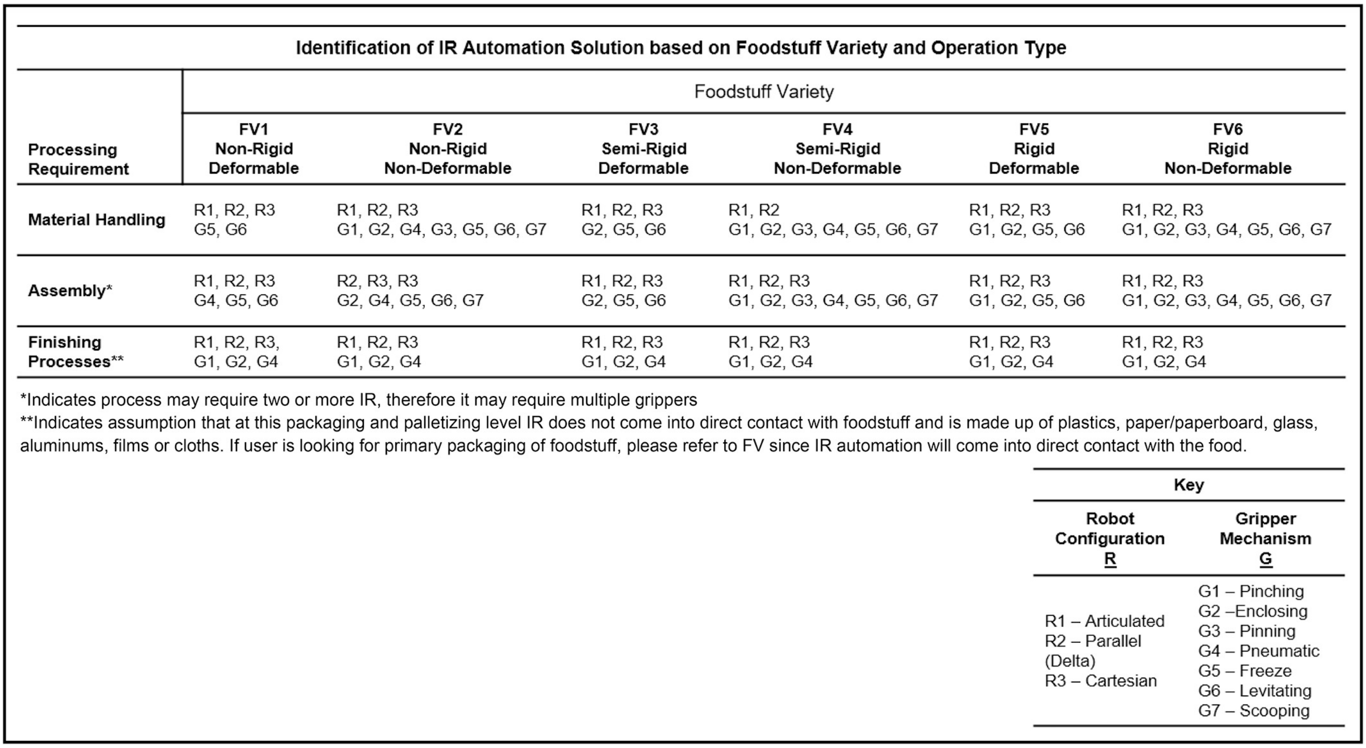
Fig. 3 outlines the operation types that are included as part of FIRM. It is expected that with new innovations in IR configurations and foodstuff handling mechanisms the list of operation types will be significantly extended in future applications of FIRM.

2.1.4. Step 4: Identify IR Parameters

The fourth and final step of FIRM focuses on identification of physical parameters that determines the most suitable IR configuration as well as end effector for a food manufacturing application based on information collected in previous three steps. The process of structuring IR's physical parameters begins with understanding their basic three parts, which resembles a human's shoulder, arm and wrist. The base of the robot is the shoulder; mounted on the floor, wall or ceiling, it can remain immobile or attached to a wheeling base for transportation between production lines. Robot's also have an arm which can move up to 6 degrees of freedom, at the end of which the 'wrist' holds the IR's instrument for manipulation. These parts are connected by joints which control their collective movement. There are many varieties of these IR parts (Duyzinx & Geradin, 2004; Jazar, 2007) designed to address various application requirements.

2.1.4.1. IR Configurations. The selection and arrangement of the base and arm typically forms a specific IR configuration. There are three physical configurations which have been utilised by the food industry (Groover, 2016; Jazar, 2007). These are:

1. *Articulated*; This IR configuration resembles the human arm the most. Often also referred to as jointed-arm or anthropomorphic, these IR move around the base in a spherical workspace, allowing for increased flexibility. They are also known for their high speeds and payloads, and can also be used in a variety of food applications owing to their versatility.
2. *Parallel (Delta)*; These IR are aligned in tricept form working in a hemispherical workspace. Typically, such an IR will have between three to six articulated arms attached to a base with several rotational joins for optimal flexibility (BARA, n.d.). The arms control the end effector with high accuracy and speed. Typical applications for this type of configuration includes pick and place tasks such as material handling, as well as packaging and palletising.
3. *Cartesian*; these IR are capable of moving vertically and horizontally in a rectangular workspace, operating high payloads and completing tasks with high accuracy. Currently these are cheapest type of IRs in the market because of their rigidity and limited flexibility. In the food industry they are predominantly employed in finishing processes such as packaging and palletising.



Identification of IR Automation Solution based on Foodstuff Variety and Operation Type

Processing Requirement	Foodstuff Variety FV1 Non-Rigid Deformable	FV2 Non-Rigid Non-Deformable	FV3 Semi-Rigid Deformable	FV4 Semi-Rigid Non-Deformable	FV5 Rigid Deformable	FV6 Rigid Non-Deformable
Material Handling	R1, R2, R3 G5, G6	R1, R2, R3 G1, G2, G4, G3, G5, G6, G7	R1, R2, R3 G2, G5, G6	R1, R2 G1, G2, G3, G4, G5, G6, G7	R1, R2, R3 G1, G2, G5, G6	R1, R2, R3 G1, G2, G3, G4, G5, G6, G7
Assembly*	R1, R2, R3 G4, G5, G6	R2, R3, R3 G2, G4, G5, G6, G7	R1, R2, R3 G2, G5, G6	R1, R2, R3 G1, G2, G3, G4, G5, G6, G7	R1, R2, R3 G1, G2, G5, G6	R1, R2, R3 G1, G2, G3, G4, G5, G6, G7
Finishing Processes**	R1, R2, R3, G1, G2, G4	R1, R2, R3 G1, G2, G4	R1, R2, R3 G1, G2, G4	R1, R2, R3 G1, G2, G4	R1, R2, R3 G1, G2, G4	R1, R2, R3 G1, G2, G4

*Indicates process may require two or more IR, therefore it may require multiple grippers

**Indicates assumption that at this packaging and palletizing level IR does not come into direct contact with foodstuff and is made up of plastics, paper/paperboard, glass, aluminums, films or cloths. If user is looking for primary packaging of foodstuff, please refer to FV since IR automation will come into direct contact with the food.

Key

Robot Configuration R	**Gripper Mechanism G**
R1 – Articulated R2 – Parallel (Delta) R3 – Cartesian	G1 – Pinching G2 –Enclosing G3 – Pinning G4 – Pneumatic G5 – Freeze G6 – Levitating G7 – Scooping

Fig. 5. Industrial robot parameters look up table.

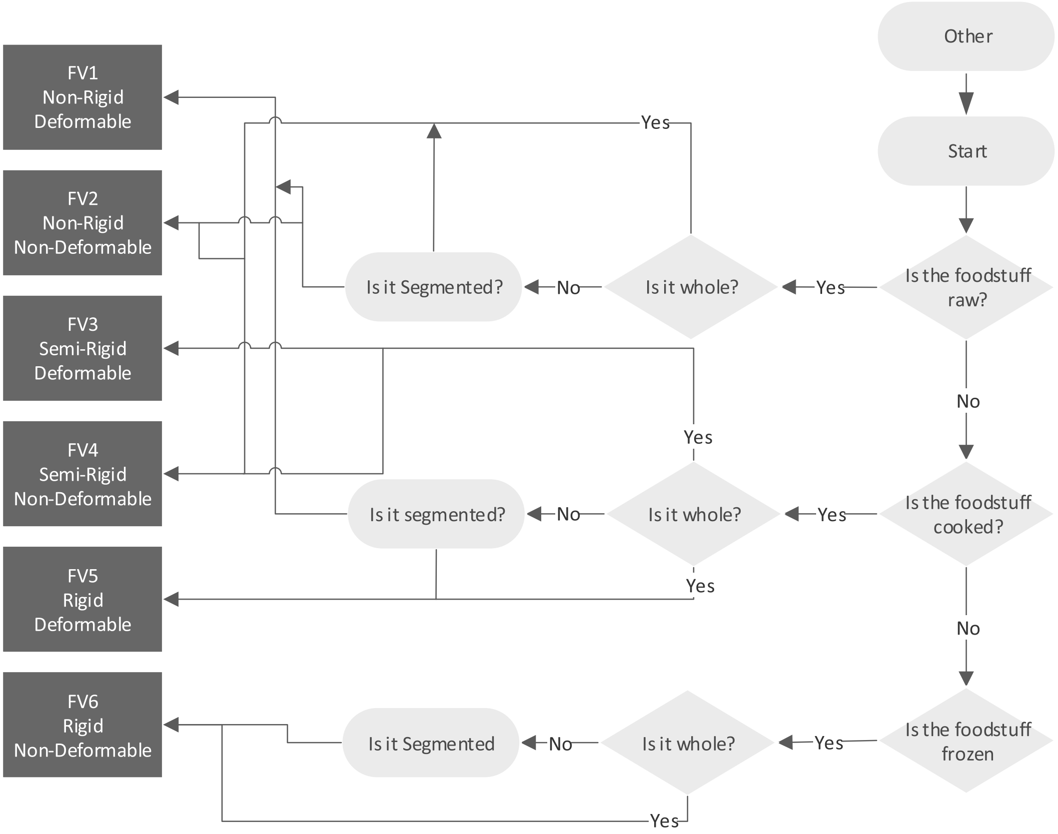


Fig. 6. Meat and poultry foodstuff variety decision tree.

2.1.4.2. IR end effector. The attachment at the end of the IR's 'wrist' is referred to as the end effector, also dubbed end of arm tooling (EOAT), their type, design, shape and size is dependent on the operation and product requirements. Gripper end effectors are suitable for grasping objects. Many mechanisms can be employed in the design of grippers to achieve actions such as pick and place. FIRM considers six gripping mechanisms suitable for the food industry and categorises them as pinching, enclosing and pinning, as well as other mechanisms such as pneumatic, freeze levitating methods. Definitions, benefits, disadvantages and applications of these gripper mechanisms are summarised in Table 4.

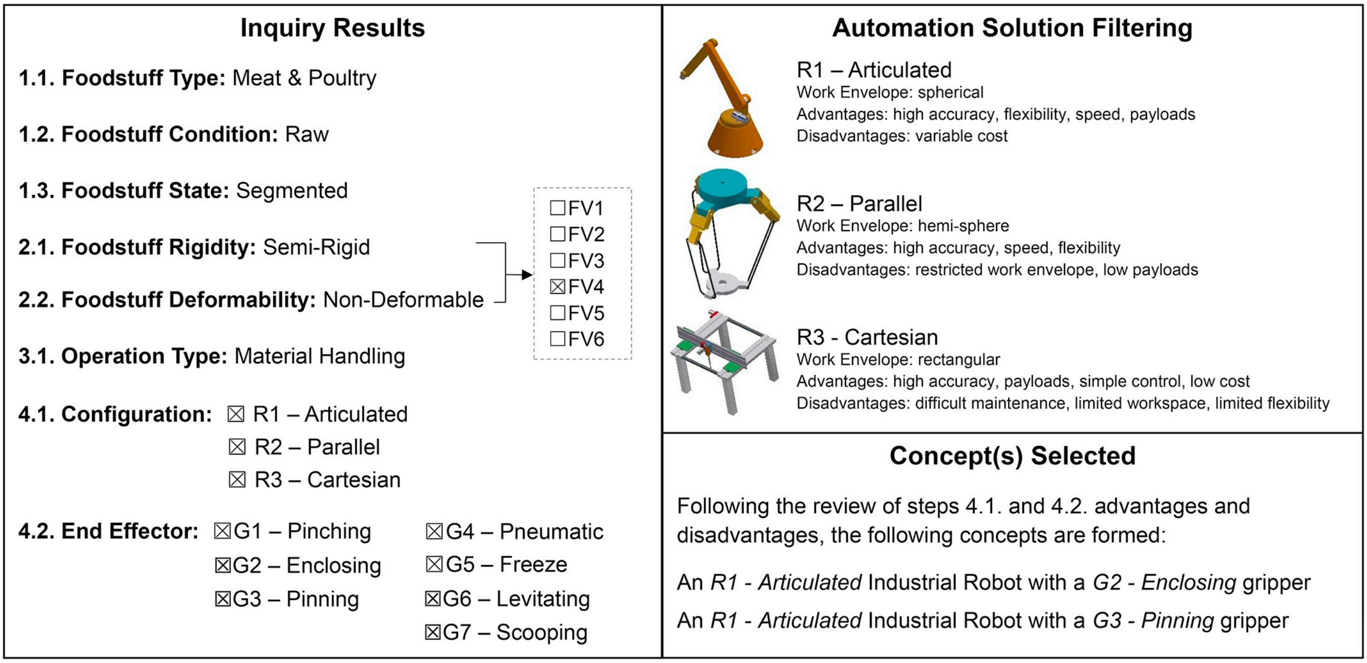
The complete flow of information throughout four steps of FIRM is shown in Fig. 4. To identify the IR parameters based on the information collated during step 1–3, a look-up table has been devised (see Fig. 5) where each of the six FV classified in step 2 is matched with the appropriate IR solution based on the operation type specified in step 3. This then provides system developers with the IR automation concept most suitable for the requirements determined by the various steps thus far. Each FV can have multiple IR automation concepts that are applicable, providing decision makers with multiple options for further investigation. The look up table displays the FV (i.e. foodstuff requirements) against the handling requirements (i.e. operation type) and offers the appropriate robot configuration, gripper and/or tool, which are coded and defined in the key.

2.2. Example Application

The meat processing is a major part of the UK food manufacturing industry. Between 2017 and 2018, 800 small and medium sized enterprises (SMEs) were registered under meat and meat product producers, valuing at a total of £3.7 billion in revenue (DEFRA, 2019). It currently employs approximately 75,000 people (WRAP, 2017), many of whom possess specific butchery skillsets, which are in themselves strenuous, meaning finding skilled employees has become very challenging. The conditions of meat processing facilities and the operations that are required to transport, slaughter, cut and package meat products pose many risks to the employees (BMPA, n.d.). There are a range of work-related injuries associated with the meat processing industry, caused by heavy machinery such as bandsaws, skinning tools, slips and falls as well as the cold temperatures of meat processing and storage rooms. These factors make working in the meat industry unappealing to potential employees, increase the difficulty of finding workers, and thus provide many benefits for the application of IR within meat processing industry (Rachana, Polson, & Saraswathy, 2017). One of the top strenuous and mundane tasks within a meat processing facility is the transport and packaging of readily cut 170 g fillet steaks from carrier tubs into individual plastic trays on a continuous conveyor belt. The following considers this process through the FIRM as:

Step One; the foodstuff is defined as meat and poultry (step 1.1), in its raw form (step 1.2.) and, as it is in pieces, then is it segmented (step 1.3.).
Step Two; using the decision tree for meat and poultry, shown in Fig. 6, this foodstuff is classified as FV4; i.e. semi-rigid (step 2.1.) and non-deformable (step 2.2.).

Step Three; the task at hand is the transportation of raw meat pieces into plastic trays, this operation falls under primary packaging and is therefore classified as material handling (step 3).
Step Four; the automation look-up table, shown in Fig. 5, identifies that IR type R1, R2 or R3 (step 4.1.) are feasible with G1, G2, G3, G4, G5 and G6 (step 4.2.) for material handling of FV4. These form the basis for the start of the investigation. Delving deeper into the application of these available grippers using Table 4, users narrow down their options after considering the advantages and disadvantages of these mechanisms. The enclosing gripper was chosen



Inquiry Results

1.1. Foodstuff Type: Meat & Poultry

1.2. Foodstuff Condition: Raw

1.3. Foodstuff State: Segmented

2.1. Foodstuff Rigidity: Semi-Rigid

2.2. Foodstuff Deformability: Non-Deformable

☐FV1
☐FV2
☐FV3
☒FV4
☐FV5
☐FV6

3.1. Operation Type: Material Handling

4.1. Configuration: ☒ R1 – Articulated
☒ R2 – Parallel
☒ R3 – Cartesian

4.2. End Effector: ☒G1 – Pinching ☒G4 – Pneumatic
☒G2 – Enclosing ☒G5 – Freeze
☒G3 – Pinning ☒G6 – Levitating
☒G7 – Scooping

Automation Solution Filtering

R1 – Articulated
Work Envelope: spherical
Advantages: high accuracy, flexibility, speed, payloads
Disadvantages: variable cost

R2 – Parallel
Work Envelope: hemi-sphere
Advantages: high accuracy, speed, flexibility
Disadvantages: restricted work envelope, low payloads

R3 - Cartesian
Work Envelope: rectangular
Advantages: high accuracy, payloads, simple control, low cost
Disadvantages: difficult maintenance, limited workspace, limited flexibility

Concept(s) Selected

Following the review of steps 4.1. and 4.2. advantages and disadvantages, the following concepts are formed:

An *R1 - Articulated* Industrial Robot with a *G2 - Enclosing* gripper

An *R1 - Articulated* Industrial Robot with a *G3 - Pinning* gripper

Fig. 7. Identification of IR automation prospectus; transportation of meat example.

due to its simple and effective mechanism, and its ability to avoid food residue build up. The runner up concept selected is the pinning gripper based on its quick release and hygienic abilities.

To display the results from the application of FIRM in a concise and easily accessible method, an IR summary form has been developed for users to log their findings as they progress through the steps of the methodology, review their options and outline the most appropriate IR concept. Fig. 7 shows the IR summary form for the meat processing example.

3. Conclusions

The applications of IR within many manufacturing sectors are rapidly increasing due to many benefits that include cost savings, improved productivity and replacing human operators in unsafe and unappealing operations. This study set out to develop a methodology for the selection of appropriate IR to aid with largescale adoption of such flexile automation within food manufacturing sector. The FIRM presented by this paper outlined the ability to classify IR capabilities and match them to specific characteristics of foodstuffs and requirements for their processing based on four steps that navigate eight tasks. Overall, this supports the notion of increasing implementation of IR in the food industry, as it is simplifying the process of identification and selection of feasible and suitable automation, therefore overcoming the knowledge and information barrier that previously limits IR uptake. While a food manufacturing company could use this methodology to begin their journey of IR selection and implementation, there are many other factors that require identification such as sensors, safety guards and actuators. This work also identified many factors that should lay the groundwork for future research in application of IR within food manufacturing. These include many challenges of food industry IR such as the need to design bespoke grippers and apparatus, improve the ease of maintaining the hygiene standards, provide simple training tools to aid with reskilling of operators, and clarifying the long-term benefits of implementing IR technology.

CRediT author statement

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