UNIVERSITY OF TARTU
Faculty of Science and Technology
Institute of Technology

Ahmed Hassan Helmy Mohamed

SOFTWARE INTEGRATION OF AUTONOMOUS ROBOT SYSTEM FOR MIXING AND SERVING DRINKS

Bachelor's Thesis (12 ECTS)

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Supervisor:

Assoc. Prof. Karl Kruusamäe

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Software integration of autonomous robot system for mixing and serving drinks

Abstract:

Robots are now breaking into all areas of society and they perform useful services for humans and their environment. With increasing sanitation standards and retail demands, food and beverage manufacturers are also relying on robotics systems to perform the necessary tasks. The objective of this thesis is to examine the ability of robots to be integrated in beverage industry to work as a bartender to do specific and precise task in short time in terms of mixing and serving a drink.

A software integration was created for a prototype bar equipped with a Franka Emika Panda 7-degree-of-freedom robot manipulator, Kinova KG-3 gripper, and a setup to incorporate holders for 45 bottles, 3 soft drink dispensers, and ice-machine. ROS and C++ were used for the entire software integration. As a result, the functionality of the robotic bar was demonstrated by fully autonomous preparation of multi-component drinks.

CERCS: T125 Automation, robotics, control engineering; T120 Systems engineering, computer technology

Keywords: robotics, automation, ROS, software integration, service robots, bar, drink, beverage

Jooke valmistava ja serveeriva robotsüsteemi tarkvaralahendus

Lühikokkuvõte:

Robotite roll ja olulisus ühiskonnas on järk-järgult kasvamas. Toidu- ja joogitootjad on üha enam hakanud tootmis- ja teenindusprotsessidesse kaasama roboteid, mis aitavad täita rangeid sanitaarnõudeid ja võimaldavad toota vastavalt nõudlusele. Käesoleva bakalaureusetöö eesmärgiks on töötada välja tarkvaralahendus robotbaarile, mis integreeriks kogu riistvara, et see suudaks täpselt kokku segada ja serveerida erinevaid jooke.

Töö tulemusena valmis tarkvara robotbaari prototüübile, mis integreeris Franka Emika Panda 7 vabadusastmega robotmanipulaatori, Kinova KG-3 haaratsi ja muud baari seadmed nagu 3 karastusjoogi kraani, jäämasin ja 45 joogidosaatorit. Kogu töö käigus valminud tarkvara teostati kasutades robootika tarkvararaamistikku ROS (Robot Operating System) ja programmeerimiskeelt C++. Valminud lahenduse võimekust demonstreeriti mitmekomponendilise joogi valmistamise näitel, kus robotbaar toimis täiestit autonoomselt.

CERCS: T125 Automatiseerimine, robootika, control engineering; T120 Süsteemitehnoloogia, arvutitehnoloogia

Võtmesõnad: robootika, automatiseerimine, ROS, tarkvara integreerimine, teenindusrobotid, baar, jook

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ACRONYMS AND ABBREVIATIONS

- **Ubuntu 16.04**: Linux-based Computer Operating system
- **ROS**: Robot Operating System
- **ROS Kinetic**: ROS distribution compatible with Ubuntu 16.04
- **ROS node**: A process that perform computation in ROS
- **Yanu**: The commercial project name
- **RViz**: 3D visualizer for displaying sensor data and state information from ROS
- **MoveIt!**: A software runs on the top of ROS. Its main task is to provide the necessary trajectories for the arm of a robot to put the end effector in a given place
- **JSON**: JavaScript Object Notation. It is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate [1]
- **SSH Tunnel**: a method of transporting arbitrary networking data over an encrypted SSH connection
- **Franka Emika Panda**: Robot manipulator with 7 DOF made by Franka Emika GmbH Company
- **Kinova Gripper KG-3**: 3-fingers gripper made by Kinova Inc.
- **Xacro file**: an XML macro language
- **WebSocket**: A Computer communications protocol, it provides a full-duplex communication channels over a single TCP connection [2]
- **RFID**: Radio-frequency identification, uses electromagnetic fields to automatically identify and track tags attached to objects [3]

INTRODUCTION

In the last 5 years, automation technology has entered various aspects of our life and has become an integral part of the scientific and practical fields [4]. Various industrial, commercial and service sectors are using this technology which combines the use of computers, devices based on processors or controllers and software to ensure the conduct of procedures and work in a mechanical precision with minimal potential error [4].

In recognition to that automation has been implemented in most of the fields which include but are not limited to industrial production, management, food and beverages production, and chemical production, this thesis focuses on the automation and robotics for the preparation and serving of beverages.

Robotic bars can solve the current issues which might occur during ordering a drink. For instance, waiting in line, some places accept cash only and the drink might be improperly prepared due to inaccurate or unbalanced ingredients.

Yanu – a prospective robotic bar solution – has an application for smart phones and also 3 touch screens under each serving dock where customers can use them or their smart phones to place their orders and no need to wait in line, Yanu meets the current life style where customers can pay using credit cards. Yanu prepares the drink with so precious ingredients and the drink taste never changes if ordered again and again.

The objective of this thesis is to integrate a robot manipulator in a bar to work as bartender to prepare and serve drinks. This thesis describes how the robotic bar (Yanu) receives the customer order, processes it and finally serves it on the serving dock.

1 LITERATURE REVIEW

In order to exemplify the role that robots play in modern day food and beverage industry, some characteristic examples from the application domain are discussed in this chapter. The chapter is divided into two parts: the first focusing on the application of robots in the food industry whereas the second part elaborates their use in handling and serving beverages.

1.1 Robots in food industry

Nowadays robots are being used in several fields especially in food sector [5]. Such industries have grown into more complicated processes that involve several steps like preparing, sorting, cooking, picking and placing products and packaging [6]. In order to save time and space alongside with improving the cleanliness and safety as well, industrial robots can be integrated into this industry to collaborate as well as interact with humans [7]. For example, robots can be considered rather hygienic – the probability of transferring of germs and pathogens is very low, thus reducing the risk of contamination [8].

Furthermore, robots can assist humans in potentially harming environments. For instance, working in very low or high temperature place (e.g., refrigerated food storerooms or area of ovens within a kitchen) can potentially affect the health conditions of workers (e.g., their stamina and blood pressure) [9]. Some tasks like pick and place, sorting and labeling that need repeating the same steps over and over again are tedious for humans as it tends to increase stress levels and reduces attention.

Despite several advantages, integrating robots in food industry has been relatively slow [10]. However, with the fast development in sensing and image processing technology, gripper manufacturing and artificial intelligence, the robots now are being used to handle several steps in the processing and production of food such as cleaning [11], cutting [12], sorting [13], and even cake decoration [14].

There are several examples how robots are being used in the food industry [10]. The robotics in food industry can broadly be categorized as manufacturing, cooking and serving. The next subsections from 1.1.1 to 1.1.3 will introduce some key examples of the state of the art.

1.1.1 Robotics in food manufacturing

Robots in food manufacturing are automated, programmable, and capable of performing tasks such as cutting meat in the butchering process [12]. Butchering process can be considered extremely challenging as every animal carcass is different in the shape and positioning of the bones and meat. Recently, a JBS meat packing plant in Greeley, Colorado has introduced robotic butchery to perform some dangerous tasks like rib cutting which involves operating a high-speed circular saw for several hours [15].

The JBS plant robot (figure 1.1) is capable to determine the cut specifications of the carcass by scanning its RFID and by using a number of sensors, it analyzes the carcass to calculate the cut coordinates before placing two cuts across the ribs [15].

Figure 1.1: *Butcher robot with circular saw* [15].

Another example of robot in a food manufacturing is Deco-Bot (figure 1.2) by Unifiller [14]. It can pipe decorations onto cakes that are moving on a conveyor.

Figure 1.2: *Deco-Bot by Unifiller* [14].

A Silicon Valley pizza producer Zume [16] uses two robots in their pizzeria (figure 1.3): a delta robot spreads tomato sauce on the dough whereas the staff will place the toppings and send it to an ABB robot manipulator [17] to place the pizza in the oven.

Figure 1.3: *ABB manipulator for making pizza at Zume Pizza* [18].

1.1.2 Robotics in cookery

Cookery robots are the robots that can be used to cook the food using the standard kitchen tools. Compared to the other stages of the food supply chain, cookery robots are still in their infancy. In figure 1.4, a dual arm Yaskawa Motoman robot [19] was used by RS Tech company [20] to prepare an egg sandwich. The arms use a special egg cooker pan where they place the bread slices and use the egg cracker tool to crack the egg on a special place in the pan to be cooked and after around 10 minutes the sandwich will be ready, and the arms take it out from the pan.

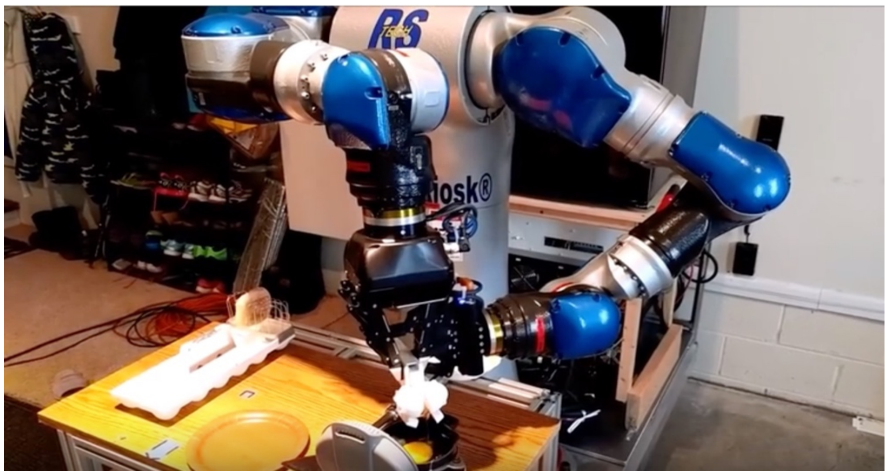

Figure 1.4: *RS kiosk robot - cooking egg* [20] .

1.1.3 Robots in food serving

Serving food is a new approach of robots use in food industry. Sushi in Japan has started the idea of automated food lines. Figure 1.5 illustrates one such idea in which the wheeled footed serving robot presents the food to the consumers.

Figure 1.5: *Wheeled footed serving robot* [4] .

1.2 Robots in beverages industry

Very often when the robots have been introduced to the beverages industry, their role has been limited to tasks such as inspection of bottles, picking and placing bottles, packaging of boxes, and distribution of packages from the manufacturing to the delivery areas. However, recently robots are being integrated outside the factories, especially the lightweight manipulators [21] that can work in small spaces and perform versatile tasks.

1.2.1 Beverages handling robots

Kawasaki's beverage robot (figure 1.6) fulfills a wide range of handling processes, including bottle positioning, capping, filling, sterilizing and high-speed picking and sorting [22].

Figure 1.6: *Kawasaki Robot* [22].

1.2.2 Beverages serving robots

Robots in beverage serving can prepare a drink with a single ingredient, make cocktails, serving or combine all these together. Despite this field still being in the beginning stage, it has generated a lot of momentum and there are already several examples with varying complexity. Four examples have been chosen for comparison in this thesis:

1- Chassis robot (figure 1.7) - a mobile robotic operated by a remote control, it is a simple drink serving robot that can be used for small parties or inside small workplaces [23].
2- Ratio robot (figure 1.8) - bar that operates as a cafe by day and cocktail bar by night [24].
3- Café X robot (figure 1.9) - coffee kiosk [25].
4- Bionic bar robot (figure 1.10) - bar with two industrial manipulators [26].

Table 1.1 gives an overview of the main characteristics of these robots by comparing their:

design, drink limitations, robot specifications, drink preparation time and price.

Figure 1.7: *Chassis Robot* [23]

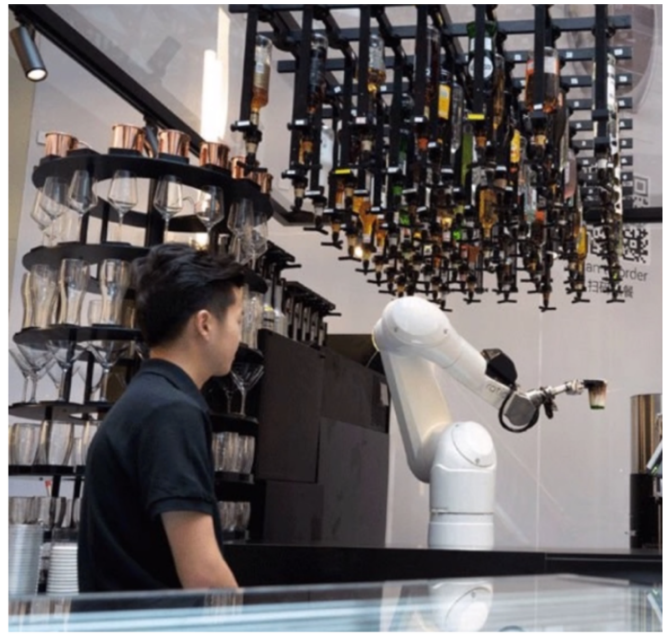

Figure 1.8: *Ratio Robot* [24]

Figure 1.9: *Café X Robot* [25]

Figure 1.10: *Bionic bar Robot* [26]

Table 1.1: *Drink serving robots*

Items	Chassis robot	Ratio robot	Café X robot	Bionic bar robot
Design	Controlled by operator and it has interactive features like eye blinks and head-propeller.	Fully autonomous robot. Handles the drink preparing and serving processes.	A person still mans the kiosk from outside to tell people about the coffees Cafe X serves.	Fully autonomous robot. Handles the drink preparing and serving processes.
	139.7 cm high, 76.2 cm wide, and 25.4 kg. Arms extend 38.1 cm. Soft rubber wheels are non-marking and work on most floor surfaces including low carpet.	A small bar that consists of manipulator with a gripper and the drink bottles are hanged in the ceiling area. Garnishing and adding ice, is performed by humans. Glasses and coffee machine are placed close to the robot.	The robot is placed inside a small kiosk along with coffee machines and cups. The robot prepares the drink and serves it via movable docks.	Standard shape of a bar. 170 bottles of different spirits stored in its overhead rack. Washing tap to rinse the small end-effector container after each drink.
Drink Limitations	Only 1 drink type	Coffee – alcoholic & non-alcoholic drinks	Coffee	alcoholic & non-alcoholic drinks
Specifications	Actuators and wheels. Consists of chilled and insulated beverage container and a pressure system to dispense the beverage.	Manipulator with 5 DOF and 2-finger gripper to pick, fill the cup and serve it.	6-DOF manipulator with 2 finger gripper.	KUKA robot manipulator [27] and a small steel cup as its end-effector.
preparing rate	~ 240 drink / hour	NA	120 drink / hour	120 drink / hour
Price	NA	30,000 USD (price of the manipulator)	25,000 USD (price of the manipulator)	112,000 USD (the entire system)
Order Type	Manually	Smart phone app	Smart phone app – tablets	Smart phone app – pads

2 YANU BARTENDING UNIT

Yanu is intended to be a fully autonomous robot empowered bartending unit to serve drinks, handle payments, identify and communicate with clients [28]. The initial design of Yanu bartending unit (figure 2.1) includes a large number of bottles in the overhead rack while ice and soft drinks machines are integrated to the back panel. There are 3 serving counters: on the left, right and in the center of the bar [28].

Figure 2.1: *The Artist's rendition of Yanu bartender* [28].

Yanu will have interactive touchscreen and mobile ordering, credit card and mobile payment, and cloud based administration and monitoring [28]. It is designed to serve up to 200 drinks per hour and stocks up to 2000 drinks and cocktails at a time [29].

3 OBJECTIVE AND REQUIREMENTS

The objective of this thesis is to integrate a robot manipulator in a bar to work as a bartender to take orders, prepare drinks and serve them to customers. In order to achieve the required objective, an algorithm that can perform these tasks has to be created.

The software algorithm should be able to operate the manipulator, the gripper, the ice and soft drinks dispensers, communicating with the backend for taking the drink orders and performing the drink preparing and serving processes as smooth as possible.

3.1 Functional requirements

- Receive and process drink orders from a cloud-service backend.
- Pick up a glass from above dock using the gripper.
- Filling the glass with ice, soft drink or drink (based on the order ingredients) using the manipulator.
- Serving the drink on the dock stations using the manipulator.

3.2 Hardware requirements

- Franka Emika Panda manipulator for mixing the drink.
- Kinova KG-3 gripper for retrieving, holding and releasing the drink.
- EtherCat coupler to control the valves of ice-machine and soft drink dispensers and to read all available sensors within a YRC.
- Actuators for the glass dispenser.

3.3 Software requirements

- Ubuntu 16.04
- ROS Kinetic
- Preferably C++
- Communication with backend using REST API (receiving drink orders and reporting robotic cell status)

4 YANU DESIGN

4.1 System overview

4.1.1 System architecture

The primary use-case and the process diagram for the robotic drink serving system is depicted in figure 4.1 and 4.2. The customer chooses a drink using a mobile app that transmits the order to a cloud service which then relays the order to the closest Yanu robotic cell (YRC). The YRC will consequently prepare the drink and serve it on a dock where the customer can pick it up.

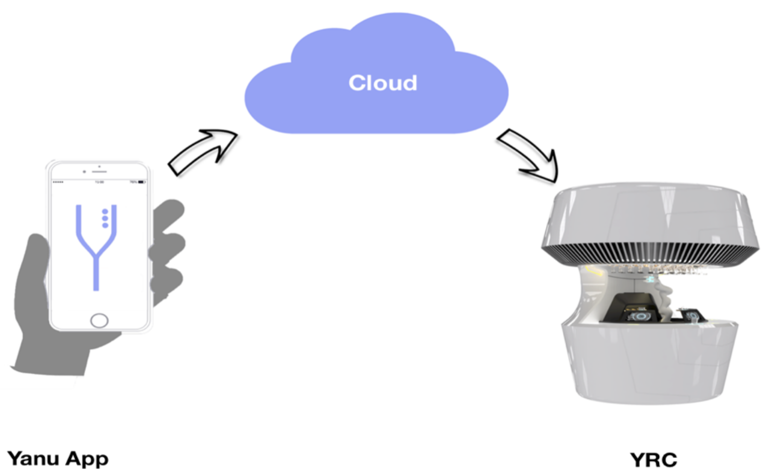

Figure 4.1: *Order request schematic*

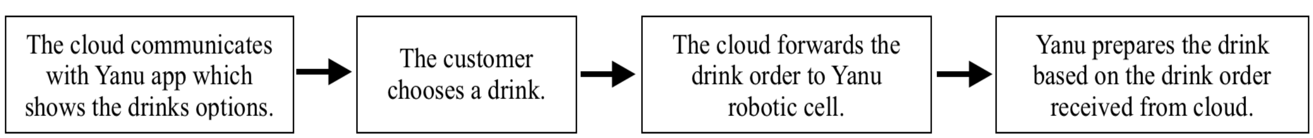

Figure 4.2: *Order processing schematic*

- This thesis focuses on the software integration of the YRC (figure 4.3) which consists of following components:
- Franka Emika Panda manipulator with Kinova KG-3 gripper: responsible for preparing and serving the drinks.
- 45 bottles equipped with upside down dispensers are hung above the manipulator work area.
- Serving glasss can be grasped from two outlets in the overhead panel.

- Ice machine is located at the backside of the manipulator, the manipulator can position an empty glass under its nozzle to include ice in the drink.
- Three soft drink dispensers are located at the backside of the manipulator (next to the ice-machine), the manipulator can position a glass under 3 different soft drink nozzles to add soft drinks.
- Three serving docks are located on the curved counter of a YRC.

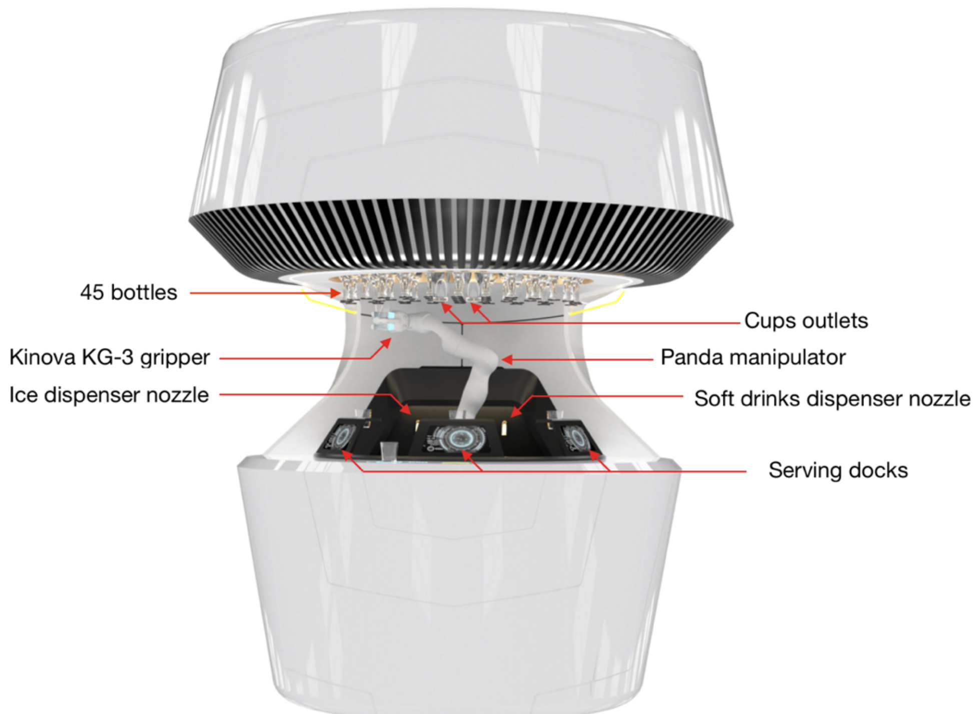

Figure 4.3: *Components of YRC*

The entire software architecture is distributed over Yanu App, Yanu Cloud, and YRC. The software at the YRC will handle the following tasks:

- Communication with Yanu Cloud (e.g., receiving drink orders, sending status reports).
- Grasping the glass and executing a series of movements with a manipulator to fill the glass with the ordered drink.
- Serving the drink on a serving dock.
- Controlling and reading all available sensors within a YRC.
- Controlling the actuators of the glass dispenser.
- Controlling the valves of ice-machine and soft drink dispensers.

The connection diagram of a single YRC is given in figure 4.4. Kinova KG-3 gripper is mounted as the end-effector to a Franka Emika Panda manipulator. Panda controller connects to the on-site controller by a CAT7 network cable. Kinova controller connects to the on-site controller via USB2 cable. In order to communicate with all the sensors and actuators of a YRC, the on-site controller connects to a Wago EtherCat coupler via ethernet cable. The connection with the backend cloud-service is achieved via wireless internet connection.

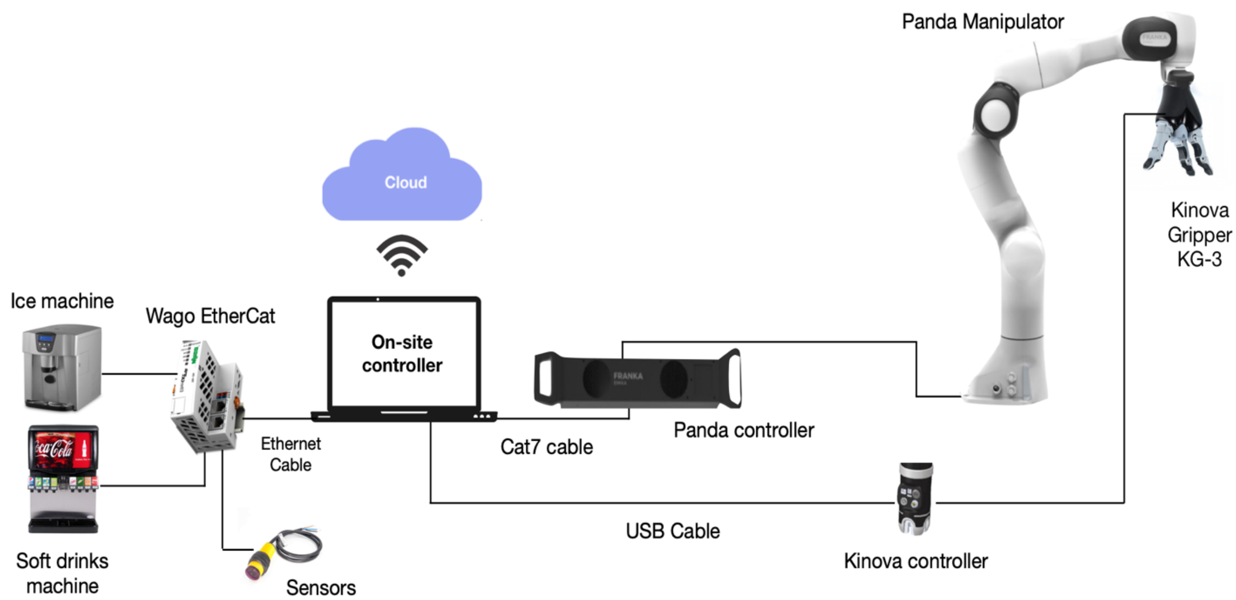

Figure 4.4: *Yanu connection diagram*

4.1.2 Franka Emika Panda

Franka Emika Panda manipulator (figure 4.5) has been designed for cost-effective human-robot collaboration, its key characteristics are highlighted in table 4.1.

Franka Emika Panda manipulator has torque sensors in all seven joints to stop on a time in case of collision - this provides safety in workspace and for the customers as well. Its payload of 3 kg and a repeatability of 0.1 millimeter is sufficient for holding and serving a single drink (large drink weights approximately 340 g and a small drink 220 g). With its 7 degrees of freedom (7 DOF), it provides a lot of maneuverability in tight spaces e.g., accessing soft drink nozzles in motioned constrained scenarios [30].

Table 4.1: *Franka Emika Panda specifications* [31].

Item	Details
Degrees of freedom	7 DOF
Payload	3 kg
Sensitivity	Torque sensors in all joints
Reachability	859 mm
Communication	Ethernet (TCP/IP)
Controller size	355 x 483 x 89 mm (D x W x H)

Figure 4.5: *Franka Emika Panda manipulator and its controller* [30].

4.1.3 Kinova Gripper KG-3

Kinova KG-3 gripper (figure 4.6) is a three-finger gripper that is approximately the size of a human hand, thus making it suitable for grasping cocktail glasses. Relevant technical description of KG-3 gripper is given in table 4.2. The KG-3 gripper is mounted as an end-effector for the Franka Emika Panda manipulator.

Figure 4.6: *Kinova Gripper KG-3 and its controller unit* [32].

Table 4.2: *Kinova Gripper KG-3 specifications*[32].

Item	Details
Opening (fingertip)	175 mm
Object diameter for cylindrical grip	45 mm (Min) – 100 mm (Max)
Total weight	727 g
Gripping force	25 N
Opening or closing travel time	1.2 Sec
Controller unit ports	USB 2.0 - Ethernet – power supply

4.1.4 ROS

ROS (Robot Operating System) is a software platform for robots that provides the necessary libraries, packages and tools to create and develop robot applications. Among other core capabilities, ROS incorporates tools for describing the kinematics of serial manipulators as well as generating continuous and collision-free motion for such manipulators. MoveIt! builds on the ROS messaging and build systems and utilizes some of the common tools in ROS like the ROS Visualizer (RViz) and the Unified Robot Description Format (URDF) [33]. MoveIt! uses OMPL (Open Motion Planning Library) [34] to calculate collision free trajectories for serial manipulators. In short, MoveIt! handles all the necessary kinematics and inverse kinematics calculation along with collision-free motion planning to ensure and execute safe motion of the robot manipulator between any two poses within its work envelope.

4.1.5 On-site controller

The role of the on-site controller computer is to receive drink orders from the cloud-based backend, convert the incoming orders into a sequence of movements for the Panda manipulator and KG-3 gripper, and communicate with all additional actuators and sensors of the YRC. The hardware specification for the computer is given in Table 4.3.

Table 4.3: C*omputer specification*

Item	Details
Processor	Intel ® core ™ CPU 2.5 i5
Memory	8 GB
Operating System	Ubuntu 16.04
USB Ports	3 x USB 2.0
Ethernet Port	1
Wireless Interface	IEEE 802.11

Ubuntu 16.04 and ROS Kinetic were installed on the on-site controller. All the necessary libraries and ROS packages of Franka Emika Panda manipulator and Kinova KG-3 gripper were compiled from the source code available at their respective GitHub repositories [31] [35].

In order to control Franka Emika Panda manipulator, the on-site controller uses real-time kernel version 4.14.12-rt10.

Connection to the backend cloud service was established using internet connection via the built-in wireless network card.

5 DESCRIPTION OF DEVELOPED SOFTWARE

Figure 5.1 shows how the software packages that have been created during the work are connected to each other. And Figure 5.2 shows the structure of the software packages.

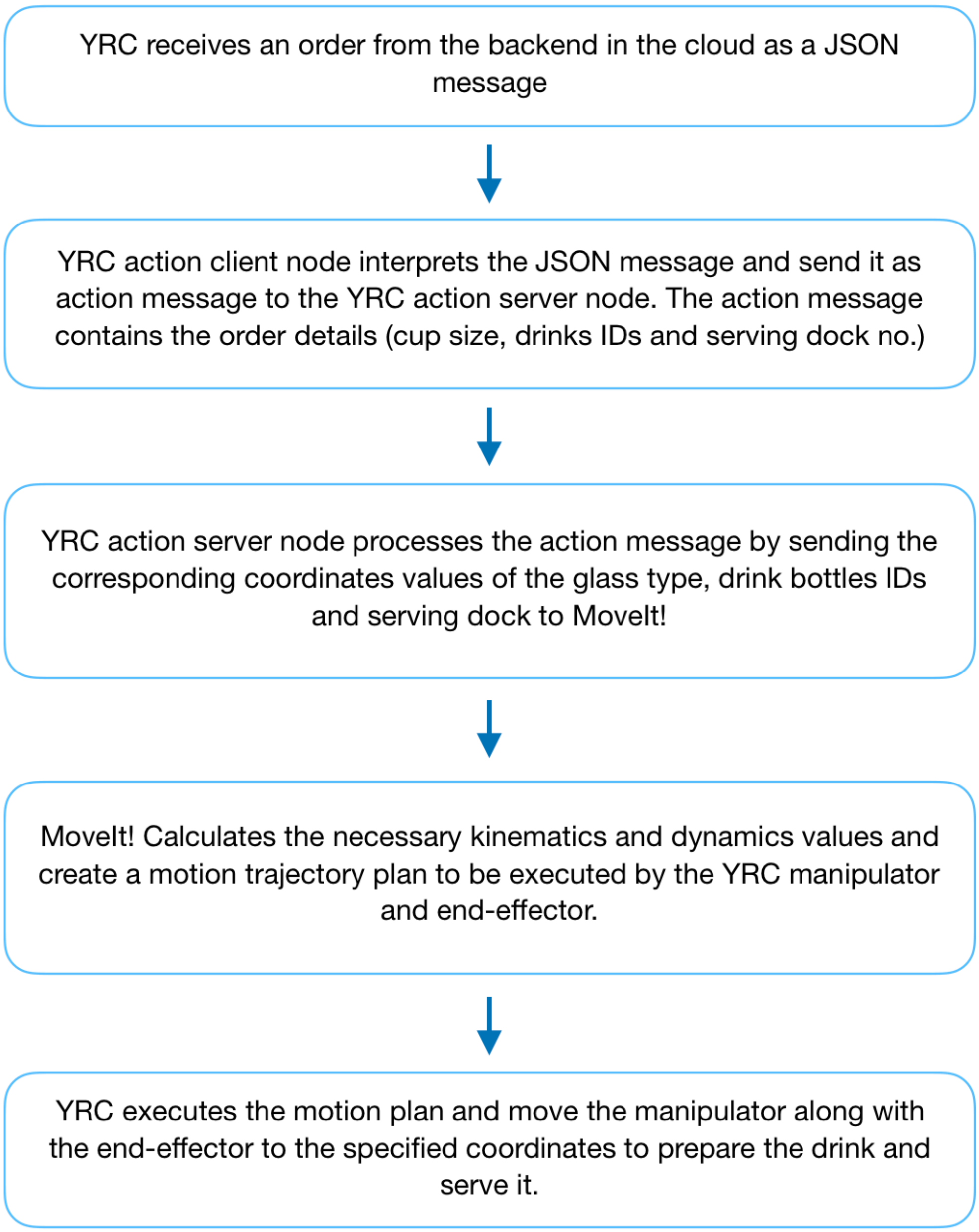

Figure 5.1: *The flowchart of YRC tasks.*

ihelmi Adding read and write functions	
kinova-ros	Kinova Ros Packages
kinova_flash	Kinova installation files for usb cable
robobar_bringup	Launch files to bring up Franka Arm and Kinova Gripper
robobar_demo	Adding read and write functions
robobar_description	URDF and Meshes Files
robobar_engine	updating serving pose coordinates
robobar_gripper_description	URDF and Meshes Files
robobar_mockup_moveit	Moveit pkg for Robobar Mockup
robobar_msgs	Refactored engine client; untested
robobar_newgripp_moveit	Moveit pkg for visualization the new gripper
.gitignore	Initial commit
README.md	Important instructions

Figure 5.2: *Yanu Software structure.*

5.1 Communication with backend

Backend communicates with both; the customers by taking their order and with YRC by sending the order in the form of JSON message (figure 5.3) to a specific port in the on-site controller via reverse SSH port forwarding protocol [36]. Communication with the backend is handled by robobar_action_client node in robobar_engine package which receives a JSON message by listening to the specified network port of the on-site controller.

```
{
    "drink_order":{
        "type":[
            {
                "cup_size":"SMALL",
                "has_ice":false
            }
        ],
        "ingredients":[
            {
                "type":"ALCOHOLIC",
                "coordinateId":1,
                "coordinate":"0.11x0.22x0.33",
                "amount":"0.04"
            },
            {
                "type":"NONALCOHOLIC",
                "coordinateId":4,
                "coordinate":"0.55x0.003x0.011",
                "amount":"0.50"
            }
        ]
    }
}
```

Figure 5.3: *The structure of a JSON message specifying a drink order.*

5.2 Conversion of order into a ROS message

The robobar_action_client node (figure 5.4) parses the contents of a JSON message, converts it to a ROS action message (figure 5.5) to be sent to robobar_action_server node. The YRC-specific ROS messages are defined within robobar_msgs package and depicted in figure 5.5.

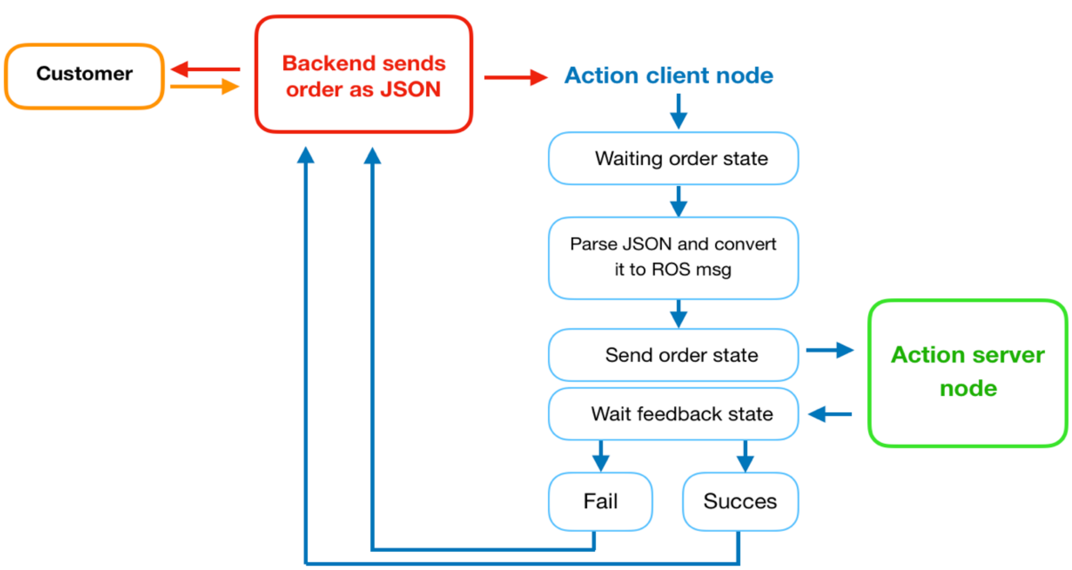

Figure 5.4: *Robobar action client node algorithm.*

```
#goal definition
drink[] drinks
___
#result definition
int32 sequence
___
#feedback
int32 sequence
```

a) *ROS action file*

```
string cup_size
bool has_ice
ingredient[] ingredients
```

b) *ROS drink message*

```
int32 bottle_id
float32 amount
```

c) *ROS ingredient message*

Figure 5.5: *The nested structure of ROS messages created for YRC.*

5.3 Move Group Interface

The robobar_action_server node in robobar_engine package uses Move Group Interface to communicate with MoveIt! that handles motion planning for the Panda manipulator. The robobar_mockup_moveit is the configuration package required for interfacing serial robots to MoveIt!. It is generated based on the URDF (Unified Robot Description Format) file which is located in robobar_description and specifies the serial kinematics of the entire YRC (figure 5.6). Figure 5.7 shows robobar action server node algorithm.

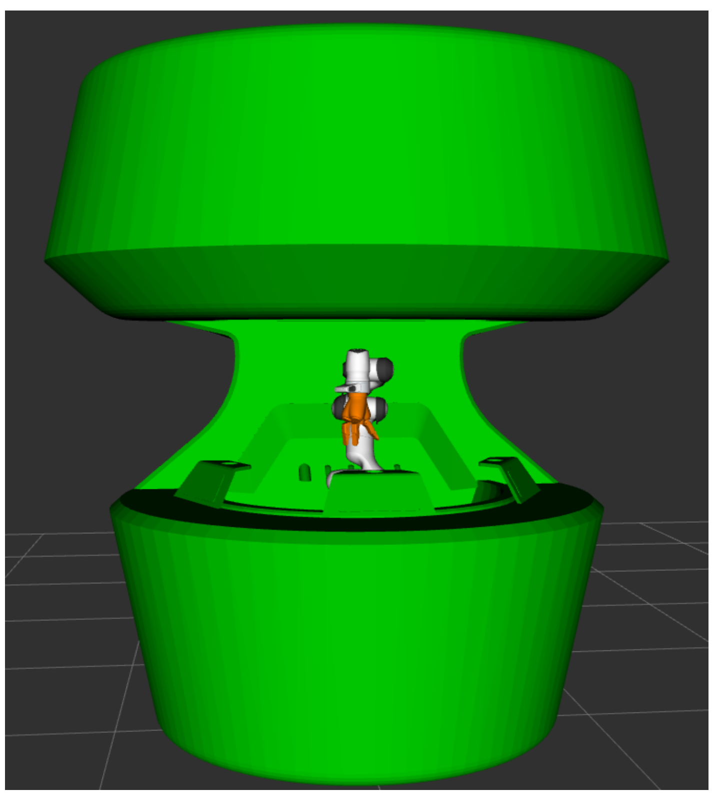

Figure 5.6: *Graphical visualization of YRC kinematics in RViz.*

After MoveIt! calculates a collision-free motion plan for the Panda manipulator, the movement trajectory is forwarded to the robot controller for execution on the real robot.

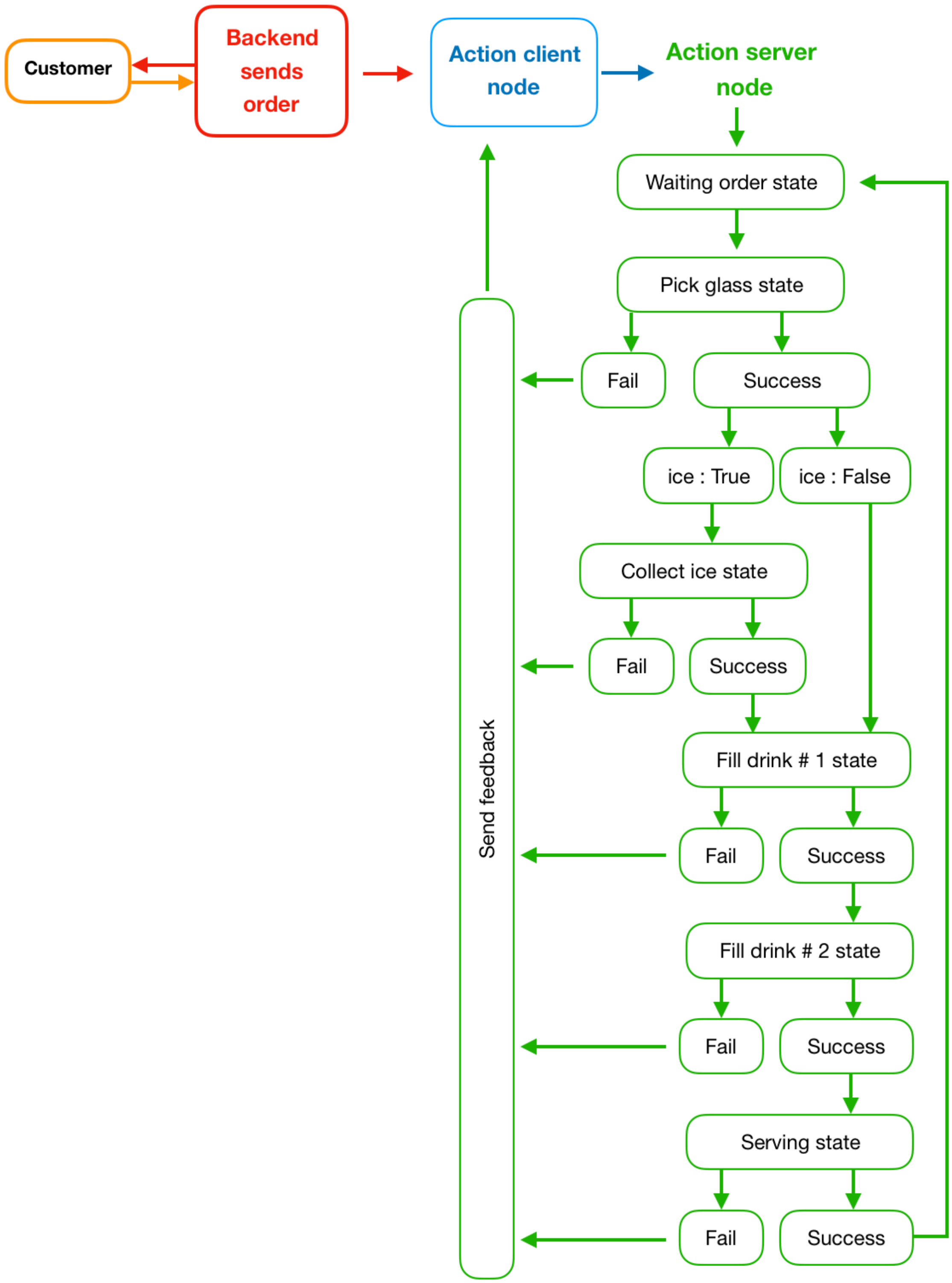

Figure 5.7: *Robobar action server node algorithm*

5.4 Drink preparation algorithm

YRC executes the motion plan and prepares the drink order by grasping a glass (small or large), filling it with ice (optional) and then adding in sequence a given amount of different drinks, and eventually serving the glass on the dock (figure 5.8).

a) Grasping a glass

b) Filling it with ice

c) First ingredient (alcoholic shot)

d) Second ingredient (soft drink)

e) Serving the glass

Figure 5.8: *Drink preparation diagram*

When robobar_server_action node receives the drink order from robobar_action_client, it will process it as follows (figure 5.7):

1. **Glass size:** YRC will pick the glass from the small or large glass outlets according to the glass size in the order.
2. **Ice:** if the order contains ice, YRC will add ice to the glass, otherwise this step is skipped.
3. **Drink ID:** YRC will fill the glass with the first ingredient then with the second ingredient.
4. **Serving:** YRC will serve the drink on the serving dock and send a feedback on drink completion to the action client node.
5. The YRC resumes to wait for the next order from the action client node.

If for any reason YRC encountered an error that resulted in failure of the drink preparation process during any step, then robobar_action_server node will send a feedback to the robobar_action_client node which will forward it to the backend to inform the customer that the drink was cancelled for technical reasons. The same feedback shall be sent to the technician in order to investigate and fix the potential error.

6 RESULTS

The software integration developed as a result of this thesis confirmed the following:

1) YRC is able to reach the two outlets for grasping empty glasss (figure 6.1), all the 45 drink dispensers in the overhead rack (figure 6.1), the ice and soft drinks nozzles, and the three serving docks.
2) YRC can prepare the drinks by grasping a glass from the outlet, filling it with ice and drinks, and then serving it on the dock.
3) Each bottle point has been tested several times during the project period (10 months) and YRC was able to perform all required tasks with no errors.
4) The drink preparing time ranges between 26 sec to 1.12 min according to the order ingredients (table 6.1).

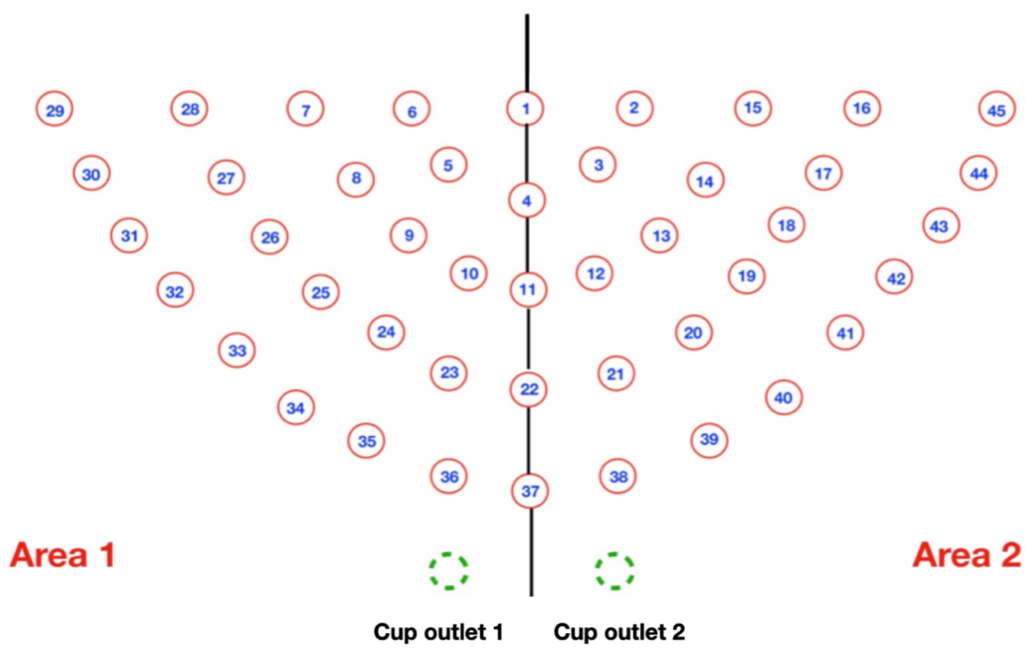

Figure 6.1: *Bottom-up view of YRC overhead rack and the distribution of the 45 bottles and 2 outlets for empty glasss.*

Table 6.1: *YRC drink preparing estimation time*

Drink Options	Ice	Drink # 1	Drink # 2	Preparing Time	Actual Time
One drink only	-	Nearest	-	31 sec	26 sec
	-	Farthest	-	35 sec	30 sec
Two drinks in the same area	-	Nearest	Nearest	37 sec	32 sec
	-	Nearest	Farthest	40 sec	35 sec
Two drinks in different areas	-	Nearest	Nearest	44 sec	39 sec
	-	Farthest	Farthest	48 sec	43 sec
Ice + Soda	✓	Nearest	-	50 sec	45 sec
	✓	Farthest	-	54 sec	49 sec
Ice + One drink	✓	Nearest	-	55 sec	50 sec
	✓	Farthest	-	1 min	55 sec
Ice + Soda + Drink	✓	Nearest Soda	Nearest (A2)	1 min	55 sec
	✓	Nearest Soda	Nearest (A1)	1 min 4 sec	59 sec
	✓	Nearest Soda	Farthest (A2)	1 min 4 sec	59 sec
	✓	Nearest Soda	Farthest (A1)	1 min 7 sec	1 min 2 sec
	✓	Farthest Soda	Nearest (A2)	1 min 3 sec	58 sec
	✓	Farthest Soda	Farthest (A2)	1 min 7 sec	1 min 2 sec
	✓	Farthest Soda	Nearest (A1)	1 min 7 sec	1 min 2 sec
	✓	Farthest Soda	Farthest (A1)	1 min 10 sec	1 min 5 sec
Ice + Two drinks in the same area	✓	Nearest (A2)	Nearest (A2)	1 min 1 sec	56 sec
	✓	Nearest (A2)	Farthest (A2)	1 min 3 sec	58 sec
	✓	Nearest (A1)	Nearest (A1)	1 min 5 sec	1 min
	✓	Nearest (A1)	Farthest (A1)	1 min 8 sec	1 min 3 sec
Ice + Two drinks in different area	✓	Nearest (A1)	Nearest (A2)	1 min 5 sec	1 min
	✓	Nearest (A1)	Farthest (A2)	1 min 10 sec	1 min 5 sec
	✓	Farthest (A1)	Farthest (A2)	1 min 12 sec	1 min 7 sec
	✓	Farthest (A2)	Farthest (A1)	1 min 17 sec	1 min 12 sec

Some final remarks associated to the table 6.1:

- Preparing time starts when the YRC moves to grasp the glass, fill and serve it then goes back to the waiting pose.
- Actual time ends as soon as YRC served the glass on the dock (i.e. it excludes the going back to waiting new order pose which takes 5 s).
- Ice collecting process takes 30 s (i.e. starting from glass grasping, collecting the ice from the machine, leaving ice machine area and then getting ready to go to the bottle).
- YRC waits for 3 s to collect the ice, 3 s to add soft drink, and 2.5 s to fill from one bottle.
- Actual Shortest Time was 26 s when preparing only one drink without ice.
- Actual Longest Time was 1 m 12 s when preparing 3-component drink (ice and 2 ingredients); the first drink was the farthest in the Area # 1 (which is away from ice dispenser) and the second drink was the farthest in the Area # 2.

CONCLUSION

The objective of this thesis was to integrate a robot manipulator to work as bartender for preparing and serving drinks.

The thesis discussed the different types and uses of robots in both food and beverage industries. It also described the design, structure, functional, hardware and software requirements of robotic bar and the implementation of the algorithm and software required to perform the required tasks.

The results showed that the robotic bar was successfully able to achieve the tasks that it was built for:

1. The manipulator can reach all the positions in the bar that are needed to prepare the drink (glass outlets, 45 bottles nozzles – ice and soft drinks dispenser nozzles – serving docks)
2. Communicating with customers by taking their orders and notifying them when their drinks are ready.
3. Preparing the drink by grasping a glass (small or large), filling it with ice (optional) and then adding in sequence a given amount of different drinks, and eventually serving the glass on the dock.

Integration of robots in food and beverage industries will solve many issues especially the time consuming and contamination issues. Thus, will enhance and improve the productivity and will be eventually reflected on the business. However, the awareness of the importance and beneficial effect of robots integration in food and beverage sectors should be raised in order to overcome and solve several issues in both sectors.

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