Autonomous Restaurant

A Multi-Agent, Robotics and IoT based approach

1st Eduardo Silva
Data Engineer
Critical TechWorks
Porto, Portugal
1180881@isep.ipp.pt

2nd Michel Silva
Engineering Lead
Farfetch
Porto, Portugal
1200169@isep.ipp.pt

3rd Miguel Costa
Software Engineer
Critical TechWorks
Porto, Portugal
1210064@isep.ipp.pt

4th Rui Oliveira
RPA Developer
Sonae MC
Porto, Portugal
1210067@isep.ipp.pt

***Abstract*—With technology becoming more and more present in our day to day lives, the demand for more intelligent environments, capable of adapting to our actions and needs, is increasing as time passes.**

One such environment are restaurants, which are still mostly operated by humans without the aid of technology to facilitate and agilize the workflow, which inevitably leads to stress, fatigue and, thus, a bad experience for the clients.

As such, a solution is proposed that aims to incorporate robot-waiters in a restaurant, supported by a network of IoT devices and a multi-agent system, as a decision making and planning tool, allowing for an autonomous and more efficient management of a restaurant floor, always with the best possible experience for the client in mind.

These claims are backed up by the results obtained during this study, as they show that such as system allows restaurants to autonomously adapt to dynamic circumstances and optimize the time necessary to serve the clients, no matter how busy the scenario at hand may be.

***Keywords*—Retail, Restaurant, Autonomy, Management, Artificial Intelligence, Multi-Agent, Robotics, IoT, Simulation, Negotiation, Collaboration, Competition.**

I. INTRODUCTION

In retail, client satisfaction must always be the centre focus and indicator of success for companies when evaluating their performance. As such, many are the strategies and tools currently being employed in order to ensure client satisfaction and confidence in the services provided.

In the past, the team had the opportunity to work on such solutions: a **Client Satisfaction Diagnosis** tool, capable of identifying dissatisfied clients and coming up with plans to build their trust back; a **Store Layout and Shelf Planning** tool, that analyses historical sales data to come up with a plan tailored to clients' habits and expectations; and a **Digital Sales Assistant**, a chat bot capable of accompanying clients on an e-commerce platform just as an assistant would in a physical store.

This time around, it was found that as technology advances and devices that surround people get smarter, the demand for smarter environments keeps increasing as time passes [1] [2] [3]. Just as a smartphone adapts to its user's actions, environments such as houses, factories and entire cities should also be able to adapt to people's habits and routines, resulting in more efficient resource management, enhanced productivity and an overall better experience [1].

In the field of retail, restaurants are an example of such environments, which nowadays are still mostly being operated by humans naturally susceptible to factors such as stress, anxiety and fatigue, which negatively impact the work performance and, consequentially, the client experience.

As a response to this, experiments have been conducted in India and China, in 2022, having shown that the transition to fully autonomous restaurants, operated by robots, resulted in streamlined cooking procedures, reduction in operational expenses and an overall better experience, as clients state that less time is spent waiting and the theme of the restaurant immediately caught their attention [4] [5].

As such, the present article presents a study on a restaurant operated by robot waiters, supported by a network of IoT devices and a multi-agent system. The latter serves as a decision making and planning tool, which is capable of simulating and automating the tasks performed by waiters in a restaurant floor, taking advantage of the communication and collaboration between agents to result in more adaptability to the surroundings and a more efficient workflow.

In the next few chapters, the reader will first be presented with a state of the art analysis of autonomous restaurants and how fields such as multi-agent systems, robotics and IoT are being applied toward this goal.

Afterwards, an overview of the proposed solution's design and architecture is presented, followed by an analysis of study's results, a reflection on future work and a few closing remarks.

II. STATE OF THE ART

In order to produce a state of the art solution that enables restaurants to be autonomously and efficiently operated by robots, a thorough analysis and application of state of the art techniques also becomes a requirement.

As a result, in the following sections, the reader will be presented with a brief analysis of how the fields covered in this project (i.e. multi-agent systems, robotics and IoT) are being integrated in restaurants and which techniques are being applied in order to tackle the issues involved in each of them.

A. *Multi-Agent Systems*

In the field of Distributed Artificial Intelligence (DAI), multi-agent systems aim to take advantage of social concepts such as communication, cooperation and negotiation between autonomous entities, known as agents, in order to simulate, control and monitor complex real systems [6].

Nowadays, these systems are mainly being employed in restaurants as a decision-making tool used by their employees, with the goal of optimizing the efficiency of their services, through a simulation of the environment and the interactions that take place between the clients and the restaurant staff [7].

It is worth noting that in the article [7], the multi-agent system comprises of 3 types of agents: clients, waiters and kitchen staff, that transition between different states throughout the simulation, with an example of state-condition transitions being described in the diagram of figure 1, for the Client agent.

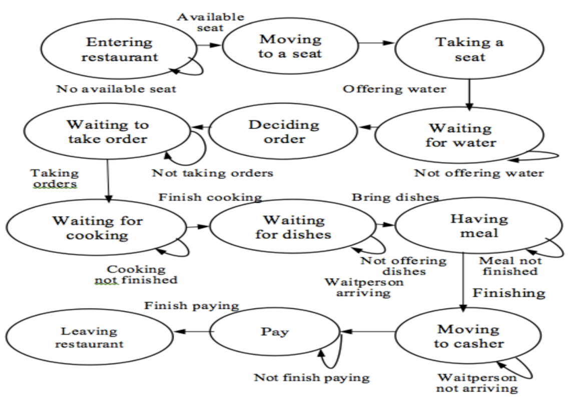

Fig. 1. Client agent - State-condition transitions

Bearing the goal of autonomous restaurant management in mind, despite the proven benefits of these tools, these are still operated by human employees and, as such, their effectiveness is still dependent on the mental and physical conditions of the staff, which is not ideal [7].

With this project, it is intended to take advantage of the benefits provided by the usage of such decision-making tools and implement a multi-agent system that can be integrated with robots and IoT devices, allowing a restaurant floor to be autonomously and efficiently managed, even in more complex and busy working conditions.

Additionally, it is worth noting that the most common technologies being used in multi-agent systems nowadays are JADE (Java Agent Development Framework) and SPADE (Smart Python Agent Development Environment) [8] [9] [10].

Studies conducted to understand which offers the best value have shown that both tools are mature and adequate, independently of the type of system being implemented, with the choice ultimately coming down to the preference on the programming language, as JADE is written in Java and SPADE is written in Python [11] [12], although JADE reportedly has a broader support and implementation throughout the research community and even in the industry [10].

B. *Robotics*

While some people in the industry believe that robots are a menace, as they would be stealing jobs and eliminating the human touch of hospitality, the benefits that they bring to the table can not be overlooked and must be taken advantage of.

As mentioned earlier in this article, human beings may be very intelligent and effective in their work, but are always susceptible to anxiety, stress and fatigue, caused by the work environment, which over time deteriorates their performance and capacity to correspond to their responsibilities.

As a response to this, in the last few years, service robots have been successfully integrated in various fields, with retail and restaurants being some examples. The effectiveness displayed by these robots when executing their tasks has been building confidence from retail companies to incorporate them more and more in their physical spaces, in some cases working alongside humans, in other cases replacing or letting them work on other issues [13].

This idea is backed by the CEO of Spyce, one of the industry leading robotic restaurants, when he stated in an interview conducted in 2019 that the automation of everyday tasks can empower staff to focus on the more exciting, rewarding aspects of working in the restaurant industry [14].

In restaurants, robots have mainly been integrated either as cooks or as waiters, with the latter involving complex tasks such as ordering, fetching and delivering food. Researchers have found that for a robot waiter to successfully perform these tasks and navigate autonomously in the restaurant floor, it must be capable of identifying the working areas (e.g. tables) and obstacles, through the use of ultrasound, lasers or even cameras, with computer vision [15].

In Portugal, these kind of robots have already been integrated in spaces such as shopping centers, with Garçon being an example, in NorteShopping (Porto), resulting from an initiative from Sonae Sierra, that started in December 2021 [16]. Naturally, this robot is still in an initial stage of its lifecycle and displays some limitations when compared to other more sophisticated robots being deployed around the world.

One such example of a more sophisticated robot is BellaBot, a robot designed by Pudu, which features an innovative bionic design language, an ergonomic design, multi-modal interaction and many other functions, with the goal of providing clients with an unprecedented food delivery robot experience [17].

This robot makes use of several 3D sensors and a RGB-D camera in order to allow Laser SLAM and Visual SLAM, while also featuring a design that allows food to easily be placed and picked up by staff members and clients [17], as perceived in figure 2.

Fig. 2. BellaBot - a smart delivery robot

It is also interesting to note that this robot is integrated with a software named Pudu Scheduler, which features a decentralized, flexible ad hoc network communication scheme and algorithm architecture [17].

This software allows each robot to directly communicate with any robot in the same network, while making quick calculations and decisions [17], similar to the multi-agent system that is implemented in this project.

Given the constraints in which this project is being developed, an alternative was sought to the aforementioned robot that features the same characteristics and sensors, is more easily be integrated in a virtual simulation and can be customized for this project's needs.

This alternative was found in TurtleBot, a low-cost personal robot kit with open-source software and easily integrable with the Robot Operating System (ROS) libraries and the Gazebo software, the latter being the simulation tool that is used in this project [18].

Fig. 3. Newest TurtleBot 4 models

C. Internet of Things

In retail, IoT is estimated to play a significant role in offering tangible and commercial benefits to the companies, by allowing their operational processes to be more efficient and productive [19].

Companies that have integrated IoT devices in their physical spaces have noticed benefits when controlling the quality of food products, planning waste management of the items that have exceeded their shelf life, and managing the temperature at the store, freezers and other equipment, contributing to the reduction of energy consumption [19].

In restaurants, the benefits of IoT have also been felt, with technologies such as Radio-Frequency Identification (RFID) and Global Positioning System (GPS) allowing the implementation of solutions such as food ordering systems [20] and food waste management systems [21].

In a restaurant floor, other problems arise such as counting the number of seats and tables being occupied at a given time or measuring the temperature of the meals that have to be delivered, for which other types of sensors are required (e.g. a pressure sensitive sensor in the chairs for the former, a thermometer for the latter), installed in appropriate hardware, such as an Arduino microcontroller.

It is important to note that, as a means of communicating with the robots and respective agents, a middleware implementing the MQTT protocol should be in place, such as Eclipse Mosquitto [22].

Eclipse Mosquitto is described as a lightweight open source message broker that implements the MQTT protocol [22] and allows the publishers (i.e. IoT devices installed in the restaurant) to publish topics for subscribers to consume (i.e. the agents). An example of a topic in this context is a person that stood up or sat down in a given chair, allowing the agents to update their representation of the environment.

III. Proposal

In the following chapter, a brief overview of the solution's design will be presented, followed by a closer look into each of the components that make up the proposed solution.

A. Overview

The design of the system architecture for this project, given the various components that make up the solution (i.e. multi-agent system, robotics and IoT), resulted in a modular architecture that is easy to maintain and extend as necessary, as presented in the component diagram displayed in figure 4.

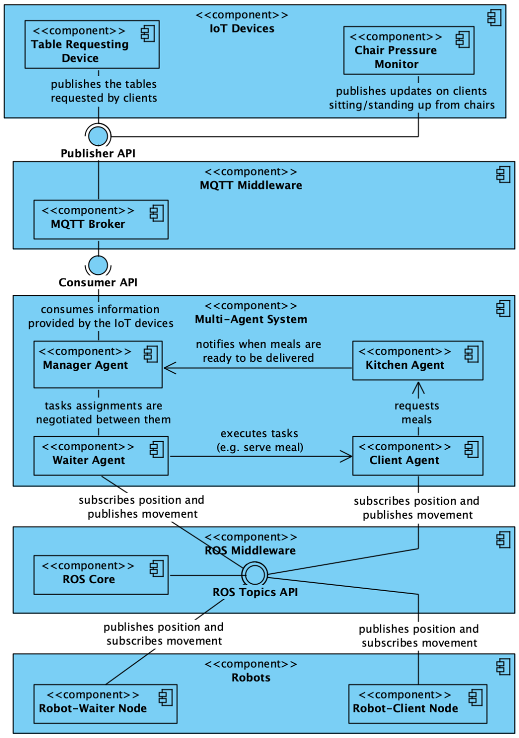

Fig. 4. System architecture

This architecture essentially comprises of 3 components with 2 middlewares establishing communication between them, both of them supporting pub/sub messaging, which is ideal for an asynchronous system such as this one.

Below, some of the technologies applied in each of these components are presented:

- **Multi-Agent System:** JADE, Java
- **ROS Middleware and Robots:** ROS, Python
- **IoT Devices:** Arduino, C++
- **MQTT Middleware:** Mosquitto

B. Multi-Agent System

Taking a closer look at each of the components, starting with the multi-agent system, four different agents can be identified, with the possible interactions between them registered in the diagram presented in figure 5.

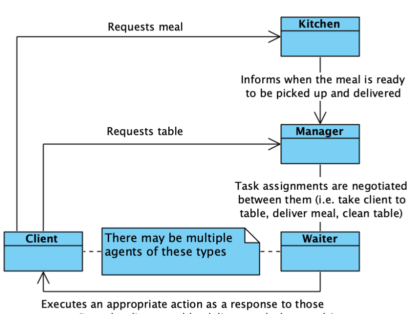

Fig. 5. Multi-agent system - Architecture

It is worth noting that the interactions taken place in this system follow the Agent Communication Language (ACL) protocol, defined in the Foundation for Intelligent Physical Agents (FIPA) standards and supported natively in JADE.

In the sequence diagram presented in figure 6, the sequence in which these interactions occur is systematized, with the negotiation portion being simplified, as it will be later analysed in more detail.

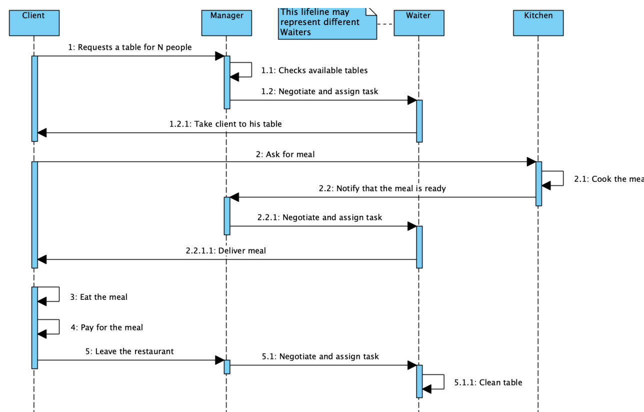

Fig. 6. Multi-agent system - Interaction sequence diagram

Taking a closer look into each agent present in this system, their goals and underlying architecture are presented below:

- Client

The goal of the Client agent is to simulate the behaviour of a human client, although at a much higher level of abstraction and simplicity when compared to the waiters.

As a result, this agent has a basic reactive architecture, as it simply executes a sequence of actions that moves the simulation forward (i.e. ask for a table, go to table, ask for meal, eat the meal, and so on).

It is important to note that these agents represent individual clients and not groups. The approach taken to represent groups in the simulation is to have a head of the group, that actively communicates with the other agents and hands the responses to the other clients in the group (e.g. the head of the group asks for the meals and, when he receives it, hands the meals to each client in the group).

As future work, it would be interesting to further extend the behaviour of the clients to incorporate characteristics such as patience and food preference, as it would enrich the simulation.

- Kitchen

The goal of the Kitchen agent is to simulate the work of a kitchen, as a black box that receives meal requests and, after some time, makes the meals available for the waiters to pick up and deliver.

Similar to the clients, this agent's architecture is purely reactive, as its only concern is to receive meal requests, cook the meals and then hand them to the waiters.

- Waiter

The goal of the Waiter agent is to simulate the behaviour and accomplish the tasks performed by a human waiter.

Although the bigger goal, the performance of the restaurant, is common to every restaurant staff, including the manager and kitchen, the waiters may also have personal goals (e.g. win the manager's trust, performance bonuses) and, as such, can be considered both collaborative and competitive at the same time.

It is worth noting that, as it is currently implemented, waiters are not collaborative between them, but rather competitive. When negotiating the task assignment with the manager, waiters always try to estimate the best possible time they believe it is possible to complete the task, as they want to offer better conditions than the other waiters in order to get the task assigned to them.

This estimation is based on their characteristics (e.g. movement speed) and their current pessimism, an attribute that is dynamically updated based on the waiter's task performance and aims to accommodate for possible unpredictable obstacles and delays. Essentially, the better the tasks are being performed, the less pessimistic the agent becomes, and vice versa.

Naturally, this agent's architecture is deliberative in nature, as they keep a representation of their environment and take that into consideration when planning their response to a given goal, as represented in the diagram of figure 7.

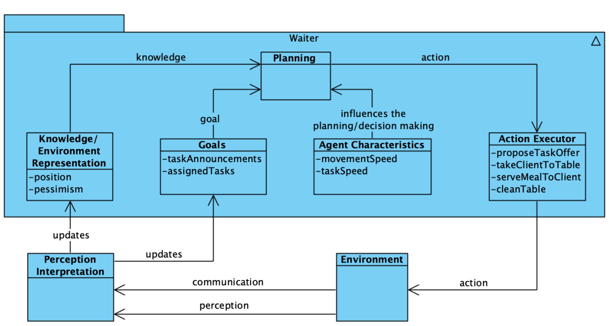

Fig. 7. Waiter agent - Architecture

- Manager

The goal of the Manager agent is to mediate the operation of the restaurant, by subscribing to the information being published by the IoT devices and receiving requests from other agents, which in turn results in the announcement, negotiation and, finally, the assignment of tasks for the waiters.

Given the task-oriented work performed by the waiters, this agent resulted from the need to establish a contract net as a means of coordinating the waiters' work.

Similar to the waiters, this agent's architecture is deliberative, as it keeps track of the changes occurring in the environment (e.g. clients standing up or sitting down in the chairs) and acts based on that (e.g. when everyone leaves their seats in a given table, that table should be cleaned), as represented in the diagram of figure 8.

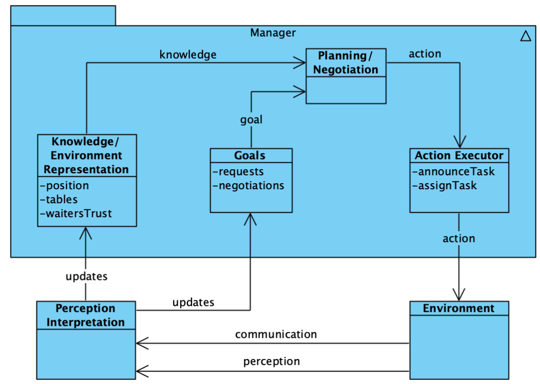

Fig. 8. Manager agent - Architecture

Furthermore, when negotiating the attribution of a given task, the manager goes through an evaluation process, where every offer is analysed and the agent with the best offer gets to execute the task.

Essentially, in this evaluation process, every offer goes through an evaluation function, which takes into account different attributes such as the time estimated by the waiter to complete the task and the trust that the manager has in that waiter's judgement, an attribute that, similarly to the pessimism of waiters, is updated dynamically based on their reported performance.

It is worth noting that the negotiation process follows a Vickrey approach, where a closed auction takes place and every waiter makes a blind offer to get the task at hand, without any knowledge of the other waiter's conditions, as represented in the sequence diagram of figure 9.

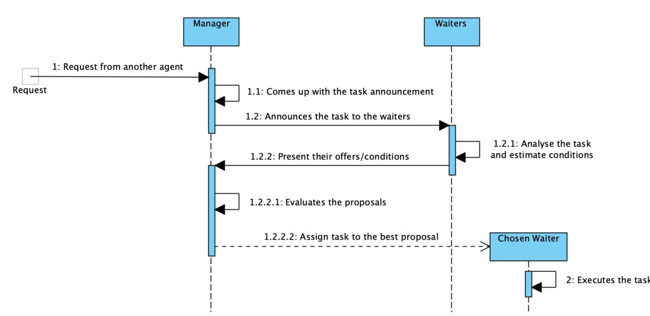

Fig. 9. Task negotiation - Sequence diagram

C. Robotics

Moving on into robotics, from the diagram in figure 4 it is possible to perceive that there is a ROS node associated with each of the robot waiters in the restaurant, that allows agents to control its movement and keeps them updated on their GPS position, all through the use of the ROS topics presented in figure 10.

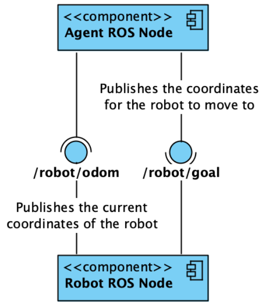

Fig. 10. Handled ROS topics

It must be noted that the robots and restaurant in this project are simulated through the Gazebo software, with the robot waiters being implemented in TurtleBot 3 Burger models, the very same model shown in figure 11.

Fig. 11. Waiter robot - TurtleBot 3 Burger model

As a showcase of the simulation executed in Gazebo, in the screenshot displayed in figure 12, a robot waiter can be seen roaming the restaurant environment.

Fig. 12. TurtleBot 3 Burger in the Gazebo simulation

It must be noted that given the complexity of including humans in simulation, a TurtleBot3 Waffle model shall be used to simulate humans and, as such, they also require a ROS node, which would not be the case in a real scenario with actual human beings.

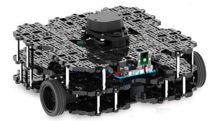

Fig. 13. Client robot - TurtleBot 3 Waffle model

The movement of the robot-waiters was implemented with the help of a graph consisting in a set of waypoints, where there were service points close to the tables and points to help with the movement in general.

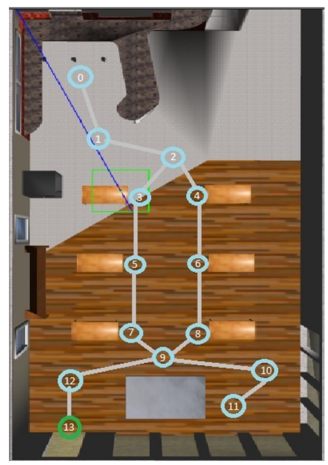

Fig. 14. Waiters graph

Following the same logic, another graph was built to help move the robot-clients. This one, in turn, was more complex because it has more nodes that represented the chairs where clients should sit.

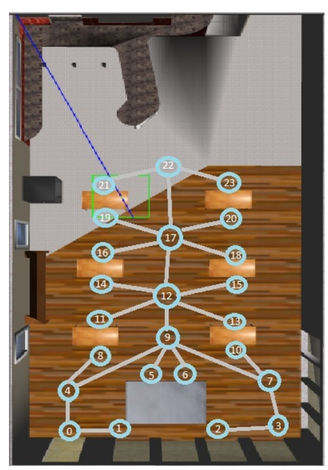

Fig. 15. Clients graph

Through the use of graphs and an algorithm that calculated the robot's initial waypoint, taking into account its current position, it was possible to implement the Dijkstra algorithm to calculate the shortest path from point A (robot's current location) to a point B (goal) in order to optimize the movement of the robots.

Furthermore, in order for the robots not to collide with each other, an anti-collision functionality was implemented using the TurtleBot's own LaserScan, where different degrees of the robot were checked so that a rotation in the movement (left or right) was made in order to avoid a given obstacle.

D. Internet of Things

In an intelligent restaurant, many are the IoT devices that can be put in place, in order to continuously provide information to the robot-waiters, allowing them to better adapt to their surroundings.

As a proof of concept, two simple IoT devices were implemented in this study, all of them connected to the MQTT middleware represented in figure 4, providing information to the interested agents and, thus, allowing for their environment representation to be updated and more informed decisions to take place.

- Table requesting device

This device, comprising of a keypad and LCD screen, although ideally implemented via a touchscreen, allows clients to request a table for a given number of people, with the request eventually reaching a robot-waiter that accompanies the clients to their assigned table.

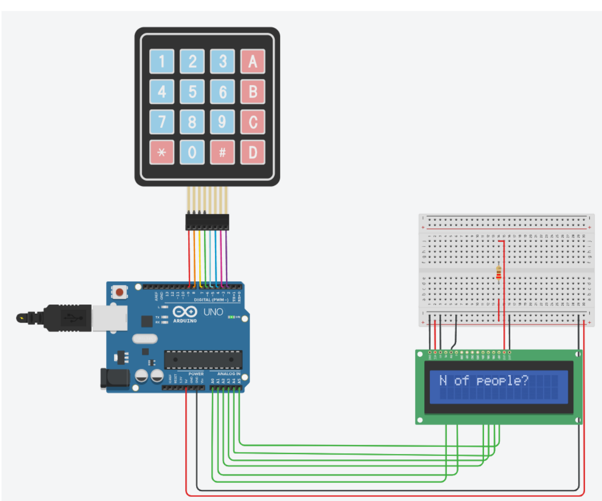

Fig. 16. Table requesting device - Circuit design

- Chair pressure monitor

Through the use of a pressure sensitive sensor, this device is capable of notifying when a client sits down or stands up from a given chair in the establishment, allowing for the agents to know how many people are in a specific table and in the restaurant at a given moment.

This way, agents such as the Manager, can send a waiter to clean a given table, when all the clients leave, or call more waiters to the restaurant floor, when it detects a significant number of clients entering the facility.

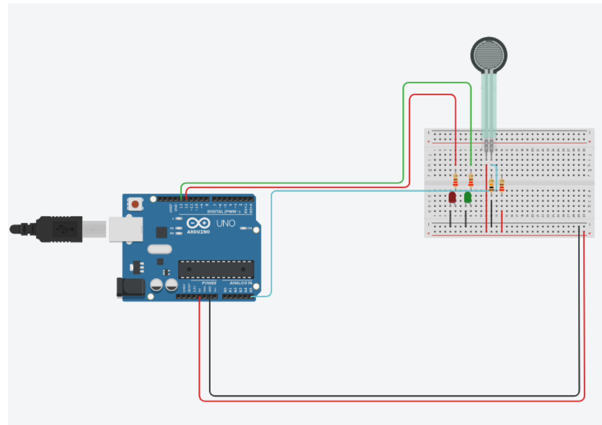

Fig. 17. Chair pressure monitor - Circuit design

IV. Results

In the following chapter, a brief evaluation of the solution's will be presented, followed by an analysis on the solution's strengths and limitations when comparing it with other existing solutions.

A. Evaluation

By the end of the solution's implementation, through the use of the Gazebo simulation software, the team is able to apply the obtained solution in a virtual restaurant, with Gazebo providing a sophisticated simulation, closely resembling what could be seen in a real restaurant.

When running some scenarios through the system, the first thing to be noticed was how scalable it is, as it is able to successfully respond to both calmer (one or two groups of two clients) and busier scenarios (various groups coming in quick succession), with the collaboration between all the restaurant staff and the competitive nature of the waiters allowing the restaurant to adapt to dynamic conditions and optimize the time necessary to serve every client in the restaurant.

Unfortunately it was not possible to perform during this study, but the ideal test would be to finally compare these same scenarios with a restaurant operated by human waiters and see how the robots fare in comparison.

On the other hand, it is interesting to notice that the initial pessimism value set for each waiter does not significantly impact the performance of the restaurant, since for extreme initial values of pessimism, a drop in performance (i.e. total simulation time) around 10 to 15% was noticed.

The drop in performance is not significant because the agents tends to update and stabilize their pessimism values in a mid to low value (around 30% to 40%), since they need to provide competitive offers while still being a bit cautious and accommodating to possible obstacles and delays, otherwise the manager's trust in them would be at risk.

B. Strengths

When comparing this solution, for instance, to the multi-agent system described in the article [7], a clear advantage is the integration with the robots and IoT devices, extending its utility from a plain decision making tool that can be consulted by restaurant staff to a system that provides robots, and the restaurant in general, the intelligence it needs to be autonomously operated.

On the other hand, the modular architecture, low coupling between the different components and use of pub/sub messaging between components, will allow the system to be easily expanded without significant effort in future work (e.g. inclusion of new agents, robots or IoT devices).

C. Limitations

Given the the proof of concept nature of this study, some aspects of this implementation present limitations, such as the robots having limited functionality, as only movement is supported, and even that functionality not being fully refined (i.e. collision detection/avoidance).

If this solution were to be worked upon and expanded into a production state, its functionality would have to be expanded by integrating more IoT devices (e.g. measurement of the food's temperature, in order to prioritize tasks), adding more functionality to the robot (e.g. clean tables, pick up and put down meals) and expanding the behaviour and interaction between agents (e.g. have waiters collaborate between them to further optimize the workflow).

Furthermore, the integration of other techniques such as machine learning might be interesting. A possible use case for machine learning could be to predict how many clients would be attending the restaurant at a given time of the day, helping the manager decide how many robot-waiters need to be deployed in the restaurant floor, which in turn helps optimize the restaurant's energy consumption.

It is worth noting that the dataset used for this use case could be collected by the system itself (e.g. record the table requests made throughout the day).

V. Conclusion

Looking towards the future of restaurants, the demand for more intelligent environments and the use of technology is increasing as time passes, with artificial intelligence, robotics and IoT having an important role in the response to that demand.

With this study, it is hoped that a valuable contribution was made for the scientific community and more awareness is brought upon the subject at hand, as robot-waiters appear as a viable alternative for restaurants to integrate in their workspace and demonstrate the benefits that technology brings to the table.

These claims are backed up by the results demonstrated by the proof of concept developed during this study, as it displayed satisfactory results, being both efficient and scalable, despite having clear limitations and future work being necessary.

As such, the scientific community is urged to continue where this study has been left off, working towards a future where restaurants become more intelligent and technologic, always with the goal providing clients with the best possible consumer experience in mind.

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