UNIVERSIDAD SANTO TOMÁS

Implementation of a testbed for multi-agent systems for the Robotics Laboratory of the Santo Tomas University

Made by

Juan Esteban Romero Velásquez

Preliminary project sent in compliance with the partial requirement to opt for the degree in Electronic Engineering.

GED Research Group (Robotics Study and Development Group)
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Directed by

Sindy Paola Amaya M.Sc

Co-Directed by

Juan Manuel Calderón Chávez Ph.D,
David Alejandro Martínez Vasquez Ph.D

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Content

Chapter 1

Problem Statement

1.1 Approach

In today's world, research on multi-agent systems can be found across various domains. These works encompass diverse areas such as government processes [1] [2], enhancements to smart grid technology [3], implementation in business processes, and applications in the oil and gas industry [4], among others. Each domain tailors a distinct form of multi-agent system to address specific needs, displaying the adaptability of this approach.

Nevertheless, the previous examples share a common thread: not all implementations require the use of external robots but only the multi-agent system in the digital form. There are also research works that involve the incorporation of external agents or are designed to be implemented within them. Instances like aerial swarms [5], search and rescue operations during natural disasters or emergencies [6], or the synchronization of autonomous cars in traffic congestion fall into this category. However, a challenge persists: there is a scarcity of laboratories or real-life implementations for such cases. Most of the research of this nature remains confined to simulations.

Nonetheless, there are research works that specifically focus on this aspect, such as the previous search and rescue study, or efforts aimed at creating Labtest implementations for such cases [1] [7]. However, for distinct reasons, these initiatives are not currently operational, and neither cities nor countries have the necessary laboratories where we can implement a multi-agent system. At the university level, Santo Tomás University (USTA) [8] has several robots that can be used to implement multi-agents, but each robot is extremely expensive and not efficient. Based on the reasons mentioned earlier, there is a need for the implementation of a testbed at the USTA that can facilitate the implementation of a multi-agent system. This Testbed should be designed to be cost-effective and easily replicable.

1.2 Problem question

For the research works and development of multi-agent systems, relying solely on simulation tests is not enough. This is because they ignore various aspects that could lead to failures during the actual implementation. Therefore, how can a Testbed for a multi-agent system be built in a physical environment in the USTA robotics lab?

Chapter 2

Justification

According to the approach outlined in the problem statement, it is evident that there is a need to have a testbed that allows testing different multi-agent systems. This testbed would support the advancement of multi-agent systems to the national level and potentially even the global level. This is because the implementation of multi-agent systems is currently quite limited [5]. By having a testbed, we would enable the implementation of these systems, resulting in improved multi-agents that are not only prepared for the planned problems but also for RealWorld challenges that might not be apparent in simulations. This would bring us one step closer to implementing robots with multi-agent systems to solve everyday problems, transforming the USTA into a leader of research about multi-agents. Furthermore, if the creation of all robots is low cost, our country can become a hub of progress and innovation with the support of universities.

With this project, we can test and implement different multi-agent systems, ranging from centralized (all agents controlled by one computer) [3] to individual (each agent works on its own) [1]. This would allow us to test a wide range of multi-agent systems, optimizing the functioning and performance of each one. We could obtain a better model of a system with a more defined function.

Although this project is important and can open many opportunities in research, this type of laboratory is not common (In all of America, there is only one in the United States), finding even three laboratories in the world is a challenge. In comparison to other areas of research, this is a small number. Additionally, the documentation for these laboratories is limited [7], which gives rise to potential problems that are not considered during the proposal stage. Issues such as robot identification, terrain unevenness, and other challenges may arise only when the system is being tested [6]. We will have to identify and resolve these problems along the way. We can encounter problems of all types, ranging from hardware issues like problems with drivers, engines, or cameras, to software problems like the correct functioning of the multi-agent system and the proper use of engine drivers. These are just a few examples of the problems that we anticipate encountering.

Chapter 3

Social impact

This project is focused on students conducting research with multi-agent systems, ranging from undergraduates to master's level. Depending on the complexity of the system, this research can be quite labor-intensive. This project enables students to implement and test these systems, allowing them to make more considerable progress in their research rather than relying solely on simulations. This approach allows the creation of systems where implementation involves building robots tailored to specific problems. Importantly, there is a sense of security in knowing that their multi-agent systems function as intended.

This opportunity is open to students who are part of research groups, such as the robotics group at the USTA [8], working on small systems for synchronizing in situations of traffic jams or scanning terrain with different agents. They can participate in competitions held in various parts of the world, thereby enhancing the university's reputation in RoboCup [9].

It is also valuable for professors who wish to demonstrate the functions and characteristics of a multi-agent system with simple examples, like Robotarium [7], also in collaboration projects with other universities as District University or National University, enabling them to utilize the test lab and conduct community research., but with hands-on manipulation. Hereafter, there is the potential for remote functionality, which could enable students from our city or country to utilize this testbed for research and guidance in creating new testbeds or implementing them in real-world environments.

In any scenario where this testbed is employed, individuals can observe their systems in action, analyze their behaviors, track their paths, and understand their positions relative to other robots and the environment. If obstacle detection is included, it can suggest optimal routes to reduce time and energy consumption. All of this facilitates the planning of top strategies for varying cases and types of robots. Given that robots possess distinct characteristics such as robotic arms, temperature sensors, proximity sensors, or other components for interacting with the environment, these strategies can be tailored accordingly.

Chapter 4

State of the art

4.1 Multi-Agent

In the research on multi-agents, we can discover various applications, such as the implementation of multi-agents to enhance the functioning of a smart grid [3]. For the proper operation of this system, it is necessary to read and obtain information from certain components that are not related to it. Multi-agents are used to analyze each component, consolidate the data for interpretation, and perform various optimizations to improve the functions of the smart grid.

A similar function can also involve implementing multi-agent systems in a country's fiscal system, such as China's [2]. In this country, there is an implementation of multi-agent systems and various optimization techniques, such as game theory, can enhance the interactive strategies among polluting enterprises (PEs), local government regulators (LG), and central government planners (CG) in China.

In the application of a multi-agent system, navigating through environments, as seen in rescue applications [6], involves analyzing various obstacles within the environment. For instance, it is crucial to assess whether greater mobility is needed for unstable terrain or if the robot requires additional functions like a mechanical hand. Multiple types of robots may be necessary for efficient task execution.

Communication among all robots in the environment and various agents is vital. This includes scanning the terrain, adding new tasks, reporting problems, or anything that requires reporting. Another essential function for these robots is interacting with humans when they need to operate interactively with external humans.

The final operation encompasses perception and planning strategies for solving problems in real-time situations. All these cases are extensively studied in research to determine the most effective organization for completing tasks with all agents, facilitating communication among robots, receiving tasks or controls from humans. Additionally, research delves into identifying specific types of robots suitable for different natural disasters or emergency scenarios.

In research focusing more on the trajectory of multi-agents, we can observe the utilization of multi-agents in drones for terrain scanning and efficient mobility [10]. These drones are adept at evading obstacles and navigating from point A to B in minimal time, achieving this by employing cameras that detect obstacles and their distances from the drone. The gathered information is then transmitted to all drones, allowing them to collectively plan the most optimal route.

Furthermore, all components necessary for this process are incorporated into a small robot measuring only 8 cm from motor to motor. Using the transmitted information, a 3D map with all obstacles is generated. In this research, various methods for incorporating multi-agents into trajectory planning are explored. These methods include equations for obstacle avoidance and route planning.

4.2 Swarm robots

In nature, various animals work together in complete harmony and synchronization, demonstrating highly efficient energy utilization. It is possible to replicate this cooperative work in robots to reduce energy costs and save time by incorporating diverse types of robots.

First, we need to identify the various applications, and through research, we have discovered several uses [5]. For example, in entertainment, multiple robots create aerial displays with drones during different events. To achieve synchronization, swarm programs are incorporated, resulting in various captivating aerial shows.

Another application of swarm robots is in surveillance and security, where distinct types of robots are employed, ranging from drones to cameras with rotation capabilities. They monitor specific locations, scan areas quickly, and prioritize certain areas for inspection.

Additionally, swarm robots can be utilized to transport objects that a single robot cannot handle alone, achieving mobility through the synchronization of multiple robots.

In researching the capacity of swarm robots to enhance their functionality, we have encountered numerous studies focused on the development and creation of such systems [11]. Within these research endeavors, we have come across different programming languages, with C++ and Python being the most prominent. These languages provide us with a plethora of programs for simulating different environments, including Stage, Gazebo, and TeamBots. These simulation tools facilitate program development and testing across diverse environments.

Additionally, we have explored various robots available for purchase or implementation, each manufactured in different years and equipped with a range of sensors, steering mechanisms, and computing capabilities. This diversity allows us to select robots based on specific situations or environments, aligning the choice with the intended use of the robot. However, it is worth noting that implementing swarm robots can be expensive.

4.3 Artificial Intelligence

Artificial intelligence has gained significant popularity today, with the release of numerous freely available Artificial Intelligence (AI) tools. AI is a means to enhance the efficiency of various tasks, making it a valuable opportunity to improve programs. We have come across various introductory documents on this subject [12], which provide insights into the current types of AI, including Deep Learning, Machine Learning, and Reinforcement Learning, along with their respective advantages and disadvantages.

One such application can be observed in the field of robot communications [13]. In different communication scenarios where data volumes significantly vary, optimizing communication is highly productive. AI enables us to collect essential data, structure the information, and transmit it efficiently.

However, organizing this data can take various forms, prioritizing distinct types of information. This adaptation depends on the specific situations or environments in which communication is implemented. Consequently, a range of organizational methods and AI types are incorporated into these functions, each tailored to specific needs. Such adaptability is essential for strategies involving distributed multi-agents.

AI is also integrated into the planning of paths or routes for different robots, as exemplified in drone navigation [14]. This is because there are multiple forms and strategies for planning a route. For instance, there are equations that assign values to obstacles, and by replacing these values in the equation, we can calculate a route. However, this might not always yield the most optimal path for the drone.

There are other methods for calculating routes that consider additional factors, such as the presence of other drones or faster routes. To address this complexity, AI is incorporated to compare different route calculation methods, even employing various forms of AI. This leads to the generation of graphs that compare and evaluate the performance of each approach.

When conducting more specific and detailed research, we come across documents that delve deeper into certain types of AI, such as Q-learning [15]. Beginning with reinforcement learning, these documents explain its structure, various utilities, and use cases. They shed light on applications and then proceed to explain what Q-learning is and why it is implemented. It is pointed out that this form of reinforcement learning utilizes tables for the learning process, displaying its training performance and presenting diagrams of its AI structure.

The documents conclude by discussing how this AI is incorporated into various simulators and different scenarios within swarm systems, elucidating the decisions made by AI in these contexts. This AI can be incorporated into distinct parts of the project, specifically in mobility and communication.

Chapter 5

Objectives

5.1 General objective

To build a testbed for a multi-agent system, designing the necessary components, to enable the implementation and execution of tests in the Robotics laboratory of USTA.

5.1.1 Specific objectives

- To design a 3D model for the robotic structure through the computer aided design software to include all the required components.
- To assemble three robotic platforms according to the printed design, incorporating the processing elements, power supply components, and actuators while validating their individual functionality for implementation.
- To implement a multi-agent strategy through test scenarios within a centrally controlled structure.
- To validate the performance of the multi-agent system through test scenarios verifying its functionality.

5.2 Scope

With this project, we obtained three robots that move autonomously on a flat surface within the range of the ceiling-mounted camera. The different problems we may encounter include parts not fitting correctly, necessitating model adjustments and reprints, the camera not capturing everything correctly, requiring adjustments, or the robots not operating as expected in comparison to the simulation, necessitating a review of various variables to correct them.

Chapter 6

Methodology

We will employ a mixed methodology, using qualitative methods for researching multi-agents and swarm robots, and quantitative methods for creating distinct parts and assembling all purchased components. This process encompasses a total of six stages in the project's development. We begin with the research phase, followed by design and assembly, concluding with the incorporation of the multi-agent system and the final documentation.

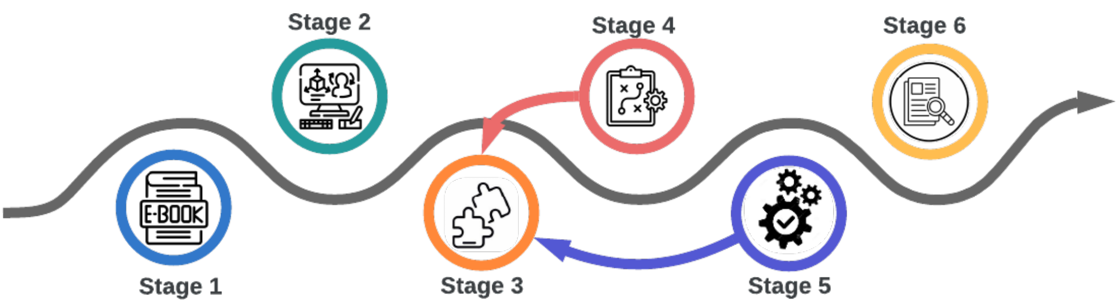

FIGURE 1: Steps to Follow

6.1 Stage 1: Bibliographic Inspection

In the stage of bibliographic inspection, we search for research that shares common themes or components with our research, such as artificial intelligence, swarm robots, multi-agents, and the implementation of multi-agents leaning in the database of USTA. Additionally, we explore websites that provide supplementary information for our research, including resources from our university and examples of multi-agent applications in other places, such as Robotarium.

6.2 Stage 2: 3D Design

We will create 3D models of various robot components, including machines, computers, and all purchased parts, utilizing 3D design software like SolidWorks or AutoCAD. We will also employ moderate AI capabilities, as found in software such as AutoDesk or Fusion 360. This approach enables us to compare these components with the supports and structures we have designed, ensuring a higher level of precision during the assembly of all parts.

6.3 Stage 3: Assembly

We will assemble all the parts, including the 3D-designed components and the pieces used by the robot, such as machines and computers. In case any part does not align correctly, it is necessary to return to the previous stage for redesign. We connect the machines, drivers, and computers, placing each within the chassis or on the supports. This process results in the robots that we can use to implement the multi-agent system. Additionally, we install a camera on the ceiling to monitor all the functions of the robots.

6.4 Stage 4: Strategy Implementation

We incorporate a small program that enables us to control each individual robot for testing their functionality. After verifying the operation of all the robots, we proceed to implement a multi-agent system. This system allows us to observe the interactions among the multi-agents and their operations in a real environment, utilizing programming languages such as Python or C++.

6.5 Stage 5: Verification Of Correct Operation

In the final stage, we will make corrections and adjustments if any problems or incorrect operations arise to ensure proper functioning. We will conduct tests in the robotics laboratory where the system will be installed. Potential issues may arise at various stages, such as during assembly if the robot exhibits structural inconsistencies or during strategy implementation if there are errors in navigation or synchronization.

6.6 Stage 6: Document writing

In the final stage, we complete the project documentation, which includes a comprehensive record of each step we have undertaken, along with any problems encountered and their respective solutions.

Chapter 7

Schedule

We will carry out the project over a period of five months, commencing in June with the pre-project testing phase. This phase will conclude in November, allowing us sufficient time to present the complete project and address any potential issues or corrections needed for the reviewer's evaluation.

- Bibliographic Inspection
  - 1.1 Search for research related to the project [Find at least 10 articles related to the project]
  - 1.2 Reading, analysis of the research obtained [Obtained some problems that I may have]
- 3D Design
  - 2.1 Creation of 3D models of purchased parts as processing elements, power supply components, and actuators [3D models of purchased parts]
  - 2.2 Creation of chassis to use for each robot that protect all elements of functionality [3D models of chassis]
  - 2.3 Creation of parts necessary for assembly that support the elements of functionality [3D models of supports]
- Assembly
  - 3.1 Assembly of purchased parts and supports [Complete parts for assembly]
  - 3.2 Total assembly of each robot [Robots]

- 3.3 Control camera installation [Camera in operation]

- Strategy Implementation
  - 4.1 Simulate the Multi-agent strategy [Simulation in operation]
  - 4.2 Implementation of test program to control each robot [Each robot with an operational program]
  - 4.3 Implementation of multi-agent strategy in robots [Multi-Agent system in operation]

- Verification Of Correct Operation
  - 5.1 Structural testing of each robot [Ensure correct functioning of each robot without instabilities]
  - 5.2 Directed navigation test [Robots with manual navigation programs]
  - 5.3 Autonomous navigation test [Robots with autonomous navigation programs]
  - 5.4 Correction of Reviewers [Reviewer approval]

- Document writing
  - 6.1 Creation of final presentation [Slideshow]
  - 6.2 Final presentation [Exposure]
  - 6.3 Preparation of Final Project [Research document]

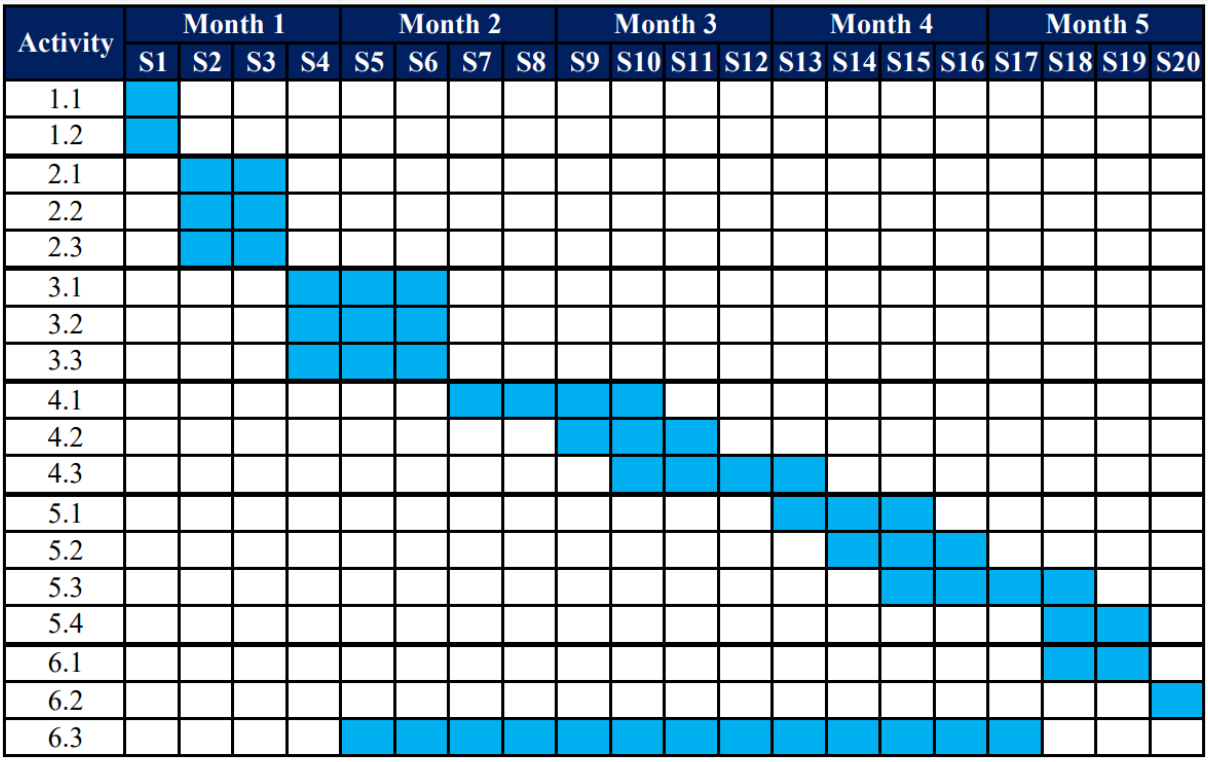

FIGURE 2: Week By Week Schedule

Chapter 8

Budget

In the last table (Figure 3), we can see the complete production cost, including equipment, software, and wages.

Category	Amount	Unit	Worth	Total	Responsible for Expense
Human Resources					
Director	24	Hours	$ 35.000,87	$ 840.020,88	University
Co-Director	24	Hours	$ 40.850,00	$ 980.400,00	University
Co-Director	24	Hours	$ 48.000,00	$ 1.152.000,00	University
Investigator	7	Months	$ 612.720,00	$ 4.289.040,00	Student
Total Human Resources				$	7.261.460,88
Services					
Internet	7	Months	$ 40.000,00	$ 280.000,00	University
Total Services				$	280.000,00
Equipment and Software					
Python	1	License	$ -	$ -	
CAD (Solid Edge)	3	Months	$ 1.129.837,50	$ 3.389.512,50	University
Engines	6	Unit	$ 92.251,85	$ 553.511,10	University
Robot Computer	3	Unit	$ 102.878,80	$ 308.636,40	University
Drivers	1	Unit	$ 47.511,15	$ 47.511,15	University
Power Supply	3	Unit	$ 160.782,00	$ 482.346,00	University
Camera	1	Unit	$ 496.166,92	$ 496.166,92	University
3D Printer	1	Unit	$ 76.220,90	$ 76.220,90	University
Computer	1	Unit	$ 74.126,20	$ 74.126,20	Student
Total Equipment and Software				$	5.428.031,18
Subtotal				$	12.969.492,06
Unforeseen 10%				$	129.694,92
Total				$	13.099.186,98

FIGURE 3: Total Budget Elements

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