Enviado: 10/12/2022 Recibido: 16/12/2023 Aceptado: 16/04/2023

UNIVERSIDAD DISTRITAL FRANCISCO JOSE DE CALDAS

VISIÓN ELECTRÓNICA

https://doi.org/10.14483/issn.2248-4728

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Robotic system based on ant behavior for optimizing shortest path finding

Sistema robótico basado en el comportamiento de las hormigas para la optimización en la búsqueda de rutas más cortas

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Abstract

In recent decades, bio-inspired systems or biological systems have become essential elements for the understanding and explanation of the logic and complexity of life.[1] Given a problem or task, it is always possible to find a way to find a solution, but when the tasks to be performed become complex, so do the solutions. Given a problem or task, it is always possible to find a way to find a solution, but when the tasks to be performed become complex, so do the solutions become more complex, so it is more practical to provide solutions from bio-inspired systems that have already provided solutions to many existing problems in our

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reality through evolution, which leads to the implementation of a bio-inspired algorithm, which takes as a basis the behavior of what nature already provides and uses it in its favor to solve real-life problems more efficiently [2][3].

Keywords: Algorithms, Ants, Bio-inspired, Communication, Robotics.

Resumen

En las últimas décadas, los sistemas bio-inspirados o sistemas biológicos se han convertido en elementos imprescindibles para la comprensión y la explicación de la lógica y la complejidad de la vida.[1]

Dado un problema o tarea siempre se puede buscar la manera de dar con una solución, pero cuando las tareas a realizar se vuelven complejas, así mismo se hacen más complejas las soluciones, por lo cual es más práctico dar solución desde los sistemas bio-inspirados que ya han dado solución a muchos problemas existentes en nuestra realidad por medio de la evolución, lo cual lleva a la implementación de un algoritmo bio-inspirado, que toma como base el comportamiento de lo que ya otorga la naturaleza y lo usa en su favor para así resolver de manera más eficiente problemas de la vida real [2][3].

Palabras clave: Algoritmos, Hormigas, Bioinspirado, Comunicación, Robótica.

1. Introduction

The development of robotics as a new branch of knowledge began in the 60's, concentrating the interest of a large number of researchers over time [3]. Since then, robotics has been immersed in all kinds of fields, from specialized areas such as aeronautics, the military, or industry, to entertainment, becoming part of everyday life [3].

In recent decades the idea of recreating biological systems has become an essential element for the understanding and explanation of the logic and complexity of life, giving way to the design of robotic systems that become a reflection of complexity and organization, where the aim is to take patterns that already exist in nature and use them in favor of the development of new technologies [1].

Currently, bio-inspired robotic systems represent a great opportunity in technology development, since, when a task to be performed becomes complex, so does the solution, so a structure that in principle seems simple can help to model complex systems, such systems are modeled by behaviors already existing in nature, a clear example is in ant colonies, which as the most characteristic element has route generation by means of certain chemicals called pheromones. These substances function as attractors for the entire colony, generating over time a real path between the food source and the anthill.[4] The pheromones are also used to attract ants.

Since the volumes of information became massive and robotic systems started to become more structured, it has become clear that technology has become a fundamental ground for both the progress of knowledge and its impact on society and nature.[1] Generating highly robust but computationally expensive structures where conventional algorithms cannot cope when the problem grows, a new approach to solving complex problems opens a gap for bio-inspired systems and more precisely artificial life, becoming the very foundation of complex systems engineering. Bio-inspired engineering is then configured as complex systems engineering.

Ants can then develop very complex tasks such as finding the shortest paths from the anthill to the places in the environment where food is available, organizing themselves into crowded patrols to go hunting or building gigantic tunnel structures to live comfortably; most ant species have as their main sensory source the ability to track pheromones that they have been leaving themselves, converging on a path between the food source and the anthill[5].

According to Klaus Jaffé, it is because of this organization that outstanding results are achieved when searching for and transporting food. Although there are many species of ants, in general the different species tend to share similar characteristics such as: communication systems based on pheromones, changing some interactions for other simpler ones depending on the environment in which they are found and the evolution of the species itself.

Ants have multiple communication systems, most of them based on chemical signals. Of the known communication systems, we can name alarm communication, recruitment, territory signaling and recognition of nest mates. For all these communication systems different pheromone species or pheromone complexes responsible for communication have been found. In some species, however, communication occurs through non-chemical signals such as visual, sound or tactile signals. Although ant societies use different types of signals in their intraspecific communication, chemical signals seem to be the most important. Ant species with more complex societies with respect to the number of individuals per colony, nest sophistication and division of labor, base their communication almost exclusively on chemical signals [6].

With this description on ant communication it is now defined that robots are part of a multi-robot system are oriented to solve problems in which the participation of a single robot is not sufficient or proves to be very costly, in terms of design and time, such as transport of bulky objects, handling of hazardous material, exploration and terrain coverage [7].

2. State of the art

The following is a brief description of the state of the art in implementing different types of bio-inspired systems, using the presentation of articles, research related to different environments, emulation of animal behaviors, their uses, among others, that have been collected.

2.1 International Research

2.1.1 Bio-Inspired algorithms for off-line planning of serial robot trajectories

In this work, Álvaro Gutiérrez Martín, Felix Monasterio-Huelin Maciá Universidad Politécnica de Madrid, introduce the first notions about bio-inspired algorithms and the social hierarchies of ants. They also propose a model of what can be an emulation of the pheromone search algorithm so well known by ants, in addition to the locomotion method used. It consists of giving the end-effector of the robot the necessary trajectories to move in its workspace and execute different tasks by means of a virtual environment in which both the robot and the environment it is part of are simulated. This article presents a review of the techniques traditionally used in the development and optimization of off-line trajectory planning in serial robots. The benefits and multidisciplinary character of bio-inspired algorithms are highlighted thanks to their use as a search and optimization tool in problems of different areas of knowledge. Finally, the main applications in off-line trajectory planning in which bio-inspired algorithms have contributed as an alternative for the search and optimization of solutions in serial robot trajectories are presented [4].The article by Yang Jian, Yang Li, presents significant improvements in the development of an algorithm that is similar to the one presented by Álvaro Gutiérrez Martín, with the exception that it presents a greater use of environment variables to describe the phenomenon more accurately, as well as a feedback component for error handling. A comparison of different bio-inspired algorithms is presented with the purpose of being used to find the optimal structure of an artificial neural network. In the first part, the reviewed algorithms are presented and the reason for the selection of the compared algorithms is explained. Subsequently, a comparison of their performance in optimizing difficult-to-optimize functions is made. Finally, the best algorithms are used to find the optimal structure of a backpropagation type artificial neural network, that is, to find both the number of neurons and the number of layers of the network [3].

2.2. Local Investigations

2.2.1 Implementation of a multi-robot system based on ant behavior.

Leidy López establishes her project on the basis of cooperative robotics and its principles, and also formalizes the behavior of the system based on the organizational structure of ants. This article shows the design, development and results of a system that will use three LEGO® type robotic platforms in a controlled environment, which are inspired by the behavior of ants in terms of search and transport of food; two platforms represent the role of the workers, which are responsible for the search and transport of "food" to the "anthill", the third platform "the queen" reaches the food after being collected. The mechanical part of the platforms is made with LEGO® MINDSTORMS® kit chips, while the control and communication system is implemented with a Microchip PIC® microcontroller and XBEE modules supported under the ZIGBEE® protocol respectively. This in order to strengthen the research lines in cooperative robotics and bio-inspired robotics of the Robotics research group [5].

2.2.2 Search and transport of objects with bio-inspired lego-like robotic platforms in a known environment

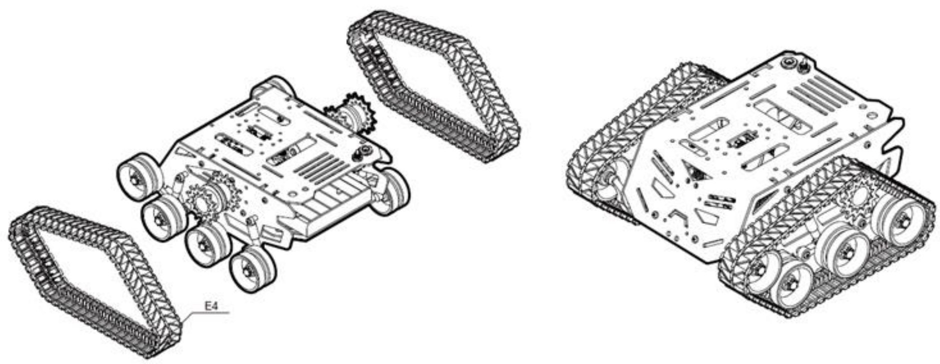
Ants are very simple insects that live in colonies with a highly structured social organization. Thanks to cooperative work, they can perform very complex tasks such as finding the shortest paths from the anthill to places in the environment where food is available, organizing themselves into crowded patrols to go hunting, or building gigantic tunnel structures to live comfortably. [2]

3. Methodology

3.1 Robotic platform

This article describes a system based on the biological behavior of ants, trying to emulate their ability to find the shortest path between two points and the communication between them, for this a robot is implemented with a mobile robot platform with caterpillars, this platform is built with a high strength aluminum alloy and is extremely strong and durable, this due to the conditions to which the platform must be subjected to the search of routes, In addition to this, it also has a modular implementation that allows the use of a variety of modules for the control of the motors and the addition of sensors for the characterization of the space, these platforms have communication to know what information the previous platform collected after iterating the ant colony algorithm, seeking the addition of a second platform as the project progresses.

Figure 1. Mobile platform [7].



3.2 Components

3.2.1 TF Luna: This sensor measures distance by calculating how long it takes for light to travel to an object and back to the sensor, having a wide measurement range measuring from 0.2m to 8m with 90% effectiveness according to the manufacturer (Figure 2a).

3.2.2 MMA8452Q (3-axis 12bit accelerometer): it is a 3-axis linear accelerometer, with this you can know what are the variations of velocity with respect to time in each of the coordinate axes (x, y, z), thus knowing if the platform is tilted and to where (Figure 2b).

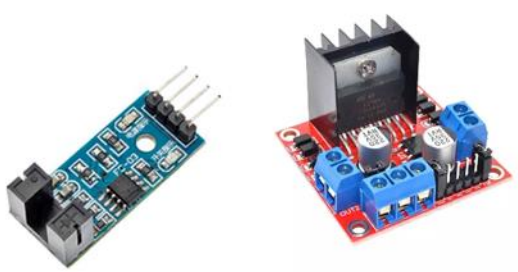
3.2.3 Bluetooth module HC-05: This module is used to communicate the information collected by the platform, the objective is that the first platform travels the surface and finds the shortest path and transmits it to the base (ant hill) (Figure 2c).

3.2.4 Infrared speed sensor for encoder: The function of the speed sensor is to send the speed of the platform in RPM and thus consolidate the information sent by **it (Figure 2d).**

3.2.5 H-bridge L298: The bridge driver determines the speed of the motors that serve as traction, and the speed of the motors is controlled by means of pwm and the application of control methods to mitigate errors due to motor dynamics (Figure 2d).

Figure 2. a) TF-Luna LiDAR module **b)** L298N **c)** MMA8452Q **d)** HC-05 bluetooth module **e)** Infrared speed sensor for encoder.

a) **b)** **c)**



d) **e)**

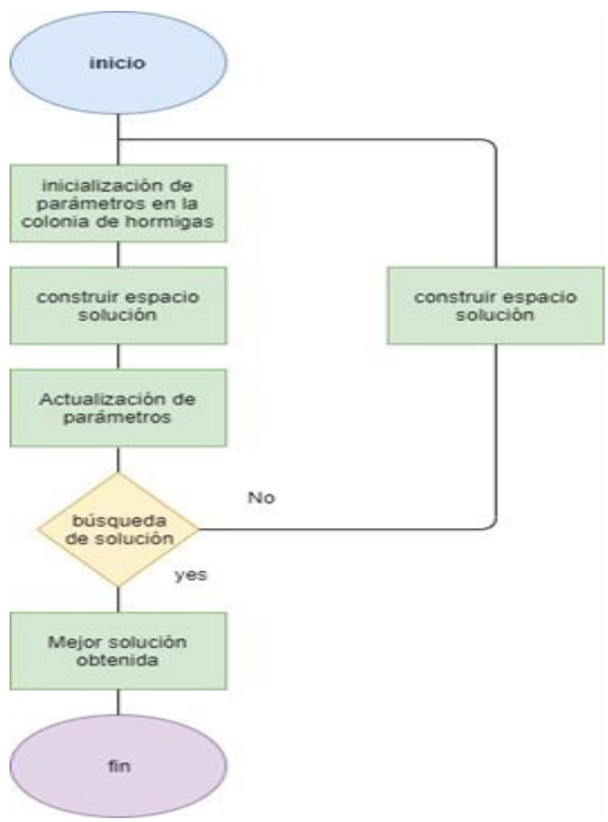
In addition to the previous devices, there is an STM32 Nucleo L476RG microcontroller that allows performing a series of tasks and has free RTOS that makes a better use of the microcontroller resources.

3.3 Programming

3.3.1 Construction of the solution space

Making a brief description of the block diagram, it is given the initialization of the environment variables, initial conditions of the robotic platforms as well as the knowledge of the target (hive) and the amount of pheromones in the environment, once all these initialization parameters have been given, we proceed to apply the ant colony algorithm, If with the system update the solution has been reached, it is said that the desired solution has been reached, otherwise it continues iterating until the solution is found, thus reaching the end of the algorithm.

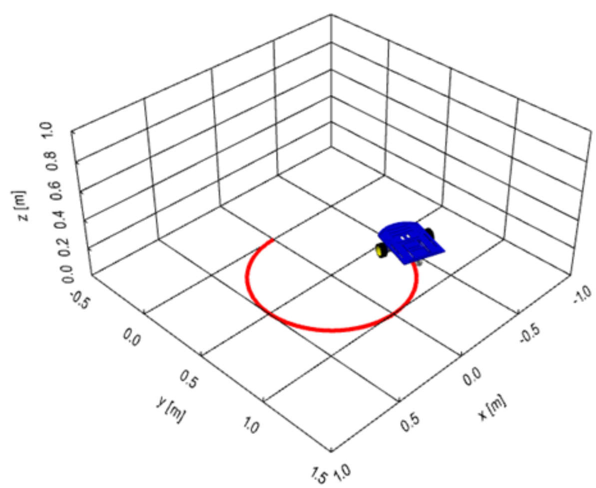
Figure 3. Block diagram (Source)



3.3.2 Display environment

The environment was designed in Python, where we took the existing simulation modules, Figure 4, and open to the community, we proceeded to adapt what was already implemented for the needs, since in itself the software only works for simulation and what is sought is to know the state of the robot in real time, in this program the different trajectories are tested depending on the speeds of each wheel of the robot makes a different trajectory is generated, all this without taking into account errors of odometry, dynamics and inertia of the motors.

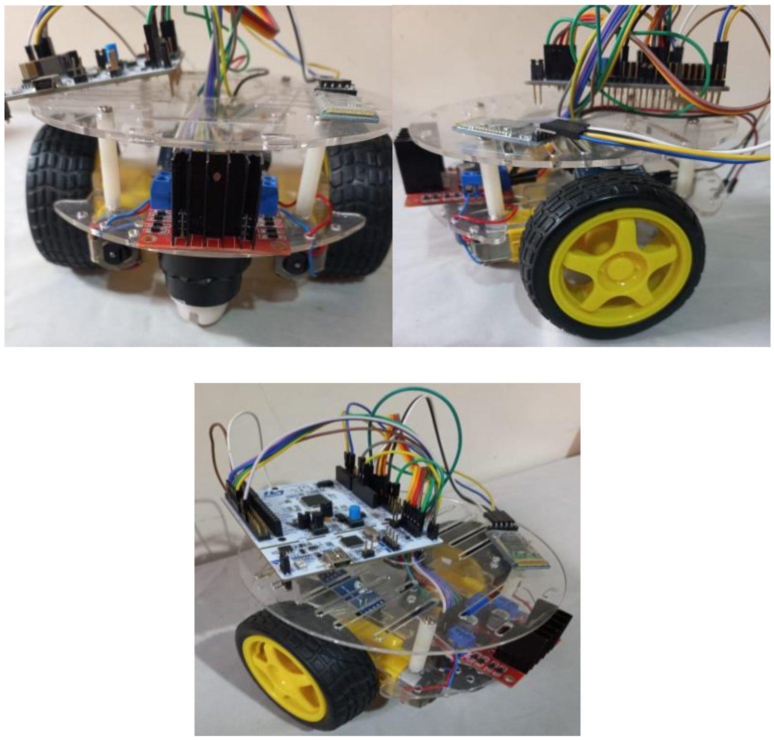
Figure 4. Graphic environment



4. Results

After analyzing the implementation of different mobile platforms, it was decided to choose a caterpillar type mobile platform because it is the most versatile at the time of overcoming small obstacles and it is easy to handle because this platform is not intended to be heavy, due to the capacity of the engines and its own maneuverability, In addition to that, it was taken into account that this platform should have easy access and mobility in small spaces and complex terrains, the first tests are performed on a mobile platform adapted according to the needs, as shown in Figure 5, this first platform is not of the caterpillar type and carries a programming card (MBED).

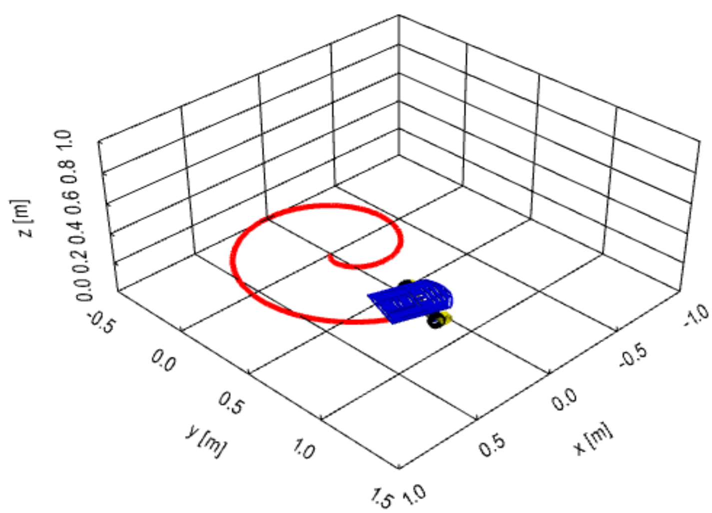
Figure 5. Initial mobile platform (own source)



To perform the distance measurements, tests are carried out with different sensors in charge of taking the data to be able to concatenate the information, however, after performing several tests, it is evident that an optimal and adequate way to take these values is implementing a lidar. A lidar is a device that allows to determine the distance between the platform and an object, to implement it was necessary to take into account different references in order to fully understand the operation of the same and how to replicate it, based on this some planes are taken which give light to make 3D prints of the base of the lidar, also being a distance sensor based on the time of flight of the speed of light, therefore, response times are minimal.

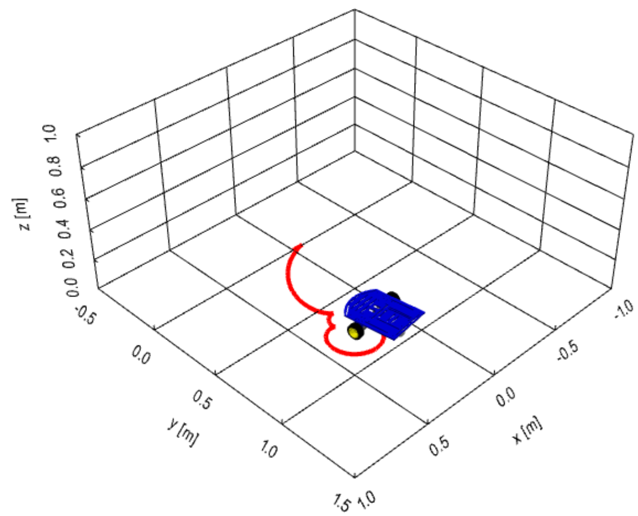
Implementation of the algorithm in python, as explained above the software is implemented by third parties, which serves to simulate the kinematics of a differential mobile robot, now well modifications are made so that this through the bluetooth communication module, can acquire the speed data resulting from the process of measuring the speed of the wheels by odometry, being important because with this adjustment instead of seeing a simulation will see one as the platform is really moving, of course it should be clarified that does not show the environment only displacement.

Figure 6. Simulation changing the velocity parameters in the motors



In Figure 6 the simulation is performed by changing the velocity parameters in the motors, since the kinematic model is arranged based on the velocities of the motors, these velocities are the linear velocities and the angular velocity, to know the position the model has to be integrated with respect to time, with which the kinematic problem is solved in the simulation, giving the values of velocity and position at each instant of time and this is shown in the simulation.

Figure 7. Simulation changing the velocity parameters

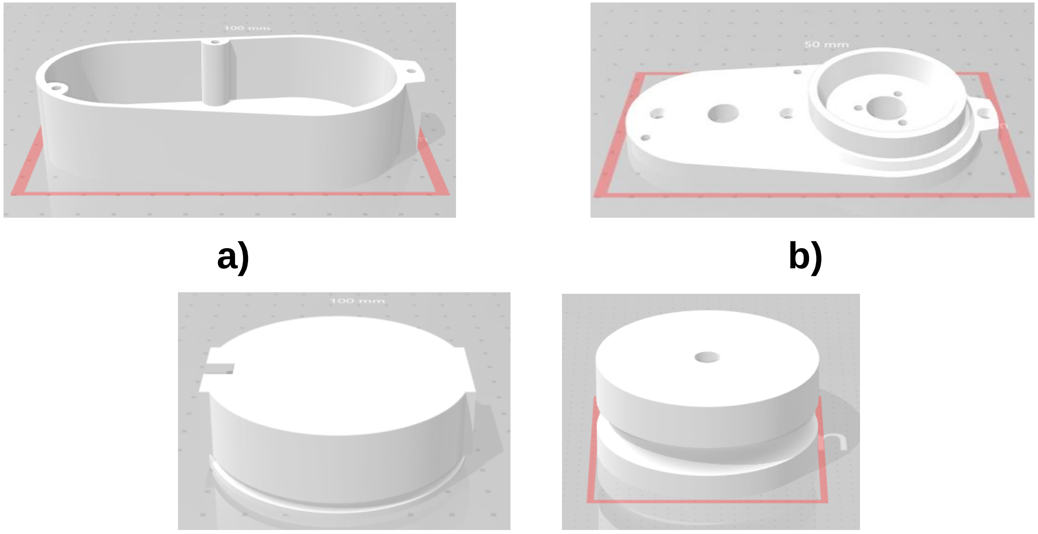


When performing the simulation again, but in this case the velocity parameters are changed, being the linear velocity **0.1*(1-2*np.cos(t))*np.ones(N)** where this velocity depends on the sampling time and simulation time, on the other hand we have the angular velocity **0.2*t*np.ones(N)** which also depends on the sampling time and simulation time, with these modifications we see that the behavior of the platform is different, with this you can build a path that passes through the destination.

3D Printed designs were made, Figure 8, for the development of the lidar sensor, 3D printed rigid polyurethane, which in itself offers a rigid and lightweight structure, which is where the parts of the lidar sensor will fit a stepper motor and the distance sensor that with the proposed configuration, will serve to find the obstacles around the platform thus avoiding a possible collision when navigating in the environment.

As can be seen in Figure 9, there are photos with different plans of the results of the 3D prints and files with .stl extension that are a true reflection of what is needed for the project.

Figure 8. 3D files **a)** stl box **b)** stl support **c)** stl cover **d)** stl pulley (own source)



a) **b)**

c) **d)**

Figure 9. 3D Prints **a)** Printed zenithal plane photo **b)** Printed pitted plane photo. (own source)

a) **b)**

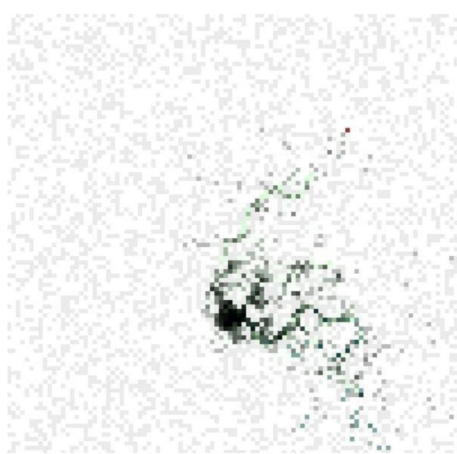
The ant colony algorithm as a method of trajectory planning offers a number of advantages that although, by the progress of the project has not yet been measured are known through the investigation of the associated literature, offering in the first place a probabilistic part of the method where they define how the deposition of pheromones by an ant will be made, secondly, knowing where the pheromones have been placed, it is understood that a trajectory is generated and through a high number of iterations on this trajectory it acquires more points which makes it a smooth trajectory, also making the method itself to eliminate the errors by evaporating the pheromones every so often, leaving only the path generated by the most traveled pheromones.

As can be seen in Figures 10 and 11 respectively, it can be seen firstly a series of information concerning food data, its position in space and most importantly the steps necessary to reach the food source, on the other hand, a visible image of how the algorithm looks like in execution, useful for its further implementation.

Figure 10. Results of the algorithm execution (own source).

Hormiga numerada			cantidad de comida y su ubicación (x,y)					número de pasos
Hormiga numerada	52429688	fundar	50	unidades de alimentos en coordenadas	70	55	aa	64.941125 ¡pasos!
Hormiga numerada	74613674	fundar	50	unidades de alimentos en coordenadas	77	70	aa	64.455844 ¡pasos!
Hormiga numerada	39012438	fundar	49	unidades de alimentos en coordenadas	70	55	aa	68.698485 ¡pasos!
Hormiga numerada	97779742	fundar	49	unidades de alimentos en coordenadas	77	70	aa	68.698485 ¡pasos!
Hormiga numerada	82519813	fundar	48	unidades de alimentos en coordenadas	70	55	aa	72.941125 ¡pasos!
Hormiga numerada	94455127	fundar	48	unidades de alimentos en coordenadas	77	70	aa	74.112698 ¡pasos!
Hormiga numerada	74674460	fundar	47	unidades de alimentos en coordenadas	70	55	aa	77.870058 ¡pasos!
Hormiga numerada	84577446	fundar	47	unidades de alimentos en coordenadas	77	70	aa	67.941125 ¡pasos!
Hormiga numerada	28422783	fundar	46	unidades de alimentos en coordenadas	70	55	aa	84.840620 ¡pasos!
Hormiga numerada	15839476	fundar	45	unidades de alimentos en coordenadas	70	55	aa	75.485281 ¡pasos!
Hormiga numerada	75227175	fundar	44	unidades de alimentos en coordenadas	70	55	aa	81.284271 ¡pasos!
Hormiga numerada	83474937	fundar	43	unidades de alimentos en coordenadas	70	55	aa	82.112698 ¡pasos!
Hormiga numerada	95150021	fundar	42	unidades de alimentos en coordenadas	70	55	aa	82.698485 ¡pasos!
Hormiga numerada	37635176	fundar	46	unidades de alimentos en coordenadas	77	70	aa	56.870058 ¡pasos!
Hormiga numerada	31657271	fundar	41	unidades de alimentos en coordenadas	70	55	aa	89.769553 ¡pasos!
Hormiga numerada	48616801	fundar	40	unidades de alimentos en coordenadas	70	55	aa	90.597980 ¡pasos!
Hormiga numerada	65565503	fundar	39	unidades de alimentos en coordenadas	70	55	aa	88.698485 ¡pasos!
Hormiga numerada	23655207	fundar	45	unidades de alimentos en coordenadas	77	70	aa	94.497475 ¡pasos!
Hormiga numerada	83879724	fundar	38	unidades de alimentos en coordenadas	70	55	aa	93.426407 ¡pasos!
Hormiga numerada	56186048	fundar	44	unidades de alimentos en coordenadas	77	70	aa	94.254834 ¡pasos!
Hormiga numerada	43252802	fundar	43	unidades de alimentos en coordenadas	77	70	aa	61.698485 ¡pasos!
Hormiga numerada	55959529	fundar	37	unidades de alimentos en coordenadas	70	55	aa	60.041631 ¡pasos!
Hormiga numerada	88593005	fundar	36	unidades de alimentos en coordenadas	70	55	aa	66.870058 ¡pasos!
Hormiga numerada	74333766	fundar	35	unidades de alimentos en coordenadas	70	55	aa	50.970563 ¡pasos!

Figure 11: Algorithm execution in bitmap (own source)



5. Conclusions

It should be clarified that this research project is under development, however, it cannot be left aside that it was endorsed by the Center for Research and Scientific Development - CIDC - of the Universidad Distrital Francisco José de Caldas, through the institute of research and innovation in engineering i3+, who through a call for proposals granted economic sponsorship to 3 projects, among which is the project "Cooperative robotics based on colony of ants for the optimization in the search for shortest routes".

The platform that was chosen is the result of taking into account the application and the environment in which the study will be developed, then the subsequent application of the ant colony algorithm, the platform that was initiated is a not very elaborate differential type platform made of acrylic, Although the platform fulfilled in the section of the integration of sensors and actuators, this platform was not prepared to meet the expectations of maneuverability and management of obstacle avoidance, so opt for the robotic platform with caterpillars.

Acknowledgments

To the research group in Autonomous Mobile Robotics (ROMA) headed by the project director Eng. Kristel Solange Novoa, for her advice and constant collaboration during the development of the research.

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