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Localization and Navigation for Autonomous Mobile Robots using Petri Nets in Indoor Environments

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ABSTRACT In this paper, mobile robotics and present tools used in localization, mapping, and navigation of a mobile robot are discussed. The main purpose of this work is, given a map represented by the incidence matrix of a Petri Net (PN), to evaluate the use Radio-Frequency IDentification (RFID) technology to recognize the position of a robot in this map, as well as use the PN dynamics as the cognition system of this robot. Thus, cards with RFID technology were placed at each intersection of structured environment (labyrinth) ways. A robot equipped with an RFID reader at its bottom moves until it passes over these cards. When this happens, the vehicle performs actions like turning right or left according to the map defined in its algorithm. Once the actions above are performed, it goes straight to the next card. To ensure that this happens, there is a black line connecting each card to its neighbor cards. The robot is equipped with three infrared sensors so it can detect and follow these lines. The results show that the robot can get out of one RFID card and reach the next one since they are connected by a black line. Without these lines, due to limitations in the structure of the robot, it loses its way and can not return. Still, the robot is able to execute the necessary navigation movements, in the case of stopping, moving forward, turning right and left. These movements are correctly coordinated by the PN dynamics. The robot knows which card it is on and goes to the next card according to the previously established map. Each path of the robot is mathematically modeled by the incidence matrix of a Petri Net. Therefore, it managed to reach the destination in each of the four proposed paths. The PN that represents path 1 has the same number of places and transitions and has curves only to the left. On path 2 a right turn was added. In 3, besides the two-way curves and RP has more places than transitions. Lastly in 4 there is a crossing in the path, that is, the robot goes through the same card twice, making the right and different decision in each case according to the respective maps. Experimental results show that this approach has feasibility and effectiveness.

INDEX TERMS Smart campus, Robot Perception, Localization, Navigation, Mobile Robotics, Radio-frequency Identification (RFID), Petri Net modeling.

I. INTRODUCTION

Robots are mechatronic devices used to assist humans in various activities, whether dangerous or not, repetitive and unhealthy [1]. They are used in indoor environments such as offices, hospitals, production lines, and cargo transportation in the industry. In the latter case, the Auto-Guided Vehicles (AGVs) stand out. AGVs are machines capable of moving and performing various tasks without the intervention of humans [2].

This category of robots, through sensors and actuators, interacts with the environment in order to move and perform its functions in an autonomous manner. The movement is commanded by the robot's navigation system. Given a partially known environment, Siegwart and Nourbakhsh [3] present navigation as the ability of the mobile robot to move through the environment until one or a series of goal positions, based on its knowledge and information provided by its sensors, as reliable as possible.

The navigation system of this kind of robot is typically constituted by modules of perception, localization, cognition and movement control. These modules are essential to the execution of aerial, terrestrial, and aquatic autonomous robot projects. This is proven by the different areas of activity in which this type of machine is inserted. For instance, companies use mobile robots to identify heating points in substations or cracks in pipes. Military personnel use robots to deactivate bombs and clean hostile buildings [4], [5]. In addition, mobile robots perform tasks such as educating, helping or entertaining [6], cleaning buildings and subways, or transporting food and medicine [3].

A typical mobile robot is composed by the modules: perception, localization, navigation or movement control, and motion [3]. The cycle of actions of a mobile robot begins with the extraction of data from the real environment (Perception Module) through the sensors coupled to the robot such as infra-red, ultrasound, cameras, RFID readers. This data is processed and used as input parameters of algorithms so that the robot can locate itself (Localization Module). After the localization of the robot is estimated, it is compared with a global map and the Cognition Module determines which next action to take. The robot then executes movements and navigates through the environment until it reaches the goal position (Movement Control Module).

Among these four modules, localization is the problem most frequently approached in the literature. Lim et al. [7] state that a key prerequisite for success in navigating the robot is to identify exact current localization. In addition, it is important to highlight that, besides determining its absolute position in space, localization also means constructing a map and determining the position of the robot in relation to it [3].

Localization can be divided in local and global localization. Overall, using the Global Positioning System (GPS) solves the problem of global localization efficiently [8]. The main discussions are instead related to local localization in indoor environments.In this case, methods such as Odometry [9], Computer Vision [10], QR code [11], RFID [12], among others, will be discussed later in this paper. In relation to other methods, RFID technology is presented as simple, cheap, efficient, and reliable.

Once the localization is carried out, the robot needs to know which movements to make until it reaches the goal position. In this case, methods such Guidewire [13], Line Following [9], Wall Following [14] among others, will be discussed later in this paper. In this context, although commonly PN is related to the idea of supervising and/or selecting as shown in [15] and [16], this paper presents this tool to model the path that the robot must follow, as well as the dynamics of the PN which define the actions that the AGV must execute.

Thus, the main contributions of this work are to use radio frequency identification to determine the localization of the robot in relation to the path to be navigated and to use RP in the mapping and cognition modules of the mobile robot. The methods most presented in the literature for local localization of mobile robots are Odometry and Computational View.

The Odometry presents accumulations of error in the estimated position of the robot, because the wheels slide on the surface. On the other hand, the localization through the reading of cards with RFID technology presents itself as a solution that does not accumulate errors and indicates the localization of the robot in relation to the main map efficiently. Computational Vision is also efficient, however, it requires considerable computing power, in order to perform algorithms for pre-processing, segmentation, attribute extraction and pattern recognition in captured images. While the proposed localization method with cards and RFID reader demands low computational processing to perform the tasks of reading the cards; check if the card is part of the predefined route, that is, if it is registered and identify which place of the RP has a card, that is, the position of the state matrix of the RP has a value of 1.

Another contribution of this work is to mathematically model the paths (mapping) to be covered by the robot using RP. Computational vision is used principally in the literature to create the topological map of the environment in which the robot is inserted. The processes of treatment of the images captured by the computer vision are greatly influenced by the illumination, whether natural or artificial. In addition, movements of the robot's trepidation instructed to the displacement process can blur and / or erase the photograph, rendering it unusable. Mapping using RP, on the other hand, is robust and does not suffer interference from environmental conditions, because it is fully digital.

Finally, another contribution is the purpose for which the Petri Net is used in this work. PN has been widely approached in the literature as a supervisory tool to identify bottlenecks in the process. In this paper PN is used as an active tool in the construction of the paths to be covered by the robot and not for process monitoring as is commonly used in the literature.

Thus, the general objective of this paper is, given a map represented by the incidence matrix of a Petri Net, to use RFID technology to determine the position of the robot in this map, as well as to use the PN dynamics as the cognition system of this robot. It is distributed cards with RFID technology at each intersection of labyrinth ways.A robot equipped with an RFID reader at its bottom moves until it passes over one of these cards. When this happens, the AGV performs actions like turning right or left according to the map defined in its algorithm. Once the actions above are performed, it goes straight to the next card. To ensure that this happens, there is a black line connecting each card to its neighbors cards.

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The robot is equipped with three infrared sensors so it can properly follow these lines.

As the novelty and the focus of this work is to present a novel method of localization and mapping for mobile robots, the practical experiments of this work are carried out in a structured and controlled environment, free of obstacles.

This paper is organized as follows: in section II, mobile robotics are approached and discussed, then techniques used in robot navigation are presented and compared, more specifically related to mapping, localization and movement control; In the next section, Petri Nets, Identification by Radio Frequency, Arduino and the other materials and methods used in this research are described; In sections IV and V it is shown the results and conclusion obtained regarding the application of localization and navigation systems using RFID and PNs in a mobile robot controlled by an Arduino electronic board. Finally, it has been the bibliographical references.

II. RELATED WORKS

Mobile robotics is expanding and its contribution is present in many areas, such as exploration of environments, security, education, entertainment, performing of dangerous tasks, among many other applications.

Thus, for each type of situation there is a suitable mobile robot. Evaluating the indoor case, in an industrial environment, robots with wheels are most commonly used. In case of offices, houses, and restaurants, humanoid robots can be used. When speaking of environments with uneven terrain with ramps, slopes and protrusions the ideal are robots with treads or hexapod robots. As a matter of fact, independent of the environment, a characteristic common to AGVs is the existence of a navigation system. More specifically, attention is focused on the robot's mapping, localization, and movement control modules. The localization and navigation of mobile robots have been widely studied according to an extensive published literature, as shown in Table 1.

The idea of localization, whether local or global, is closely associated with the existence of a map. This map can be metric or topological. Metric maps capture the geometric properties of the environment, whereas topological maps describe the connectivity of different places [31].

Cordeiro [9] estimates the absolute position of the robot based on odometry. Besides odometry, Santos [10] uses computational vision for the same purpose. Regarding the use of computational vision, Bessa et al. [1] use pattern recognition techniques in omnidirectional images to estimate the localization of the robot.

Yuan et al. [22] make simultaneous mapping and localization based on data from an RGB-D camera and nonholonomic constraints path planning algorithm. It is proposed an Extended Kalman Filter (EKF) powered by data encoders and landmarks to estimate the position and pose of the robot. Laser is used to identify static and moving obstacles, so that if the object is too close, the robot takes action to avoid collision.

Binu et al. [8] build the floor map of an indoor environment from arrays composed by the value of the Earth magnetic field at different points along a route. To make the map more accurate, Google Maps Route Boxer algorithm is used. Then, an Android application is used for tracking localization in that environment, based on the said map (stored in a database).

Awad et al. [24] uses a Wi-Fi access point to set the localization. When a device connects to a Wi-Fi network, there is an Received Signal Strength Indication (RSSI). This, in turn, has a mathematical relationship with the distance to the access point. Thus, from a uniform collection of RSSI data in a known environment, the article proposes an optimization of the WiMAP algorithm (Where is My Access Point) to define the position of the autonomous mobile robot. Tests were performed with the robot in several scenarios and the results show that the optimized version of the WiMAP algorithm surpasses the previous one in both time and localization accuracy.

Xu and Chou [29] join Wi-Fi fingerprint and AMCL to discover the exact localization of the robot. The Wi-Fi fingerprint algorithm makes a rough estimate of localization based on the strength of the Wi-Fi signal. Thus, for a more accurate localization, it uses the Monte Carlo Localization Algorithm (AMCL). The idea is to integrate the information of the environment map, odometry and Inertial Measurement Unit (IMU) through AMCL. The experimental results show that the Wi-Fi-AMCL method can effectively shorten the iterative time and improve the localization accuracy. Error in this case is less than 50 cm.

Dewi et al. [25] apply Neural Networks in a control mesh of a mobile robot, considering the kinematic and dynamical modeling of the robot as input data. The output is a Jacobian matrix (velocities) and hence, the localization of the robot is known. It makes a comparison with other studies in which sensor data are considered as input and disregard the kinematic and dynamic models of the robot. The results show better performance for controller whose data of the kinematic modeling and dynamics of the robot are considered.

Xu et al. [30] use DM (Data Matrix) tags equally spaced at 50 cm along the ground. A robot equipped with a camera passes over these tags and identifies these landmarks, therefore knowing its relative position in that indoor environment. So the idea is to use these tags as landmarks to review the data obtained by odometry using Unscented Kalman Filtering (UKF). This technique is compared to the conventional use of Odometry and the results for robot localization are better, showing that the method is feasible and effective.

Zhang et al. [11] use a camera at the top of the robot to read more quickly the QR codes that exist in the ceiling of the environment. Thus, the localization of the robot is estimated based on its distance to these landmarks. Also, to avoid collisions, it uses a Laser Ranger Finder (LRF). Dijkstra algorithm is used to plan global path and Dynamic Window Approach (DWA) to plan local path, which is based on the package Navigation provided by ROS (Robot Operating

TABLE 1. Related works.

Author	Mapping	Localization	Cognition
Abdelgawad (2014) [12]	-	Robot uses the reading of 3 RFID tags located at fixed points. Localization is estimated from the time the signal spends to exit the tags and reach the robot	-
Cordeiro (2014) [9]	-	Odometry	Line Following
Ismail et al (2014) [14]	-	-	Cognitive Mapping Algorithm as an alternative way for the navigation system of the robot
Bessa et al (2015) [1]	-	Pattern recognition techniques in omnidirectional images	-
Karakurt et al (2015) [17]	-	-	Movement control system of a spider robot based on Petri Nets
Lim et al (2015) [7]	-	Particle filter algorithm	-
Mardiyanto et al (2015) [18]	Kinect, in addition to an encoder, to compose the system for creating a 2D map	-	-
Zhang et al (2015) [11]	2D map is built from a laser range finder	QR code	Path planning is made by Dijkstra algorithm and Dynamic Window Approach (DWA)
Baldoni et al (2016) [19]	Fuzzy Petri nets (FPNs) with embedded memory module	-	-
Bao et al (2016) [13]	-	-	The robot moves by sliding through a guidewire
Binu et al (2016) [8]	Floor map built from arrays composed by the value of the Earth magnetic field at different points along a route and Google Maps Route Boxer algorithm	-	-
Boniardi et al (2016) [20]	-	-	Robot navigates through an environment from the sketch of a trajectory drawn manually on an interface created by them
Nguyen et al (2016) [21]	-	RFID and RGB-D for object localization	-
Yuan et al (2016) [22]	Simultaneous mapping and location based on data from an RGB-D camera and nonholonomic constraints path planning algorithm	-	
Avutu et al (2017) [23]	-	-	The robot moves to the coordinate (rooms) determined by the touch point of the user on the touch screen device
Awad et al (2017) [24]	-	Wi-Fi access point	-
Dewi et al (2017) [25]	-	-	Apply Neural Networks in a control mesh of a mobile robot, considering the kinematic and dynamical modeling of the robot
Furlan et al (2017) [26]	-	-	Fuzzy Logic to determine actions to be performed by a humanoid robot and Petri Nets are used to monitor the navigation of the robot
Mohanty et al (2017) [2]	-	-	Deep-Q-Learning
Motroni et al (2017) [27]	-	Fixed RFID tag, in which a robot moves along a known path and performs successive readings of the same tag. The distances between the robot and the tag are calculated for each reading. Thus, it is possible to know the relative localization.	-
Wang et al (2017) [28]	Odometry, laser 2D and RGB-D camera to simulate and simultaneously generate a 3D map of the path to be traveled by a robot	-	
Xu and Chou (2017) [29]	-	Join Wi-Fi fingerprint and AMCL to discover the exact localization	-
Xu et al (2017) [30]	-	Odometry and Unscented Kalman Filtering	-
This work (2018)	Incidence matrix of a Petri Net	Cards and RFID reader	Dynamic of the Petri Net

System).

Abdelgawad [12] presents a robot which uses the reading of 3 RFID tags located at fixed points. Thus, from the time the signal spends to exit the tags and reach the robot (Time Difference Of Arrival - TDOA), its localization is estimated.

Nguyen et al. [21] use RFID and RGB-D for localization. Uses only RFID for rough object localization. Thus, it obtains a more limited region where the object is found, which in turn is projected on a 2D map from an RGB-D of a Kinect. Finally, it implements the HOG-SVM technique to detection of objects in the RoS (Region of Search) of the RGB image. As the author sates, this technique decreases computational processing, avoids false positives and false negatives.

Motroni et al. [27] present a method with a fixed RFID tag, in which a robot moves along a known path and performs successive readings of the same tag. The distances between the robot and the tag are calculated for each reading. Thus, it is possible to know the relative localization of the robot. The author also comments that other tags could be queued to increase the coverage area. The accuracy is in the order of centimeters when at least 10 readings are taken and the robot is about 1 m away from the tag.

The following are some observations regarding the use of the proposed localization methods. Odometry alone is not reliable because the robot skips [3] and accumulates error [32]. It is usually used with other methods to be reset at certain times along the trajectory. Meanwhile, the use of the gyroscope sensor is good for short periods but, just like Odometry, in long-time work condition accumulates measurement error [32].

Computational vision is very efficient, however it is very much influenced by ambient lighting. Also, GPS is widely used for global localization, however it has low accuracy in indoor environments. Meanwhile, the Kalman Filter (KF) presents excellent localization results, provided the system is linear and Gaussian. However, these two conditions greatly limit the use of KF in practice [33].

The Monte Carlo algorithm overcomes the KF deficiencies, since it can be applied in non-linear and non-Gaussian systems. It is one of the most widely used and efficient methods of localization, but in large environments there is the risk of particle degradation, where the weight of many particles becomes very small over a large number of iterations [29].

QR code is cheap and quite efficient as a landmark and even to determine the absolute position of the robot, but if the QR code is obstructed, even partially, by a sheet of paper, for example, the camera can not detect it correctly.

In this paper, it is presented RFID to determine the local position of the robot. RFID stands out positively because it does not accumulate errors, is not influenced by the luminosity of the environment, requires low computational power, has low cost, maintains the efficiency even after a long time. Also, it functions correctly even when totally obstructed by thin objects such as papers, tree leaves, or plastics.

About the navigation system and strategies of the robot mapping. Lope et al. [34] use site references and navigation strategies between sites to construct the model of the environment with a Fuzzy Petri Net. According to the same author, because the application of inference tools is very useful for route planning. Karakurt et al. [17] propose the movement control system of a spider robot based on Petri Nets.

Batista [35] also uses Petri Nets to model the navigation system of a mobile robot. However, he uses Colored Petri Nets (CPN), which is justified due to the fact that no application of CPN to the proposed problem had been found.

Alexopoulos et al. [36] use associative memory for the robot to remember the paths it has traveled previously within a known environment. In addition, it learns new (unknown paths on–line). The more the robot moves, the more reliable the results. Navigation monitoring is done through Modified Petri nets.

Bao et al. [13] presents an interesting navigation model, in which the robot moves by sliding through a guide-wire. Meanwhile Cordeiro [9] uses the Line Following method, which can be a line painted on the ground or a magnetic tape as the robot's navigation system. Since the robot follows a predefined route with efficiency, this is a valid and simple alternative. He also uses Kinect as a low-cost solution, when compared to lasers, for identification of obstacles. Mardiyanto et al. [18] also use Kinect, in addition to an encoder, to compose the system for creating a 2-D map for robot navigation.

Baldoni et al. [19] propose the use of a Fuzzy Petri Nets application with built-in memory module to optimize the obstacle bypass process. This way, the time to perform the mapping is shorter, it is possible to map and avoid obstacles simultaneously, and the robot navigates with greater fluidity, avoiding unnecessary actions.

Wang et al. [28] used odometry, laser2D and RGB-D camera to simulate and simultaneously generate a 3D map of the path to be traveled by a robot with wheels in an unstructured indoor environment. It is worth mentioning that the use of camera and laser increases the costs of a project, as well as requires greater computational power. These two questions together can make a project unfeasible. The results of simulations in a real environment proved the efficiency and effectiveness of the system.

Furlan et al. [26] use Fuzzy Logic to determine actions to be performed by a humanoid robot, such as turning left or right. Petri Nets are used to monitor the navigation of the robot. Meanwhile Boniardi et al. [20] present an interesting proposal in which the robot navigates through an environment from the sketch of a trajectory drawn manually on an interface created by them.

Avutu et al. [23] divide a rectangular environment into 4 rooms. This environment is proportionally represented by a Touch Screen. Thus, the robot moves to the coordinate (rooms) determined by the touch point of the user on the touch screen device. The robot is controlled by an Arduino board and equipped with an ultrasonic sensor to avoid obstacles.

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Ismail et al. [14] present the Cognitive Mapping Algorithm as an alternative way for the robot navigation system. The validation of their technique is made comparing its performance to the one of a navigation system algorithm of a wall following robot.

In this work, it is proposed that the movements of the robot must be defined by the dynamics of a Black Petri Net and Line Following, which are a simpler solutions and present feasibility and effectiveness when compared to previously discussed methods.

III. MATERIALS AND METHODS

In this work, PNs are used for modeling the trajectory that an autonomous mobile robot controlled by an Arduino MEGA board must execute. For such a robot to be able to locate itself during its movements, it uses Radio Frequency Identification. In the following subtopics are described in more detail each of the aforementioned materials and methods.

A. PETRI NET – PN

Discrete Event System (DES) is defined as a system that requires the occurrence of events to change its state. The open/close process of a door, for instance, is a DES, since it will remain open or closed, i.e., in the same state until some action is performed on it.

PN is a technique used for modeling DESs, whether complex or not, which is performed by means of graphic or matrix representation. In the graphical representation, there are four basic components:

1) **Places:** Graphically represented by circles. Places store tokens.
2) **Tokens:** Represented by dots, are shifted from one place to another by the triggering of transitions.
3) **Transitions:** Are enabled if the immediately preceding place(s) have a number of tokens equal to or greater than the weight of the bow that departs from the place(s). They are represented by rectangles.
4) **Arcs:** Are represented by arrows and must necessarily connect a place to a transition or vice versa. Its weight indicates how many tokens will be taken from one place and be sent to another.

Figure 1 shows the graphical model of a generic black-token PN.

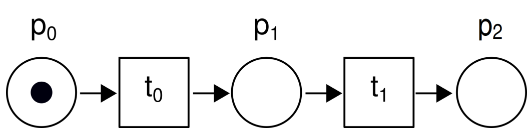

FIGURE 1. Model of a generic Petri Net.

Thus, p0, p1 and p2 are places; t0 and t1 are transitions; the arrows are the arcs and the black point indicates that the place p0 has a token, which means that the initial marking (the matrix representation of the number of tokens that each place has at the instant analyzed) E_0 is [1 0 0]. Therefore, the marking E_{i+1}, for i = 0,1,2,3 ..., of a PN is defined by Equation (1).

$$E_{i+1} = E_i + T_i * G \tag{1}$$

Where:

- E = marking matrix
- G = incidence matrix
- T = transition matrix

This way, regardless of the path to be followed by the robot, the value of the first term of the initial marking matrix is always 1 and the other values of the matrix are 0. The transition matrix is composed of the indication of which transitions are enabled and which transitions are not for each marking T_i. Thus, for the PN presented in Figure 1, T_0 is [1 0].

Each path has an identity, which is represented by the incidence matrix A. The number of rows and columns in this matrix is determined by the number of transitions and places, respectively. Figure 2 shows a Generic Incidence Matrix G.

$$G = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix}$$

FIGURE 2. Generic Incidence Matrix.

where:

$$a_{nm} = a^{+}_{nm} - a^{-}_{nm} \tag{2}$$

From Equation (2), a^{+}_{nm} is equal to the weight of the arc leaving transition *n* and arriving at place *m*. In an analogous way, a^{-}_{nm} is equal to the weight of the arc leaving place *m* and arriving at the transition *n*.

The Petri Net used in this work is of the black-token type and was developed in the TIme Petri Net Analyzer (TINA), which is a toolbox for editing and analysis of Petri Nets developed by the Laboratory for Analysis and Architecture of Systems (LAAS / CNRS). Although TINA has several configurations for editing and simulation of Petri nets, Time Petri Nets and Automata, in this work only Petri nets are used, whose parameters are number of places, transitions, weight of the arcs and quantity of tokens in each place. The path 1 has the same number of places and transitions and has curves only to the left. On route 2 a right turn was added. In 3, besides the two-way curves and RP have more places than transitions. And in 4 there is a crossing in the path, that is, the robot goes through the same card twice, making the right decision in both cases. The token of PN is represented by the mobile robot, so all the arcs have unit weight.

B. RADIO FREQUENCY IDENTIFICATION – RFID

This form of communication became popular in World War II, when it was used by radars to identify allied and enemy

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aircrafts. Powerful antennas were used for communication over long distances. However, after the evolution of this technology, today there are more compact versions with less reach, used, for instance, as access keys for electronic locks.

Regarding this latest version, to make Radio Frequency Identification possible, two components are required: the RFID reader and the RFID card. The reader is responsible for emitting and receiving electromagnetic signals at a specific frequency such as 13.56 MHz.

The card can be passive (which is energized when approaching the RFID reader and then sends a message) or active (has its own power supply). For the application of this work, it is used passive cards with a maximum range of approximately 3.5 cm. As the reader approaches the label, the latter receives an electromagnetic signal and responds to it by sending a message (another electromagnetic signal). Considering that they are operating at the same frequency, the reader receives the electromagnetic signal and converts it into an electrical signal that can be read by a microcontroller, such as the one on the Arduino board.

C. ARDUINO

Arduino is an electronic board composed of a microcontroller and peripheral devices. Some models, such as UNO and MEGA, provide ease of use even for beginners. Other electronic components, such as sensors and actuators, can be connected to it in order to automate a process. It can be programmed through a open–source Arduino Software (IDE), by using a programming language similar to C ++.

D. ROBOTS

Robots are mechatronic devices capable of performing autonomous and/or controlled actions. Among the variety of robots that exist, in this work a mobile autonomous robot is used to navigate a structured environment, based on a map.

The robot used in the tests, shown in Figure 3, consists of an acrylic chassis, two motors (12 V DC) with gearboxes, two wheels, an H bridge, an Arduino MEGA 2560 board, jumper cables, an embedded power source (7.2 V batteries), 13.56 MHz RFID reader, and a 170 point breadboard.

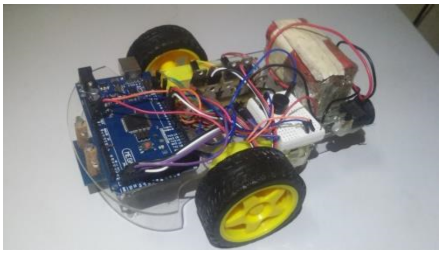

FIGURE 3. Robot used in the tests.

E. MAPPING AND LOCALIZATION OF ROBOTS

The robot must follow the map of a known environment, i.e., be able to locate itself in that space and move from one point to another, according to previous programming.

Among the kinds of maps available, it was decided to use topological maps, since the accuracy of the position of the robot is not essential for navigation. Lope et al. [34] explain that metric models are suitable for situations where high precision is required in robot navigation, whereas topological models are best suited for situations where the precision is not critical but sufficient for navigation.

The robot is equipped with an RFID reader and must follow the map based on the reading of RFID card. Throughout the environment there are RFID cards with Unique IDentification (UIDs) distributed at each intersection of structured environment (labyrinth) ways. Thus, according to the path to be covered by the robot, only part of that cards are recorded in the algorithm, so that the robot can pass over unregistered cards, ignore them and move on. On the other hand, when arriving at a registered card, the matrix of Future Marking is calculated according to Equation 1. From this information, it is known to which place of the RP the token should go. It is considered that a place of the PN is represented by an RFID card and the token is represented by the robot.

F. ALGORITHM

Figure 4 shows the logical sequence that controls the actions of the mobile robot. Initially, it makes configurations such as the inclusion of libraries, declaration of variables, declaration of the incidence matrix of the PN that models the path to be followed, start the RFID reader and the Serial Peripheral Interface (SPI). Then the PN waits until the robot is manually placed in the initial position of the route.

After that occurs, the robot reads RFID cards. If a card is unregistered, then MoveOn. If the card is registered, then verify if the robot is not on the goal point card, if not, then a value is assigned to k, updates E_{i+1} and T_{i+1}, and updates data logging. If the robot is on the goal point card tough, then Stop, Horn, Reset all variables and goto Start.

The marking matrices and current transitions are calculated so that, when applying Equation 1, the future marking matrix is found, which determines the next place where the token has to go to, and, consequently, what action the robot must perform. This way, the robot performs the movements of turning left, turning right or moving on. When performing a movement, if the robot does not find a new card, it moves forward until it reaches one. When this happens, the cycle restarts.

G. METHODOLOGY

The path to be followed is represented by the incidence matrix of a Petri Net. The algorithm that contains this matrix is loaded on the Arduino board beforehand. Then, the mobile robot is positioned at the starting point of the aforementioned path. The movement is performed according to the position of the robot in relation to the trajectory. The robot's position is set from reading the RFID cards. Thus, whenever the robot arrives at a card, a transition of Petri Net is enabled and the place that received the token determines the action that must

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FIGURE 4. Logical sequence that controls the actions of the mobile robot.

be performed by the robot. The paths traveled by the robot during the tests are shown in Figure 5.

The maps to be followed can be represented in two ways. In the first, mathematically, the map is represented by the incidence matrix of a Petri Net. Thus, for each path there is a specific matrix that needs to be loaded on the Arduino board before the robot initiates the movement through that path.

Adapted incidence matrices are shown in Figure 6 and are, respectively, the PNs shown in Figure 7. It is important to note that due to reasons of algorithm implementation, matrices A are the transpose of the incidence matrices.

The second way of representing the maps, graphically, is shown in Figure 7. The places are represented by the circles and connected by arcs (arrows) and transitions (squares), indicating the path to be traveled by the robot. The token (black dot) indicates the initial position of the robot. The circles labeled as P1 are the starting points, whereas the circles with the labels P4, P5 and P6 are the points of arrival. Besides, the paths taken by the robot are represented by dashed lines.

The robot is placed at the starting point and its objective is, obeying the dynamics of the PN, to reach the point of arrival. At each crossing (where two or more paths connect) there is an RFID card for localization of the robot. Each card has a unique ID. With this, the robot identifies its position and performs one of the following movements: move forward,

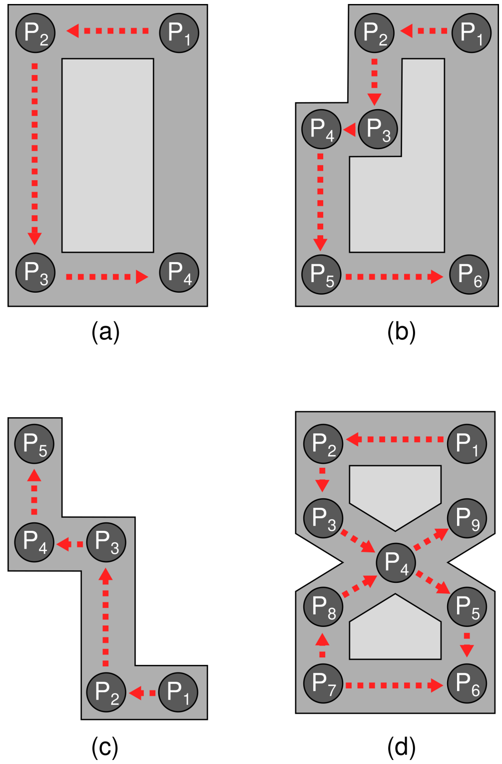

FIGURE 5. Representation of the paths (A) 1, (B) 2, (C) 3 e (D) 4 traveled by the robot.

$$A_1 = \begin{bmatrix} -1 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & 0 & 1 & -1 \end{bmatrix}$$

(a)

$$A_2 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$

(b)

$$A_3 = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(c)

$$A_4 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$

(d)

FIGURE 6. Incidence matrices of the paths (A) 1, (B) 2, (C) 3 e (D) 4.

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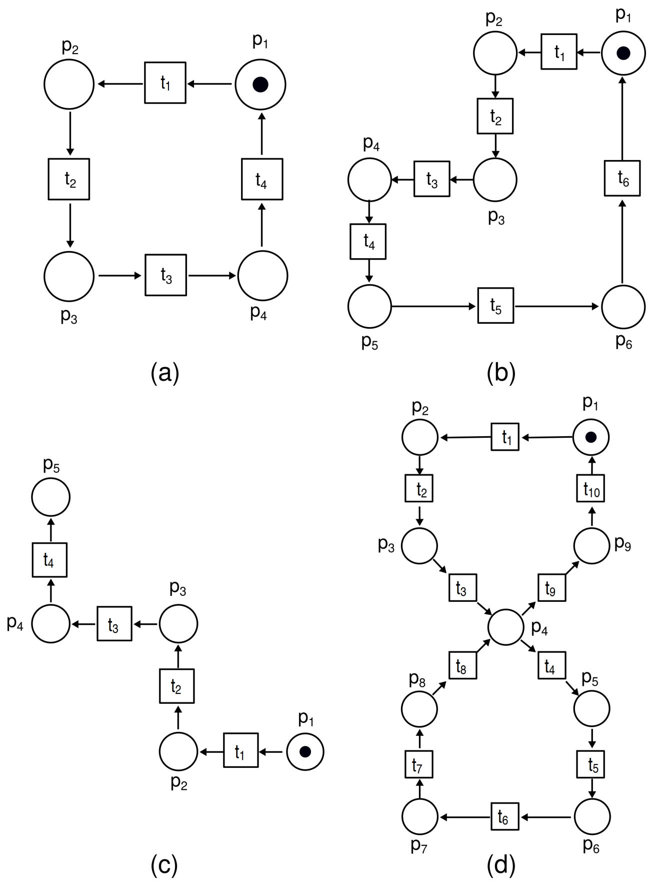

FIGURE 7. Petri Net that represents the paths (A) 1, (B) 2, (C) 3 e (D) 4.

turn left, turn right or stop.

It is important to emphasize that the PN determines what movement should be performed when the robot encounters the card. However, to ensure that the robot can reach the cards it is necessary that it has a line following module.

Without this module, due to several factors such as misalignment of the wheels, the robot, which should ideally move forward, might for instance deviate from the trajectory and not reach the next card. Therefore, it is used a module composed of three optical sensors model TCRT5000. The logic of the line following module is shown in Table 2.

TABLE 2. Logic of the line following module.

	Left Sensor	Central Sensor	Right Sensor	Action
Reading	1	1	0	Turn Right
	1	0	0	Turn Right
	1	0	1	Move Forward
	0	1	1	Turn Left
	1	1	1	Turn Left

Note: A 0 represents the sensor over the black tape and a 1 represents the sensor outside it

Therefore, when arriving at a crossing, the robot stops, reads the RFID card, locates itself (place P_i), interacts with the map, defines the action to be performed (from the triggering of the transition T_i), and finally, moves to the place P_{i+1}. This cycle of actions is compiled and presented in Figure 8.

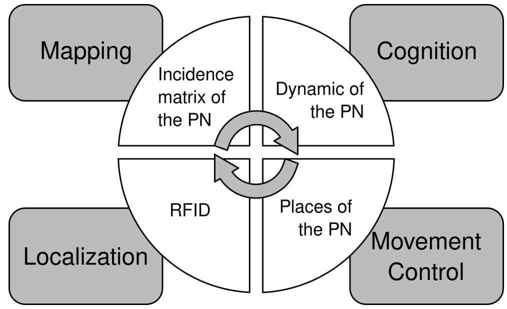

FIGURE 8. Cycle of actions executed by the proposed robot.

H. TESTS

The tests were performed in a labyrinth. Thus, at each intersection labyrinth ways, there is an RFID card. When the robot passes over the card, the future marking matrix of the RP is updated, that is, the token is moved to the next place in the RP. Thus, the algorithm determines which card the robot should go to.

The robot was previously programmed and placed it at the starting point P1. When the robot arrived at its destination, a buzzer sounded. It is carried out the tests on the four trajectories mentioned above. The four paths chosen have specific characteristics to make the robot more robust, overcoming different situations.

Path 1 is the most basic. All its curves are to the left, as shown in Figure 5 (a). Path 2 presents curves to the left and to the right, as shown in Figure 5 (b), whereas path 3, according to Figure 5 (c), also includes curves to the left and to the right. Nevertheless, its incidence matrix is not square, which means that the number of transitions of the PN that defines this map is different from the number of places. At last, path 4, as shown in Figure 5 (d), represents a peculiarity. The robot passes through the place P4 twice and follows different ways according to the path defined by the PN. The results and considerations for the tests performed are presented bellow.

IV. RESULTS

The results are compiled in Table 3. The movement control of the robot is essential for the execution of the task of following the map. The rows 1 and 2 of Table 3 present satisfactory results for this action, since the robot can identify the black line and perform the movements necessary to remain on the path without deviations.

Along the route, more precisely at the crossing of tracks, there are RFID cards to locate the robot regarding the map of the environment. The use of RFID cards to determine the position of the robot generated partially satisfactory results, as shown in the row 3 of Table 3. This method is efficient for flat floors, given the proximity that the RFID reader, which is coupled to the robot's bottom, must be to the card.

TABLE 3. Compilation of results.

Actions	Question	Answer
Drive and synchronization of the motors	Is the robot able to perform the intended movements?	The robot can stop, turn left, turn right and move forward
Reading and interpretation of the line follower module	Does the robot recognize when it is on the black line?	The sensors can identify regions with black line and without it
Reading and identification of RFID cards	Does the robot identify and interpret the cards?	The robot always performs the movement required by the card when using the line following system
Mapping of the environment by using PN	Is the robot able to interpret the map represented by a PN?	The robot follows the map if it is placed in the initial position of the path
Integration of the actions	Has the overall project objective been achieved?	The robot is able to locate itself using RFID and efficiently follow the map modeled by PN

It is important to highlight that the robot reads unregistered cards that may appear in its trajectory, but it ignores them. Also, when there is no black line, the robot does not always identify the card. This happens because in order to the reading be possible, the maximum distance to the reader has to be 3.5 cm, and they must be conveniently aligned.

Following lines is a technique widely used for indoor testing. As Cordeiro [9] emphasizes, the navigation method known as Lines System is widely used in small robots intended for indoor localization.

The trajectory to be traveled by the robot is modeled by Petri Nets. Thus, making an analogy between the PN and a physical system, it is assumed that the token is the robot, the place is where the registered card is located and the transition is the RFID card.

Therefore, the use of PN for the situation proposed, presents partially satisfactory results, according to the row 4 of Table 3, because for the robot to interpret and follow the map, it is necessary that its initial position is the place P1. Respecting this condition, the robot was able to perform the planned route in an autonomous way and navigate through the map in a satisfactory manner, since it arrived at the place of destination.

V. CONCLUSION

Considering the general objective of this work, which is, given a map represented by the incidence matrix of a Petri Net, to use RFID technology to know the position of the robot in this map, as well as to use the PN dynamics as the cognition system of this robot, results are satisfactory, as shown in the row 5 of Table 3. RFID cards can be used to identify the position of a robot in relation to a trajectory, which in turn, is modeled by Petri Nets. The tests were performed in a structured environment composed of four different paths. Thus, the robot traveled through the paths correctly whenever its initial position was the place P1. The experimental results show that this approach is efficient and feasible. As future work, Machine Learning and Computer Vision Techniques will be applied to substitute RFID tags.

REFERENCES

[1] J. A. Bessa, D. A. Barroso, A. R. da Rocha Neto, and A. R. de Alexandria, "Global location of mobile robots using artificial neural networks in omnidirectional images," IEEE Latin America Transactions, vol. 13, no. 10, pp. 3405–3414, Oct. 2015.
[2] P. K. Mohanty, A. K. Sah, V. Kumar, and S. Kundu, "Application of deep q-learning for wheel mobile robot navigation," in 2017 3rd International Conference on Computational Intelligence and Networks (CINE). IEEE, Oct. 2017.
[3] R. Siegwart and I. R. Nourbakhsh, Introduction to autonomous mobile robots. Cambridge: The MIT Press, 2004.
[4] G. E. Marchant, B. Allenby, R. Arkin, E. T. Barrett, J. Borenstein, L. M. Gaudet, O. Kittrie, P. Lin, G. R. Lucas, R. O'Meara, and J. Silberman, "International governance of autonomous military robots," The Columbia Science and Technology Law Review, vol. 12, pp. 272–276, 2011.
[5] P. W. Singer, "Military robots and the laws of war," The New Atlantis, no. 23, pp. 25–45, 2009.
[6] G. Bekey and J. Yuh, "The status of robotics," IEEE Robotics & Automation Magazine, vol. 15, no. 1, pp. 80–86, Mar. 2008.
[7] J. Lim, S. Lee, G. Tewolde, and J. Kwon, "Indoor localization and navigation for a mobile robot equipped with rotating ultrasonic sensors using a smartphone as the robot's brain," in 2015 IEEE International Conference on Electro/Information Technology (EIT). IEEE, May 2015.
[8] P. K. Binu, R. A. Krishnan, and A. P. Kumar, "An efficient indoor location tracking and navigation system using simple magnetic map matching," in 2016 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC). IEEE, Dec. 2016.
[9] T. F. Cordeiro, "Sistema de deteção e contorno de obstáculos para robótica móvel baseado em sensor kinect," Engenharia Industrial, Escola Superior de Tecnologia e Gestão do Instituto Politécnico de Bragança, Bragança, 2014, 126 p.
[10] G. L. Santos, "Localização de robôs móveis autônomos utilizando fusão sensorial de odometria e visão monocular," Engenharia de Computação, Universidade Federal do Rio Grande do Norte, Natal, 2010, 66 p.
[11] H. Zhang, C. Zhang, W. Yang, and C.-Y. Chen, "Localization and navigation using QR code for mobile robot in indoor environment," in 2015 IEEE International Conference on Robotics and Biomimetics (ROBIO). IEEE, Dec. 2015.
[12] A. Abdelgawad, "Localization system for indoor robot using RFID," in 2014 IEEE Symposium on Industrial Electronics & Applications (ISIEA). IEEE, Sep. 2014.
[13] X. Bao, S. Guo, N. Xiao, Y. Wang, M. Qin, Y. Zhao, C. Xu, and W. Peng, "Design and evaluation of a novel guidewire navigation robot," in 2016 IEEE International Conference on Mechatronics and Automation. IEEE, Aug. 2016.
[14] A. R. Ismail, R. Desia, M. F. R. Zuhri, and R. M. Daniel, "Implementation of cognitive mapping algorithm for mobile robot navigation system," in 2014 4th World Congress on Information and Communication Technologies (WICT 2014). IEEE, Dec. 2014.
[15] C. bae Moon and W. Chung, "Design of navigation behaviors and the selection framework with generalized stochastic petri nets toward dependable navigation of a mobile robot," in 2010 IEEE International Conference on Robotics and Automation. IEEE, May 2010.
[16] I. J. L. Batista, G. C. Barroso, O. de M. Almeida, A. T. Varela, and J. R. B. Sousa, "Navegação de robôs móveis com ênfase em planejamento e supervisão de trajetórias," XVIII Congresso Brasileiro de Automática, 2010.
[17] T. Karakurt, A. Durdu, and E. H. Dursun, "Petri-net based control of six legged spider robot," in 2015 International Conference on Advanced Robotics (ICAR). IEEE, July 2015.

[18] R. Mardiyanto, J. Anggoro, and F. Budiman, "2d map creator for robot navigation by utilizing kinect and rotary encoder," in 2015 International Seminar on Intelligent Technology and Its Applications (ISITIA). IEEE, May 2015.
[19] P. D. Baldoni, Y. Yang, and S.-Y. Kim, "Development of efficient obstacle avoidance for a mobile robot using fuzzy petri nets," in 2016 IEEE 17th International Conference on Information Reuse and Integration (IRI). IEEE, July 2016.
[20] F. Boniardi, A. Valada, W. Burgard, and G. D. Tipaldi, "Autonomous indoor robot navigation using a sketch interface for drawing maps and routes," in 2016 IEEE International Conference on Robotics and Automation (ICRA). IEEE, May 2016.
[21] T.-S. Nguyen, T.-H. Tran, and H. Vu, "Accurate object localization using RFID and microsoft kinect sensor," in 2016 Eighth International Conference on Knowledge and Systems Engineering (KSE). IEEE, Oct. 2016.
[22] W. Yuan, Z. Li, and C.-Y. Su, "RGB-d sensor-based visual SLAM for localization and navigation of indoor mobile robot," in 2016 International Conference on Advanced Robotics and Mechatronics (ICARM). IEEE, Aug. 2016.
[23] S. R. Avutu, D. Bhatia, and B. V. Reddy, "Design of touch screen based robot with obstacle detection module for autonomous path navigation," in TENCON 2017 - 2017 IEEE Region 10 Conference. IEEE, Nov. 2017.
[24] F. Awad, A. Omar, M. Naserllah, A. Abu-Hantash, and A. Al-Taj, "Access point localization using autonomous mobile robot," in 2017 IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies (AEECT). IEEE, Oct. 2017.
[25] T. Dewi, P. Risma, Y. Oktarina, and M. T. Roseno, "Neural network controller design for a mobile robot navigation: A case study," in 2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI). IEEE, Sep. 2017.
[26] F. Furlan, E. Rubio, H. Sossa, and V. Ponce, "Humanoid robot hierarchical navigation using petri nets and fuzzy logic," in 2017 56th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE). IEEE, Sep. 2017.
[27] A. Motroni, A. Buffi, and P. Nepa, "Localization of a mobile device equipped with an RFID reader," in 2017 IEEE International Conference on RFID Technology & Application (RFID-TA). IEEE, Sep. 2017.
[28] C. Wang, L. Meng, S. She, I. M. Mitchell, T. Li, F. Tung, W. Wan, M. Q.-H. Meng, and C. W. de Silva, "Autonomous mobile robot navigation in uneven and unstructured indoor environments," in 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, Sep. 2017.
[29] S. Xu and W. Chou, "An improved indoor localization method for mobile robot based on WiFi fingerprint and AMCL," in 2017 10th International Symposium on Computational Intelligence and Design (ISCID). IEEE, Dec. 2017.
[30] B. Xu, X. Zhou, T. Cheng, Z. Su, and J. Wu, "A new proposal for localization of omni-directional mobile robot by DM tag in indoor environment," in 2017 IEEE International Conference on Cybernetics and Intelligent Systems (CIS) and IEEE Conference on Robotics, Automation and Mechatronics (RAM). IEEE, Nov. 2017.
[31] S. Thrun, "Robotic mapping: A survey," School of Computer Science, Feb. 2002.
[32] Y. Xiao, Y. Ou, and W. Feng, "Localization of indoor robot based on particle filter with EKF proposal distribution," in 2017 IEEE International Conference on Cybernetics and Intelligent Systems (CIS) and IEEE Conference on Robotics, Automation and Mechatronics (RAM). IEEE, Nov. 2017.
[33] Z.-B. Song, Y. H. Zweiri, L. D. Seneviratne, and K. Althoefer, "Nonlinear observer for slip estimation of tracked vehicles," Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, vol. 222, no. 4, pp. 515–533, Apr. 2008.
[34] J. Lope, D. Maravall, and J. G. Zato, "Topological modeling with fuzzy petri nets for autonomous mobile robots," Lecture Notes in Artificial Inteligence, pp. 290–299, 1998.
[35] I. J. L. Batista, "Modelo de navegação para robôs móveis baseado em redes de petri coloridas," Engenharia de Teleinformática, Universidade Federal do Ceará, Fortaleza, 2008, 87 p.
[36] A. Alexopoulos, L. Zouaghi, and E. Badreddin, "Associative memory for modified petri-net based monitoring of mobile robot navigation," in 2012 First International Conference on Innovative Engineering Systems. IEEE, Dec. 2012.

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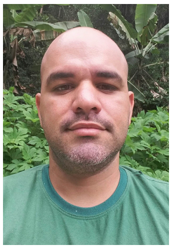

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