NAVIGATION SYSTEM OF AUTONOMOUS MOBILE ROBOT USING OMNIDIRECTIONAL VISION AND FUZZY CONTROLLER

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***Abstract**. Omnidirecional Vision System are presented as appropriate to the tasks of navigation of independent mobile robots, providing information regarding the work environment of the robot with a 360º panoramic image. This paper presents the implementation of a navigation system, based on Omnidirecional Vision and Fuzzy Controller, using a low cost camera (WebCam) and a mirror constructed in polishing metal (conical mirror), under a LINUX Platform, guaranteeing the portabilidade of the solution in an environment of open code. The considered system was implemented in the Platform of Autonomous Mobile Robot of the Laboratory of Automation and Evolutive Computing - LACE, of the Department of Computing and Statistics Sciences - UNESP – São José do Rio Preto.*

***Keywords**: Omnivision, Robot Vision, Neural Networks, Autonomous Mobile Robot.*

1. Introduction

In the context of Mobile Robots navigation, some specific tasks are essential. The robot must be able to sensing its environment and to construct a local representation that is enough in details and precision to allow the robot choose the movement ways. The robot must also be capable of auto locating, or either, determining its position and orientation in the environment and to mapping this information in its local representation and of its neighborhood. The robot can then move to its goals positions, detecting and preventing stationary and mobile obstacles (BARTH & BARROWS, 2003). A traditional camera, aligned with the displacement axle is not enough for the navigation of vehicles with capacity of displacement in diverse directions and construction of local representations and localization inside of the environment. For such tasks, the use of a sensor that produce panoramic images (360º images of the environment) simplifies the navigation task and provides necessary information for the control of vehicle (YAGI et al., 2003, ISHIGURO et al., 2003; MATSUMOTO et al., 2003). Another important problem related to the independent navigation of robots is the necessity to deal with the great amount of inherent uncertainties to environments where the robot must act. Due to inexistence of a mathematical formularization for the problem of the navigation and guidance of the mobile robot in real interior environments and to the little accurate values that are associates to the sensing systems of these environments, becomes necessary one technique that uses a human knowledge base. Fuzzy Logic presents as one appropriate technique to treat such problems. The use of such systems, with omnidirectional vision and fuzzy controllers, in autonomous vehicles (autonomous mobile robots) comes being proposed but are few the platforms implemented in Brazil. This work contemplates a system of this type and will be able, after concluded its implementation, to provide to a platform of tests for new approaches and implementations in this area.

2. Navigation of Mobile Robots

Navigation is the technique to find the position, the course and in the distance covered by a vehicle. A navigation system consists basically of a device that answers three questions: Where I am? For where I go? How I will go until there? (BORENSTEIN & KOREN, 1996). In the context of mobile robots the navigation can be defined as "the task to guide a mobile robot of an initial position for another position desired through a way with certain characteristics". Navigation in this context implies that the problem of the localization is decided. The navigation task assumes that the position of the robot is always known with an adequate level of precision. The main objectives, related to the context of mobile robot navigation involve: To minimize the size of the way; To minimize the distance covered; To minimize the fuel/electricity use and To maximize the security (distance of objects). The navigation, beyond the extraction of data of the real world, needs (THRUN & BUCKEN, 1996): Map of localization: a representation of the navigation environment is necessary so that through information comings of the sensors it is possible to determine the localization of the mobile robot in the environment; Planner: using the information of the navigation map the navigation plan will be constructed, that will go to trace the route to be covered; Navigator: will use the information of the plan to navigate and to fulfill the objective waited. Mobile robots navigate and play tasks with certain degree of autonomy. Tasks for independent robots consist of planning of trajectory, auto-locating, landmark visual tracking of the environment, detection and obstacles avoidance, construction of maps of the environment, amongst others. The maps of the environment are constructed to be used in posterior tasks of navigation, supplying to the robot subsidies the recognition of the environment of navigation, planning of trajectory, auto-localization and accomplishment of too much tasks. For the construction of a map, an environment can be classified as structured or not structured. Essentially, in a structured environment, geometric restrictions exist that can be used for the construction of models, such as straight lines and plans. In the case not structured, do not exist restrictions geometric that can be used as parameters or used to represent a map, not being possible to construct maps using straight lines, plans or other geometric primitive. In this case, beyond not existing auxiliary hypothesis that simplify the construction of the maps, the movement of the robot is more general, that is, instead of walking on a plain floor, it can walk on irregular land, therefore it is more difficult of being treated. Another classification of environment types is if this is external or internal, being able to be structured or not. As example of navigation in external structured environments is autonomous car navigation in roads, whose structure can be characterized by a plan of navigation with bands that delimit the road (GIACHETTI et al., 1998). As example of navigation in not structured external environments is navigation in planets (GOLDBERG et al., 2002) or submarine robots (VAN DER ZWAAN & SANTOS-VICTOR, 2001), where no structure can be extracted. Internal environments as rooms, corridors and laboratories can be considered as structured. In its majority they contain straight lines (vertical and horizontal) and plans, which can be collected for the creation of a representative model of the environment. Thus, in the internal environment case, the navigation can be assisted by a map that describes the structure or the position of objects in the environment. The internal environment maps can be constructed in a stage of previous exploration to the stage of navigation (YAMAUCHI, 1997), or can simultaneously be constructed to the navigation problem (REKLEITIS & DUJMOVIC, 1999). There are also situations where navigation is carry through without the construction or use of maps of environment (GOLDBERG et al., 2002; VAN DER ZWAAN & SANTOS-VICTOR, 2001) Typically exists two approaches for map representation of the environment: geometric and topological maps. Geometric maps: contain necessary information of the geometry of the environment, the position of objects and distances between these. Topological maps: do not possess any information on the geometry of the environment, being represented by links and nodes. The recognition of visual landmarks gives to the robot a qualitative localization in the environment, getting its position in terms of how much it is next or more distant of the target. In the navigation with geometric maps the localization is quantitative, knowing the robot which is its accurate position in the environment. In mobile robots applications is interesting to have a more general visual field of the one than gotten with a common camera and lens. A system of panoramic or omnidirectional vision supplies an image of 360º of the environment and comes being used for the navigation of mobile robots (MATSUMOTO et al., 2000; GASPAR & SANTOS-VICTOR, 1999; GASPAR et al., 2002). The use of this technique allows: acquisition of panoramic images, obstacles detection, free space for navigation verification, collision obstacles avoidance and landmark recognition in the environment.

2.1. Fuzzy Controllers

The navigation, even so assisted for techniques as omnidirectional vision, is a very complex task to be automatized through the use of conventional computing techniques. Fuzzy Logic is one technique that incorporates in many control systems the human form to think. A typical fuzzy controller can be projected to behave as the deductive reasoning, inferring conclusions based on information that they already know. Of simple form, fuzzy logic can be characterized as a type of logic that recognizes more of the one than simple values of true or false. With the fuzzy logic, proposals can be represented with degrees of truth and falseness. Although the conventional control, based in controllers PID and functions of transference, either appropriate for most of the situations, fuzzy logic implementations frequently are more efficient, had the following characteristics: fuzzy control is born of the experience instead of mathematical models, therefore a linguistic implementation is much more easy and fast of being defined; rare or exception control conditions can be incorporated with little computational cost, remaining the transparent and understandable system still; the implementation of the logic fuzzy is frequently more efficient in terms of codification and computational time of execution. A controller fuzzy normally is composed for an **input interface**, into which the discrete values (not fuzzy) of the input variable are converted to values covered for the pre-defined universes of speech for each input variable, using functions of the knowledge base and converting the input signals into a [0,1] interval that can be associated to linguistic labels; a **Base of Knowledge**, which represents the model of the system to be controlled, consisting of a database (functions of linguistic relevancy) and a base of linguistic fuzzy rules, supplying the necessary numerical definitions to the functions used in the set of fuzzy rules, characterizing the objectives of control and the used strategy of control, by means of a set of linguistic rules of control; a **System of Inference**, which uses fuzzy implications to simulate human decisions, generating inferred actions of control from a set of entrance conditions; and an **Output Interface**, which has the function to get an only usable discrete value in a concrete control action in the real world from gotten output fuzzy values (this discrete value represents a commitment enters the different contained values fuzzy in the output of the controller).

3. Implementation

The Mobile Robot Navigation system described in the present work, based on omnidirectional vision, was implemented in an Autonomous Mobile Robot Platform, of the Laboratory of Automation and Evolutive Computing - LACE - of the Department of Computing and Statistics Sciences - DCCE - IBILCE - UNESP. This vehicle has as on board controller a Pentium Microcomputer, which, through a Radio Modem, connects it a Controlling Microcomputer, as shown in Figure 1, to follow.

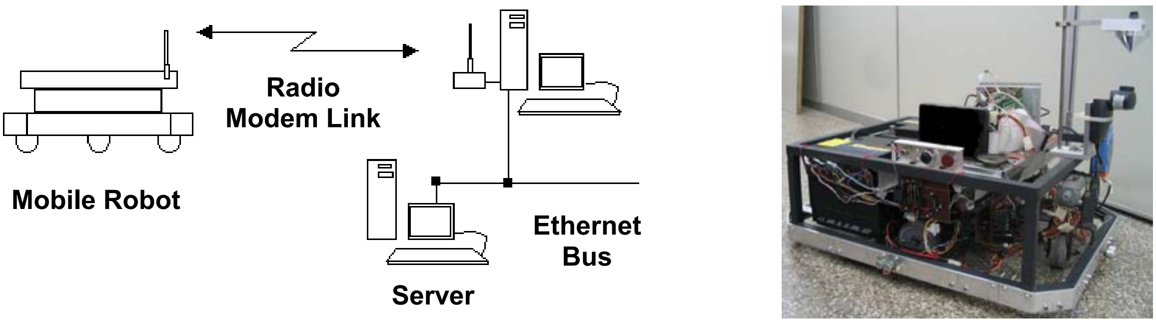

Figure 1. Platform of Autonomous Mobile Robot of LACE - DCCE - IBILCE - UNESP..

The developed navigation system provides to the mobile robot the capacity to move between two places, in a structured internal environment. The navigation environment of the mobile robot is previously known and represented through a map, that is used to determine the navigation routes. The modules that compose the navigation system are integrated as shown in figure 2.

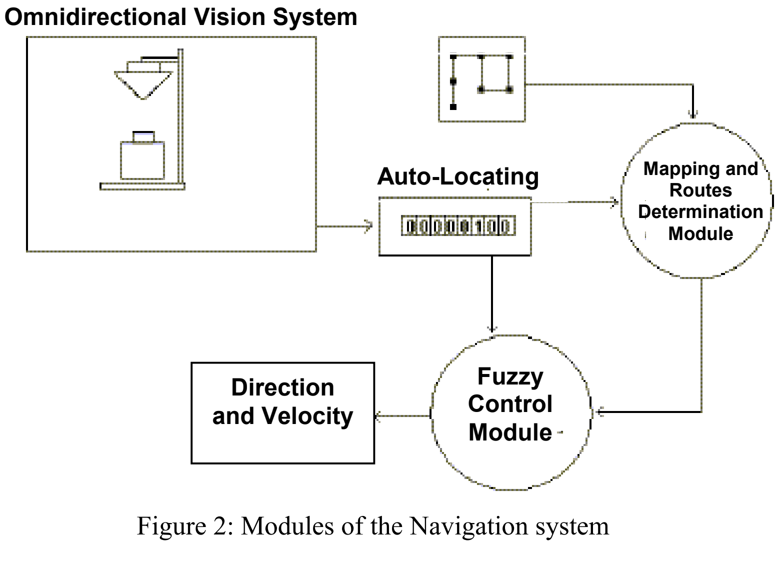

Figure 2: Modules of the Navigation system

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The Mapping and Routes Determination module is responsible for interpreting the environment map and determining the route of navigation and the directions of conversion of the robot from its auto-locating informations supplied for the vision system; Fuzzy Control module is responsible for controlling the direction and the speed of the robot in the determined route. The Omnidirectional Vision System is composed for four modules: Capture Module, which makes the acquisition of the omnidirectional image and converts it into a panoramic image, Pre-processing Module, responsible for the edge detection and binarization of the panoramic image, Pattern Generating Module, which associate the image captured to a place and position previously defined for processing for the Neural Network; and

Localization Module that uses a Neural Network to generate the necessary information to navigation (position and direction of the robot).

Mobile Robot´s Omnidirectional Vision System uses a catadioptric system composed by a camera of video (webcam) connected to a conical mirror. This system allows the robot to capture 360° images of the environment. These images are acquired in some places previously identified in the navigation environment, pre-processed using edge detection technique and then they are used to train an artificial neural network that is responsible for classifying the images captured during the displacement through the route, supplying the information of auto-locating of the mobile robot in the environment in real time. Figure 3 shows as the modules of the omnidirectional vision system are integrated.

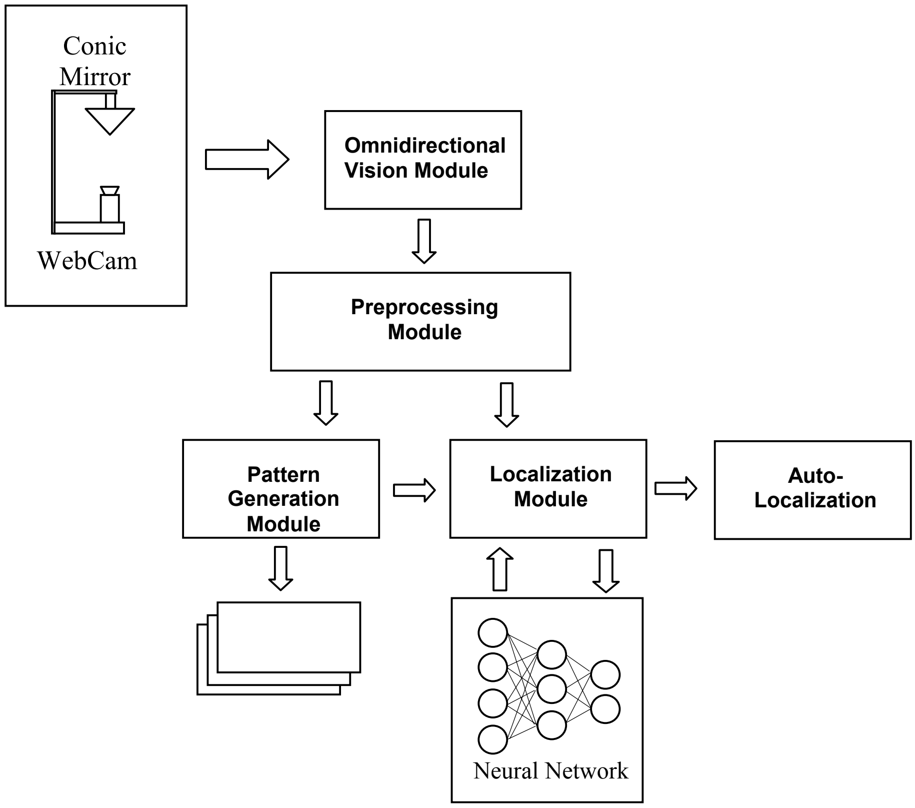
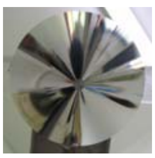


Figure 3. Omnidirectional Vision System Modules.

Figure 4, to follow, shows an example of omnidirectional image and processed panoramic images.

Mirror with Camera

Panoramic Image



Ominidirectional Image

Pre-Processed Panoramic Image

Figure 3. Processed images for the ominidirectional vision system.

The localization module has as objective to associate the images generated for the Pre-processing module with a previously determined position in an internal environment in which the robot moves. For such, a Neural Network is trained with images captured in previously determined places of this environment and used to generate information of auto-locating to the mobile robot related to these places. The Neural Network possess 200 neurons in input layer (the image generated for the pre-processing module possess 50 pixels of width for 4 pixels of height). In the output layer, was adopted the association of a neuron with each place to be recognized. However, the orientation of the robot also must be determined. Thus, for each place exist four output neurons being that each one of the four is a direction related to a fixed referential in the environment. In an environment with N different places to be recognized, the output of Artificial Neural Net is composed for (4 x N) neurons. Figure 4 shows the implemented Net. The function that active the Neural Net receives a vector I contend the input values of the net and returns another vector with the output values. The input vector is gotten converting black pixels of the pre-processed panoramic image for 1 and the whites for 0. The use of a WTA strategy (Winner takes all) where the neuron of output of the Neural Net with the biggest value are considered to determine in which place the mobile robot is not a better choice, therefore when the mobile robot will be moving between two places exists the possibility of the Neural Network to generate an output that does not correspond to none of the two places. However, as the robot to approximate of a determined point, the output value of the corresponding neuron to this point increases and the value of the corresponding neuron to the point that the robot moves away is decreased. To solve this problem it is necessary to know which are the two involved places in the displacement of the robot, thus only the referring neuron to the place for which the robot is moving is monitored. While the robot is moving, all the pictures captured for the camera are analyzed by the neural network and a word of control is generated in real-time following the criteria above. Table 1 illustrates a word of control that represents the localization of the robot in the environment (place 2, direction North) and Table 2 the possible directions that the robot can assume in this environment.

	Place						Direction	
Control Word	0	0	0	0	1	0	0	0
Bit Position	7	6	5	4	3	2	1	0

Table 1. Word of Control (Example).

Bit 1	Bit 0	Direction
0	0	North
0	1	West
1	0	South
1	1	East

Table 2. Mobile Robot possible directions.

To the map construction of the navigation environment for the mobile robot it was used the topological mapping technique, in which a global map that defines the overall environment of navigation of the robot is represented through a graph. The vertices of the graph represent the strategical places for which the system of omnidirectional vision was trained to recognize. The strategical places for the navigation also correspond to the possible places of conversion of direction of the mobile robot and the possible places of final destination of the navigation routes. The edges of the graph represent the relations of adjacency between the places, or either, a place is adjacent to another one if exists a free way between them.

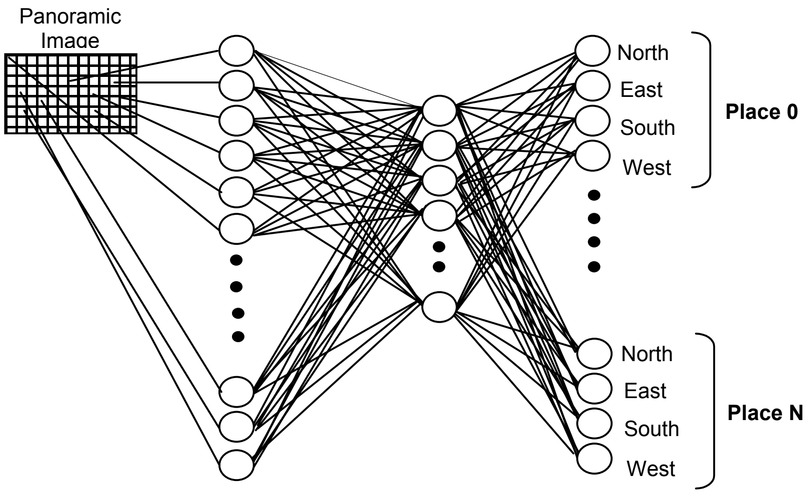


Figure 4. Neural network of the Localization Module.

So that the mobile robot, from the place where it meets, can move until a destination place, through the lesser possible way, was used a determination of excellent routes strategy, using the algorithm of Dijkstra (GOLDBARG & LUNA, 2000). The module of mapping and determination of routes generates, through this algorithm, a vector with a sequence of places that the mobile robot must cover to reach the final destination. However, besides knowing this sequence of places, the mobile robot must know which direction to take in each place of the navigation route. For this was considered the directions of the edges that had been defined in the graph and stored in an adjacency matrix. In the navigation environment a reference direction was defined, that passed to be considered as being the geographic north of the environment; the others directions east, south and west had been defined from the adopted direction north. These directions are adopted for the environment map construction and for training of the neural network omnidirectional vision system. Table 3 shows the relations of the directions of the edges with the movement that the robot must execute.

Next / previous	North	South	East	West
North	Forward	Backward	Right	Left
South	Backward	Forward	Left	Right
East	Left	Right	Forward	Backward
West	Right	Left	Backward	Forward

Table 3. Directions of conversion..

Fuzzy Control Module

The Fuzzy Control module implements the subsystem that controls the direction and the speed of the mobile robot during the navigation route, considering that the robot only must effect a conversion when he will be very next to the place where it must move of direction, and also the speed of the mobile robot must be adjusted for each stretch of the navigation route. Figure 5 shows to the integration of the components of the fuzzy controller

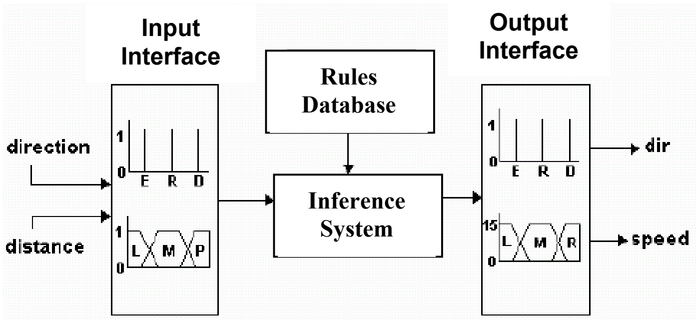


Figure 5: Fuzzy Controller.

The Fuzzy Control module fuzzy uses two input variables, distance and direction and supplies two output variable, dir and speed. The number of functions that enclose the universe of speech of the variable, the types of functions of relevancy used (trapezoidal and singleton fuzzy) and the degree of overlapping of the functions, had been defined from the behavior of the input variable and also for the actions proposals for the accomplishment of the task of navigation of the robot. The distance variable represents the distance relative of the mobile robot until the place of destination of the edge that it is covering (L - far: 0.0 to 0,75, P - close 0.6 to 0,95 and MP - much close: 0.8 to 1.0). The variable direction denotes the direction that the mobile robot must take when reaching the place of destination of the edge that it is covering (E - left: 1.0, R - straight: 2.0 and D - right: 3.0). the output variable speed indicates which must be the speed of the robot for determined stretch of the route. This speed is inferred from the direction of conversion and the distance of the robot in relation to the place of conversion (SLW - slow: 0.0 to 0,06, MD - average: 0.03 to 0,12 and FST - fast: 0.09 to 0.15). The conversion of the output variable fuzzy for a discrete value is made by the output interface of the Fuzzy Control module using the method of the centroid that calculates the point that divides the composed area in two equal parts. The output speed vary between 0,0 m/s to 0.15 m/s. The output variable dir indicates which must be the positioning of the wheels of the robot for each stretch of the route, indicating the directions of right or left conversion only when the distance of the robot in relation to the conversion place is very small (E - left: 1,0. R - straight: 2.0 and D - right: 3.0). The definition of the fuzzy rules was based on the objectives considered for the controller, or either, of that the mobile robot only must effect a curve when will be to a distance very next to the conversion place, a time that the robot can identify this place being to a considerable distance of the ideal point of conversion. The robot also must move of slower form when he will be next to the places where it must make a conversion or next to the final destinations to the navigation route.

4, Experimental Results

To verify the behavior of the Omnidirectional Vision System of the robot, were carried through a test that consisted of capturing and classifying the images during the passage of one determined route. Figure 6 shows the variation of the values of the corresponding neurons to the places of destination in each segment of the navigation route. The displacement for the route was made with constant speed of approximately 15 cm/s.

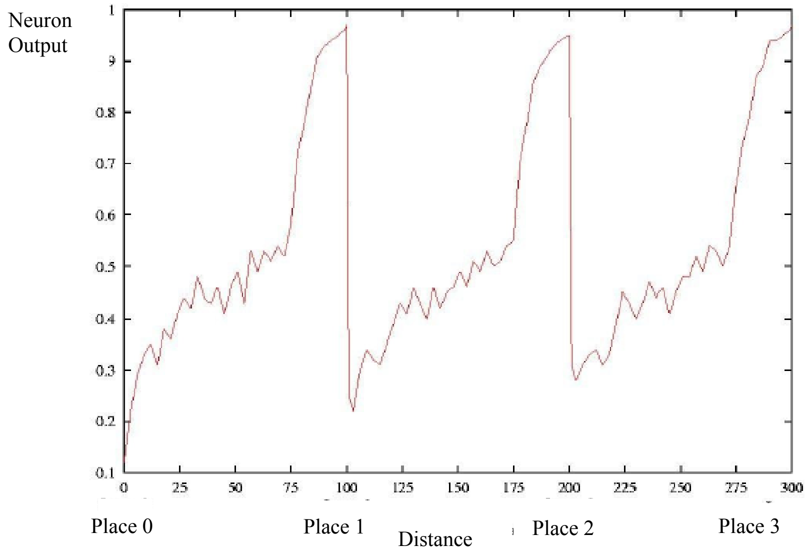
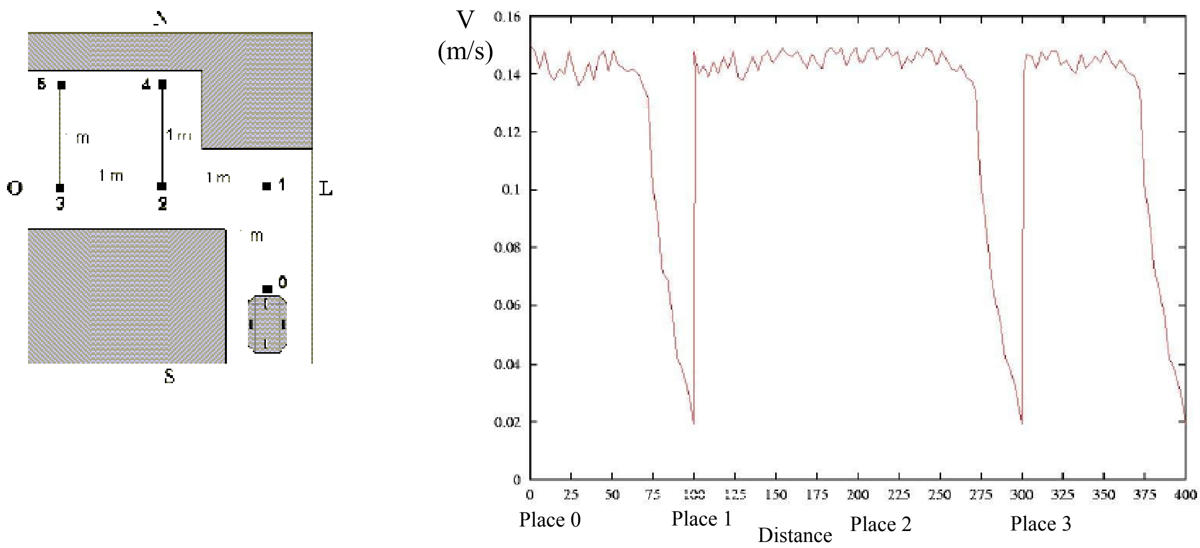


Figure 6. Localization Module output.

In the graph of figure 6, the values had varied between 0 and 1 interval, assuming lesser values when the robot was next to the origin place and increasing gradual the measure if approximate to the place of destination of each segment of the route; to one given distance (between 25 cm and 10 cm) of the destination place, the growth of the value of the variable was greater of that the observed previously, arriving a value very next to one when the robot reaches of fact the place. Tests of performance in the omnidirectional vision system had previously demonstrated that the average rate of processing of the images, since the capture until the classification, was of approximately 5,95 pfs (pictures for second), being 98% of the time expense with the synchronism of the capture device. This performance is enough for the application due low the speed of displacement of the robot, therefore in the maximum speed defined for the robot (15 cm/s) the system it processes at the very least 1 picture to each 2,5 centimeters covered. The topological map of the environment of LACE was constructed to test the displacement of the robot in laboratory environment. The environment was mapped with 6 vertices equally spaced, as shown in figure 7. This figure also show the output of the Fuzzy Controller for the speed variable, that denotes the speed of the robot in the tested route.



a

B

Figure 7. Graphical representation of LACE map (a) and Output of Fuzzy Controller for the speed variable (b).

By analyzing the figure 7 (b) graph, can to perceive that the robot initiates the displacement for the route with speed very next to the maximum, that was defined in the functions of relevancy for the speed variable, keeping this speed while meets distant of place 1, where must execute a conversion to the left. By approximate to the place the 1 speed it is reduced quickly, being very low in the place where the robot effects the conversion. After the conversion the speed is reestablished for the maximum and kept while the robot approximate to the next place (place 2). In this place, we perceive that the controller does not reduce the speed of the robot, therefore it does not effect a conversion of direction in this place. The speed is kept high until the approach of place 3 where the variation of the speed if holds as in place 1, therefore the robot executes a conversion to the right in this place.

5, Conclusions

The technique of omnidirectional vision revealed adequate for the application of navigation of the robot, supplying its auto-locating in appropriate time conditions to the actions of robot controller. The behavior of the value of the output of the neural network neurons made possible its use in the controller fuzzy, supplying a relation of distance of the robot to the trained places to be recognized in the navigation environment. The strategy of topological mapping, used to construct the map of the navigation environment showing to be a appropriated solution for the considered environment of navigation. The Fuzzy Controller module functioned correctly in tests, supplying the correct direction and speed to the robot in each segment of the navigation route. The control of the speed revealed useful for the capture and processing of a bigger number of images in the segments next to the conversion places, considering a rate of processing of the vision system and the maximum speed of displacement of the mobile robot. The navigation technique using omnidirectional, topological mapping of the environment and determination of excellent routes, beyond the control direction and speed using fuzzy logic, had shown to be appropriated for the task of navigation of mobile robots.

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