

Fuzzy Control System for Autonomous Navigation of Thymio II Mobile Robots

Fatma Boufera
Mascara University
Faculty of Science and
Technology, Algeria
fboufera@yahoo.fr

Fatima Debbat
Mascara University,
Faculty of Science and
Technology, Algeria
Debbat_fati@yahoo.fr

Francesco Mondada
EPFL, Lausanne
Robotic Systems
Laboratory
francesco.mondada@e
pfl.ch

M. Faycal Khelfi
RIIR Laboratory
Faculty of Exact and
Applied Sciences,
University of Oran
Algeria
mf_khelfi@yahoo.fr

Abstract—This paper treats the autonomous navigation problem of robotic systems in a dynamic and uncertain environment. In particular, we are interested in determining the robot motion to reach the target while ensuring their own safety and that of different agents that surround it. To achieve these goals, we have adopted a fuzzy controller for navigation and avoidance obstacle, taking into account the changing nature of the environment. The approach has been tested and validated on a ThymioII robots set. As application field, we have chosen a parking problem..

Index Terms—Robotics, Navigation Autonomous, Fuzzy Logic, ThymioII Robot.

I. INTRODUCTION

In unstructured environments, robot controller must be able to operate under conditions of imprecision and uncertainty and efficient response to events [1]. Obstacle avoidance is an essential component to achieve successful navigation. Several research works have been reported in this area. Several trajectory tracking and path following algorithms have been proposed to steer the mobile robot along a path to a desired goal in order to prevent collisions with obstacles. Many researches turned their attention to the obstacle avoidance problem developing interesting real-time behavior for mobile robots in unknown environment. The most well know are, the potential field method, vector field histogram and the method of deformable virtual zone. The first one was introduced by [2] imagines the virtual forces acting on the robot. This method assumes that the robot is driven by virtual forces that attract it towards the goal, or reject it away from the obstacles. The actual path is determined by the resultant of these virtual forces, the second method is introduced in [3] which corresponds to local occupancy grid, constructed from the sensors of the robot; this method was improved in [4], landmark learning [5], edge detection, graph-based methods [6], Limit-cycles method [7] and many others. However, relatively few of them are suitable for real-time and embedded applications on very low-cost systems. Among them, the methods that use artificial intelligence approaches as:-Neural Network [8]: this approach is applied to determine the optimal neural networks structure for real-time obstacle avoidance task.

In [9], the paper proposes a neural network that uses Qlearning reinforcement technique for solving the problem of obstacle avoidance. -Multi Agent System: In [10], a new local collision avoidance algorithm between multiple robots for real-time navigation is presented. This algorithm is based on multi agent system and quadratic optimization method for a collision free navigation and to compute the motion of each robot. -Hybrid Neural Network Genetic Algorithm: [11] used a hybrid neural network, genetic algorithm and local search method for solving the problem of finding the optimal collision free path in complex environments for mobile robot. -Particle Swarm Optimization: In [12], the author proposed two extensions of Particle Swarm Optimization (PSO) and Darwinian Particle Swarm Optimization (DPSO) to solve the problem of obstacle avoidance for multi robot.

All these methods require to be implemented on robots with a sufficiently complex functional structure. The robot must possess capabilities of perception, decision, evaluation of the action and a relatively high computational power and/or memory.

This paper mainly deals the navigation control and obstacle avoidance. Our objective is to develop a simple and reactive obstacle avoidance tool that can be implemented on an extremely compact such as the Thymio II [13]. In this context, we propose an intelligent and fast fuzzy controller system for navigating in real-time. The fuzzy logic is certainly one of the most adopted approaches in industry. It addresses such applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information. It fills an important gap in engineering design methods left vacant by purely mathematical approaches (e.g. linear control design), and purely logic-based approaches (e.g. expert systems) in system design. The advantage of using fuzzy logic for navigation is that it allows for the easy combination of various behaviors outputs through a command fusion process. The navigation system in this case consists of two behaviors an obstacle avoidance behavior and a goal seeking behavior[14][15].

A set of experimentations is realized to demonstrate the feasibility of this approach for navigation, avoiding

static and dynamic obstacles (other robots) and aggregation (in our case, parking in the edges of environment) for ThymioII mobile robots.

Besides this introduction, the structure of the paper is as follows: Section 2 gives the specifications of the robot platform and its functioning under ASEBA tool. Section 3 presents the description of fuzzy logic controller. Section 4 shows different experimentations for testing the proposed approach. Conclusions and perspective are given in Section 5.

II THYMIO II AND ASEBA PRESENTATION

The system consists of a set of ThymioII mobile robots (<https://thymio.org>) navigating in a dynamic and uncertain environment. The robots must explore the environment and avoid static and dynamic obstacles (other robots).

2.1 Thymio II Robot

Thymio II is an affordable educational robot (<100\$). It provides three main features: a large amount of low-cost sensors and actuators, a specific interactivity based on light and touch, aimed at increasing the understanding of the robot functionalities and a very efficient programming environment based on Aseba (<https://aseba.wikidot.com/en:start>). Its interactivity is based on several functionalities: capacitive touch buttons, color of the body (full RGB spectrum) and LED associated with each robot functionality (<https://aseba.wikidot.com/fr:thymioprogram>). This robot is representative of low-cost mass-produced systems: A control method applied on the Thymio II robot can be deployed at very low cost: <2\$ for the processor, <1\$ for each proximity sensor, <1\$ per motor.

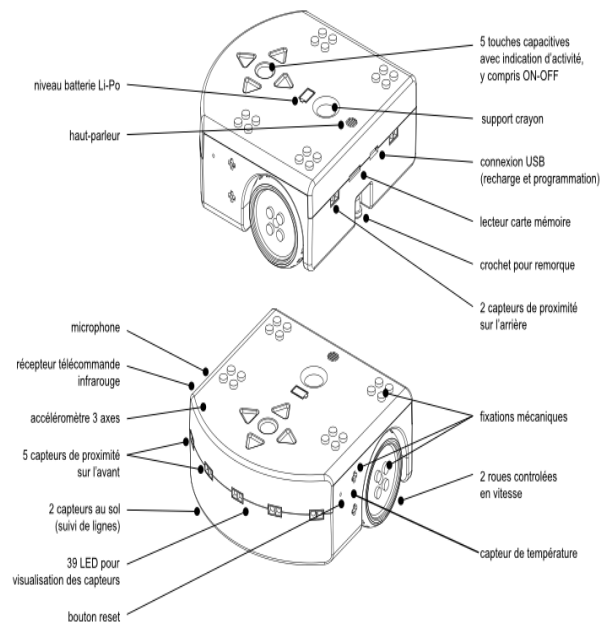


Figure 1. The ThymioII robot Platform and its structural component.

2.2 ASEBA Environment

Aseba is a set of tools which allow novices to program robots easily and efficiently. It is an event based architecture for real-time distributed control of mobile robots. It targets integrated multi-processor robots or groups of single-processor units, real or simulated. The core of Aseba is a lightweight virtual machine tiny enough to run even on microcontrollers. With Aseba, we program robots in a user-friendly scripting language using a cosy integrated development environment. (<https://aseba.wikidot.com/en:description>).

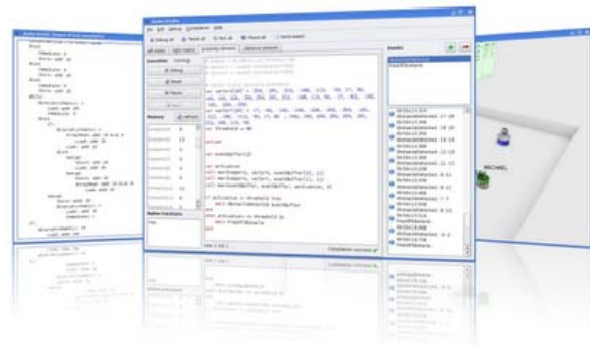


Figure 2. Aseba environnement (<http://www.mobsysa.org/robot/logiciels>).

III NAVIGATION PROPOSED APPROACH

In order to avoid static and dynamic obstacles and permit parking in the edges of the environment by the robot Thymio II, we proposed and developed a reactive system control of navigation using fuzzy logic (Figure 3). The robot reacts according to the changes in environment. The fuzzy system determines the two wheels speed of

ThymioII robot so that it avoids obstacle and go to the reach.

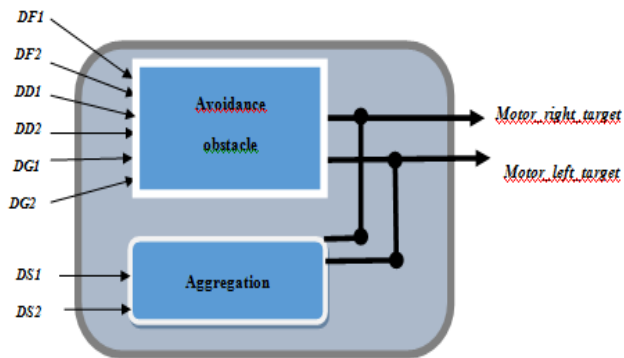


Figure 3. ThymioII robot navigation controller.

The fuzzy control system is composed of two modules based on inputs sensory of the ThymioII robot:

- ✓ Avoidance obstacle module
- ✓ Aggregation module.

A fuzzy system that determines the speed of right and left wheels: **motor_right_target**, **motor_left_target** based on the distance of the obstacles around the robot measured by the sensors: **C0**, **C7**, **C6**, **C5**, **C1**, **C2** and values given by the two sensors **DS1** and **DS2**.

TABLE 1.

THE MEASURED DISTANCES OBSTACLES-ROBOT

Obstacle direction	Sensors	Distances given
Frontal obstacle	C ₀	DF1
	C ₇	DF2
Left Obstacle	C ₆	DD1
	C ₅	DD2
Right Obstacle	C ₁	DG1
	C ₂	DG2

3.1 Avoidance Obstacle Module

In the next section, we describe different stages of the fuzzy control for avoidance obstacle (Fuzzification, fuzzy inference and Defuzzification).

• Inputs fuzzification

We first proceed to the fuzzification of the distances: DF1, DF2, DG1, DG2, DD1, and DD2. The same fuzzy model used for the different measured distances.

These distances are represented by **proxy_horizontal** variable which is calculated by Aseba tool.

The membership functions of these distances near and far have been fixed after several tests and experiments.

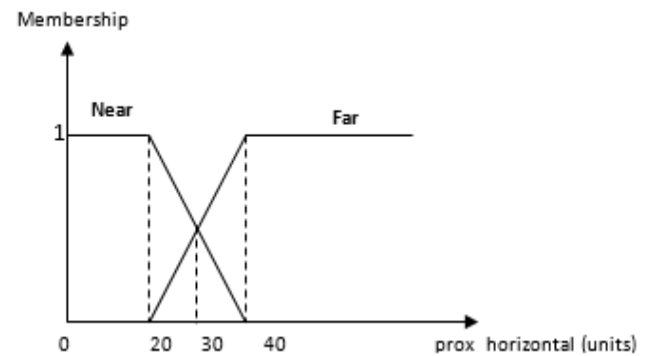


Figure 4. The fuzzy sets of proxy_horizontal variable

The **prox_horizontal** variable is calculated by Aseba tool.

• Outputs fuzzification

The speed fuzzification of the right and left wheels: **motor_right_target** and **motor_left_target** is presented in figure 5.

The membership functions for this variable are: Dacc (deceleration), Zacc (no speed change) and Accc (acceleration).

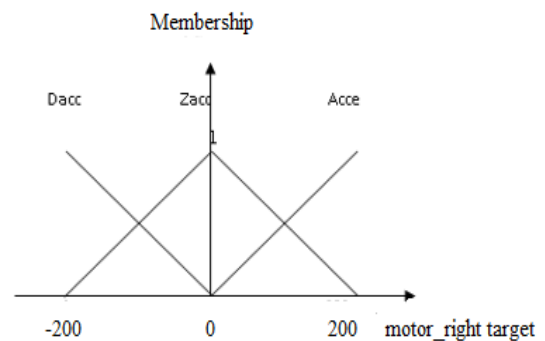


Figure 5. Fuzzy sets of motor_right_target and motor_left_target variable.

• Fuzzy inference

This step presents the inference rules elaboration to determine the robot behavior according to its intrinsic parameters. It will be seen later that the number of potential rules of reaction increases directly with the number of labels of the variables.

According to the membership degree of the different distances measured by the robot sensors, each values combination of these input variables, a command presented by the outputs variables (**motor_right_target** and **motor_left_target**) is associated with it.

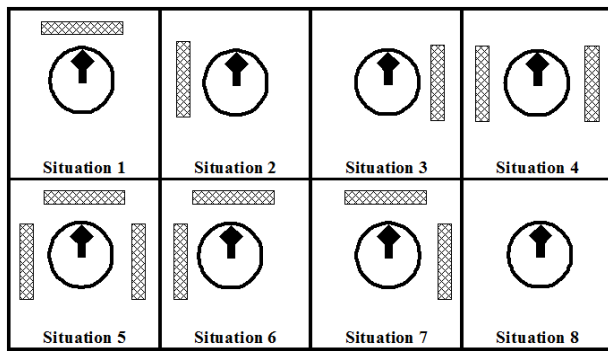


Figure 6. The eight situations of avoidance obstacle

The inference rules definition are based on the following situations (figure 6) which shows the different cases of avoidance obstacles that the robot can undergo during its navigation.

Each situation is defined by a set of inference rules depending on the distances of obstacles-robot. As example, we give the set rules of situation 1: «**Front close**».

The robot stops and performs randomly one of the following maneuvering:

- Deviation in a right.
- Deviation in a left.
- A half-rotation.

TABLE 2.
RULE INFERENCE OF SITUATION 1 "FRONT-CLOSE".

If	Distance sensor	Fuzzy Value	Then	Action	
	DF1	Near		Deviation in right	
	DF2	Near		Deviation in right	
	DD1	Far		Motor_left_target	200
	DD2	Far		Motor_right_target	-200
	DG1	Far			
	DG2	Far			

2.2.3 Defuzzification

In this section, we present a defuzzification process used in our fuzzy system. The defuzzification step allows the transformation of the output fuzzy values into the corresponding physical values.

We opted for the defuzzification method called "average weighted method". This choice is usually conditioned by a compromise between implementation ease and computing performance [16].

2.2.2 Aggregation Module

The objective of this module is to stop the robot when it is on the environment edges.

To define these edges, we used another color (black) different in the light intensity with the inside area color (white) where the ground sensors of Thymio robot can detect it easily.

The variables measured by these soil sensors are:

- ✓ **prox.ground.ambient**: ambient light intensity on the ground, varies between 0 (no light) and 1023 (maximum light).
- ✓ **prox.ground.reflected**: quantity of light received while the sensor emits infrared, ranging from 0 (no reflection) and 1023 (high light).
- ✓ **prox.ground.delta**: difference between reflected light and ambient light, related to the distance and color of the soil.

Membership degree

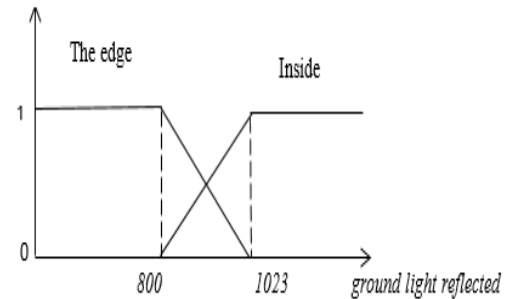


Figure 7. Fuzzy sets of ground light reflected

The variation of the light reflected from the ground is described by two subsets: at edges and Inside.

IV SIMULATION AND RESULTS

In this section, we evaluate the proposed approach efficiency by a set of experimentations on Thymio II robots group.

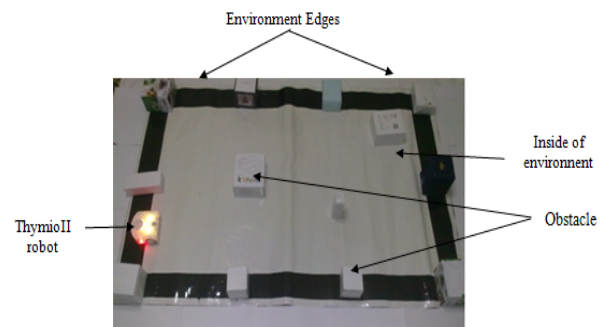
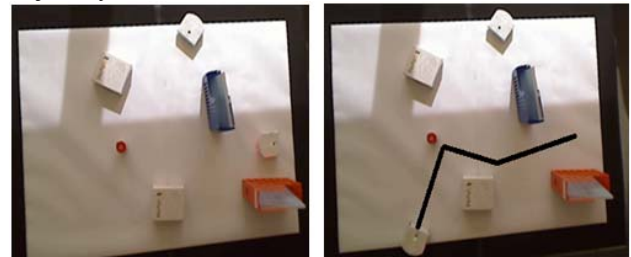
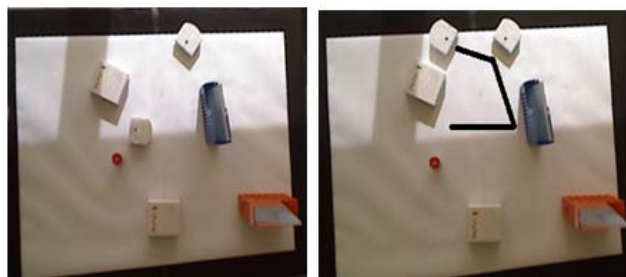


Figure 8. Experiment environment for Thymio II robot.

The experimentation scenes are timed and filmed by several cameras. In Figures 9-10, we show several cases of environments simple and complexes to validate the proposed approach. The bold line represents the trajectory of the robot.



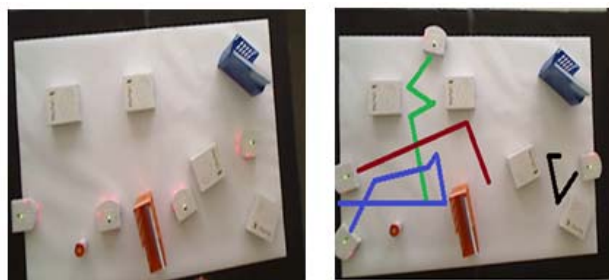
(a) First position (b) Final position
Figure 9. Navigation and avoidance obstacle in the environment 1.



(a) First position

(b) Final position

Figure 10. Navigation and avoidance obstacle in the environment 2



(a) First position

(b) Final position

Figure 11. Navigation and avoidance obstacle in the environment 3.

In these various cases of test we can see that the proposed approach is safe and efficient.

Even if the environment is complex and dynamic (several obstacles and active robots), the ThymioII robot is able to avoiding different static and dynamic obstacles encountered with a flexible navigation and stop at the environment edges.

CONCLUSION

In this article, a proposed solution has been presented to the problem of navigation and obstacle avoidance by developing a fuzzy navigation controller dedicated to ThymioII robots under Aseba environment. The experimental results are satisfactory and validate the proposed approach. The robot navigates autonomously and safe despite the complexity of the environment.

REFERENCES

- [1] Adouane, L, and N. LeFort-Piat, 2004, Hybrid Behavioural Control Architecture for the Cooperation of Minimalist Mobile Robots, In Proceedings of the International Conference on Robotics and Automation ICRA04, pp. 3735-3740, New Orleans-USA).
- [2] Khatib, O, 1986, "Real time obstacle avoidance for manipulators and mobile robot", international journal robotics research 5(1) 90-80.
- [3] Kren, Y, and J. Borensrein, 1991, "Potential Field Methods and their inherent limitations for mobile robot navigation", IEEE conference on robotics and automation. 1398- 1404.
- [4] Ulrich, B, 1998, "Reliable obstacle avoidance for fast mobile robots", in IEEE int conf on robotics and automation. Leuven, Belgium.
- [5] Meyer, J.A, and D. Filliat, 2003, "Map-based navigation in mobile robots a review of map- learning and path-planning strategies", Journal of Cognitive Systems Research.4 (4), 283317.
- [6] Adouane, L, 2009, "Orbital obstacle avoidance algorithm for reliable and on-line mobile robot navigation", In Proceedings of the In 9th Conference on Autonomous Robot Systems and Competitions.
- [7] Adouane, L, and A. Benzerrouk, and P. Martinet, 2011, "Mobile Robot Navigation in cluttered Environment using Reactive Elliptic Trajectories", In Proceedings of the 18th IFAC World Congress, Milano-Italy.
- [8] Hoang, T and T. Nguyen, 2007, "Obstacle Avoidance for Power Wheelchair Using Bayesian Neural Network", Proceedings of the 29th Annual International, Conference of the IEEE EMBS, Cit International, Lyon, FranceIn.
- [9] Duguleana, M, and F. Barbuceanua, and A.Teirelbarb, and G.Mogana, 2012, "Obstacleavoidance of redundant manipulators usingneuralnetworks based reinforcement learning", Robotics and Computer-Integrated Manufacturing, Volume 28, Issue 2, Pages 132146
- [10] Guy, S, and J.Chhugani and C.Kim and N.Satish and M.Lin and D. Manocha and P.Dubey, 2009, "ClearFootpath: Highly Parallel Collision Avoidance for Multi-Agent Simulation", Eurographics/ ACM SIGGRAPH Symposium on Computer Animation, E. Grinspun and J. Hodgins (Editors).
- [11] Hosseinzadeh, A and H.Izadkhah, 2010, "Evolutionary Approach for Mobile Robot PathPlanning in Complex environment", IJCSI International Journal of Computer Science Issues, Vol. 7, Issue 4, No 8.
- [12] Couceiro, M.S, and R.P. Rocha and N.M.F. Ferreira, 2011, "A novel multi-robot exploration approach based on Particle Swarm Optimization algorithm Safety, Security, and Rescue Robotics (SSRR)", IEEE International Symposium on.
- [13] MagnenatS., RiedoF., Bonani M. and MondadaF, 2012., "A Programming Workshop using the Robot "Thymio II": The Effect on the Understanding by Children", The IEEE International Workshop on Advanced Robotics and its Social Impacts, Munich, Germany.
- [14] Cherroun. L, r. mechgoug, m. boumehraz. 2011, "path following behavior for an autonomous mobile robot using fuzzy logic and neural networks. courrier du savoir. n°12, octobre, pp.63-70.
- [15] Melin.p, o. mendoza, o. Castillo, 2011, "face recognition with an improved interval type-2 fuzzy logic sugeno integral and modular neural networks. IEEE transactions on systems, man, and cybernetics, part a 41(5): 1001-1012.
- [16] Lee, and Wang, 1994, "collision avoidance by fuzzy logic control for automated guided vehicle navigation", journal of robotics system, vol. 11 no.8, pp 743-760