# The New Hardware Structure of the Emmy II Robot

**Cláudio Rodrigo Torres and Régis Reis**

**Abstract** This work presents an implementation of the Emmy II Autonomous Mobile Robot [1–3] control system in a new hardware structure. The main objective of this robot is to avoid reaching any obstacle in a non-structured environment. The control system is based on the Paraconsistent Annotated Evidential Logic—Eτ. In this work, it is also detailed the mechanical platform used in the robot and the tests performed.

**Keywords** Paraconsistent annotated evidential logic · Autonomous mobile robot · Control system

## 1 Introduction

This work presents an implementation of the Emmy II autonomous mobile robot control system in a new hardware structure. The main objective of this robot is to avoid reaching any obstacle in a non-structured environment.

The project presented here is an evolution of the Emmy II robot [1–4]. The Emmy II robot is an autonomous mobile robot able to move in a non-structured environment avoiding collisions. Its control system is based on the Paraconsistent Annotated Evidential Logic Eτ.

Basically, the robot proposed here is similar to the Emmy II, but with a modern hardware structure. The objective is to build a new Emmy II robot able to receive upgrades in its functionalities.

This paper is divided as the follow: first there is a description of the Paraconsistent Annotated Evidential Logic Eτ; afterwards there is a description of

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the autonomous mobile robot Emmy II. At the end of the text, there is a description of the hardware structure proposed and a description of tests performed.

## 2 Paraconsistent Annoted Evidential Logic—Eτ

Paraconsistent Logics is a kind of logics that allows contradictions without trivialization. A branch of it, the Paraconsistent Annotated Evidential Logic Eτ, which is employed in this work, also deals with the concept of fuzziness. Its language consists on propositions (p) in the usual sense together with annotation constants: (μ, λ) where μ, λ ∈ [0, 1] (real unitary interval). Thus, an atomic formula of the Logic Eτ is of the form p(μ, λ) which can be intuitively read: the favorable evidence of p is μ and the contrary evidence of p is λ. A detailed description of the subject is found in [5–11].

The Favorable Evidence Degree (μ) is a value that represents the favorable evidence in which the sentence is true; this value is between 0 and 1.

The Contrary Evidence Degree (λ) is a value that represents the contrary evidence in which the sentence is true; this value is between 0 and 1.

Through the Favorable and Contrary Degrees, it is possible to represent the four extreme logic states, as shown in the Fig. 1.

The four extreme logic states are: True (V), False (F), Paracomplete (⊥) and Inconsistent (T).

In [12, 13] it is proposed the Para-analyzer Algorithm. By this algorithm it is also possible to represent the non-extreme logic state. The Fig. 2 shows this.

The eight non-extreme logic states are: Quasi-true tending to Inconsistent—QV → T, Quasi-true tending to Paracomplete—QV → ⊥, Quasi-false tending to Inconsistent—QF → T, Quasi-false tending to Paracomplete—QF → ⊥, Quasi-inconsistent tending to True—QT → V, Quasi-inconsistent tending to False—QT → F, Quasi-paracomplete tending to True—Q⊥ → V and Quasi-paracomplete tending to False—Q⊥ → F.

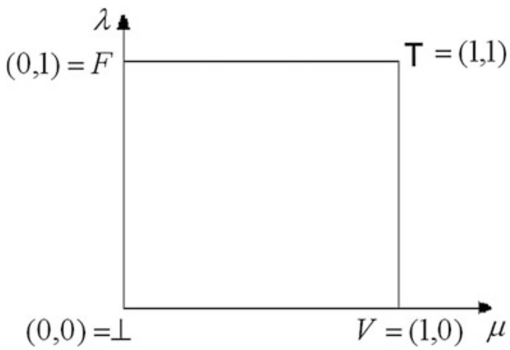



**Fig. 1** The extreme logic states

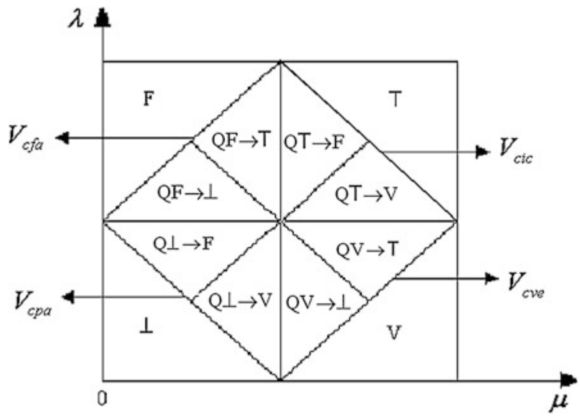



**Fig. 2** The non-extreme logic states

It is also defined the Uncertainty Degree: $Gun(\mu, \lambda) = \mu + \lambda - 1$ and the Certainty Degree: $Gce(\mu, \lambda) = \mu - \lambda$ $(0 \leq \mu, \lambda \leq 1)$.

Some additional control values are: Vcic = maximum value of uncertainty control, Vcve = maximum value of certainty control, Vcpa = minimum value of uncertainty control and Vcfa = minimum value of certainty control.

## 3 Autonomous Mobile Robot Emmy II

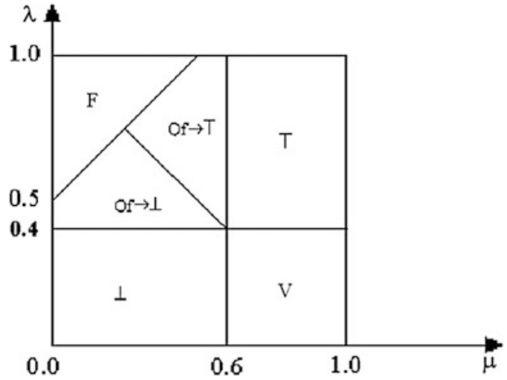
The Emmy II robot is an autonomous mobile robot able to avoid obstacle while it is moving in a non-structured environment.

The control system of the Emmy II uses six logic states instead of 12 logic states used in the Para-analyzer Algorithm.

Two sensors are responsible for verify whether there is any obstacle in front of the robot or not. The signals generated by the sensors are sent to a microcontroller. These signals are used to determine the favorable evidence degree (μ) and the contrary evidence degree (λ) on the proposition "The front of the robot is free". The favorable and contrary evidence degrees are used to determine the robot movements.

The signal generated by the sensor 1 is considered the favorable evidence degree and the signal generated by the sensor 2 is considered the contrary evidence degree of the proposition "The front of the robot is free". When there is an obstacle near the sensor 1 the favorable evidence degree is low and when there is an obstacle far from the sensor 1 the favorable evidence degree is high. Otherwise, when there is an obstacle near the sensor 2 the contrary evidence degree is high and when there is an obstacle far from the sensor 2 the contrary evidence degree is low. The Emmy II controller decision of what movement the robot should perform is based on the reticulated showed in Fig. 3.

**Fig. 3** Lattice of Emmy II controller




The decision for each logic state is the following:

- Robot goes ahead. DC motors 1 and 2 are supplied for spinning around forward.
- Robot goes back. DC motors 1 and 2 are supplied for spinning around backward.
- Robot turns right. Just DC motor 1 is supplied for spinning around forward.
- Robot turns left. Just DC motor 2 is supplied for spinning around forward.
- Robot turns right. Just DC motor 2 is supplied for spinning around backward.
- Robot turns left. Just DC motor 1 is supplied for spinning around backward.

The justification for each decision is the following:

When the logic state is true (V), it means that the front of the robot is free. Therefore, the robot can go ahead.

In the inconsistency (T), μ and λ are high (i.e., belong to T region). It means that the sensor 1 is far from an obstacle and the sensor 2 is near an obstacle, so the left side is more free than the right side. Then, the behavior should be to turn left by supplying only the DC motor 2 for spinning around forward and keeping the DC motor 1 stopped.

When the Paracompleteness (⊥) is detected, μ and λ are low. It means that the sensor 1 is near an obstacle and the sensor 2 is far from an obstacle, so the right side is more free than the left side. Then, the behavior should be to turn right by supplying only the DC motor 1 for spinning around forward and keeping the DC motor 2 stopped.

In the false state (F) there are obstacles near the front of the robot. Therefore the robot should go back.

In the QF → T state, the front of the robot is obstructed but the obstacle is not so near as in the false state and the left side is a little bit more free than the right side. So, in this case, the robot should turns left by supplying only the DC motor 1 for spinning around backward and keeping the DC motor 2 stopped.

In the QF → ⊥ state, the front of the robot is obstructed but the obstacle is not so near as in the false state and the right side is a little bit freer than the left side. So, in

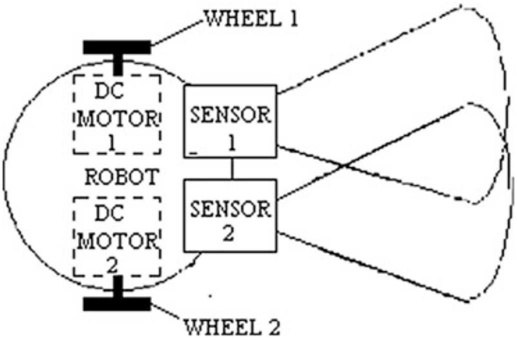



**Fig. 4** The Emmy II robot basic structure

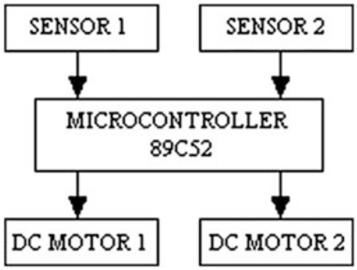



**Fig. 5** Emmy II block representation

this case, the robot should turns right by supplying only the DC motor 2 for spinning around backward and keeping the DC motor 1 stopped.

The basic structure of the Emmy II robot is showed in the Fig. 4.

The Emmy II controller system uses six logic states instead of 12 logic states used in the Emmy I controller. Moreover, it may present some commands that do not exist in the Emmy I robot:

1. Velocity control: the Emmy II controller allows the robot to brake, turn and accelerate “in a smoothly way” what is not possible in the Emmy I robot.
2. The Emmy II controller allows backward motion. In some situations the robot may move backward or turns with a fixed wheel and the other spinning around backward. There are not these types of movements in the Emmy I robot.

It can be seen in the Fig. 5 a simplified block representation of Emmy II robot.

The Fig. 6 shows a picture of the robot Emmy II

It is shown in the Fig. 7 the down part of the Emmy II robot.

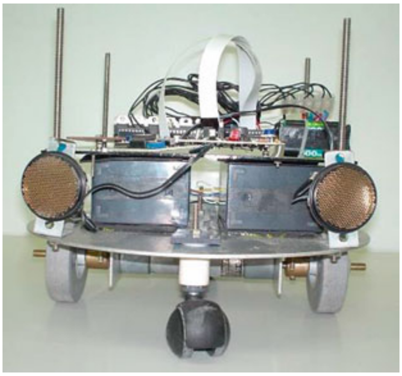


**Fig. 6** The front part of the Emmy II robot

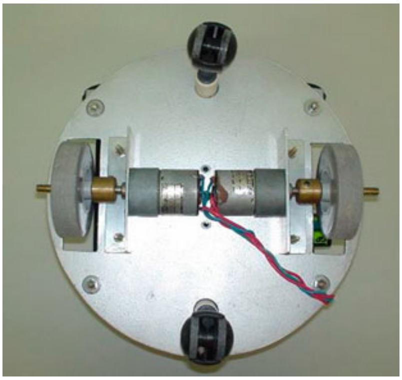


**Fig. 7** The down part of the Emmy II robot

### *3.1 Tests of Emmy II Robot*

Aiming to verify Emmy II robot functionally, it has been performed 4 tests. Basically, counting how many collisions there were while the robot moved in an environment as showed in Fig. 8.

The time duration and results for each test have been the following:

- Test 1: Duration: 3 min and 50 s. Result: 13 collisions.
- Test 2: Duration: 3 min and 10 s. Result: 7 collisions.
- Test 3: Duration: 3 min and 30 s. Result: 10 collisions.
- Test 4: Duration: 2 min and 45 s. Result: 10 collisions.

The sonar ranging modules used in the Emmy II robot can't detect obstacles closer than 7.5 cm. The sonar ranging modules transmit sonar pulses and wait for them to return (echo) so that it can determine the distance between the sonar ranging modules and the obstacles; however, sometimes the echo doesn't return,

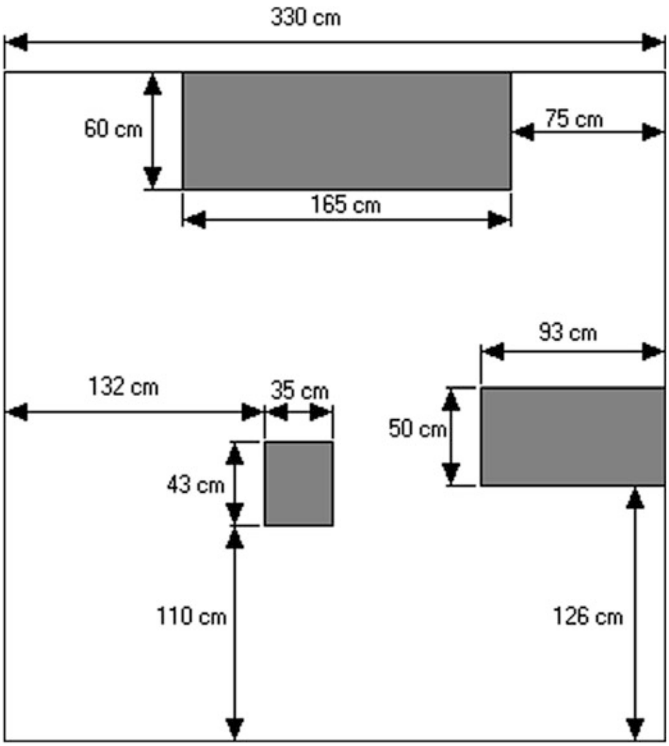



**Fig. 8** Environment used to perform the Emmy II tests

because it reflects to another direction. These are the main causes for the robot collisions:

Test 1: Collisions: 13.
Collisions caused by echo reflection: 4.
Collisions caused by too near obstacles: 9.

Test 2: Collisions: 7.
Collisions caused by echo reflection: 2.
Collisions caused by too near obstacles: 5.

Test 3: Collisions: 10.
Collisions caused by echo reflection: 5.
Collisions caused by too near obstacles: 5.

Test 4: Collisions: 10.
Collisions caused by echo reflection: 4.
Collisions caused by too near obstacles: 6.

There is another robot collision possibility: when the robot is going back. As there is no sonar ranging module behind the robot, it may collide.

Fig. 9 The mechanical platform

## 4 The New Emmy II Hardware Structure

The mechanical platform showed in the Fig. 9 had been built in order to perform the Emmy II control system algorithm.

The platform is composed of three subsystems: Control and Planning Subsystem, Moving Subsystem and Sensing Subsystem. These subsystems work together although each one is responsible for a part of whole system. The robot system may be modelled as presented in Fig. 10.

### 4.1 Moving Subsystem

The Moving Subsystem is composed of a chassis, 4 wheels, 4 DC motors and potency drivers for DC motors supply. The chassis is a metallic structured aiming to

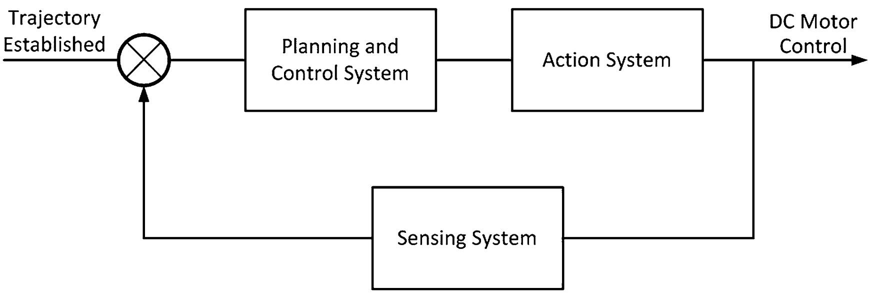



Fig. 10 The robot system model

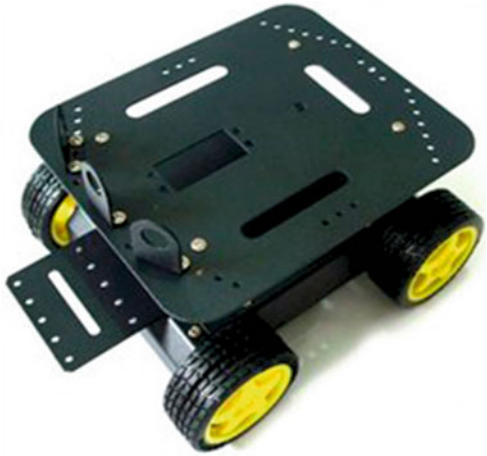


**Fig. 11** The robot chassis

fix all robot devices. It is possible to see in Fig. 11 the chassis with the DC motors and wheels fixed.

The four DC Motors are of low potency and consumption because the robot is projected to move in smooth surfaces. The chosen DC motor model is the DFRobot130 with mechanical reduction by gears. This DC motor has the following operational characteristics:

- Gear ratio: 1:120.
- No-load speed (6 V): 180 rpm.
- No load current (6 V): 160 mA.
- Locked-rotor current (6 V): 2.8 A.
- Size: Long. 55 mm; Width 48.3 mm; High 23 mm.
- Weight: About 45 g.

The DC motors are supplied by signals from the Control and Planning Subsystem. These signals must be amplified because they are of low potency. The signals can be sent to the DC motors only after the amplification.

The amplification is made by two potency drivers as showed in Fig. 12. The main component of the potency driver is the integrated circuit L298N from ST Electronics. This component is composed of two H bridge encapsulated in just one involucre. And has the objective of amplify the electric current and control the DC motor rotation direction.

The electric circuitry used for supplying the DC motors of the right wheels (driver 1) is showed in Fig. 13.

It is used an electric circuitry similar to the one showed in Fig. 10 for supplying the DC motors connected to the left wheels.

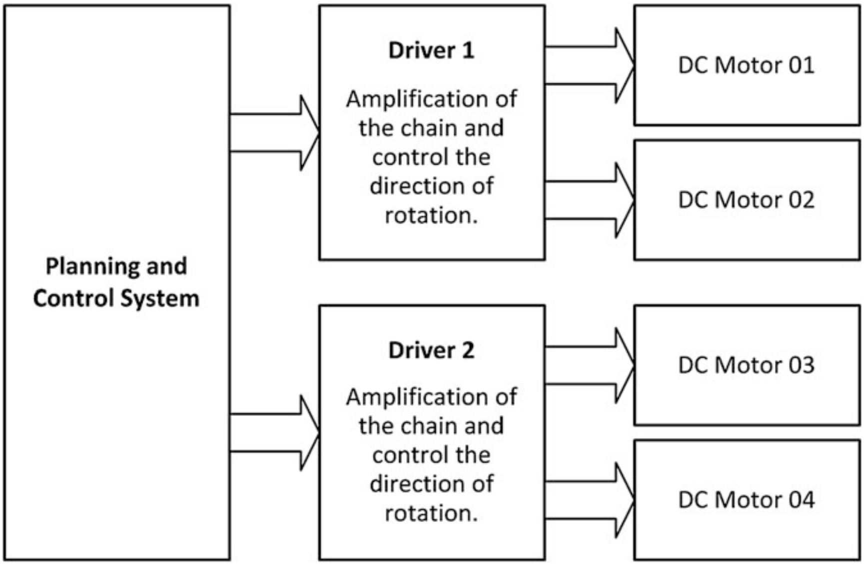



**Fig. 12** DC motors supply structure

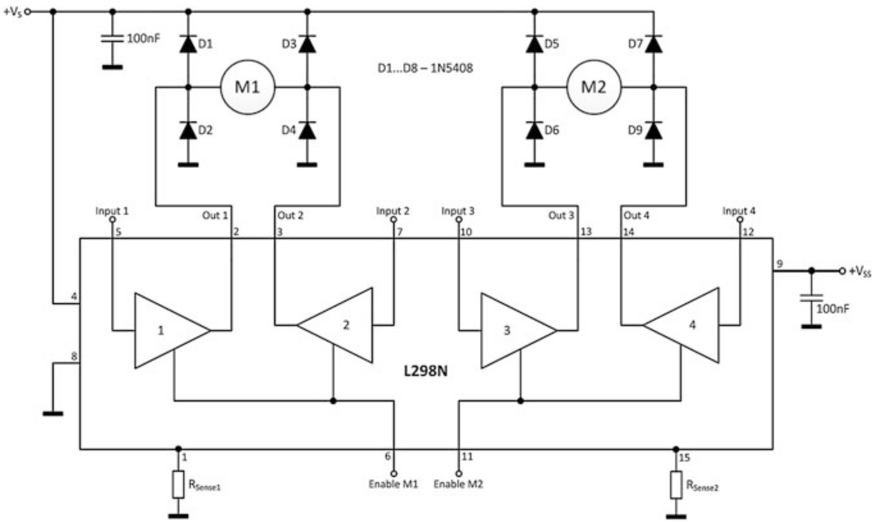



**Fig. 13** Electric circuitry used for supplying the DC motors

## 4.2 Sensing Subsystem

The Sensing Subsystem is composed of three ultrasonic sensors and two encoders connected to the robot frontal wheels. The ultrasonic sensors are of the model PING ((( from Parallax and are fixed on the frontal part of the robot. They are fixed as showed in Fig. 14.

The ultrasonic sensor may cover a range of 100º as showed in Fig. 15.

The Parallax Ping((( sensor is able to measure an interval from 2 to 300 cm precisely. The sensor emits ultrasonic waves of 40 kHz for 200 µs. A microcontroller determines when the ultrasonic wave emission starts. The sensor starts sending a signal to the microcontroller when the ultrasonic wave emission is finished. This signal sending is finished when the ultrasonic sensor receive the echo of the ultrasonic waves emitted before. Then, the microcontroller may determine the distance of the object from the sensor by the duration of the signal sent by the sensor. Figures 16 and 17 illustrate the process of obstacle detection.

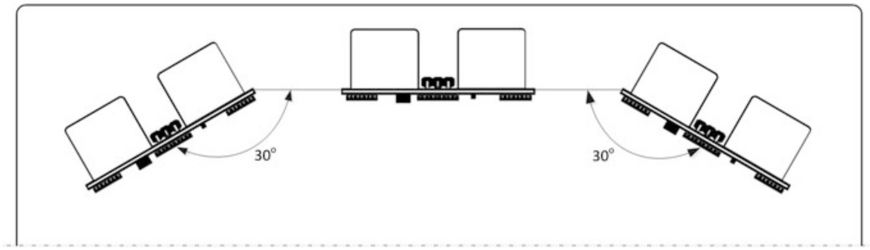



**Fig. 14** Ultrasonic sensors robot position

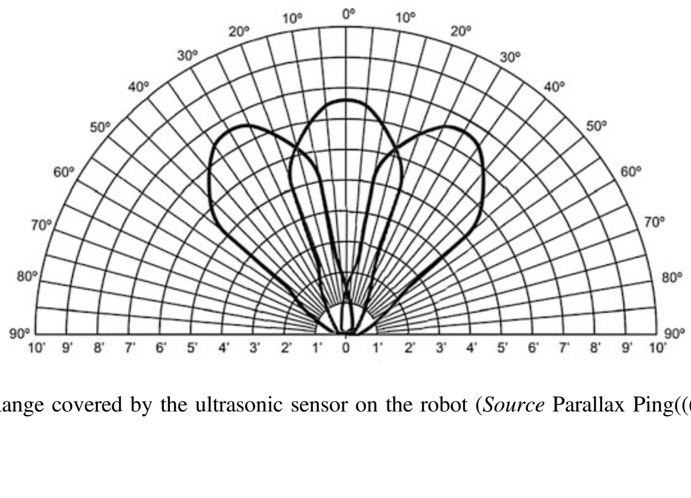



**Fig. 15** Range covered by the ultrasonic sensor on the robot (*Source* Parallax Ping(((datasheet)

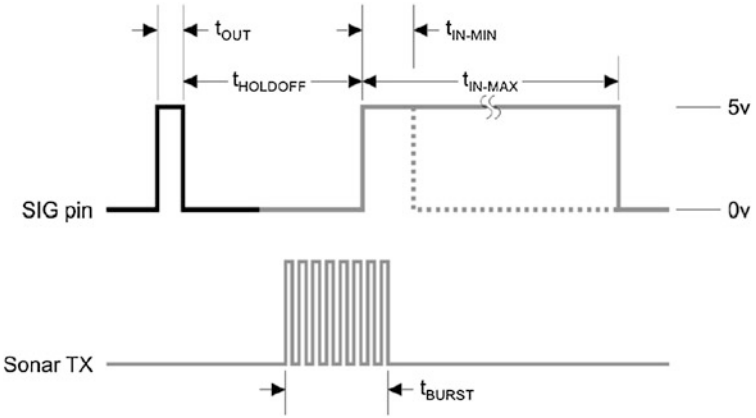



**Fig. 16** Ultrasonic sensor process of wave emission and echo receiving. (*Source* Parallax Ping(((datasheet)

| | | | | |
|---|---|---|---|---|
| | Host Device | Input Trigger Pulse | $t_{OUT}$ | 2 µs (min), 5 µs typical |
| | PING))) Sensor | Echo Holdoff | $t_{HOLDOFF}$ | 750 µs |
| | | Burst Frequency | $t_{BURST}$ | 200 µs @ 40 kHz |
| | | Echo Return Pulse Minimum | $t_{IN-MIN}$ | 115 µs |
| | | Echo Return Pulse Maximum | $t_{IN-MAX}$ | 18.5 ms |
| | | Delay before next measurement | | 200 µs |

**Fig. 17** Ultrasonic sensor time intervals of the emission and receiving ultrasonic waves (*Source* Parallax Ping(((datasheet)

## *4.3 Control and Planning Subsystem*

The control algorithm is implemented in this subsystem. The aim of this subsystem is to receive the signals from the Sensing Subsystem, processes them and sends the results of the control algorithm to the Moving Subsystem.

This subsystem is composed of a Digilent ChipKit Uno32 prototyping platform. A PIC32MX320F128 is the microcontroller which process the programs implemented in the prototyping platform. Figure 18 shows the prototyping platform.

The subsystems presented in this text are also projected to be used in the Emmy III robot in the future. For Emmy III robot, the control subsystem is going to determine a track for the robot. The Emmy III control system is based on Paraconsistent Neural Network.


**Fig. 18** Digilent ChipKit Uno32 prototyping platform

## 5 Tests of the Emmy II New Hardware Architecture

Aiming to verify the behavior of the new Emmy II hardware structure, many tests were performed. These tests consist of the observation of the robot behavior when there is an obstacle in front of the robot while it is moving forwards. So, it was possible to verify if the robot took the right decision.

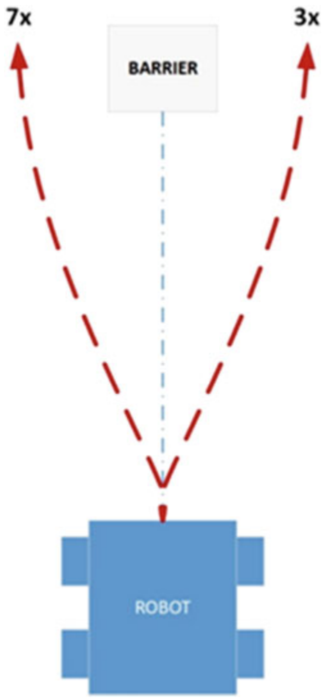



**Fig. 19** Representation of the first type of test performed by the robot

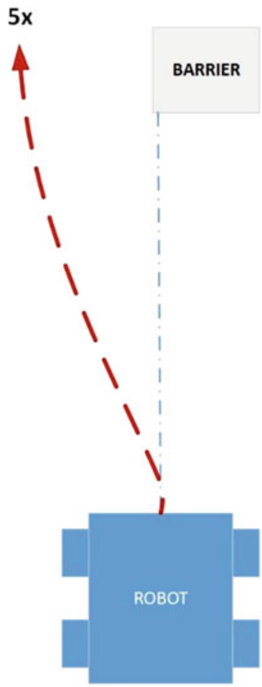



**Fig. 20** Representation of the second type of test performed by the robot

At first, it was put an obstacle exactly in front of the robot as showed in Fig. 19. In this case it was expected that the evidence degrees μ and λ were the same value (both equal to 0, 5). In a situation like that, the robot must turns left.

Anyway, in a real test condition, it is must difficult to reach a situation that μ is equal to λ. It was expected that there were a small difference between them. So, the robot should turn to the left or to the right as μ or λ were bigger. This experiment were repeated 10 times and in seven occasions the robot turned to the left and in three occasions the robot turned to the right

In the second type of test, there was an obstacle in the right side of the robot as showed in the Fig. 20. In a situation like that, it is expected that the robot turn to the left. Five tests were performed and in all cases, the robot turned to the left.

In the last type of test, an obstacle was put in the right side of the robot as showed in the Fig. 21. In five occasions, the robot turned to the left as expected.

## 6 Conclusions

This text presents a new hardware structure for the Emmy II robot. This new hardware architecture is an evolving of the robot proposed in 2004. The Emmy II control system is based on the Paraconsistent Annotated Evidential Logic Eτ.

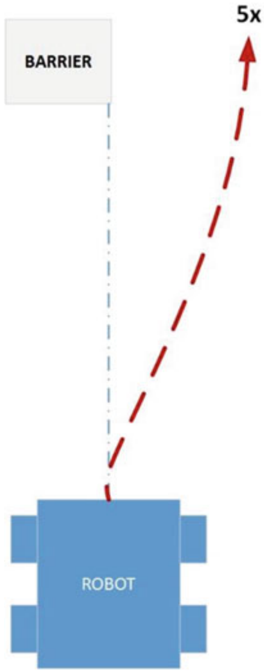



**Fig. 21** Representation of the third type of test performed by the robot

The proposed robot is divided into three subsystems: Control and Planning Subsystem, Sensing Subsystem and Moving Subsystem.

The Sensing Subsystem is responsible to capture information from the environment around the robot and sent them to the Control and Planning Subsystem. The Moving Subsystem is composed of DC motors and wheels. The objective of the Control and Planning Subsystem is to receive signals from the Sensing Subsystem, process them and control the Moving Subsystem.

The functioning of this new robot was satisfactory.

The structured proposed for this robot is going to be used in future projects, as the building of the Emmy III [14–19].

## References

1. Abe, J.M., Torres, C.R., Lambert-Torres, G., Nakamatsu, K., Kondo, M.: Intelligent paraconsistent logic controller and autonomous mobile robot Emmy II. Lect. Notes Comput. Sci. **4252**, 851–857 (2006)
2. Abe, J.M., Torres, C.R., Lambert-Torres, G., Nakamatsu, K., Kondo, M.: Intelligent paraconsistent logic controller and autonomous mobile robot Emmy II. In: Proceedings of the 10th International Conference on Knowledge-Based, Intelligent Information & Engineering Systems, KES2006. KES Pub., Bournemouth, UK (2006)

3. Torres, C.R., Lambert-Torres, G., da Silva, L.E.B., Abe, J.M.: Intelligent system of paraconsistent logic to control autonomous moving robots. In: Proceedings of the 32nd Annual Conference of the IEEE Industrial Electronics Society, IECON'06. IEEE Press, Paris (2006)
4. Torres, C.R.: Sistema inteligente baseado na lógica paraconsistente anotada Eτ para controle e navegação de robôs móveis autônomos em um ambiente não estruturado, in Portuguese. Ph.D. thesis, Federal University of Itajubá, Itajubá, MG, Brazil (2010)
5. Abe, J.M., Lambert-Torres, G., da Silva Filho, J.I., Torres, C.R., Martins, H.G.: Paraconsistent autonomous mobile robot Emmy III. In: Proceedings of the 6th Congress of Logic Applied to Technology—LAPTEC'2007, São Paulo, Brazil (2007)
6. Abe, J.M.: Fundamentos da lógica anotada, (Foundations of annotated logics), in Portuguese. Ph.D. thesis, University of São Paulo, São Paulo (1992)
7. Abe, J.M., da Silva Filho, J.I.: Manipulating conflicts and uncertainties in robotics. Multiple-Valued Logic and Soft Comput. **9**, 147–169 (2003). ISSN 1542–3980
8. da Silva Filho, J.I., Abe, J.M.: Para-control: an analyser circuit based on algorithm for treatment of inconsistencies. In: Proceedings of the World Multiconference on Systemics, Cybernetics and Informatics, ISAS, SCI 2001, vol. XVI, Cybernetics and Informatics: Concepts and Applications (Part I), pp. 199–203, Orlando, Florida, USA (2001). ISBN 9800775560
9. da Silva Filho, J.I., Abe, J.M.: Paraconsistent analyzer module. Int. J. Comput. Anticipatory Syst. **9**, 346–352 (2001). ISSN 1373-5411, ISBN 2-9600262-1-7
10. da Silva Filho, J.I., Abe, J.M.: Para-control: an analyser circuit based on algorithm for treatment of inconsistencies. In: Proceedings of the World Multiconference on Systemics, Cybernetics and Informatics, ISAS, SCI 2001, vol. XVI, Cybernetics and Informatics: Concepts and Applications (Part I), pp. 199–203, Orlando, Florida, USA (2001), ISBN 9800775560
11. da Silva Filho, J.I., Abe, J.M.: Paraconsistent analyzer module. Int. J. Comput. Anticipatory Syst. **9**, 346–352, (2001) ISSN 1373-5411, ISBN 2-9600262-1-7
12. da Silva Filho, J.I., Abe, J.M.: Emmy: a paraconsistent autonomous mobile robot. In: Laptec' 2001 The 2nd Congress of Logic Applied to Technology, São Paulo, Brazil. Logic, Artificial Inteligence and Robotics, vol. 1. pp. 53–61. IOS Press, Amsterdam, Holanda (2001)
13. da Silva Filho, J.I.: Métodos de Aplicações da Lógica Paraconsistente Anotada de Anotação com Dois Valores LPA2v com Construção de Algoritmo e Implementação de Circuitos Eletrônicos", in Portuguese. Ph.D. thesis, University of São Paulo, São Paulo (1999)
14. Torres, C.R., Abe, J.M., Lambert-Torres, G, da Silva Filho, J.I.: Autonomous mobile robot Emmy III. In: Gacovski, Z. (ed.) Mobile Robots—Current Trends (2011). ISBN: 978-953-307-716-1, InTech http://www.intechopen.com/articles/show/title/autonomous-mobile-robot-emmy-iii
15. Torres, C.R., Lambert-Torres, G., Abe, J.M., da Silva Filho, J.I.: The sensing system for the autonomous mobile robot Emmy III. In: Proceedings of 2011 IEEE International Conference On Fuzzy Systems, 2011, Taipei-Taiwan, pp. 2928–2933 (2011). http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=6007529
16. Torres, C.R., Lambert-Torres, G., da Silva Filho, J.I., Martins, H.G.: Results of a sensing system for an autonomous mobile robot based on the paraconsistent artificial neural network. Int. J. Reasoning Based Intell. Syst. **3**, 108–114 (2011)
17. Torres, C.R., Aplicações da Lógica Paraconsistente Anotada Evidencial Et em Robôs Móveis Autônomos In: Aspectos de Lógica e Teoria da Ciência.1 ed. São Paulo : Instituto de Estudos Avançados da Universidade de São Paulo, 2011, vol. 1, pp. 84−139. Referências adicionais: Brasil/Português. Meio de divulgação: Meio digital, ISBN: 9788563007025, http://www.iea.usp.br/textos/livroaspectosdelogica.pdf

18. Torres, C.R., Abe, J.M., Lambert-Torres, da Silva Filho, J.I., Martins, H.G.: A sensing system for an autonomous mobile robot based on the paraconsistent artificial neural network. Lect. Notes in Comput. Sci. Springer, Berlin, vol. 6278, pp. 154–163 (2010)
19. Torres, C.R., Abe, J.M.; Torres, G.L., da Silva Filho, J.I., Martins, H.G.: Autonomous mobile robot Emmy III. In: Nakamatsu, K., Phillips-Wren, G., Jain, L.C., Howlett, R.J. (Org.) New Advances in Intelligent Decision Technologies, vol. 199, 1st edn, pp. 317–327. Springer, Helderberg (2009)