Simulating Inconsistencies in a Paraconsistent Logic Controller

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Abstract

In this paper we present a simulator based on the paraconsistent annotated logic $E\tau$ (Para-Sim) that allows to deal with inconsistent or paracomplete signals in a non-trivial manner, besides dealing with fuzzy information. The simulator Para-Sim allows parameters to be modified by a paraconsistent analysis and conditions in order to obtain the optimization of the qualitative notions of real size, as distance between the robot and the obstacles, and also navigation speed.

Key words: non-classical logic and simulating, autonomous mobile robot, paraconsistent logic and applications, logic controller.

1 Introduction

The researches trying to find appropriate systems for control that qualifies robots with behavior that "imitates" the human being have been done in the last decades. However, when it is endowing robots with decision autonomous making, it several difficulties are faced. This is due to many factors where, the main is technological difficulty found in the construction of control systems. Usual control systems employed in robots are built with their basis mainly on classical logic or on its several extensions, which is inefficient in a countless number of situations that the robot faces in the real world. We will focus on some of these difficulties, namely, inconsistency[a] and paracompleteness[b].

When the robot is mobile and autonomous, the difficulties still imposed by the own structural nature that forces all the electro-electronic installation of the robot to be embarked, as well as its own sources of energy and its sensors. Our aim is to find means of projecting control systems that can react appropriately to the real situation, as the one of inconsistency, paracompleteness and fuzziness. The underlying logic considered in this work is a non-classic logic, namely, paraconsistent annotated logic $E\tau$, and it has shown efficiency in the treatment of signals that can be contradictory. Para-Sim simulates an analysis using paraconsistent logic in an autonomous mobile robot.

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[a] Intuitively, a value corresponding to a proposition and its negation both true at same time.
[b] Intuitively, a value corresponding to a proposition and its negation both false at same time.

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2 The control system based on $E\tau$

The atomic formulas of the paraconsistent annotated logic $E\tau$[c] is of the type $p_{(\mu,\ \lambda)}$, where $(\mu, \lambda) \in [0, 1]^2$ and [0, 1] is the real unitary interval (p denotes a propositional variable). There is an order relation defined on $[0, 1]^2$: $(\mu_1, \lambda_1) \leq (\mu_2, \lambda_2) \Leftrightarrow \mu_1 \leq \mu_2$ and $\lambda_1 \leq \lambda_2$. Such ordered system constitutes a lattice that will be symbolized by τ.
$p_{(\mu,\ \lambda)}$ can be intuitively read: "It is believed that p's belief degree (or favorable evidence) is μ and disbelief degree (or contrary evidence) is λ."
So, we have some interesting examples:

- $p_{(1.0,\ 0.0)}$ can be read as a true proposition.
- $p_{(0.0,\ 1.0)}$ can be read as a false proposition.
- $p_{(1.0,\ 1.0)}$ can be read as an inconsistent proposition.
- $p_{(0.0,0.0)}$ can be read as a paracomplete[d] (unknown) proposition.
- $p_{(0.5,\ 0.5)}$ can be read as an indefinite proposition.

The consideration of the values of the belief degree and of disbelief degree is made, for example, by specialists that use heuristics knowledge, probability [Dempster 68] or statistics [Duda, Hart, Konolid & Reboh 79].

There is a natural operator $\sim : |\tau| \rightarrow |\tau|$ defined in the lattice:
$\sim [(\mu, \lambda)] = (\lambda, \mu)$[e].

The lattice τ can be represented by the usual Cartesian system.

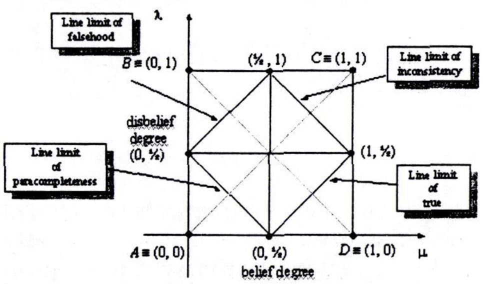

Fig. 1: Unitary square with new segments defining sub-regions.

We can consider several important segments:
Segment DB - segment perfectly defined: $\mu + \lambda - 1 = 0$
Segment AC - segment perfectly undefined: $\mu - \lambda = 0$
We define the following concepts:

- Contradiction degree: $G_{ct} = \mu + \lambda - 1$;
- Certainty degree: $G_c = \mu - \lambda$
- Inconsistency degree: $G_{ic} = \mu + \lambda - 1$ *if and only if* $(\mu + \lambda) \geq 1$
- Paracompleteness degree: $G_{id} = \mu + \lambda - 1$ *if and only if* $(\mu + \lambda) < 1$
- Truth degree: $G_t = \mu - \lambda$ *if and only if* $\mu \geq \lambda$;
- Falsity degree: $G_f = \mu - \lambda$ *if and only if* $\mu < \lambda$

[c] A detailed account is to be found in [Abe 92].
[d] The concept of paracompleteness is the "dual" of the concept of inconsistency.
[e] Such operator works as the "meaning" of the negation logic connective.

The certainty degree axes and the contradiction degree axes can be represented as in Figure 2.

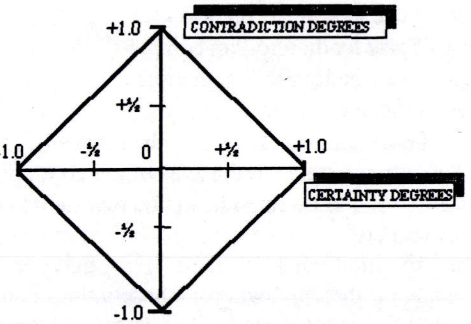

Fig. 2: Representation of the certainty degrees and of the contradiction degrees.

With these values in the lattice, some regions can be considered in the unitary square of the Cartesian plan that will define the *outputs resulting states*. These states can be described with the values of the certainty degree and contradiction degree. In this work we have chosen the resolution 12 (number of the regions considered according in the Figure 3), but the resolution is totally dependent on the precision of the analysis required in the output. Also, the resolution can be easily modified according to each application and precision required. In order to make easier the recognition of each region, each one received a denomination in agreement with its proximity with the extreme states of the lattice.

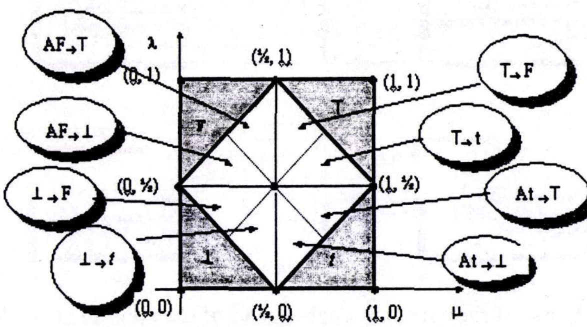

Fig. 3: Representation of the *extreme* and *non-extreme* states regions.

The extreme logical states (regions of the unitary square) with its corresponding symbols are:

T ⇒ Inconsistent

F ⇒ False

⊥ ⇒ Paracomplete

V ⇒ True

And the non-extreme logical states (regions of the unitary square):

$\perp_{\to} f$ ⇒ Paracomplete tending to False

$\perp_{\to} v$ ⇒ Paracomplete tending to True

$T_{\to} f$ ⇒ Inconsistent tending to False

$T_{\rightarrow} v \Rightarrow$ Inconsistent tending to True

$At_{\rightarrow} T \Rightarrow$ Almost - True tending to Inconsistent

$Af_{\rightarrow} T \Rightarrow$ Almost - False tending to Inconsistent

$Af_{\rightarrow} \perp \Rightarrow$ Almost - False tending to Paracomplete

$At_{\rightarrow} \perp \Rightarrow$ Almost - True tending to Paracomplete

The extreme states in the axes of the certainty values were defined by the true degree ≥ ½ to be considered "True". To be considered "False" the degree of falsehood is ≤ -½.

In the same way the extreme states in the axes of the contradiction values were defined by degree of the inconsistency ≥ ½ to be considered "Inconsistent" and Paracomplete degree ≤ -½ to be considered "Paracomplete".

As observed before, the limit values of the extreme and non-extreme states are project decision, therefore it depends on the applications. These values can be adjusted and they are denominated Control Values (in this work we have chosen ½), where:

- Max_{vcc} = maximum value of certainty control
- Max_{vctc} = maximum value of contradiction control
- Min_{vcc} = minimum value of certainty control
- Min_{vctc} = minimum value of contradiction control.

In this work, the lattice of the logic *Eτ* represented by the unitary square in the Cartesian plan was built with areas defined by values of control ½ and with resolution 12. The representation of this configuration is shown in the next figure.

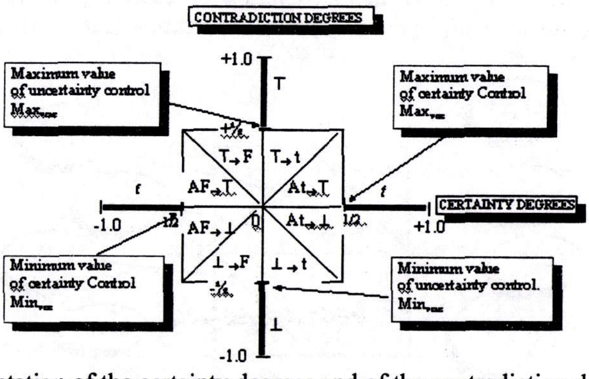

Fig. 4: Representation of the certainty degrees and of the contradiction degrees with the control values: $Max_{vcc} = Max_{vctc}$ = ½ and $Min_{vcc} = Min_{vctc}$ = -½.

With these considerations, we can introduce the "Para-analyzer".

3 Algorithm Para-Analyzer

*/ Definitions of the values */

$Max_{vcc} = C_1$ */ *maximum value of certainty Control*/*

$Max_{vctc} = C_2$ */ *maximum value of contradiction control */*

$Min_{vcc} = C_3$ */ *minimum value of certainty Control */*

$Min_{vctc} = C_4$ */ *minimum value of contradiction control*/*

*/ Input Variables */

μ

λ

*/ Output Variables */
digital output = S1
Analogical output = S2a
Analogical output = S2b
* / Mathematical expressions * /
being:
$0 \leq \mu \leq 1$ e $0 \leq \lambda \leq 1$
$G_{ct} = \mu + \lambda - 1$
$G_c = \mu - \lambda$
* / determination of the *extreme states* * /
if $G_c \geq C_1$ then $S_1 = t$
if $G_c \geq C_2$ then $S_1 = f$
if $G_{ct} \geq C_3$ then $S_1 = \top$
if $G_{ct} \leq C_4$ then $S_1 = \bot$
*/ determination of the *non-extreme states* * /
for $0 \leq G_c < C_1$ and $0 \leq G_{ct} < C_3$
if $G_c \geq G_{ct}$ then $S_1 = At_{\rightarrow}\top$
else $S_1 = \top_{\rightarrow} t$
for $0 \leq G_c < C_1$ and $C_4 < G_{ct} \leq 0$
if $G_c \geq | G_{ct} |$ then $S_1 = At_{\rightarrow}\bot$
else $S_1 = \bot_{\rightarrow} t$
for $C_2 < G_c \leq 0$ and $C_4 < G_{ct} \leq 0$
if $|G_c| \geq |G_{ct}|$ then $S_1 = AF_{\rightarrow}\bot$
else $S_1 = \bot_{\rightarrow} f$
for $C_2 < G_c \leq 0$ and $0 \leq G_{ct} < C_3$
If $|G_c| \geq G_{ct}$ then $S_1 = AF_{\rightarrow}\top$
else $S_1 = \top_{\rightarrow} f$
$G_{ct} = S_{2a}$
$G_c = S_2$
*/ *END* */

In this way, contradictory, paracomplete, and uncertainty information can be treated in a close way of the reality, through combinations of evidences.

The external adjusts permitted in the regions considered, make the applications of the "Para-analyzer" easier and more faithful when in the elaboration of control systems for Automation areas, Artificial Intelligence, and Robotics. The Para-analyzer also allows optimization and offers a good controllability of systems, including important situations of the real world. The visualization through the Hasse's diagram of the lattice, with the axes of values of certainty degrees and of the contradiction degrees, gives a more realistic vision of the situations through sensor information of the environment at any moment, portraying several situations in a more complete and faithful way. Therefore, the fundamental importance of the algorithm presented is to show that the Paraconsistent logic is applicable in real systems.

The algorithm Para-Analyzer of the software Simulator makes every analysis in a control system of the paraconsistent logic controller-Para-control. The values μ_1 and μ_2 are considered as inputs and by the equations of the definition of certainty and contradiction values we get the analogic values of D_c and D_{ic} besides a binary word composed by 12 digits. Each active digit corresponds to the resultant output logical state.

The robot control system working with coming signals of two sensors are more efficient to extract values expressing the physical reality.

3 The Paraconsistent Logical Simulator Paraconsistent: Para-Sim

The simulation through softwares is efficiently a powerful support tool for the Robotics. The great advantage of the simulation is that in the autonomous mobile robot the variables of the control process are difficult to be monitored. We can mention as an example: path, position and the robot's speed. The simulated robot can be activated as many times as needed no matter energy usage, physical damage, collision, etc.

In the peculiar case of a virtual robot's simulation that works based on the annotated paraconsistent logic it is extremely important that the variables and the adjustments of the lattice can be modified offering a more precise analysis of the consequences of these variations.

The Para-Sim it is a software simulator of the method of application of the paraconsistent annotated logic $E\tau$ in Robotics. The illustration below displays the main screen of the Para-Sim where we can find: the virtual robot with two sensors of ultrasonic sound waves, the obstacles in the environment of the robot's navigation and the right of the screen detaches the representative lattice of the logic $E\tau$. In the lattice associated to the logic $E\tau$, a sign X represents where the result of the computation of the certainty degrees D_c and of contradiction D_{ct} are placed. The signals are positioned as the equations of the paraconsistent analysis are shown previously.

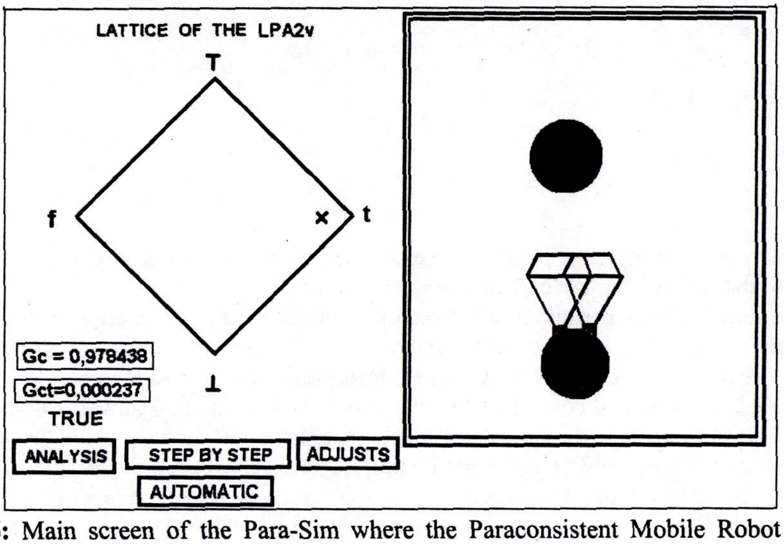

Fig. 6: Main screen of the Para-Sim where the Paraconsistent Mobile Robot moves in a virtual environment where a circular obstacle exists.

The Para-Sim allows tests to be made and also several virtual analyses of the optimization of the robot's behavior. That is why modifications are made in the adjustments of the algorithm and the consequences in the system of paraconsistent logical control are verified through the visualization of the robot's behavior. The adjustments that characterize the analysis and the possible modifications in the lattice of $E\tau$ can be visualized through a second screen, according to the next illustration.

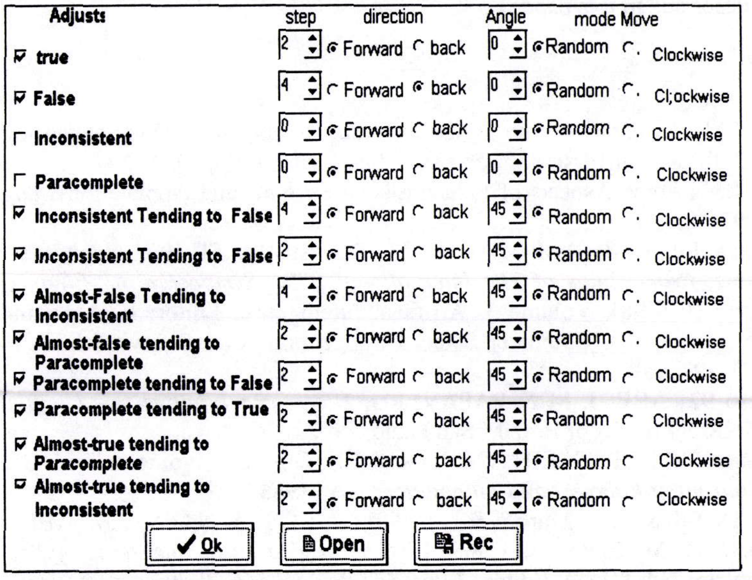

Fig. 7: Permission Screen for modification of adjustments and control characteristics.

4 Conclusion

Analysis of real situations can receive information that generate inconsistent signals bringing for the control contradiction situations that are unable to be conveniently treated for the Classic Logic. The application of the paraconsistent logic $E\tau$ in Robotics demonstrates that the analysis of signals of information on the environment using the algorithm Para-analyzer gives an efficient treatment to several problems caused by contradictory and paracomplete situations.

The Para-Sim Simulator, totally built based on the logic $E\tau$ comes as an efficient tool for analyses, tests and control optimization aiming applications in systems of control for Robotics. The possibility of modifications in the values of the adjustments of the lattice will give to the planner conditions of doing the Robot's behavior analyses in an environment not structured, of difficult obtaining in practice. These virtual simulations allow the results to be transferred for the reality and that the inconsistencies can be treated in a close way to the real conditions, through the consideration of evidences. The adjustments and modifications in the control, with observations of the Robot's behavior in the virtual environment, eases the optimization of the control system in practice.

The Simulator Para-Sim presented in this work is a significant progress in the analysis and researches of the logic $E\tau$ bringing new forms of giving appropriate treatment to signals of contradictory information.

Through the Para-Sim Simulator the applicability of the paraconsistent logics is demonstrated in real systems bringing for the area of the Robotics new forms of working with real situations of uncertainty.

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References

[Abe 92] ABE, J.M., *Fundamentos da lógica anotada*, (Foundations of annotated logics), in Portuguese, Ph.D. thesis, University of São Paulo, São Paulo, 135p, 1992.

[Abe 97] ABE, J.M., Some Aspects of Paraconsistent Systems and Applications, *Logique et Analyse*, 157(1997), 83-96.

[Abe & Da Silva Filho 98] ABE, J.M. & J.I. DA SILVA FILHO, Inconsistency and Electronic Circuits, *Proceedings of The International ICSC Symposium on Engineering of Intelligent Systems* (EIS'98), Volume 3, Artificial Intelligence, Editor: E. Alpaydin, ICSC Academic Press International Computer Science Conventions Canada/Switzerland, ISBN 3-906454-12-6, 191-197, 1998.

[Abe & Papavero 92] ABE, J. M & PAPAVERO, N., *Teoria Intuitiva dos Conjuntos*, (in Portuguese) MAKRON Books of Brazil - São Paulo, 1992.

[Borestein & Koren 88] BORESTEIN, J. & Y. KOREN, Obstacle Avoidance with Ultrasonic Sensors, IEEE *Journal of Robotics and Automation*, N.Y, 1988.

[Da Costa, Abe, Da Silva Filho, Murolo & Leite 99] DA COSTA, N.C.A., J.M. ABE, J.I. DA SILVA FILHO, A.C. MUROLO & C.F.S. LEITE, *Lógica Paraconsistente Aplicada*, (in Portuguese) ISBN 85-224-2218-4, Editôra Atlas, São Paulo, 214p, 1999.

[Da Costa, Abe & Subrahmanian 91] DA COSTA, N.C.A., J.M. ABE & V.S. SUBRAHMANIAN, Remarks on Annotated Logic, *Zeitschrift fur Mathematische Logik und Grundlagen der Mathematik*, Vol.37, pp.561-570, 1991.

[Da Silva Filho 97] DA SILVA FILHO, J.I., Implementação de circuitos Lógicos fundamentados em uma classe de Lógicas Paraconsistentes Anotada, in Portuguese, Master Thesis, University of São Paulo, São Paulo, 1997.

[Da Silva Filho 99] 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.

[Da Silva Filho & Abe 99] DA SILVA FILHO, J.I. & J.M. ABE, Para-Analyser and Inconsistencies in Control Systems, Proceedings of the IASTED *International Conference on Artificial Intelligence and Soft Computing* (ASC'99), August 9-12, Honolulu, Hawaii, USA, 78-85, 1999.

[Da Silva Filho & Abe 01a] DA SILVA FILHO, J.I. & J.M. ABE, Paraconsistent analyser module, *International Journal of Computing Anticipatory Systems*, vol. 9, 346-352, 2001.

[Da Silva Filho & Abe 01b] DA SILVA FILHO, J.I. & J.M. ABE, Para-Control: An Analyser Circuit Based On Algorithm For Treatment of Inconsistencies, Proc. of the *World Multiconference on Systemics, Cybernetics and Informatics*, ISAS, SCI 2001, Vol. XVI, Cybernetics and Informatics: Concepts and Applications (Part I), ISBN 980-07-7556-0, 199-203, Orlando, Florida, USA, 2001.

[Da Silva Filho & Abe 01c] DA SILVA FILHO, J.I. & J.M. ABE, *Fundamentos das Redes Neurais Paraconsistentes* – Destacando Aplicações em Neurocomputação, Editôra Arte & Ciência, ISBN 85-7473-045-9, 247 págs., 2001.

[Da Silva Filho & Abe 01d] DA SILVA FILHO, J.I. & J.M. ABE, Emmy: a paraconsistent autonomous mobile robot, in Logic, Artificial Intelligence, and Robotics, Proc. 2nd *Congress of Logic Applied to Technology* – LAPTEC'2001, Edts. J.M. Abe & J.I. Da Silva Filho, Frontiers in Artificial Intelligence and Its Applications, IOS Press, Amsterdan, Ohmsha, Tokyo, Editores, Vol. 71, ISBN 1 58603 206 2 (IOS Press), 4 274 90476 8 C3000 (Ohmsha), ISSN 0922-6389, 53-61, 2001.

[Dempster 68] DEMPSTER, A.P, Generalization of Bayesian inference, Journal of the Royal Statistical Society, Séries B-30, 205-247, 1968.

[Duda, Hart, Konolid & Reboh 79] DUDA, R.O., P.E. HART, K. KONOLID, & R. REBOH, A computer-based Consultant for Mineral Exploration, TR, SRI International, 1979.

[Elfes 87] ELFES, A., Sonar based real-world mapping and navegation, IEEE *Journal of Robotcs and automation*, N.Y, 1987.

KHEPERA - User's manual K-Team - Microinformatique Laboratorie, Lausane, 1994.

[McKerrow 92] McKERROW, P., *Introduction to Robotcs*, Addison-Wesley Publishing Company, New York, 1992.

[Sylvan & Abe 96] SYLVAN, R. & J.M. ABE, On general annotated logics, with an introduction to full accounting logics, *Bulletin of Symbolic Logic*, 2, 118-119, 1996.