Unisanta Science and Technology, 2017, 18, December
Published Online 2017 Vol.6 N°2 http://periodicos.unisanta.br/index.php/sat)

UNISANTA
Science and Technology
ISSN 2317-1316

The Paraconsistent Annotated Logic with annotation of two values (PAL2v) in the context of the Industry 4.0 - An Approach for the Cyber-Physical Systems (CPS)

Mauricio Fontoura Blos, Hyghor Miranda Cortes e João Inácio da Silva Filho

Unisanta – Universidade Santa Cecília –Programa de Mestrado em Engenharia Mecânica -PPGEMec Laboratory of Applied Paraconsistent Logic, Santa Cecília University, Santos-SP, Brazil.

E-mail: mauricioblos@unisanta.br
Received November, *2016*

Abstract: Regarding the global productive systems such as manufacturing industry (automotive, electronics, etc), they always have problems of contradictory ∕ inconsistent data information on their control systems. Even in service sector such as health care (eg. devices for health control), always there exist contradictory ∕ inconsistent data information to be considered for decision making. Therefore, in the context of the Industry 4.0, the contradictory ∕ inconsistent data information problem, certainly, happen into the Cyber-Physical Systems (CPSs). Inserted into the group of Non-Classical Logics, the Paraconsistent Annotated Logic with annotation of two values (PAL2v) presents conditions to compute contradictory signals without the conflict of information that invalidates the conclusions. Thus, this paper proposes a PAL2v to solve the contradictory ∕ inconsistent data information problem in the context of the Industry 4.0 as a decision learning approach for the CPSs. The findings of the two examples demonstrated that the experiments are really promising and the developed control systems based on PAL2v are suitable for the Industry 4.0 environment.

Key words: Paraconsistent Logic Controller, Paraconsistent Logic with annotation of two values (PAL2v), Industry 4.0, Cyber-Physical Systems (CPS).

A Lógica Paraconsistente com anotação de dois valores (LPA2v) no contexto da Indústria 4.0 – Uma aplicação aos Sistemas Ciber-Físicos (SCFs)

Resumo: Em relação ao sistema global de produção, tal qual as industrias de manufatura (automotiva, eletrônica, etc), sempre existiram problemas de contradições ∕ inconsistências nas informações de dados nos sistemas de controle. Até mesmo nos setor de serviços, tal qual sistemas de saúde (eg. equipamentos de controle de saúde), sempre existiram contradições ∕ inconsistências nas informações de dados a serem considerados na hora de tomadas de decisão. Portanto, no contexto da Indústria 4.0, essa contradição ∕ inconsistência de informação de dados, certamente acontece nos Sistemas Ciber-físicos (SCFs). Inserida no grupo de lógica não-clássica, a lógica paraconsistente com anotação de dois valores (LPA2v) apresenta condições para computar sinais de contradições sem ter conflitos de informação que invalidem a conclusão. Desta forma, este artigo propõe usar a LPA2v na resolução de problemas de contradições ∕ inconsistências de informação de dados no contexto da Indústria 4.0 como uma aplicação para os SCFs. Com base na aplicação de dois exemplos, foi demonstrado que os experimentos com essa aplicação é realmente promissora, o qual os sistemas de controle com base na LPA2v é favorável ao ambiente da Indústria 4.0.

Palavras chave: Controlador Paraconsistente, Lógica Paraconsistente com anotação de dois valores (LPA2v), Indústria 4.0, Sistemas Ciber-Físicos (SCF).

1. Introduction

The contradictory ⁄ inconsistent data information also called "noise", produced by the electronic devices (eg. error on transmited signals) represent a great problem for the industries. As we know, a noise can be generated in many ways and it can affect electronic and radio frequency, RF circuits and systems. A noise by its very definition is random. It extends in various forms across the frequency spectrum, although not always in the same amplitude.

In this scenario, is born the fourth industrial revolution, which is marking its presence. The also called Industry 4.0 is in its initial steps and just in some countries (Germany, USA, Japan, etc), it is in a great pace. There are many research papers being published abouth Cyber-Physical Systems (CPS) on the context of Industry 4.0. Most of the research papers are related to manufacturing process, control in process and architecture [1-13]. However, there isn't any research paper about a *controller to deal with noises on the context of Industry 4.0*. Therefore, this paper proposes a Paraconsistent Annotated Logic with annotation of two values (PAL2v) to deal with the noise (contradictory ⁄ inconsistent data information) problem for the CPSs in the context of the Industry 4.0. On section 2, it is showed the literature review on the PAL2v and the Industry 4.0 and the Cyber-Physical Systems (CPS). Section 3 demonstrates the problem statement. Section 4 shows possible problem solutions through some examples of controllers using PAL2v to the CPSs. Finally, section 5 concludes this work.

2. Literature Review

In this section, a literature review, by considering the PAL2v and the Industry 4.0 with the Cyber-Physical Systems (CPS) is done.

2.1 The PAL2v.

Inserted into the Group of non-classical Logics, the LPA2v is a special type of Paraconsistent Annotated Logic which presents conditions of compute contradictory signals without the conflict of information invalidates the conclusions. According to [14][15] it is possible to obtain a representation on how accurate the annotations (or the evidences) are on a proposition P using a lattice formed by ordained pairs, such as: $\tau = \{(\mu, \lambda)|\mu, \lambda \in [0, 1] \subset \Re\}$. In this case, an operator ~ is introduced: $|\tau| \rightarrow |\tau|$.

The operator ~ constitutes the "meaning" of the logical symbol of negation $\neg$ of the system to be considered [15]. This way, a four-vertex lattice associated with the Annotated Paraconsistent Logic with annotation of two values (PAL2v).The first element (μ) in the ordained pair (μ, λ) is the degree in which the favorable evidences support the proposition P, and the second element (λ) represents the degree in which the unfavorable evidences, or contrary, deny or reject the proposition P. Thus, the intuitive Idea of the association of an annotation (μ, λ) to a P proposition means that the degree of favorable evidence in P is μ, and the degree of unfavorable (or contrary) evidence is λ. In an intuitive manner [15], in such Lattice we have the annotations:

(1, 0) → indicating existence of *total favorable evidence and unfavorable zero evidence*, attaching a true logical connotation to proposition P.

(0, 1) → indicating existence of *zero favorable evidence and total unfavorable evidence*, attaching a connotation of falsity logical to proposition P.

(1, 1) → indicating existence of *total favorable evidence and total unfavorable evidence*, attaching an inconsistency connotation logical to proposition P.

(0, 0) → indicating existence of *zero favorable evidence and unfavorable zero evidence*, attaching an indeterminate logical connotation to proposition P.

The formula ($\neg A$) is read "the negation or weak negation of A"; ($A \wedge B$), "the conjunction of A and B"; ($A \vee B$), "disjunction of A and B"; ($A \rightarrow B$), "the implication of B by A".

Based on Figure 1, the annotations above are represented as follow:

$P(\mu, \lambda)$: T = **Inconsistent** ➔ $P(1, 1)$,
F = **False** ➔ $P(0, 1)$,
t = **True** ➔ $P(1, 0)$,
$\perp$ = **Indeterminate** ➔ $P(0, 0)$.

According to [16-18], the PAL language, the semantics of a complete set of connectives and axioms are described with details.

With the values considered in an *unitary quadrant of the Cartesian plane* (UQCP) it is possible to find linear transformations to a Lattice k of analog values to the Lattice associated to the PAL2v [19-21]. Therefore, the linear transformation is represented by the equation:

$$T\,(X,Y) = (x - y\,,\, x + y - 1) \tag{1}$$

In UQCP the values of Favorable Evidence Degree μ are exposed in the axis x, and the values of Unfavorable Evidence Degree λ in the axis y. From the first term (X) from the equation of the final transformation, we have: $X = x – y = \mu – \lambda$, which is denominated of Certainty Degree (D_C). Therefore, the Certainty Degree of the PAL2v analysis is obtained:

$$D_C = \mu – \lambda \tag{2}$$

Its values, which belong to the set $\Re$, vary in the closed interval +1 and –1, and are in the horizontal axis of the Lattice, called "degrees of certainty axis".

From the second term (Y) of the final transformation, there is: $Y = x+y-1 = \mu+\lambda-1$, which is denominated Contradiction Degree (Dct). Therefore, the Contradiction Degree of the PAL2v analysis is obtained by:

$$Dct = (\mu + \lambda) - 1 \tag{3}$$

Its values, which belong to the set $\Re$, vary in the closed interval +1 and –1, and are in the vertical axis of the diagram, called "degrees of contradiction axis" [22].

The results of the linear transformation in Eq. (1) indicate that, in the notation of PAL2v [14], Eqs. (2) and (3) are functions of μ and λ that may represent a paraconsistent logical state ετ. Therefore:

$$\varepsilon_{\tau(\mu,\lambda)} = (\mu - \lambda, \mu + \lambda - 1) \tag{4}$$

or

$$\varepsilon_{\tau(\mu,\lambda)} = (D_C, Dct) \tag{5}$$

Where ετ is a paraconsistent logical state.

D_C = degree of certainty, computed as a function of two degrees of evidence; μ and λ.

Dct = degree of contradiction, computed as a function of two degrees of evidence; μ and λ [15, 18].

From previous detailed study [15, 16, 23], we can define a *real certainty degree* (D_{CR}) as a D_C value without the effects of contradiction.

As seen in figure 1, the D_{CR} value is on the axis of the degree of certainty on the PAL lattice and is calculated as follows:

If $D_C > 0$.

$$D_{CR} = 1 - \sqrt{(1-|Dc|)^2 + D_{ct}^2} \tag{6}$$

If $D_C < 0$

$$D_{CR} = \sqrt{(1-|Dc|)^2 + D_{ct}^2} - 1 \tag{7}$$

Where D_C = f(μ, λ) and Dct = f(μ, λ) from Eqs. (2) and (3). From D_{CR} it can be find its normalized value, called the resulting evidence degree (μER) [15, 18, 24]. Therefore:

$$\mu_{ER} = \frac{DCR+1}{2} \tag{8}$$

2.2 A glimpse on the Industry 4.0 and the Cyber-Physical Systems (CPS)

According to the *Final Report of the Industrie 4.0 Working Group* in Germany, developed by [26], the current moment of the technological evolution can be described as the fourth stage of industrialization. The first industrialization began with the introduction of mechanical manufacturing equipment at the end of the 18th century. The second industrialization began around the turn of the 20th century and involved electrically-powered mass production of goods based on the division of labour. The third industrial revolution started during the early 1970s and has continued right up to the present day around the world (Fig.2). Based on some industrial initiatives, we can find the face of the Industry 4.0 well represented and slowly it is being developed around the world. According to [27], the Industry 4.0 is the term that originated in the area of manufacturing engineering and represents the fourth industrial revolution: the ability of industrial components to communicate with each other.

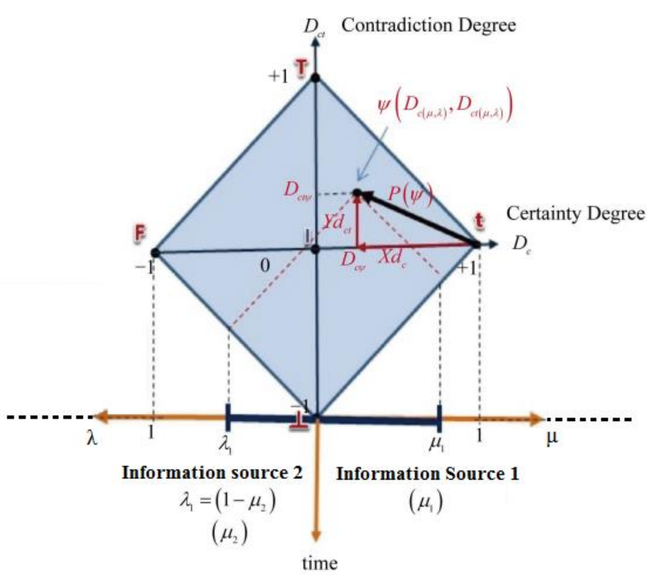


Fig. 1. Determination of the real certainty degree (*D*CR), Resulting value in the lattice of PAL2v. (Adapted from [24])

The industry 4.0 is a term introduced by Siemens and refers to the integration of interconnected systems into the industry and is known as the fourth industrial revolution. Furthermore, the industrial sector has undertaken the new paradigm shift from the traditional manufacturing information system to the contemporary cyber physical system (CPS). From the financial point of view, it is estimated that German gross value can be boosted by a cumulative 267 billion euros by 2025 after introducing Industry 4.0 [28]. A brief comparison between current and Industry 4.0 factories is presented in Table 1.

Industry 4.0 is the triad of physical objects, their virtual interpretation and services, and applications on top of those. In implementing Industry 4.0, the aim is to create an optimal overall package by leveraging existing technological and economic potential through a systematic innovation process drawing on the skills, performance and know-how of the applied workforce. Industry 4.0 focus on the following overarching aspects: Horizontal integration through value networks, End-to-end digital integration of engineering across the entire value chain, Vertical integration and networked manufacturing systems. By considering the Industry 4.0, the manufacturing location decision will be decided in partnership, where there is a coordinator (responsible for general manufacturing decisions) and many local parnerners (responsible for local manufacturing decisions). Furthermore, the design principles, conceived to develop production processes aligned with the Industry 4.0 vision [29] are: interoperability, virtualization, decentralization, real-time capability, service orientation and modularity.

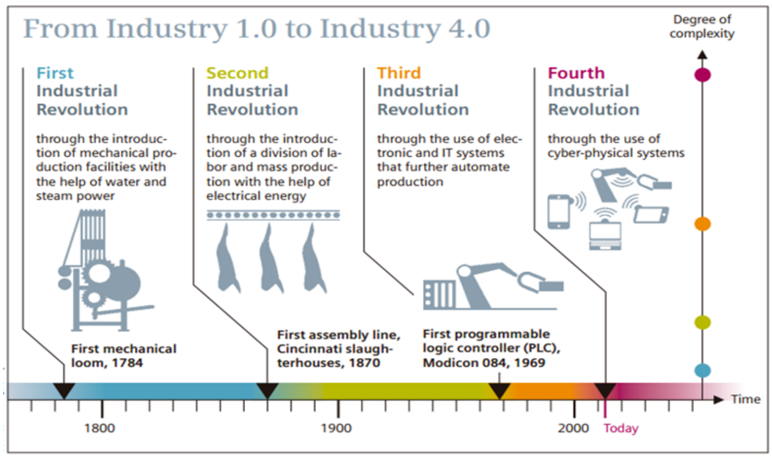


Fig. 2. The Four Stages of the Industrial Revolution.
Source: [29].

Table 1 – Comparison of today's factory and an Industry 4.0 factory (Source: [13])

Data Source		Today's Factory		Industry 4.0	
		Attributes	Technologies	Attributes	Technologies
Component	Sensor	Precision	Smart Sensors and Fault Detection	Self-aware Self-predict	Degradation monitoring & remaining useful life prediction
Machine	Controller	Producibility & Performance	Condition-based Monitoring & Diagnostics	Self-aware Self-predict Self-compare	Up time with predictive health Monitoring
Production System	Networked System	Productivity & OEE	Lean Operations: Work and Wast Reduction	Self-configure Self-maintain Self-organize	Worry-free productivity

 Unisanta Science and Technology (69-79) p.p. ISSN 2317-1316

According to [30~34] a CPS is a system featuring a tight combination of, and coordination between cyber (computing and networking) and physical (mechanical, electrical, and chemical processes) elements by communication networks, which provide us the following technologies and environment:

1) Enabling Technologies:

CPS provides the enabling technologies such as sensing technologies, RFID technologies, communication technologies and embedded intelligent control systems, which are deployed in manufacturing resources (e.g., manufacturing devices, WIP, manufacturing materials) and compose the layer of CPS infrastructure. Furthermore, CPS systems are the foundation of a wide vision of the future: Self driving cars communicating with their surroundings, ambient assisted living for senior citizens who get automated assistance in case of medical emergencies and electricity generation and storage oriented at real time demand are just a few examples of application. By sensing technologies (e.g., pressure sensors, velocity sensors), the real-time physical states of manufacturing sources can be sensed in running time. By RFID tags and RFID readers, real-time, accurate and automatic information acquisition in manufacturing process can be realized.

The communication technologies (e.g., networks, Internet of things) enable the access of the physical entities and the embedded intelligent control systems pave the way for feedback-based, closed-loop control of manufacturing resources.

2) CPS environment:

The sensing model refers to the overall image of the running time physical states of a manufacturing resource, which can be formally defined as follows:

$$R(m) = \{\langle \text{attribute}, \text{state} \rangle | \text{attibute} \in A_m\} \qquad (9)$$

R(m) denotes the overall image of a manufacturing resource *m*; Vector *Am* denotes the universal attribute set of *m*; *state* denotes the description or real-time measurable value of an *attribute*.

The cognitive model reflects the instantaneous service performance of a component MRS, which can be defined as follows:

$$Q^P(S) = f^P(A_m^P) \qquad (10)$$

$Q^p(s)$ denotes a quantitative expression of a performance index *p* of the component MRS *s* that is provided by a manufacturing resource *m*; Vector *Apm* denotes the *p* related subset of the universal attribute set of *m*. f^p denotes the relationship between attribute set *Apm* and performance índex *p*, which can be determined in the context of practical applications. By means of the CPS infrastructure, the sensing model and cognitive model are enabled to bridge the control and physical processes.

According to [8], the physical platforms which support CPS offer five capabilities: computation, communication, precise control, remote collaborative and autonomous capabilities. Fig. 3 shows the three essential concepts in CPS, that is, computation, communication and control.

Examples of CPS include medical devices and systems, aerospace systems, transportation vehicles and intelligent highways, defense systems, robotic systems, process control, factory automation, building and environmental control and smart spaces.

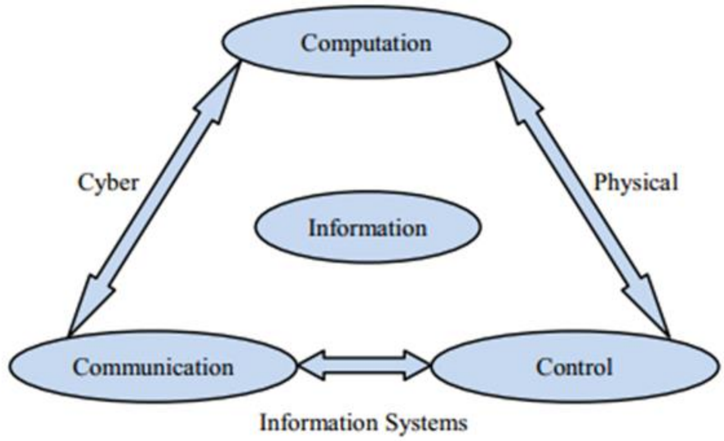


Fig.3. Concepts in CPS (Source: [8])

3. A Problem Description

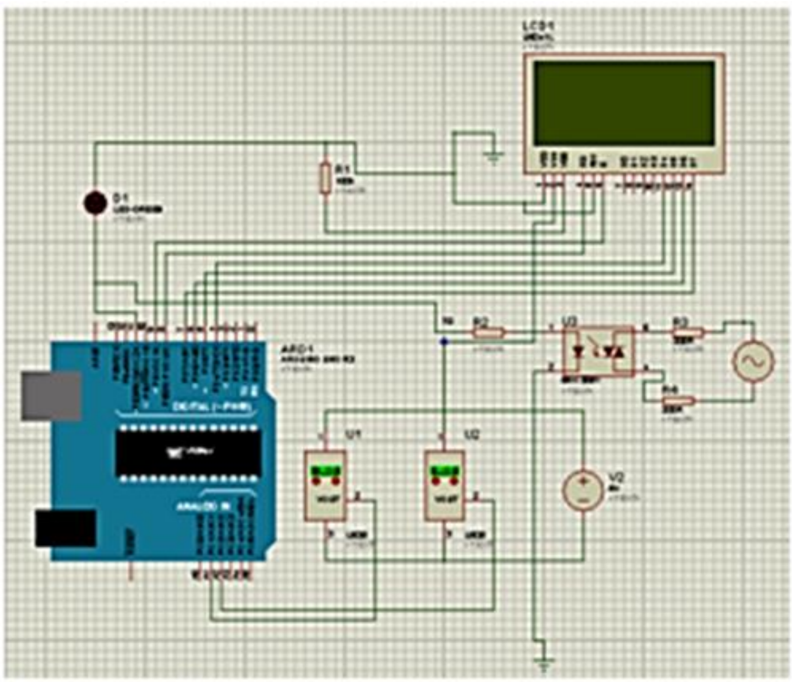
According to [35], it will be needed some capabilities for the CPSs to achieve the concepts of Industry 4.0. Those capabilities are: self-awareness, self-prediction, self-comparison, self-reconfiguration and self-maintenance. Furthermore, a CPS asks for accurate and reliable control, which requires applying software methodologies to be extremely precise. In contrast to traditional embedded systems, CPS interface directly with physical world. The precision of computing must interface with the uncertainty and the noise (contradictory ⁄ inconsistent data information) in the physical environment. In this scenario, this paper proposes a PAL2v as a possible solution for the noise in the physical environment as a decision learning approach. For more details, see the PAL2v application examples on the next section.

4. Possible Problem Solution

The problem solutions suggested in this chapter uses PAL2v as a base to the controllers to improve the CPS in the context of Industry 4.0. Thus, it was developed the $\text{ConTemp}_{\text{LAP2v}}$ and the Digital Para-*Fuzzy* PID. Furthermore, the findings from these two controllers demonstrate that the experiments are really promising.

4.1 The $\text{ConTemp}_{\text{LAP2v}}$

[36] created a Paraconsistent Logical Controller, or the $\text{ConTemp}_{\text{LAP2v}}$ (Fig.4.), to control the contradictory ⁄ inconsistent data information on a temperature controller. In order to simulate the PAL2v application to an electronic device, it was used an Arduino board based on an Ante microcontroller ATM8.



~

Fig.4. The $\text{ConTemp}_{\text{LAP2v}}$ Diagram (Source: [36]).

The ConTemp$_{LAP2v}$ controls the environment temperature as a thermometer. The *set point* of the temperature control is represented by λ (unfavorable degree of evidence). The process variable has its temperature measure value represented by μ (favorable degree of evidence). The Paraconsistent Logic States are identified according to each control actions. The intersection of the values λ and μ in the UQCP results in a Paraconsistent logic state, respectively. Each Paraconsistent Logic State corresponds to an Output Control Action through a Potency Percentage. And this value is applicable in form of signal PWM (Pulse Width Modularity) to a module RSS (Relay State Solid), which delivers the potency necessary to the process. The ConTemp$_{LAP2v}$ was used to control a small furnace, where it established a temperature *set point* of 70^{o}C and it was measured the sample values during a certain time. The same process was repeated to a commercial controller (GEFRAN model 1000) programmed to operate on ON / OFF and PID. By analyzing the curves demonstrated on the graphics of the Fig.5, the ConTemp$_{LAP2v}$ presented a better result.

4.2 Digital Para-*Fuzzy* PID

As part of the contribution to the Laboratory of Applied Paraconsistent Logic (LabAPL) at Santa Cecília University, it was created by the Master's degree student Mr. Hyghor M. Côrtes the Para-*Fuzzy* PID [37], which is based on the treatment of inconsistencies both in the Paraconsistent Logic and in the Fuzzy Logic. Initially the Para-*Fuzzy* PID controller was built and tested in an isolated Matlab environment and then compared to the equivalent Fuzzy PID function of this software for standard excitations such as step.

After this step, a level control plant was modeled to execute the controller function on a physical model, making the tests closer to the actual ones. For this, the control parameters (proportional, integral and derivative) were calculated for the configuration of the fuzzy controller conventional and of the PID Digital Paraconsistent-Fuzzy, and the control meshes in Matlab were assembled with the respective transfer function of the plant.

Finally, the results of the comparison of the level process control between the Digital Paraconsistent-Fuzzy PID controller and the conventional Fuzzy PID controller were presented. Furthermore, a block with "Para-*Fuzzy*" algorithm is used in order to act on the error in the input of the proportional, derivative and integral arguments as shown in figure 6.

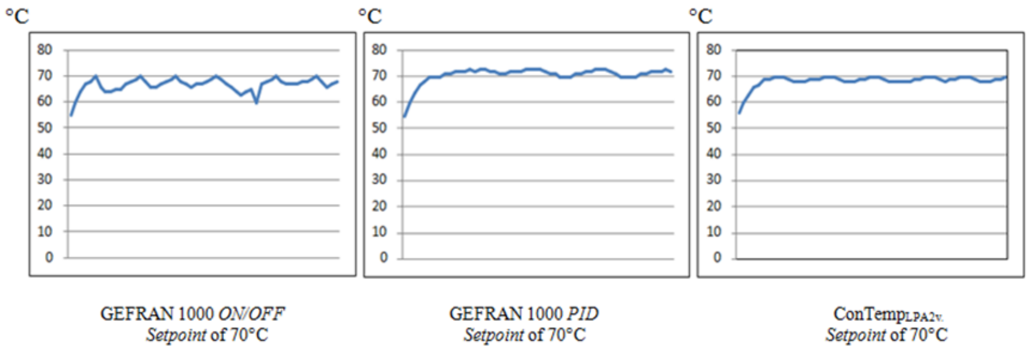


Fig. 5. Behavior of the Controllers: GEFRAN 1000 and the ConTemp$_{LAP2v.}$ (Source: [36]).

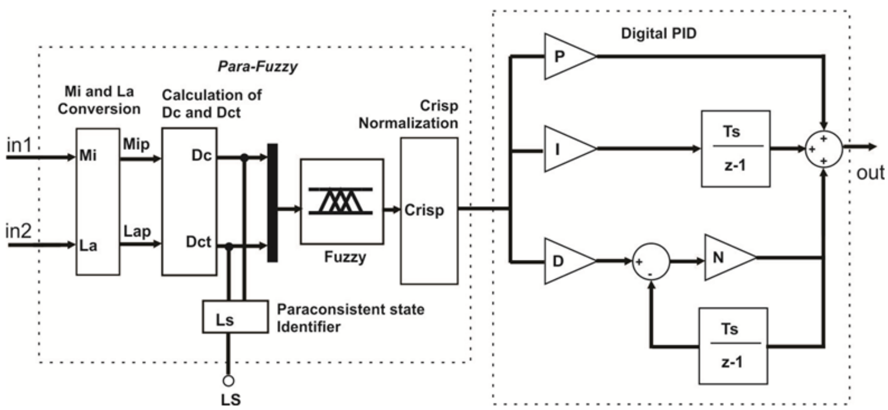


Fig. 6 Digital-to-*Fuzzy* PID block diagram with 220 state lattice.

 Unisanta Science and Technology (69-79) p.p. ISSN 2317-1316

In the Para-*Fuzzy* subsystem we have the “***μ and λ converter block***” that uses a 1st degree function to transform the set point values and process variable in the range of 0 to 1. The “***calculation block D_{ct} and D_{ct}***” that through μ and λ extracts the degrees of Certainty D_c and Contradiction D_{ct}, the “***block logical state identifier***" that through G_c and G_{ct} computes the paraconsistent logical state in the range 1 and 220. The “***fuzzy block***” that generates the *crisp value* from -1 to + 1 according to the logic state of the lattice and the “***crisp value normalization block***” that uses a 1st degree function to return the value to the real environment.

The next figure (Fig.7) shows the comparisons of the conventional digital PID controller with the Digital Para-*fuzzy* PID in response to the unit step for ***P=12, I=4 e D=1.5***.

In figure 7, for (1) we have the unitary step; For (2) we have the response oftheconventional Digital PID and for (3) we have the response ofthe Digital PID to Fuzzy.

It was observed that for the simulation of 2 seconds in response to the unitary step with proportional gains of 12, integral of 4 and derivative of 1.56, there was a difference of 6 between the pulses of the derivative being controller 1 (Digital PID) in $\boldsymbol{pd_{cc}}$= 162 and the controller 2 (PID Digital Paraconsistent-Fuzzy) at $\boldsymbol{pd_{cpf}}$ = 156. In theend of integration showed a difference of 0.06 being controller 1 in $\boldsymbol{id_{cc}}$= 17.4 andthe controller 2 at $\boldsymbol{id_{cpf}} = 17.35$.

4.2.1 Example Application

Consider the process composed of 2 tanks according to figure 8. The volumetric flow rate in the tank1 isq_{in} (cm^3/min). The volumetric flow rate of the tank1 for the tank 2 is $q_1(cm^3/min)$, and the volumetric flow rate of the tank 2 is $q_0(cm^3/min)$. The height of the liquid level is $h_1(cm)$ in the tank 1 is h_2 in the tank 2 (cm). Both tanks have the same cross-sectional area, tank area 1 is A_1 (cm^2) and the area of the tank 2 is A_2 (cm^2).

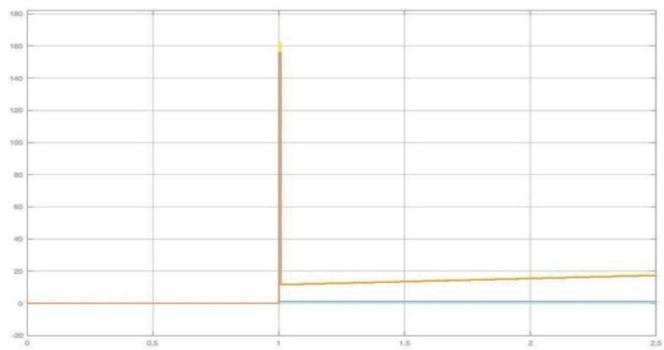


Fig. 7 Digital PID comparison with Digital to-Fuzzy PID in response to the unit step.

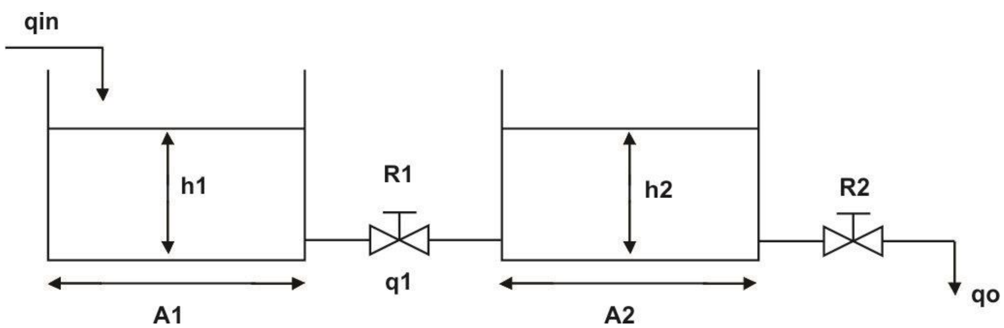


Fig.8 The block diagram of the two connected liquid tanks.

For tank 1:

$$A_1 \frac{dh_1}{dt} = q_{in} - q_1 \qquad (1)$$

Assuming a linear variation of the flow we have:

$$q_1 = \frac{h_1 - h_2}{R_1} \qquad (2)$$

So,

$$A_1 \frac{dh_1}{dt} = q_{in} - \frac{h_1 - h_2}{R_1} \qquad (3)$$

$$R_1 A_1 \frac{dh_1}{dt} = R_1 q_{in} - h_1 + h_2 \qquad (4)$$

Applying Laplace on both sides of eq. (4) there is provided:

$$R_1 A_1 S h_1(s) + h_1(s) - h_2(s) = R_1 q_{in}(s) \qquad (5)$$

$$h_1(s)(R_1 A_1 S + 1) - h_2(s) = R_1 q_{in}(s) \qquad (6)$$

For tank 2:

$$A_2 \frac{dh_2}{dt} = q_1 - q_0 \qquad (7)$$

Assuming a linear variation of the flow, we have:

$$q_0 = \frac{h_2}{R_2} \qquad (8)$$

So,

$$A_2 \frac{dh_2}{dt} = \frac{h_1 - h_2}{R_1} - \frac{h_2}{R_2} \qquad (9)$$

$$R_2 A_2 \frac{dh_2}{dt} + h_2 + \frac{R_2}{R_1} h_2 = \frac{R_2}{R_1} h_1 \qquad (10)$$

Applying Laplace on both sides of eq. (10) we have:

$$R_2 A_2 S h_2(s) + h_2(s) - \frac{R_2}{R_1} h_2(s) = \frac{R_2}{R_1} h_1(s) \qquad (11)$$

$$h_2(s)\left(R_2 A_2 S + \frac{R_2}{R_1} + 1\right) = \frac{R_2}{R_1} h_1(s) \qquad (12)$$

To obtain $h_2(s)/q_{in}(s)$, we have to cancel $h_1(s)$ in equations (5) e (12)

therefore:

$$\frac{h_2(s)}{q_{in}(s)} = \frac{R_2}{A_1 R_1 A_2 R_2 s^2 + s(A_1 R_1 + R_2 A_1 + A_2 R_2) + 1} \qquad (13)$$

Using the values shown in Table II, We find the following transfer function from eq. (14) [38]).

$$\frac{h_s(s)}{q_{in}(s)} = \frac{0.01}{6.25\, s^2 + 7.5s + 1} \qquad (14)$$

We used a PID controller calculated by the tunning method according to [38]. With this guideline the following parameters are reached: proportional in 12, integral in 4 and derivative in 12. The Figure 9 shows the diagram of blocks made in *Matlab* for control of the level plant, with the performance of the conventional Digital PID controller and the Digital PID Para-*Fuzzy* for comparison of the answers. For controller 1 (Digital PID) we had: $\boldsymbol{ts_{cc}}$ (rise time) at 40,36s, $\boldsymbol{ta_{cc}}$ (accommodation time) at 62,1s e $\boldsymbol{erro\_of_{cc}}$ (off-seterror) at 0,05. For controller 2 (PID Digital Para-*Fuzzy*) we had: $\boldsymbol{ts}$ (rise time) at 40,8s, $\boldsymbol{ta_{cpf}}$ (accommodation time) at 61,5s and $\boldsymbol{erro\_of_{cpf}}$(off-seterror) at 0,00.

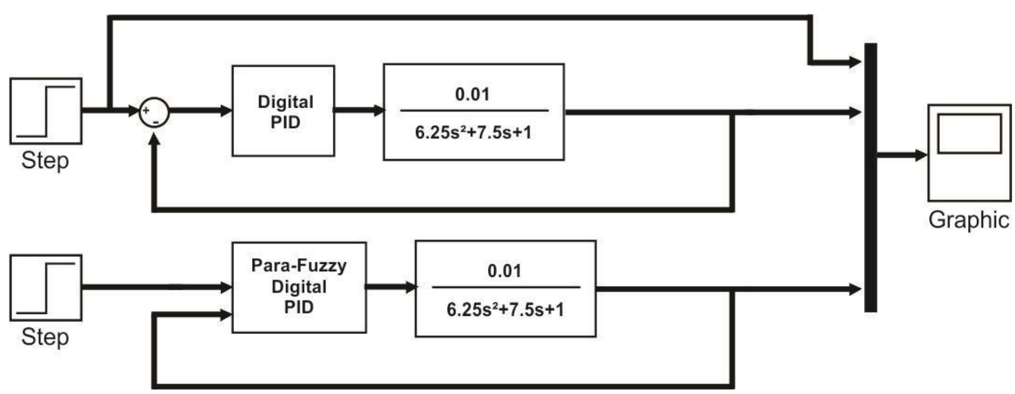


Fig. 10. Block Diagrams Conventional and Para-Fuzzy Digital PIDs with propotional value of 12, integral of 4 and derivative of 12.

5. Conclusion

According to [15], the basis of our current technology supported by classical science, with its reductionist principles, works with little effectiveness in environments considered complex, which are represented by incomplete information and often contradictory. In this context, PAL2v as a non-classical logic, presents conditions to compute contradictory signals without the conflict of information that invalidates the conclusions for the Industry 4.0 environment. Considering the Industry 4.0 environment, a CPS asks for accurate and reliable control of contradictory ⁄ inconsistent data information. Therefore, the applicability of the proposed PAL2v, as the heart of a controller, seems to be the solution to the "noise problem". In the first example, the controller $\text{ConTemp}_{\text{LAP2v}}$ was used to to control the contradictory ⁄ inconsistent data information of a temperature controller and showed a better result than commercial controllers. In the second example, the Digital Para-*Fuzzy* PID, presented a better result than the conventional Digital PID (although the results were based on computerized simulations, the results are promissing). For future studies, such experiments will be replicated to manufacturing processes.

References

[1] Brecher, C.; Ecker, C.; Herfs, W.; Obdenbusch, M.; Jeschke, S.; Hoffmann, M. and Meisen, T. 2017. Chapter 21 – The Need of Dynamic and Adaptive Data Models for Cyber-Physical Production Systems. Cyber-Physical Systems. 321-338.

[2] Blackburn, M. and Denno, P. 2014. Virtual Design and Verification of Cyber-Physical Systems: Industrial Process Plant Design. Procedia Computer Science. 28, 883-890.

[3] Riedl, M., Zipper, H., Meier, M., and Diedrich, C. Cyber-Physical Systems Alter Automation Architectures. Annual Reviews in Control. V.38, 2014, p.123-133.

[4] Dombrowski, V.; Wagner, T. and Riechel, C. 2013. Concept for a Cyber-Physical Assembly System. IEEE. 293-296.

[5] Liu, W. and Su, J. A. 2011. Solution of Dynamic Manufacturing Resource Aggregation in CPS. Information Technology and Artificial Intelligence Conference (ITAIC). 6th IEEE Joint International. 65-71.

[6] Kaihara, T. and Yao, Y. 2012. A New Approach on CPS-Based Scheduling and Wip Control in Process Industries. Proceedings of the Winter Simulation Conference. IEEE. 2062-2072.

[7] Bagheri, B.; Yang, S.; Kao, H.A. and Lee, J. 2014. Cyber-Physical Systems Architecture for Self-Aware machines in Industry 4.0 Environment. IFAC-Papers Online. 48, 1622-1627.

[8] Klimĕs, J. 2014. Using Formal Concept Analysis for Control in Cyber-Physical Systems. 24th DAAAM International Symposium on Intelligent Manufacturing and Automation. Procedia Engineering. 69, 1518-1522.

[9] Fawzi, H.; Tabuada, P. and Diggavi, S. 2014. Secure Estimation and Control for Cyber-Physical Systems under Adversarial Attacks. IEEE Transactions on Automatic Control. 59(6), 1454-1467.

[10] Dartmann, G.; Almodaresi, E.; Barhoush, M.; Bajcinca, N.; Kurt, G.K.; Lücken, V.; Zandi, E. and Ascheid, G. 2017. Chapter 2 – Adaptive Control in Cyber-Physical Systems: Distributed Consensus Control for Wireless Cyber-Physical Systems. 15-30.

[11] Yan, J.; Chen, C.L.; Luo, X.Y.; Yang, X.; Hua, C.C. and Guan, X.P. 2016. Distributed Formation Control for Tele operating Cyber-Physical System under Time Delay and Actuator Saturation Constraints. Information Sciences. 370-371, 680-694.

[12] Cassandras, C.G. 2017. Chapter 3 – Online Control and Optimization for Cyber-Physical Systems. Cyber-Physical Systems. 31-54.

[13] Lee, J., Bagheri, B. and Kao, H.A. 2015. A Cyber-Physical Systems Architecture for Industry 4.0 – Based Manufacturing Systems. Research Letters. 3, 18-23.

[14] Abe, J. M. and Da Silva Filho, J. I. 2003. Manipulating conflicts and uncertainties in robotics. Journal of Multiple-Valued Logic and Soft Computing. 9 (2), 147-169.

[15] Da Silva Filho, J. I., Lambert-Torres, G. and Abe, J. M. 2010. Uncertainty treatment using paraconsistent logic - introducing paraconsistent artificial neural networks. IOS Press, Amsterdam. 211.

[16] Da Costa, N. C. A. 1974. On the theory of inconsistent formal systems. Notre Dame Journal of Formal Logic. 15(4), 497-510.

[17] Subrahmanian, V. S. 1987. "On the semantics of quantitative logic programs," Proceedings of 4th IEEE Symposium on Logic Programming, Computer Society Press, Washington D.C.

[18] Da Costa, N. C. A. and Marconi, D. 1989. An overview of paraconsistent logic in the 80's. The Journal of Non-Classical Logic. 6, 5-31.

[19] Da Costa, N. C. A., Abe, J. M. and Subrahmanian, V. S. 1991. Remarks on annotated logic. Zeitschrift fur Mathematische Logik und Grundlagen der Mathematik. 37, 561-570.

[20] Da Silva Filho, J.I., Rocco, A., Mário, M.C. and Ferreira, L.F.P. 2006. Annotated paraconsistent logic applied to expert systems dedicated for supporting in an electric power transmission system re-establishment. IEEE PES – PSC 2006 Power Systems Conference and Exposition. 2212-2220.

[21] Da Silva Filho, J. I. 1999. Métodos de interpretação da lógica paraconsistente anotada com anotação com dois valores LPA2v com construção de Algoritmo e implementação de cirtuitos eletrônicos". PhD thesis in Portuguese. Polytechnic School of the University of São Paulo.

[22] Da Silva Filho, J. I. and Rocco, A. 2008. Power systems outage possibilities analysis by paraconsistent logic. Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy in the 21st Century. IEEE. 1-6.

[23] Da Silva Filho, J. I., Lambert-Torres, G., Ferrara, L. F. P., Mário, M. C., Dos Santos, M. R., Onuki, A. S., Camargo, J. de Melo, Rocco, A. 2011. "Paraconsistent algorithm extractor of contradiction effects-Paraextrctr". Journal of Software Engineering & Applications. 4 (1), 579-584.

[24] Da Silva Filho, J. I., Nunes, C. V., Garcia, D. V., Mário, M. C., Giordano, F., Abe, J. M., Pacheco, M. T. T. and Silveira, L. 2016. Paraconsistent analysis network applied in the treatment of Raman spectroscopy data to support medical diagnosis of skin cancer. Journal of International Federation for Medical and Biological Engineering. Springer Berlin Heidelberg. 54(10), 1453-1467.

[25] Da Silva Filho, J. I. 2012. Algorithm based on paraconsistent annotated logic for applications in expert systems. Expert Systems Software. Nova Science Publishers, Inc. Chapter 1. 1-40.

[26] Kagermann, H.; Wahlster, W. and Helbig, J. 2013. Final Report of the Industrie 4.0 Working Group. Federal Ministry of Education and Research. 82.

[27] Pan, Ming; Sikorski, Janusz; Kastner, Catharine A.; Akroyd, Jethro; Mosbach, Sebastian; Lau, Raymond and Kraft, Markus. 2015. Applying Industry 4.0 to the Jurong Island Eco-Industrial Park. The 7th International Conference on Applied Energy – ICAE2015. Energy Procedia. 75, 1535-1541.

[28] Heng, S. 2014. Industry 4.0: Huge potential for value creation waiting to be tapped.

[29] Kagermann, H., Wahlster, W. & Helbig, J. 2013. Recommendations for Implementing the Strategic Initiative Industrie 4.0. Heilmeyer und Serman, Germany.

[30] Krogh, B. et al. 2008. Cyber-Physical Systems, Executive Summary. Ed. CPS Steering Group.

[31] Lee, E. A. 2008. Cyber-Physical Systems: Design Challenges. Object Oriented Real-Time Distributed Computing. 11th IEEE International Symposium. 363-369.

[32] Wolf, W. 2009. Cyber-Physical Systems. Computer. 42, 88-89.

[33] Jamshidi, M. 2011. From Large-Scale Systems to Cyber-Physical Systems. Journal of Internet of Things. 12, 367-374.

[34] Lee, J.; Kao, Hung-An and Yang, S. 2014. Service Innovation and Smart Analysis for Industry 4.0 and big data environment. Product Services Systems and Value Creation. Proceedings of the 6th CIRP Conference on Industrial Product-Service Systems. Procedia CIRP. 16, 3-8.

[35] Da Silva, L.C. R.; Mario, C. M. and Da Silva Filho, J. I. 2016. Ensaio de um Controlador Lógico Paraconsistente para Aplicação em Processos Industriais. (Translation: *A Logical Paraconsistent Controller to be Applied on Industrial Processes*). Revista Seleção Documental (in Portuguese). N.41. p.20-24.

[36] Liu, W.et al.. 2010. RFID-enabled real-time production management system for Lancin motorcycle assembly line. International Journal of Computer Integrated Manufacturing. 25, 86-99.

[37] Côrtes, H.M., Da Silva Filho, J.I., Blos, M.F. and Zanon, B.S. 2017. Implementation of a Paraconsistent-Fuzzy Digital PID Controller in a Level Control Process. *Paper accepted on the 19th International Conference on Fuzzy Computation and Application (ICFCA)*, Kyoto - Japan.

[38] Fellani, M.A. and Gabaj,A.M. 2015. PID Controller design for two Tanks liquid level Control System using Matlab. International Journal of Application or Innovation in Engineering & Management (IJAIEM). V.4, Issue 5, p.5-10.

