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Paraconsistent Annotated Evidential Logic Eτ Applied to Autonomous Robots in Logistic Center

Flávio Amadeu Bernardini[1[0000-0002-6292-0617]], Marcia Terra da Silva[1[0000-0002-5314-4978]], Jair Minoro Abe[1[0000-0003-2088-9065]], Luiz Antonio de Lima[1[0000-0003-4228-2387]]

[1]Graduate Program in Production Engineering
Paulista Univesity Rua Dr. Bacelar 1212 CEP 04026-002 – Sao Paulo – SP – BRAZIL
flavioambernar@gmail.com,marcia.terra@uol.com.br,jairabe@uol.com.br,luiz@wcisp.com.br

Abstract. Due to the momentum of Industry 4.0 in various product and service sectors, academic and business investments in the development of new technologies in the logistics sector also stand out. Based on these trends, bibliographical research was carried out of articles dedicated to robotics with application in the logistics sector. Based on the bibliographic survey results, this work proposes a prototype of an autonomous terrestrial mobile robot that must go through corridors in specific layouts in logistics centres focusing on the aid of control tasks and management information for decision making. The main contribution is testing a para-analyzer algorithm based on non-classical logic such as Paraconsistent Annotated Logic Eτ, as the decision-making tool to avoid obstacles.

Keywords: Autonomous Technology, Non-Classic Logic, Paraconsistent Logic.

1 Introduction

The "Digital Transformation" driven by Industry 4.0 is about to change countless companies and organizational models profoundly. This also applies in the manufacturing sector, where many companies will face various challenges from different perspectives, which four key components will govern: CPS (Cyber-Physical Systems), IoT (Internet of Things), Internet of Services, Intelligent Factory [1].

For all this, an increasing number of companies seek to automate their production lines, streamline processes, improve the transportation of inputs in the productive sector, streamline all logistics processes, and reduce costs.

AGV (Automatically Guided Vehicles) is an excellent example used in large logistics centres, implemented by already well-established technologies. In research carried out in this work, it was found that several lines of research seek to enable the implementation of these technologies both in the logistics sector and in the manufacturing sector.

Because of this scenario, the authors [2] conducted bibliographic research on multi-robot localization in a highly symmetrical environment. A team of robots, adequately coordinated, can perform complex tasks such as surveillance, monitoring, mapping, etc. The correct and reliable location concerning a known map is essential in these tasks and represents one of the most significant mobile robotics challenges. They have done several studies on emerging technologies for the location and displacement of multi robots and propose a solution free of external locators such as GPS, as they highlight the possibility of interrupting this communication indoors. For the multi-robot locomotion solution, the authors propose to perform small asymmetric markings in an environment of symmetrical corridors, such as in a logistics centre. These markings are the references used by an algorithm based on Cartesian information about the site. They used the Pioneer P3DX differential robot prototype equipped with ultrasonic sensors to avoid obstacles.

Regarding navigation techniques, the authors [3] used a differential robot prototype equipped with three front ultrasonic sensors and, through an algorithm based on Fuzzy logic, controls displacement and avoids collision with obstacles. According to the authors, the robot's direction is controlled by the rotation of the front wheels, and the rear freewheel serves only as support. The front wheels are also equipped with sensors whose information is transformed into the robot's angular and linear speed, which are necessary for positioning in a Cartesian system.

This article proposes applying the Paraconsistent Annotated Evidential Logic Eτ in a terrestrial mobile robot's navigation system in corridors of logistics centres and warehouses. This work's main objective is to develop a paraconsistent algorithm capable of avoiding obstacles and the possibility of integration with other navigation systems.

1.1 Paraconsistent Annotated Evidential Logic Eτ Applied in Robotics

The Paraconsistent Annotated Evidential Logic Eτ is a non-classical logics known as paraconsistent logics. Roughly, paraconsistent logic is a logic that serves as underlying logic for inconsistent but non-trivial theories. It has as atomic formulas propositions of the type $p(\mu, \lambda)$, where p is a proposition in a usual sense, and $\mu, \lambda \in [0, 1]$ (closed real unitary interval). The remaining formulas are obtained through Boolean combinations of connectives of the logic. Intuitively, μ indicates the degree of favourable evidence of p, and λ indicates the degree of unfavourable evidence of p. The reading of the μ, λ, depends on the most diverse applications considered and may change.

With these applications' effect, μ may be the degree of favourable belief, and λ may be the degree of belief contrary to proposition p. In some specific applications, μ may also indicate the probability expressed by p occurring and λ, the improbability expressed by p of occurring and other readings. An order relation is defined in $[0, 1]^2$: $(\mu_1, \lambda_1) \leq (\mu_2, \lambda_2) \Leftrightarrow \mu_1 \leq \mu_2$ and $\lambda_2 \leq \lambda_1$, forming a lattice, symbolized by τ, which is represented in Figure 1 [4].

Concerning the Paraconsistent Logic application, in 1999, the Emmy I autonomous mobile robot was built consisting of a mobile tower with a circular aluminium base of 30 cm diameter and 60 cm in height. The robot was designed on four overlapping electronic circuit boards separated by function in the control system to facilitate the visualization of each module's action in the robot's movement control [5]. The authors used two ultrasonic devices called Parasonic in front of the mobile robot to detect possible obstacles.

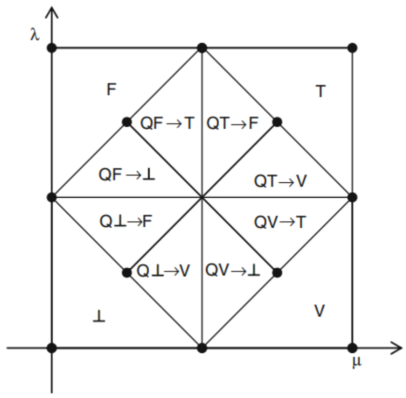

Fig. 1. The Lattice τ of decision-making

Despite technical difficulties such as braking, lack of multi-speed and rotational timings between engines, they claim that the tests performed show that Paracontrol performed well to solve problems related to robot navigation. The system demonstrated a good ability to modify the robot's behaviour when unexpected changes occur in environmental conditions.

In 2004 the Emmy II appeared with a significant reduction in the robot structure's height and with a diameter of 25 cm. Similarly, its predecessor also used two ultrasonic sensors to detect obstacles and programming based on the Annotated Paraconsistent Logic [6, 7]. According to the authors, the modifications made both in the structural parts and in the electronic circuit of the autonomous mobile robot allowed a significant improvement in the performance of the robot's movement. To show it, the robot was submitted to four performance tests in a square environment with a side of 3.3 m and with three internal obstacles. The authors recorded an average of 10 collisions per test and claimed that most were because of a deficiency of ultrasonic sensors, especially when obstacles are too close to the robot.

A more advanced version emerged in 2009 with the Emmy III prototype, whose design was divided into three parts: mechanical subsystem, path planning and sensing. The authors' main idea was to improve this version to expand the navigation capabilities of the robot through a task with an origin and a destination to be fulfilled as a goal.

For this, they developed a computer system that receives information from sensors distributed in the environment, maps the environment by coordinates, and transmits commands to the robot's mechanical system during displacement. With the use of Paraconsistent Evidential Logic, the proposed sensing system aims to generate a degree of favourable evidence in each environmental position. The degree of favourable evidence is related to the sentence: "There is an obstacle in the position analyzed." Thus, through the input information of the ultrasonic sensor, the distance between the sensor and the obstacle, the angle between the horizontal axis of the environment and the direction to the front of the sensor, the coordinate (X, Y) where the robot is about the environment is determined. The authors performed three system performance tests and presented Cartesian graphs with variations in the degree of favourable evidence, which prove the correct functioning of the algorithm [8, 9].

1.2 Project Proposal Structure and Prototype of the Mobile Robot

To develop the autonomous terrestrial robot project, a structure consisting of corridors was elaborated to simulate a production line's environment. Based on proportional relationships was defined width of 80 cm for corridors of the production line. Figure 2 shows the prototype of the robot in the simulation environment. The simulation of the robot navigation performance in this environment was significant for the tests foreseen in the project.

Fig. 2. Terrestrial autonomous robot in a logistic centre

The project proposal is to build a prototype of an autonomous terrestrial mobile robot that will go through corridors of production lines, which will perform monitoring, tracking, and transport of materials. Figure 3 shows the overall structure and all the electrical and electronic devices that were used. Two front ultrasonic sensors monitor the robot that sends signals to the microcontroller, warning of possible obstacles. The left and right side sensors inform the lateral distances so that the robot maintains a central position in the corridor during displacement.

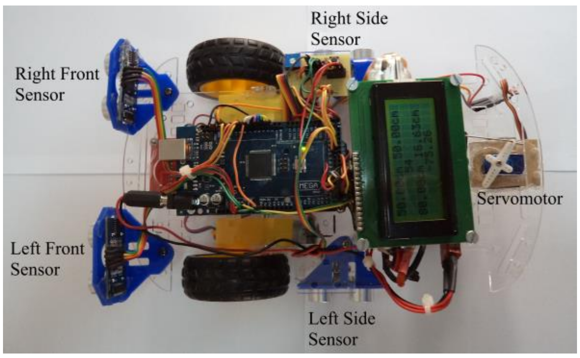

Fig. 3. Prototype of the terrestrial robot

The Atmega 2560 microcontroller will be programmed in C language, with technology embedded in the concepts of the Paraconsistent Annotated Evidential Logic Eτ. After receiving the information from the sensors, the paraconsistent algorithm will assist in decision-making. This information will be transformed into electrical signals and sent to the control devices of the traction motors and the servo motor that will control the direction of the autonomous terrestrial mobile robot, thus avoiding collisions during displacement. A differential of this prototype will be installing an LCD for monitoring sensor readings and the angle of the steering control servo motor. During the mobile robot's trajectory, these variables will be observed to make the necessary adjustments in the programming of the paraconsistent algorithm. We opted for a Lithium battery to equip the prototype because it is very light and with considerable energy storage capacity.

2 Methodology

Initially, the concepts of Paraconsistent Annotated Evidential Logic Eτ, through a built-in paraconsistent algorithm, will play a fundamental role in decision-making assistance [10].

Then, based on the lattice properties represented in Figure 1 and on the proposition: "The front of the robot is free", Table 1 was elaborated. The distances measured by the left and right sensors were converted, respectively, by the μ and λ, through a normalization calculation of these values.

Table 1. Paraconsistent algorithm values.

Front Sensors					**Degree of uncertainty**	**Setpoint (º)**
Situation	**Left (cm)**	**μ**	**Right (cm)**	**λ**		
1	20	0,1	200	0	-0,9	-85,23
2	40	0,2	180	0,1	-0,7	-66,29
3	60	0,3	160	0,2	-0,5	-47,35
4	80	0,4	140	0,3	-0,3	-28,41
5	100	0,5	120	0,4	-0,1	-9,47
6	120	0,6	100	0,5	0,1	9,47
7	140	0,7	80	0,6	0,3	28,41
8	160	0,8	60	0,7	0,5	47,35
9	180	0,9	40	0,8	0,7	66,29
10	200	1	20	0,9	0,9	85,23

Then, the degree of uncertainty was calculated through the concepts of Paraconsistent Logic and provided precise and decisive values to determine the servo motor's correct position for each situation under the presence of obstacles. In the last column of Table 1, the setpoint values of the servo motor already calculated are observed.

The following is presenting a programming excerpt performed in C language, which was divided into three main blocks. Frontal paraconsistent logic, lateral paraconsistent logic, and servo motor control. In the first block, the variables perceived by the left and right frontal sensors (sr_lf and sr_rf) have already gone through the normalization process and follow the concepts of paraconsistent logic. These values were converted into the variables (mi1 and la1) respectively in μ_1 and λ_1, as described in the Lattice of Figure 1. Next, the degree of uncertainty of the frontal decision was calculated and stored in the variable (deg_unc1). In the second block, the same process is repeated for the values read by the left and right side sensors and converted to (mi2 and la2), respectively μ_2 and λ_2. Then, the degree of uncertainty of the lateral decision is stored in the variable (deg_unc2). The third block constantly receives the values of the degree of frontal and lateral uncertainty variables, so the microcontroller, through logical constraints, controls the variable (sv_set_pt) of decision-making of the steering servo of the autonomous terrestrial robot.

```
// frontal paraconsistent logic//
mi1 = (sr_lf/50); // conversion of left front sensor reading into mi1 variable
la1 = (1-(sr_rf*0.02)); // conversion of right front sensor reading into la1variable
deg_unc1 = ((mi1+la1)-1); // calculation of the degree of uncertainty of the frontal sensors
//sv_set_pt = 538.42*gra_unc+551.5;// determination of the servo motor set point
sv_set_pt = 300*gra_unc1+511.5;
// lateral paraconsistent logic//
mi2 = (sr_ls/80); // conversion of left lateral side reading into mi2 variable
la2 = (1-(sr_rs*0.0125)); // conversion of right side sensor reading into la1variable
deg_unc2 = ((mi2+la2)-1)); // calculation of the degree of uncertainty of the lateral sensors
//sv_set_pt = 538.42*gra_unc+551.5; // determination of the servo motor set point
sv_set_pt = 200*gra_unc2+511.5;
// servo motor control//
valor_motor = map(sv_set_pt, 0 , 1023, 0, 180); // servo motor control
servo.write (valor_motor);
ang_sv = gra_inc1*95; // calculation of the angle of the servo motor
```

3 Experiments and Results

According to the project's initial proposal, the next step was to perform the physical tests and submit the terrestrial robot autonomous to move in a structured environment. This environment has an 80 cm wide corridor and 3 m long, which simulates a supposed production environment. Table 2 shows the tests were repeated ten times at each of the three standardized speeds to verify performance and possible collisions with obstacles or collisions with the side barriers.

Table 2. Robot performance tests.

Number of collisions X speed			Type of Obstacle
0.25m/s	**0.5m/s**	**0.75m/s**	
0	3	2	**Left side boundary**
0	1	3	**Right side boundary**
0	4	5	**Rectangular obstacle object**

The robot will be able to perform tasks such as providing components for these product lines. Figure 4 shows this test with an obstacle on the robot's right side, perceived by the right front sensor (Sensor λ_1).

Fig. 4. Robot navigation test in a structured environment

At point A of the red line, there is a tendency to deviate to the left, and at point B, there is already a perception of the proximity to the left lateral limit by the left lateral sensor (Sensor μ_2). At point C, the two lateral sensors (Sensor μ_2 and λ_2) are responsible for maintaining the robot's rectilinear trajectory and maintaining the robot's displacement in the middle of the corridor. This test was also performed with an obstacle on the robot's left side, which similarly swerved to correct its trajectory.

4 Discussion

The authors [2] conducted studies on emerging technologies in robotic navigation and researched multi-robot use in structured and highly symmetrical environments, such as logistics centres and industrial production lines. The GPS robotic navigation technology researched by the authors showed some deficiencies in internal communication. In such cases of lack of communication, the navigation system with a paraconsistent algorithm could be used in conjunction with GPS and avoid collisions with obstacles. In other studies, the authors [3] and the authors [8] built prototypes of differential robots with a free rear wheel only as support. In these cases, the steering is determined by the difference in the rotation of the traction wheels. This type of prototype is very subject to inaccuracies because of slippages. With the placement of the servomotor instead of the freewheel, as in the case of this work, there is a better performance in the movement of the robot's prototype due to the accuracy of the servomotor combined with the paraconsistent algorithm. The results obtained in the tests at a speed of 0.25 m/s without collisions with obstacles or collisions with the lateral limits showed to be very promising.

5 Conclusion

This article began with the proposal to apply paraconsistent logic to control an autonomous terrestrial mobile robot. Historically, research has revealed numerous studies with the application of the Paraconsistent Annotated Evidential Logic Eτ in the development of robotic navigation systems. The paraconsistent algorithm developed in the C language showed the possibility of integration with other robotic navigation systems to act in symmetrical environments, such as logistics centres and industrial production lines. Another observation of this work was using a servomotor for robot steering control to improve the accuracy of movements. As future work, Paraconsistent Logic can be integrated with other navigation systems, such as odometric navigation. The algorithm developed showed the possibility of implementing the prototype in logistic centres, performing component transport and monitoring tasks.

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