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Intuitionistic fuzzy robot motion control

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Abstract: *The paper is dedicated to the application of the intuitionistic fuzzy formalism to control the robot motion. The control model is presented as production rules of intuitionistic fuzzy parameters, on which an inference is processed. The defuzzificaion is applied to get the crisp value of the control action. The obtained results from the robot case study are discussed.*

Keywords: Intuitionistic fuzzy sets, knowledge base, inference, robot motion, defuzzification

1. Introduction

Last decade was marked with increased interest to robots and particularly to those, which could assist disabled and people in the hospitals. We will illustrate this interest with just one fact from the hospitals practice, which concerns the movement of empty beds for washing.

According Eurostat, there are on average 526 hospitals beds per 100,000 inhabitants [1]. If we assume EU population as 508 million and that these beds are washed only once per week, the EU-wide market of autonomous hospital beds transport is estimated to over 2.6 million hospital bed.

In [2] an estimation of the cost of delivery in the hospitals, done manually (physically) and by robots, is presented (Fig.1). The comparison shows that the robotized internal hospital transport reduces the cost of delivery by 50-80%.

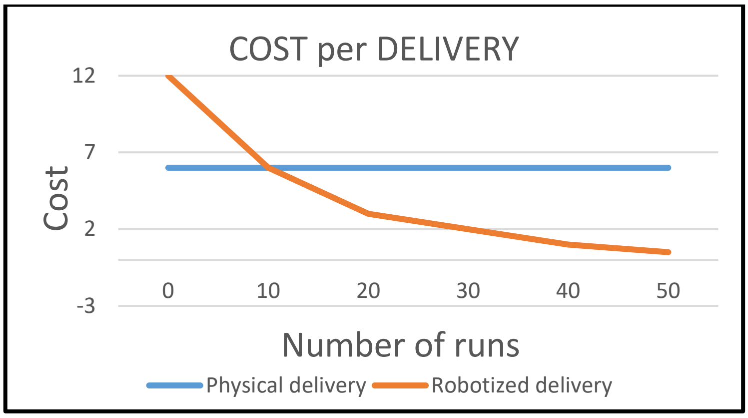

Fig.1. Robotized vs. Physical delivery cost

For this particular application and especially for disabled people assistance the robot control systems should operate precise and "soft". The traditional methods from control theory are well –known way for achieving a precise motions. Recently the artificial intelligence methods become more and more popular as they do not require availability of a precise mathematical model of the controlled object. Instead these methods utilize the human intuition, formalized in production rules, based on fuzzy logic. The, so called fuzzy control has been implemented successfully widespread from consumer electrical appliances to complex train control systems [3,4].

Further development of the fuzzy theory has been proposed by K.Atanassov, who proposed generalization of fuzzy variables presentation with membership and non-membership functions, known as Intuitionistic fuzzy logic [5,6]. Despite of the relatively more complex calculation the intuitionistic fuzzy logic attracted the researchers to apply it to the control tasks because of its generalized approach to the solved problems. Moreover the existence of the "freedom" in interpreting the intuitionistic fuzzy variables (in terms of their linguistic meanings) by playing with membership and non-membership functions (limited by the intuition) promises implementation of more flexible, error-tolerant and thus robust control systems.

Quite productive is this approach in solving decision-making tasks [9,10] as well as control problems [8].

In this article we will present how the paradigm of intuitionistic fuzzy logic is applied to control a movement of a robot.

2. Basic definitions

First we will review shortly a basic definitions from the intuitionistic fuzzy logic, which will be useful in the further presentation.

Definition 2.1: [5] An Intuitionistic Fuzzy Set A in X is defined as an object of the form $A = \{< x, \mu A(x), \nu A(x)>: x \in X\}$ where the functions $\mu A : X \to [0, 1]$ and νA :

$X \to [0, 1]$ define the degree of membership and the degree of non-membership of the element $x \in X$, respectively, and for every $x \in X$ in A, $0 \leq \mu A(x) + \nu A(x) \leq 1$ holds

Definition 2.2: [5] For every common fuzzy subset A on X, intuitionistic fuzzy index of x in A is defined as $\pi A(x) = 1 - \mu A(x) - \nu A(x)$. It is also known as degree of hesitancy or degree of uncertainty of the element x in A. Obviously, for every $x \in X$, $0 \leq \pi A(x) \leq 1$.

Definition 2.3: [5] Let $p = (\mu p, \nu p)$ and $q = (\mu q, \nu q)$ be two intuitionistic fuzzy propositions, then

- $p \vee q = (\max(\mu p, \mu q), \min(\nu p, \nu q))$
- $p \wedge q = (\min(\mu p, \mu q), \max(\nu p, \nu q))$
- $-p = (\nu p, \mu p)$
- $p \to q = (\max(\nu p, \mu q), \min(\mu p, \nu q))$

3. Intuitionistic fuzzy method and architecture.

The proposed approach, known in the Artificial Intelligence as an Expert System, is based on the knowledge base paradigm, where the studied object (its behaviour) is described in terms of production rules (if-then type) [7]. The conditional (if) part of the rules consists of the input variables (parameters), which influence on the object behaviour, while the conclusion (then) part is providing a product – value of the output variable, which is giving the decision. The rules are processed by the inference machine, a part of the system, which activates (fires) them, when corresponding conditions are satisfied.

As we will use intuitionistic fuzzy sets for description of the target object additional processing of the system variables (parameters) has to be foreseen, namely intuitionistic fuzzification of the input parameters and intuitionistic defuzzification of the output parameters. The architecture of the described system for intuitionistic fuzzy rule-based control is shown on Fig.2.

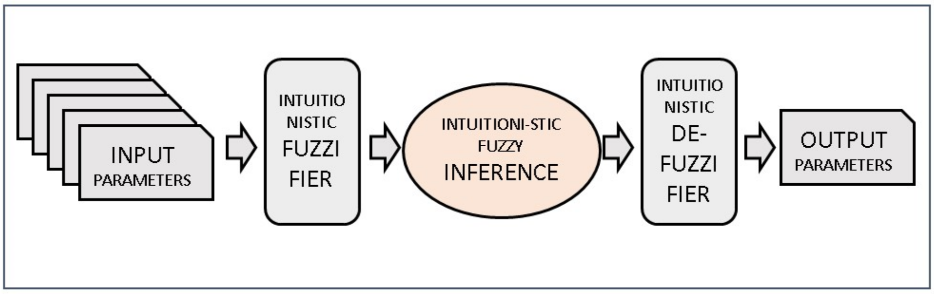

Fig.2. Intuitionistic fuzzy rule-based controller architecture

4. Case study of an intuitionistic fuzzy robot motion control system

Now we will use the above-described method of intuitionistic fuzzy rule-based inference to control the motion of a robot (robocar).

Fig. 3 presents the situation of a robot, moving along the wall. The robot should keep a distance X from it. At the moment it is oriented not parallel to the wall, i.e. deviated by angle B. Thus, the task of the control system we will be as follows: on the base of input parameters position X and orientation B to provide a corrective control action - C, which to normalize the position of the robot.

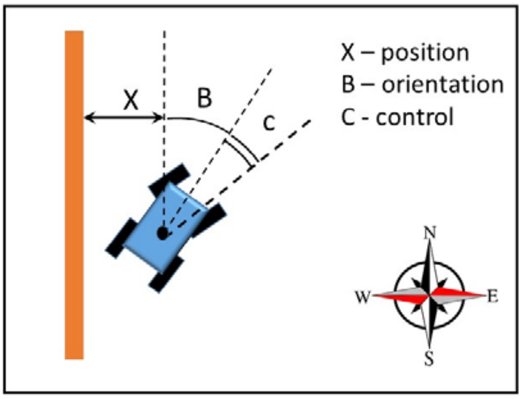

Fig.3. Robot control parameters

In order to implement the intuitionistic fuzzy approach, the following algorithm will be fulfilled [8]:

- Definition of the linguistic values of the input (position and orientation) and output (control) parameters
- Assignment of the membership (μ) and non-membership functions (ν) to the linguistic values
- Construction of the intuitionistic fuzzy rules base
- Evaluation of the rule base and calculation of membership (μ) and non-membership functions (ν) of the output variables of the fired rules
- Defuzzificate the output variables of the satisfied rules to receive the crisp value of the control parameter for correction of the robot trajectory.

5. Implementation of the intuitionistic fuzzy rule-based algorithm to robot control

5.1. Definition of the linguistic values.

According to the algorithm we will define the linguistic values of the input and out put parameters in the following way:

- Position X (input) is determined by negative (N), positive (P) and neutral (Z) values
- Orientation B (input) is determined by Nord (N), South(S), West (W) and East (E) values
- Control C (output) is determined by left (L), right (R) and straight (S)

5.2. Assignment of the membership (μ) and non-membership functions (ν)

Next we intuitionistic fuzzify these parameters, i.e. assign membership and non-membership functions to each of the linguistic parameter values. We will use a triangular function to represent certainty and uncertainty of these values, as follows, both analytically and graphically:

Position X - Membership functions – μ_X

N(X)		
μ_X =	-0.1X	if -10<X<0
	else 1	if X<-10
	else 0	

P(X)		
μ_X =	0.1X	if 0<X<10
	else 1	if X>10
	else 0	

Z(X)		
	1-0.1X	if 0<X<10
μ_X =	1+0.1X	if -10<X<0
	else 0	

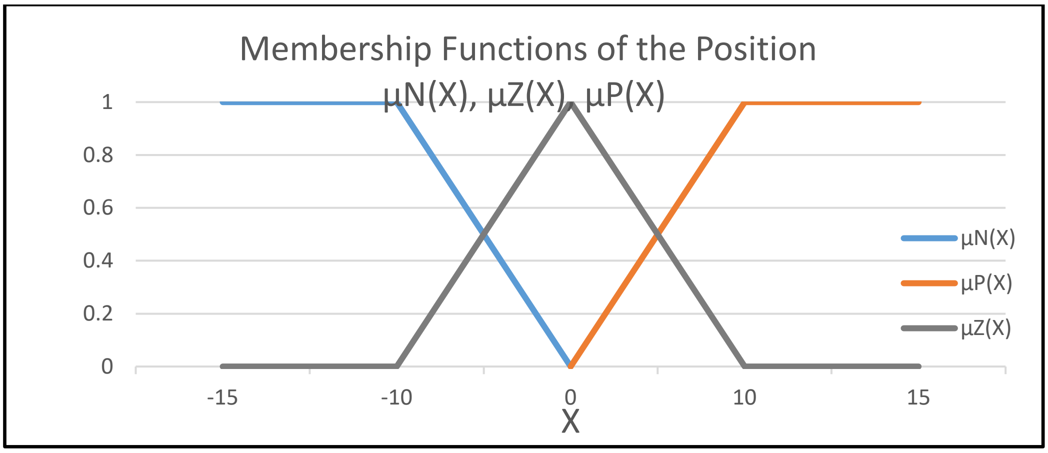

Fig.4. Membership functions of the position X

Orientation B - Membership functions – μ_B

N(B)		
	$(B-270^0)/90^0$	if $B>270^0$
μ_B =	$(90^0-B)/90^0$	if $B<90^0$
	else 0	

W(B)		
	$B/90^0$	if $B<90^0$
μ_B =	$(180^0-B)/90^0$	If $90^0<B<180^0$
	else 0	

S(B)		
	$(B-90^0)/90^0$	If $90^0<B<180^0$
μ_B =	$(270^0-B)/90^0$	If $180^0<B<270^0$
	else 0	

E(B)		
	$(B-180^0)/90^0$	If $180^0<B<270^0$
μ_B =	$(360^0-B)/90^0$	If $270^0<B<360^0$
	else 0	

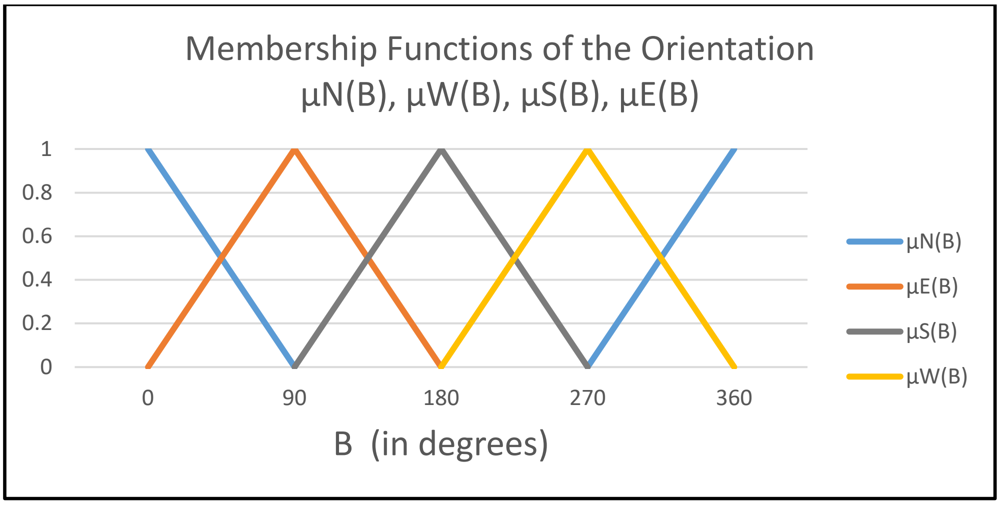

Fig.5. Membership functions of the orientation B

Control C - Membership functions – μ_C

L(C)		
μ_C =	0.02C	if $0<C<50^0$
	else 0	

R(C)		
μ_C =	-0.02C	if $-50^0<C<0$
	else 0	

S(C)		
	1-0.02C	if $0<C<50^0$
μ_C =	1+0.02C	if $-50^0<C<0$
	else 0	

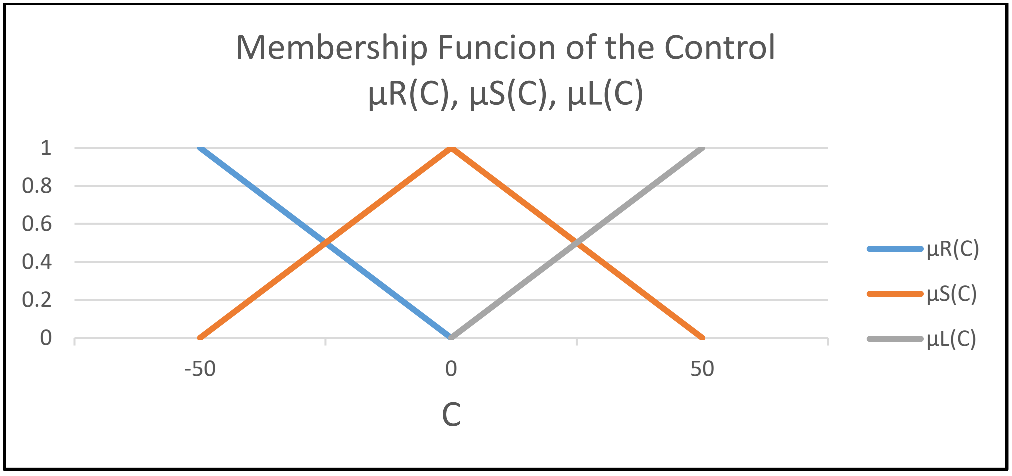

Fig.6. Membership functions of the control C

Position X - Non-Membership functions – ν_X

N(X)		
ν_X =	$1+0.125X$	if $-8<X<0$
	else 0	if $X<-8$

Z(X)		
	$0.083X$	if $0<X<12$
ν_X =	$-0.083X$	if $-12<X<0$
	else 1	

P(X)		
ν_X =	$1-0.125X$	if $0<X<8$
	else 0	if $X>8$

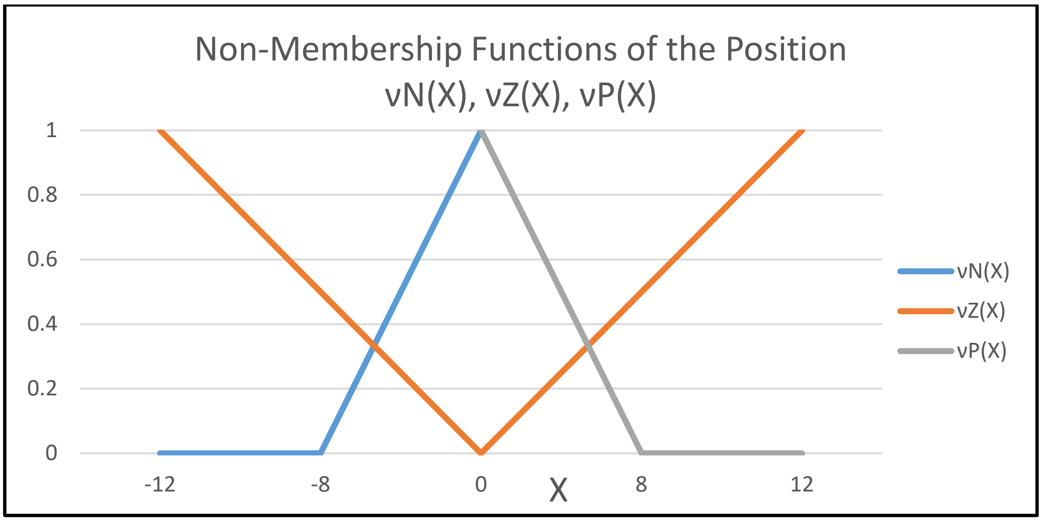

Fig.7. Non-Membership functions of the position X

Orientation B - Non-Membership functions – ν_B

N(B)		
	$(350^0-B)/90^0$	if $350^0>B>270^0$
ν_B =	$(B-10^0)/90^0$	if $10^0<B<100^0$
	else 0	

W(B)		
	$(90^0-B)/110^0$	if $0<B<90^0$
ν_B =	$(B-90^0)/110^0$	If $90^0<B<200^0$
	else 0	

S(B)		
	$(180^0-B)/100^0$	If $80^0<B<180^0$
ν_B =	$(B-180^0)/100^0$	If $180^0<B<280^0$
	else 0	

E(B)		
	$(270^0-B)/110^0$	If $160^0<B<270^0$
ν_B =	$(B-270^0)/110^0$	If $270^0<B<360^0$
	else 0	

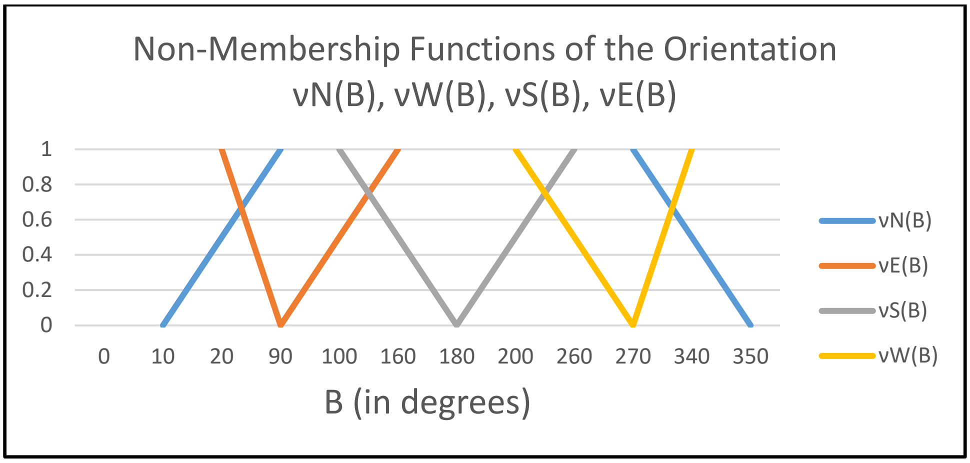

Fig.8. Non-Membership functions of the orientation B

Control C - Non-Membership functions – ν_C

L(C)		
ν_C =	1-0.025C	if $0<C<40^0$
	else 0	

R(C)		
ν_C =	1+0.025C	if $-40^0<C<0$
	else 0	

S(C)		
	1-0.017C	if $0<C<60^0$
ν_C =	1+0.017C	if $-60^0<C<0$
	else 1	

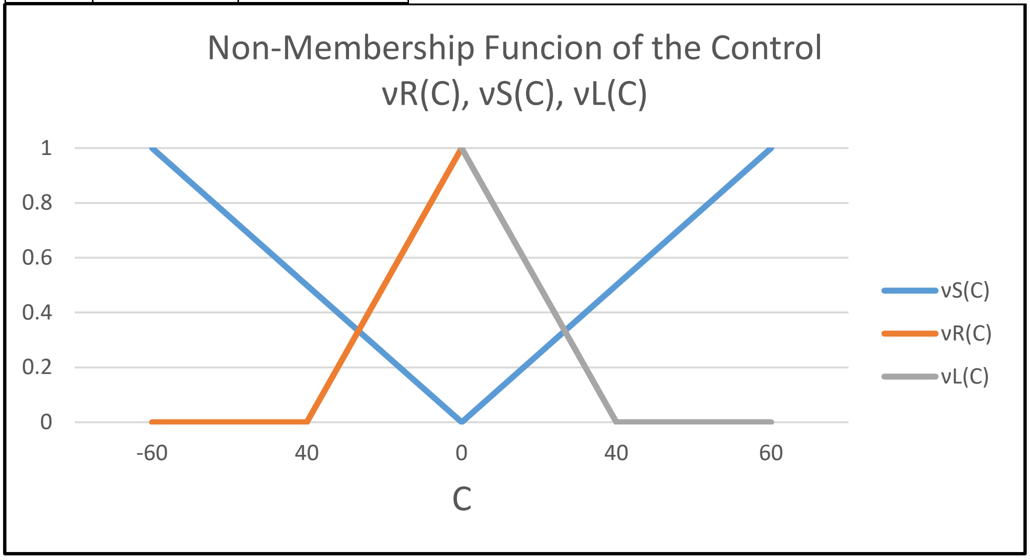

Fig.9. Non-Membership functions of the control C

5.3. Construction of the intuitionistic fuzzy rules base

Then we construct the knowledge base, filling it with IF-THEN rules, which model the robot behaviour, in the following way:
IF the orientation is Nord (NB) AND position is neutral (ZX) THEN control is straight (SC),
or written as logic notion: $NB \wedge ZX \rightarrow SC$.
The full KNOWLEDGE BASE is presented below:

$NB \wedge ZX \rightarrow SC$
$NB \wedge NX \rightarrow RC$
$NB \wedge PX \rightarrow LC$
$SB \wedge ZX \rightarrow LC$
$SB \wedge NX \rightarrow LC$
$SB \wedge PX \rightarrow RC$

$WB \wedge ZX \rightarrow RC$
$WB \wedge NX \rightarrow RC$
$WB \wedge PX \rightarrow SC$
$EB \wedge ZX \rightarrow LC$
$EB \wedge NX \rightarrow SC$
$EB \wedge PX \rightarrow LC$

For convenience, we present the knowledge base in a table form:

	NX	ZX	PX
NB	RC	SC	LC
EB	SC	LC	LC
SB	LC	LC	RC
WB	RC	RC	SC

5.4. Evaluation of the rule base and calculation of membership (μ) and non-membership functions (ν) of the output variables of the fired rules

Having the knowledge base and fuzzified parameters we will reason to get a proper control action. Suppose the robot situation is determined by the position X=6 and the orientation $B=70^0$. The corresponding certainty and uncertainty values of these parameters, calculated analytically or graphically from fig.4 and 5 are:
For position X
$\mu_{\mathbf{x}} N(6) = 0$ $\nu_x N(6) = 0$
$\mu_{\mathbf{x}} Z(6) = 0.4$ $\nu_x Z(6) = 0.498$
$\mu_{\mathbf{x}} P(6) = 0.6$ $\mu_{\mathbf{x}} P(6) = 0.25$
For orientation B
$\mu_{\mathbf{B}} N(70) = 0.22$ $\nu_B N(70) = 0.66$
$\mu_{\mathbf{B}} E(70) = 0.78$ $\nu_B E(70) = 0.18$
$\mu_{\mathbf{B}} S(70) = 0$ $\nu_B S(70) = 0$
$\mu_{\mathbf{B}} W(70) = 0$ $\nu_B W(70) = 0$
In order to evaluate the rules we substitute the above values in the rule base table and apply the intuitionistic fuzzy conjunction formula from the Definition 2.3, as follows:

μ(C)	**NX=0**	**ZX=0.4**	**PX=0.6**
NB=0.22	RC=0	SC=0.22	LC=0.22
EB=0.78	SC=0	LC=0.4	LC=0.6
SB=0	LC=0	LC=0	RC=0
WB=0	RC=0	RC=0	SC=0

ν(C)	**NX=0**	**ZX=0.25**	**PX=0.498**
NB=0.66	RC=0	SC=0.66	LC=0.66
EB=0.18	SC=0	LC=0.25	LC=0.498
SB=0	LC=0	LC=0	RC=0
WB=0	RC=0	RC=0	SC=0

The result of the inference is satisfaction of 4 rules, which leads to the expected decision that the robot should turn to LEFT.

5.5. Defuzzification of the output variables derived from the satisfied rules to receive the crisp value of the control parameter for correction of the robot trajectory

The last step of the inference process is to defuzzify the intuitionistic fuzzy control parameter – C to a crisp value. For this purpose we will apply the well-known Takagi-Sugani's formula [11]:

$$x = \frac{\sum_{j=1}^{M} x^j \left((1-\pi_A)+\mu_A\pi_A\right)}{\sum_{j=1}^{M}\left((1-\pi_A)+\mu_A\pi_A\right)}$$

where:

$\mu_{A^j} = \wedge_{i=1}^{n} \mu_{A_i^j}(x)$

,$\nu_{A^j} = \vee_{i=1}^{n} \nu_{A_i^j}(x)$ and

$\pi_{A^j} = 1 - \mu_{A^j} - \nu_{A^j}$

As the fired rules conclude a control action LC, i.e. left turn, we will apply the above formula to the membership and non-membership functions of LC linguistic value of the control parameter C (fig. 6 and 9 respectively).

The corresponding calculations are given in Table 1.

Table 1. Defuzzification of the control parameter - C

C	μ	ν	π	A=(1-π)μ	B=πμ	A+B	C*(A+B)
0	0	0,25	0,75	0	0	0	0
10	0,2	0,25	0,55	0,09	0,11	0,2	2
20	0,4	0,25	0,35	0,26	0,14	0,4	8
30	0,6	0,25	0,15	0,51	0,09	0,6	18
40	0,6	0	0,4	0,36	0,24	0,6	24
50	0,6	0	0,4	0,36	0,24	0,6	30
					Σ =	2,4	82
					C	34,17	

Thus, we got the crisp value of the control parameter C, which has to correct the robot trajectory by forcing it to turn LEFT to $34{,}17^0$.
In case of bigger deviation we could expect more hairpin turn and visa versa. Then after several steps we could expect that the robot will be controlled mostly by the rule NB^ZX→SC , which will keep the needed trajectory.

6. Conclusions

The artificial intelligence approach of using paradigm of expert system inference on intuitionistic fuzzy rules has been successfully applied to control the robot motion. The advantage of the intuitionistic fuzzy approach over already traditional fuzzy one is in the “softness’’ and robustness (in terms of error tolerance) of the control, due to the possibility to balance the levels of the certainty and uncertainty of the corrective action, i.e. availability of a two degrees of freedom to control the process. Of course, it is paid by more computational power needed to reason, especially in the real-time operations, which on the other hand could not be an obstacle for the today’s microcontrollers.

The further development of the work intends to study the stability and the speed of iteration of the intuitionistic fuzzy rule – based robot control.

Acknowledgement

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Интуиционистки нечеткое управление движением робота

Марин Маринов, Владимир Лазаров

Резюме: *Статья посвещена применению формализма интуиционистких нечетких множеств для управления движением робота.Управляющая модель предствлвна продукционной системой правил с интуиционистки нечеткими параметрами,из которых делается логический вывод. Дефаззификационный метод применяется для получения четкого значения управляющего воздействия. Полученные резултаты обсуждаются.*