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Designing a Control Vision System for FMS Cells Based on Fuzzy Petri Nets

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Abstract— ***This paper discusses representation and planning of operation sequences in a robotic system using fuzzy Petri nets. The FMS cell described in this paper consists of a robot, a vision system, a computer numerical control (CNC) cutting machine, two conveyor belts and a bin. The Petri net approach can be used to describe sequences of events at different levels in this system. We used fuzzy logic control and Petri Nets. This method uses a modelling approach utilizing fuzzy rules based on a knowledge-based system. The fuzzy rules determine the behavior of the vision system decisions and robots in the FMS. The proposed approach can be used as a modelling tool for monitoring ambiguous and uncertain cases. Furthermore it can be used for specifying the quality of output products in an FMS cell.***

Keywords—***Petri net, Robotic system, FMS, Control Cutting Machine, Fuzzy logic***

I. INTRODUCTION

Flexible manufacturing systems (FMS) can share many resources such as computer numerical control (CNC) machinery, robots and vision systems. Such systems fall into category of the, type which exhibits synchronicity and concurrency. Petri nets have been applied to the modelling, analysis, control and simulation of FMS's and can model and monitor events at different levels of activity, thereby leading to an increase in system efficiency and flexibility [1],[2],[3],[4].

Recently, Fuzzy logic with Petri nets (Fuzzy Petri nets) has been used to model imprecise and uncertain situations which can arise within FMS's [5],[6]. In general Fuzzy Petri nets can model vagueness and uncertainty by using fuzzy rules based on a knowledge-based system [7]. In Fuzzy Petri nets (similar to ordinary Petri nets); places are denoted by circles, transitions are denoted by bars and the routes from places to transitions and from transitions to places are denoted by arcs. Firing a transition in a Fuzzy Petri net depends upon the fuzzy conditions associated with the transition. The object of this work is to produce a Fuzzy Petri net which defines how a vision system might make a crisp decision suitable for activating a robot.

II. PETRI NETS

PETRI Net (PN) (also known as a place/transition net or P/T net) is one of several mathematical modelling languages for the description of Discrete Event Systems (DES). PNs were emerged in 1962 from the PhD thesis of Carl Adam Petri and proved to be quite effective tool for graphical modelling, mathematical modelling, simulation, and real time control by the use of places and transitions. However, there was an intuitive need for a system, which would be able to address uncertainties and imprecision of the real world systems, because of increase in the complexity of industrial and communication systems. Fuzzy logic proved to be an appropriate complement because of its possiblistic nature to handle vague data.

Up till the date, numbers of ways have been proposed for combining PN with fuzzy logic, according to different applications. But with the increasing applications of these nets, there is an increase in the ambiguity about their types and structures. Almost in every new research on Fuzzy Petri Nets (FPN), researchers claim to have come up with new type of FPN. Therefore, for the ease of future researcher and engineers, it was essential to categorize FPN on the basis of some criteria. As PN can be timed and/or colored, similarly FPN can also be timed and/or colored to include the temporal effect and/or enhance their visibility. Like that of Neural Networks (NN), FPN can also do learning, and can be trained in order to get adapt to the changing situations. And as Fuzzy logic is being combined with PN to get FPN, in the same way FPN can be combine with other Artificial Intelligence (AI) tools, and mathematical models to become more efficient, and powerful. On the basis of structures and algorithms FPNs have been classified as; Basic Fuzzy Petri Nets (BFPN), Fuzzy Timed Petri Nets (FTPN), Fuzzy Colored Petri Nets (FCPN), Adaptive Fuzzy Petri Nets (AFPN), and Composite Fuzzy Petri Nets (CFPN).

III. BASIC FUZZY PETRI NETS

BFPN or simply FPN is a combination of PN and fuzzy logic. PN are graphical, and mathematical modelling tool usually used for discrete event systems. The term "fuzzy logic" emerged in the development of the theory of fuzzy sets by Lotfi Zadeh (1965). Fuzzy logic is a set of methodologies that functions effectively in an environment of imprecision and/or uncertainty. Combination of these two gives a powerful tool to work efficiently in a real world system [9].

A. Combination of Fuzzy logic with Petri nets

FPN was being proposed as 8-tuple.

FPN = (P, T, D, I, O, f, α, β)

P = {p1, p2, . . . , pn} was a finite set of places.

T = {t1, t2, . . . , tm} was a finite set of transitions.

D = {d1, d2, . . . ,dn} was a finite set of propositions.

$P \cap T \cap D = \Phi$, $|P|=|D|$

I and O were the function of set of input and output places of transitions, where

I: P→T was the input function, a mapping from transitions to bags of places.

O: T→P was the output function, a mapping from transitions to bags of places.

f: T→[0,1] was an association function, a mapping from transitions to real values between zero and one.

α: P→[0,1] was an association function, a mapping from places to real values between zero and one.

β: P→D was an association function, a objective mapping from places to propositions.

B. Modelling of Fuzzy Petri nets

Basic steps involved in the modelling of FPN are; first extract information from experts and/or databases, and then fuzzify the information from crisp set to fuzzy set by defining membership function. Next step is to construct PN by designing rule base, and inference rules, and in the last, defuzzifiation of the results. Process is shown in Fig 1. [9]

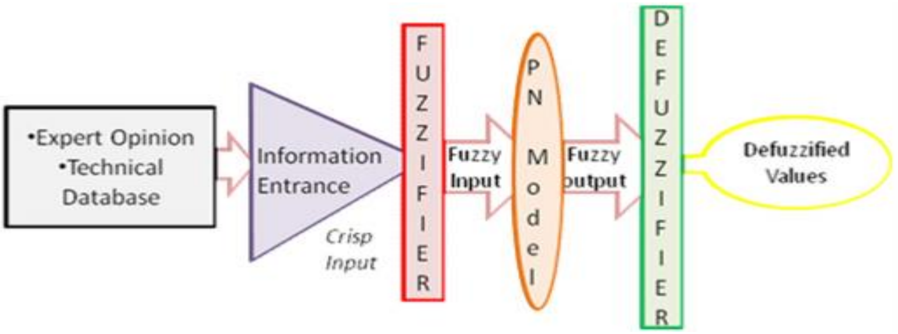

Fig. 1 Methodology of modelling Fuzzy Petri Nets

An example presented is shown in Fig. 2. It represented the relationship between fuzzy logic, and PN. In that example, there was an antecedent condition that “temperature is hot”, and its consequent was “humidity is low”.[10]

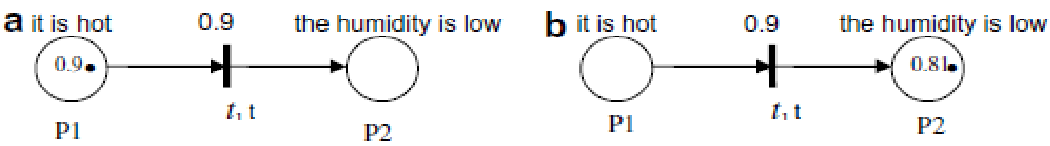

Fig. 2 Firing of Fuzzy Petri Nets; (a) before and (b) after

P={p1,p2}, T={t1}, D={it is hot, the humidity is low}

I(t1)={p1}, O(t1)={p2}

f(t1)=0.9

α(p1)=0.9, α(p2)=0

β(p1)=it is hot

β(p2)=the humidity is low

IF…THEN rule in that example was expressed as IF β1THEN β2 (CF), where β1 was antecedent qualification, β2 was consequent result, and CF was the “Certainty Factor”, a larger CF value indicated a higher certainty of the rule. In the above example “temperature is hot” with the membership degree of0.9 and CF for the truthiness of the result is 0.9, so the membership degree of the consequent that “humidity is low” was 0.81.There may be many different ways of inference of rules according to the needs of the system like MAX-operator or t-norms or s-norms, and so on. Similarly there may be number of ways of combining PN and fuzzy sets. One way is may be to define fuzzy marking by denoting place token loads by means of fuzzy numbers. Another way may be to define fuzzy marking by attaching location of fuzzy set of places to each token. Still another way is to associate fuzzy variable with tokens. It is also possible to define fuzzy firing sequence which is more or less likely to be fire. Whatever the way of combining PN with fuzzy sets maybe used, basic principles of PN had to be respected for the success of FPN [11], [12].

IV. PETRI NET CONTROL FOR THE FMS CELL

The FMS cell example used in this paper can be decomposed into the following elements: 1) robot, 2) CNC-cutting machine, 3) computer vision system, 4) conveyor systemsC1 and C2, 5) bin for discarded workpiece. The operation of the FMS cell (Fig. 3) is as follows: An incoming conveyor C1 transports the workpieces to the manufacturing cell; the robot picks the incoming material from the conveyor and feeds the CNC-cutting machine in the facility. The robot then returns to its normal position waiting for the CNC-cutting machine to complete its cycle. When the CNC-cutting machine has finished its task, the robot arm is extended to the design position where it picks up the workpiece from the CNC-cutting machine and puts it on the inspection table within the vision system for inspection. The robot then places the workpiece on the conveyor C2 or in the bin according to the decision taken by the fuzzy logic control architecture [8].

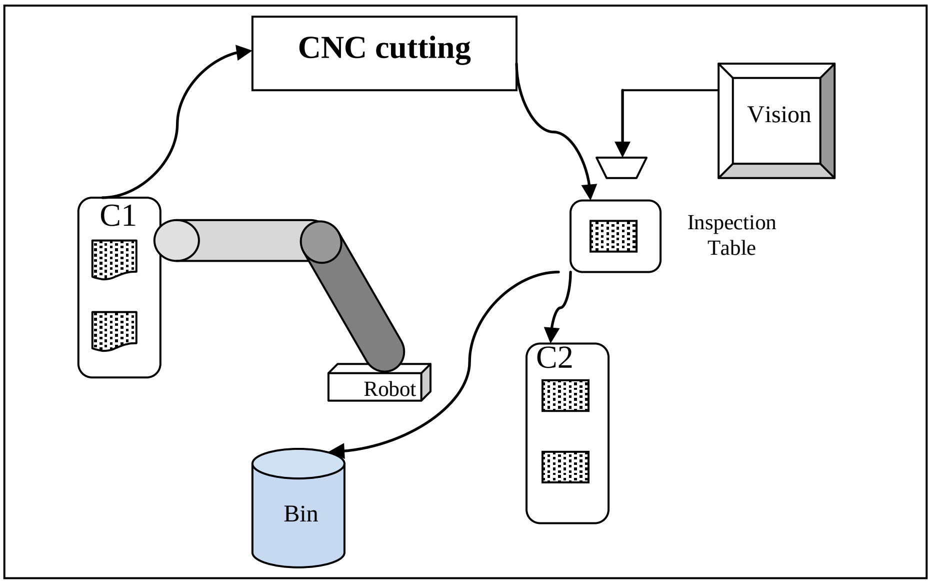

Fig3. FMS Layout

1. Pi fires automatically after the PLC powers up based on the assumption that all flags in the PLC are reset on power up,
2. Ti fires when all the s/w and h/w elements within the cell have been initialized and informs the cell control net that the initialization is complete.
3. Tr fires when all the cell elements (robot, vision system, CNC cutting machine and conveyor C1, C2) are in a safe condition and the **start** button is pressed.
4. T1 fires when the robot picks the workpiece from conveyor Cl and has placed it in the design position on the bed of the CNC- cutting machine.
5. T2fires when the CNC- cutting machine has completed its cycle.
6. T3fires when the workpiece has been placed on the vision table for inspection.
7. T4fires when the vision system **has** inspected the workpiece and the decision made to place the rejected workpiece in the bin. The methodology **used** to accomplish **this** stage is based on the Fuzzy Petri net.
8. T5 fires when the vision system has inspected the workpiece and the decision made to place the accepted workpiece on conveyor C2. The methodology **used** to accomplish **this** stage is based on the Fuzzy Petri net.
9. T6 fires when the robot **has** placed the rejected workpiece in the bin
10. T7 fires when the robot has placed the accepted workpiece on the conveyor C2.
11. T8 fires if a demand comes from the cell controller to repeat the cycle (robot picks another workpiece and places it on CNC- cutting machine).
12. T9 fires if a demand comes from the cell controller to return to (cell ready).

V. FUZZY PETRI NET

This section illustrates how the decision taken by the vision system can lead to an uncertain situation which may affect the FMS cell performance. The vision system within the cell proceeds in the following manner: Once the robot has placed the workpiece on the inspection table a signal is sent to the vision camera to it. The vision algorithm decides if the height and weight of the workpiece made by the cutting tool in the workpiece is to be accepted or rejected and the vision system outputs a signal directing the robot to put the workpiece in the bin or on the conveyor C2. An uncertain situation can arise when the robot receives ill-known knowledge from the vision system. Under these circumstances the robot may fail to identify the correct path decision i.e. put the workpiece on conveyor C2 or in the bin. To deal with this kind of uncertainty, a Fuzzy Petri net is used to monitor and control the vision system decision and determine subsequent robot action. In order to achieve this objective, fuzzy logic control architecture is constructed within the vision control Petri net (Fig. **5)** in order to control the robot action.

In this net, P2 represents the *fuzzy* logic control algorithm which:
1- Converts the input data to a *fuzzy* form (Fuzzification).
2- Evaluates the *fuzzy* control rules (Inference).
3- Computes an output value from the fuzzy value determined from 1 and 2 (Defuzzification).

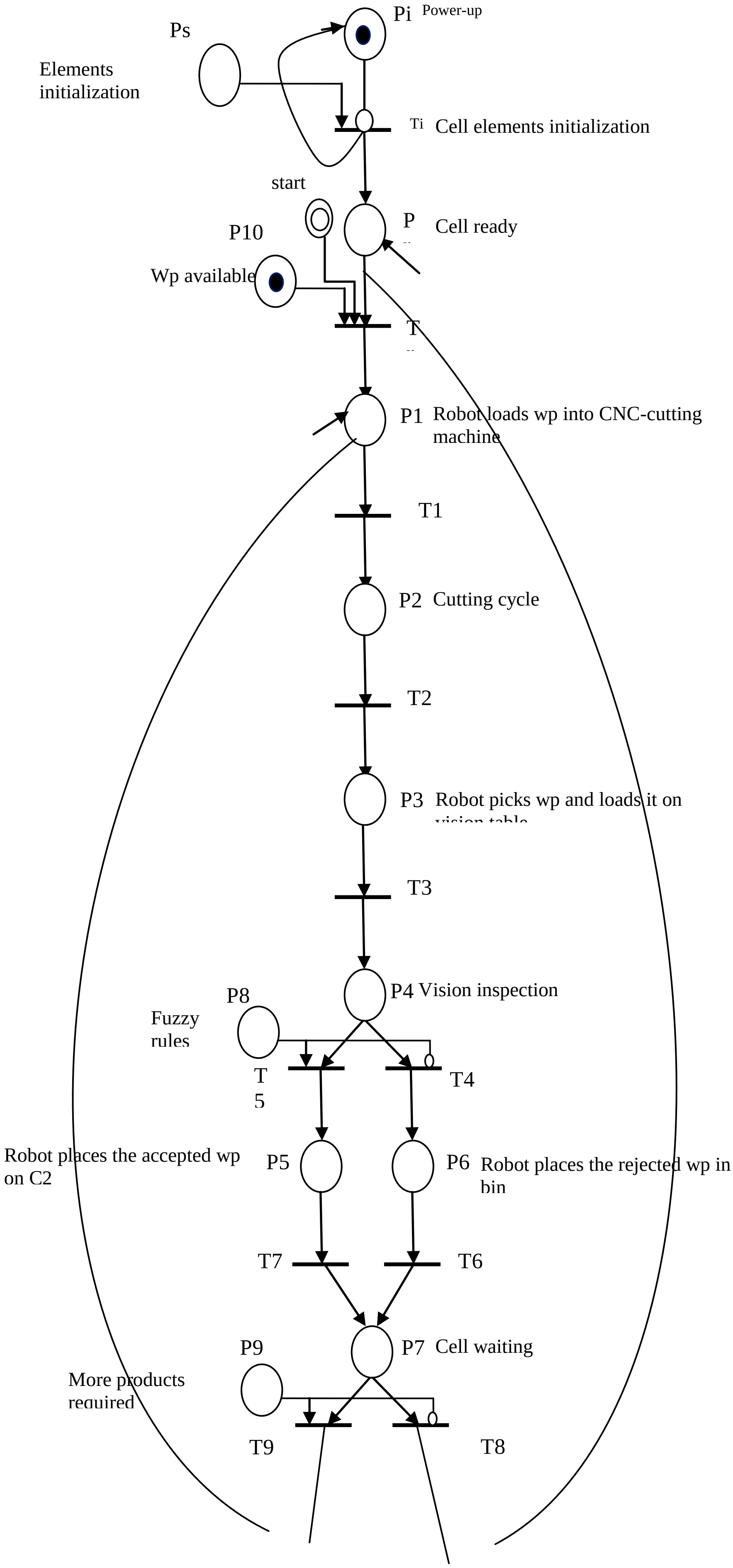

Fig 4. FMS Cell Petri Net

ACKNOWLEDGMENT

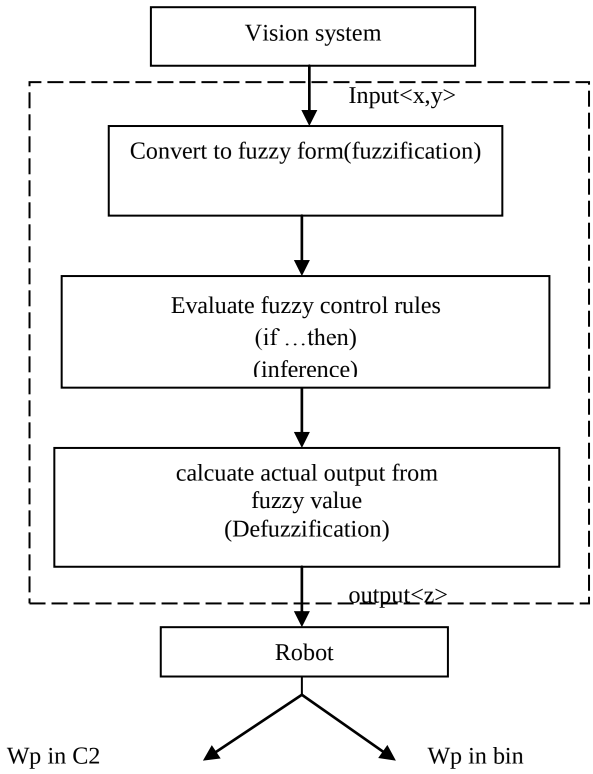

Fig5 .vision system petri net based on fuzzy logic control rchitecture

With *fuzzy* logic it is possible to interpret the fuzzy modelling in terms of a qualitative model which describes the system behavior using a natural language such as "small", "medium" or "large", similar to the way human observation can be expressed. Unlike binary logic, which can evaluate two states of events, fuzzy logic allows intermediate states to be represented and thus an object can be more than just small or large. [13]

The fuzzy logic control architecture consists of:

1-Fuzzy set: Contains the elements x_i with the degree of membership $\mu_i$belonging to them.

2-Linguistic variable: A variable word used to describe fuzzy sets for example, "small", "medium", "large".

3-Membership function: A function $\mu_s(x)$, $\mu_m(x)$**,** $\mu_h(x)$describing the members of an element x in fuzzy sets S(small)**,** M(medium)and L(Large). (Fig 7)

4-Degree of membership: Describes the association between an element x and a fuzzy set S. For example, $\mu_S(x)$ = 0.70.

5-Fuzzy operators: Combines degree of membership in logical expressions, for example, *OR / AND.*

6-Knowledge-based rule: A method similar to that used by an expert system (IF - THEN).

7-Fuzzification: Conversion of a physical input variable to a fuzzy form.

8-Fuzzy inference: Derivation of fuzzy information based on IF-THEN rules .

9-Defuzzification: The procedure to obtain a deterministic value of the output y from a fuzzy value .

The defuzzification procedure is a centre of gravity method, which can be calculated using the following equation:[13],[14]

$$z = \frac{\sum_{i=1}^{n} z_i \cdot \mu(z_i)}{\sum_{i=1}^{n} \mu(z_i)}$$

The input to the fuzzy logic control is defined by x and y (where x represents the weight and y represents the height of the workpiece as a result of the cutting operation on the workpiece) and the output from the fuzzy logic control is defined by z (where z represents the quality of the machining operation, i.e., high or low). For example, if z is ≥ 60% thisimplies the quality of the workpiece is high and consequently, the robot places it on conveyorC2. The fuzzy model on which the vision system decision is based uses six rules in this example:

IF x is small and y is small **THEN** z is low. (fig 8)

IF x is medium and y is large **THEN** z is high.

IF x is medium and y is small **THEN** z is high.

IF x is large and y is small **THEN** z is high.

IF x is medium and y is medium **THEN** z is high. (fig 8)
IF x is large and y is large **THEN** z is high.

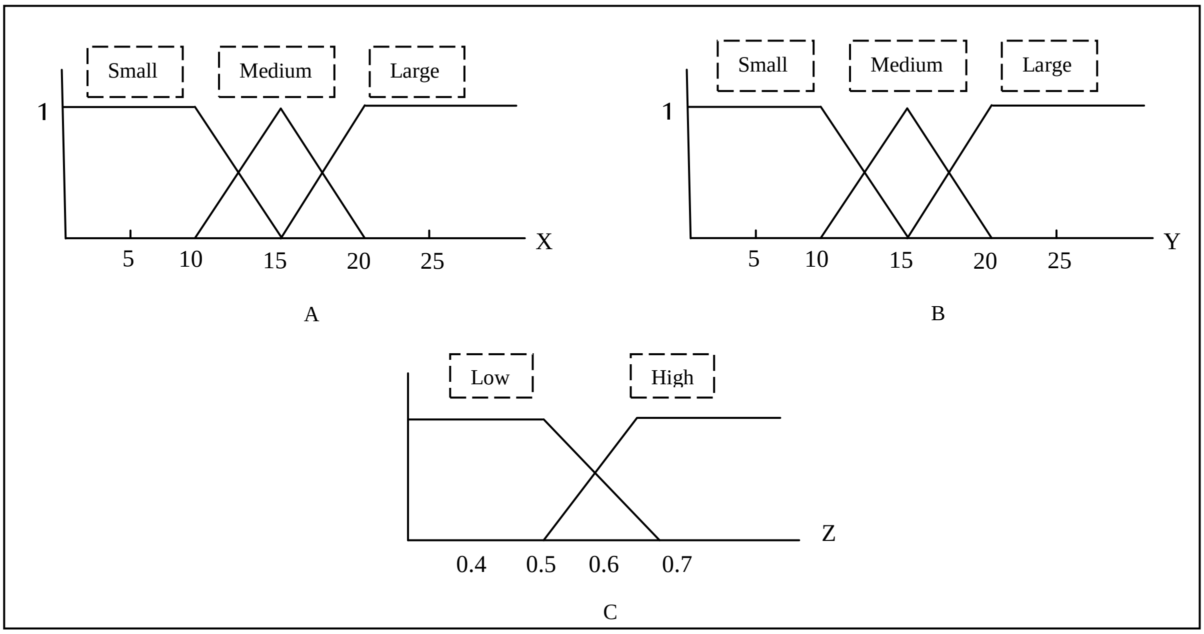

Fig 7: Fuzzy form, a: x(height), b: Y(weight), c :Z(quality)

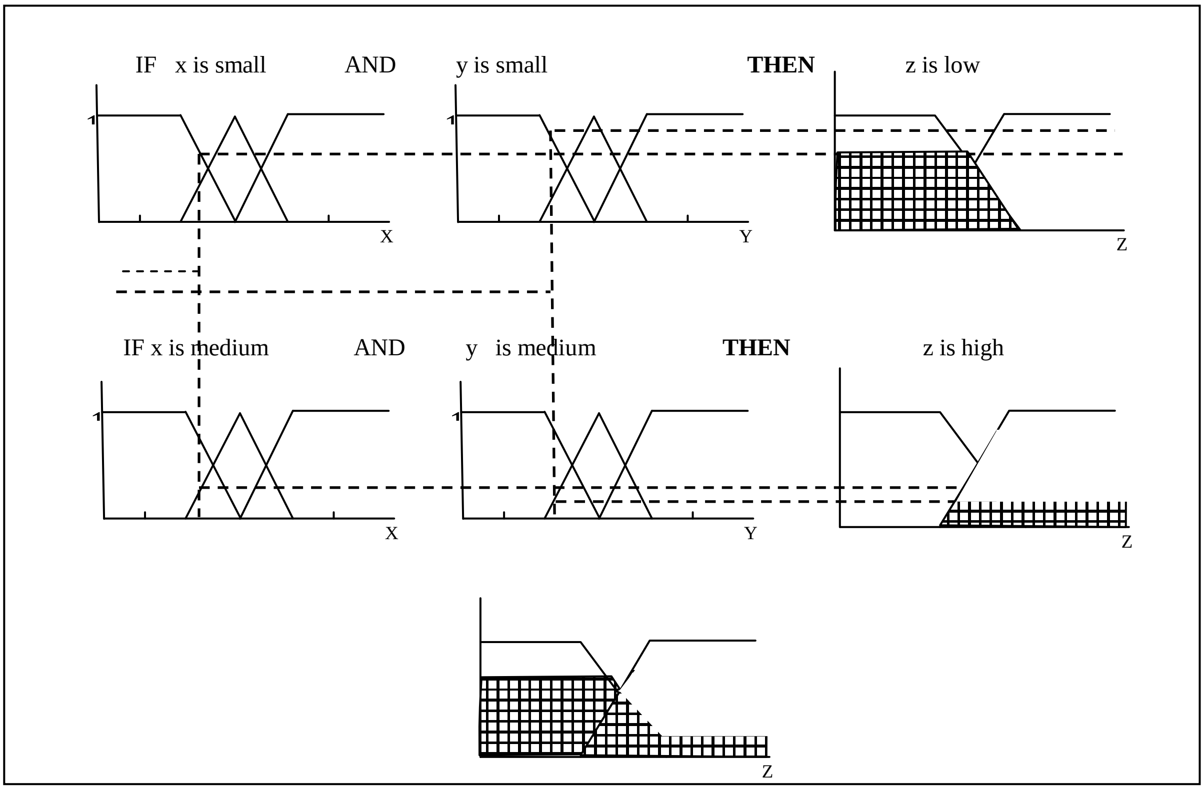

Fig8. Fuzzy controller with 2 rules

We test Fuzzy Petri net with some values for <X, Y>. First X and Y are selected in range [0 30], then we evaluate membership function μ_s ,μ_m,μ_l for X and Y. The largest membership function is selected as result for x ,y. Then, we inspection fuzzy rules and calculate output Z. Table I comprise some values for <X, Y> , and table II show the results of fuzzy rules.

TABLE I: INPUT <X, Y>

X	5	13	24	10
Y	18	16	15	8

TABLE II
FUZZY INPUT WITH DEGREE OF MEMBERSHIP

Input<X>	μ_s	μ_m	μ_h	result	Input<Y>	μ_s	μ_m	μ_h	result	Output<Z>
X_1=5	1	0	0	small	Y_1=18	0	0.4	0.5	large	high
X_2=13	0.4	0.8	0	medium	Y_2=16	0	0.9	0.1	medium	high
X_3	0	1	0	medium	Y_3	0	0	1	large	high
X_4	1	0	0	small	Y_4	1	0	0	small	low

VI. **Conclusion**

This paper discusses the problem of representation and planning of operations sequences in a robotic system using fuzzy Petri nets. The FMS cell described consist of a robot, vision system, computer numerical control (CNC) cutting machine, two conveyors and a bin. Fuzzy logic with Petri nets (Fuzzy Petri nets) has been used to model imprecise and uncertain situations which can arise within FMS's.

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