A GENERALIZED NET MODEL OF A MATERIAL-PROCESSING REACTOR EQUIPPED WITH CHROMATIC MONITORING AND CONTROL BASED ON INTUITIONISTIC FUZZY EVALUATION OF THE CHROMATICITY

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Abstract

A flow reactor for material processing monitored and controlled by a tri-stimulus chromaticity sensor is described by a generalized net. The GN model incorporates knowledge-based decision making that uses results of intuitionistic fuzzy sets evaluation of the chromaticity signal.

Keywords: generalized nets, intuitionistic fuzzy sets, chromatic monitoring, material processing reactors

1 Introduction

The flow reactor is a device used for material processing which consists of (gas or liquid) flow, input and output (Fig.1). Materials (reactants) and energy are fed at rates ***g*** and ***w*** through the input. Due to heating, mixing and chemical reactions, at the output the flow acquires certain properties such as temperatures, densities and velocities of its components. As these in most cases are not directly measurable, indicators for the reactor operation are parameters measured by a special device (monitor) - e.g. chromaticity parameters *R, G, B* [1]. The monitor gives out information to the "operator" (human or machine), which provides feedback for control purposes (Fig.1).
Reactors of this scheme have been employed in a number of technological processes [2]. The output flow must have specific properties in order to ensure high quality end product. In large scale industrial applications on-line inspection of the product is not an option. The alternative is to use the monitor data *R, G, B* (Fig.1) after *preliminary tests* made in order to correlate these with the end product quality. Other tests that find relations to the inputs ***g*** and ***w*** are to be run regularly (*regular tests*).
Our first GN model of flow reactors has recently been proposed [3]. Here an alternative model is presented with an emphasis not only on decision making, but also on intuitionistic fuzzy evaluation.

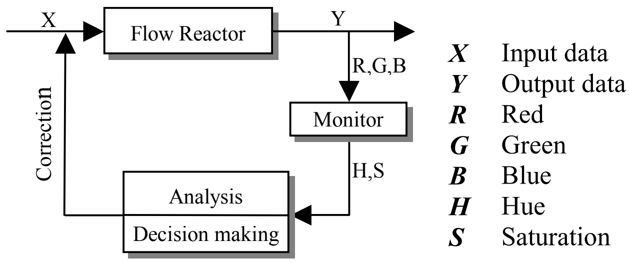

Figure 1: Flow reactor system: schematic diagram

2 Short remarks on generalized nets and intuitionistic fuzzy sets

2.1. The concept of a Generalized Net (GN) is described in [4]. A given GN may not have some of the components, and such GNs give rise to special classes of GNs called "reduced GNs". For the needs of the present research we shall use (and describe) a reduced GN. The way of defining the GNs is principally different from the ways of defining the other types of Petri nets. The first basic difference between GNs and the ordinary Petri nets is the "place - transition" relation. Here, transitions are objects of a more complex nature.
Formally, every GN-transition is described by a seven-tuple, but here we shall discuss its reduced form

$$Z = < L', L'', r >,$$

where:

a) **L′** and **L″** are finite, non-empty sets of places (the transition's input and output places, respectively);
b) **r** is the transition's condition determining the tokens which will transfer from the transition's inputs to its outputs; it has the form of an index matrix (see [4]):

$$r_{i,j}= \begin{array}{c|ccccc} & L''_1 & \dots & L''_j & \dots & L''_n \\ \hline L'_1 & & & & & \\ \vdots & & & & & \\ L'_i & & & r_{i,j} & & \\ \vdots & & & & & \\ L'_m & & & & & \end{array}$$

where $r_{i,j}$ ($1 \le i \le m$; $1 \le j \le n$) are predicates and ***(i,j)*** denotes the element which corresponds to the ***i***-th input and ***j***-th output places; these elements are predicates and when the truth value of the ***(i,j)***-th element is true, the token from ***i***-th input place can be transferred to ***j***-th output place; otherwise, this is not possible.
The ordered four-tuple (also for the reducing case):

$$E= < A, K, X, \Phi>$$

is called a *reduced Generalized Net*, if:
a) ***A*** is a set of transitions;
b) ***K*** is the set of the GN's tokens;
c) ***X*** is the set of all initial characteristics the tokens can receive on entering the net;
d) ***Φ*** is a characteristic function which gives new characteristic to every token when it makes a transfer from an input to an output place of a given transition.

2.2. Here, we shall introduce some elements of the intuitionistic fuzzy logic (see [5]).
To each proposition (in the classical sense) we can assign its truth value: truth - denoted by ***1***, or falsity - ***0***. In the case of fuzzy logic this truth value is a real number in the interval **[0,1]** and may be called ***degree of validity*** of a particular proposition.
Here, we add one more value - ***degree of non-validity*** - which will be in the interval [0,1] as well. Thus two real numbers, ***μ(p)*** and ***ν(p)***, are assigned to the proposition ***p*** with the following constraint to hold: $\mu(p) + \nu(p) \le 1$. Let this assignment be provided by an evaluation function ***V*** defined over a set of propositions ***S*** in such a way that:

$$V(p) = <\mu(p), \nu(p) >.$$

Let

$$\pi(p) = 1 - \mu(p) - \nu(p).$$

Therefore, ***π(p)*** in **[0, 1]** is the ***degree of uncertainty***.

3 A generalized net model

The graphical structure of the GN model for a reactor with chromatic monitoring and control is shown in Fig.2. The net includes 6 transitions and 14 places, from which 2 inputs and 2 outputs. The tokens enter the input places with initial characteristics.

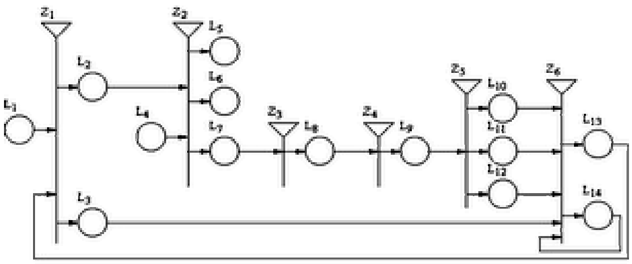

Figure2: GN model

The meaning of the positions is as follows:

L_1 – Initial parameters (***g*** – gas flow rate, ***w*** – power);
L_2 – Controlled input parameters (***g, w***);
L_3 – Without characteristic
L_4 – Other input parameter e.g. cooling agent;
L_5 – Product;
L_6 – Material and power losses;
L_7 – Chromaticity vector [*R G B*] (Red, Green, Blue);
L_8 – Chromaticity vector [*H S*] (Hue, Saturation);
L_9 – Intuitionistic fuzzy evaluation of results;
L_{10} – Evaluation in area 1 (Fig.3);
L_{11} - Evaluation in area 2 (Fig.3);
L_{12} - Evaluation in area 3 (Fig.3);
L_{13} – Knowledge based decision for correctives;
L_{14} – Data Base (incl. results of preliminary and regular tests, see Introduction).

The transitions and their index matrices and predicates are shown in Table 1, where:

"Evaluation in area 1" $\Delta g=0$ and $\Delta w=0$;

"Evaluation in area 2" $\{g,w\}=F\{H,S\}$,

$$\Delta g = \frac{\partial F_1}{\partial H}\Delta H + \frac{\partial F_1}{\partial S}\Delta S \text{ and } \Delta w = \frac{\partial F_2}{\partial H}\Delta H + \frac{\partial F_2}{\partial S}\Delta S$$

"Evaluation in area 3" $\Delta g=-g$ and $\Delta w=-w$.

Table 1: Descriprion of the transitions, with their index matrices and predicates

	Transitions, index matrices and predicates
1	Input and correctives $z_1 = \langle \{L_1, L_{13}\}, \{L_2, L_3\}, r_1 \rangle$ $\begin{array}{c\|cc} & L_2 & L_3 \\ \hline L_1 & W_{1,2} & F \\ L_{13} & F & T \end{array}$ $W_{1,2}$ = “Token from position L_1 enters position L_2 with characteristic depending on current characteristic of token in position L_{13}”
2	Flow reactor $z_2 = \langle \{L_2, L_4\}, \{L_5, L_6, L_7\}, r_2 \rangle$ $\begin{array}{c\|ccc} & L_5 & L_6 & L_7 \\ \hline L_2 & T & T & T \\ L_4 & F & T & F \end{array}$
3	Calculation of ***H*** and ***S*** $z_3 = \langle \{L_7\}, \{L_8\}, r_3 \rangle$ $\begin{array}{c\|c} & L_8 \\ \hline L_7 & T \end{array}$
4	Estimation of fuzziness in chromaticity vector $z_4 = \langle \{L_8\}, \{L_9\}, r_4 \rangle$ $\begin{array}{c\|c} & L_9 \\ \hline L_8 & T \end{array}$
5	Evaluation and classification of operating regime by use of chromaticity $z_5 = \langle \{L_9\}, \{L_{10}, L_{11}, L_{12}\}, r_5 \rangle$ $\begin{array}{c\|ccc} & L_{10} & L_{11} & L_{12} \\ \hline L_9 & W_{9,10} & W_{9,11} & W_{9,12} \end{array}$ $W_{9,10}$=”Evaluation in area 1” $W_{9,11}$=”Evaluation in area 2” $W_{9,12}$=”Evaluation in area 3”
6	Decision making $z_6 = \langle \{L_3, L_{10}, L_{11}, L_{12}, L_{14}\}, \{L_{13}, L_{14}\}, r_6 \rangle$ $\begin{array}{c\|cc} & L_{13} & L_{14} \\ \hline L_3 & F & T \\ \hline L_{10} & T & F \\ \hline L_{11} & T & F \\ \hline L_{12} & T & F \\ \hline L_{14} & F & T \end{array}$

4 Intuitionistic fuzzy evaluation of chromaticity vector <H,S>

In the HS plane there have been experimentally determined three limit areas – concentric circles, as it is shown on Figure 3. We assume that if the value of $<H,S>$ is in limit circle 1, the quality of the product is good, if it is outside circle 1 and inside circle 2 then some adjustments to the input parameters should be made, and, finally, if the value is outside circle 2 – the quality is bad. Let $<H_0,S_0>$ be the common centre of the circles and $<H,S>$ is the received chromaticity (see Figure 3). Let

$$x = \sqrt{(H - H_0)^2 + (S - S_0)^2}$$

be the Eucledian distance of $<H,S>$ to $<H_0,S_0>$. We use intuitionistic fuzzy (IF) evaluation of the validity of the product, according to the chromaticity measurement. Let us assume that the radii of the circles 1, 2 and 3 are *a*, *b* and *c*, respectively and *r* is the radius of the small shaded circle, where possible values of different measures are distributed. As the circle is on the boundary between two limit areas, we have uncertainty in the decision to which limit area the measurement belongs. In order to model this degree of uncertainty, we use an IF evaluation, according to the position of the circle, i.e. the distance *x*.

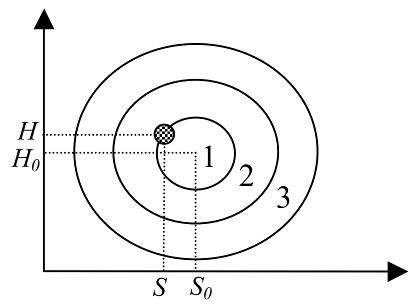

Figure 3: Regions of reactor operation in the HS plane

In our example we use piecewise linear dependency, as shown in Table 2.

Table 2: Piecewise linear dependency used in intuitionistic fuzzy evaluation

$\langle 1,0 \rangle$	$0 \le x \le a - r$

$\left\langle 1-\frac{\gamma}{r}(x-(a-r)),0\right\rangle$	$a - r \le x \le a$
$\left\langle 1-\frac{\gamma}{r}(x-(a-r)),2\frac{\gamma}{r}(x-a)\right\rangle$	$a \le x \le a + r$
$\left\langle 2\delta+\frac{(b-r)-x}{(b-a)-2r}(1-2(\gamma+\delta)), (1-2\delta)-\frac{(b-r)-x}{(b-a)-2r}(1-2(\gamma+\delta))\right\rangle$	$a + r \le x \le b - r$
$\left\langle 2\frac{\delta}{r}(b-x),1-\frac{\delta}{r}((b+r)-x)\right\rangle$	$b - r \le x \le b$
$\left\langle 0,1-\frac{\delta}{r}((b+r)-x)\right\rangle$	$b \le x \le b + r$
$\left\langle 0,1\right\rangle$	$b + r \le x \le c$

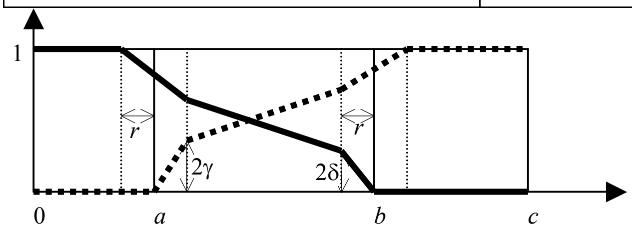

Figure 4: Graphic of the dependency of the degrees of validity and non-validity on the distance *x*

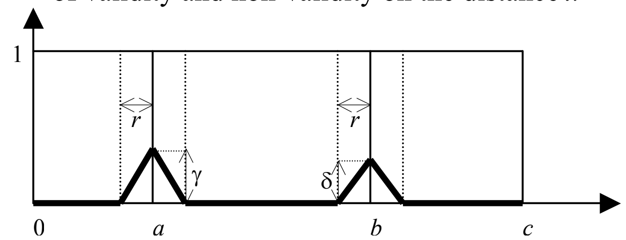

Figure 5: Graphic of the dependency of the degree of uncertainty on the distance *x*

When the circle crosses the boundary between limit areas 1 and 2, i.e. $|x - a| \le r$, we have degree of uncertainty γ. Similarly, when $|x - b| \le r$, we have degree of uncertainty δ. With all other values of *x* we have degree of uncertainty 0, i.e. classical fuzziness. The distribution of IF values as well as degrees of uncertainty are shown in Figures 4, 5.

It is stipulated that γ and δ are proportional to *r/a* and *r/(b-a)*, respectively. An example for the degree of uncertainty is:

$$\gamma = k\frac{r}{a} \text{ and } \delta = k\frac{r}{b-a},$$

where *k* is determined in such a way that (γ + δ) < 0.5. As γ and δ vary with the value of *r*, we obtain different evaluations.

5 Conclusions

Along with the basic structure and behaviour of a flow-type material processing system provided with a means for monitoring and control, the present model incorporates knowledge-based decision making. The latter feature is further elaborated to take into account the superposition of fuzziness due to two effects: statistical fluctuations in the monitor output signal and finite size of the region of "correct operation".

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