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GENERALIZED NETS MODELLING AND CONTROL OF MODULAR MOBILE ROBOTIC SYSTEM

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Abstract: Modular Robotic Systems (MRSs) are entities, composed of units, that can be reconfigured independently for group (swarm), solving different tasks. These robots have many potential applications in hazardous and unknown environments like exploration of other planets in the universe. Such systems have to be able to deal with dynamic changes in the environment that potentially lead to failures and goal changes. Groups of robots will need to plan, execute, and then re-plan in real-time, while simultaneously being robust enough to avoid robot damage and complete mission failure.

Generalized Nets (GNs), on the other hand, are ascertained at the present paper because they have proved to be very useful and convenient tool for description, modelling and training of different elements from the Artificial Intelligence area, including robotics.

The paper will discuss some possibilities and results for Generalized Nets representation, modelling and control of mobile modular robotic systems.

Key words: generalized nets, modular robots, modelling, simulation, control

1.Introduction

Modular Robotic Systems (MRSs) are a collection of autonomous controlled units capable to connect, disconnect, and climb over adjacent units or to move independently [5], [6], [24]. These systems have a lot of possible applications in hazardous and unknown environments in other planet investigation in the universe [23], [25].

They could also be utilized in the following applications: obstacle avoidance in highly constrained and hostile environments (under the sea, at the scene of natural calamities), growing structures (consisting of different units for building bridges, buttresses and other civil structures), in the military area (systems for reconnaissance and neutralization) [5], [22].

The present paper will be based on the idea of considering different units from MRSs as elements (agents) that are part of an abstract multi-agent system, desribed in Genaralized Nets terms.

The theory of Multi-Agent Systems (MAS) is an extension of Artificial Intelligence (AI) theory but concerns distributed AI in multiple reasoners [8].

Although there is no global ascendancy in MASs and the agents are communicating with intrinsic mechanisms like *negotiations* or *collaborations* for common goal achievements, the present paper is also based on some hierarchical notations [8] for modelling and control - rather similar to the idea of *prominence* [18].

For more than a decade of years these robots have been formally divided in three main groups:

- lattice type systems;
- chain (string) type systems;
- mobile type systems.

The lattice type robots change their shape by moving into positions on a virtual grid or lattice. Like chain robots, all the modules remain attached to the robot. The lattice element possesses a spatial symmetry in accordance to its structure and it could be of 2D or 3D-type, [10], [15], [20], [21], [24].

The chain type robotic systems create themselves by attaching and detaching chains of modules to and from themselves, with each chain always attached to the rest of the modules at one or more points. Nothing ever moves off on its own. Some practical implementation of these robots could be found in [6], [7], [16], [17].

The mobile type of modular robots, change their shape by detaching and moving modules from their main body and linking up at a new location in order to form new configurations or to share a common goal achievement without any links, but by utilizing information exchange techniques [4], [9], [13], [14], [23].

Generalized Nets (GNs) [1] - an extension of Petri nets [19], from the other hand, are a convenient tool for modelling, simulation, optimization and control of different parallel processes from the artificial intelligence area [2], [11], [12], [14].

The present paper will describe a GN model for modelling and control of the third type of MRSs-mobile MRS. The model is based on the IFS algorithm, described in [13].

2. A common GN model of a single module from an abstract MRS

A common GN model of a single module from an abstract MRS will be described in this section. The model is not considering any definite type of MRS but describes only the most general features necessary to a single module, which is a part of MRS and communicates with it.

Symbols and signatures could be found in [1].

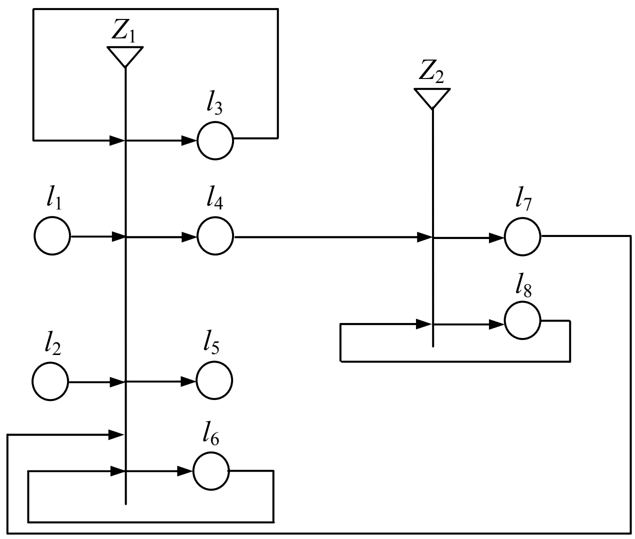

Fig.1. A GN model of a single module from an abstract MRS

This GN model of a single abstract module contains two transitions - Z_1 and Z_2. The first one represents module’s (agent 's) intelligent part and the second one - his effectors.

Transition Z_1 has the following structure:

$$Z_1 = \langle \{l_1, l_2, l_3, l_6, l_7\}, \{l_3, l_4, l_5, l_6\}, r_1, \vee(l_1, l_2, l_3, l_6, l_7)\rangle,$$

where:

$r_1 =$		l_3	l_4	l_5	l_6
	l_1	$W_{1,3}$	*false*	*false*	*false*
	l_2	*false*	*false*	*false*	$W_{2,6}$
	l_3	*true*	*false*	*false*	$W_{3,6}$
	l_6	*false*	$W_{6,4}$	*false*	*true*
	l_7	*false*	*false*	$W_{7,5}$	*false*

and: $W_{1,3}$ = "present module is switched on", $W_{2,6}$ = "other MRS modules are switched on", $W_{3,6}$ = "information for the external environment current state is already processed", $W_{6,4}$ = "present module has taken an action decision", $W_{7,5}$ = "other MRS modules require information for the present module".

Transition Z_2 has the following structure:

$Z_2 = \langle\{l_4, l_8\}, \{l_7, l_8\}, r_2, \vee(l_4, l_8)\rangle$,

where:

$r_2 =$		l_7	l_8
	l_4	$W_{4,7}$	$W_{4,8}$
	l_8	*false*	*true*

and: $W_{4,7}$ = "module's effectors have reached the new desired state", $W_{4,8}$ = "module's effectors are switched on".

2.1. Model work

The GN model work will be described in 6 steps that considers one loop of its work. This loop could be repeated from the beginning if the number of time steps should be extended k times, i.e. $t^* = k.6$, where t^* has the sense of [1]

For further description of GN model work it is assumed that tokens ψ, ξ, λ are already in places: l_3, l_6 and l_8 (transitions Z_1 and Z_2) with the following initial characteristics: X_0^ψ = "external environment previous state", X_0^ξ = "other MRS modules previous state" and X_0^λ = "module's effectors previous state".

Step I: Tokens α and β enter places l_1 and l_2 of transition Z_1 with the following initial characteristics:

X_0^α = "raw external environment current state information";

X_0^β = "raw MRS modules current state information".

Step II: Token α enters place l_3 (transition Z_1), and unites with token ψ. Token β, enters place l_6 (transition Z_1) and unites with token ξ. This is conceivable if predicates: $W_{1,3}$ = "present module is switched on" and $W_{2,6}$ = "other MRS modules are switched on" are true.

The new characteristics of tokens ψ and ξ are:

X_1^ψ = "processed external environment current state information";

X_1^ξ = "processed MRS modules current state information".

Step III: Token ψ is divided into two new tokens - ψ and γ. The first token (ψ) stays at place l_3 (transition Z_1) during the GN work like a memory for the external environment states, and the second one (γ) enters place l_6 (transition Z_1). This is conceivable if predicate: $W_{3,6}$ = "information for the external environment current state is already processed" is true.

The initial characteristic of token γ is:

X_0^{γ} = "processed external environment current state information".

Step IV: Token γ unites with token ξ and token ξ is divided into two new tokens - ξ and δ. Token ξ stays at place l_6 (transition Z_1) during the GN work like a memory for other MRS modules states, and token δ enters place l_4 (transitions' couple Z_1 - Z_2). This is conceivable if predicate: $W_{6,4}$ = "present module has taken an action decision" is true.

Token δ obtains the following initial characteristic:

X_0^{δ}= "module's effectors new desired state".

Step V: Token δ is divided into two new tokens δ and χ. Token δ enters place l_7 and token χ enters place l_8 and unites with the token λ. This is conceivable if predicates: $W_{4,7}$ = "module's effectors have reached the new desired state" and $W_{4,8}$ = "module's effectors are switched on" are true.

Tokens δ and λ obtain the following new characteristics:

X_1^{δ}= "module's effectors current state".
X_1^{λ} = "module's effectors current state".

Step VI: Token δ enters place l_5 (transition Z_1). This is conceivable if predicate $W_{7,5}$ = "other MRS modules require information for the present module" is true.

Token δ obtains the following new characteristic:

X_2^{δ}= "module's current state".

The revealed GN model of a single agent could be implemented in another GN model for control of a group (swarm) of Mobile MRS (MMRS) by utilizing some of the hierarchical operators defined over GNs. In the present paper the H_6 operator has been chosen because it is a new one [3] for GNs and is very flexible, compared to the other operators defined over GNs (see next section).

3. Short description of H_6 operator

Over GNs there have been defined six groups of operators [1] - global, local hierarchical, reducing, extending and dynamic. They do not exist either for ordinary Petri nets, nor for some of their extensions, but could be transformed for them (where it is possible).

Hierarchical operators are forming one of these groups. They are divided into two main groups - shrinking (H_2, H_4 and H_5) and extending (H_1, H_3, H_5, H_6) operators.

In accordance with the object of influence they are divided into three main groups: acting upon or giving as a result a place (H_1 and H_2), a transition (H_3, H_4 and H_5) or even a subnet (H_5 and H_6).

Operators H_1 and H_3 transform a place (H_1) or a transition (H_3) of a given GN to a new GN (that becomes a subnet of the first one). On the contrary, operators H_2 and H_4 replace a subnet of a given GN with a new place (H_2) or a new transition (H_4). Finally, operator H_5 replace one subnet with another and operator H_6 replace a token from one GN with a brand new subnet (see below).

Tokens in generalized nets are among their most important components because they are responsible for the information exchange in the net. Token (in GN) is an object, which enters GN with an initial characteristic and during his motion (in the GN) obtains new characteristics, while keeping all it's previous.

So, we could use GN-tokens as an interpretation of different complex objects, including whole GNs.

As it was mentioned above, the sixth hierarchical operator H_6 transforms a certain GN token that is in some place of the GN to a brand new GN for a given time moment and period.

This gives a possibility to construct a GN, which contains other GNs as subnets that will be accomplished in different situations (time moments) if needed.

After [3], the H_6 operator has the following graphical definition:

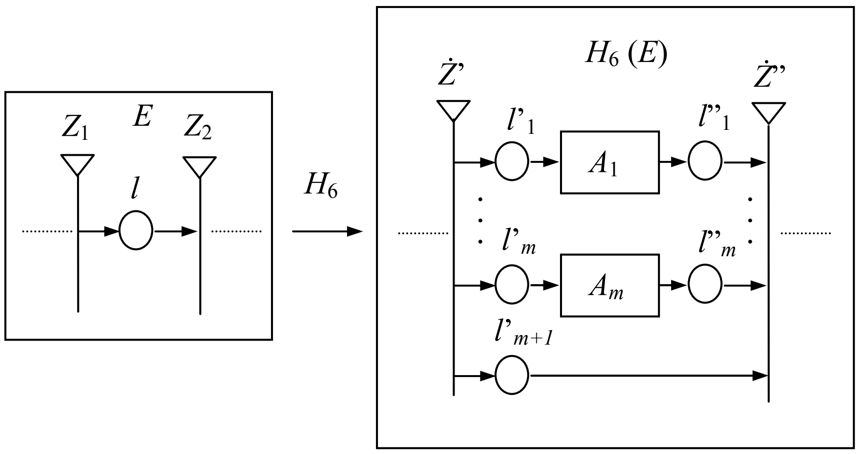

Fig.2. A graphical interpretation of H_6 operator

where: transitions' couple: Z_1 - Z_2 and place l are an abstract initial example; m is the number of tokens: $\alpha_1,\ldots,\alpha_m$ that will be transformed into: $A_1,\ldots,A_m$ GNs; $l'_1,\ldots,l'_m$ and $l''_1,\ldots,l''_m$ are the output and input places of two abstract transitions: $\dot{Z}'$ and $\dot{Z}''$ [3].

It is important to notice that the application of H_6 operator is also possible for one place of a given transition. So, you could extend any token that is a member of a GN without any necessity for adding auxiliary components that represent the relations between nets. By utilizing H_6 operator, the basic GN will be changed only in the point, where the token of interest is placed.

4. A GN model for control of a Mobile Modular Robotic System - MMRS

As it was mentioned in section 1, the model that will be revealed here is based on the Intuitionistic Fuzzy Sets (IFS) algorithm for control of MRS, described in [13] and in some sense is an extension of the GN model described in section 2 (see below).

The model consists of three basic transitions. Transition Z_1 describes an action selector that determines the action of the MMRS in accordance with its state. The possible states of the whole system are generalized to S, where: S = {IFS square construction, IFS square investigation, IFS positions optimization}. These states are defined in accordance with [13]. Similar to S, possible actions for each of the modules, could be generalized to A, where: A = {initialize module, move to coordinates (x,y), stop at coordinates (x,y)}.

Transition Z_2 describes a low level action translator with memory that transforms a certain action into an equivalent machine code. Finally, transition Z_3 describes a generalized MMRS with a feedback to the action's translator Z_2 memory (place l_5) for control of the action execution. Additionally, it should be noted that each of the tokens that are in places $l_{5,1}$, …., $l_{5,m}$ could be extended to the GN model of a single module from section 2.

The GN model for control of a MMRS is depicted in Fig. 3:

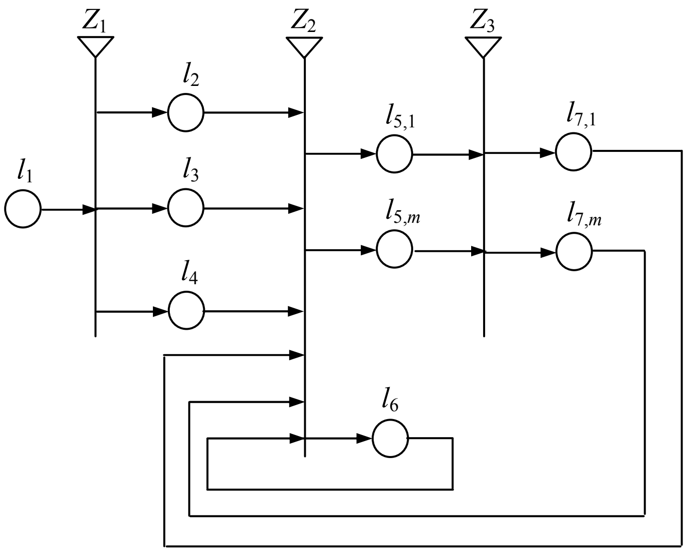

Fig.3. A GN model for control of MMRS

Transition Z_1 has the following structure:

$$Z_1 = \langle \{l_1\}, \{l_2, l_3, l_4\}, r_1 \rangle,$$

where:

r_1 =

	l_2	l_3	l_4
l_1	$W_{1,2}$	$W_{1,3}$	$W_{1,4}$

and: $W_{1,2}$ = "current state s = pr$_1$ S", $W_{1,3}$ = "current state s = pr$_2$ S", $W_{1,4}$ = "current state s = pr$_3$ S", S = {IFS square construction, IFS square investigation, IFS positions optimization} [13].

Transition Z_2 has the following structure:

$$Z_2 = \langle \{ l_2, l_3, l_4, l_6, l_{7,1},\ldots, l_{7,m}\}, \{ l_{5,1},\ldots, l_{5,m}, l_6\}, r_2 \rangle,$$

where:

r_2 =

	$l_{5,1}$	…	$l_{5,m}$	l_6
l_2	*false*	…	*false*	$W_{2,6}$
l_3	*false*	…	*false*	$W_{3,6}$
l_4	*false*	…	*false*	$W_{4,6}$
l_6	$W_{6,5,1}$	…	$W_{6,5,m}$	*true*
$l_{7,1}$	*false*	…	*false*	$W_{7,1,6}$
…	…	…	…	…
$l_{7,m}$	*false*	…	*false*	$W_{7,m,6}$

and: $W_{2,6}$ = "token α is in place l_2", $W_{3,6}$ = "token α is in place l_3", $W_{4,6}$ = "token α is in place l_4", $W_{6,5,i}$ = "token γ_i is in place l_6", $W_{7,i,6}$ = "token γ_i is in place $l_{7,i}$", $i = 1, 2, \ldots, m$, $m \in \boldsymbol{N}$.

Transition Z_3 has the following structure:

$$Z_3 = \langle \{l_{5,1}, \ldots, l_{5,m}\}, \{l_{7,1}, \ldots, l_{7,m}\}, r_3, \wedge(l_{5,1}, \ldots, l_{5,m}) \rangle,$$

where:

$$r_3 = \begin{array}{c|ccc} & l_{7,1} & \ldots & l_{7,m} \\ \hline l_{5,1} & W_{5,1,7,1} & \ldots & W_{5,1,7,m} \\ \ldots & \ldots & \ldots & \ldots \\ l_{5,m} & W_{5,m,7,1} & \ldots & W_{5,m,7,m} \end{array}$$

and: $W_{5,i,7,i}$ = "token γ_i is in place $l_{5,i}$", $i = 1, 2, \ldots, m$, $m \in \boldsymbol{N}$.

4.1. Model work

The model work will be described in 6 steps that considers one loop of its work. This loop could be repeated from the beginning if the number of time steps should be extended k times, i.e. $t^* = k.6$, where t^* has the sense of [1].

For further description of GN model work it is assumed that token β is already in place l_6 of transition Z_2 with the following initial characteristic: X_0^{β} = " a ", $a = pr_1 A$, A = {initialize module, move to coordinates (x,y), stop at coordinates (x,y)}. It should also be noted that in this GN model it is accepted that the execution of a certain action a ($a \in A$) is possible for one step.

Step I: Token α enters place l_1 of transition Z_1 with the following characteristic:

X_0^{α} = "information for the MMRS".

Step II: Token α enters some of the places: l_2, l_3 or l_4 (of transitions Z_1 - Z_2 couple). This is conceivable if some of predicates: $W_{1,2}$ = "current state $s = pr_1\ S$", $W_{1,3}$ = "current state $s = pr_2\ S$", $W_{1,4}$ = "current state $s = pr_3\ S$", S = {IFS square construction, IFS square investigation, IFS positions optimization}, [13], is true.

The new characteristic of token α is:

X_1^{α} = "s", $s \in S$.

Step III: Token α enters place l_6 of transition Z_2 where it unites with token β. This is conceivable if some of predicates: $W_{2,6}$ = "token α is in place l_2", $W_{3,6}$ = "token α is in place l_3", $W_{4,6}$ = "token α is in place l_4", $W_{6,5,i}$ = "token γ_i is in place l_6", $W_{7,i,6}$ = "token γ_i is in place $l_{7,i}$", ($i = 1, 2, \ldots, m$, $m \in \boldsymbol{N}$), is true.

The new characteristic of token β is:

X_1^{β} = "*s* and execution of *a* is not finished", $s \in S$, where *S* has the sense from the previous step and $a = \text{pr}_j A$, *A* = {initialize module, move to coordinates (x,y), stop at coordinates (x, y)}, *j* = 2, 3.

Step IV: Token β is divided into *m* new tokens - γ_i that enter places $l_{5,i}$ (transitions Z_2 - Z_3). This is conceivable if some of predicates: $W_{5,i,7,i}$ = "token γ_i is in place $l_{5,i}$" ", ($i = 1, 2, \ldots, m$, $m \in \boldsymbol{N}$), is true.

Tokens γ_i obtain the following initial characteristics:

$X_0^{\gamma_i}$ = "execute action *a* with respect to *s*", $i = 1, 2, \ldots, m$, $m \in \boldsymbol{N}$, $a \in A$ and $s \in S$.

Step V: Tokens γ_i enter places $l_{7,i}$ (transitions Z_2 - Z_3). This is conceivable if some of predicates: $W_{5,i,7,i}$ = "token γ_i is in place $l_{5,i}$", ($i = 1, 2, \ldots, m$, $m \in \boldsymbol{N}$), is true.

Tokens γ_i obtain the following new characteristic:

$X_1^{\gamma_i}$ = "machine equivalent of *a*", $a \in A$.

Step VI: Tokens γ_i enter place l_6 of transition Z_2 where they unite with token β. This is conceivable if some of predicates: $W_{7,i,6}$ = "token γ_i is in place $l_{7,i}$", ($i = 1, 2, \ldots, m$, $m \in \boldsymbol{N}$), is true.

Token β obtains the following new characteristic:

X_2^{β} = "*s* and execution of *a* is finished", $s \in S$, where *S* has the sense from the previous step.

5.Conclusion

The revealed GN models give a possibility for detail and common description modules that are part of MMRS and could be reckoned as agents. Above all, it is also possible to extend the model from section 4 by the model from section 2 due to the application of the hierarchical operator - H_6. This allows creation of simple GNs models predisposed to later enlargement of their abilities with the help of preliminary defined algorithms, described in GN terms.

So, GNs could be considered as a simple and flexible likelihood for modelling, optimization and control of real Modular Robotic Systems.

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