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ALGORITHM FOR COMPACTING A THREE DIMENSIONAL PETRI NETWORK THAT SIMULATES THE RECONFIGURABLE MANUFACTURING SYSTEM OPERATION

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Abstract. The reconfigurable manufacturing system (RMS) involves the capability of the system to change its physical structure (reposition of resource and modification of their functionality, for example) in order to adapt them for new production standards or to process new type of parts. Modeling RMS functionality is possible using the existing Petri nets, but the dynamics and complexity of the system, generated by its reconfigurability features, needs a more compact representation, with more variables, in order to shape more accurate the normal functioning of RMS and to monitor and model the reconfiguring processes inside the system. The whole process can be modulated by associating a generic tridimensional developed Petri net (PN3D) to each of the system's resource and each technological operation, which differ only by parameters and status. These generic PN3Ds can be predefined, editable and saved as modules, the individual values for the working parameters of the product as well its manufacturing process being stored in a database. Modeling the manufacturing of a simple product (5-6 technological processes for 2-3 machine tools, controlled by an industrial robot, with stocks for finished and semi-finished parts plus the necessary connections for non blocking the system and error correction subnets) with a classical Petri net would produce a model with tens of positions and transitions and thousands of connections between

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them. Such a model would have a dominant vertical representation, with a ratio of 6÷20 between the axes, the entire net being difficult to read. To manufacture a complex product (involving tens of technological operations, tens of machine tools, industrial robots, elements of transportation and stock systems, etc. with reconfiguring possibilities) would require a classical Petri net with thousands of elements and connections. It would be almost impossible to read such a net as a whole, but applying a third dimension to the net would produce a more compact representation solving also the problem of following the feedback links between end transitions and first positions. Our objective is to present the compaction algorithm for PN3D module, which is a part of the PN3D net that simulates the RMS operation.

Key words: PN3D, reconfigurable manufacturing systems, algorithms, compaction, layer architecture.

1. Introduction

Regarding the reconfigurable manufacturing system, large number of researchers is involved in approaching and trying to give a solution to representing graphically the whole network that simulates its operation, through various approaches, as follows:

- Creating a whole new model a Petri net – e.g. (Marinescu, 2000), (Brezovan, 1998) and (Bauman *et al.*, 1986);
- Trying to establish the design principles – e.g. (Reuven, 2007);
- Thinking new ways to reconfigure a manufacturing system – e.g. (Epureanu *et al.,* 2008), (Sherman *et al.,* 2007) and (Kiran, 2003).

All that various approaches watch a RMS as a system based on hierarchical layer architecture (Fig 1):

- **Layer 0** – the external command level of the application (manual commands of an operator, automatic commands from protocols, etc.), for example the command to change phase for a resource.
- **Layer 1** – the internal command level of the application (in automatic phase selects the commands to be given in order to operate one of the manual commands given in Layer 0).
- **Layer 2** – the PN3D modules layer which model resources (machine tools, stocking systems for parts and tools – buffers, storage, transport systems – AGVs, conveyor strips, robot manipulating systems).
- **Layer 3÷6** – the layers of the PN3D modules, which models technological processes for maximum 4 products.

To order the subsystems activities, aiming the subsystems ordering, during the new developed Petri net modeling (Marinescu, 2000)) we maintain the positions witch control the needed information (named ***C-positions***).

Usually a control position is inserted at the entering of the first transition of the subsystem to command the beginning of the activity and to count the number of the commanded cycles. A control position also is inserted at the exit of last transition of the last operation in order to control and count the activity cycles of the subsystem for each type of part manufactured by the system. Based on the premise according to which the PN3D modules models (the function of the RMS resources) are the same, no matter the dimensions or time, on can create PN3D generic modules for main types of resources.

In a comparison with (Marinescu, 2000) as a novelty, in the tridimensional model, we introduced the scale feature (representation of the same element at 0.5x of his normal scale or 2x or 3x), a larger representation of an PN3D element suggesting the importance of the element (robots, other important resources).

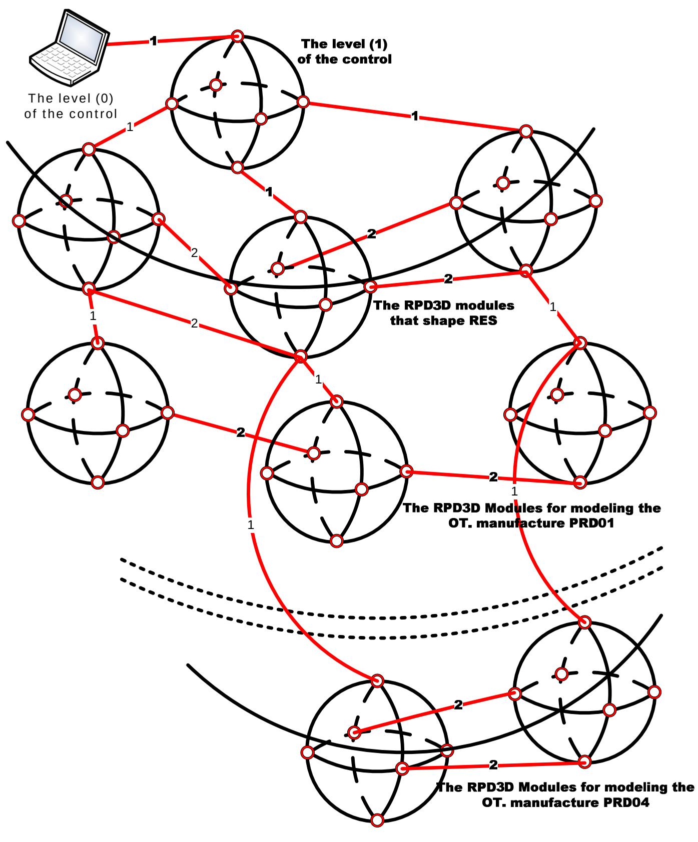


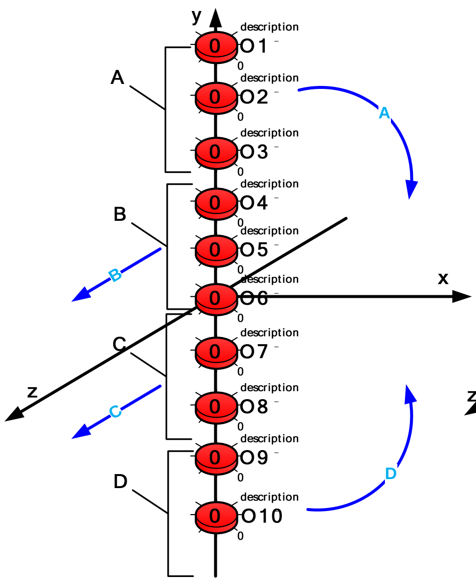
Fig.1 − Representation of the RMS hierarchical levels.

Thus, the positions witch models resources (variable or fixed) will be represented at a scale of 2x or 3x, the positions and operational transitions (manufacturing, assembling) at a normal scale and the control positions as well the intermediary and control transitions at a scale of 0.5x.

To create a PN3D module the elements are distributed from the beginning on Oz axis, by setting the z elevation for each element as following: type O positions at z=0, type C positions at z=20, type V positions at z=10, type R positions at z= -20, transitions at z= -10.

2. Algorithm for Compaction

Algorithm for compaction implies two actions: *i) net rolling* on the Oz axis and *ii) shortening* (net confinement) the length of the connections between links. The purpose of rolling is to shorten the length of the net and to transform the column of rows of operational positions (z=0) into a cylinder with the radius equal to ¼ from the length of the column. The change is made by marking the quarters of the column with A, B, C, D starting from Oy+ to Oy- and then by moving the quarters B and C to Oz+ and quarters A and D to Oz- (Figs 2 and 3). Thus, the feedback or rebooted connections can be equaled in size with the others.



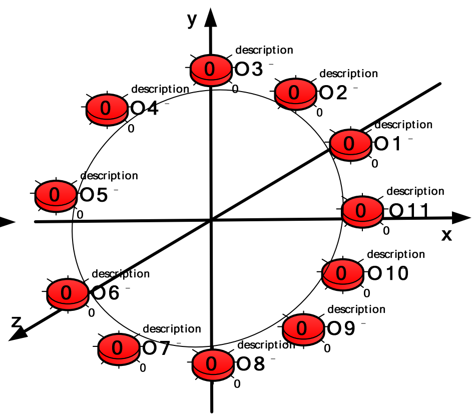


Fig.2 − Initial representation PN3D (editable). Fig.3 − Compact representation PN3D.

In the middle of the cylinder, we put the most important resource (the one with maximum of connections), usually a type R position/s (fixed resource – robots, AGVs, etc.). The other positions and transitions are initially moving in the middle of the virtual cylinder on operational positions.

We introduce the algorithm for net confinement, which consist in moving the transitions of the operational positions while the V type positions (variables resources) and C type positions (control operations) will move outside the cylinder. The algorithm steps are the following:

1. Calculate the lengths of connections and add them.
2. Differentiate between the longest and shortest connection and divide the difference to an animation factor F_a=10 (or 100) to obtain the increment for elements movement.
3. For all the connections, mark a starting element (operational position) and move with an increment the ending element on the axis corresponding to the greatest difference between the coordinates.
4. Continue until this distance among PN3D elements becomes 4f, in which case the connection will jump to the next set of movements.
5. Continue for the sum of the connections lengths would increase.

The compacted net is framed in a sphere by measure the maximum dimensions of the net. After that draw marks M1÷M6 and link the corresponding control positions as in Fig 4. PN3D net data would be saved in a MySQL database in classic format (for easy editing) and compact format. During RMS operation a resource can achieve one of the six stages: Ready (R), Work (W), Damaged (D), Pause (P), Error connection (E), IntoRMS (I). (I) means that the resource is ready but needs time to be incorporated into RMS.

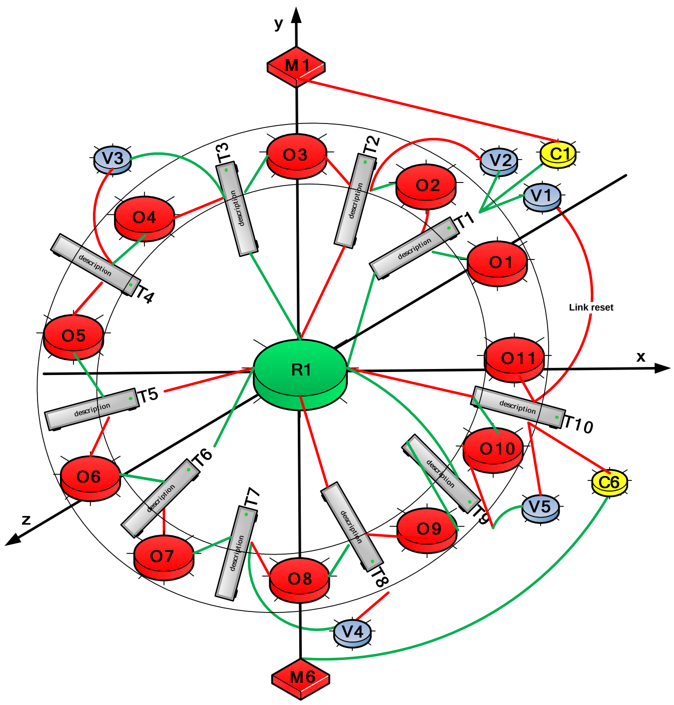


Fig.4 − Compact representation of a PN3D corresponding to a technological operation using a single tool.

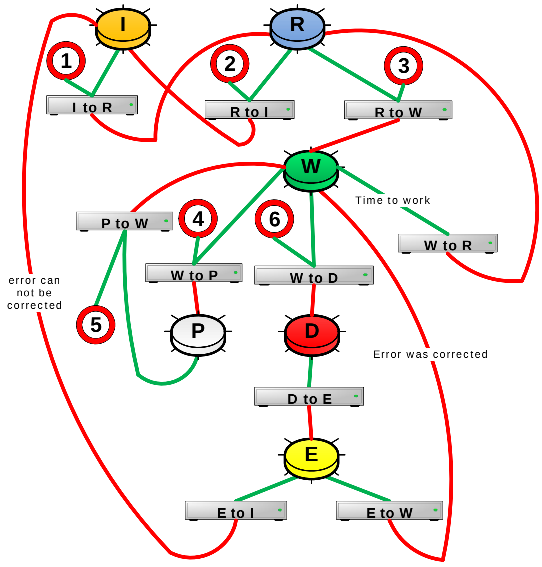


Fig.5 – The RMS resource six stages.

The transition between stages may be automatic (P to W, W to R, E to I, E to W) or may depend by the changes occurred to one of the six marks M1÷M6 (ON - the marking is active and the stage can be changed, OFF – the marking is inactive and blocks the change of the status) as can be view in Fig 5.

Compaction of a net which models a simple technological operation using a simple tool to leads to a relatively simple net (as can show in Fig. 6) because it does not possess the specific sequences of a net modulating a resource (D+E, P+I). The difference between the 3D representations of nets modeling a technological operation using a single tool and the nets using machine tools, resources, stocks for semi-finished parts, finished tools or parts, industrial robots or AGVs etc., consists in two more virtual cylinders for the sequences D+E and P+I. The cylinders are on the right and left side of the main cylinder depicting the stages R and W of the resource, as seen in Fig. 7. After running the confiding algorithm, the transitions reach operational positions whilst the V type positions (variable resources) and C type positions (control operations) reach positions outside the cylinder.

This placement is necessary to create weak connections between C type positions and connectors M1 and M6 of PN3D in order to control the start and stop of the activities simulated by the net. In case of V type positions such a placement is needed to create several strong connections between them and connectors M2÷M5 of PN3D, the connectors also having strong connections with connector M1 (resource Work) and M6 (resource Ready) of the resource represented in PN3D by the V type positions used for simulating the resource capacities.

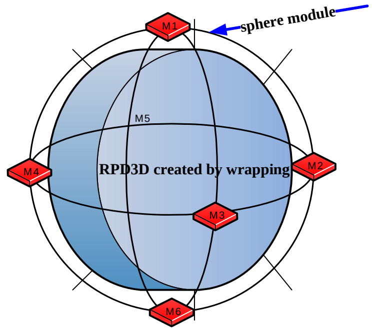


Fig.6 – A PN3D corresponding to a technological operation using a single tool in compact form.

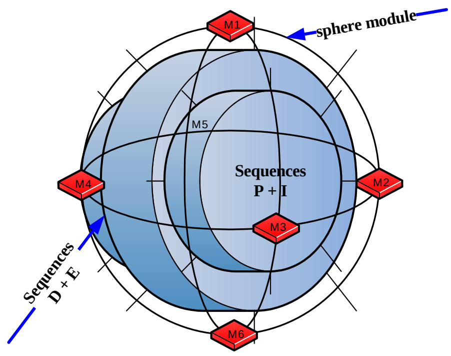


Fig.7 – A PN3D corresponding to a RMS resource in compact form.

3. Conclusions

Compactation of the RPD3D modules is useful for resources assembling and RMS building in a production workshop, each resource corresponding to a compact PN3D module. Thus, in the PN3D for RMS the parts of the net simulating the function of a system resource as well as the connections between parts are clearly individualized, especially the connections which appear when adding a resource to RMS or disappear once the resource is removed from RMS or only inactive. Using such a representation, on can easily observe the effects of reconfiguration of different types of RMS and will easily track them inside of larger systems (RMS with many technological operations, many resources or/and many products simultaneously manufactured).

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ALGORITM DE COMPACTARE A UNEI REȚELE PETRI TRIDIMENSIONALE CE SIMULEAZĂ FUNCȚIONAREA UNUI SISTEM DE FABRICAȚIE RECONFIGURABIL

(Rezumat)

Conceptul de sistem de fabricaţie reconfigurabil presupune, printre altele, capabilitatea sistemului de a-şi schimba structura fizică (repoziţionarea resurselor, modificarea funcţionalităţii acestora etc) pentru a se adapta noilor cerinţe de producţie sau pentru a prelucra piese din aceiaşi familie de piese sau dintr-o familie nouă. Funcţionarea unui sistem de fabricaţie reconfigurabil poate fi simulată cu reţele de tip Petri, tridimensionale. Aceste reţele generice sunt predefinite, editabile şi salvate sub formă de module, valorile parametrilor de lucru ce individualizează produsul, respectiv procesul tehnologic de fabricaţie al acestuia, fiind salvate într-o bază de date.

O astfel de rețea reprezentată în formatul clasic ar fi aproape imposibil de vizualizat în ansamblul ei, dar adăugând o a treia dimensiune rețelelor Petri clasice, putem obține o reprezentare compactă, chiar frumoasă, care să rezolve inclusiv problema urmăririi dificile a unei legături de tip feedback (reinițializare) dintre una din ultimile tranziții cu una dintre primele poziții, tip de legătură des folosită. Scopul lucrării este de a prezenta mecanismul de compactare a unui modul RPD3D, parte integrantă a rețelei RPD3D ce simulează funcționarea unui sistem de fabricație reconfigurabil.