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Aspects concerning modeling of self-reconfigurable parallel robots

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1. Introduction

The development of fabrication systems has experienced in the last period substantial modifications, resulting as a consequence of the changes taken place in the dynamics of consumption and also of work force on a global level. As a consequence this globalization process forced the companies to look for solutions of a flexible production which would assure product quality, salable at accessible and personalized prices in the way that this can respond to specific requests of the customers.

Hybrid fabrication system with reconfigurable structure is a solution used by the companies to solve the constraints imposed by the globalization process. The hybrid fabrication system is defined as the fabrication system that has in its components a minimal number of automatic installations (robots, alimentation/evacuation installations, etc) in such a way that human work force has higher importance in the fabrication process.

An important component of automated installations that have to be designed in a modular and reconfigurable manner is represented by robots. Parallel robots have, in comparison with the serial ones, besides dynamical and kinematical advantages the advantage to perform manipulation and assembly tasks and the tasks specific for machine tools.

Actual stage in research of parallel robots with self-reconfigurable topology can be emphasized by the following open problem.

a) Topological synthesis of RPR (Reconfigurable Parallel Robots) [1-3]. The topological synthesis is based on already existing results in the domain of simple or reconfigurable parallel robots and it seeks to determine that configurations that can turn in self-reconfigurable configurations.

b) Kinematics and dynamics of RPR [4-6]. The development of kinematics and dynamics is performed using classical methods used for parallel robots. The present realizations are singularizing these methods (geometrical, kinematic, dynamical parameters, etc) for some particular variants of RPR.

c) Virtual models of RPR [7-9]. The research in this direction have been concentrated in the implementation of mathematical models of RPR in different software environments being developed either at the university level either utilizing commercial ones like Visual C++, Delphi etc.

d) Determination of the work space for RPR [10-12]. The work space is a very important indicator for the user. In particular the work space for RPR is difficult to determine because the topology modification can radically determine the shape and dimensions of the work space. The methods used are based on solving algorithms of direct and/or inverse problem.

e) Calibration of RPR. The problem of RPR calibration is very important with direct influence on the accuracy regarding functional parameters (orientation and positioning precision, keeping in precise limits technological forces at the end-effector, etc). The methods utilized are based on using pseudo sensors, on determination of absolute position of mobile platform with the help of laser, on the use of mathematical model for auto calibration, etc.

f) Control of RPR [13, 14]. On this component the research have followed the development of different types of algorithms like it would be the control algorithm based on fuzzy logic, adaptive control algorithms, etc. It is worth to emphasize that a special attention is given to the control algorithm *s* that take into consideration the interaction with the environment, e.g. hybrid control.

g) Integration of RPR into reconfigurable fabrication systems [10, 15-18]. The main problem approached from this point of view refers to the necessity the entire fabrication system to allow trough its properties to be reconfigured. The problems that can appear are related to the equilibration of flux lines when the configuration is changed, the communication between different components in new conditions of topology modification, etc.

2. Basic concepts

The basic elements for the optimization of mathematical model are based on the introduction of two new notions.

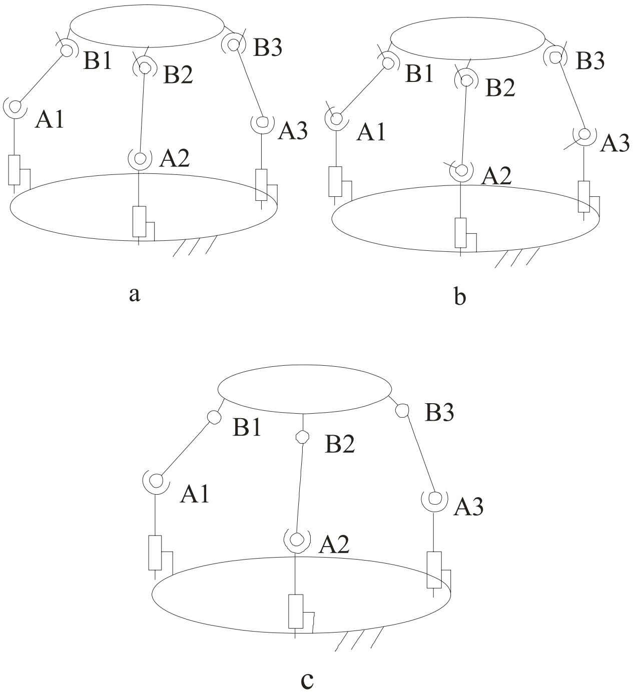
a) Intelligent articulation defined as the articulation that has the following characteristics:

- it can modify in a controlled manner the number of degrees of freedom (dof);
- it can measure the values of the parameters that characterize its function;
- it can communicate with other components of the robot.

The main property of the intelligent articulation would be the controlled change of its number of degrees of freedom. This modification would be possible through the incorporation of actuators in its mechanical structure. These actuators would have exclusive function in modifying the number of degrees of freedom. For measuring the parameters values like kinematic parameters (position velocity and acceleration) adequate sensors would be used.

b) Family of self-reconfigurable parallel robots is defined as a family of parallel robots formed from parallel robots resulting trough the union of hard and soft modules prior defined.

For example, is considered the parallel robot with three degrees of freedom having one mobile platform and three identical kinematic loops that connect this platform with the fixed one (Fig. 1).



a

b

c

Fig. 1 Self-reconfigurable parallel robots

We consider that three identical chains have the power supply unit (PSU) structure, where *P* is prismatic joint (1 dof), *S* is spherical joint (3 dof) and *U* is universal joint (2 dof). If *m*1 designates the number of degrees of freedom of intelligent articulation from point A1 (Fig. 1, a) and *m*2 the number of degrees of freedom of intelligent articulation B1 (Fig. 1, a) the following variants for parallel robots can result: 1) Fig. 1, b: parallel robot with 3 dof, the mobile platform executing only translations (very useful in the case of machine tools); 2) Fig. 1, c: parallel robot with 3 dof, the mobile platform executing general movements, the variant that is good for manipulation tasks. The two variants are different in their kinematics and dynamics and the switch from a variant to another is possible if at the level of intelligent articulations from the points: A1, A2, A3 and respectively B1, B2, B3 the degrees of freedom are modified in a controlled manner. For example for the transition from the variant (b) to variant (c) it is necessary to block rotation in the joints at B1, B2, B3 points and unblock rotation in the joints from the points A1, A2, A3 in a controlled way.

3. Modular synthesis

Structural synthesis of parallel mechanisms could be made if the number of degrees of freedom is

$$M = (6-m)n - \sum_{k=1}^{5}(k-m)C_k - M_p \tag{1}$$

where *m* is the total number of common constraints for all the elements, *n* is the number of the mobile elements, *k* is the number of constraints which define a joint (for example in the case of prismatic joint *k* = 5), C_k is the number of joints with (6-*k*) degrees of freedom and M_p is the number of identical degrees of freedom.

In the case of parallel mechanisms without common constraints and without identical degrees of freedom the relation (1) becomes

$$M = 6n - \sum_{k=1}^{5} kC_k \tag{2}$$

Let *N* be the number of mobile platforms and D_k – the number of joints with (6-*k*) degrees of freedom which directly connect the platforms of the mechanism. We can also assume three types of basic modules (named basic legs) which can connect the platforms of the mechanism (*f* is the number of degrees of freedom of the joint). Let a_1 be the number of the loops with prismatic - universal - spherical (PUS) topology, let a_2 be the number of the loops with prismatic - rotational - spherical (PRS) topology.

In the case of parallel mechanisms which are used in the field of machine tools, it is common to consider

$$N = 1,\ D_k = 0,\ k = \{1,\ldots,5\} \tag{3}$$

and also to consider that each loop contains only one degree of freedom.

Thus, it results

$$\left.\begin{aligned} M - 6 + a_2 &= 0 \\ a_1 - M + a_2 &= 0 \end{aligned}\right\} \tag{4}$$

Eq. (4) gives all possible variants of self reconfigurable robots in the frame of assumed hypothesis.

4. Kinematics

General algorithms used to solve direct problem of kinematics in case of parallel mechanisms consider that for each independent loop of the mechanism one vector equation can be written. Thus, a nonlinear system of scalar equations is obtained. Usually, this system of equations can be solved only by numerical methods and for this an accurate initial value of the solution is required. This initial value is strongly related to the geometric parameters of the mechanism. When the geometric parameters of the mechanism are changed the initial solution must be changed too. According to that, parallel mechanism kinematics will be developed in a modular manner, based on kinematics of the legs which connect the platforms and in order to ensure an analytical value for the initial solution. Each leg is in fact the right (or left) side of one independent closed loop and can be described by two coordinate systems: one attached to the frame and the other one attached to the mobile platform (Fig. 2). The relationship between these coordinate systems is given by

$$H_{iml} = \prod A_{il}\left(q_{il}\right) \tag{5}$$

for the left part of the independent loop and

$$H_{imr} = \prod A_{ir}\left(q_{ir}\right) \tag{6}$$

for the right part. H_{iml}, H_{imr} are absolute transformation matrices and A_{il}, A_{ir} are relative transformation matrices.

For an independent loop it results:

$$H_{iml} = H_{imr} \tag{7}$$

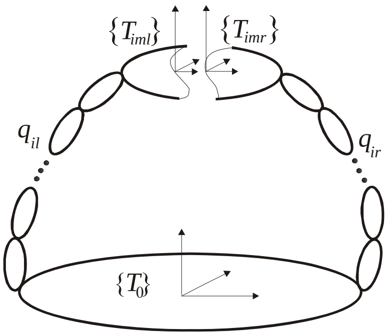


Fig. 2 “Cut body” method

Matrix Eq. (7) leads to six independent scalar equations. For whole parallel mechanism, a nonlinear system of equations (with 6n independent scalar equations, where n is the number of independent loops) will be obtained. This system of equations can be solved only by numerical methods. Generally, legs of the parallel component have the same topology. The result is that relative transformation matrices for the left and right part of each loop are similar. Therefore, for each topology of the legs, a formal mathematical entity (named LMM - Leg Mathematical Model) was developed. Similarly a modular kineto-static model was also developed. This mathematical model leads to non.linear system of equations. Classic algorithms of numerical methods, e.g. Newton-Raphson, can be used in order to solve this system of equations.

5. Virtual models and prototypes

Based on relations (5),…, (7) and using MOBILE software package several kinds of virtual models may be developed. Thus, Fig. 3 presents virtual models of the robots with $3 < M < 6$.

Also, Fig. 4 presents the configurations with 5 (a) and 6 dof (b).

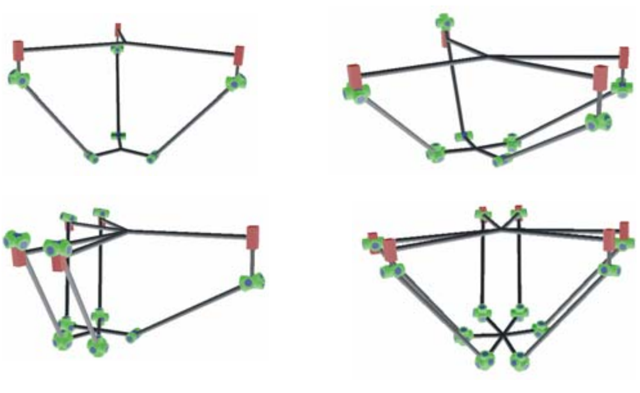
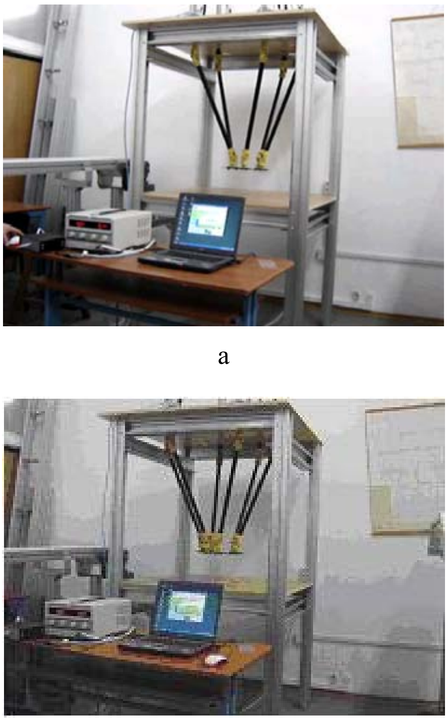


Fig. 3 Self reconfigurable robots – different configurations



a

b

Fig. 4 Prototype of self reconfigurable robots – configurations with 5 (a) and 6 (b) dof

6. Conclusions

The conclusion can be drawn as follows.

Based on assumed modules and on relation of the number of degrees of freedom of a mechanism, a topologic synthesis can be done.

The kinematics of the whole mechanism can be developed in a modular manner, each module based on the kinematics of one leg.

Solving inverse problem of kinematics for one leg it is possible to find an analytical expression of the initial value of the solution of the system of equations, describing direct kinematics of the mechanism.

Analytical expression of the initial value of the solution of the system of equations corresponding direct kinematics of the mechanism increases significantly the flexibility of simulation model. Thus, it is possible to change automatically and in interactive manner geometric parameters of the mechanism and its topology during simulation.

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KONFIGŪRACIJĄ KEIČIANČIŲ LYGIAGREČIŲJŲ ROBOTŲ MODELIAVIMO ASPEKTAI

Reziumė

Straipsnyje nagrinėjama perkonfigūruojamų ir konfigūraciją keičiančių robotų koncepcija. Šie robotai yra pagrindinis intelektualiųjų gamybinių sistemų komponentas. Straipsnyje pateikiami svarbiausi šio tipo robotų principai ir virtualiems modeliams sudaryti naudojami kinematikos metodai. Pateikti skaitmeniniai rezultatai, virtualūs modeliai ir išvados.

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ASPECTS CONCERNING MODELING OF SELF-RECONFIGURABLE PARALLEL ROBOTS

Summary

This paper deals with the concept of reconfigurable and self reconfigurable robots. These robots are intended to be used as a main component of intelligent manufacturing systems. The paper presents basic concepts of this type of robots, kinematical methods used to build virtual models, numerical results and virtual models. Also, conclusions are at the end.

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АСПЕКТЫ МОДЕЛИРОВАНИЯ САМОПЕРЕСТРАИВАЮЩИХСЯ ПАРАЛЛЕЛЬНЫХ РОБОТОВ

Резюме

В настоящей работе проведен анализ принципов переналаживаемых и самоперестраивающихся роботов. Упомянутые роботы являются основным компонентом интеллектуальных производственных систем. В статье представлены основные принципы роботов упомянутого типа, освещены методы кинематики, используемые для создания виртуальных моделей. Представлены численные результаты, виртуальные модели и выводы.

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