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ASPECTS ON SYNTHESIS AND MODELING OF THE PARALLEL MINI-ROBOTS AND MICRO-ROBOTS

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ABSTRACT

All over the world it can be noticed that the product miniaturisation is a central theme in product development for different application areas. In robotics scientific research one of the most important approaches is concerning the raise of the positioning accuracy by the use of parallel structures. The progress of the industrial production, especially the development of the industrial robotics is more and more based on a new generation of robots based on closed kinematic chains mechanisms, the parallel robots. In the paper are presented a structural synthesis of the parallel robots which leads to some variants of parallel mini-robots and micro-robots with different degrees of freedom. These parallel robots are used for manipulation within the high precision assembling processes. Some parallel robots were developed the geometric virtual models by using the Solid Edge virtual modeling software packages. Based on the corresponding geometric models, the modeled solutions are developed with classical joints and with pseudo-elastic joints.

Keywords: parallel robots, micro-robots, synthesis, modeling, kinematics.

1. INTRODUCTION

The parallel kinematic structures have a series of advantages that makes them proper for mini-robots and micro-robots building: the actuators positioned on the seating, actuators separation from the workspace, miniaturization capabilities, stiffness, high positioning precision and repeatability.

One of the most important interests in the world scientific research concerning the increase of accuracy in positioning is the use of parallel structures.

Parallel micro-robots are the result of the parallel robots knowledge, being a miniaturization of a structure or a succession of one or more conventional elements which has as purpose the obtaining of the same function as from classical parallel robots.

The majority of the existing simulation systems have been used for the serial robots. Based on the library and the Internet research, where considered more than 900 simulation systems including commercial brands (i.e. RobCad®, SCORob®, Robosoft, RoboWorks™etc.) software for specialized research (i.e ALPHA/Sim®). Only about 2% seems to be adequate to manage the the parallel robots parameters. The parallel robots kinematic and the dynamic models are more complicated and require laborious calculus and longer implementation time. In the parallel robots case each structure must be practically separately generated and studied. Modeling and simulation are the first steps – initial stages of designing and construction of parallel mini and micro-robots, using specialized software in 3D modeling (e.g. SolidWorks, SolidEdge, Unigraphics, CATIA, Inventor).

Current general CAD software packages are however very complex and it is not obvious for the designer or for an industrial corporation how to fully utilize the potential of these new tools. Several important questions are still under discussion in industry, e.g. whether an integrated environment or a distributed simulation with communication between different types of simulation software should be preferred, if simple geometry models should be created directly in the simulation software or if a CAD solid model always should be used as a master model for all analyses etc. There is obviously a need for a systematic approach in modeling and simulation. The use of simulation software should be different during the various design phases for a product development project. Design theory and product development models from design research have an obvious potential and should be used as a basis for an improved and efficient methodology and approach to modeling and simulation in the design of mechanical products. The optimal combination of simulation and physical prototype testing is another important issue in industry. Simulation results should be utilized to minimize testing effort and to concentrate the expensive testing to the most relevant cases. Test results on the other hand, should be used to improve mathematical models of basic or product specific phenomena and to incorporate empirical knowledge in the simulation models.

2. STRUCTURAL SYNTHESIS OF PARALLEL ROBOTS AND MICRO-ROBOTS

There are established the equations for the structural synthesis of parallel mechanisms with two up to six degrees of mobility, which could contain the following joints: screw joint; rotary joint; prismatic joint; all having one degree of freedom, cylindrical joint; cardanic joint; having two degrees of freedom; spherical joint with three degrees of freedom.

The following symbols are used: M = mobility degree of the mechanism; F = mechanism family; N = number of mobile elements; C_i = number of “i” class joints; k = number of kinematic chains which connect the mobile platform to the base, n = number of elements of a kinematic chain for platform guidance for symmetric structures; c_i = number of “i” class joints of a kinematic chain for platform guidance. The number of common constraints for all mechanism elements represents the mechanism family.

For a parallel mechanism of F family, the number of degrees of mobility is determined using the equation [6]:

$$M = (6-F)\cdot N - (5-F)\cdot C_5 - (4-F)\cdot C_4 - (3-F)\cdot C_3 - (2-F)\cdot C_2 - (1-F)\cdot C_1 \quad (1)$$

The number of mobile elements result by finding an integer solution for the equation, which derives from (1):

$$N = \frac{1}{6-F}\left[M + (5-F)\cdot C_5 + (4-F)\cdot C_4 + (3-F)\cdot C_3 + (2-F)\cdot C_2 + (1-F)\cdot C_1\right] \quad (2)$$

For the symmetric parallel structures with identical kinematic chains the following equations can be used:

$$N = k\cdot n + 1, \quad C_i = k\cdot c_i \ (i = 1,2,\ldots,5) \quad (3)$$

Using (3) the number of elements of a guidance kinematic chain results from (2):

$$n = \frac{1}{k(6-F)}\left\{M - (6-F) + k\left[(5-F)\cdot c_5 + (4-F)\cdot c_4 + (3-F)\cdot c_3 + (2-F)\cdot c_2 + (1-F)\cdot c_1\right]\right\} \quad (4)$$

For $M = 6 - F$ the number of elements of one guidance chain of the platform is independent on the number k of guidance chains:

$$M = 6-F,\ n = \frac{1}{6-F}\left[(5-F)\cdot c_5 + (4-F)\cdot c_4 + (3-F)\cdot c_3 + (2-F)\cdot c_2 + (1-F)\cdot c_1\right] \quad (5)$$

In the case when the parallel mechanism has only class 5 joints, meaning:

$$C_4 = C_3 = C_2 = C_1 = 0, \quad c_4 = c_3 = c_2 = c_1 = 0 \quad (6)$$

equations (1), (2), (4), (5) become:

$$M = (6-F)\cdot N - 5(5-F)\cdot C_5 \quad (7)$$

$$N = \frac{1}{6-F}\left[M + (5-F)\cdot C_5\right] \quad (8)$$

$$n = \frac{1}{k(6-F)}\left[M - (6-F) + k(5-F)\cdot c_5\right] \quad (9)$$

$$M = 6-F; \quad n = \frac{5-F}{6-F}c_5 \quad (10)$$

The equations (1), respectively (7) represent structural analysis relations for symmetric and asymmetric parallel mechanisms, (2) and (8) are structural synthesis equations for asymmetric parallel mechanisms while (4) and (5) respectively (9) and (10) are equations used for the structural synthesis of symmetric parallel mechanisms.

3. MODELING OF PARALLEL MINI-ROBOTS AND MICRO-ROBOTS

3.1. Modeling of joints for parallel robots

In the parallel robots case it is possible to use classical joints and elastic joints. In the figure 1 the spherical, rotation and prismatic joints are graphically represented in both situations (classic and elastic ones).

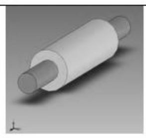
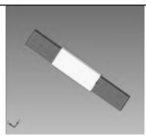
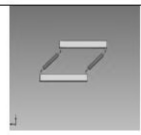
Joint	*Classic*	*Elastic*
Spherical		
Rotation		
Translation		

Figure 1. Modeling of classical and elastic joints

Figure 2. The virtual model using classic joints

The advantages of elastic joints could be mentioned [1, 2]: There is no linear friction; There are no backlashes; There is no need to lubrification; Compactness; Easy to manufacture; Possibility of design in a small scale. Elastic joints are normally used in high accuracy systems with a limited workspace and payload.

Further on, there are presented several examples of parallel mechanisms having three degrees of mobility, ones suitable for mini-robots and ones suitable for micro-robots, having as active joints linear actuators and for the passive ones rotary and spherical joints.

3.2. Modeling of some parallel robots

The 3D functional model of the parallel structure allows the designer to understand better its form and its functionality. Using the Solid Edge Assembly module [8] it is possible to impose the assembling conditions between the components including the mounting possibilities and the tolerance for and between the parts. A simulation system for parallel robots has been developed and the models for different parallel robots could be analyzed [4]. The parallel structure geometrical dimensions could be easy modified within the simulation system. Each component or each subassembly are characterized by a variable table, which contains the geometrical characteristics of the assembly. The assembly relations between parts or between parts and subassemblies could be also modified. The parallel structure parameterization enables the possibility to develop a study regarding the geometric optimization and the robot workspace shape.

This parallel structure from the figure 2 has three degrees of freedom and it is virtually modeled with classical joints. The kinematic scheme of the DELTA type parallel structure with three linear drives is presented in figure 3. The structure is formed by three identical spatial parallelograms that impose to the mobile platform to remain always parallel to the fixed platform. The active joints are prismatic ones. The platform is linked to the piston rods through three parallelograms using spherical joints. The kinematical algorithms were already presented in [5, 6].

Introducing the "constraint condition" for each kinematic chain by the dimensional function we have calculated the linear driving displacements in accordance with the following equations (11), depending on the end-effector coordinates and the geometrical parameters:

$$q_i = -(X_i' - R)s\alpha_i - Z_i'c\alpha_i \pm \sqrt{[(X_i' - R)s\alpha_i + Z_i'c\alpha_i]^2 + M^2 - (X_i' - R)^2 - (Y_i')^2 - (Z_i')^2}\text{, i=1,2,3} \quad (11)$$

In figure 3 is presented a planar parallel 3-RPP robot (rotation, prismatic, prismatic) having also three degrees of freedom [3]. The structure is formed by three identical kinematic chains between the base and the mobile platform. The active joints are the prismatic one. The passive joints are on the mobile platform. The geometric model is easily obtained using the closure equations for each kinematic chain. The models with classic (figure 3) and elastic joint (figure 4) for this parallel robot have been developed and integrated in the simulation system.

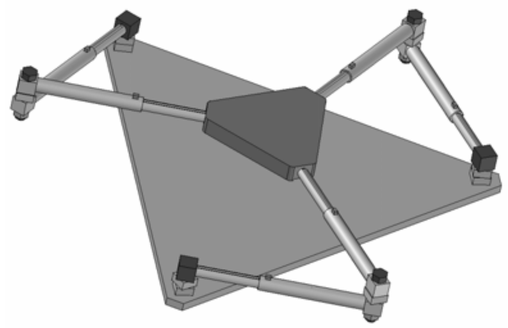


Figure 3. The virtual model using classic joints

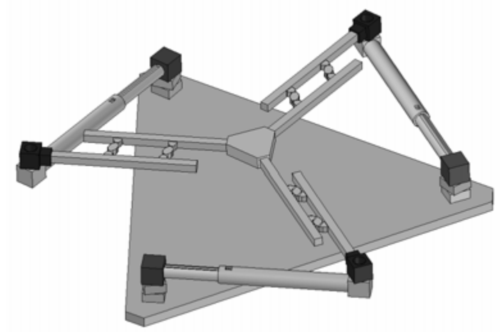


Figure 4. The virtual model using elastic joints

4. CONCLUSION

Starting from the developed general synthesis formulae one can obtain parallel mechanisms with different degrees of mobility having either symmetric or asymmetric structure. This synthesis is very useful for development of adequate solution of parallel robots with specific tasks. Modeling and simulation are important and essential stages in the engineering design and in the problem solving process, because it allows to prevent the risks and to lower the costs that appear with the design, construction and testing stage of a new robot. Modeling of parallel mini-robots and micro-robots allow obtaining optimal variants of assembling the part elements from a mechanical architecture of these and choosing of motion rules which persuade the relative position of two elements. In this paper, it is also emphasized the usage of elastic joints in the manufacturing of parallel micro-robots, because they are easy to realized, economic and compact.

5. ACKNOWLEDGEMENTS

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