

Study of design, kinematics and virtual control of 4 degrees of freedom parallel robot

D. Verdeş*, S.-D. Stan, R. Bălan***, M.Coman******

**Technical University of Cluj-Napoca, C. Daicoviciu no. 15, 400020 Cluj-Napoca, Romania,
E-mail: verdes.dan@gmail.com*

***Technical University of Cluj-Napoca, C. Daicoviciu no. 15, 400020 Cluj-Napoca, Romania,
E-mail: sergiustan@ieee.org*

****Technical University of Cluj-Napoca, C. Daicoviciu no. 15, 400020 Cluj-Napoca, Romania,
E-mail: radubalan@yahoo.com*

*****Technical University of Cluj-Napoca, C. Daicoviciu no. 15, 400020 Cluj-Napoca, Romania,
E-mail: coman_mirceal@yahoo.com*

1. Introduction

The need to use parallel robots in various domains like manipulation operations, testing, tracking, guiding, machining has led to many researches in this domain. At first the researches were focused on the six DOFs Gough-Stewart-type parallel robots, but in the last decade studies have been done in the field of less than six degrees of freedom type because of the suitability to handle tasks that need lower mobility robots.

Although, in general, motion planning and end-effector, in the case of parallel robots, is more complicated than for the serial ones, parallel structures have the advantage of being better in the following domains: stiffness, accuracy, load to weight ratio and dynamic performances [1-3].

2. Design of the T3R1 parallel robot

The Isoglide T3R1 is a parallel mechanism obtained by parallel concatenation of 4 simple limbs.

The mechanism has three limbs of type $P||R||R||R$ and one limb of type $P||R||R||R$. In each limb, the axes of the first three rotation joints are parallel to the direction of the prismatic joint. The last rotation joint of the four limbs have parallel axes [4].

This parallel robot has three translations and one rotation about an axis of fixed direction. In Fig. 1 the model of the parallel robot designed in SolidWorks can be seen. This type of robot has four arms, and the final-effector is a mobile platform which is presented in Fig. 2.



Fig. 1 CAD model of the T3R1 parallel robot

The model of the arm is presented in Fig. 3. The arm is made of two elements, one of these elements is connected to the mobile platform and another one is connected to the translational actuator. The parallel robot T3R1 has four translational actuators. This robot has four degrees of freedom. The elements of the arm and connection between the arm and mobile platform and the actuator can be seen. Between the arm actuator and mobile platform there are only revolute joints.

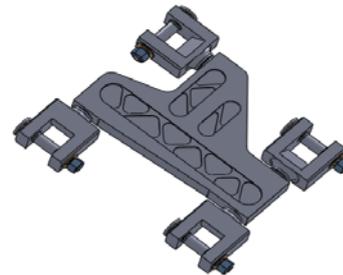


Fig. 2 CAD model of the final-effector

An important parameter in robot design is the dextrous workspace, defined as all possible locations of an operating point which all orientations are possible.

Dexterity of the workspace analysis should preferably be done in association with singularities, accuracy and rigidity. Near singularities the accuracy and the rigidity change drastically, especially in high dynamics conditions. Dimensions, shape, tolerances, mechanical properties and technological solutions for links joints play a crucial role in robot accuracy and dexterity.



Fig. 3 Robot arm and connections with mobile platform and actuator

In design process, they represent the main parameters for robot dimensioning and optimization along with other factors, including reliability, safety, cost, ease of operation and settling time.

3. Modelling and simulation of T3R1 parallel robot in Matlab/Simulink and virtual reality

Simulink is an environment for multidomain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing.

After building the model of T3R1 in Simulink, it can simulate its dynamic behaviour and view the results in real time. Simulink software provides several features and tools to ensure the speed and accuracy of your simulation, including fixed-step and variable-step solvers, a graphical debugger, and a model profiler [5].

With Simulink, a detailed block diagram of parallel robot T3R1 using a comprehensive set of predefined blocks can be quickly created, modelled, and maintained. The Simulink model is presented in Fig. 4

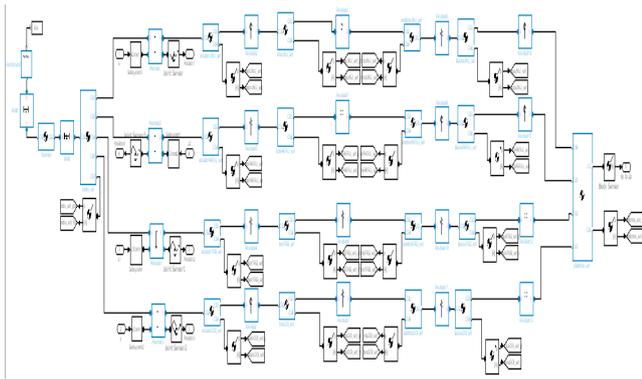


Fig. 4 Simulink model for the T3R1 parallel robot

Simulink provides tools for hierarchical modelling, data management, and subsystem customization, making it easy to create concise, accurate representations, regardless of your system's complexity.

Virtual Reality (VR) Toolbox for MATLAB makes possible a more realistic rendering of bodies. Arbitrary virtual worlds can be designed with Virtual Reality Modelling Language (VRML), and interfaced to the Sim-Mechanics model. The procedure of modelling in VR in details is described in Fig. 5.

The user simply describes geometrical properties of the robot first. Then, in order to move any part of the robot through 3D input devices, the problems are automatically solved in real time.

The interface was also designed to provide the user decision capabilities when the problems such as singularities are encountered.

VR interface enables users to interact with the robot in an intuitive way. This means that the operator can pick and choose any part of the robot and move it using translation and rotation using 3D sensors, as easily as a “drag and drop” operation is.

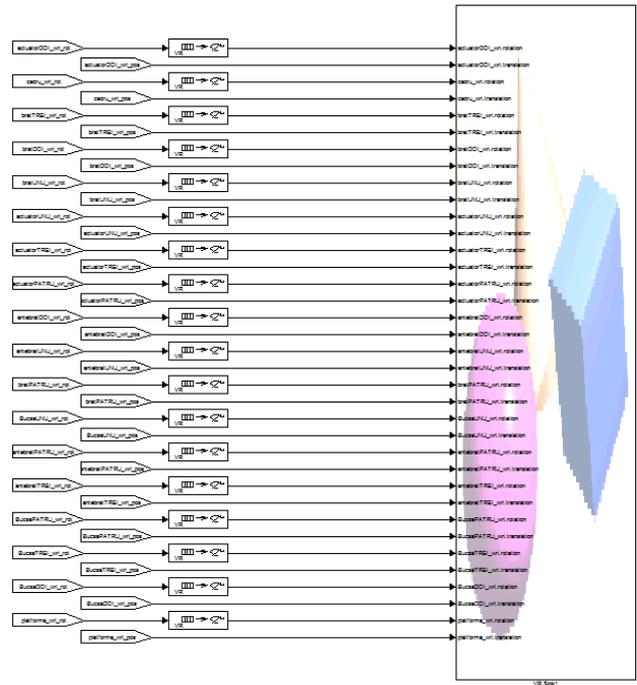


Fig. 5 VR parameter block for the T3R1 parallel robot

Thus, trajectories can be easily defined, optimized, and stored. Not only that, but the virtual world can be accessed and controlled via the Internet, too.

The use of a VR interface to simulate robots drastically improves the “feeling” for the robot. The model in VR is presented in Fig. 6.

In particular, the interface allows user to understand behaviour of an existing robot, and to investigate performance of a newly designed structures without the need of hardware implementation of and the cost associated with.



Fig. 6 Parallel robot T3R1 in Matlab/Virtual Reality

4. Simulation results

There are several reasons for realizing a model of the platform. Firstly, it is possible to check the functionality of the construction and to determine the working area by simulation. Furthermore, control program can be developed and tested before the real platform is available.

The mechanical construction is performed with the CAD program SolidWorks and the data is exported to Sim-Mechanics, a simulation tool for mechanical systems.

Using Sim-Mechanics the dynamic behaviour of the platform can be tested with a real or simulated control before it is set up. The trajectory block in Simulink is presented in Fig. 7.

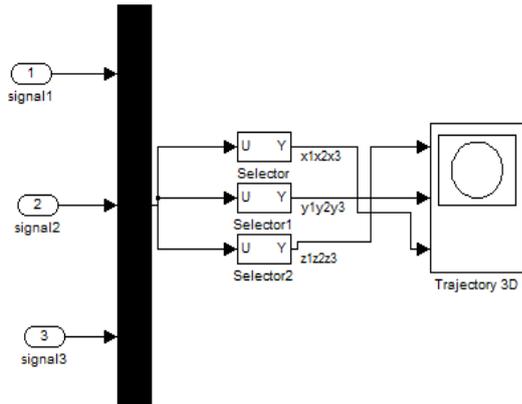


Fig. 7 Trajectory generation block of T3R1 parallel robot

The model of the manipulator respects geometrical constraints, joints and mass distribution. Friction is neglected in this model. In order to simulate behaviour of the robot, a dynamic model of the robot has to be built.

This is a complex subject and different methods were developed in order to solve it.

A classical approach to closed-chain dynamic modelling is to first consider an equivalent tree-structure, and then to consider system constraints via Lagrange multipliers or d'Alembert's principle [6].

Other approaches include the use of virtual work, Lagrange formalism, Hamilton's principle, and Newton-Euler equations.

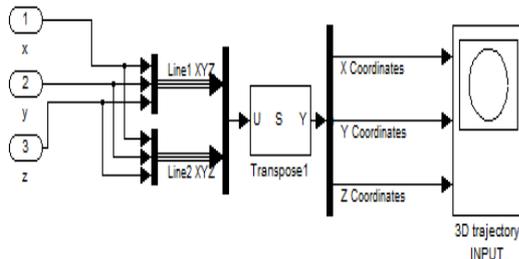


Fig. 8 Trajectory input of the T3R1 parallel robot

In this article the dynamic model of the robot is built using the SimMechanics toolbox from Simulink. The toolbox uses the standard Newtonian dynamics of forces and torques in order to solve both the direct and the inverse problem.

The model was built from Simulink blocks that represent the kinematic elements and joints of the robot.

These blocks allow modelling of mechanical systems consisting of any number of rigid bodies, connected by joints representing translational and rotational degrees of freedom.

In order to build a SimMechanics model, one has to specify the inertial properties of the body degrees of freedom and constraints, along with coordinate systems that are attached to each body of the structure.

This procedure can be very difficult for bodies with complex geometric forms; however, the process can be simplified by use of a SolidWorks tool.

All three kinematic chains are defined by body and joint blocks. The inertia properties and the coordinates of the joints for each body were determined automatically when the CAD model was imported in MATLAB/Simulink environment.

The trajectory generation block of T3R1 parallel robot is presented in Fig. 7 and the trajectory input generated in Matlab/Simulink is presented in Fig. 8. The blocks of the movement of one actuator is presented in Fig. 9.

The connection of the mechanical model of the robot to the rest of the robot model was realized via actors and joint blocks. Inputs of the model can be the following: the generalized force, the position, speed, or the acceleration of the motor joints.

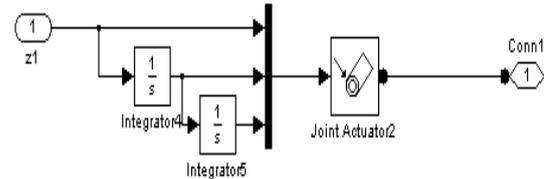


Fig. 9 Movement of translational actuator

In this paper, the inputs chosen were the speed of all three motor joints of the robot.

As outputs, the angles of each motor element were chosen. In addition, sensors were used to determine the position of the end-effector.

The next step in the simulation of the robot is motion control. For doing that multiples types of trajectory were generated using user made blocks that generate them. Two of these subsystems are illustrated in the one of this the circle generating subsystem is shown in Fig. 10 and the square generating signal block is presented in Fig. 11.

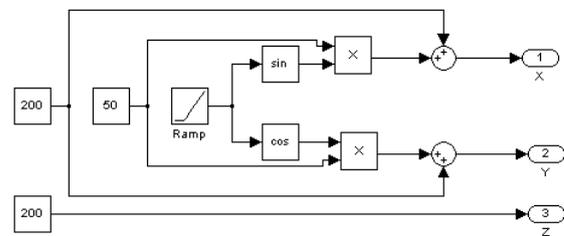


Fig. 10 Circle generating subsystem

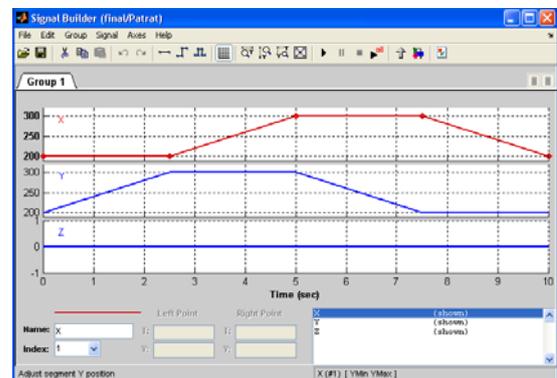


Fig. 11 Square generating signal bloc

Another interactive method that was used consists in using a joystick to control it. The signal from the joystick was filtered, amplified and then used to control the speed of the end-effector for each axis, and his angle. The blocks that do that are illustrated in the Fig. 12.

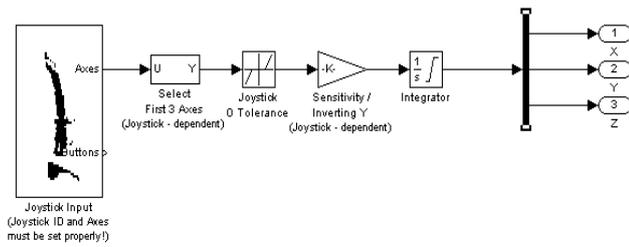


Fig. 12 Joystick block

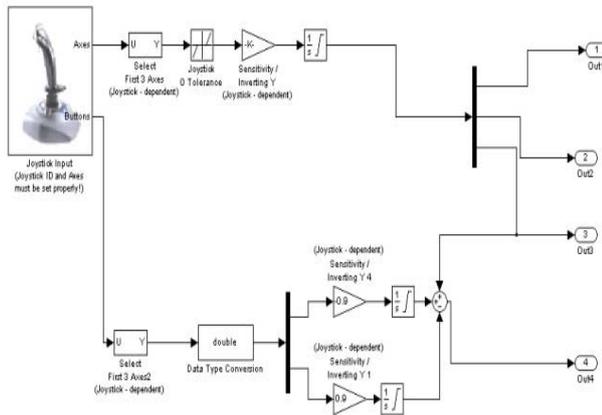


Fig. 13 Joystick control blocks

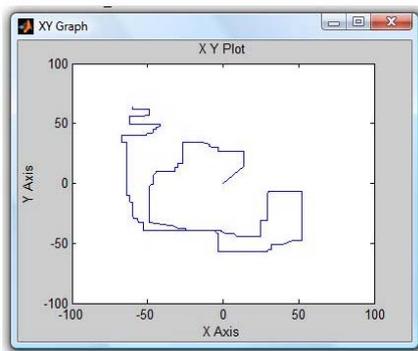


Fig. 14 End-effector trajectory

The main block for this task, the joystick block, can be found in the libraries of Simulink in the Virtual Reality Toolbox. This block can be used as input or as output in Simulink, depending on the capabilities of the joystick that is connected to the computer. When it is used as an output it controls the force feed-back of the joystick, if the device is capable for that. In the case that the block is used as an input source the block outputs the position of the joystick and the state of its buttons. In the case of this structure the position of the lever is used to control the position along the O_x and O_y axis and the flap from the back of the joystick is used to control the position along the O_z axis. To do that from the axis output of the joystick block the three signals are selected and put in the desired order so that the control to be as natural as possible. The next step consists in eliminating small value signals to ensure the possibility of achieving more easily the 0 position of the lever. The signals were then amplified with the values that permit good visualisation of the movement and comfortable control, and some of the signals signs were changed.

The resulting signals were then integrated. Thus results the position of the 3 actuators. For the fourth actua-

tor, its position is identical with the third one when the platform maintains its orientation.

To control the angle of the mobile platform two buttons were chosen and their state was read by selecting them from the output buttons of the block.

The signal obtained was integrated and amplified. One of the signals was added and the other one subtracted to the position of the fourth actuator. The resulting signal from the two buttons represents the difference between the third and fourth actuator; and it remains unchanged as long as they are not pushed. The resulting system that controls the position and orientation of the mobile platform is presented in Fig. 13.

The trajectory of the platform using the joystick as an input device is presented in Fig. 14.

5. Conclusions

The use of virtual control in simulation process is a very helpful tool in understanding the behaviour of the structure. The possibility of visualising the structure during the simulation process permits to observe any anomalies that can occur during movement of the parallel robot. This enhanced way of displaying the results has the advantage of illustrating in a friendly manner the results that can be further analysed using virtual graphs. The possibility of viewing the structures from different points of view permits the user to quickly analyze the movement of every element in the structure.

Another advantage of the use of Virtual Reality offered by MATLAB is the possibility of importing the model from a CAD program, in this case SolidWorks. This option permits simulating very complex structures more easily and study their behaviour.

The option of using the joystick as an input for the movement of the parallel robot offers to the user the possibility to study quickly many types of movements. It offers the possibility of movement on different axes, individually or in combined movement. Also with the help of the buttons parameters of the movement or of the simulation can be changed very quick and easy.

Acknowledgment

This work was financially supported by CNCSIS 1072 (IDEI type), title of the project 'Researches regarding the advanced control with applications in mechatronics'.

References

1. Stan, S., Mătiș, V., Bălan, R. Optimal design of 2 DOF Parallel Kinematics Machines. PAMM-Berlin: Wiley, 2006, p.705-706.
2. Brisan, C., Rusu, C. Aspects concerning modeling of self-reconfigurable parallel robots. -Mechanika. -Kaunas: Technologija, 2008, Nr.1(69), p.59-62.
3. Tatar, O., Mandru, D., Ardelean I. Development of mobile minirobots for in pipe inspection tasks. -Mechanika. -Kaunas: Technologija, 2007, Nr.6(68), p.60-64.
4. Gogu, G. Structural synthesis of fully-isotropic translational parallel robots via theory of linear transformations. -European Journal of Mechanics, A -Solids, 2004, v.23, p.1021.

5. **Stan, S.-D. R. Bălan, V. Mătieș.** Modelling, design and control of 3DOF medical parallel robot. -Mechanika. -Kaunas: Technologija, 2008, Nr.6(74), p.68-71.
6. **Neagoe, M., Gogu, G., Diaconescu, D.** High degree accuracy modelling and calibration of serial robots with large errors. -Product Engineering. -Springer-Verlag, p.397-408.

D. Verdes, S.-D. Stan, R. Balan, M. Coman

KETURIŲ LAISVĖS LAIPSNŲ LYGIAGREČIOJO ROBOTO PROJEKTAVIMO, KINEMATIKOS IR VIRTUALIOJO VALDYMO TYRIMAS

R e z i ū m ė

Straipsnyje nagrinėjama keturių laisvės laipsnių lygiagrečiojo roboto projektavimas, valdymas ir kinematika. Roboto CAD modelis yra sudarytas „SolidWorks 2009“ sistemoje. Virtualusis valdymas atliktas naudojant „Matlab/Simulink“ programą. „Simulink“ yra daugiavienė modeliavimo programa, naudojama modeliavimui, duomenų valdymui ir dinaminiam imitavimui. Naudojant šias priemones buvo patikrintos roboto dinaminės savybės bei valdymo imitavimas.

D. Verdeş, S.-D. Stan, R. Bălan, M. Coman

STUDY OF DESIGN, KINEMATICS AND VIRTUAL CONTROL OF 4 DEGREES OF FREEDOM PARALLEL ROBOT

S u m m a r y

The paper present the design control and kinematics study of 4 degrees of freedom parallel robot. CAD-model of the robot is obtained in SolidWorks 2009. Virtual

Reality control was obtained in Matlab/Simulink. Simulink is an environment for multidomain simulation and provides tools for modelling, data management and dynamic simulation. With these tools the dynamic behaviour of the robot was tested and simulated control was done.

Д. Вердес, С.-Д. Стан, Р. Балан, М. Цоман

ИССЛЕДОВАНИЕ ПРОЕКТИРОВАНИЯ, КИНЕМАТИКИ И ВИРТУАЛЬНОГО УПРАВЛЕНИЯ ПАРАЛЛЕЛЬНОГО РОБОТА 4-ЕХ СТЕПЕНЕЙ СВОБОДЫ

Р е з ю м е

В статье рассматривается проектирование, управление и кинематика параллельного робота 4-ех степеней свободы. САД модель робота составлена в SolidWorks 2009 системе. Виртуальное управление осуществлено используя Matlab/Simulink программу. Simulink является многофункциональной программой моделирования используемой для моделирования, управления данными и динамического имитирования. При использовании этих средств в статье проверены динамические свойства робота и осуществлена имитация управления.

Received June 30, 2009

Accepted February 25, 2010

DOI: 10.5755/j02.mech.15518