

Modelling, design and control of 3DOF medical parallel robot

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1. Kinematics of the 3 DOF ISOGLIDE3 parallel robot

Robot usage outside of the automobile, appliance, undersea, space, and hazardous materials industries has increased over the past decade. Robots have potential for enormous benefit to the medical field, but researchers must proceed with care to ensure human safety. With the rising cost of medicine, automation may be one way to make medicine affordable [1-3].

The trend is to work side-by-side with specialists of other fields so as to gain insight into the problems hitherto remaining untouched. One such environment has been the hospitals in general and the operation theatres in particular where it is seen that the abilities of a surgeon carrying out a difficult surgical operation gets enhanced by working side-by-side with such robots. Those robots, popularly known as medical robots are meant for tackling the three main areas of medicine - surgery, hospital service and rehabilitation. The most popular and demanding application areas amongst those is surgery [4-6]. The high precision of the robot manipulator, minimally invasive access, enhanced prospects for tele-surgery are some of the reasons behind the justification of a robotic approach to surgery.

Industrial robots are being used in the operating room, and two classes of robot systems can be defined in this area: robots that assist the surgeon in surgery, and robots that actually perform the surgery. The following discussion comprises a 3 DOF parallel robot that can be used for surgery. The structure of the 3 DOF ISOGLIDE3 parallel robot is shown in Fig. 1, where a mobile platform is coupled with the fixed base by three legs of type PRRR (Prismatic Revolute Revolute Revolute). The realized robot made at Mechatronics Dept. is presented in Fig. 2.

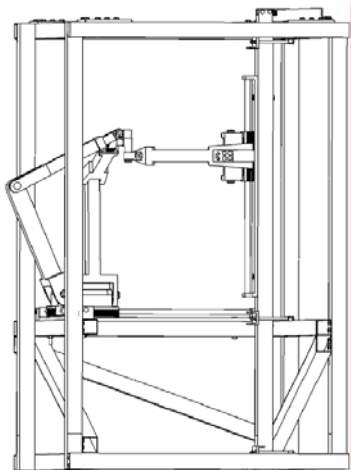


Fig. 1 CAD design of 3 DOF ISOGLIDE3 parallel robot



Fig. 2 ISOGLIDE3 parallel robot realized at Mechatronics Department

The mobile platform can be visualized as a square whose side length $2L$ is defined by B_1 , B_2 , and B_3 points. The fixed base is defined by three guide rods that pass through A_1 , A_2 , and A_3 points, respectively (Fig. 3).

Fixed coordinate frame originates at the point O . In Fig. 3, the reference frame XYZ is attached to the fixed base. All links are connected then to the mobile platform or the end-effector (Fig. 4).

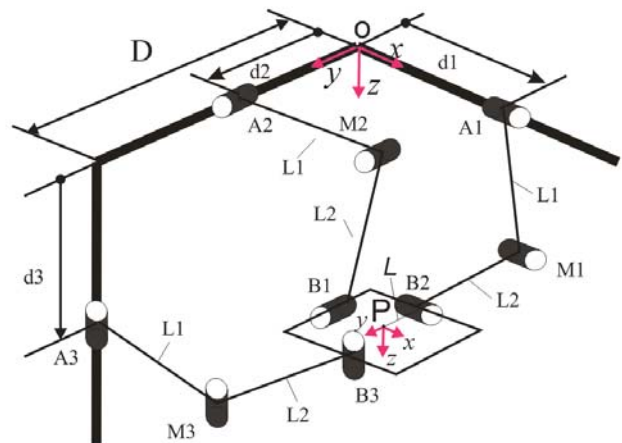


Fig. 3 Kinematic scheme of 3 DOF ISOGLIDE3 parallel robot

The three revolute joint axes at each of these links are parallel to the ground connected prismatic joint axis, and are located at points A_i , M_i , and B_i , respectively. Also, the three prismatic joint axes passing through points A_i , for $i = 1, 2, 3$, are parallel to the X , Y , and Z axes, respectively.

The first prismatic joint axis lies on the X -axis; the second prismatic joint axis lies on the Y -axis; while the third prismatic joint axis is parallel to the Z -axis.

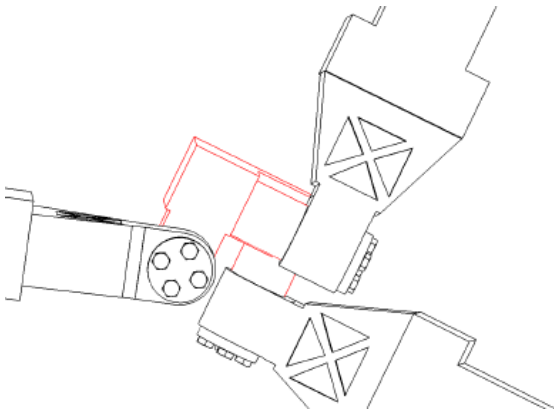


Fig. 4 The mobile platform of 3 DOF ISOGLIDE3 parallel robot

Consequently, the location of point P is determined by the intersection of three planes. The forward and inverse kinematic analysis is trivial. A simple kinematic relation can be written as

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \end{bmatrix}$$

This robot architecture was also implemented and known in the literature under the name of ISOGLIDE3-T3 [7, 8], Orthogonal Tripterion [9], or CPM [10].

2. Trajectory planning of ISOGLIDE3 parallel robot

A path is defined as the sequence of robot configurations in a particular order without regard for timing of these configurations while trajectory is concerned when each part of the path must be obtained thus specifying timing.

Control of the robot is implemented using a joint-based control scheme. In such a scheme, the end effector is positioned by finding the difference between the desired quantities and the actual ones expressed in the joint space. Simulink model of the ISOGLIDE3 parallel robot is presented in Fig. 5.

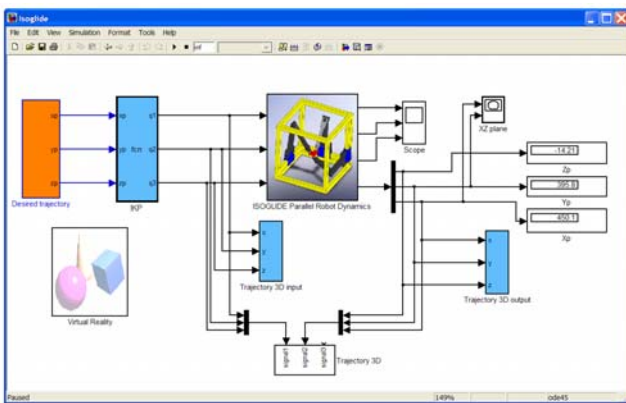


Fig. 5 Simulink model of the ISOGLIDE3 parallel robot

The first tests on the prototype encourage the direction of the research: the chosen control algorithms emphasize peculiar characteristics of the parallel architecture and, in particular, good dynamic performance due to the

limited moving masses, and advantageous robot behaviour. SimMechanics generated model of the ISOGLIDE3 parallel robot is presented in Fig. 6.

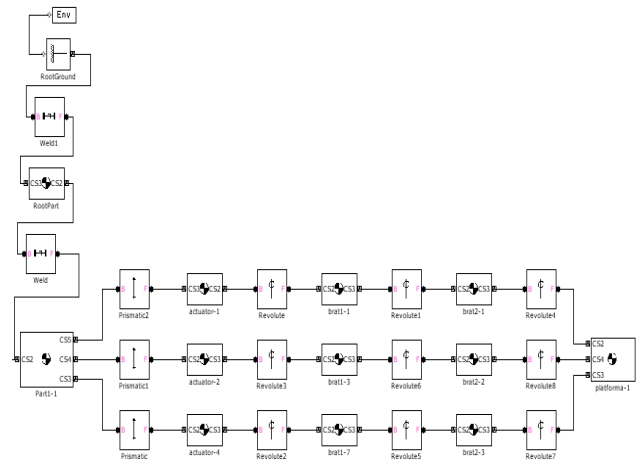


Fig. 6 SimMechanics generated model of the ISOGLIDE3 parallel robot

The interface is based on virtual reality approach in order to provide the user with an interactive 3D graphical representation of the parallel robot. The interface was designed to give a novice user an intuitive tool to control any kind of mechanical structure (serial, parallel or hybrid), requiring no programming skills. Computer based simulation allows mimicking a real life or potential situations. SimMechanics models, however, can be interfaced seamlessly with ordinary Simulink block diagrams. For example, this enables the user to design mechanical and the control system in one common environment. Virtual model interface of the ISOGLIDE3 parallel robot is presented in Fig. 7.

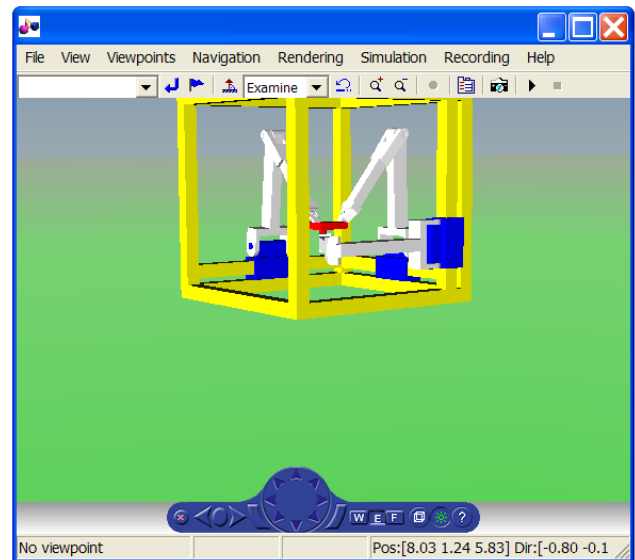


Fig. 7 ISOGLIDE3 virtual reality robot interface

In addition, Virtual Reality Toolbox for MATLAB makes it possible a more realistic rendering of bodies. Arbitrary virtual worlds can be designed with Virtual Reality Modelling Language (VRML), and interfaced to the SimMechanics model. The procedure of modelling in Virtual Reality in details is described in [11].

3. Simulation results

The sample trajectory of the end-effector is chosen to be a circular path with the radius of 0.3 meters and its center is $O(0, 0, 0)$.

This path is designed to be completed in 7 seconds when the end-effector reaches the starting point $P_1(0.3, 0, 0)$ again with constant angular velocity $\omega = 0.5\pi$ rad/sec. The end-effector path is shown in Fig. 8.

The desired force obtained from the actuators to move the end-effector of the ISOGLIDE3 parallel robot along the desired trajectory is shown in Fig. 9. Dynamic model was presented in [10]. Optimal design of parallel robots can be found in [7-16].

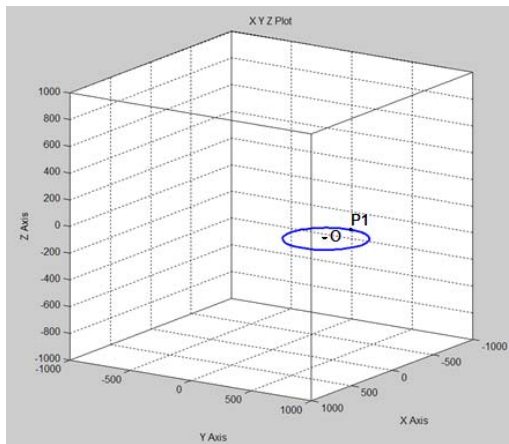


Fig. 8 End-effector path for the circular trajectory

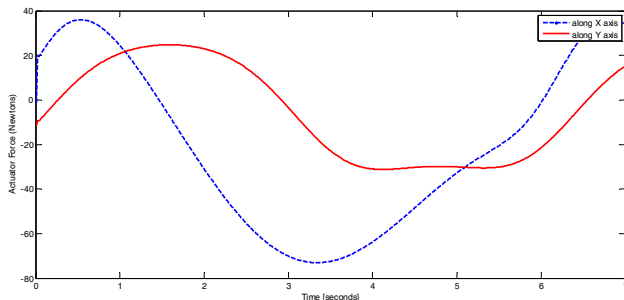


Fig. 9 The desired force obtained from the actuators

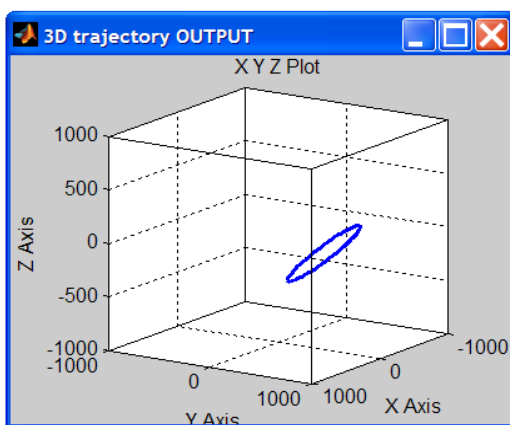


Fig. 10 End-effector path for the circular trajectory

The desired force obtained from actuators to move the end-effector of the ISOGLIDE3 parallel robot for the trajectory presented in Fig. 10 is shown in Fig. 11.

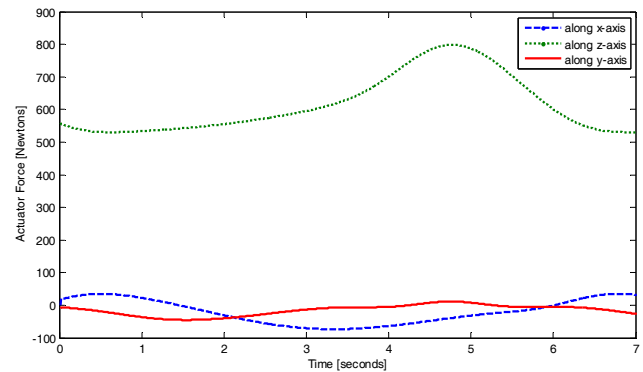


Fig. 11 The desired force obtained from actuators

4. Conclusions

The paper presents modeling, design and control simulations of ISOGLIDE3 medical parallel robot. This robot was realized at Dept. of Mechatronics, Technical University of Cluj-Napoca.

Also a Virtual Reality Interface for the 3 DOF ISOGLIDE3 parallel robot (IG3PR) control is presented. An evaluation model from the Matlab/SimMechanics environment was used for the simulation. An interactive tool for dynamic system modeling and analysis was presented in Virtual Reality environment of this ISOGLIDE3 parallel robot. The main advantages of this parallel manipulator are that all the actuators can be attached directly to the base, that closed-form solutions are available for the forward and inverse kinematics, and that the moving platform maintains the same orientation throughout the entire workspace.

By means of SimMechanics, the authors considered robotic system as a block of functional diagrams. Besides, such software packages allow visualizing motion of mechanical system in 3D virtual space. Especially non-experts will benefit from the proposed visualization tools, as they facilitate modeling and interpretation of results.

5. Acknowledgment

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TRIJŲ LAISVĖS LAIPSNŲ MEDICININIO
LYGIAGREČIOJO ROBOTO MODELIAVIMAS,
PROJEKTAVIMAS IR VALDYMAS

Re z i u m ė

Straipsnyje supažindinama su lygiagrečiojo roboto ISOGLIDE3 projektavimu ir jo valdymo imitavimu.

Pateikiama novatoriška vartotojo sąsajos programa, skirta trijų laisvės laipsnių lygiagrečiojo roboto kokybiškam valdymui. Sukurta sąsajos programa buvo imituojama ir bandoma virtualioje aplinkoje, gauti rezultatai pateikiami MATLAB, Simulink ir SimMechanics sistemose. Palyginti su kitais lygiagretaus tipo manipulatoriais, roboto ISOGLIDE3 charakteristikos yra geresnės kokybės, pavyzdžiui, jo konstrukcija yra lengva. Dėl savo tikslumo, gerų dinaminių charakteristikų aprašomas trijų laisvės laipsnių lygiagretusis robotas gali būti naudojamas chirurgijoje.

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MODELLING, DESIGN AND CONTROL OF 3DOF
MEDICAL PARALLEL ROBOT

S u m m a r y

The paper presents design and control simulations of ISOGLIDE3 parallel robot. An innovative user interface for high-level control of a 3 DOF parallel robot is also presented. The robot interface using virtual reality was verified and tested, and results in MATLAB, Simulink, and SimMechanics were presented. The ISOGLIDE3 robot offers the superior characteristics with regards to the other parallel manipulators, such as the light weight construction. The presented 3 DOF parallel robot can be used for surgery due to its overall precision, good dynamic behavior.

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МОДЕЛИРОВАНИЕ, ПРОЕКТИРОВАНИЕ И
УПРАВЛЕНИЕ МЕДИЦИНСКОГО
ПАРАЛЛЕЛЬНОГО РОБОТА ИМЕЮЩЕГО ТРИ
СТЕПЕНИ СВОБОДЫ

Р е з ю м е

В статье представлены особенности проектировании, имитации управления параллельным роботом ISOGLIDE3. Также представлен оригинальный интерфейс пользователя, предназначенный для качественного управления параллельным роботом с тремя степенями свободы. Созданный интерфейс имитировался и тестировался в виртуальной среде, а полученные результаты представлены в системе MATLAB, Simulink и SimMechanics. По сравнению с другими манипуляторами параллельного типа, характеристики робота ISOGLIDE3 выделяются более высоким качеством, например, его конструкция более легкая. Из-за его точности, хороших динамических характеристик представленный параллельный робот с тремя степенями свободы может использоваться в хирургии.

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