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Kinematics and fuzzy control of ISOGLIDE3 medical parallel robot

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1. Kinematics of the 3 DOF ISOGLIDE3 parallel robot

The artificial intelligence techniques have been recognized approach to adaptation and conversion of human knowledge into a form understandable by computers. Advanced control based on artificial intelligence techniques is typically referred to as intelligent control.

Medical parallel robots, on the other hand, have gained much popularity because of their:

- intimate interaction with humans;
- unstructured, irregular and dynamic environment;
- unpredictable actions/response of operator/patient;
- complex tasks on irregular subjects;
- serious consequences of error or failure;
- high likelihood of emergency situations.

Nowadays, medical robots are used in orthopaedic interventions on the femur. The head, or condyle, of the femur forms the ball of the hip ball-and-socket joint.

The condyle is joined to the femur by a narrow neck where the most common type of fracture occurs. Surgical repair involves stabilizing the fracture with a stainless steel fixture secured in place by screws.

The 3 DOF ISOGLIDE3 parallel robot and its structure are shown in Fig. 1, where a mobile platform is coupled with the fixed base by three legs of PRRR type (Prismatic Revolute Revolute Revolute).

The forward and inverse kinematic analysis is trivial. The three translational motions of the moving platform coincides with the motions of the three linear actuators ($x = d_1$, $y = d_2$ and $z = d_3$).

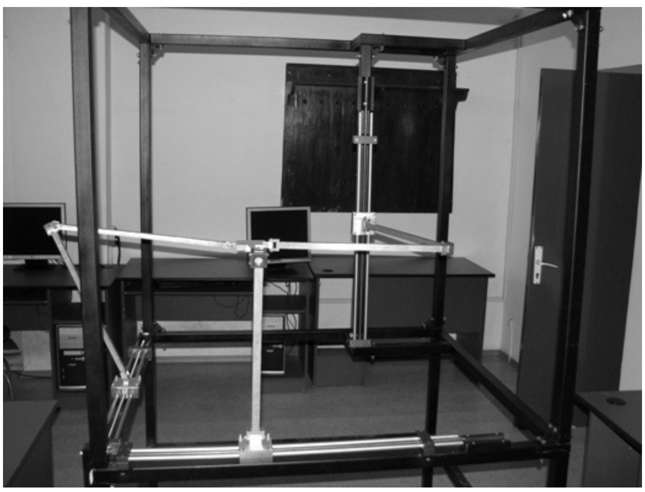

Fig. 1 3 DOF Isoglide3 parallel robot

This robot architecture was also implemented and known in the literature under the name of ISOGLIDE3-T3 [1]-[2], Orthogonal Tripteron [3], or CPM [4].

2. Fuzzy control of the 3 DOF parallel robot

A Fuzzy Logic is a technique to embody human-like thinking into a control system. A fuzzy controller can be designed to emulate human deductive capabilities into in a control system. Fuzzy control incorporates ambiguous human logic into computer programs.

It suits control problems that cannot be easily represented by mathematical models due to their inherent imprecisions such as: parameter variation, unavailable or incomplete data, very complex processes. Examples can vary from optical fuzzy controllers, via control of RAID systems, to control of decision making.

Industrial electronic applications are typically based on the proportional - integral - derivative (PID) control, implemented by embedded system or programmable logic control (PLC) programming. The classical controller development approach relies on a linearisation of system dynamics and on the application of a PID controller to compensate the effects of the nonmodelled nonlinearity. Problems could be existent in the case when the set point is changeable within wide operating range. Fuzzy controllers have become popular in recent years because they do not necessarily require a theoretical model of the plant which is to be controlled. Therefore, in order to develop a fuzzy controller, one needs to first have access to a human expert, find quantifiable means to present the expert's experience, and determine a mapping from states of the plant to the fuzzy measures with which the expert's knowledge is quantified. PID control works well for linear process, but does not perform satisfactory when it comes to nonlinear proceses. The idea of fuzzy control of the parallel robots was tested and demonstrated in ANFIS MATLAB environment tool [5].

Design of a fuzzy controller requires more design decisions than usual, for example regarding rule base, inference engine, defuzzification, and data pre- and post processing. Fig. 2 presents the Simulink model of the ISOGLIDE3 parallel robot using fuzzy controller. Fig. 3 presents the model of the robot using fuzzy controllers.

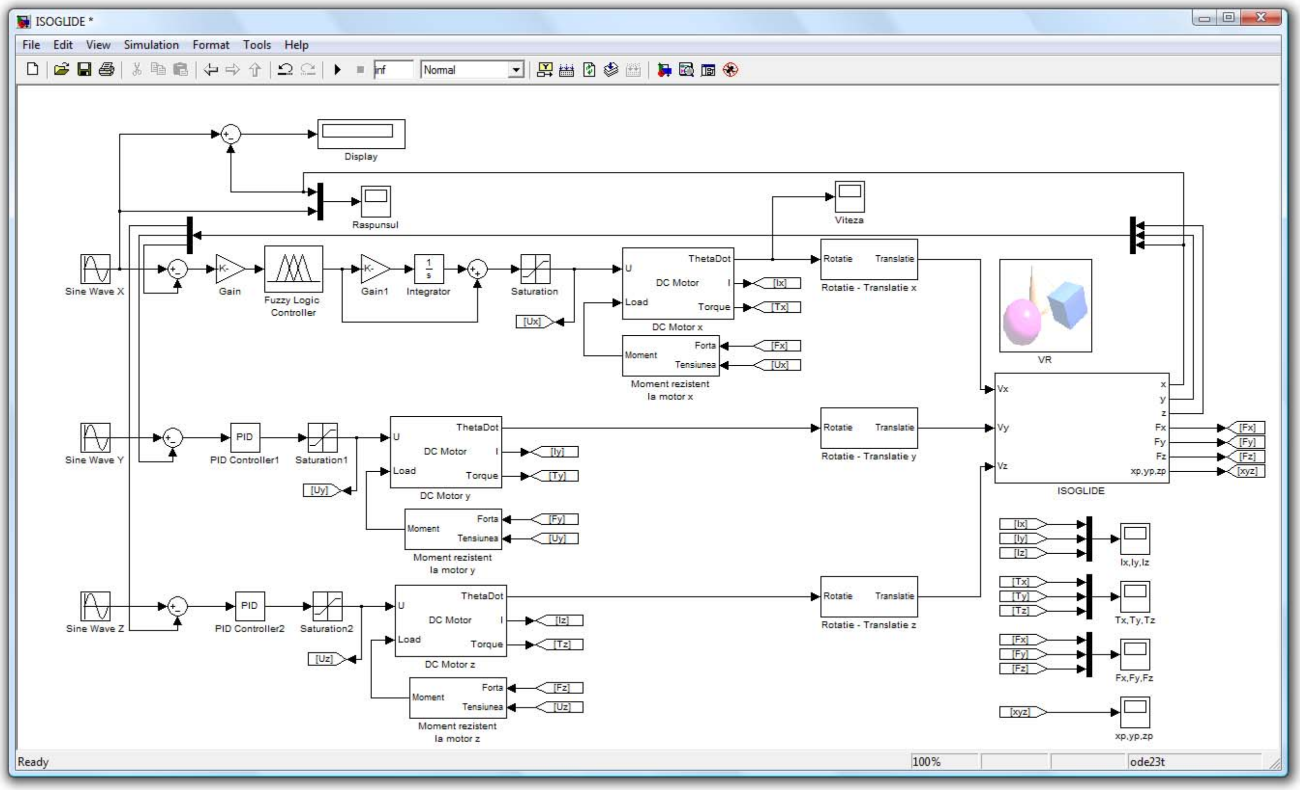

Fig. 2 Simulink model of the ISOGLIDE3 parallel robot using fuzzy controller

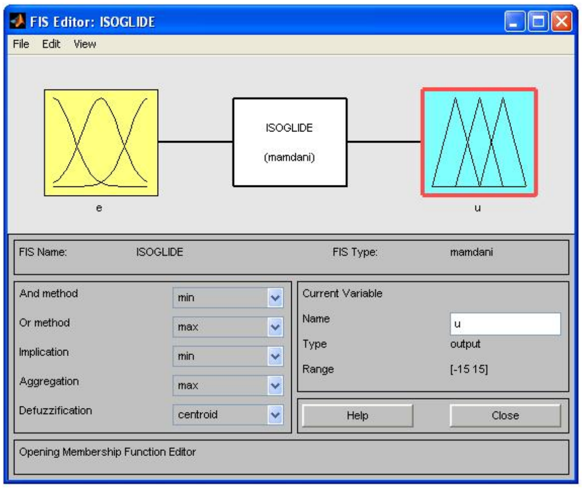

Fig. 3 Fuzzy block scheme for 3 DOF ISOGLIDE3 parallel robot

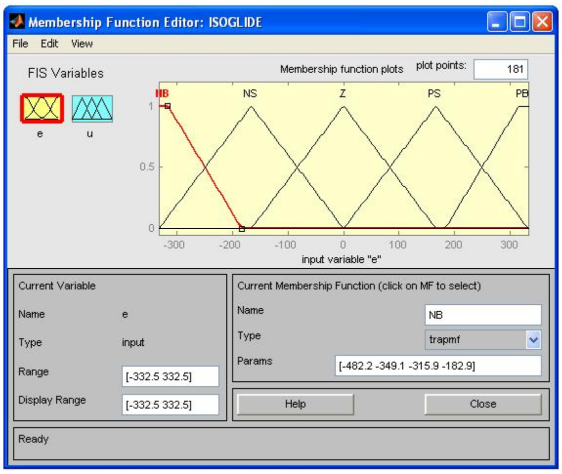

Fig. 4 Membership function block for input variable

The first block inside the controller is the fuzzification module, which converts each piece of input data to degrees of membership by a lookup in one or several membership functions (Figs. 3 and 4). The rule used for the fuzzy control of the 3 DOF parallel robot is presented in Fig. 5.

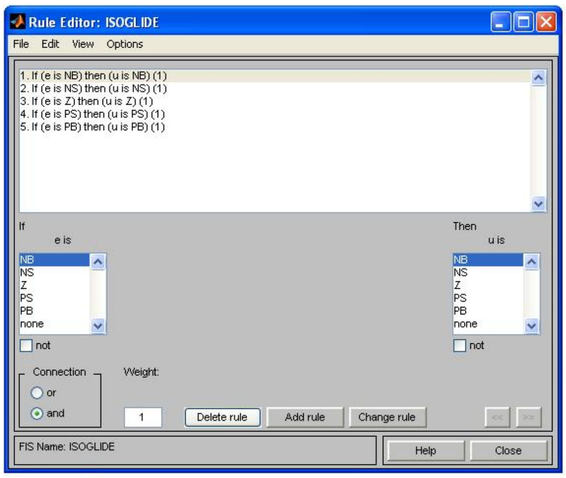

Fig. 5 Rule based editor from MATLAB/Simulink

Design of efficient control for dynamic system usually requires a prior knowledge of the process to be controlled. The first step is to obtain mathematical model for the process, actuator and the controller.

Sometimes, the accurate modeling is very difficult or nearly impossible in which cases Fuzzy Logic Controllers (FLC) have been successfully applied. Fig. 6 presents the membership function block for output variable. Fig. 7 presents the Simulink block scheme for the motor dynamics, while Table 1 presents the DC motor parameters used in the simulation.

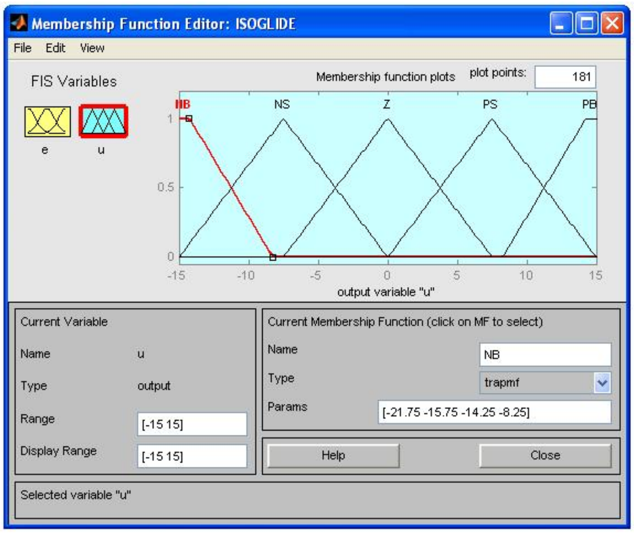

Fig. 6 Membership function block for output variable

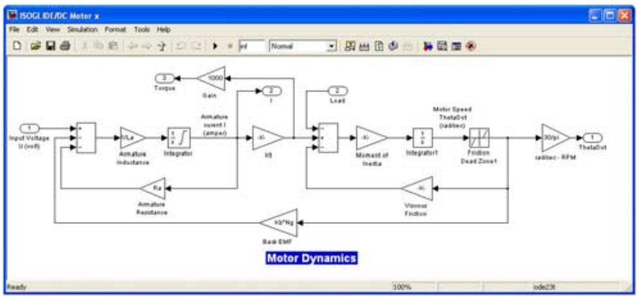

Fig. 7 Simulink block scheme of the motor dynamics

Table

DC motor parameters

Armature resistance *Ra*, ohm	0.334
Armature Inductance *La*, H	0.000085
Torque Coefficient *Kt*, Nm/A	0.0194
Back EMF Coefficient *Kb*, Vs/rad	0.0194
Gear Ratio *Ng*, rad/rad	4.8
Moment of Inertia of Armature *Ja*, kgm^2	0.00000676
Moment of Inertia of Gear/Load *Jg*, kgm^2	0.0000156175
Coefficient of viscous friction at armature *Ba*, Nms/rad	0.000062
Coefficient of viscous friction at gear *Bg*, Nms/rad	0.00001
Current saturation coefficient *Isat*, A	4
Friction dead zone coefficient *dz*, Nms/rad	0.1

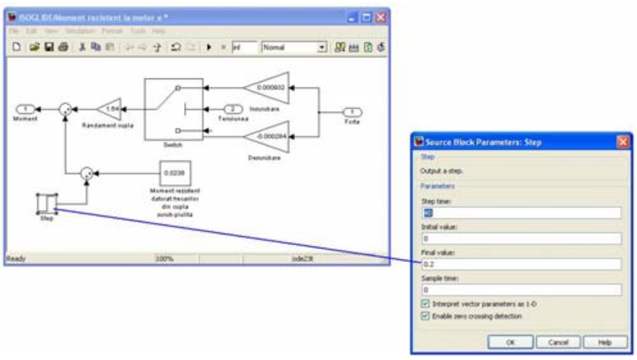

Fig. 8 Simulink model for resistant moment of actuators

Fig. 8 presents the Simulink model for resistant moment of actuators.

There is no design procedure in fuzzy control such as root-locus design, frequency response design, pole placement design, because the rules are often nonlinear.

3. Numerical simulations of the 3degrees of freedom parallel robot

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

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

The interface is based on a virtual reality approach in order to provide the user with an interactive 3D graphical representation of the parallel robot. The ISOGLIDE3 virtual model of the robot is presented in Fig. 9.

The sample trajectory of the end-effector is chosen to be a circular path with the radius of 0.4 meters and its center is O(0, 0, 0). The end-effector path is shown in Fig. 10.

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. 11.

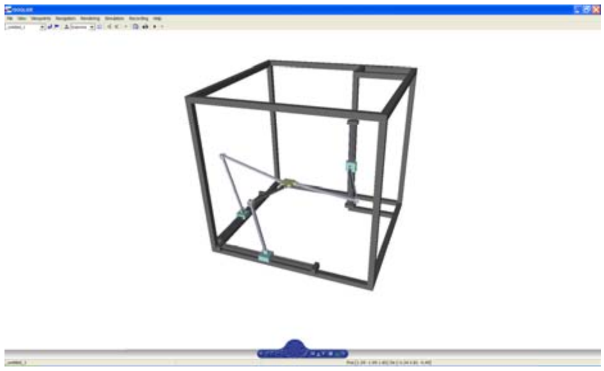

Fig. 9 ISOGLIDE3 virtual reality robot interface

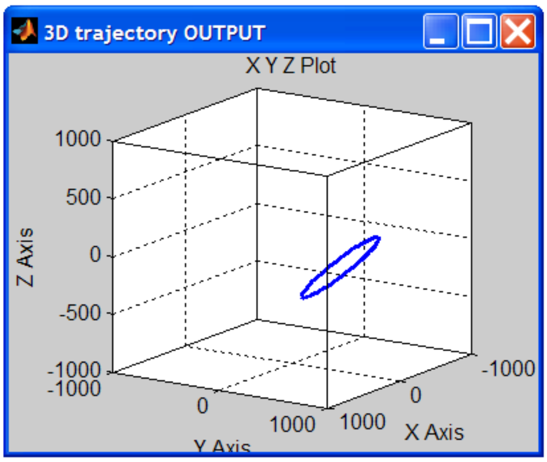

Fig. 10 End-effector path for the 3D circular trajectory

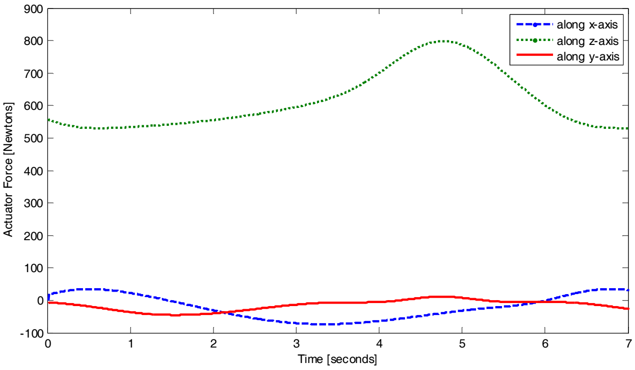

Fig. 11 The desired force obtained from the actuators

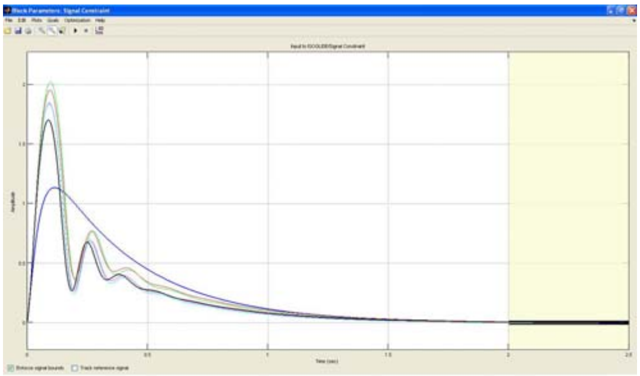
Fig. 12 PID optimization

The controller parameters *kp, ki* and *kd* were optimized for a given trajectory and a maximum error, using the block Signal Constraint from the Simulink Response Optimization toolbox (Fig. 12). After optimization it was found the following PID parameters: *kp* = 3.8755, *ki* = 9.0888 and *kd* = -0.0270. Fig. 13 presents the PID parameters optimization results.

Figs. 14 and 15 presents the simulation results, as one can see the fuzzy control presents better performances as PID. In a fuzzy controller the data passes through a preprocessing block, a controller, and a postprocessing block.

The steps that were applied in the design procedure based on PID and fuzzy control were:

- tune a PID controller;
- replaced it with a linear fuzzy controller;
- fine-tune it.

Preprocessing consists of a linear scaling as well as quantization in case the membership functions are dis-

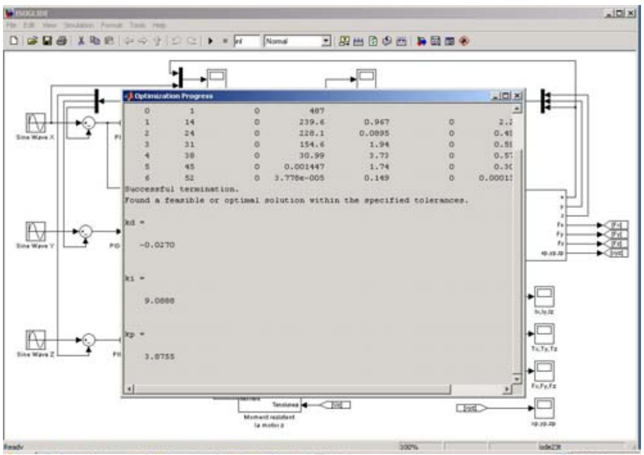
Fig. 13 PID optimization results

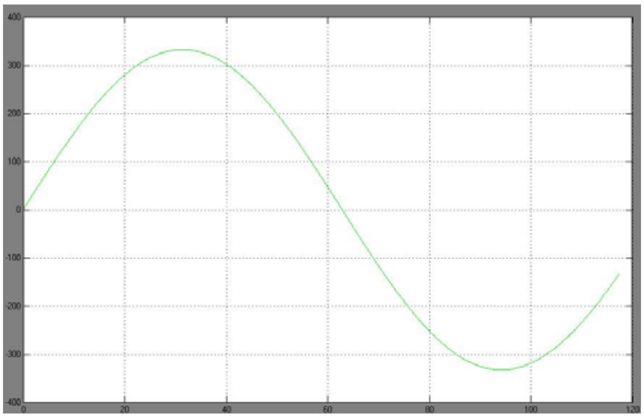
Fig. 14 Fuzzy control results for sinus tracking error

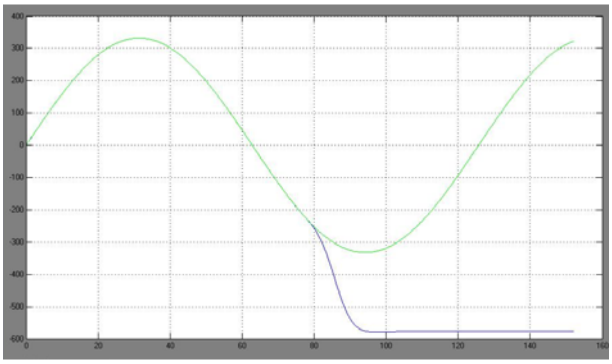
Fig. 15 PID control results for tracking error

cretised (vectors); if not, the membership of the input can just be looked up in an appropriate function.

The root of the problem is the conventional PID controller cannot adapt to the dynamics of the process. So we need some algorithm to adjust PID controller according to the dynamics of the process (Fig. 15).

So we need algorithm that can adapt with nonlinear behavior. Fuzzy logic matches to solve these problems because Fuzzy controller has some advantages:

- membership functions are simple triangular with fuzzy logic rules [6 - 9];
- stability of these fuzzy PID controllers is guaranteed [10 - 13].

4. Conclusions

The applications of micromachine, mechatronics and robotics in medicine are widely spread in clinical use. There are a number of areas in which robotic technology has the potential to contribute positively to the provision of healthcare. The paper presents a fuzzy and PID control for the 3 DOF ISOGLIDE3 parallel robot. Fuzzy controllers are being used in various control schemes. The controller is here a fuzzy controller, and it replaces a conventional controller, a PID controller and proves to have better results.

Acknowledgment

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MEDICININIO LYGIAGREČIOJO ROBOTO ISOGLIDE3 KINEMATIKA IR FUZZY VALDYMAS

R e z i u m ė

Medicininiai robotai – tai palyginti nauja robototechnikos sritis. Straipsnyje supažindinama su novatoriška vartotojo sąsajos programa, skirta trijų laisvės laipsnių lygiagrečiojo roboto ISOGLIDE3 valdymui. Palyginti su kitais lygiagretaus tipo manipuliatoriais, ISOGLIDE3 roboto charakteristikos yra geresnės kokybės, pavyzdžiui, jo konstrukcija lengvesnė. Šiame straipsnyje aprašoma vartotojo sąsajos programa leidžia tuo pačiu metu taikyti PID ir fuzzy reguliatorius. Roboto sąsajos su vartotoju programa buvo išbandyta ir patikrinta virtualioje aplinkoje, gauti rezultatai pateikiami MATLAB, Simulik ir SimMechanics sistemose. Fuzzy reguliatorius buvo išbandytas skaitmeniniu būdu modeliuojant sekiklio trajektoriją. Modeliavimo rezultatai parodė fuzzy tipo valdymo pranašumą, palyginti su tradiciniu PID tipo valdymu.

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KINEMATICS AND FUZZY CONTROL OF ISOGLIDE 3 MEDICAL PARALLEL ROBOT

S u m m a r y

Medical robotics is a relatively new branch of robotics. The paper presents an innovative user interface for the control of a 3 DOF ISOGLIDE3 parallel robot. The ISOGLIDE3 robot described in (Stan, 2008), offers the superior characteristics with regards to the other parallel manipulators, such as the light weight construction. The interface presented in this paper enables the user to apply PID and fuzzy controller together. The robot interface using virtual reality was verified and tested, and results presented in MATLAB, Simulink, and SimMechanics. The fuzzy controller was numerically simulated on problems of trajectory tracking. The simulation results demonstrated the superiority of fuzzy control over traditional PID control.

С.-Д. Стан, Р. Балан, В. Матиес, С. Рад

КИНЕМАТИКА И FUZZY КОНТРОЛЬ МЕДИЦИНСКОГО ПАРАЛЛЕЛЬНОГО РОБОТА ISOGLIDE3

Р е з ю м е

Медицинская робототехника – относительно новая ветвь робототехники. В статье представлен инновационный интерфейс пользователя, предназначенный для управления параллельным роботом ISOGLIDE3 с тремя степенями свободы. По сравнению с другими манипуляторами параллельного типа, характеристики ISOGLIDE 3 робота более высокого качества, например, более легкая его конструкция. В статье описан интерфейс пользователя, позволяющий одновременно использовать регуляторы fuzzy и PID типа. Интерфейс пользователя с роботом тестирован в виртуальной среде. Полученные результаты представлены в системах MATLAB, Simulik и Sim Mechanics. Fuzzy регулятор исследовался при моделировании траектории руки робота цифровым методом. Результаты моделирования показали превосходство fuzzy регулятора по сравнению с регулятором типа PID.

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