International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 03 - Issue 12 || December 2017 || PP. 104-108

Kinematic and Dynamic Analysis of the 3-PRS Parallel Mechanism Based on Virtual Prototype

Guoqiang Chen[1], Zhuangzhuang Mao[1], Shanshan Dang[1], Jianli Kang[2], Ruidong Xu[1]
[1](*School of Mechanical and Power Engineering/Henan Polytechnic University, P.R. China)*
[2](*School of Computer Science and Technology/Henan Polytechnic University, P.R. China)*

Abstract: Aiming at the complicated problem of kinematic and dynamic analysis, the method based on the virtual prototype technology is proposed to study the 3-PRS parallel mechanism. The 3D modeling software is discussed to establish the virtual prototype. The virtual prototype modeling procedure is proposed and presented, and then the virtual prototype of the 3-PRS parallel mechanism is established. Finally four examples are given to verify the feasibility and effectiveness of the prototype. The established prototype lays a foundation for further study of the 3-PRS parallel mechanism.

Keywords: Parallel mechanism, Virtual prototype, Kinematic analysis, Dynamic analysis, 3D modeling

I. INTRODUCTION

The parallel mechanism, called parallel robot sometimes, has many advantages of high precision, strength and stiffness and good carrying capacity, and has gained plenty of application in all kinds of fields, such as machining tools, driving simulators, recreation equipments and medical apparatus and instruments[1-7]. Not all the parallel mechanisms possess 6 degrees of freedom (DOFs), and the deficient DOF mechanism has Broad application and presents prominent performance in many fields, among which the 3-PRS parallel mechanism with two parasitic rotational motions and one parasitic translational motion is typical in the deficient DOF parallel mechanism. The characteristic of the 3-PRS mechanism is very complicated because it includes working space, kinematics, dynamics and so on. The theoretical analysis procedure refers to the nonlinear equation system and trigonometric functions, and the analysis procedure and solution is always complicated, confusing, tedious and non intuitive. The physical experiment has the real performance and the mechanism can present its real characteristics. But the characteristic is the result of many influencing factors, so it is always very difficult in finding the causal link between the influencing factor and the extrinsic phenomenon. In addition, the physical is always expensive and time-consuming. The virtual prototype technology can reduce development expenses, shorten development cycle and improve design performance. Therefore a virtual prototype for the 3-PRS parallel mechanism is established to analyze its kinematic and dynamic characteristic.

II. ARCHITECTURE OF THE 3-PRS PARALLEL MECHANISM

The 3-PRS parallel mechanism is composed of a moving platform, three limbs, three vertical rails and a fixed platform (base)[8-12], as shown in Figure 1. Three vertical rails vertically link to the fixed platform (base) B_1 B_2 B_3. Moreover, B_1 B_2 and B_3 form an equilateral triangle that lies on a circle with the radius R .The axis of each revolute pair C_i for $i=1,2$ and 3 is perpendicular to the corresponding prismatic pair. Each limb L_i for $i=1,2$ and 3 connects the corresponding rail by a prismatic pair C_i. The moving platform and three limbs are connected by three spherical pairs P_1, P_2 and P_3.

Three spherical pairs form an equilateral triangle that lies on a circle with the radius r. The cutter is placed at the center of the moving platform. The feeds of the three prismatic pairs are given as H_i for $i=1,2$ and 3. The angle θ_i for $i=1,2$ and 3 is defined from the vertical rail to its corresponding limb L_i. As shown in Figure 1, a fixed Cartesian reference coordinate system OXYZ is located at the center point O of B_2 B_3. The X-axis and the Y-axis are in the base plane B_1 B_2 B_3, the X-axis points in the direction of O B_1, and the Z-axis is normal to the base plane and points upward. The 3-PRS parallel mechanism possesses 3 DOFs that are a rotational motion about the Z-axis, a rotational motion about the Y-axis, and a translational motion along the Z-axis.

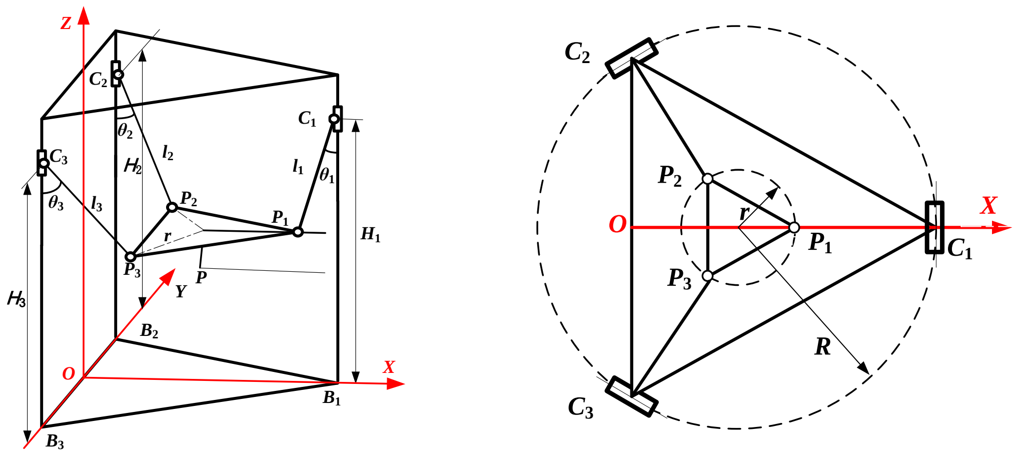


Figure 1. The schematic diagram of the 3-PRS parallel mechanism

III. ESTABLISHMENT OF THE VIRTUAL PROTOTYPE

There are a great number of excellent three-dimensional design /CAD/simulation packages that can be used to establish the virtual prototype, such as SolidWorks developed by Dassault Systemes S.A, UG(Unigraphics NX) developed by Siemens PLM Software, CATIA (Computer Aided Three-dimensional Interactive Application) developed by Dassault Systemes, Pro/E(Pro/Engineer) developed by PTC(Parametric Technology Corporation) and ADAMS(Automatic Dynamic Analysis of Mechanical Systems) developed by Mechanical Dynamics Inc. And every of these packages has its advantages and disadvantages. The kinematic and dynamic characteristic of a mechanical mechanism can be fully exploited by combination with other computation software, such as MATLAB (MATrix & LABoratory) developed by MathWorks, Maple developed by Waterloo Maple Software and Mathematica developed by Wolfram Research.

The virtual prototype is established in a two-stage procedure shown in Figure 2 and some schematic assembly icons are excerpted from CATIA. The first stage includes modeling the each part of the 3-PRS mechanism. It should be noticed that maybe several parts are modeled as a whole one or a certain some part is replaced in other way in order to simplify the task. The parts are assembled in the second stage.

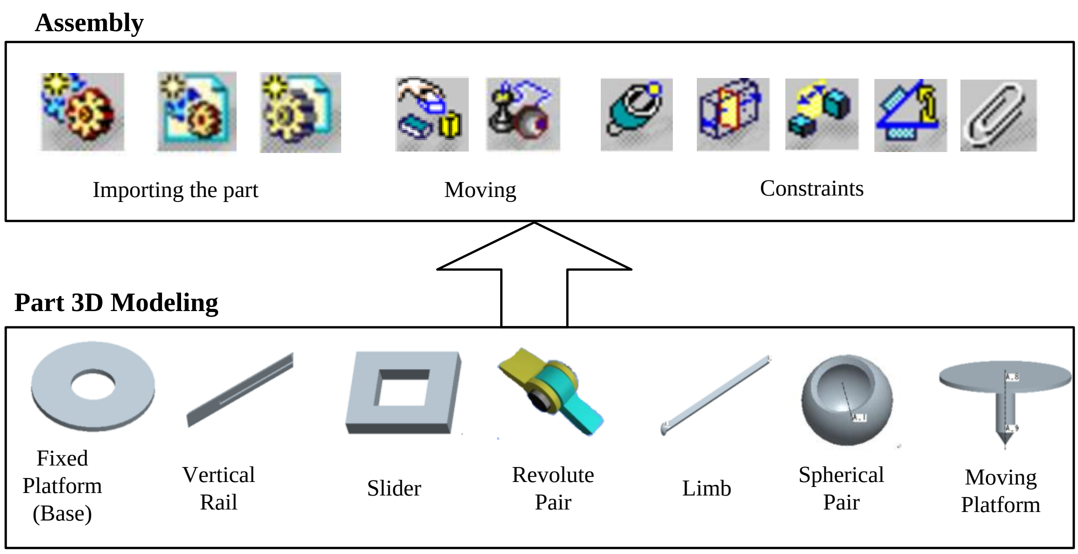
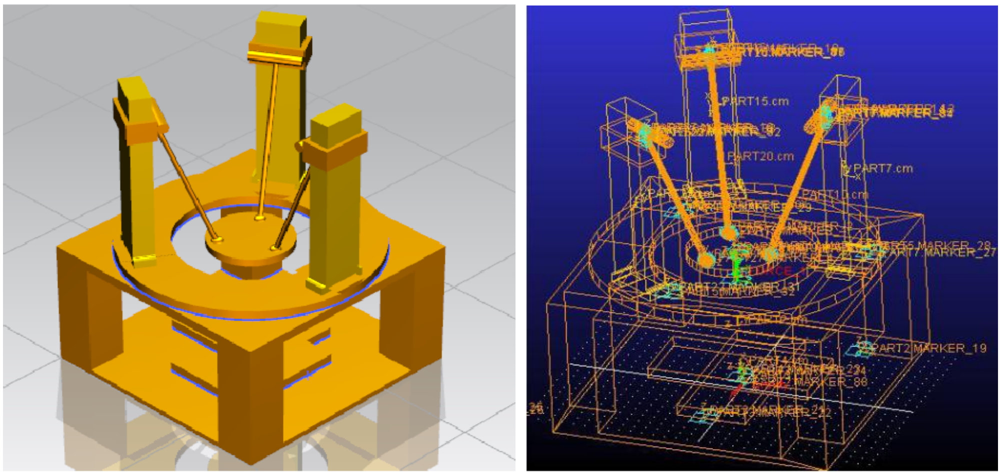


Figure 2. The virtual prototype modeling procedure of the 3-PRS parallel mechanism

If a 2-DOF X-Y table is introduced and fixed bellow the fixed platform(base), a 5-DOF series-parallel robot is built and the corresponding virtual prototype is shown in Figure 3.



(a)Without constraints (b)With constraints

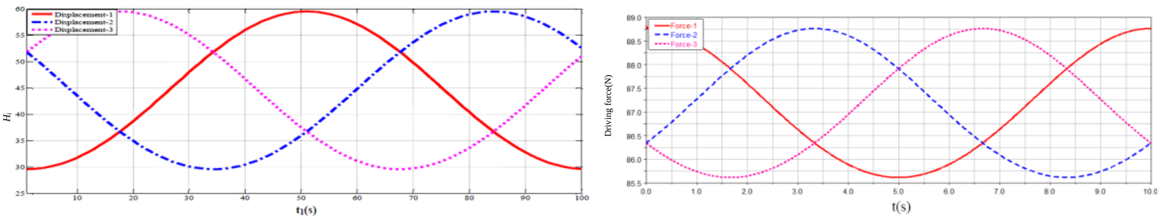
Figure 3. The virtual prototype of the series-parallel robot based on the 3-PRS parallel mechanism

IV. RESULTS

Example 1:The characteristic highly depends on the mechanism parameter. The limb length is 820mm, the radius R and r are 350mm and 150mm respectively and the cutter length is 150mm. The moving trajectory is expressed as

$$\begin{cases} x = 15\cos(2\pi t) \\ y = 15\sin(2\pi t) \\ z = 0 \end{cases} \quad (1)$$

The feeds H_i of the three prismatic pairs can be computed and the Point Control algorithm is used. The load force is along the cutter axis. The Coulomb friction model is utilized with the static friction coefficient and dynamic friction coefficient set. The simulation results are shown in Figure 4.



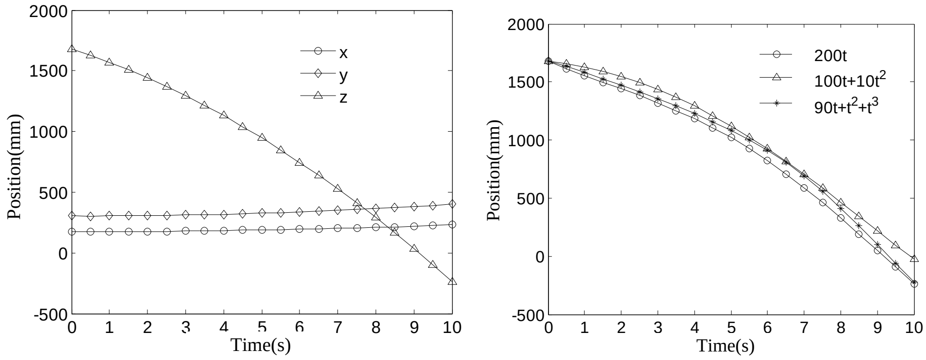
(a)Slider height (b)Driving force on the slider

Figure 4. Results of Example 1

Example 2: The limb length is 1107mm, the radius R and r are 350mm and 200mm respectively and the cutter length is 280mm. The slider moving law is set as

$$\begin{cases} H_1 = 3107 - (100t + 10t^2) \\ H_2 = 3107 - (100t + 9t^2) \\ H_3 = 3107 - (100t + 9t^2) \end{cases} \quad 0 \le t \le 10 \quad (2)$$

If H_3 is replaced by $3107 - 200t$ and $3107 - (90t + t^2 + t^3)$ respectively, the cutter trajectories are shown in Figure 5.



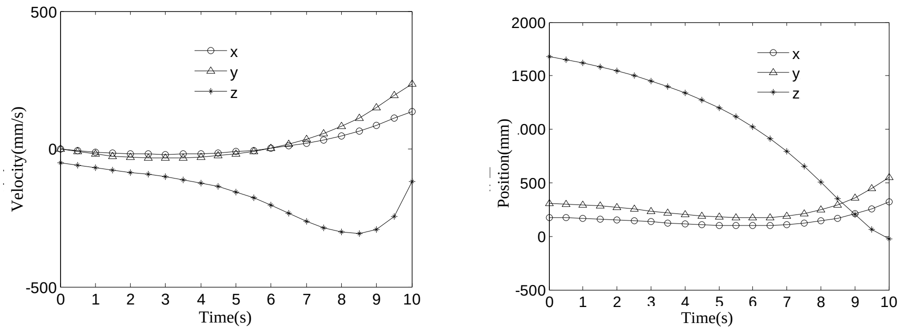
(a)For Equation (2) (b) For replaced H_3

Figure 5. Cutter trajectories of Example 2

Example 3: The test structure parameters for Example 2 is used again but now with the three slider velocities expressed as

$$\begin{cases} v_1 = 50 + 2t + 3t^2 + 0.16t^3 \\ v_2 = 50 + 25t \\ v_3 = 50 + 25t \end{cases} \qquad 0 \le t \le 10 \tag{3}$$

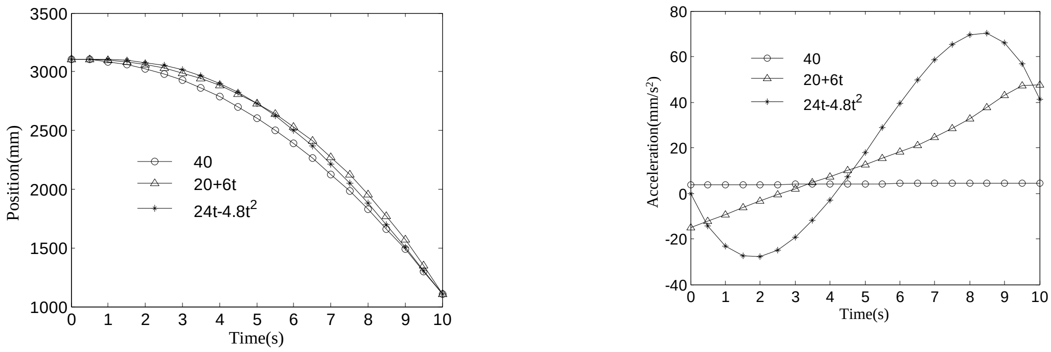
The cutter trajectory and velocity are shown in Figure 6.



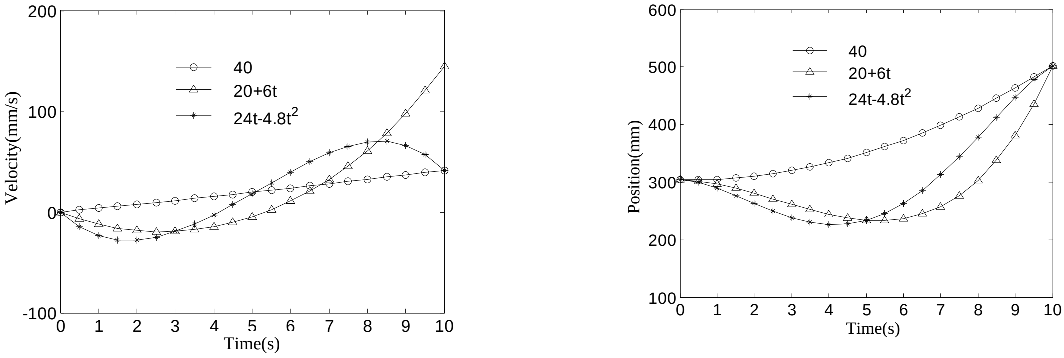
(a) Velocity (b) Trajectory

Figure 6. Cutter trajectories of Example 3

Example 4: The test structure parameters for Example 2 is used again. The first and second slider accelerations are set as 35 mm/s^2, and the first accelerations is set as 40 mm/s^2, $20+6t$ and $24t-4.8t^2$ in sequence. The cutter trajectory and velocity are shown in Figure 7.



(a) Slider position (b) Cutter acceleration in direction y



(c) Cutter velocity in direction y (d) Cutter position in direction y

Figure 7. Results of Example 4

V. CONCLUSION

The 3D modeling software is discussed to establish the virtual prototype. The virtual prototype modeling procedure is proposed and presented, and then the virtual prototype of the 3-PRS parallel mechanism is established. Finally four examples are given to verify the feasibility and effectiveness of the prototype. The established prototype lays a foundation for further study of the 3-PRS parallel mechanism, for example finite element analysis for error and structural strength.

VI. ACKNOWLEDGEMENTS

This work is supported by Scientific and Technological Project of Henan Province of China with grant No. 172102310664. The authors would like to thank the anonymous reviewers for their valuable work.

REFERENCES

[1] Ming H, Wen Y T, and J S S, Manipulability analyses of the 3-DOF parallel machine tool, Applied Mechanics and Materials, 16-19, 2009, 1351-1354.
[2] HOU Y L, LI Z S, WANG Y and et al, Mechanics unloading analysis and experimentation of a new type of parallel biomimetic shoulder complex, Chinese Journal of Mechanical Engineering, 29(4) , 2016, 649-658.
[3] Vallés M, Cazalilla J, Ángel Valera, and et al, A 3-PRS parallel manipulator for ankle rehabilitation: towards a low-cost robotic rehabilitation, Robotica, 35,2015, 1-19.
[4] LU G D ,ZHANG A M, ZHOU J, and et al, Statics analysis and examination research of 3-RSS/S parallel mechanism, Journal of Machine Design30(3) , 2013,26-31.
[5] WANG M F, and CECCARELLI Marco, Topology search of 3-DOF translational parallel manipulators with three identical limbs for leg mechanisms, Chinese Journal of Mechanical Engineering, 28(4), 2015, 666-675.
[6] LU Y and HU B, Development evaluation of limited-DOF parallel manipulators, Journal of Yanshan University, 2011, 35(5): 377-384.
[7] KANG J L, CHEN G Q, ZHAO J W. Analysis on workspace of 3-PRS mechanism based on monte carlo method, Journal of Henan Polytechnic University(Natural Science), 2014,33(4):478-481.
[8] Liu W, and Chang S, Study on structural design of a parallel robot and applications in automobiles, Machinery Design & Manufacture, (6),2012,141-143.
[9] Liu X, Wu C, Wang J, and BONEV I, Attitude description method of [PP]S type parallel robotic mechanisms, Chinese Journal of Mechanical Engineering, 44(10),2008, 19-23.
[10] Tsai M-S, and Yuan W-H, Dynamic modeling and decentralized control of a 3 PRS parallel mechanism based on constrained robotic analysis, Journal of Intelligent and Robotic Systems: Theory and Applications, 63(3-4),2011, 525-545.
[11] G Abbasnejad, S Zarkandi, and M Imani, Forward kinematics analysis of a 3-PRS parallel manipulator, World Academy of Science, Engineering and Technology, 37(Jan.),2010, 329-335.
[12] Li Q, Chen Z, Chen Q, Wu C, and Hu X, Parasitic motion comparison of 3-PRS parallel mechanism with different limb arrangements, Robotics and Computer-Integrated Manufacturing, 27(2), 2011, 389-396.