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Study on the Control System of the End Effector in Minimally Invasive Surgery Robot

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Abstract: As A New Research Field, Minimally Invasive Surgical Robot Technology Has Great Value For The Research And Development Of Motion Control System. From The Aspects Of Robot Configuration, Surgical Trajectory Planning And Control System, This Paper Introduces The Design And Implementation Of The Minimally Invasive Surgical Robot End Effector. The Control Strategy Of Minimally Invasive Surgery Robot, The Selection Of Control System Hardware And The Software Development Process Are Described. A New Type Of Minimally Invasive Surgery Robot Adopts The Parallel Structure And The Control Strategy Based On The Calculated Torque/Displacement, Which Realizes The Control Of The Trajectory Tracking, And Can Complete The Simple Minimally Invasive Operation Under The Doctor's Operation.

Key Word: *Minimally Invasive Surgical Robot; Robot Configuration; Trajectory Planning; Control System1*

I. INTRODUCTION

Minimally Invasive Surgery Is To Open One Or More 0.5cm～3cm Incision In Patients In Vitro, The Surgical Instruments Were Implanted Into The Patient Through A Small Wound, And The Doctor With The Help Of An Image Visualization System To Perform The Specific Surgical Treatment For The Removal And Repair Of Diseased Cells. Compared With Traditional Open Surgery, Minimally Invasive Surgery Has Many Advantages, Such As Less Trauma, Less Blood Loss, Faster Postoperative Recovery And So,Therefore, It Has Been Widely Used In The Field Of Surgery[1]. But Because Of The Minimally Invasive Surgery Has A Series Of Problems Need To Be Solved, Such As During The Operation Process, The Doctor Hand Eye Coordination Is Poor, Easy To Fatigue, Less Freedom Of Surgical Instruments, Resulting In Poor Flexibility In Operation, Hand Tremor Seriously Affect The Accuracy Of Surgery, Etc.. In Order To Effectively Solve The Problems In Minimally Invasive Surgery, The Robot Technology Is Introduced Into Minimally Invasive Surgery, The Combination Of The Two Is Bound To Be The Main Direction Of The Future Development Of Minimally Invasive Surgery[2]. Minimally Invasive Surgical Robot System Overcomes The Shortcomings Of Traditional Minimally Invasive Surgery, While Providing A Good Working Environment For The Doctor, In The Premise To Ensure The Safety Of Patients Under Greatly Improve The Quality Of Minimally Invasive Surgery.

At Present, Minimally Invasive Surgical Robot Technology Has Become The International Multitudinous Universities And Research Institutes Of The Research Focus, Which Studies In The Minimally Invasive Surgical Robot Technology In The United States And The European Research Institutions In The International Leading Level,One Of The Most Representative Of The United States In 1996 Computer Motion R & D Zeus Robot System[3]And In The United States In 1999 Surgical Da Vinci Robot System[4]. In 2001, Da Vinci Minimally Invasive Surgery Robot System Developed By The American Intuitive Surgical Company Successfully Passed The Food And Drug Administration Certification [5], Has Achieved The Commercialization Of Minimally Invasive Surgery Robot System.

2 Robot Configuration

Independent Research And Development Of The Parallel Robot Configuration Has Been Used On The End Effector Of A New Type Of Minimally Invasive Surgery Robot, By The Double Parallel Parallelogram Mechanism Realize Reliability Centered Maintenance And Decoupling Function,Has The Advantages Of Simple Structure, Good Flexibility, The Structure Configuration As Shown In Figure 1. The End Effector Can Not Only Realize The Pose Position Of The Operating Range, But Also Ensure The Stability And Flexibility Of The Robot.

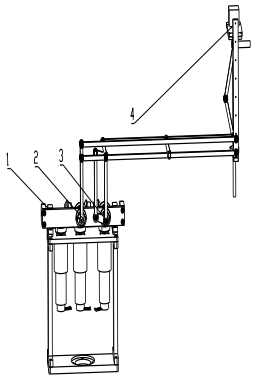

Fig.1 The End Effector Of The Minimally Invasive Surgical Robot

The End Effector Of The Surgical Robot Is Composed Of One Or Two And Three Or Four Joints. The First Joint Is Rotating Joint To Realize The Rotation Of The End Actuator; The Second Joint Is A Rotating Joint To Realize The Rotation Of The Front Parallelogram Mechanism; The Third Joint Is A Rotary Joint,Which Uses The Parallelogram Mechanism To Convert The Rotary Motion Into The Linear Motion Of The Joint Four, And The Linear Stretching Motion Of The Surgical Instrument Is Realized; The Fourth Joint Is A Rotating Joint To Realize The Rotation Of The Surgical Instrument.

3 Surgical Trajectory Planning

In The Process Of Minimally Invasive Surgery,Doctors Can Operate Robots, First, The Surgical Instruments Were Moved From The Distal To The Proximal Point, And The Location Of The Incision Was Precisely Located. After The Doctor Again Through The Operation Of The Robot End Effector Do Fixed-Point Motion, Surgical Instruments Will Be Slowly Inserted Into The Patient's Body Along The Incision Point That Has Given Before Operation Scheme, And According To The Specific Situation Around The Incision Point At A Certain Angle Swing, To Reach Any Position Of The Operation Area, The Completion Of The Lesion Cells In Vivo Excision And Repair Of Concrete The Surgical Treatment Of The Task.

4 Robot Control System

4.1 Study On The Control System

By Analyzing The Kinematics And Dynamics Of The End Effector Of The Surgical Robot, That Can Get The Motion Space, Displacement And Velocity About Each Joints Of The End Effector. In Order To Improve The Surgical Robot End Effector Has Good Stability In The Work Process, So Installing Force And Displacement Sensor At The Joint Of The Surgical Robot End Effector, Which Better Reflects The Working State About The End Effector Of The Surgical Robot. Different From The PD Control System Or PD Control System Based On Gravity Compensation, Aiming At The Design Of The End Effector Of The Surgical Robot, A Control Strategy Based On Torque And Displacement Error Compensation Is Presented, Ensuring In The Motion Process To Meet The High Precision Control Requirements, Improving The Reliability Of The End Mechanism. According To The Lagrange Equation Establish The Dynamic Model Of The Robot End Effector, And The Terminal System Is Considered As An Idealized Linear System, Introducing Corresponding Control. According To The Dynamic Equation Get The Effective External Load Control Equation About The End Effector.

$$F_1 = M(\mathrm{s})(\ddot{s}_d + K_d\dot{e} + K_p e) + N(s,\dot{s})\dot{s} + \mathrm{G}(\mathrm{s})$$

Among:

F_1—Joint Driving Force Under Dynamics;

S—Actual Position Of Joint;

$\dot{s}$ —Actual Speed Of Joint;

s_d —Theoretical Trajectory Of Joint;

$\ddot{s}_d$ —Theoretical Acceleration Of Joint;

$N(s,\dot{s})\dot{s}$ —Inertia Force;

K_d、K_p—Differential Constant And Proportionality Constant;

E—The Deviation Between The Actual Position And The Theoretical Position Of Each Joint;

G（S）—Gravity Term.

Considering The Effect Of The Contact Force Between The Surgical Instruments And The Environment In The

Process Of Operation, The Joint Driving Force Of The Robot Is Obtained Under Static Condition:

$$F_2 = JF_3$$

Among:

J—Force Jacobian Matrix;

F3—Effective Load.

Minimally Invasive Surgery Robot Joint Effective External Load:

$$F = F_1 + F_2 = M(\mathrm{s})(\ddot{\mathrm{s}}_d + K_d\dot{e} + K_p e) + N(s,\dot{s})\dot{s} + \mathrm{G}(\mathrm{s}) + JF_3$$

4.2 Design Of Hardware Structure

In Order To Meet The Needs Of The Minimally Invasive Surgery Robot Control System, Such As Accurate Drive, High Speed Operation And Data Processing. The Control System Is Based On The Upper And Lower Computer Control Unit Of High Performance Industrial Computer And Motion Control Card To Build Control Structure Of Robot, And The Communication Mode Of PCI Field Bus Is Adopted. The PCI Field Bus Communication Mode Is Also Used Between Minimally Invasive Surgery Video Cart And High Performance Industrial Computer. The Hardware Structure Of The End Effector Of The Robot Is Shown In Figure 2.

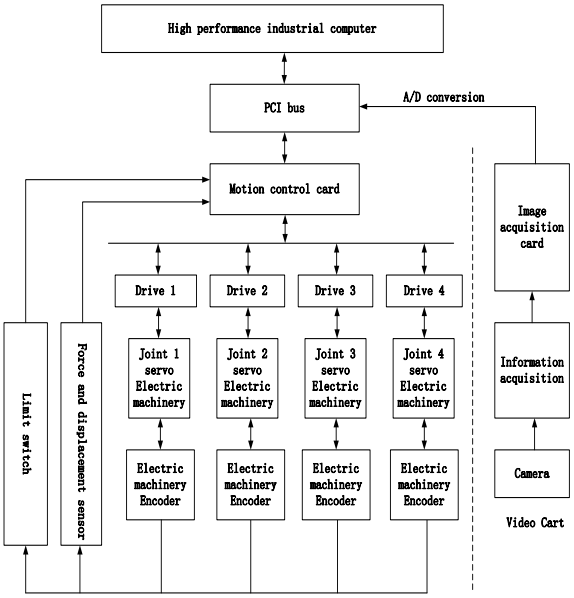

Fig. 2 Hardware Structure Of The Control System Of The End Effector Of Surgical Robot

The Upper Control Unit Of The Control System Is Mainly Composed Of High Performance Industrial PC, Which Completes The Processing Of Information And Real-Time Monitoring Of The Signal; The Lower Computer Control Unit Is Mainly Composed Of Motion Control Card, Which Completes The Communication Between The Upper Computer Control Unit And The Signal Data, The Upper Computer Control Unit And The Lower Computer Control Unit Are Connected Through The PCI Communication Bus.In The Control System, Industrial PC Can Do Kinematics And Trajectory Planning According To The Control Command, And The Results Of Information Will Be Transmitted To The Lower Computer Control Unit, The Lower Computer Control Unit Through The Motion Control Card, Servo Motor And Driver Accurately Control Each Joint's Pose And Velocity Of The Minimally Invasive Surgery Robot End Effector, The Industrial PC Complete To Monitor The Working State Of The Motor In Real Time By The Signal Of The Motor Encoder And The Force Sensor. The Minimally Invasive Video Cast Will Collect The Image Information From The Operating Area By The Micro HD Camera, Which Is Sent To The Image Acquisition Card For Processing,And Through The PCI High-Speed Bus Transmission To The Industrial PC Machine, Realizing The Real-Time Monitoring Of The Whole Operation Process, Which Will Reduce The Risk Of Surgery To Ensure The Safety Of Patients.

4.3 Design Of Software Structure

The Design Of Software System Structure Is An Important Part Of The Whole Control System. The Function And Reliability Of The Software Will Directly Affect The Performance Of The Control System. The Control System Of The End Effector Of The Minimally Invasive Surgical Robot Adopts The Windows7 System, Using The C Language As The Programming Language.

The Software Structure Of The Control System Is Shown In Figure 3.

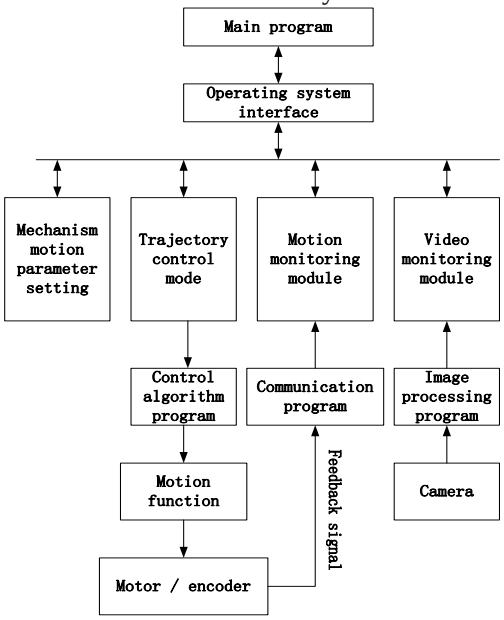

Fig.3 Software Structure Of Control System

Control System Software Development And Design Phase, As Shown In Figure 4.

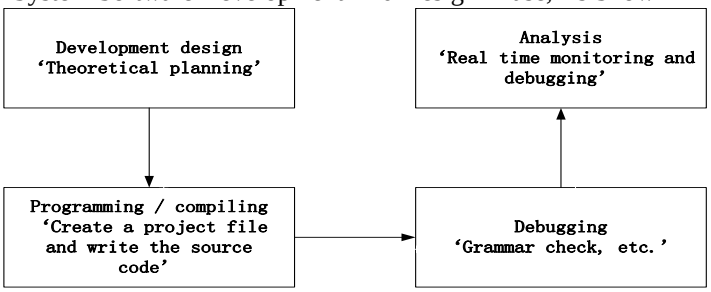

Fig.4 Software Development Design

The Development Phase Of The Software Is The Application Code Which Is Written By The User Based On The C Language Development Environment, Which Is Suitable For The End Effector Of The Robot,And Finally Get The Target Code, To Achieve All The Functions Of The End Effector.

The Operating Process Of The Control System Software, As Shown In Figure 5.

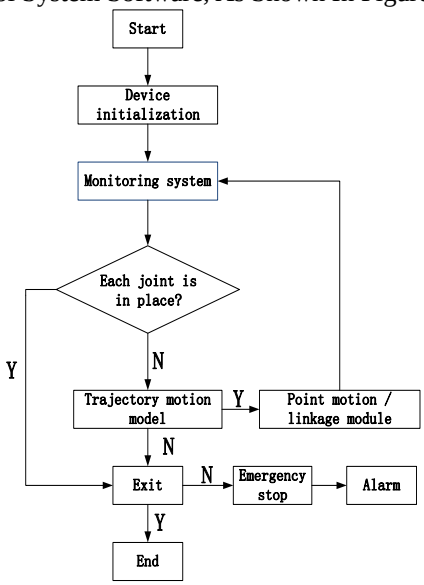

Fig.5 Software Flow Chart

Mainly Includes: The Parameters Of Surgical Robot Setting, Equipment Initialization; The Robot End Position Is Transmitted To The Monitoring System For Real-Time Monitoring, Implementation Of Monitoring The Whole Operation Process; If The Joint Did Not Arrive At The Designated Location, Location Using Motion Pattern Adjustment; The Joint Real-Time Emergency Stop, Reset And Automatic Alarm Function.

II. CONCLUSION

Minimally Invasive Surgical Robot System Is An Interdisciplinary Research Area Which Combines Medical Science, Robotics And Mechanics. The Ultimate Goal Of Minimally Invasive Surgery Robot System Is Not A Substitute For The Surgeon, But As A Tool To Expand The Operation Ability Of The Doctors, And Overcome The Shortcomings Of Manual Movement Limitation Of Minimally Invasive Surgery, Give Full Play To The Advantages Of Minimally Invasive Surgery, So As To Improve The Operation Efficiency, Alleviate The Work Intensity Of Doctors. The Research Of The End Effector Of A New Type Of Minimally Invasive Surgery Robot, Adopting The Parallel Structure And The Control Strategy Based On The Calculated Torque/Displacement. The Trajectory Planning Of The Surgical Operation Is Realized By The Trajectory Motion The Robot End Effector Joints.Analysis Of Experimental Data Shows That The Robot End Control System Has Good Stability. The Next Step Will Be To Add Three Degrees Of Freedom To The Existing End Mechanism To Help The Surgical Robot To Achieve More Sophisticated And Minimally Invasive Surgery.

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