OPERATION AND CONTROL OF SPACE REMOTE MANIPULATOR

* Li Daming , Zhang Xiaodong, Tang Zixin

Beijing Key Laboratory of Intelligent Space Robotic Systems Technology and Applications, Beijing Institute of Spacecraft System Engineering Beijing E-mail: 15810002976@139.com

ABSTRACT

As the development of space technology, the Space Remote Manipulator (CSRM) will play a critical role in the assembly, maintenance and servicing of the space mission. CSRM is an intelligent robotic system with large-scale movement, functional agility, and autonomous ability, and it can be operated by astronauts in the space station or be controlled by the ground operator in the remote operation mode. To realize the autonomous movement and capture mission of CSRM, autonomous programming strategy based on multi-camera vision fusion, intelligent control and hand-controller with force feedback is designed for the better precision, and a kind of distributed control system hierarchy is designed and reliability is considering to guarantee the abilities of control system. The results of electronic tests demonstrate that the control system can fulfill the needs of function, real-time and reliability.

1 INTRODUCTION

The Space Remote Manipulator is an important and necessary equipment in the assembly, maintenance and servicing of the Space Station[1], and which has been researched and used by many countries which include the SRMS on American shuttle, SSRMS on the International Space Station[2,3], ERA and JEMRMS. As the development of Chinese space technology, the Space Manipulator will be an indispensable space robotic system, especially for the space station on-orbit servicing and space exploration.

To satisfy the requirement of manipulator functions, the system configurations of CSRM is introduced firstly, and the manipulation mode and control mode are introduced. CSRM can be operated by astronauts in the space station or be controlled by the ground operator in the ground, On-orbit Operation Console is used to operate manipulator by astronaut to realize the human-in-loop real-time operation; Ground remote operation console aim to efficiently make use of limited communication channel resource, and remove the communication delay to realize the data response smoothly and accurately. Ground remote operation console has the same configuration with on-orbit Operation Console which includes the data process unit, graphics processing unit, command and calculation unit, and so on.

Then, a hierarchical multi-processor computing architecture is introduced. Mission and operating management computer (Centre Computer) is the top-level supervisory control devices which include the mission management, system initialization, control mode selection, health monitoring and failure detection, etc. Joint controller will drive the movement of manipulator by the receiving commands, and complete all kinds of operation missions. The image from the camera will be compressed and the object position and orientation will be detected by the camera controller.

The motion control strategies of manipulator are also introduced include the control mode, trajectory planning, dynamic arithmetic, and joint servo control. To get the higher agility and the accurate position and orientation of object, and satisfy the requirement of different object, servo-control with the artificial vision measurement data feedback control and torque control with 6-axis force-moment sensor on each end-effector and the torque sensor in every joint are designed.

Finally, the design of operation and control can also be used in the on-orbit service and other dexterous operation mission, the applicability and impetus are perspective.

2 OVERVIEW OF MANIPULATOR

2.1 Roles and Functions

The manipulator has been assigned a predominant role in satisfying the following functions[4]:

1) Assembly of Space Station, space station module is transferred to one side after docking by the manipulator;
2) Deployment, retrieval and assistant docking of free flying vehicles, capture the free flying vehicles and transfer it to the berthing docking mechanism;
3) Support astronaut extra-vehicular activities; astronaut can be fixed on end tip of manipulator, finish the designed mission by the assistant of manipulator;

4) Transportation of external payloads and exchange, realize the assembly, exchange and maintenance of space station platform and the heavy payload;

5) Monitor and inspect of External Surface, realize the periodical inspection by the camera and movement ability.

So, the manipulator has to satisfy the following functions:

1) Multi-freedom movement functions at the condition of the heavy payloads, and fulfill the transportation of heavy external payloads.

2) "stepping" function which will allow the manipulator to access any places of the station area to satisfy the transport of huge devices, the monitoring and the measuring of the whole surface of station.

3) Trajectory planning function which will support position and orientation plan abilities in many kinds of constrained conditions and control modes, and implement detection and avoidance of the collision.

4) Temperature control function which will guarantee the on-orbit work and storage temperature conditions.

5) Objection monitor and measuring function which include the objection recognize and position, monitoring of work environment and operation conditions, and the detection of surface of station.

6) Accurate and dexterous operation abilities with impedance control system which will be used in the plug and pull of experiment payloads, the change of experiment devices.

2.2 Configurations of Manipulator

The CSRM can be controlled by the in-orbit operation console in the pressurized module of space station, which also provides the power, data, instruction coding to the manipulator, and the CSRM also can be operated by the remote control from the ground via the communication of in-orbit. The remote operation platform can also be used for the trajectory planning of in-orbit mission, movement control and operation management, inspection of fault diagnosis. Fig.1 provides an overview of whole system architecture.

For the requirement of manipulator functions, the manipulator is designed as a large robotic system with seven rotary joint. Every joint is a rotary motion device and it is the most basic movement unit of manipulator. The manipulator has seven joints arranged in cluster of three at each end forming "wrist" and "shoulder" and one central joint forming the "elbow", the "wrist" or the "shoulder" incorporates a yaw joint, a pitch joint and a roll joint. To realize the snare and latch requirement, each end of the manipulator terminates has a latching end-effector (LEE) which incorporate a force-moment sensor and a "wrist" object monitor and measuring Camera. There are two booms connected "wrist" joint, "elbow" joint and the "should" joint. Each side of the "elbow" joint has two monitoring and measuring camera on the boom.

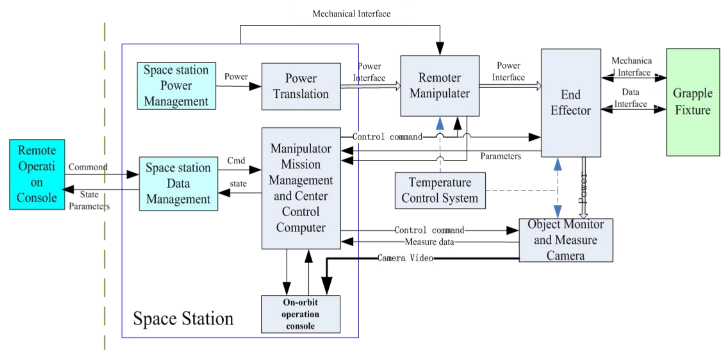

Fig.1 the system architecture of manipulator

Mission and operating management computer (Centre Computer) is the core unit of whole control system which was placed in the pressurized modules and in charge of the data exchange with the ground remote console and on-orbit operation console. Center computer is in charge of the mission management, information management and trajectory planning. In every control mode, the commands received by the center control computer are resolved to joint rate commands and joint position commands based on the inverse kinematics of the manipulator. Then, the joint commands are sent to each of the joint servos to drive the manipulator.

The seven joints of manipulator form the kinematic redundancy which increase the operational flexibility and help to avoid kinematic singularities. The End-effector is designed to attach to payloads and to serve as a base for Manipulator to mount Space Station, and the symmetric arrangement of the seven joints and the LEE enable either end of the Manipulator to function as the base or tip and permits the Manipulator to relocate by stepping from one Power and Data Grapple Fixture (PDGF) to another. The Space Station has placed many Grapple Fixture to allow the Manipulator accessing to areas beyond its reach. The architecture of manipulator is shown as fig.2.

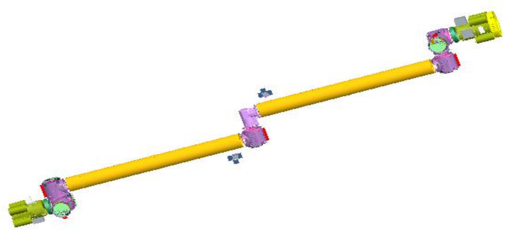

Fig.2 The architecture of manipulator

Object monitoring and measuring camera is used to get the vision view and realize the artificial vision feedback control for the astronaut and ground operator. Object monitoring and measuring camera can make sure the accurate position and orientation of object by the image process technology, and upload the measuring data to realize the automatic control of space manipulator. In order to satisfy the requirement of different object, many cameras are necessary which include the panoramic camera on the module for coarse positioning of the long distance, “elbow” camera for the middle distance, and the “wrist” camera for accurate positioning of short distance.

There is a force-moment sensor between each end-effector and joint on the “wrist”. There are two functions for the force-moment sensor, one is the force and moment measured and used as the force moment accommodation control to justify the motion of the tool by modifying the path reference, the other is to automatically limit the manipulator endpoint forces and moments in the selected axis[5,6]. Constitution of the space station manipulator is shown as fig.3.

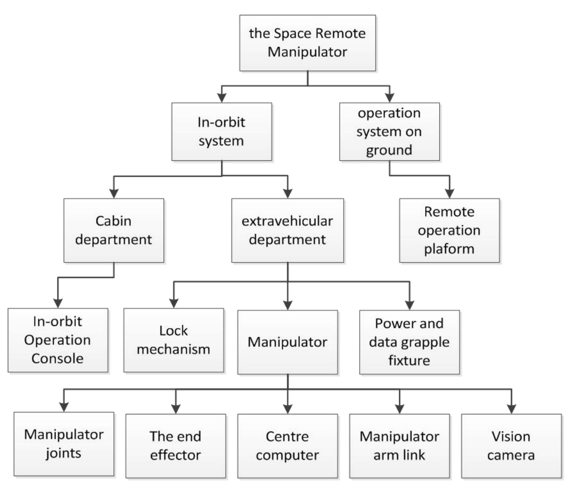

Fig.2 Constitution of the space station manipulator of china

3 Operation and Control System

3.1 Operation design

In-orbit Operation Console is used to operate manipulator by astronaut to realize the human-in-loop operation; the astronaut commands the end-point rates using hand controllers at operation console and the feedback video from the camera can be shown on the console, and the end-point position, orientation, velocities, joint position and state parameters, force-moment sensor measuring parameters can be displayed selectively.

Ground remote operation console can operate the in-orbit manipulator by the ground operator, Ground remote operation aim to efficiently make use of the limited communication channel resource, and remove the communication delay to realize the data response smoothly and accurately. Ground remote operation console has the same configuration with in-orbit Operation Console which includes the data process unit, graphics processing unit, command and calculation unit, and so on.

Compared with the in-orbit operation, the remote operation using the hand controller has to provide the interactive information of manipulator and environment real-time. In order to avoid the influence of time delay, a virtual forecast system is designed, the operator can control the virtual manipulator which will provide the torque feedback and position feedback according to the execution of commands in time and don’t have the time delay between the virtual manipulation and operator. Based on the virtual forecast model, the operator can finish the mission with the interactive force between the manipulator and environment real-time and no distortion. The communication loop of remote operation system is showed as fig.4.

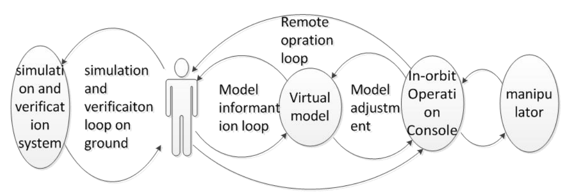

Fig.4 The communication loop of remote operation system

4.2 Control System Architecture

Every devices of manipulator has an independent control unit, such as every joint has a joint motion controller and a temperature controller, every end-effector has a motion controller also, every camera has a electronically processor, and so on. In order to guarantee the abilities and reliabilities of control system, a kind of distributed control system hierarchy is designed. Fig.5 provides an overview of whole control system architecture.

Centre Computer is the top-level supervisory control devices which include the mission management, system initialization, control mode selection, health monitoring and failure detection, etc. All the commands from the on-orbit operation console and ground remote operation console are sent to joints, end-effectors, and camera control unit after resolving of Centre Control Computer. To realize motion control of manipulator, Centre Computer translate the endpoint point-of-resolution to joint rate commands and position commands based on the reverse-kinematic arithmetic and dynamic arithmetic, then the commands are send to joint motion controller, and the joint motion parameters are feedback to Centre Control Computer by data bus.

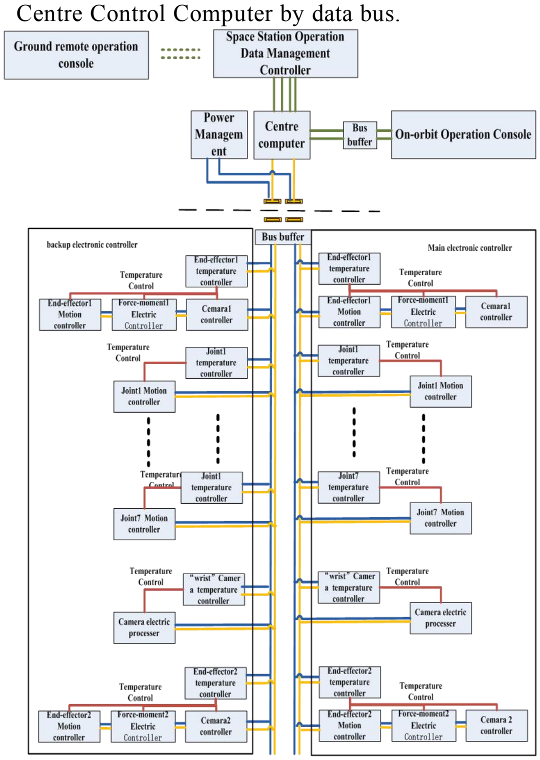

Fig.5 The distributed control system architecture of manipulator

Joint controller will drive the movement of manipulator by the receiving commands, and complete all kinds of operation missions. Joint controller incorporates power management, processor unit, motor driver, sensor signal process and collection, and communication bus interface, and so on. Joint servo control system includes the position loop, velocity loop and current loop, and real-time dynamic feedback and friction feedback are used to improve the control precision of joint. The signal processing of position sensor, servo control system is all integrated on the joint controller. When the object touched by the endpoint of manipulator which will be impacted by the collision, and the dynamics architecture will change after grabbing the object, so the flexible vibration may be excited. Some control methods on vibration constrain is necessary on the joint controller.

There are two road video data from every camera which one road video data output to in-orbit operate platform for display and another road video data for image procession. The image from the camera will be compressed by the camera controller, and upload to in-orbit Operation Console and Ground remote operation console. After the A/D translation of image data, the object position and orientation will be detected by the camera controller, and which will be uploaded to center computer by data bus to realize the autonomous control of manipulator based on artificial vision.

3.2 Motion Control of Manipulator

The motion control software of manipulator includes control mode, trajectory planning, dynamic arithmetic, actuators' servo control.

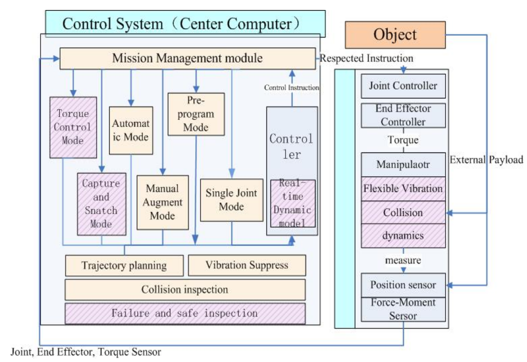

Fig.6 System architecture of centre computer

The following control mode can be selected by operator：

1) Single Drive Mode.
2) Pre-program On-orbit Operate Mode;
3) On-orbit Manual Augmented Mode;
4) Automatic Mode;
5) force-moment accommodation control.

In the single joint drive mode, the motion of manipulator can be commanded on a joint-by-joint sequent; the position planning is based on the trapezoidal joint rate trajectory intergrades parabola arc and finished in the joint controller by the receiving expected joint position.

In the pre-program operate mode, the operator selects a previously stored a sequent position data, then the selected position data is downloaded to center computer. The kinematic arithmetic is not applied in this mode.

In on-orbit manual augmented mode and remote operate mode, the operator can command the translational and rotational velocities of endpoint of manipulator by the hand controller of operate console, then the position and orientation commands received by the arm computer are resolved into the joint's rate commands, and which are sent to each of joint controller to drive joint movement.

In the automatic mode, the target position and orientation commands obtained by the vision camera unit are received by arm computer, and then the resolved joint's rate commands are sent to each of joint controller to drive joint movement. The collision avoidance arithmetic can be invoked by the vision camera's obstacle inspection in this mode.

In the constrained motion situations such as snare and latch of end-effector, the force-moment accommodation control can be used4, the force and moment data from a 6-axis force-moment sensor at the tip of the manipulator is sent to the arm computer, then the position and orientation of endpoint of manipulator are adjusted automatically by the force-moment accommodation control arithmetic.

3.3 Multi-camera Artificial Vision

To get the higher agility and precision, artificial visual feedback has important roles for the complexity and indetermination of space mission. Camera is used to get the vision view and realize the artificial vision measurement data feedback control for the astronaut and ground operator.

To get the accurate position and orientation of object, and satisfy the requirement of different object, many cameras are used, which include the panoramic camera, "elbow" camera and "wrist" camera. These cameras will play different roles like as:

1) panoramic camera on the module for coarse positioning of the long distance;

2) "elbow" camera for the middle distance;

3) "wrist" camera for accurate positioning of short distance.

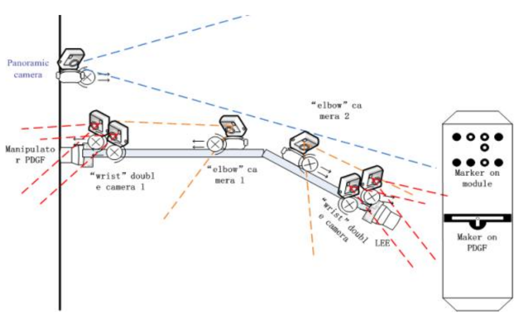

Fig.6 The configurations of artificial vision

The "wrist" cameras adopt the configuration of double cameras that have the higher precision, redundancy design and 3D target measure ability. Optimal selection of multi-camera is necessary to realize the gapless transition measure data of three cameras, the rules of optimal selection is listed as:

Table2 : optimal selection of cameras

panoramic	**"elbow"**	**"wrist"**	**Optimal selection**
active	active	active	"wrist"
active	active	inactive	"elbow"
active	inactive	inactive	panoramic

4 CONCLUSION

The Space Remote Manipulator fulfills an important and critical role in the assembly, maintenance and servicing of the Space Station. A kind of distributed control system hierarchy is designed is designed for the control system implementation. By the optimal position and orientation data searching rules, autonomous tracking control is realized based on the multi-camera's artificial visual feedback; Finish the position to target module by the artificial visual measurement from far to close, and from coarse to fine, and finish the autonomous movement and target capture mission finally.

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