ISSN: 2664-9640

Kinematics control of a high voltage transmission line inspection robot

Linping Ma[1], Qingfeng Gao[2] and Wenhe Fu[3]

[1]School of Energy Power and Mechanical Engineering, North China Electric Power University, Beijing 102206, China

[2]School of Energy Power and Mechanical Engineering, North China Electric Power University, Beijing 102206, China

[3]School of Energy Power and Mechanical Engineering, North China Electric Power University, Beijing 102206, China

Abstract

The normal state of high-voltage transmission lines is the basis for the normal operation of the power grid, but the exposed transmission lines are prone to failure; the transmission line inspection robot can completely autonomously inspect the transmission lines to ensure the stability of the transmission lines. According to the working environment and working state requirements of a certain type of line patrol robot, this paper designs the control system of the robot, analyzes its motion process, and calculates the optimal joint variables of the robot motion process based on its energy supply mode and joint power.

Keywords

Transmission Line; Line Inspection Robot; Kinematics control.

1. Introduction

The safe operation of high-voltage transmission lines is an important guarantee for the stability of the transmission system, but they may be damaged by wind, frost, rain and other natural environments and their own tension, such as broken strand, wear and corrosion, etc., which requires regular inspection for troubleshooting[1]. The existing inspection methods such as manual inspection, helicopter inspection and uav inspection have various limitations, and transmission line inspection by robot has become a new development trend. The line patrol robot carries detection equipment on the high-voltage transmission line to carry out close detection, and needs to cross all kinds of obstacles on the line such as gold tools and towers. Therefore, it is of great significance to study the control system to guarantee the walking and obstacle crossing of line patrol robot[2].

In the process of robot inspection, it needs to cross various obstacles, such as hardware, etc. In order for the robot to complete the obstacle-crossing action, it needs to be kinematically controlled. The kinematics control first needs to carry out kinematic modeling, and the methods for modeling the robot include the SDH method based on ZX transformation and the MDH method based on XZ transformation. According to the existing structural analysis of the robot, both the SDH method and the MDH method are not suitable for the robot modeling in this paper. In this paper, the method of combining the distributed modeling of the robot is used to model it.

ISSN: 2664-9640

2. Mechanical structure of line patrol robot

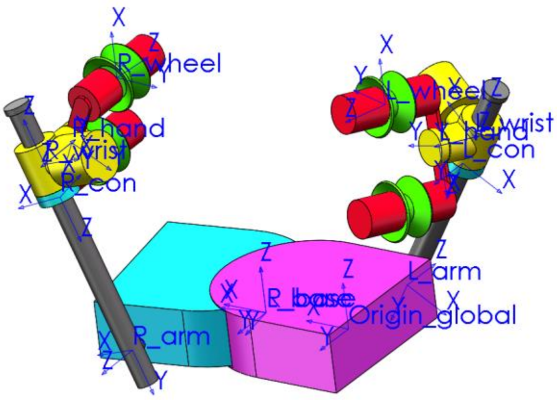

Fig.1 Simplified model and joints

The mechanical structure of the line-following robot is shown in the figure on the left, and the figure on the right is a simplified model of its joints. The structure is mainly composed of a driving mechanism (driving wheel and driving motor) on the double arms, a clamping mechanism, a deflection mechanism, a telescopic mechanism and a steering mechanism. The robot arms are hung on the power line through the driving wheels, and the clamping mechanism provides the robot with the friction force required for climbing by applying a clamping torque during the climbing process. The figure on the right is a simplified model of its joint variables. The joints appear in pairs, and the joints are defined as wheel joints (R/L_wheel), wrist joints (R/L_wrist), hand joints (R/L_hand), and continuous joints (R/L_con) , the arm joint (R/L_arm), and the base joint (R/L_base). The robot has a total of eleven joints, all of which are symmetrical joints except the base joint, the hand joints are translational sliding joints, and the other joints are cylindrical rotation joints. The base joint is divided. Each joint is controlled by a stepper motor, and the stepper motor is connected with the single-chip microcomputer through the motor controller. The specific joint connection sequence is as follows:

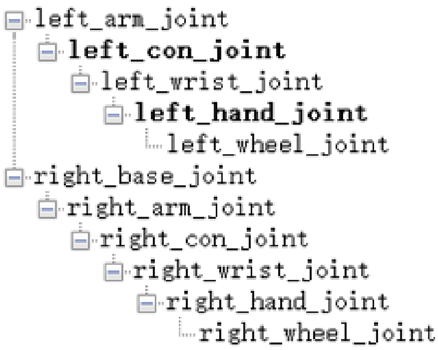

Fig.2 Joint connection sequence

3. Motion model modeling of line patrol robot:

The main methods of modeling rotary joint and translation joint robot are DH method and MDH method[8].Taking L_wheel as a starting point, SDH is used to model:

ISSN: 2664-9640

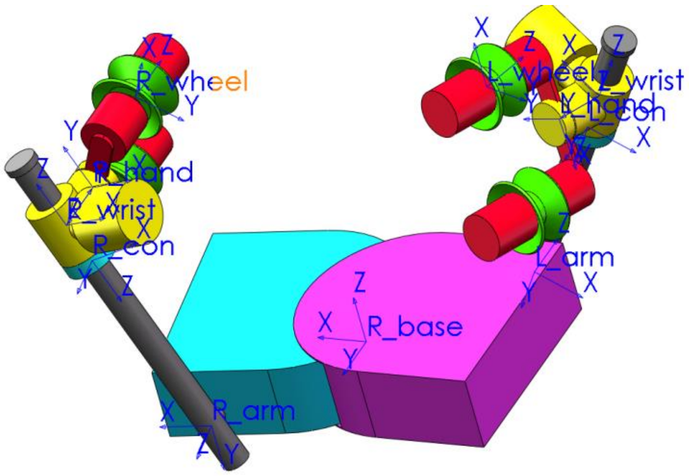

Fig.3 SDH modeling joint model

The SDH joint changes to ZX transformation. Using SDH to model the joints of the robot will produce singularity in the L_arm and later joints. The reason is that the base joint rotation axis is perpendicular to the front and rear joint rotation axes, resulting in the R_arm joint transformation unable to express the joint motion, and even After the R_base joint, the joint variables are all 0, and the relative motion relationship of the joint cannot be described.

Table 1 SDH modeling joint variables

L_wheel	ai	α	d	θ	
L_hand	85	0	93	180-θ1	
L_wrist	0	90	72	90-θ2	
L_con	0	0	60	180-θ3	L3 is the distance from the top of the slider
L_arm	0	-90	340-L3	0	
R_base	160	-90	168	180-θ5	
R_arm	160	90	0	θ6	
R_con	0	90	0	θ7	l7
R_wrist	0	0			

Taking L_wheel as a starting point, MDH is used to model:

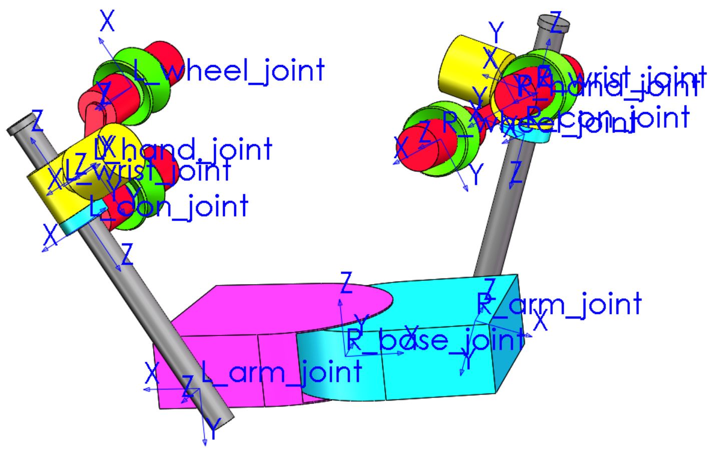

Fig.4 MDH modeling joint model

ISSN: 2664-9640

The MDH joint is changed to XZ transformation. Using MDH to model the joints of the robot will produce singularity in the L_wrist and later joints. The reason is that the XZ transformation leads to the loss of the joint motion parameters after the L_wrist joint, so that the R_arm joint transformation cannot express the joint motion. Even after the L_wrist joint, the joint variables are all 0, and the relative motion relationship of the joints cannot be described.

Table 2 MDH modeling joint variables

	ai	α	d	θ
L_wheel	85Ca1	0	0	0
L_hand	0	90	93	e2
L_wrist	0	180-0	0	0

SDH can correctly describe the relationship from L_wheel to L_base, and the robot has a symmetrical structure, so the robot is modeled from SDH to L_wheel to L_base and R_wheel to R_base, combined with rotation transformation to combine L_base and R_base, and to the process of R_wheel to R_base The complete kinematic modeling of the robot can be successfully carried out by using the inverse operation.

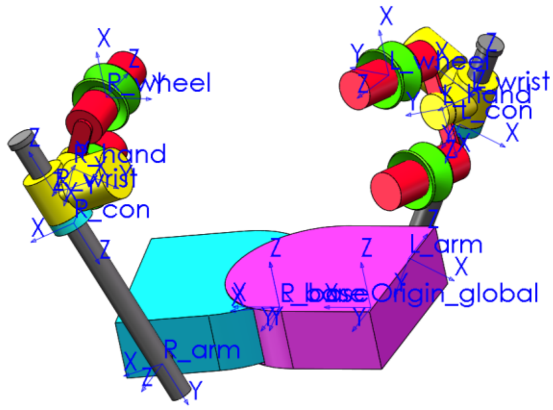

Fig.5 Combined modeling joint models

Using combinatorial modeling can fully express the direct transformation between each joint of the robot. The joint parameters are as follows:

Table 2 MDH modeling joint variables

0	R_wheel	ai	α	d	θ
1	R_hand	85	180	-93	180+e
2	R_wrist	0	-90	72	90+e
3	R_con	0	180	-60	180+e
4	R_arm	0	90	340-l	0
5	R_base	-160	90	-168	-e
6	L_base	0	0	0	-e
0	L_wheel	ai	α	d	θ
1	L_hand	85	180	-93	180+e
2	L_wrist	0	-90	72	90+e
3	L_con	0	180	-60	180+e
4	L_arm	0	90	340-l	0
5	L_base	160	-90	-168	180-e

ISSN: 2664-9640

In order to maintain the direction of the 0 coordinate system, θ0 and θ1 are equal, so that the x-axis of the 0 coordinate system is vertically upward.

4. The forward kinematics of the motion model of the line patrol robot:

Through the true kinematics analysis of the robot, it is verified whether the parameters of each joint of the robot are correct, so as to ensure the correct follow-up work of the robot. SDH is ZX transformation, and its transformation matrix is:

$$Ai = Rot(z, \theta)Trans(0,0, d)Trans(\alpha, 0,0)Rot(x, \alpha)$$

The transformation matrix from the robot head joint L_wheel to the robot end R_wheel is:

$$TH=T_{L}Rot(T_{R}^{-1})$$

TL is the transformation matrix on the left side of the robot, Rot is the rotation matrix from L_base to R_base of the robot, and TR is the transformation matrix on the right side of the robot. It is verified by matlab matrix operation. In order to ensure that the X axis of L_wheel is vertically upward, it is convenient to observe the posture of the end of the robot, so that the parameters of the first joint and the second joint of the robot are consistent, the input joint parameters are: X=[30,30,10,10 ,10,10,10,10,10,30,0]; the joint variable matrix is:

```
R=[ 85, 180*pi/180,    -93,  (180+X(1))*pi/180;
     0, -90*pi/180,     72,   (90+X(2))*pi/180;
     0, 180*pi/180,    -60,  (180+X(3))*pi/180;
     0,  90*pi/180, 340-X(4),        0*pi/180;
  -160,  90*pi/180,   -168,     (-X(5)*pi)/180;
     0,       0,        0,     (-X(6)*pi)/180];
L=[ 85, 180*pi/180,    -93,  (180+X(11))*pi/180;
     0, -90*pi/180,     72,   (90+X(10))*pi/180;
     0, 180*pi/180,    -60,   (180+X(9))*pi/180;
     0,  90*pi/180, 340-X(8),         0*pi/180;
   160, -90*pi/180,   -168,((180-X(7))*pi)/180];
```

The rotation calculation matrix is:

```
L_Trans=trans(R(1,:))*trans(R(2,:))*trans(R(3,:))*trans(R(4,:))*trans(R(5,:))*
trans(R(6,:));
R_trans=inv(trans(L(5,:)))*inv(trans(L(4,:)))*inv(trans(L(3,:)))*
inv(trans(L(2,:)))*inv(trans(L(1,:)));
Trans=L_Trans*R_trans;
Pos=L_Trans*(R_trans*[0;0;0;1]);
```

Pos is the relative position of the origin of the R_wheel coordinate system in the L_wheel coordinate system obtained according to the input parameters. Bring in the joint motion data X matrix to get the end matrix: [-59.35; 332.19; 54.38; 1], the measured data of the model diagram is:

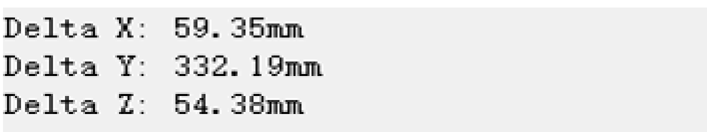

Fig.6 3D model measured data

ISSN: 2664-9640

The calculation is consistent with the measured data, and it can be seen that the composite transformation is effective.

References

[1] Jaensch G , Hoffmann H , Markees A . Locating defects in high voltage transmission lines[C]// Transmission & Distribution Construction, Operation & Live-Line Maintenance Proceedings, 1998. ESMO '98. 1998 IEEE 8th International Conference on. IEEE, 1998.

[2] Jones, D. [IEE IEE Forum on: Autonomous Systems - London, UK (28 Nov. 2005)] IEE Forum on: Autonomous Systems - Power line inspection - a UAV concept[C]// IEEE Forum on Autonomous Systems. IEEE Xplore, 2005:6-6.

[3] R. Dai, G. Liu and X. Zhang, "Transmission Technologies and Implementations: Building a Stronger, Smarter Power Grid in China," in IEEE Power and Energy Magazine, vol.18,no.2, pp. 53-59, March-April 2020, doi: 10.1109/MPE.2019.2957623.

[4] Jaensch G, Hoffmann H. Markees A. Locating defects in high voltage transmission lines [A]. Proceedings of the 1998 IEEE 8th International Conference on Transmission & Distribution Construction, Operation & Live-line Maintenance[C]. Orlando, FL USA: 1998. 179--186.

[5] Whitworth C C, Duller A W G. Jones D I, et a1. Aerial video inspection of overhead power lines[J]. Power Engineering Joumal, 2001, 15(1): 25--32.

[6] Quanta services. Line master robot arm.

[7] http://www.quantaenergized.com/proprietary-tools-and-techniques/

[8] J. Sawada, K. Kusumoto, T. Munakata, Y. Maikawa and Y. Ishikawa, "A Mobile Robot for Inspection of Power Transmission Lines," in IEEE Power Engineering Review, vol. 11, no. 1, pp. 57-, January 1991, doi: 10.1109/MPER.1991.88671.

[9] Davidson J K , Hunt K H , Pennock G R . Robots and Screw Theory: Applications of Kinematics and Statics to Robotics[J]. Journal of Mechanical Design, 2004, 126(4).

[10] AOSHIMA S, TSUJIMURA T, YABUTA T.A wire mobile robot with multi-unit structure[C]//IEEE/RSJ International Workshop on Intelligent Robots and Systems. Tsukuba, Japan: IEEE, 1989: 414-421.

[11] HIGUCHI M, MAEDA Y, TSUTANI S, et al. Development of a mobile inspection robot for power transmission lines[J].Journal of the Robotics Society of Japan, 1991, 9(4): 457-463.

[12] PEUNGSUNGWAL S, PUNGSIRI B, CHAMNONGTHAI K, et al. Autonomous robot for a power transmission line inspection[C]//IEEE International Symposium on Circuits and Systems . Sydney, Australia: IEEE, 2001: 121-124.

[13] CAMPOSMF M, BRACATENSEA Q, PEREIRAGA S, et al. A mobile manipulator for installation and removal of aircraft warning spheres on aerial power transmission lines[C]// IEEE International Conference on Robotics & Automation. San Francisco, USA: IEEE, 2002: 3559-3564.

[14] JIANG B, MAMISHEV A. Robotic monitoring of power systems[J].IEEE Transactions on Power Delivery, 2004, 19(3): 912-918.