ISSN: 2664-9640

Research and application of cable climbing robot

WeihuaYang[1,3, a], Shanqing Xu[2], ZifanFang[1, 2], Kongde He[1,2], Shaopeng Liu[1,2]

[1] Yichang Key Laboratory of Robot and intelligent System, China Three Gorges University, Yichang 443002, China;

[2]Mechanic and Power College, China Three Gorges University, Yichang 443002, China

[3]Hubei Key Laboratory of Hydroelectric Machinery Design and Maintenance, China Three Gorges University, Yichang 443002, China

[a]ywhuactgu@126.com

Abstract

On the basis of summarizing the relevant literature of cable climbing robot, prototype design, kinetic modeling and analysis and engineering application of cable climbing robot are discussed in this paper. Then the application status, common types, performance characteristics, bionic design method and common methods of kinetic and dynamic analysis are expounded respectively. Finally, the future development direction and existing problem about the key technology of cable climbing robot are put forward, which can provide reference for related researchers.

Keywords

Cable climbing robot; Research status; Application status; Existing problems; Development direction.

1. Introduction

In the modern production and life, working high above the ground is increasing, such as inspection and maintenance of high voltage transmission cable, painting and detection of cable, etc. [1].These works are completed in the dangerous environment, and often expend long working time with high labor intensity and lead to safety accidents. Cable climbing robot (CCR) is the typical application of robot technology in the extreme environment of working high above the ground. It can not only replace automatic climbing, but also carry relevant maintenance and testing equipment to complete the corresponding altitude operation, which has a wide universality and broad market application prospects [2, 3]. The research and development of CCR has been carried out all around the world in recent years. The application prospect of CCR working high above the ground has attracted the attention of scholars in the world, and has been hot in research.

CCR belongs to the special robot. As a new robot in the application field, the development and research of CCR have not a long history. Different from robot working on the ground, CCR can move along the cable when it overcome its gravity, and it mostly need to climb the surface to get climbing friction. Consequently, it is difficult for the design structure of CCR. In the worldwide, Japan, the United States, Canada and other countries have conducted research on CCR, and many prototypes have been developed.

It is important for CCR that it can move and attachment on the cable. There are four ways of movement: peristalsis type, track type, wheel type and foot type. There are two ways of attachment: clamp type and adsorption type. Many universities and research institutes at home and abroad have carried out relevant research and design of CCR[4]. In all, there are five types

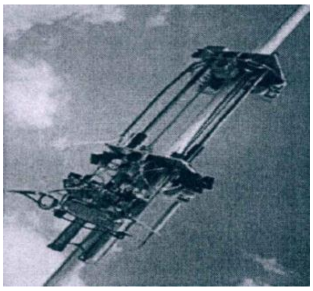
ISSN: 2664-9640

of cable climbing robot: clamping peristalsis type, spiral climbing type, multi-foot walking type, track crawler type and wheel type.

The clamping peristaltic robot has a bigger clamping force, and has a strong adaptability to the cable diameter size and cable surface status. It is useful widely because it can carry heavy detection and maintenance equipment .The representative robot was firstly developed by Shanghai Jiao Tong University (as shown in figure 1), it can move and climb on the cable at any dip angle using cylinder clamping peristalsis climbing driven by pneumatic device, and to help the staff complete the painting, maintenance and other work [5].

Based on the bionics principle, the clamping peristaltic robots are developed, such as imitating ruler, sloth and human climbing, which is characterized by intermittent movement, slow climbing speed, large volume, complex structure, high cost, low work efficiency and high environmental requirement.Spirspiral climbing robot also adopts the bionics principle, which imitate the snake movement characteristics and include multiple joint mechanisms that is a highly redundant system. It can be bent in space with three-dimensional movement ability. This kind of robot is flexible with good ability of obstacle crossing on the cable. However, the crawling speed is slow, the execution ability is single. Due to its strong flexibility, the coordination and movement control of part is very complex. For example, the South China University of Technology has developed a modular bionic robot according to the principle of bionic (as shown in figure 2), the robot model consists of multiple rotating mechanism and two claws, it can realize the functions of movement and operation with five degrees of freedom, furthermore,it can climb on the pipeline with different gait and has better obstacle and transition ability.

Rise is a multi-foot walking robot (as shown in figure 3) which is jointly developed by many well-known universities and research units, such as Carnegie Mellon University, Stanford University, the University of California and Boston Dynamics in 2008, it is a typical multi-pedal climbing system [6]. Although it has a relatively strong athletic ability, and can adapt to various conditions theoretically, its mechanical structure and control method are more complex and high cost. Moreover, it can only climb on continuous surface, and it has poor mobility performance, so it is not suitable for climbing on the cable wire surface.



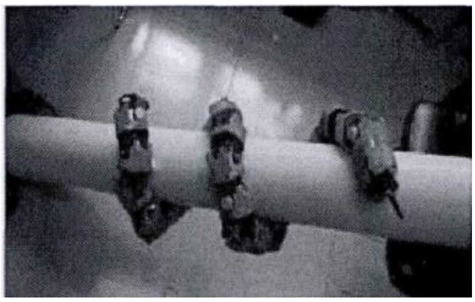


Fig. 1 Pneumatic climbing robot Fig. 2 Serpentine climbing robot

Fig.3 Multi-foot climbing robot

A representative track climbing robot using for bridge cable crawling was developed by Chengjunkan University in South Korea (as shown in figure 4) [7].It can be used on rough surface cable .Compared with wheel type climbing robot, track crawler type has better stability and obstacle ability, but it also has the disadvantages of large volume, complex and bulky structure, and easy to create overturning.

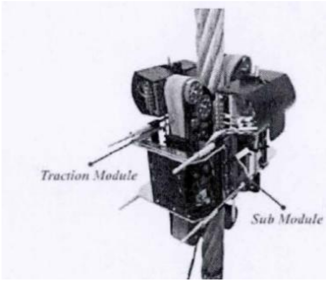


Fig. 4 Track crawler climbing robot

The wheel type robot creates the friction force by touching between the wheel and cable surface, so the potential driving ability is determined by the positive pressure between the friction wheel and the contact surface. It generally increases the positive pressure of the wheel and the contact surface through the spring force, hydraulic force ,air pressure or magnetic force. Several research institutions in China have developed and conducted experiments on wheel type cable climbing robots [8]. The representative first generation and second generation prototype was developed by the research group of Professor Zhou Yi of Chongqing University (as shown in figure 5).The structure of the wheel type robot is relatively simple, and it is easier to be controlled. However, there are some deficiencies: the volume is large, the cable holding force is not adjustable, the obstacle ability is poor, the skid or jam phenomenon often happens in the experiment. It need to be further improved in the climbing ability, operation speed and operation stability.

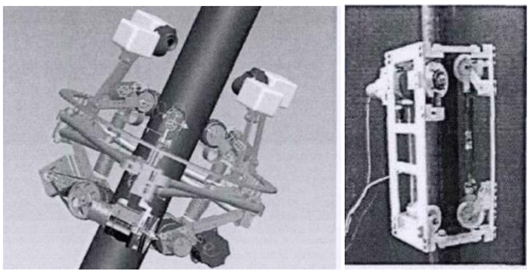


Fig. 5 The wheel type climbing robot

According to the analysis described above, the performance comparison of various cable climbing robots is shown in the table1.

Table 1 Performance comparison of various cable climbing robots

Item	Climbing speed	Volume	Cost	Obstacle performance	Applicability
1	-	+	+-	+-	+
2	-	-	+-	+	+
3	-	+-	+	+	-
4	+	+	+	+	+
5	+	+	-	-	+-

In the table 1, 1:clamping and wriggling type;2:spiral climbing type;3:Multi-foot walking robot;4:track crawler type;5:wheel type.

2. Development of biomimetic cable climbing robot

Bionic design is a modern design method developing for mechanical and electronic system.With the realization of the bionic application principle, the bionic climbing robot technology has also

ISSN: 2664-9640

gradually developed in the past 10 years, a large number of bionic climbing robots were constantly emerging, such as imitating snake crawling robot, imitating ape climbing robot, imitating gecko wall climbing robot and imitating mantis robot. These robots mainly imitate the animals in terms of movement mode and shape structure in order to achieve strong motor ability in different environment [9].

For example, the research team of the University of Tokyo in Japan has developed a joint climbing robot. The five handed claw bionic climbing robot designed by South China University of Technology is shown in figure 6.Using the principle of bionic technology, Tokyo Electric Power and TRC respectively developed an imitating ape climbing robot overhead transmission line. Northwestern Technology University has developed a new four-arm inspection robot using the climbing characteristics of gibbon. Shandong University of Science and Technology proposed a three-arm inspection robot working on high voltage transmission line based on climbing characteristics of primate.

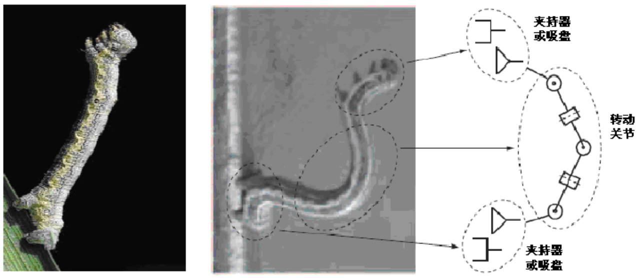


Fig. 6 The climbing robot imitating geometer

3. Theoretical research on cable climbing robot

At present, the theoretical research of climbing robot by domestic and foreign researchers mainly include the following aspects: research on the structure and grasping institution of robot, research on kinematics and dynamics, etc.

3.1. Design on robot configuration and grasping mechanism

How to choose the appropriate robot configuration is worth discussing. There are two kinds of solutions for this problem. Firstly, using artificial intelligence to complete the knowledge modeling and processing, and then assist designers in configuration analysis, selection, evaluation and decision through the establishment of configuration design system with human-computer interaction. There are some intelligent system development tools to engage in this work. Secondly, it is adopting the design method of MDOF (Minimum Degree of Freedom) to the configuration design of the robot. Taking the kinematic index of the robot as the optimization constraint, the robot configuration selection is optimized and calculated based on the traditional intelligent optimization calculation of GA.

The grasping mechanism is the important part to ensure that CCR climb smoothly and safely on the cable. At present, there are three forms of grasping mechanism: embrace type, claw type and grip type. Each has its own advantages and disadvantages, and their application environment is different. No matter which kind of grasp mechanism is used, there are some problems about grasp safety, so how to improve the grasp safety needs to be studied in depth.

3.2. Kinematics and dynamics modeling

Finding the position of the end grasping mechanism according to the movement of each joint is studied by the positive kinematics of CCR. It is commonly used in the visualization of the robot state and the determination of the environmental collision, which is the basis of the robot simulation [10]. Inverse kinematics seeks the motion of each joint according to the position of the terminal grip mechanism, which is mainly used for the control of the robot. Currently, there are three methods for solving robot kinematics. The first method is the geometry, the second method is Denavit-Hartenberg (D-H), and the third is the method of Lie group Lie algebra exponential product formulation (POE).Compared with the POE method, the D-H method can be solved analytically for the robot inverse kinematics, which has the advantages of fast computational speed and no computational error, and it is more suitable for CCR with little degrees of freedom.

The dynamics modeling of climbing robots is divided into positive and inverse dynamics problems. Inverse dynamics modeling is mainly used to control joint force of the robot. The common methods for dynamics modeling are the Lagrangian method and the Newton-Euler method [11].The Lagrangian approach is an approach to the dynamics of the plasmids with complete constraints. It finds the Lagrangian function based on the dynamics energy and potential energy of all the links, and derives the equation of motion of the robot. The main feature of the method is without regard for internal binding force, but it needs complex calculation. The Newton-Euler method treats the mutual binding and relative motion between the linkage as a vector to derive the equations of motion on the basis of equilibrium of force and moment. The main feature of the method is considering the balance of force and moment in 3 D space using iterative methods with efficient computation.

4. Summary

In summary, experts and scholars in the field of robot have conducted relevant research and made some important progress about the research on CCR in recent years, but how to improve the performance of climbing , preventing deviation and obstacle crossing needs to be studied. Especially there is not a more practical climbing robot for the cable which is the high above the ground and lathy with big inclination Angle and change diameter. Both the prototype design and theoretical analysis still has some existing problems.

1) The existing prototype of CCR is used for climbing on hard rod structure or pipe. Although the structure of cable can be approximate as rod structure, but it is different from rod structure and rigid pipe and other wire. Cable high above the ground is almost steel twisted and flexible whose surface is not completely flat, so there is few cable climbing prototype which can adapt to such high altitude cable.

2) From the perspective of configuration, the existing climbing robots are not satisfactory because they only have a single climbing gait lacking of good obstacle avoidance and operational ability.

3) From the perspective of the grasp of the medium, the current holding mechanism has less adaptability to the holding medium. The reliability of grasping is very important for CCR working in the environment of the high air, and it is affected by the wind load and vibration, but the research of this problem is still blank.

Although great development has taken place in the field of CCR, it is a long way from extensive application in social production and human life. The main reasons include the complexity of the robotic system, imperfections in its own function and high cost. Existing climbing robots are often designed for the specific use purpose and occasion lacking of functional extensibility and configuration reconstruction. Therefore, the CCR which has multi-function, easy construction and low cost is the important studied object in the future.

Acknowledgments

This work was financially supported by Yichang Key Laboratory of Robot and intelligent System fund JXYC00014 and Hubei Key Laboratory of Hydroelectric Machinery Design and Maintenance fund 2018KJX09.

ISSN: 2664-9640

References

[1] Nicolas P，Pierre-Luc R，Serge M． Line scout technology opens the way to robotic inspection and maintenance of high-voltage power lines. IEEE Power and Energy Technology Systems Journal,Vol. 2 (2015) No.1, p. 1-11.

[2] Fengyu Xu, Jingjin Shen, JinLong Hu et al. A rough concrete wall-climbing robot based on grasping claws. International Journal of Advanced Robotic Systems, Vol. 13(2016) No.5, p. 231-237.

[3] Yanheng Liu, Byoungduk Lim, Jeh Won Lee et al. Steerable dry-adhesive linkage-type wall-climbing robot.Mechanism and Machine Theory, Vol. 123(2016) , p.436-448.

[4] Fumin Gao, JianChun Fan, Laibin Zhang et al. Magnetic crawler climbing detection robot basing on metal magnetic memory testing technology. Robotics and Autonomous Systems, Vol. 125(2020) ,p.94-106.

[5] Liu Yanwei,Wang Limeng,Liu Sanwa,et al. Design and analysisof an inchworm inspired wall-climbing robot. Mechanical Transmission,Vol. 43(2019)No.8, p. 87-91.

[6] G. C. Haynes, A. Khripin, G. Lynch, et al. Rapid Pole Climbing with a Quadrupedal Robot. IEEE International Conference on Robotics and Automation. Kobe, Japan, 2009, p.2767-2772.

[7] K. Autumn, M. Buehler, M. Cutkosky, et al. Robotics in Scansorial Environments. In Proceedings of SPIE, 2005, p.291-302.

[8] Gonpalvc R S,Carvalho J C M. A mobile robot to be applied in high - voltage power lines .Journal of the Brazilian Society of Mechanical Sciences & Engineering, Vol. 37(2014) No.1, p. 1-11 .

[9] Wang Jidai，Zhen Jing，Liu Xiaochen，et al． Study on the bionicstructure of inspection robot for power transmission lines. Mechanical Design and Manufacturing，Vol. 320(2017) No.10, p. 244-247.

[10] Chen I M, Gao Y, Closed form Inverse Kinematics Solver for Reconfigurable Robots. Proceedings of the IEEE International Conference on Robotics and Automation, Seoul, Korea, 2001, p.2395-2400.

[11] Ji Hansong，Hao Jingbin，Wang Feilong，et al． Kinematics and workspace analysis of robot with two folding arms. Science,Technology and Engineering,Vol. 16(2019)No.25, p. 91-98.