Autonomous Inspection Robot for Power Transmission Lines

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Abstract: *This paper describes the development of a mobile robot capable of clearing such obstacles as counterweights, anchor clamps, and torsion tower. The mobile robot walks on overhead ground wires in high transmission power tower. Its ultimate purpose is to automate to inspect the defect of power transmission line. The robot with 10 motors and 16 relays and 4 wheels of each robot.*

1. Introduction

Power transmission line has been usually inspected manually by workers riding in gondolas that travel suspended from the transmission lines or watching with telescope in the ground. In recent years, it has become increasingly necessary to perform inspection work with the autonomous inspection robot in power transmission line.

The development of Explainer was presented, a robot running on high voltage live lines arranged in bundles of 1, 2, or 4 wires in Japan (Paulo Deepest, et al.,2008). The Line Scout Technology was presented, a mobile teleoperated robot working on live lines, up to 735 kV and 1,000 A, at Hydro-Québec Research Institute in Canada (Nicolas Poulet & Serge Montambault, 2008). An obstacle navigation control strategy was introduced for a inspection robot suspended on overhead ground wires (OGWs) of power transmission lines (Ren Zhuiqin and Runa Yet al., 2008). Inspection robot was described based line-grasping control with visual servo for power transmission line (Wang Ludden and Wang Hangarage al., 2007). An inspection robot was developed with three arm for 110kv power transmission live lines (Fengyu Zhou, Yilin Limit al., 2008). A double-arms inspection robot was developed on live lines (Xiaohui Xiao, Gongping Wu, and Sanping Li, 2007).

The impact of the overhead ground wires should be considered in the robot's dynamics analysis and controller design. The inspection tasks are performed by the robot carrying detection instruments and rolling/crawling along the overhead ground wires. Thus, the coupling dynamic performance between the robot and its moving path directly impact its motion precision. A mobile robot that can crawl along the overhead ground wires to perform part of power line inspection tasks is developed. This paper performs the dynamic posture research during obstacles- passing process. Combining the theory of flexible multi-body and rigid multi-body dynamics, we developed the robot with up-down arms for negotiating the torsion tower.

The rest of this paper is organized as follows: Section 2 describes environment of the overhead ground wires in power tower. This is followed by mechanical configurations in Section 3. Electrical configurations are proposed in Section 4. The motion control system and the application software are discussed in Section 5 and 6 respectively.

Finally, the experiments show that the robot can negotiate obstacles in the overhead ground wires in the real tower.

2. Environment of Power Transmission Lines

A 500KV torsion tower is shown in Fig. 1. The detail appearance of the overhead ground wires is described in Fig. 1(b). The inspection robot with wheel-driven can crawl along the overhead ground wires. The subsidiary equipment's of the overhead ground wires will act as obstacles to block its way. A navigation system is needed to recognize and locate the obstacles with its sensors. The control system of inspection robot will plan its motions according to the obstacle information to negotiate these obstacles autonomously. There are three typical obstacles attached to the overhead ground wires and 550KV power tower. The first type of obstacle is called counterweight which is the greatest quantity among the obstacle. The second type of obstacle is anchor tower which is easy for the inspection rotor to cross. The third type of obstacle is called torsion tower which is difficult for the inspection rotor to cross. Each type of obstacle has different spatial structure. Therefore, the inspection robot should walk with the different motion sequence according to the different obstacle.

Figure 1: A 500KV tower

It is not easy for inspection robot to cross the original torsion tower in Fig. 2(a), because there are many limits for the inspection robot, such as the mechanical structure of claws, wheels, arms, etc. This paper adopted a new method that the special bridge was installed on the torsion tower in Fig. 2(b).

3. Mechanical Configurations

The robot's mechanical structure is designed as a cable car which is shown in Fig. 3 for navigating on the wires. The robot has two arms. A set of wheel-claw mechanism is mounted on the end of each arm. The robot can climb on the wires with its arms and claws. The control system and the inspection devices are installed in the control box which is suspended under the body of the robot. Each arm has 4 DOF. The rotary joint on the arm (Joint X4 and X5) can regulate the claws for grasping object accurately. The screw and nut mechanisms are applied to drive the claws and wheels upward and downward (joint X8 and X9). The mechanisms of joint X1, X2 and X3 are the same as joint X4 and X5 and can make the arms or box move forward and backward. The worm and worm gear mechanisms are applied to drive the arms upward and downward in the joint X6 and X7.

The control box can move along the body of the robot which can balance the robot and improve the stability. The robot is 1.2m long, 0.8m high and weighs 30kg including the control box which is approximately 10kg. It can climb on the wires with the maximum inclination angle 60°.

4. Electrical Configurations

The criteria specifications for the robot control system are presented as follow, autonomous travel or motion, automatic inspection of transmission lines while crossing the towers, the reliably and robustly generating and transmitting remote control commands to the robot controller from the ground station, and satisfying the national standard for EMC.

To achieve the above specifications, a three-layers control system is proposed as shown in Fig. 4, which are the client system for supervision and management system located at the ground station (upper layer), the server system for robot control and path planning (middle layer), the actor system for the motors, drive card, and sensors (lower layer).

The roles of the upper layer are to receive the inspection images in real-time, conduct the fault detection, remotely control robot motions. The middle layer plays the role of analyzing, distributing and coordinating the tasks. It receives and analyses the commands from the upper layer, then decomposes and distributes the tasks to individual lower level actuator controllers. Under the autonomous operation mode, it takes feedback information from all sensors and makes its own decisions for planning the sequence of operations and actuations without the upper layer's involvement. The sequences of commands from the middle layer are directly sent to the lower layer actuators. The lower layer acts as executor and receptor. The motor is drove by the drive cards that communicate each other with CANopen protocol. At the same time, the drive card communicates with PC/104 by RS232 and gets the analog and digital signal from the sensors. The video of the camera is sent to the compressor card and saved to the hard disk.

Johnson DC motor of Maxon motor is selected to install in the inspection robot. Brushless DC motor is with three phases in the stator, ironless winding system rotating, neodymium permanent magnet, and speeds of up to 50 000 rpm.

1) Motor Drive
Maxon motor EPOS 24/5 was applied in this project, as it is a small-sized full digital smart motion controller. Due to the flexible and high efficient power stage the EPOS 24/5 drives DC motors with digital encoder as well as brushless EC motors with digital Hall sensors and encoder. The sinusoidal current commutation by space vector control offers to drive brushless EC motors with minimal torque ripple and low noise. The integrated position-, velocity- and current control functionality allows sophisticated positioning applications. It is specially designed being commanded and controlled as a slave node in the CANopen network. In addition the unit can be operated through any RS-232 communication port. For fast communication with several EPOS devices, use the CAN open protocol. The individual devices of a network are commanded by a CAN open master. A variety of operating modes means that all kinds of drive and automation systems can be flexibly assembled using positioning, speed and current regulation. The built-in CANopen interface allows networking to multiple axis drives and online commanding by CAN bus master units.

2) Wireless Communication
The NETGEAR WG102 ProSales 802.11g Wireless Access Point is the basic building block of a wireless LAN infrastructure. It provides connectivity between Ethernet wired networks and radio-equipped wireless notebook systems, desktop systems, print servers, and other devices. Most access points are rated between 30-50 users simultaneously.

The WG102 provides wireless connectivity with maximum outdoor range is 15.8 km (~9.8 miles) , and range estimation is based on two wireless nodes each with an ANT24D18 antenna attached, associating with each other at 11 Mbps under ideal line-of-sight conditions.

3) Video Camera
The Eurotech CTR-1475 is a real-time MPEG-4 video compressor, encoder and frame grabber module designed to capture up to four concurrent high-quality analog video and audio streams, encode them in compressed MPEG-4 or AVI formats, and send them to an embedded computer over the 32-bit PCI bus.

4) Sensor
The new sensor configuration is applied to the inspection robot. Sensors are important for the inspection robot to adapt the environment in the overhead ground wires. These sensors are installed in the inspection robot in Fig. 5.The following points should be considered in the choices of sensors:
a) Visible light camera and thermal infrared Camera are both installed in the inspection robot. The robot can detect the damages of power transmission lines equipment. The data and images detected by the robot can be transmitted to the ground base station by the wireless transmission devices. The ground base station can not only receive, store and display the data and images but also complete real-time remote control and image processing simultaneously.

b) The SICK W100L photoelectric switch series offers laser sensors in miniature housing. The small laser light spot and the high switching frequency enable the detection of small objects in high speed processes. The small and easily visible laser light spot enables easy alignment during installation.

c) The inclination sensor module uses the DX type (DX-045D or DX-008D) dual axis sensors for dual axis mode, and provides an economical and reliable tilt sensing solution for applications requiring superior Nulling capabilities with concurrent excellent Mid-Wide range linearity, resolution, repeatability and symmetry. It includes two programmable level threshold detector lines that allow the user to set level sensitive alarms for pitch and roll.
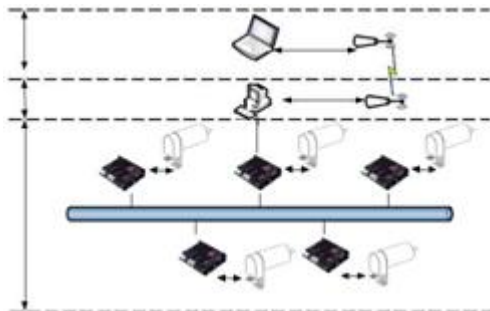
Figure 2: The sensors configurations

There are eight photoelectric switches, three cameras and one inclination sensor in the inspection robot. Photoelectric switch C1 and C2 are used for the left claws to grasp the overhead line according to that the two points determine a straight line. At the same reason, C3 and C4 are used for the right claw. C7 and C8 are applied to identify if there is a obstacle in the front of the robot. C6 and C7 are arranged to find the overhead line vertically when the arms are moved up and down. Camera 1 is set in the top of the left arm to watch the action of the right wheel and claw. Simultaneity, camera 2 is used to look over the left wheel and claw. Camera 3 is designed to inspect the power transmission line. The tilt sensor is installed in the control box to measure the inclination degree of the robot.

5. Motion Control System

1) The Electrical Control System

There are so many motors in the robots and obstacles in the ground wires. We use ACCESS database to manage these data.

Usually, walking on the ground wires, the robots must identify the obstacles, such as damper, anchor tower and torsion tower. There are many expression methods for knowledge database. The obstacle sequence of the overhead ground wires is programmed as a table of ACCESS data library in Table 1.

Table 1: Obstacle sequence library of the overhead ground wires

type	obstacle1	obstacle 2	obstacle 3	…
line 1	damper	anchor tower	damper	…
line2	torsion tower	damper	damper	…
…	…	…	…	…

There are 13 motors in the inspection robot. Action plan is composed of the sequence of action orders. According to the different action, the robot can control the running state of the joint motor in Table 2.

Table 2: Action Library of motors

Type	Motor1	Motor2	Motor3	…	Motor13
Action 1	a1 a	a2	a3	…	a13
Action 2	b1	b2	b3	…	b13
…	…	…	…	…	…

a. Data of action range

There are three key problems in negotiating obstacles. The first question is how to identify the obstacle type. The second question is how to confirm the space position. The third question is how to balance the center of gravity of the robot. These questions can be deal with laser sensors, video sensors and level sensors. After the arm and claw leave the ground wires, they try back to grip the ground wires. Actions of grip line are the most important actions, for they directly influence the safety and efficiency of the robot.

2) The Posture Plan for the Torsion Tower

We propose a new posture plan by appending the cross bridge in the torsion tower. Fig.6 shows a round iron appended in the torsion tower, and the six sequences of negotiating the obstacle while the robot walking on the bridge line. At first, rolling in the overhead ground wires, the robot inspects the power transmission lines, and then stop running when the sensors tell the robot that the torsion tower block its way. The robot climbs like a monkey from the overhead ground line to the bridge. Secondly, the robot walks along the bridge from the left side to the right side. Finally, the robot will scramble up the overhead ground wires again.

The most difficult action of the robot is to grasp the overhead ground wires. When the right claw holds the wire and the left claw want to grasp the wire, Sensor C1 and C2 are used to find the wire vertically, and Sensor C5 also is used to locate the wire horizontally. At the same time, the user can watch the movement of the left claw from the right camera 2.
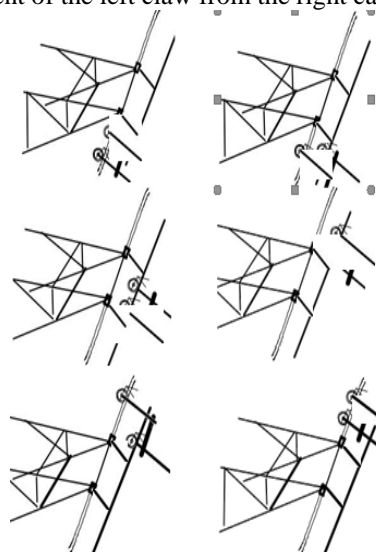
Figure 3: Obstacle clearing sequence of the inspection robot in the torsion tower

6. The Control Software

Motion Control software
The ground system has a notebook PC which is portable for the operator. With the human-machine interface in the ground system, operator can monitor the status of the robot, and teleoperate the robot if necessary. The human machine interface is programmed using VC++, as shown in Fig.7.

At first, the users select the serial number of the power transmission line, and click the display button. Then, the obstacle sequences are generated according to the ACCESS data library and displayed in the list. Secondly, the users in the human machine interface which are used to control the two claws how to grasp the overhead ground wires or bridge.

The serial communication window is used to debug the program. choose which obstacle should be started by the robot at the beginning point in the overhead ground wires and click the display button. Then, the action sequences are displayed in the list. In the automation operation window, after the users select which step should be executed and click the execution button, the 13 motor shall be started up according to the data in the list of action sequences. In the surveillance window, the user can browse the speed, current, position of the running motor. When the robot crosses the obstacle, the signal of the sensor shall be displayed in the measure list. When the robot meets a failure, and the error code should be display in the error list, regardless of each error, the motor of the robot should be halted. There are many auxiliary buttons with the wireless module, the robot system and the ground system can communicate with each other. The users can control camera and operate visible light images and thermal infrared images transmitted to the ground system in Fig. 8. The users can configure the path for save picture, GPS signal, etc. Through selection the button of the tab, the user can easy change the status mode of robot, video, and GPS.

The user can analyze the picture stored in the large capacity hard disk in Fig. 9. The users can analyze the defect in the live lines through visible images or the thermal infrared images. From the thermal infrared images, the user can get the distributing temperature of the live lines. While controlling the pan & tilt of the camera, the user can scan the A, B, or C phase power transmission lines respectively.
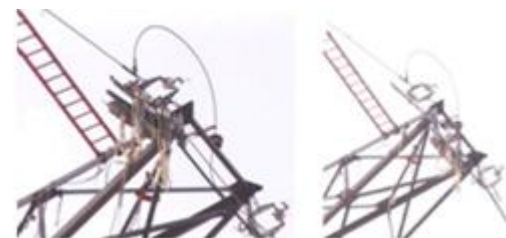
7. Experiments

Figure 4: The experiments of the inspection robot

The inspection robot was trained with the expert system for many times in the laboratory where the torsion tower and anchor tower were placed to imitate the real environment. Finally, the inspection robot was tested in the real tower. The new method of negotiating obstacles is proposed with the bridge installed in the torsion tower. Fig. 10 shows that the robot is crossing through the 500KV torsion tower in the overhead ground wires. The ladder remained in the tower after the robot was lifted to the overhead ground wires from the ground. When the experiment was finished, the ladder was taken away from the power tower. A bridge is installed on the torsion tower. The robot walked along the left overhead ground wires on the torsion tower in Fig. 10(a). The robot must walk along the bridge if it wanted to cross the torsion tower. The robot must hold the overhead ground wires with the left claw, move the control box to the left to keep its balance, and stretch the right arm to catch the bridge in Fig.10 (b).

The control box was moved to the right, and the left arm was left from the overhead ground wires and shrank to grasp the bridge with the left claw. When two wheels were posed on the bridge and two claws were relaxed, the two wheels can roll on the overhead ground wires in Fig.10 (c). In the similar way, the robot reached the middle of the bridge in Fig.10 (d) and the right of the bridge in Fig.10 (e). In the end, the robot climbed up the overhead ground wires in Fig.10 (f).

8. Conclusion

This paper presents the work environment of the inspection robot in detail. According to the special characteristic of the overhead ground wires, the obstacles are classified by the anchor tower, the torsion tower, and damper. The robot with 13 DOF is designed to imitate the monkey's behavior. The inspection robot is composed of two arms, two wheels, two claw, two wrists, etc. Posture plan is proposed to negotiate obstacles by the Cross- Bridge in the torsion tower. The software of motion control and defect analyse is designed with VC++. The experiments clearly indicate the posture plan is useful and effective and the robot can be applied to execute the navigation and inspection tasks.

References

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