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Robotic Power Line Inspection System

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***Abstract* — Provision of high quality and reliable electric power has become a necessity like air and water to the modern world. Any failure in todays power systems and grids results in to massive losses and inconvenience to consumers. The ideal conditions for any distribution company can be the ideal power network can be approached through minimizing maintenance cost and maximizing the service life and reliability of existing power networks. But both goals cannot be achieved simultaneously. Timely preventive maintenance can dramatically reduce system failures. Currently, there are three maintenance methods employed by utilities: corrective maintenance, scheduled maintenance and condition-based maintenance. Corrective maintenance dominates in today's power industry. This method is passive, i.e. no action is taken until a failure occurs. Scheduled maintenance on the other hand refers to periodic maintenance carried out at pre-determined time intervals. Condition-based maintenance is defined as planned maintenance based on continuous monitoring of equipment status. Condition-based maintenance is very attractive since the maintenance action is only taken when required by the power system components. The only drawback of condition-based maintenance is monitoring cost. Expensive monitoring devices and extra technicians are needed to implement condition-based maintenance. Mobile monitoring solves this problem.**

***Keywords* – Power Line Robot, Robot, Remote Inspection, Power Line Maintenance.**

I. Introduction

As with any preventive maintenance technology, the efforts spent on the status monitoring are justified by the reduction in the fault occurrence and elimination of consequent losses due to disruption of electric power and damage to equipment. Moreover, it is a well recognized fact in surveillance and monitoring fields that measurement of parameters of a distributed system has higher accuracy when it is when it is accomplished using sensing techniques. In addition to sensitivity improvement and subsequent reliability enhancement, the use of robotic platforms for power system maintenance has many other advantages like replacing man workers for dangerous and highly specialized operations such as live line maintenance.

Mobile monitoring involves the development of a robotic platform carrying a sensor array. This continuously patrols the power cable network, locates incipient failures and estimates the aging status of electrical insulation. Monitoring of electric power systems in real time for reliability, aging status and presence of incipient faults requires distributed and centralized processing of large amounts of data from distributed sensor networks. To solve this task, cohesive multidisciplinary efforts are needed from such fields as sensing signal processing, control, communications and robotics.

The paper presented the structure avoiding obstacle with multi-motor multi-sensor moving in three axles. The fundamental decision relates to which line components must be crossable, and which may not. First, it must be possible to simply roll over small obstacles such as splices and vibration dampers. Then, based on a thorough line component survey, the 0.76-m diameter spherical aerial marker was identified as the logical choice for the largest obstacle that could be crossed, as its size exceeds most other common obstacles (e.g., simple or double suspension clamps, corona rings and smaller aerial markers). Lastly, some less common, oversized or overly complex obstacles, like dead- end towers, can be bye passed using technology discussed in 2.4(i). We are presenting below alternative 2.4(ii).

II. Mobile Robotic System

Generally speaking, the mobile monitoring of power systems involves the following issues: SENSOR FUSION: The aging of power cables begins long before the cable actually fails. There are several external phenomena indicating ongoing aging problems including partial discharges, hot spots, mechanical cracks and changes of insulation dielectric properties. These phenomena can be used to locate the position of the deteriorating cables and estimate the remaining lifetime of these cables. If incipient failures can be detected, or the aging process can be predicted accurately, possible outages and following economical losses can be avoided.

In the robotic platform, non-destructive miniature sensors capable of determining the status of power cable systems are developed and integrated into a monitoring system including a video sensor for visual inspection, an infrared thermal sensor for detection of hot spots, an acoustic sensor for identifying partial discharge activities and a fringing electric field sensor for determining aging status of electrical insulation. Among failure phenomena, the most important one is the partial discharge activity.

2.1 The Technology

Initially developed as a mechanical de-icing solution for overhead ground wire, this Technology was soon used as a live-line inspection solution [for visual and infrared inspections, measurement of the electrical resistance of splices, and live-line replacement of overhead ground wire. A single-span approach reaches its limit once an obstacle must be crossed.

Theoretically, Rolling along high-voltage electrical lines high above the earth, a pint-sized robot packed with sensors promises to dramatically alter the way utilities inspect and maintain transmission lines. The robot moves on rollers fitted to a shield wire located above the main transmission lines OR on Transmission Lines themselves. The Robots are battery operated and can be adapted to recharge from "harvested" energy from induced current flow in the shield wire or "harvest Energy from Transmission Lines to recharge its batteries.

2.2 Sensors

Robot is fitted with GPS technology that allows for tracking and precise identification of problem spots along the line. Fitting the lines with remote radio-frequency sensors along eith Robotic inspection can be deployed in areas of environmental stress or other hazardous areas. For instance, vibration sensors would be installed in areas of high wind or leakage-current sensors in coastal areas to detect salt contamination, or pick up arcing that could be coming from a broken insulator. Maintenance personnel then would dispatch a crew to the locations for further inspection.It can also be fitted with a light detection and ranging sensor to measure vegetation, nearby structures, or conductor position. Other sensors detect electromagnetic noise along the line.

2.3 Imaging

In addition, the robot is fitted with high-definition visual and infrared spectrum cameras with advanced image processing to inspect the line's right of way and other conditions. It can determine clearance between conductors, trees, and other objects encroaching on the right of way and can compare current and past images of specific components to identify possible degradation.

2.4 By Passing Obstacles

2.4 (i) To overcome the difficulty of moving the robot around structures or marker balls that dots the line. A bypass system, a wire loop that gives the robot a way around an obstacle is constructed. When the robot senses the bypass, it detaches itself from the shield wire and connects itself to the bypass wire, moving around the obstacle. It then senses the shield wire, detaches from the bypass, and attaches back to the shield wire.

2.4 (ii) Alternatively as per the case discussed below the Robot comprising of three movable arms senses the obstacles. The retractable arms bypass the obstacles by retracting, moving forward and reattaching themselves logically avoids the obstacles. A combination of the technologies can be used to bye pass poles and insulators and other obstacles along the route of the transmission line.

III. Design of Walking Structure over Obstacle on a Power Line

3.1 System Module Composition

The walking structure over obstacle in three axles is designed by the idea of modularization and composed of three hanging arms moving in three axles and are composed of walking structure, upright flex arm, horizontal flex arm, and horizontal moving structure (Fig.1 shows).

Walking structure includes walking wheel, walking drive motor and joint, fix up bracket.

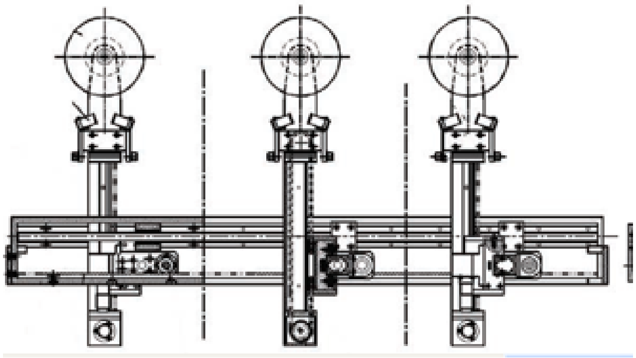

Fig.1. Side View

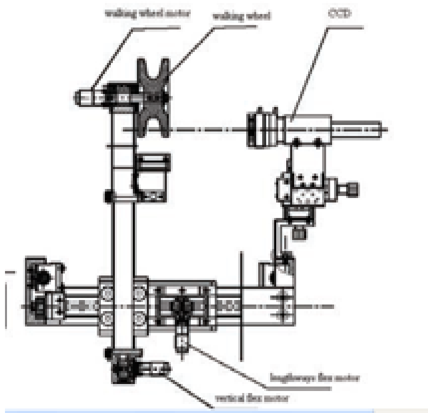

Fig.1.1. Front View

The vertical flex arm is composed of linear synchronous belt guide and vertical flex motor with the ability of brake and fasteners and connecting parts. Lengthwise flex arm is composed of linear synchronization belt and belt slider used to fix vertical flex arm, and relative movement realized by lengthwise flex motor. Three suspension arms are connected to fastening frame by the pinion-and-rack steering gear. Vertical flex arm and lengthwise flex arm are fastened perpendicularly. Each suspension arm can move straightly reciprocation at x, y, z direction.

3.2 Vertical Flex Arm Structure

Vertical flex arms are used to make walking machine breakaway or climb on electric line. Driven motor is fixed on end of guide, driving slider to move vertically relative to guide. At the same time, moving machine on the other end can move relative to whole robot bracket foundation. If a flex arm is needed to leave electric line, vertical flex arm motor drives guide to move upright relative to slide under the control command.

3.3 Lengthwise Flex Arm and Plane Moving Structure

Lengthwise flex arm is used to connect vertical flex arm and plane moving machine. Vertical flex arm is connected to lengthwise flex arm by the fix foundation of slide of lengthwise flex arm. The movement of lengthwise flex arm aims to bring vertical flex arm to leave or put on the electric line along lengthwise direction. A plane moving

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structure includes pinion-and-rack steering gear and guide, driving vertical and lengthwise flexes arms by rolling bearing. So the three flex arms can move respectively along three coordinate directions. Consequently, robot has the ability of walk over obstacle. There are photoelectric and touching sensors on the right and left of each flex arm detecting obstacle. When photoelectric sensor detects the obstacle at the distance of 10cm, walking wheel driving motor slows down to stop until touching sensor detects obstacle. This assures the dependability and security of system while detecting obstacle. The robot body includes 12 motors, 6 photoelectric sensors, 6 touching sensors, and 12 motor code wheel. There are one walking motor and three moving motors along three coordinate directions on each flex arm. Walking motor drives robot walking along electric line.

IV. Control System Design and Implements

4.1 Pace Design over Obstacle

In this paper, the object is suspension tower not strain tower, and there are three-phase electric line and grounding wires cable on tower. Fig.2. The obstacles on electric line are split at intervals of 10 - 20m, and the obstacle near suspension tower is wire clip hanging insulator string, and the obstacles on grounding wire mostly are wire clip and vibration-proof hammer.

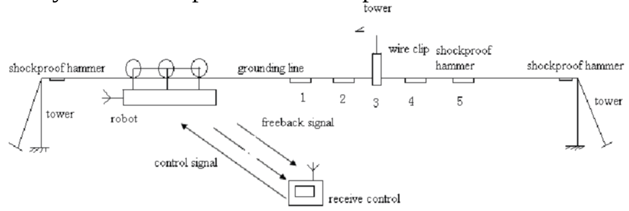

Fig.2. Schematic chart of robot pace over obstacle

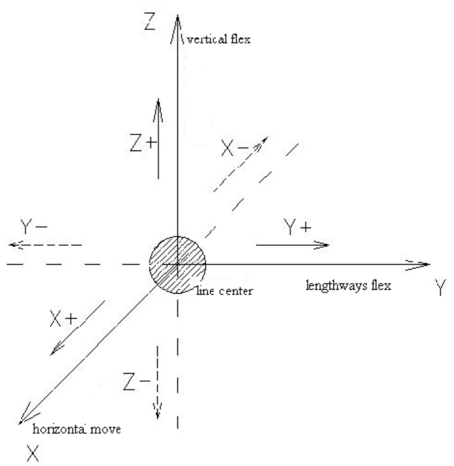

Fig.3. Three movement reference coordinates

From Fig.2, if robot can walk over this obstacle model with wire clip 3 and vibration-proof hammers 1,2,4,5, the suspension tower with 220~500kV and obstacles can be implemented using this model. Fig.3 shows three movement coordinates. The robot structure is divided into three modules A, B, C being three group of flex arms. There are three degree of freedom in one module, and the movement coordinate is (x,y,z). The location of module is expressed as A(x,y,z) ,B(x,y,z), C(x,y,z).

4.2 Software Implementation

The method for three coordinates moving robot is used here. The flow of moving control is shown in Fig.5.

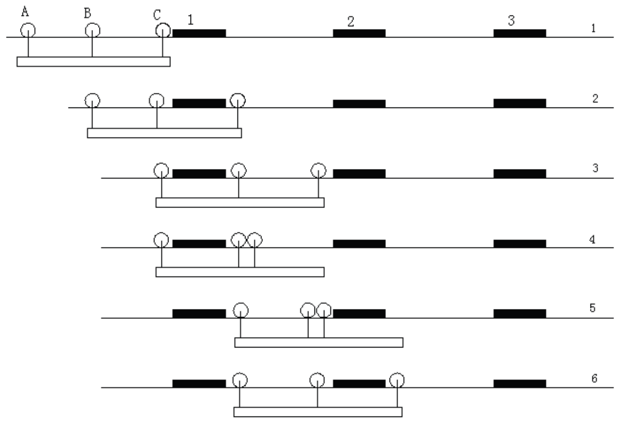

Fig.4. State chart of robot pace over obstacle

TRUTH TABLE FOR SOFTCODE						
Steps	Sensor A	Sensor B	Sensor C	Axis X	Axis Y	Axis Z
1	1	1	1	1	1	1
2	1	1	0	1	0	1
3	1	1	0	1	1	1
4	1	0	1	1	0	1
5	1	0	1	1	1	1
6	0	1	1	1	0	1
7	0	1	1	1	1	1

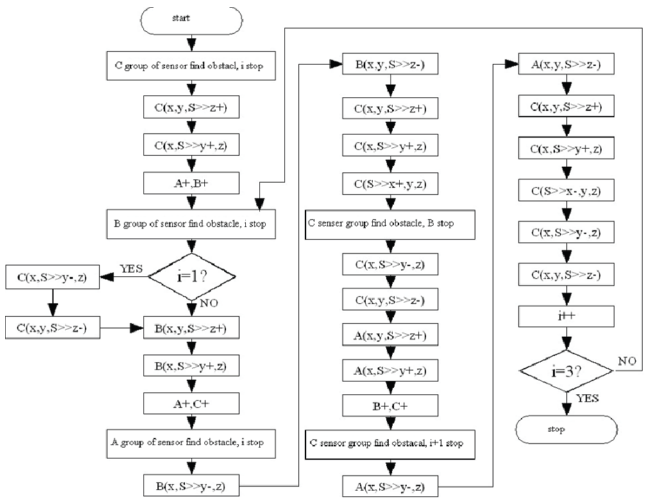

Fig.5. Flow chart of software design

4.3. Hardware Implementation

System electric design

The electric design of system is shown in Fig.6 including online and down-line modules. The online module includes CCD optic imaging and wireless image emission and CAN bus with 3 nodes wireless controlling and battery. The down-line module is composed of image wireless receiving and processing section and compute controlling and wireless controlling and battery. CCD camera is used to detect the Surface geometric imperfection (such as broken stocks, bulk of shares, split, and surface corrosion damage) of wire and grounding optical cable. Image is emitted from online, and is received and processed by offline receiving control machine. It replaced the current observation method using telescope by manpower along wire.

Single note controlling circuit

In Fig.7, a microcontroller is used to controlling four motors, and dual full bridge motor driver is used to set up motor drive circuit with 46V voltage and 4A electric current using parallel connection.

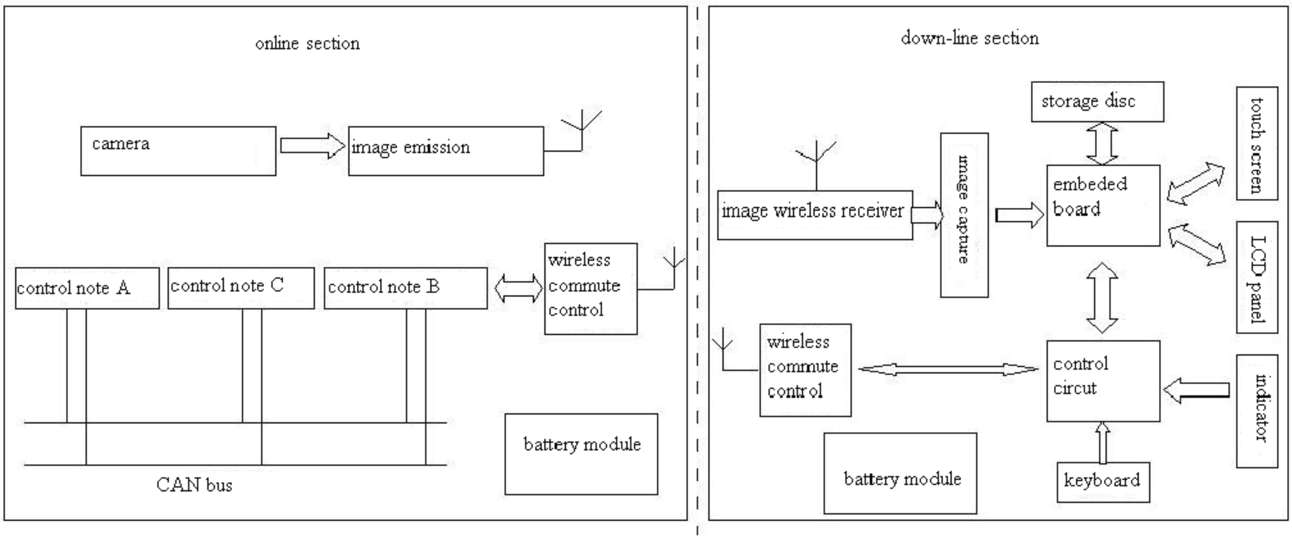

Fig.6. Electrical system of robot

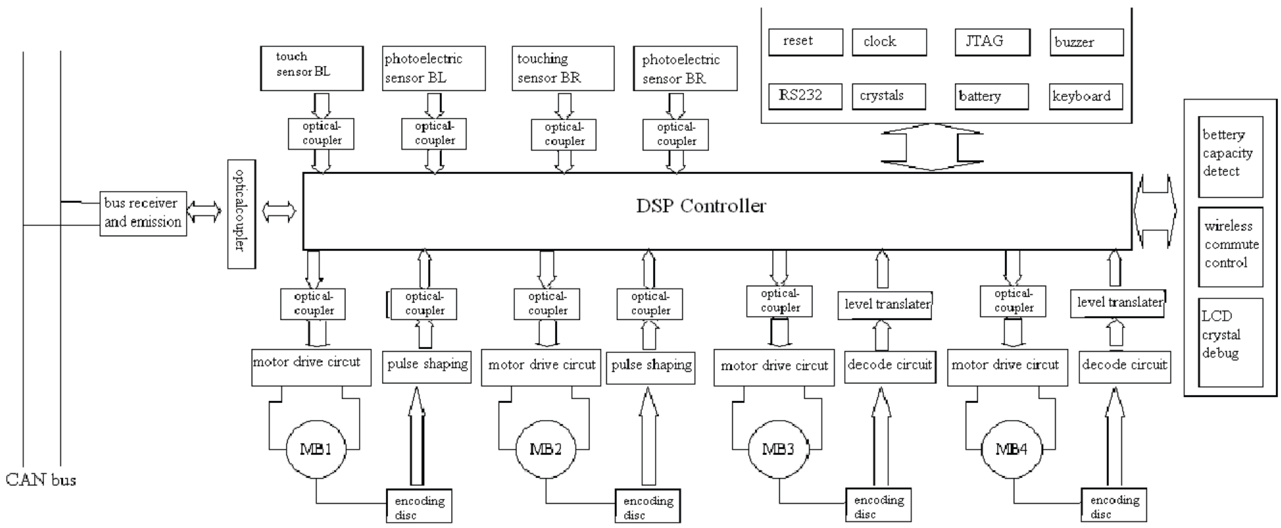

Fig.7. Single node controlling circuit

According to the weight and torque of every hanging arm, the driven motors of walking wheel and hanging arms can use DC motor with 10W power and 1.5~2.0Nm torque of reducer casing. These motors need brakes except walking driven motor. Move horizontally motor need has double end transfixion shaft and brake. Orthogonal pulse signal supported by photoelectric encoder using QEP decode circuit in EVA and EVB of DSP control vertical flex motor and lengthways flex motor.

The fixed position of horizontal move motor and walking wheel driven motor is implemented through CAP capture unit and GPIO. At the same time, GPIO captures the switch signals of four groups of sensors and cooperates with photoelectric encoder to control robot to walk over obstacle. Three groups of module communicate with each other by CAN bus, the rate can match 1Mb/s. Wireless module communicate with DSP by SCI. The battery monitor circuit is designed using A/D capture the battery capacity to feedback to the user.

4.4 System Implement and Principle Prototype

Through above analyze and design, the principle prototype machine is processed, and circuit control pan on and down line is designed, and the control software is developed. We have made experiment on prototype machine, and result shows it can walk over the obstacle.

V. Conclusion

Through above analyze and discuss, it is verified that for mobile robot for overhead power line inspection the module structure of three coordination movement is reasonable. The algorithm for controlling and gait planning ensure the implement of robot walking over obstacle. The robot can save a lot of labor and increase the detection efficiency and accuracy. Its practicality also will in the power market have broad prospect of application.

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