The Thirteenth International Symposium on Artificial Life and Robotics 2008(AROB 13th '08),
B-Con Plaza, Beppu, Oita, Japan, January 31-February 2, 2008

Inspection Robot Using the Infrared Thermal Imaging and CCD Camera

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Abstract: A new power line diagnostic robot is introduced in this paper. The diagnostic mobile robot is moving on the neural line which goes over the power lines and it passes the electric poles and selects a desired branch of neural line to follow. For the diagnosis of power lines and insulators, the infrared thermal image and CCD camera are used to improve the security, to reduce the checking time, and to improve the reliability of the data. For the autonomous navigation of the mobile robot on the neutral line, there are several problems, such as, passing the electric poles, avoiding bypassing neural lines, and selecting a desired branch of neutral line. Sensor fusion techniques are adopted to resolve these problems and to improve the reliability. The insulators and connectors in the power lines need to be checked regularly since the power lines can be disconnected by corrosion or flames. Before the disconnection, the possible faults should be detected and repaired by using the stored images of CCD camera and infrared thermal images. A diagnostic mobile robot is implemented and the real experimental results are demonstrated.

Keywords: Sensor fusion, Infrared Imaging Camera, CCD Camera, Diagnostic Robot, Power Line

I. Introduction

High quality power supply is very important currently since most of the automated systems require the power without any perturbation. To prevent any malfunctioning of the transmission line and equipment, the system need to be checked regularly and the fault prediction algorithms are necessary to be developed. There are many electric poles and insulators to transmit the power to various areas. Insulators are made of ceramic materials to support the power transmission and distribution wires mechanically as well as to keep the electrical insulation. Processed wires are normally made of plastic coated aluminum-copper alloy to transmit high voltage power, whose inner sides are filled by steel to keep the mechanical strength and to reduce the price.

The processed wires are tied to the insulators on the pylon or on the electric pole.

Since the wires and insulators are used on the air long time, there are chemical reactions, aging, and thermal erosion which cause severe power loss through the transmission. For the conventional inspection, a human operator checks the wires and insulators with the aid of infrared cameras periodically. Therefore only 7% of the supports can be inspected and prevented statistically for economy reasons. And also it lowers the safety factor of the power transmission.

II. Diagnostic robot design

This section introduces sensor fusion techniques for robot driving and methodology for fault diagnosis of power transmission lines. For the recognition of electric poles and for detecting neural wires to hold, ultrasonic sensors and infrared sensors have been utilized together to compensate for the shortcomings of the other one.

With the reliable recognition of electric poles and detection of neural wires, the mobile robot can pass through the electric poles which are obstacles for the mobile robot. While the mobile robot is moving along the neural line over power transmission lines, the electronic wave measurement system, infrared camera, and CCD camera gather the information for the fault diagnosis of wires, connectors and insulators. The mobile robot has also a GPS receiver which provides the locations of the faulty devices when the sensors detect faulty devices in real time to the industrial PC.

2.1 Sensor fusion

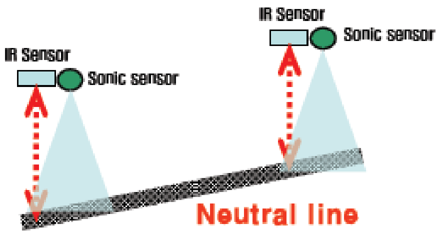

Fig. 1. Arrangement of sensors

The sensor fusion process of robot is required when

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the ultrasonic sensors and infrared sensors are activated to detect the neural wires as shown in Fig 1. The region detection capability of ultrasonic sensor has been utilized first, and the precise distance data can be obtained by the infrared sensor later. In this process, there exists an error between the distances measured by the two sensors, which is represented as

$$E_d = d_{IR} - d_{sonic} \tag{1}$$

where d_{IR} is the distance to the neural wires measured by the infrared sensor, and d_{sonic} is that of the ultrasonic sensor.

Generally, the distance value measured by the infrared sensor has high accuracy. However it is very sensitive to the density of sun ray and is not so reliable. Therefore the sensor data fusion is achieved as follows:

$$\begin{cases} d_{out} = d_{sonic} + E_d & |E_d| < \varepsilon \quad when \\ d_{out} = d_{sonic} + \dfrac{\varepsilon}{2} & otherwise \end{cases} \tag{2}$$

where d_{out} represents the determined distance from the sensor fusion, ε is the threshold value for the error. That is, when the error is less than ε, the distance measured by the infrared sensor is considered as reliable. Otherwise, the value is ignored and the output is determined by the reliable ultrasonic sensor data and the threshold value for the error. The threshold value is determined heuristically based on various experiments.

Figure 2 illustrates the distance measurement error of each sensor. The IR sensor has less than 5 [mm] error in the five measurements. However the ultrasonic sensor has relatively large error at the location where the neural line exists because of its outward- conic wave propagation property. When there is 21~25[cm] gap between the mobile robot and the neutral wire, the maximum allowable error not to cause false operation was less than 2 cm in this research.

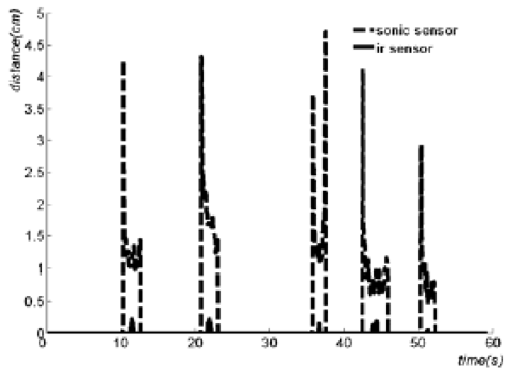


Fig. 2. Distance error

The error values are represented in Fig. 3, which are the differences to the real values for the five measurements.

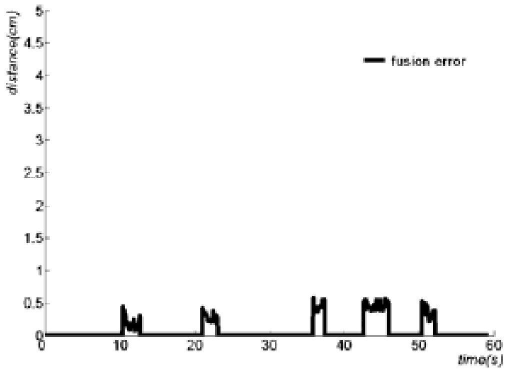


Fig. 3. Distance error after sensor fusion

The maximum error could be kept less than 5 [mm] which can be acceptable for the mobile robot while it is passing over the electric poles.

2.2 Robot controller

To control the robot which carries the inspection sensors along the neutral lines and passes the electric poles to go to a new neutral line, there several sensors, mechanical switches and motors are synchronously controlled. When the mobile robot starts autonomous navigation along the neutral line, the encoder information on current location and motion is very important for the control. Basically the robot motion control is done based on the encoder information.

However for the recognition of the electric pole, ultrasonic sensors and IR sensors are utilized. That is, when the mobile robot approaches to the electric pole closely, the precise distance control to the electric post is done based on the ultrasonic and IR sensors.

The initial position of the mobile robot can be set by a mechanical switch. For the initial installation of the mobile robot on the neutral line and also for the emergency cases, a remote controller is designed to stop all the operations on temporary. Figure 4 shows the mechanical structure of the power line inspection robot, where the left part shows a gripper to hold the electric pole while the upper-right part is rotated to hold a new neutral wire to follow.

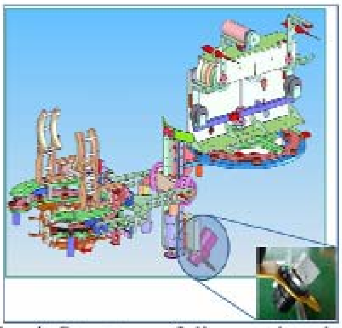


Fig. 4. Structure of diagnostic robot

2.3 Electric pole passing algorithm

The control algorithm for passing the electric pole can be summarized as following six steps:

1) Recognition of the electric pole

As the first step, the mobile robot recognizes the electric pole by the ultrasonic sensors. That is, when the mobile approaches to the electric pole, it recognizes the existence of the electric pole and slows down the speed to measure the distance precisely with the aid of IR sensor. Finally, it stops at an appropriate location to hold the electric pole.

2) Grasping of the electric pole

The gripper holds the electric pole firmly.

3) Unlock the rollers and guides for the neutral line

While the gripper is holding the electric pole firmly, the rollers and guides for the neutral line are releasing the neutral line. The release status can be checked by the IR sensors on the mobile robot.

4) Rotation of robot body to hold a new neutral line and locking the rollers and guides

The robot body is rotated to a new neutral wire by the motor at the gripper. When the rotation is completed, the rollers and guides are locked with the neutral wire to follow. For the proper and stable locking, ultrasonic sensors and IR sensors are utilized cooperatively.

5) Gripper release the electric pole

Since the robot is hold a new neutral wire, the gripper releases the electric post.

6) Start to navigate

It lowers the gripper and rotates it 180°using the motor at the body to arrange the ultrasonic and IR sensors forward for the electric pole recognition. Now the mobile robot navigates along the neutral wire until, it recognizes a new electric pole again.

Figure 5 summarizes the control flowchart of the power line inspection robot. Note that there are three different types of electric poles practically.

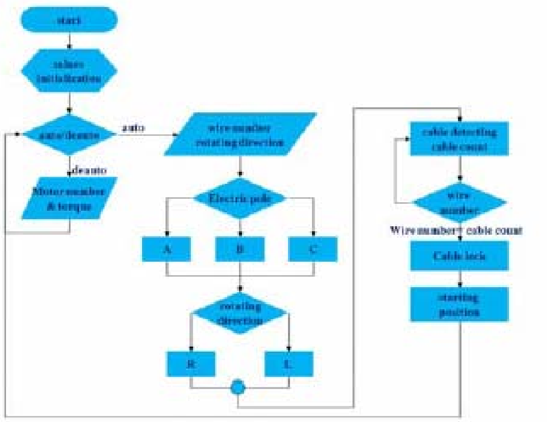


Fig. 5. Control flow chart.

III. Diagnostic experiments

The infrared camera and CCD camera installed at the body inspect the faults on the transmission wires while the mobile robot is moving along the neutral wire. And also they inspect the connectors and insulators on the electric pole while it passes over the electric pole.

When it detects a faulty device, the CCD and infrared images are captured and stored with GPS data.

The stored data can be sent to the monitoring system where an operator may decide the defection of the device finally and ask to repair the device with the location information. CCD images are properly utilized to distinguish the types of objects and environment. Figure 6 shows a monitoring system for an operator to identify and decide the faulty device finally. With this monitoring system, the operator does not need to go close to the high voltage power line, which is dangerous and undesirable.

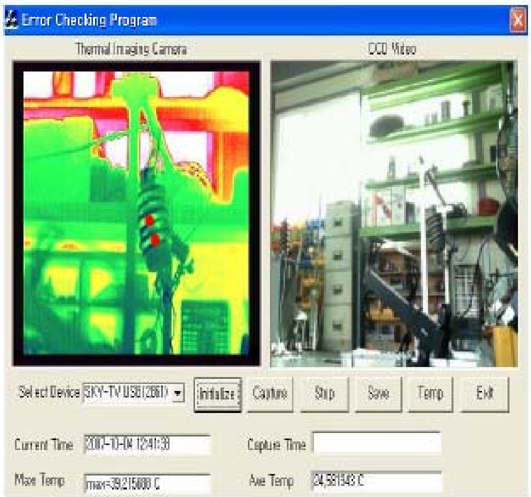


Fig. 6. Diagnostic program

The infrared camera collects necessary data from the module connected to the lens has its own reference color palette. From the reference palette values of the infrared camera module, the measurable maximum temperature (tem_{high}) and the minimum temperature (tem_{low}) are set to divide the palette into 255 slices.

To measure the temperature more accurately from the RGB color images, the palette is divided into 255 slices and temperature variation (tem_{ave}) for each slice can be calculated as follows:

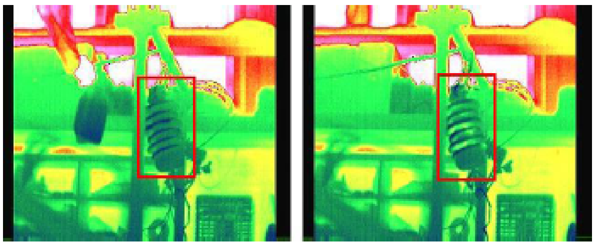
$$tem_{ave} = (tem_{high} - tem_{low}) / 255 . \qquad (3)$$

This defines the temperature variation for each slice of the palette (tem_{ave}).

The transmitted image from the infrared camera is divided into 5,600 pixels in this research. The RGB value of a pixel is compared to the reference palette to find out the mostly related slice of the palette. The corresponding counts of the slice from the minimum temperature is defined as $data_{RGB}$, and the temperature (tem) for the pixel can be calculated as

$$tem = tem_{low} + (data_{RGB} \times tem_{ave}) . \qquad (4)$$

When the pixel temperature (tem) is over than the preset maximum allowable temperature of the insulator, the infrared camera captures the image and stores into the PC with the location information from GPS receiver.



(a) Normal insulator (b) Faulty insulator
Fig. 7. Infrared images of insulates

Figure 7 (a) and (b) show the normal and faulty insulators, respectively. When the red-boxed areas are compared, the faulty insulator shows bright parts where some of leakage current increased the surface temperature irregularly. With the pre-stored reference images of the insulators, the erosion and/or aging of the insulators can be detected from this infrared image analysis.

IV. Conclusions

This paper introduces a new power line diagnostic robot which utilizes the sensor fusion technology to improve the diagnostic reliability from the images of CCD/infrared cameras and electronic wane measurement system. The diagnostic robot navigates through the electric poles while the sensors attached on the robot gather the information on the power line insulators and connectors. The gathered data by the electronic wave measurement and cameras can be analyzed to detect faulty devices and power lines. By using the robot for the power line inspection, several problems of conventional human checking system have been resolved. For examples, the inspection cost has been reduced dramatically and the inspection operation becomes safe since human operator is not going close to power lines any longer. As a future research, an intelligent sensor fusion algorithm needs to be developed to overcome the intrinsic problems of image sensors: the infrared images are sensitive to the environment temperature and CCD images are sensitive to the environment illumination.

ACKNOWLEDGMENT

This work was supported by the Brain Korea 21 project

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