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Prototype of a Transmission Line Inspection Robot

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Abstract. This paper describes the development of a prototype of a pole to pole transmission line inspection robot which is capable of inspecting a transmission line in a cost efficient manner. The novel mechanism involves the setup of a base station having the capability to interface and communicate with the robot. A scaled down model of a transmission line is considered and the robot is made to inspect that line. An artificial fault is induced which replicates and emulates the effect of a fault occurring on the transmission line. The robot consists of two arms for driving and two arms for sliding and stability purposes. The fault on the wire is detected by the use of an infrared thermometer. A Global Positioning System (GPS) is mounted which gives the position of the robot in terms of latitude and longitude as it moves along the line. A central controller integrates all the modules (Thermometer, GPS and the Zigbee) and is responsible for communicating the data to the base station. The information from both the GPS module and the sensor is sent to the central controller and transmitted to a base station via ZigBee module which is a wireless technology for low latency transmission of data. The developed robot has the ability to filter any incipient faults that occur on a transmission line by employing the sensor module, controller module and the communication module. The feasibility of the prototype model of transmission line inspection robot is tested on a 10m transmission line.

Keywords: Transmission line inspection robot, GPS, Zigbee, Central controller, Mobile robot module, Base station Module.

1. Introduction

High voltage transmission lines supply electricity and they provide a vital link between the generation company and the distribution company. The distribution company supplies power to the consumers [1]. Inspection of transmission lines are performed, to check the functionality and the efficiency in which the line operates. Losses are kept in check with proper maintenance of transmission lines. It is mandatory that high voltage lines are verified and checked at least once a year [2]. In India, manual labor is employed for the inspection of transmission lines whereas in developed countries sophisticated air vehicles are deployed for the inspection of transmission lines [3]. Inspection robots on transmission lines are the latest trend as the entire process of inspection of transmission lines are automated. Transmission line inspection robots are being developed and are researched upon on a regular basis. Researchers have endeavored to make fully autonomous and intelligent cable climbing robots equipped with necessary sensors for hot line inspection, aiming at making a cable-climbing mechanism with obstacle avoidance capability to pass the line equipment and the tower [4]. Robots are being developed which are capable of traversing along the line with power derived from the power line itself [5]. Advanced research transmission line inspection robots like LineScout [6], LineROVer [7], TI, Expliner [8] and MoboLab are being developed and perform complex tasks in scouring the line, detecting faults and performing minor repairs [9]. Transmission line robots are vital as faults are persistent in transmission lines and a major fault leads to a collapse in the system. Deformities in the line, galloping of the line, Vibrations in the line and Ice formation are faults that causes anomaly in the temperature of the transmission line [10].

Various techniques are used to identify the faults on the transmission line. Some of those techniques are:

- Infrared Photography which is based on the observation of the heat emissions from the transmission line. Change in heat levels based on the change in temperature is the principle of infrared photography. But infrared cameras tend to be expensive.

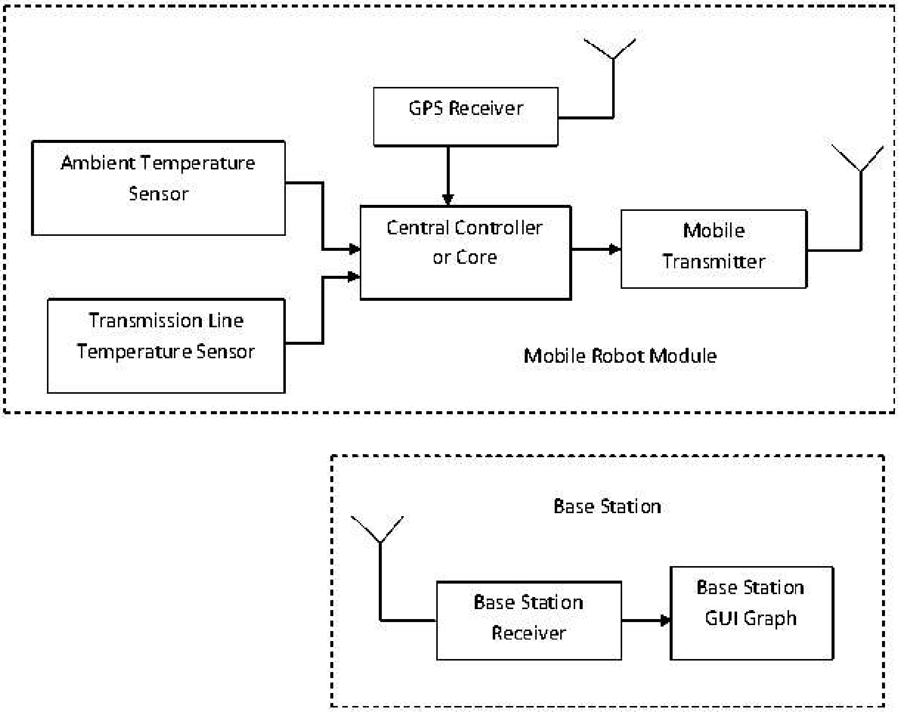

Figure 1. Transmission line inspection robot.

- X-ray imaging helps in the detection of deformities and incongruities on the line by taking X-ray films. Deformities have a major impact as they create a hotspot due to a change in resistivity. But usage of X-ray imaging declined due to the health risk of exposure to radiation.
- Corona analyzer is another technology used frequently. It works on the principle of detection of ultraviolet light by picking up electromagnetic discharges from the power line and filtering the correct signal by honing onto that particular frequency. Corona analyzers tend to be expensive and as a result are used only in advanced research technology.

The technique used in the robot namely the Infrared thermometer meets the general requirement of usage as it is compact, cheap and efficient. Thus this paper is aimed at preserving the state and condition in which the transmission line operates. Inspection of transmission lines helps in obtaining valuable data that is vital for checking the status of the line. The Prototype of a transmission line inspection robot navigates the line on a pole to pole basis. The purpose of designing the robot is to fulfill the craving need for stability in the transmission line network existing in India. The prototype detects the possibility of existence of a fault by calculating the temperature of the line. The temperature data along with the position of the robot are assimilated and transmitted to a base station. The base station processes the data and a real time graph is plotted at the base station. The graph gives details regarding the occurrence of the fault at the corresponding position. The graphical data along with the parameters collected sets the standard for the user's knowledge about the condition of the line which in turn fulfills the purpose of the robot.

The paper is organized as follows. Section 2 deals with the System description which gives a brief idea about the principle of the prototype, the various modules present and a block diagram. Section 3 explains about the Mobile Robot Module and the various components present inside the prototype. Section 4 explains the Base station, the process of analyzing the data. Section 5 explains about the Mechanical configuration of the robot. Section 6 gives a brief overview of the entire process right from the movement till the analysis of the fault at the base station. Section 7 concludes the paper with a summary of the results obtained and also about the success of the prototype.

2. System Description

Figure 1 depicts the block diagram of the Transmission Line Inspection Robot and also presents the various modules present in the prototype. The prototype consists of mainly two modules each working coherently for the sole purpose

Table 1. Classification of faults.

S. No.	Error	State	Type of Fault
1	Error $\Leftarrow$ 35	Normal	None
2	35 < Error $\Leftarrow$ 80	Faulty	Common
3	80 < Error $\Leftarrow$ 95	Faulty	Major
4	Error > 95	Faulty	Equal Emergence

of establishing a communication link between the transmission line and the user at the base station. The two modules are namely

- Base Station Module
- Mobile Robot Module

The principle of the prototype of the transmission line inspection robot is that any defect caused or existent in the transmission line is characterized by a sudden rise or drop in temperature leading to the formation of a hot spot or a cold spot [11]. The rise or fall in temperature is usually synchronized to the occurrence of the fault of a particular magnitude. The robot scours the transmission line capturing the temperature of the line at regular intervals. A sudden rise or drop in temperature is observed in the graph plotted at the base station. The temperature is measured using a wireless infrared thermometer – MLX90614-BAA. The thermometer detects the value of the temperature and feeds the data in a serial manner to the central controller via a two wire communication network. The network is called a System Management Bus (SMBus) [12]. The central controller is connected to the thermometer which collects the data and dictates the state of the line and the nature of the fault by using the"Error Algorithm" [13].

$$\text{Error} = 100 \times (X - Y)/(X - Z)\% \tag{1}$$

where,

- X is the temperature of the measuring point i.e. the temperature measured by the infrared thermometer.
- Y is the standard temperature specification of the transmission line i.e. the nominal temperature of the transmission line.
- Z is the ambient temperature i.e. the temperature of the surrounding.

The central controller dictates and decides the nature of the fault by calculating the value of ERROR and assigns a state to the condition of the line at that point.

Based on the data provided in table 1 and the value of error obtained, the fault is classified accordingly. The classification of the fault goes a long way in describing the mode of operation for mitigating the fault. The fault is classified as an common fault if the error is of a minor value and the fault is classified as a major fault if the corresponding value of error is high. This algorithm takes into the account the effect of rain, snow and environmental anomalies. The values of Y and Z are based on the nature of the transmission line and the environment respectively and as a result, for every iteration performed by the MRM; Y and Z are constants and the values are substituted accordingly.

3. Mobile Robot Module

The mobile robot module pertains to the prototype. The robot having the capability to move along the line is designed and configured. The functions of the Mobile Robot module are,

- To successfully traverse on the line on a pole to pole basis by using a motor driver L-298.
- To identify the temperature of the line as the robot moves along the line.
- To establish and assign the nature of the fault using the temperature data collected.
- To synchronize the temperature data collected with the position of the module using a GPS module.
- To transfer the data collected to the Base Station Module using Zigbee Technology.

The various components present in the Mobile Robot Module are given below:

3.1 *The infrared thermometer*

The robot captures the temperature of the line as it moves along the line and applies the "Error Algorithm" in an effective manner. For measuring the temperature of the line, an actual thermometer cannot be used because contact of the thermometer with an HV line will damage the robot and the line. The infrared thermometer can be used to measure the temperature of the line without physical contact with the line. Melexis 90614 [14] is a non contact thermometer which effectively measures temperature with very high precision. Being a small sized transducer, it precisely measures temperature up to 380°C. Also, having a resolution of 0.02°C it is capable for capturing a minute change in temperature. It is thus ideal to use an infrared thermometer in comparison with other devices, as it measures the temperature of the line without physical contact with the line. The Melexis temperature sensor has a Pulse Width Modulated (PWM) output resulting in the capture of temperature at very small intervals. Thus as the MRM moves along the line, the Melexis captures the temperature at every small distance traversed by the robot. The Melexis has SMBus compatible digital interface. SMBus is a two wire interfacing medium for lightweight communication. The data collected from the Melexis is stored in an inbuilt EEPROM (Electrically Erasable Programmable Read Only Memory) and fed as a 10-bit PWM output. This output is transmitted to the central controller through the SMBus. The SMBus is featured within the Infrared thermometer and is the default mode for communication of temperature data from the Infrared thermometer to the central controller. The SMBus is compatible with another two wire network bus called the I2C bus. The SMBus is converted into an I2C bus and its corresponding inbuilt library is used for programming the Infrared thermometer [15].

The output of the Melexis is precise to a very high order. Infrared is used as the medium of interface. There is an inbuilt optical IIR filter that is capable of blocking the visible and near infrared radiant flux. The presence of IIR filter provides immunity from stray ambient flux and flux from sunlight. This is necessary as the radiation from the sun can affect the performance of the Melexis sensor. The necessary filter is thus built within the Melexis so as to ensure that the performance of the Melexis is unaffected because of external disturbances. The mechanism of emission of IR from the head of the sensor is such that the rays emitted will converge at the measuring point which is 5cm away from the sensor.

The sensor has 4 pins – two pins SDA and SCL for the SMBus communication while the 3rd and 4th pin serve the purpose for input power and ground. The entire module i.e. the thermopile and the output processor (filter) is fitted into a single unit called the Melexis infrared thermometer.

3.2 *Central controller*

Arduino UNO R3 serves the purpose of a central core. It is responsible for interfacing all the components in the Mobile Robot Module. The central core performs the following tasks:

- To receive the serial temperature data from the Melexis sensor via the Rx pin of the central controller.
- To apply the Error Algorithm and calculate the Error using the temperature data obtained from the Melexis thermometer.
- To assign the nature of the Fault upon the calculation of the error value.
- To perform the process of extraction of the NMEA GPGGA in order to obtain the latitude and longitude values.
- To transmit data continuously to the Zigbee node at the base station via Tx pin.
- To control the forward and reverse motion of the robot using L298 motor driver.

3.3 *Motors*

Two motors are required for the entire process of driving the MRM along the line. Brushless DC Permanent magnet of torque 15 kg [16] is chosen for this purpose. The motors have the capability to traverse along the line despite the presence of minor sag on the line.

3.4 *GPS module*

A global positioning system (GPS) is used for detecting the position of the robot in a global geometrical region which includes a GPS receiver for receiving radio waves from a plurality of satellites. The output is either in a two dimensional position data indicative of the present coordinates of the robot [17]. GPS provides location and time information anywhere on the Earth where there is an unobstructed line of sight of four or more GPS satellites [18].

NMEA (National Marine Electronics Association) is the standard format used for the purpose of receiving the coordinates namely the latitude and longitude from the GPS module. NMEA is an internationally recognized system and embedded into the system are various parameters out of which latitude and the longitude are a component. In order to obtain the latitude and longitude, they must be segregated and filtered [19]. NMEA format is studied and the latitude and longitude are segregated.

In the NMEA format $GPGGA section contains the coordinates.

$GPGGA; 123519; 4807:038;N; 01131:000;E; 1; 08; 0:9; 545:4;M; 46:9;M; *47

where:

- GGA – Global Positioning System Fix Data
- 123519 – Fix taken at 12:35:19 UTC
- 4807.038,N – Latitude 48 deg 07.038' N
- 01131.000,E – Longitude 11 deg 31.000' E
- 1 – GPS Fix
- 08 – Number of satellites being tracked
- 0.9 – Horizontal dilution of position
- 545.4,M – Altitude, Meters, above mean sea level
- 46.9,M – Height of geoid (mean sea level) above WGS84 ellipsoid
- 47 – the checksum data, always begins with *

3.5 *Zigbee module*

Zigbee technology is a communication technology having the capability to connect wireless nodes through the Zigbee protocol [20]. Zigbee protocol results in a high rate of transfer of data between the nodes and another feature of the technology is the low power consumption involved during the functioning of this technology. A separate module known as the Zigbee module is placed at the nodes and act as the transceiver. The transceiver receives data from the central controller in a serial manner to the base station. Zigbee brings forth a new level of organization in the wireless mesh network standards and brings into picture the concept of a higher control of data transmission between sensors and control circuits. The concept of one-one communication existing between sensors and control circuits is avoided as the concept of a wireless, low latency network is established due to the establishment of the Zigbee network [21]. By using Zigbee technology, the data is successfully transferred from the Mobile Robot module to the Base Station where the second Zigbee node is placed [22].

4. Base Station Module

The base station module has the second node of the Zigbee module. The parameters from the Mobile Robot Module is received at the base station and sent serially to a Graphical User Interface (GUI). Figure 2 depicts the back-end employing GUI at the base station module. In the LabView's back-end Graphical User Interface, a layout is created where the content of the incoming serial communication are plotted as a graph. The graph is plotted between error and time with the position of the robot displayed below. This results in a well laid GUI created and existing at the Base Station where the user can monitor the performance of the robot and the line all at once. If the error value shoots up, the user at the base station takes the necessary action by noting the position coordinates thus mitigating the fault.

5. Mechanical Configuration of the robot

5.1 *Mechanical design of the robot*

Figure 3 depicts the basic layout of the Mobile Robot Module. The robot is built on a decking sleeve that acts as a base for the entire robot. It also acts as the support for the central controller and the batteries which are present on the lower side of the decking sleeve. Two arms are present on one side of the robot which provides the driving force. Each of the

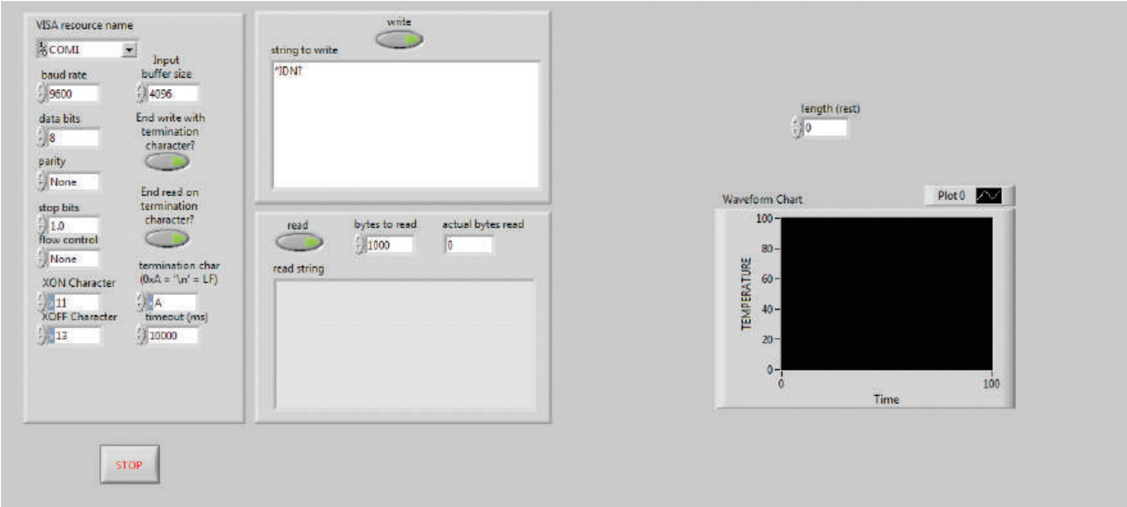

Figure 2. GUI at the Base Station Module (BSM).

Figure 3. Mechanical design of the robot.

two arms is provided with a 15 kg high torque brushless DC motor having the capability to drive the robot across the line. 3" diameter round belt pulley with the necessary rubber coating is provided in order to make the working motion more efficient. The pulley is attached to the end of the arm so that it is possible for the robot to move across the line. In a similar fashion, two other arms are present which provide stability and sliding action.

5.2 *Movement of the robot*

The transmission line is clamped in between the arms in order for the robot to be secured. The robot is suspended with the four arms clamped onto the line. The two arms have motors connected which helps in the driving of the motor. The motion of the robot is slow so as to allow sufficient time for the sensor to assimilate information and transmit the information via ZigBee.

5.3 *Transmission line setup*

The prototype is designed to move from one pole to the other pole. A standard Indian Electricity Board cable is taken and adequate support is given across the two ends of the transmission line. The robot is clamped to one end of the transmission line and is driven across till the other end. A fault or a hotspot is induced on the path of the robot and when the robot traverses on that part of the line, a fault alert is invoked based on the temperature of the line. A spike is produced in the graph at the base station GUI at that corresponding point.

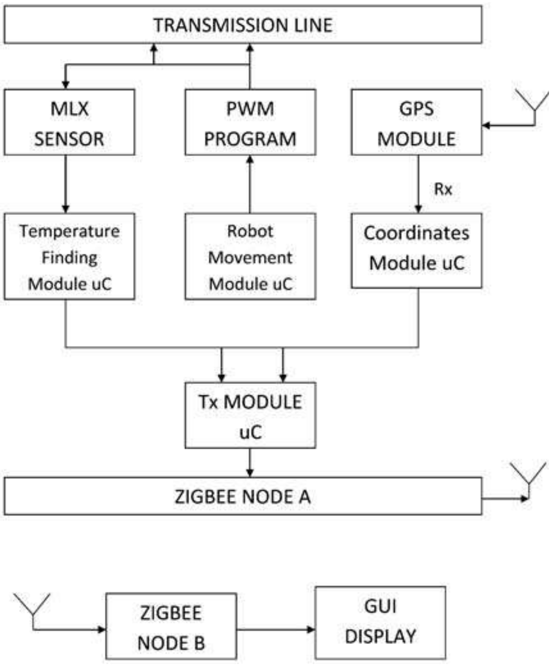

Figure 4. Process overview diagram of the transmission line inspection robot.

6. Process Overview

Figure 4 explains the process flow that occurs in both the modules. This robot has the capability to traverse along the line and perform the function of a transmission line inspection robot. Any fault that is existent on the line namely ice formation, deformities, insulator failure or surge current flow is characterized by a rise or drop in temperature and this results in the formation of a hotspot or a cold spot on the line. The robot senses the rise in temperature of the line and stores the data in the EEPROM present in the MLX sensor. The temperature is transmitted via the two wire SMBus to the central controller. A program is written and embedded onto the central controller wherein the nature of the fault is calculated by using the Error algorithm. The temperature, error and the nature of the fault are calculated and this sequence forms the interface between the controller and the infrared thermometer.

In a parallel manner, the GPS module continuously notes the coordinates in the NMEA format. A program is coded to extract the latitude and the longitude from the NMEA format. The coordinates are sent to the board in a serial manner wherein the board receives the coordinates via the Rx pin and stores the values in the memory of the central controller. The board transmits the parameters i.e. temperature data, the nature of the fault and the coordinates to the Zigbee module in a serial manner through the Tx pin. The Zigbee Module acts as Node A and transmits the information to node B at the base station. The Zigbee module at node B receives the information from the node A and transmits the data serially to the GUI. The GUI receives the data and plots the data as a graph on a real time basis. The base station receives the temperature readings corresponding to a exact position complete with accurate latitude and longitude values.

7. Result and Conclusion

Figure 5 depicts the motion of the MRM along the transmission line. The paper results in the development of a pole to pole transmission line robot's prototype. The design and mechanism is of a basic nature but the prototype as a whole has a novel mechanism of functioning and detecting the presence of a fault. Most of the high end robots use costly technologies like infrared cameras in order to clarify the value of temperature. By using the infrared thermometer, the robot obtains a similar result at a much lesser cost. This gives the robot an edge over the existing models. Further developments to the robot involve improvising the design so as to make it traverse across obstacles. By improvising, this robot will play an active role in the development and the maintenance of transmission lines.

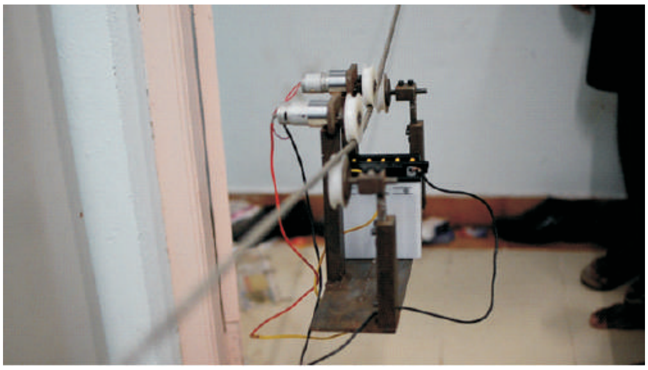

Figure 5. Motion of the MRM along the transmission line.

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