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Design of Automated Hotline Maintenance Robot Using Haptic Technology

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Abstract- This paper describes design of a semi-automated robot that can inspect power transmission lines accompanied by an operator situated in the control room. This robot mainly focuses on the most frequent problems faced by the power systems, hotlines. Thus making in ease of operation and avoiding their life risk, at least for few cases, where they can use them satisfactorily.

Index Terms- Design, analysis, material selection, assembly, programming, AVR controller, simulation, haptic glove, servo mechanism

I. Introduction

The natural resources for electricity production are unevenly dispersed in India. The Planning Commission of India has set a target of 80010MW electric power generation for 2011-2012 [1]. As the technology is developing transmission of power using HVDC is coming into light with many added advantages over the HVAC [2]. This leads to increase of transmission lines and makes it difficult to maintain. Transmission lines can have power loss due to many reasons. There are mainly four types of losses that lead to the major power loss. CONDUCTOR LOSS- occurs mainly due to current passing through the resistance, DIELECTRIC LOSS- due to voltage across insulation, SHEATH LOSS-occurs because of induced current in the sheath and the INTERSHEATH LOSS- caused due to formation of circulating currents between the sheaths in loops of different phases [3]. Maintenance of electrical transmission lines is an essential activity in power grid sector. There are mainly two types of testing methods in the hot-line maintenances department, HOTSTICK and BAREHAND technique [4].

Robotics and automation is taking a very rapid growth from the past few decades [5]. The robotics technology has even reached into power grid field. We have many robots that are available with their own working methodology in maintaining the transmission systems. Expliner-a robot running on high voltage live lines in Japan (Paulo Debenest, et al.,2008). Line-Scout Technology, a mobile teleoperated robot working on the lines, up to 735 kV and 1,000 [8] Obstacle navigation control was introduced for an inspection robot suspended on overhead ground wires of power transmission lines (Ren Zhibin and Ruan Yi,et al., 2008). A double-arm inspection robot was developed for live line inspection (Xiaohui Xiao, Gongping Wu, and Sanping Li, 2007) [6].

High electric insulating material has to be selected in order to ensure the safety of the robot. Professional plastic composites that can work as good insulators at high voltages can suit the best as per the requirement [7].

Robots developed mainly focus to inspect the fault in the line. Further repairing work would be the task for a worker. We have designed a robot that would inspect as well repair some of the major problems associated with the transmission lines. The flow chart of the system is shown in the fig.1

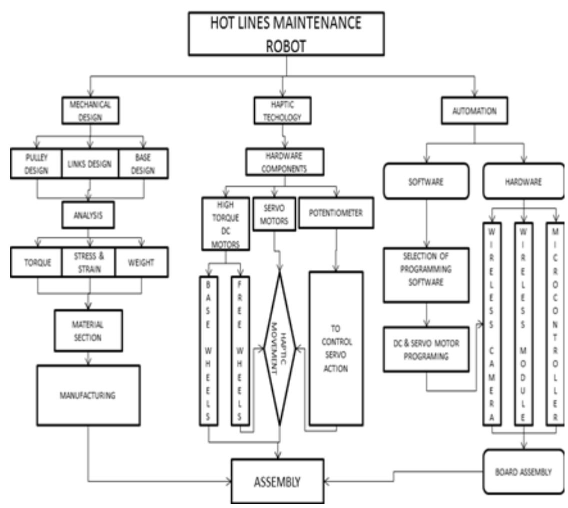

Fig.1 Flowchart of HOTLINE MAINTANANCE ROBOT production

II. PROBLEM STATEMENT

Here is a proposal for altering the risk of human loss during supervision by replacing a AUTOMATED ROBOT.
The robot is designed for the following functions:

- To travel on the charged single conductor without any throttle or imbalance.
- To check the contact resistance of a contact, using a micro-ohm meter.
- To tighten/loosen the contact nuts and bolts to reduce the contact resistance.
- To place a COME-ALONG-CLAMP on the charged conductor wire for relieving mechanical stress on the insulator, for its replacement.

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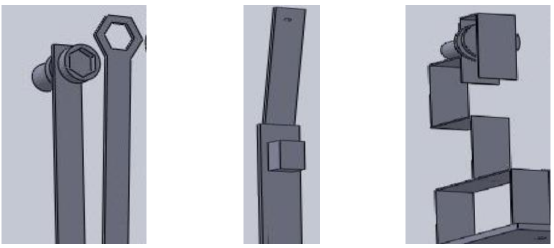
III. MECHANICAL DESIGN

For every system, design is the first and foremost task to be performed. According to the requirement of the robot, shape and size of the body has been designed.

A. *Link design*

Design of links for the robot has been obtained depending upon the type and the number of tasks to be performed by the robot and the number of arms were estimated and designed accordingly. Links are analyzed using various robotic rotational and transformational matrices to find the theoretical and practical movements of the robotic arms.



(a) (b) (c)

Fig.2: Design of the LINKS

To test the resistance of the line, the pulley [Fig.2 (b)] arm is designed such that it could test and send the resistance value present over the line. Both the pulley arms are equipped with the clamp-meter for testing before and after performing the task.

Live processing is equipped for the robot in order to view the working status of the robot. An arm is designed [Fig.2 (c)] that could show the live video of the transmission line. A COME-ALONG-CLAMP has to be designed that would be placed on to the transmission line which is used to tighten the transmission line and maintaining the proper slag angle. Assembling of COME-ALONG-CLAMP using the robot arms was designed along with the live streaming arm such that it could reduce the linkages.

B. *Base design*

Base of the robot is made according to the movements and orientation of each and every arm and also as per the task to be performed by them. In any design, material minimisation has to be taken care.

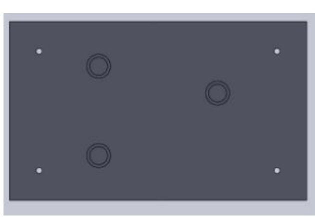


Fig.3: Design of the robot base

C. *Pulley Design*

Pulley is made taking into consideration of the transmission line diameter. It is the only part that makes a direct contact with the high voltage line. Any conduction through this results in total damage of the robot. However it would be best if it could receive the power from the line to run.

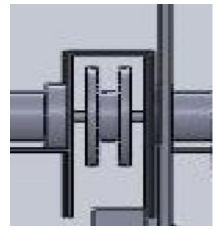


Fig.4: Design of Pulley to roll over Transmission line

D. *Motors Placement Design*

Various motors are placed on the robot. As per the requirement of the robot we have used five D.C. motors and four servo motors for the robot pulley and arm movements.

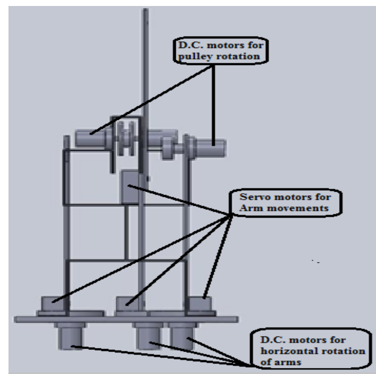


Fig.5: Design of the motors placement

E. *Assembling of the robot*

Assembling the robot arms along with the base of the robot and all the other accessories like all the motors, camera model etc. is been performed.

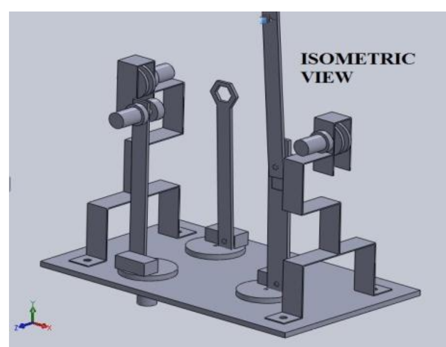


Fig.6: Assembling the Robotic parts (Isometric view)

F. *Material selection*

The basic parameter that we need to consider in selecting the material is electric insulation. Generally, materials with surface resistivity more than 10^{12} Ω/m^2 are considered to be insulating materials.

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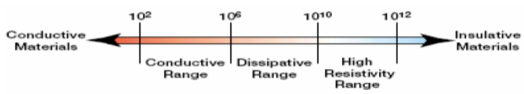

Fig.7: Resistivity of insulating materials

As per the availability, cost concern and required properties for the design of the robot, following group of materials are chosen to compare and analyse to choose the best material.

Properties	**Acrylic [14]**	**Delrin [15]**	**Fiberglass [12]**
Elastic Modulus (N/mm^2)	10.4	13.7	15.66
Poisson's Ratio	0.35	0.31	0.27
Material density (kg/m^3)	1.19	1.56	1.89
Electrical resistivity (Ω/m^2)	1.2×10^{15}	9.3×10^{14}	1.8×10^{15}
Temperature resistance (ºC)	99	115	104

Table.1: Different material properties that suit the robot

G. *Analysis of the robot*

The model has undergone stress and strain analysis with various loads applied at different places. Balancing of the robot over the transmission line, while travelling is analyzed. The model is defined with the above three mentioned materials and the obtained results are compared in order to obtain the best material.

Mainly analysis has to be done for the pulley that resists the total body weight over the transmission line.

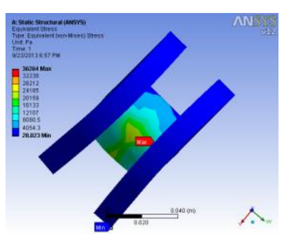

Fig.8: Pulley analysis under equivalent stress

IV. DESIGN OF CONTROL SYSTEM

A. *Microcontroller*

Every automated system has microcontroller as its base. We are working on the AVR microcontroller. It is a low power consumption device and small in size and also cost effective.

B. *Motor Driver*

The motor driver IC is used to drive the motors using a 5v signal source and can also run the motors in both reverse and forward directions.

This IC can also supply the 12V to the servo motors even though the controller voltage is of 5V. The speed of the motors in both forward and reverse direction is controlled using the microcontroller code.

C. *Wireless Transmission*

We are using RF (Radio Frequency) communication between the robot and the control system. The wireless camera used for the visualisation of the robotic operations on the high transmission lines is also communicated using the RF.

As we are working over the high transmission lines there may be attenuation in the signals that we are sending to the control system. To avoid these attenuation and noise we have to use a high-pass filter circuit which eliminates the low frequencies. The high-pass filter circuit can be as shown below

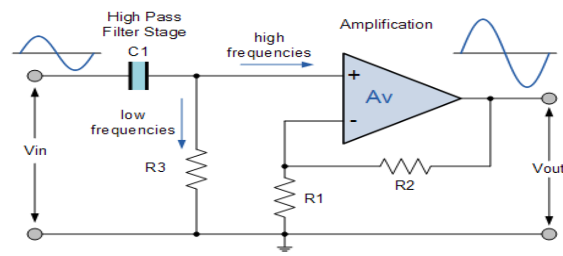

Fig 2: High-pass filter circuit for avoiding noise.

The circuit diagram for the robot is done as shown in below figure 3.

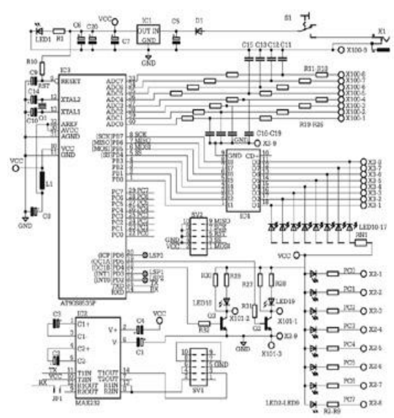

Fig 3: Schematic diagram of AVR controller

D. *Simulation*

The simulation of the above circuit is done using the PROTEUS software which is an embedded real-time simulating software tool. This is a universal software tool used for all types of controllers especially ATMEL family.

In the figure, the keypad is used to control the running of the motors. Here we are using four servo motors and two dc motors. In the four servo motors, three of them are used for 360 degrees rotation of the arms and one is placed at the joint of one arm which is used for second movement i.e., the arm has two degrees of freedom. This arm is used to fix the "come along clamp" on the high transmission lines.

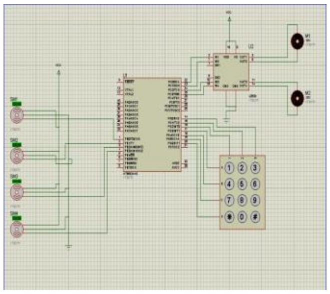

Fig 4: Simulation of the motors

The two DC motors are used for the forward and backward movement of the robot. As the dc motor cannot be driven by a microcontroller alone, we are using a driver IC to drive the motors as the dc motors require 12V supply to run and the controller cannot provide that voltage. Hence we use this driver IC for driving them. The driver IC we are using here is l293d IC. This IC can drive four motors with single way rotation or two motors with rotation on either way. Here we use only two motors for the movement of the robot, so we are using this IC. This IC will be having two voltage sources to operate i.e., 12V and 5V. The 12V supply is taken by the motors and the 5V supply used for the microcontroller.

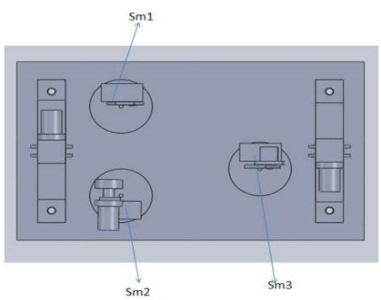

Fig 5: Bottom view of the robot showing motors

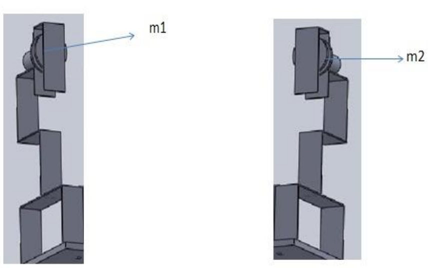

Fig 6: Pulley design showing the dc motors

The controlling of these motors is done using the keypad. According to the hardware implementation of the robot the keypad is replaced with the joystick or using the laptop keys. For the purpose of simulation we have used the 4x3 keypad as the input controlling element. The program is burned into the controller to so that we can visualize the exact hardware output in the simulation.

E. *Programming*

The programming for the HOTLINE maintenance robot is done using the WINAVR software tool.

Algorithm

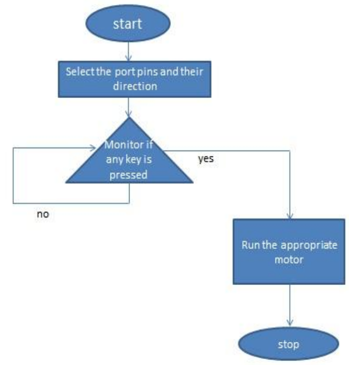

Fig 7: Algorithm for the programing

V. DESIGN OF HAPTIC SYSTEM

A. *Haptic Arm Design*

Haptic technology, or haptics, is a tactile feedback technology which takes advantage of the sense of touch by applying forces, vibrations, or motions of the user. This mechanical stimulation can be used to assist in the creation of virtual objects in a computer simulation, to control action of such virtual objects, and to increase the remote control of machines and devices (telerobotics).The haptic devices incorporate tactile sensors that measure forces exerted by the user on the interface.

This device is adjusted over the user's hand like an exoskeleton has potentiometers on joints like elbow, wrist & fingers, change in resistance with hand movement.

As we move our hand in order to tightening & loosening of contacts the haptic glove should move according to our hand movements which in return should move hand of robot in the same manner to do work on live transmission line.

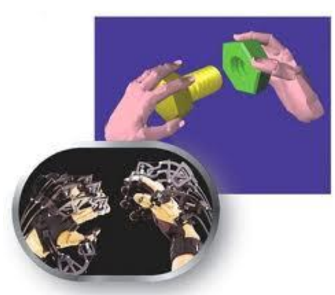

Fig.3 Tightening & loosening of contacts

The Robotic Arm is designed using the Microcontroller programming. It works on the principle of Interfacing potentiometers and servos. This is done using atmega 16 bit microcontroller. The glove is fitted with potentiometers and the servos are attached to the body of the robotic arm. Potentiometer converts the mechanical motion into electrical motion. Hence, due to the motion of the human arm, the potentiometers produce the electrical pulses, which are the signals for the avr controller. The board process the signals, which is received from potentiometers furthermore convert them into requisite digital pulses that are then send to servomotors. This servo will responds to the pulses and the moment of the robotic arm occurs.

The micro controller interfaces all these components specified above.

B. *Servo Motor*

The servo motors usually have a rotation limit from 90° to 180° and even some servos also have rotation limit of 360°. Their rotation is limited to fixed angles. In this system we have used servo motors with a limit of 180º.

Fig.2 Servomotor

C. *Potentiometer*

The potentiometer's are used to control the arms at required position, these potentiometer's are connected to our hands, As we move our hand in any position or at any angle, the same movement is done by the haptic arm, by this we can tighten/loosen the contact nuts and bolts manually as we can feel the work is really going on the line on our own hands.

VI. WORKING AND OPERATION

The task of the robot is to check the contact resistance of the contact. For this purpose the robot is specially equipped with an arm A1, which acts similarly as a human arm. It has a base motor B1 wheel and motor M1 of combination which is compared with the shoulder joint. Then there is a joint on the other end of which a servo motor (SM1) which acts as the elbow joint. To the rotor shaft a joint is fixed. This fixed arrangement completes the construction of the human arm (the comparisons were already made for better understanding). This is made as a replica of the industrial robotic arm.

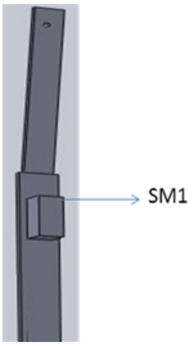

Fig.4.1 Come-Along-Clamp

The second task of the robot is to tighten/loosen the contact nuts and bolts. This is accomplished by using a drill type mechanism, which is regularly used to tighten/loosen screws. For this we have designed two arms. These both arms will have similar construction but both have mirror images to each other. It is having a base motor M2 and M3 which are mounted below the base board and above this, a wheel is affixed. Above this wheel a servo motor SM2 is mounted on the wheels using 'L' clamps. These servo motors help to raise or lower the arm on which the fitter mechanism is arranged. They are equipped such that they are controlled using an analog potentiometer. This is connected to a micro controller which converts the analog signal of the potentiometer to a pulsated signal, which is understandable by the servomotor. This setup makes it very ease in replicating the motions of the operator, and creating a virtual existence of the operator at the work place.

Whenever there is an activity of tightening of a nut and bolt mechanism, the robot is moved and positioned on the wire. Then the controls are used to move and hold the nut and bolt by using both arms, respectively. Then the holder is made to hold and opposite arm is made to rotate with sufficient torque, necessary to tighten the bolts.

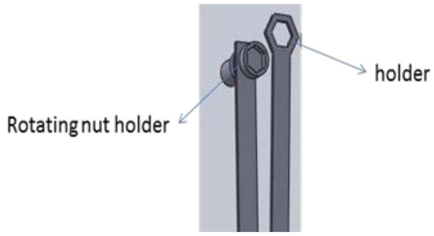

Fig.4.2 holder assembly

The last activity of the robot is the placing of the Come-Along-Clamp mechanism. The Come-Along-Clamp is placed on the edge of the arm 1 and it is controlled by using the switch controller, then after placing the COME-ALONG-CLAMP on the conductor the arms2 and 3 Holds it while the arm1 detaches the clamp from it. This is a procedure which is difficult to explain on words, but gives you a great visual experience, of the co-collaborated co-ordination of robots.

Using the potentiometers by connecting it to haptic glove we can control the servo movements by moving our hand to control the action of robotic arm in the possible way to do the work.

Fig.4.4 shows complete haptic glove

VII. CONCLUSION

Demand for electricity is going on increasing day by day in the world. This leads to construction of more number of power systems and also the transmission systems. This results in difficulty of maintaining all the lines manually being a dangerous and tedious task. This paper could suggest an alternative and a bit easier way to maintain the lines regularly and without any human loss using a robot.

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