Conceptual design for transmission line inspection robot

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Abstract. Power transmission line is used for power distribution purposes due to their cost effective measure compared to underlying cable. However, prolonged exposure to natural weather may cause fatigue stress to the lines as well as induce material failure. Therefore, periodical line inspection is considered utmost important as a preventive measure to avoid power outage. However, transmission line inspection has always been a high risk and expensive work. Hazardous works that may harm operator as well as routine that requires precise handling can be performed by robots. Various types of robots have been designed and developed for line inspection but only perform well on a straight and continuous line. As these robots encounter an obstacle during the inspection, then the real problem in terms of robot stability and smooth operation arises. In this paper, conceptual design and evaluation for transmission line inspection robot is presented. The inspection robot mobile robot must be able to bypass or avoid obstacles as it travels along the power transmission line.

1. Introduction
Power transmission lines are used worldwide to transmit electricity for power distribution purposes to the customer. The underground transmission system is environmentally preferable but has a significantly higher cost. On the other hand, the overhead lines are cheaper but are easily exposed to the changes in the natural weather. Prolonged exposure of the transmission line to the natural weather may cause stresses to the lines as much as material corrosion. Repetition of expansion and contraction of the transmission line due to temperature changes induce fatigue stress to the line mainly due to the aging of the material. It is vital for the transmission line to be inspected to prevent any fracture or deformation that may propagate along the lines and to locate hot spots to prevent further power lost during the transmission.

There are many methods to inspect the deterioration of the transmission line including conventional inspection using crane and inspection crate, aerial inspection using helicopter or unmanned aerial vehicle, ground inspection by foot or terrace vehicle patrol, as well as inspection robot. Various concepts of line inspection robot are developed in order to replace the presence of human due to high risk during the operation. Although none of the design has been mass produced, the main focus of the design process however is always the same, which is bypassing obstacles on the transmission line. Comparison between diversified concurrent transmission line inspection robots from various institution [1]–[5] is shown in Table 1.
Table 1. Concurrent Technology of Transmission Line Inspection Robot

| Robot                        | Description                                                                 |
|------------------------------|-----------------------------------------------------------------------------|
| Tokyo Electric Power Mobile  | Description: 11 kg and 3 meter  
Mechanism: Roller (transverse), Arc shaped guide rail (to bypass)  |
Slop limit: 30° maximum | Limitation: Only for single fibre-optic overhead ground wire transmission line |
| LineScout                    | Description: 112 kg and 1.37 meter  
Mechanism: Roller (transverse), robotic arm walker (bypass)  |
Slop limit: 30° maximum | Limitation: Heavy, not suitable for high tension conductor |
| Shandong University Mobile   | Description: 45 kg and 1.2 meter  
Mechanism: Roller (transverse), robotic arm (bypass)  |
Slop limit: 60° maximum | Limitation: Arm movement not flexible due to short middle arm mechanism. |
| Expliner                     | Description: 80 kg and 1.5 meter  
Mechanism: Roller (transverse), robotic arm (bypass)  |
Slop limit: 30° maximum | Limitation: Stability problem and only can be operating in double line usage |
| Wuhan University Mobile      | Description: 30 kg and 0.76 meter  
Mechanism: roller (transverse), acrobatic movement (bypass)  |
Slop limit: 30° maximum | Limitation: Unable to bypass large obstacles. |

2. Conceptual design
It is essential to understand and study the nature of the obstacles on the transmission line in terms of size and geometrical configuration. The concept generation process is closely linked to the identification of engineering specifications since the concept generated is a combination of various aspects that were derived as a solution for the engineering specifications. The robot must be able to grasp the line properly, avoid or bypass obstacles such as vibration damper, line spacer and aerial marker as well as overcome the jumper wire in order to transfer to another line span. The concepts of the transmission line inspection robot in Figure 1 are generated by means of morphological diagram as shown in Table 2.

Table 2. Morphological diagram for concept generation

| Specification                  | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 | Option 7 | Option 8 |
|--------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Main body frame                | Rigid    | Segmented| Flexible | Extendable|          |          |          |          |
| Drive system                   | Electro Motor | Bar Linkage | Hydraulic | Pneumatic |          |          |          |          |
| Steering mechanism             | Actuator at end joint | Movable arm | Manipulate weight | Movable body |          |          |          |          |
| Cable gripping mechanism       | Clipping Roller | Grooved Wheel | Robotic finger | Two large wheels | Belting | Robot weight |          |          |
| Movable part mechanism         | Gear set | Slider | Thread | Cable | Chain and sprocket | Belting | Cam and follower | Bar linkage |          |
| Bypassing tower via line jumper| Articulated arm | Adjustable arm | Manipulate centre of body mass | Swinging | Crawling | Body waving | Wheel/Roller | Acrobatic movement |          |
| Bypassing inline obstacle      | Articulated arm | Adjustable Arm | Manipulate centre of body mass | Swinging | Crawling | Body waving | Wheel/Roller | Acrobatic movement |          |
| Power Supply                   | On board (battery) | In line Energy Harvester | Off board | On board (solar) |          |          |          |          |
| Indicator                      | * Concept 1 | × Concept 2 | + Concept 3 | △ Concept 4 | ∆ Concept 5 |          |          |          |
2.1. Concept 1
This concept consists of rigid bodies with flexible joint attached with big wheel. Each of the wheels is controlled separately. Both wheels will provide gripping force exerted to the transmission line. The robot is able to bypass the obstacle just by rolling over on the obstacle.

2.2. Concept 2
For this concept, the robot has one main body attached with three articulated arms. Two motor driven wheels are attached to the gripper for locomotion. The robotic arm will provide more flexibility to the robot for the inspection exercise.

2.3. Concept 3
This concept consists of a main body, extendable platform, 2 grippers for support and a gripper for propulsion. The two grippers are attached to the extendable platform and gripper with clipping roller attached to the main body. When an obstacle is detected, the extendable platform will slide out of the obstacle. Two arms temporarily grip the line to give support to the robot while the wheel frame is driven forward to bypass the obstacle.

2.4. Concept 4
This concept consists of 3 arms attached to 3 segmented bodies which enable the robot to move to another transmission line especially for bypassing tower. When an obstacle is detected, the front gripper will disengage from the line and bypass the obstacle. As the front gripper grabs back the line, the middle gripper will be detached from line and the motor driven wheel at the front and back gripper will drive the body forward. The same process is then repeated for the back gripper. The segmented body can rotate horizontally and act as self-balancing system by manipulating the entire body mass of the robot.

2.5. Concept 5
This concept is inspired by leech movement. It consists of only 2 arms attached to segmented body and able to self-stabilize via centre of body mass manipulation. When an obstacle is detected, the front gripper will detach from the line and bypass the obstacle. At the same time, the arm will self-balance itself and grasp back the transmission line. The back gripper will then drive the whole body forward.

![Figure 1: a) Concept 1, b) Concept 2, c) Concept 3, d) Concept 4 and e) Concept 5](image)

3. Discussion
In order to choose the best concept for the transmission line inspection robot, the entire robot performance is evaluated. Each concept is compared to each other relatively as presented in Table 3. Concept 2 appears to be the best solution followed by concept 5 with ability to travel along the line, bypass obstacles and tower albeit high complexity in controls system for precise gripper coordination. On the other hand, concept 1 and 3 are suitable for continuous line and able to bypass in line obstacles. However, due to inflexibility of the main body frame, concept 1 and 3 are unable to bypass towers. Their control system is also considered simple in comparison with other concepts.
Table 3. Performance table

| Selection criteria       | Concept 1 | Concept 2 | Concept 3 | Concept 4 | Concept 5 |
|--------------------------|-----------|-----------|-----------|-----------|-----------|
| Bypass tower             | ×××       | √√√       | ×××       | ×         | √√        |
| Bypass obstacle          | √√√       | √√√       | √√√       | √√        | √√√       |
| Slope climbing           | √√√       | √√√       | √√√       | √√        | √√√       |
| Stability                | √√√       | √         | √         | √√        | √√        |
| Close-up inspection      | √√√       | √         | √         | √√        | √√        |
| Flexibility              | ×          | ×√√       | ×          | √         | √√√       |
| Slope climbing           | √√√       | √√√       | √√√       | √√        | √√√       |
| Control complexity       | √√√       | ×××       | √√√       | ×          | ×××       |

Indicator: 
× Average 
√√ Poor 
√√√ Very Poor 
√ Good 
√√ Very Good 
√√√ Excellent

4. Conclusion

The application of robot for transmission line is considered essential due to hazardous nature of inspection routine itself, low operation cost and the need of cautious handling measure during the inspection session. Even though various types of robots have been developed for line inspection, they only perform well on a straight and continuous line. Due to limitation of the robot flexibility and control complexity, the robot will encounter challenges in avoiding obstacle as well as bypass towers via line jumper. The overall robot design should be lightweight so that the transmission line suffers no additional load. The best concept to bypass in-line obstacle and tower is concept 2, followed by concept 5. However, concept 1 is the best concept for continuous straight line and bypass in-line obstacle.

Acknowledgement

The authors would like to sincerely thank the Ministry of Higher Education (MOHE) of Malaysia for the provision of a Grant with code No.20120125FRGS to support this work.

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