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A Study on a Power Transmission Line Mobile Robot for Bundled Conductor Navigation

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Abstract

We introduces a mobile robot that can navigate on a power transmission line arranged in bundled conductors. The designs of the proposed robot are performed for navigation on bundled conductors, and the navigation method for bundled conductors and obstacle avoidance are presented. The robot consists of 13 degrees of freedom (DOF) with a symmetrical structure for the left and right parts, including the four wheel joints. The navigation method is designed using a combination of three motion primitives such as linear motion of counterbalancing box, linear motion of robot arm, and rotational motion of wheel part. To examine the performance of the proposed robot, navigation simulations are conducted using ADAMS™. The robot navigations were simulated on obstacle environments that consisted of two- and four-conductor bundles. Based on the simulation results, the performance of the proposed robot was reviewed through the analysis of the trajectories of end-effectors. We confirmed that the proposed robot was capable of achieving optimal navigation on bundled conductors that included obstacles.

Keywords: *Mobile Robot, Bundled Conductor Navigation, Obstacle Avoidance, Power Transmission Line, ADAMS™*

1. Introduction

Recently, the global demand for electric power has been increasing because of population growth and industrial development. As a result, large-scale power facilities have been built to provide reliable power. Likewise, the construction of high-voltage transmission facilities is actively being implemented but the inspection and maintenance methods used for reliable power supply have not undergone significant changes. To prevent large-scale power outages for wide areas through provision of reliable power supply, the inspection and maintenance of power transmission lines (PTL) becomes very important. However, most of the PTL inspection and maintenance relies on manpower. In order to solve the existing problems, such as the reliability decline, high costs for inspection and maintenance, and personal injury, research on automated/unmanned technology is being carried out to replace manpower in many countries and institutions. Consequently, the

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inspection and maintenance methods using robots for PTL navigation can be practically applicable.

The research and development of PTL inspection robots is being carried out by countries such as Canada, USA, China, and Japan. In particular, the research of the obstacle detection and avoidance navigation method has been actively carried out through the structural transformation of the robot. The Hydro-Québec Research Institute (Canada) is actively developing a PTL inspection robot. The developed form of their inspection robot, “LineScout”, is a multipurpose mobile platform that can perform live line inspection and maintenance [1–2]. It is commercially available and has been subjected to extra high voltage (EHV) field tests. In China, the Chinese Academy of Sciences (CAS) [3] and various universities (Wuhan University [4] and Shanghai University [5]) have developed PTL inspection robots. The navigation analysis confirmed that most robots use similar mechanisms for navigation. Corporations like HiBot, Kansai Electric Power, and the Tokyo Institute of Technology have developed the inspection robot, “Expliner” (Japan) for commercialization in 2002. Unlike conventional inspection robots, the “Expliner” was designed for bundled conductor navigation, and has been developed for remote control inspection of energized high-voltage transmission lines of up to 765 kV [6–7]. The electric power research institute (EPRI) developed the inspection robot, “TI” in 2008. “TI” was evaluated in a field test under an EHV line environment [8]. Currently, PTL is consisted of bundled conductors in order to achieve an increase in the transmission capacity. However, it is difficult to navigate bundled conductors because the navigation methods of most conventional robots were made suitable for single conductors. In this paper, we propose a mobile robot that can navigate on a power transmission line arranged in bundled conductors in order to overcome the limitations of such a conventional robot. We describes the proposed robot that has been designed to navigate on PTL, consisted of bundled conductors for avoidance of electric fittings and for bypassing pylons, and the designs are performed. In addition, the navigation method is proposed for bundled conductors, gripping and obstacle avoidance, using the combination of three motion primitives. The navigation simulations are conducted using ADAMS^{TM} in order to examine the performance of the proposed robot. The robot navigation was simulated on obstacle environments, which consisted of two- and four-conductor bundles. The performance of the proposed robot was reviewed through the analysis of the trajectory tracking of end-effectors based on the simulation results.

2. Proposed Robot Design for Bundled Conductor Navigation

2.1 Robot design

In this section, the design of the proposed robot is presented for bundled conductor navigation. The proposed robot consists of four wheels, four arms, one main body, and one counterbalancing box. The driving part is connected to all nine revolute joints and four translation joints. In other words, each wheel is driven by one revolute joint, and each arm is driven by one revolute joint and one translation joint. In addition, the main body is driven by one translation joint for motion control of the counterbalancing box for adjusting the center of gravity of the robot. Figure 1 shows the structure of the proposed robot for bundled conductor navigation.

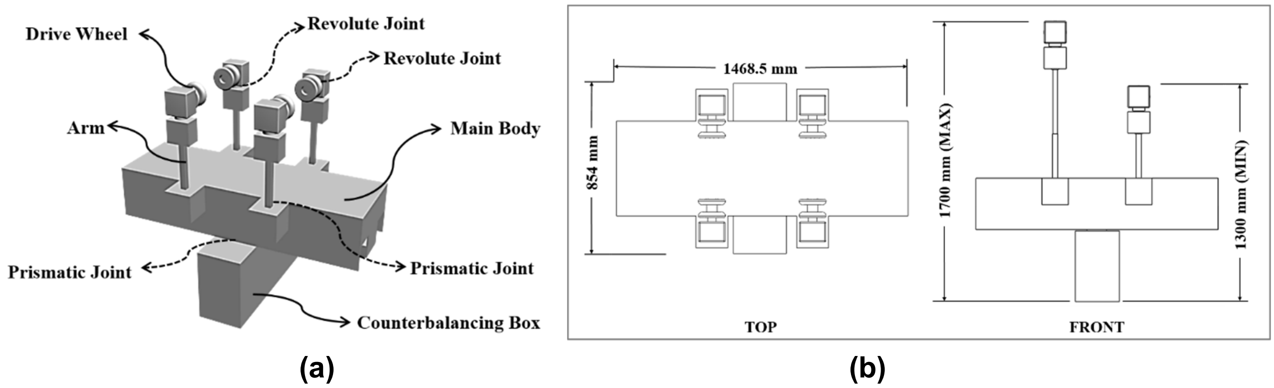


Figure 1. Structure of the proposed robot (a) design (b) dimensions

The proposed robot is composed of left/right symmetry of four arms (two pairs of front arms and two pairs of rear arms), and bidirectional driving is possible. A driving wheel is rotated using a revolute joint, and an arm is moved using a translation joint. The spacing of the two lines is 400 mm on two-conductor bundles, and the four-conductor bundles have a square form whereby the spacing of four lines is 400 mm. This distance depends on the constructed power facilities standard. The proposed robot is designed based on the actual standard of bundled conductors. The size of the robot is determined based on the distance between the left and the right wheel with respect to the surface furrow. The furrow distance between the left and right wheels is 400 mm for actual bundled conductor applications. In addition, the wheels of a robot are driven on the aluminum cable steel reinforced (ACSR) that has a nominal cross-sectional area of 480 square units. The dimensions of the proposed robot are 854×1468×1300 mm (W×L×H). The height of the front or rear arm may be changed to 1700 mm because the robot is driven with four-line gripping on four-conductor bundles. The motion range of the proposed robot is designed through the consideration of obstacle information, such as type, size, and location. The total weight of the designed robot is approximately 22 kg.

2.2 Navigation methods

In this section, the navigation methods of the proposed robot are presented on bundled conductors. The proposed navigation method depends on two factors, namely, bundled conductors and obstacles, constituting the PTL. The gripping location for the bundled conductors is an important factor in determining a stable navigation. Most conventional robots could not be grabbed over two lines because they were designed based on the single conductor navigation scheme. Figure 2 shows the proposed gripping methods for bundled conductors. The proposed robot is navigated through the gripping method using the motion of the front and rear arm, and consists of two pairs.

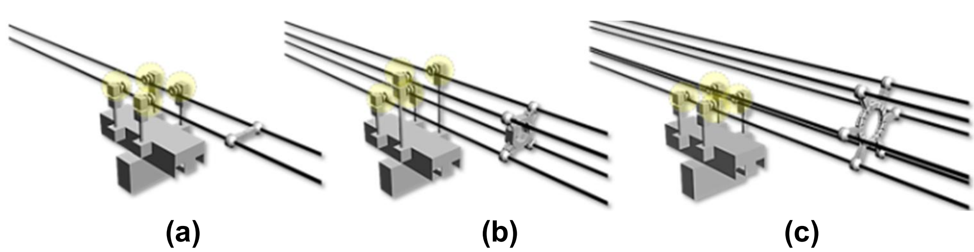


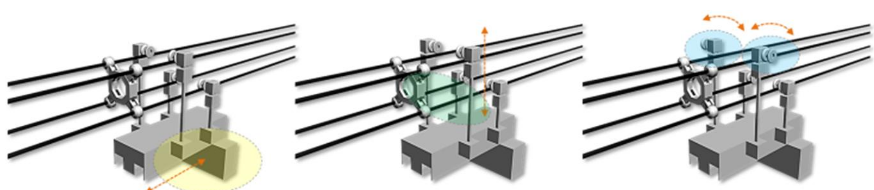
Figure 2. Gripping methods of the proposed robot for bundled conductors (a) two-conductor bundles (b) four-conductor bundles (c) six-conductor bundles

Figure 2(a) shows the gripping method for the two-conductor bundles of two lines with a parallel structure, and the robot is navigated in a state whereby gripping occurs on both of the two lines. Figure 2(b) shows the gripping method for the four-conductor bundles whereby four lines with a parallel structure make up a square array. The front part gripped the upper two lines, and the rear part gripped the lower two lines. Each part can grip the upper two lines, but may also grip the lower two lines. This means that there are no particular restrictions on the direction of motion. Figure 2(c) shows the gripping method for the six-conductor bundles, whereby six lines with a parallel structure makes up a hexagonal array. The robot is navigated in a gripping state on both the lower two lines, such as a navigation method on the two-conductor bundles.

Other factors that determine the navigation method of the proposed robot is the obstacle located within the bundled conductors. That is, the various types of obstacles, such as spacers, clamps, and stockbridge dampers are installed on the PTL. For this obstacle avoidance navigation, we propose three basic motions (motion primitives A, B, C), as described next.

- Motion primitive A: linear motion of counterbalancing box
- Motion primitive B: linear motion of robot arm
- Motion primitive C: rotational motion of wheel part

Figure 3 shows the three motion primitives of the proposed robot for obstacle avoidance. If an obstacle is detected, the counterbalancing box moves horizontally in the front or rear directions in accordance to the center of gravity, as shown by the yellow circles in Figure 3(a). In addition, the robot maintains a parallel state through the continuous movement of the counterbalancing box. By doing this, it prevents in advance the swing state caused by the release of gripping. As shown in Figure 3(b), it enables the maintenance and the release of gripping using the vertical movement of the front and rear arms (green circles). Figure 3(c) shows the obstacle avoidance through the 180° rotation of the wheel part (blue circles). The rotational angle 180° of the wheel part is the angle value needed for minimizing the swing caused by the weight of the wheels.



(a) (b) (c)

Figure 3. Depiction of the three-motion primitives of the proposed robot for obstacle avoidance (a) motion primitive A (b) motion primitive B (c) motion primitive C

The motion primitive B is divided into a vertical motion of the front arm and a vertical motion of the rear arm, and it is defined as front B (FB) and rear B (RB), respectively. Similarly, the motion primitive C is divided into a rotational motion of the front wheel part and a rotational motion of the rear wheel part, and it is defined as front C (FC) and rear C (RC), respectively. In the example listed above, the combination of the three basic motions is applied to both the front and rear parts. M1 is defined by the combination of FB and FC using the motion that is based on the front part. When B' and C' define the reverse motions of B and C, respectively, M2 (reverse motion of M1) can be defined as a combination of FC' and FB'. Correspondingly, M3 is defined as a combined motion of RB and RC based on the motion of the rear part, and refers to the rear part motion. In addition, M4 is defined as a combination of motions using the RC' and RB’, and it refers to the reverse motion of M3. Figure 4 shows the proposed navigation method based on the combination of motions using the three basic motion primitives. The robot is navigated using the motion of the four wheels until the detection of obstacles (4WM). If an obstacle is detected by a front part, the motion of the four wheels is stopped, and then M1 begins. In the next step, the robot is navigated using the motion of two rear wheels until the detection of obstacles by a rear part (RWM). If an obstacle is detected by the rear part, the motion of the two rear wheels is stopped, and then M2 begins. At the end of this process, an obstacle is located between the front and rear parts. When M2 is completed, M3 starts. When M3 is completed, the robot is navigated using the motion of the two front wheels until the obstacle avoidance of the rear part (FWM) is overcome. When the robot avoids an obstacle, M4 starts, and then the robot is navigated using the motion of four wheels. In all navigation processes, the linear motion of the counterbalancing box (A) is employed for the balance of the robot.

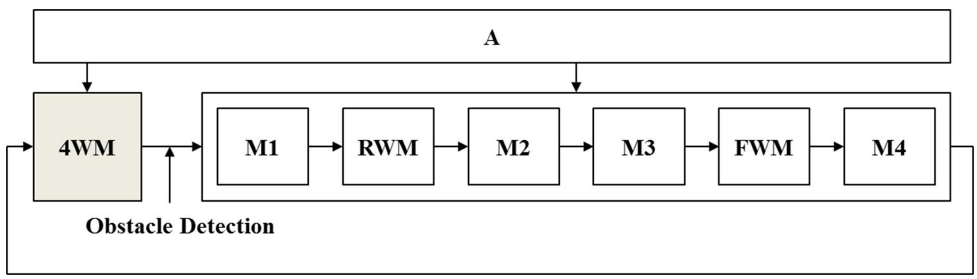
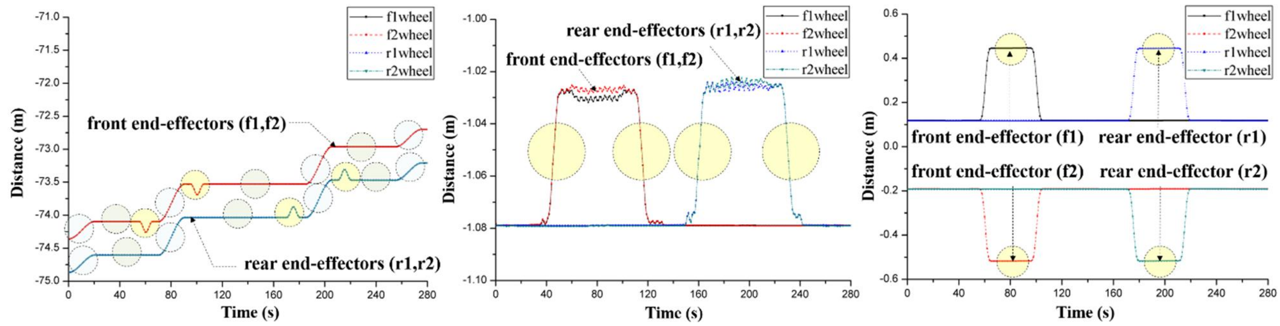


Figure 4. Navigation process using the proposed method

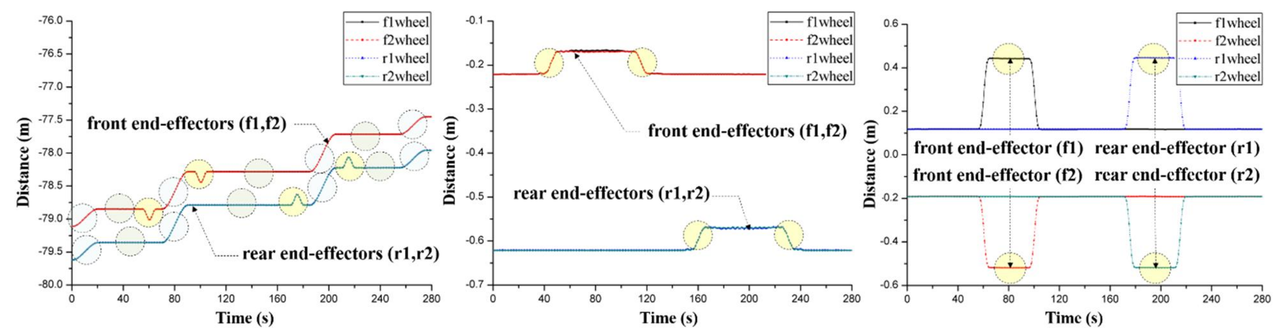
3. Simulation of Robot Navigation on Bundled Conductors

In this chapter, in order to confirm the navigation range for the prevention of obstacle collision, we analyzed the trajectory tracking for end-effectors. Figure 5 shows the results of trajectory tracking of the end-effectors on two-conductor bundles. Figure 6 shows the results of trajectory tracking of the end-effectors on four-conductor bundles. Figure 5(a) and Figure 6(a) represents the results of the trajectory of the end-effectors (along the X-axis). The section of the figure with zero slope (green circles) indicates the motion trajectory part where the robot stopped in order to avoid the obstacle. Correspondingly, the curved section (yellow circles) represents the section of the robot wheel corresponding to a 180° rotation. In addition, the movement of the robot may be determined by the section with a finite slope characteristic (blue circles). The trajectory of the two end-effectors for the front part is the same, and the trajectory of the two end-effectors for the rear part is also the same. Figure 5(b) and Figure 6(b) represents the result of the trajectory (Y axis) of the end-effectors. The robot arm was moved vertically at approximately 50 mm for the release of gripping on the two-conductor bundles, as shown by the yellow circles in Figure 5(b). The vertical distance was approximately 400 mm between the front and rear end-effectors on the four-conductor bundles, and the robot arm was moved vertically at approximately 50 mm for the release of gripping, as shown by the yellow circles in Figure 6(b). Figure 5(c) and Figure 6(c) represents the result of the trajectory of the end-effectors (Z axis), and it confirmed the motion for obstacle avoidance. It was found that the obstacle could be avoided through the release of gripping using the vertical motion of the arm and the 180° rotational motion of the wheel part (yellow circles). The distance difference between the position of the changed end-effector and the position of the previous end-effector was approximately 430 mm.



(a) (b) (c)

Figure 5. Trajectory of the end-effectors on two-conductor bundles (a) X-axis (b) Y-axis (c) Z-axis



(a) (b) (c)

Figure 6. Trajectory of the end-effectors on four-conductor bundles (a) X-axis (b) Y-axis (c) Z-axis

4. Conclusion

We introduced the design of a robot for bundled conductor navigation. The proposed robot was designed to be suitable for the bundled conductors that are often constructed as a consequence of the growing demand for electric power. Most conventional robots could not grab over two lines because they are designed based on the single conductor navigation. The design and analysis were performed for the proposed robot for bundled conductor navigation, and the navigation method was presented for bundled conductors and obstacle avoidance. The proposed navigation methods for bundled conductor gripping and obstacle avoidance were designed using the combination of three motion primitives (linear motion of counterbalancing box, linear motion of robot arm, rotational motion of the wheel part). To examine the performance of the proposed robot, simulations were conducted using ADAMS™, and the elicited results were presented and discussed. The navigation was simulated on obstacle environments that consisted of two- and four-conductor bundles. From the simulation results, the performance of the proposed robot was reviewed through the analysis of trajectory of end-effectors. In particular, we confirmed the motion range of the end-effector for obstacle collision avoidance.

References

[1] N. Pouliot and S. Montambault, "Geometric Design of the LineScout, a Teleoperated Robot for Power Line Inspection and Maintenance," in Proc. IEEE International Conference on Robotics and Automation, pp. 3970-3977, May 2008.
DOI: https://doi.org/10.1109/robot.2008.4543821.

[2] N. Pouliot and S. Montambault, “LineScout Technology: From Inspection to Robotic Maintenance on Live Transmission Power Lines,” in Proc. IEEE International Conference on Robotics and Automation, pp. 1034-1040, May 2009.
DOI: https://doi.org/10.1109/robot.2009.5152291.

[3] Y. Song, H. Wang, Y. Jiang, and L. Ling, “AApe-D: A novel power transmission line maintenance robot for broken strand repair,” in Proc. 2nd International Conference on Applied Robotics for the Power Industry, pp. 108-113, Sept 2012.
DOI: https://doi.org/10.1109/carpi.2012.6473359.

[4] W. Wei, B. Yu-cheng, W. Gongping, L. Shui-xia, and Q. Chen, “The Mechanism of a Snake-Like Robot’s Clamping Obstacle Navigation on High Voltage Transmission Lines,” International Journal of Advanced Robotic Systems, Vol. 10, No. 9, pp. 330, Sept 2013.
DOI: https://doi.org/10.5772/56767.

[5] L. Zheng and R. Yi, “Autonomous Inspection Robot for Power Transmission Lines Maintenance While Operating on the Overhead Ground Wires,” International Journal of Advanced Robotic Systems, Vol. 7, No. 4, pp. 111-116, Jan 2010.
DOI: https://doi.org/10.5772/10497.

[6] P. Debenest and M. Guarnieri, “Expliner - From Prototype Towards Practical Robot for Inspection of High-Voltage Lines,” in Proc. International Conference on Applied Robotics for the Power Industry, pp. 1-6, Oct 2010.
DOI: https://doi.org/10.1109/carpi.2010.5624434.

[7] P. Debenest, M. Guarnieri, K. Takita, E. F. Fukushima, S. Hirose, K. Tamura, A. Kimura, H. Kubokawa, N. Iwama, F. Shiga, Y. Morimura, and Y. Ichioka, “Expliner - Toward a Practical Robot for Inspection of High-Voltage Lines,” in Proc. 7th International Conference on Field and Service Robotics, pp. 45-55, 2010.
DOI: https://doi.org/10.1007/978-3-642-13408-1_5.

[8] A. Phillips, E. Engdahl, D. McGuire, M. Major, and G. Bartlett, “Autonomous overhead transmission line inspection robot (TI) development and demonstration,” in Proc. 2nd International Conference on Applied Robotics for the Power Industry, pp. 94-95, Sept 2012.
DOI: https://doi.org/10.1109/carpi.2012.6473343.