6

A Climbing-Flying Robot for Power Line Inspection

Jaka Katrašnik, Franjo Pernuš and Boštjan Likar
University of Ljubljana
Slovenia

1. Introduction

Our society is becoming increasingly more dependent on reliable electric power supply. Since power outages cause substantial financial losses to the producers, distributors and also to the consumers of electric power, it is in the common interest to minimize failures on power lines. To detect the defects early and to accordingly schedule the maintenance activities, the distribution networks are inspected regularly. Inspection of overhead power lines is usually done manually, either directly on the lines or indirectly from the ground and/or from the helicopters. All these tasks are tedious, expensive, time consuming and dangerous. Consequentially, more and more research has been focused on automating the inspection process by means of mobile robots that would possibly surpass the abovementioned disadvantages. Namely, robot-assisted inspection could be carried out faster, cheaper and more reliable, thus improving the long-term stability and reliability of electric power supply. Most importantly, the safety of the inspection workers could be increased significantly.

In this chapter the requirements for all types of robots for power line inspection and the key research problems and proposed solutions for flying and climbing robots are surveyed. Next, a new so-called climbing-flying robot, which inherits most of the advantages of climbing and flying robots, is proposed. The proposed robot is critically assessed and related to the other inspection robots in terms of design and construction, inspection quality, autonomy and universality. In conclusion, the remaining research challenges in the field of power line inspection that will need to be addressed in the future are outlined.

2. Robot Requirements

2.1 Power Line Features and Faults

Power lines are a dangerous environment. The electric potential differences between the lines are in the order of 100 kV, yielding the electric field in the vicinity of the lines close to 15 kV/cm under normal conditions and even more in the presence of defects. The magnetic field is not small either, due to the currents that are in the order of 1000 A the magnetic field on the surface of the conductor reaches values as high as 10 mT. Power lines are also a complex environment, difficult for robots to navigate. The simplest power lines have one

Based on "New Robot for Power Line Inspection", by Jaka Katrašnik, Franjo Pernuš and Boštjan Likar which appeared in 2008 IEEE Conference on Robotics, Automation and Mechatronics. © 2008 IEEE.

conductor per phase, while others may have more. The conductors are hung on insulator strings, which can either be suspension insulators or strain insulators. Besides insulators, there are other obstacles on the conductors, such as dampers, spacers, aircraft warning lights and clamps (Fig. 1).
The faults on the power lines usually occur on conductors and insulator strings (Aggarwal et al., 2000). Aeolian vibrations gradually cause mechanical damage to conductors. Strands brake, the conductor loses its strength and starts overheating. Other important conductor damaging factors are the corona effect and corrosion. Insulator strings are also prone to mechanical damage due to impact, weather and corrosion (Aggarwal et al., 2000). During inspection, it is also necessary to check for vegetation on and beneath power lines, pylon and other power line equipment condition and safety distance between conductors and other objects.

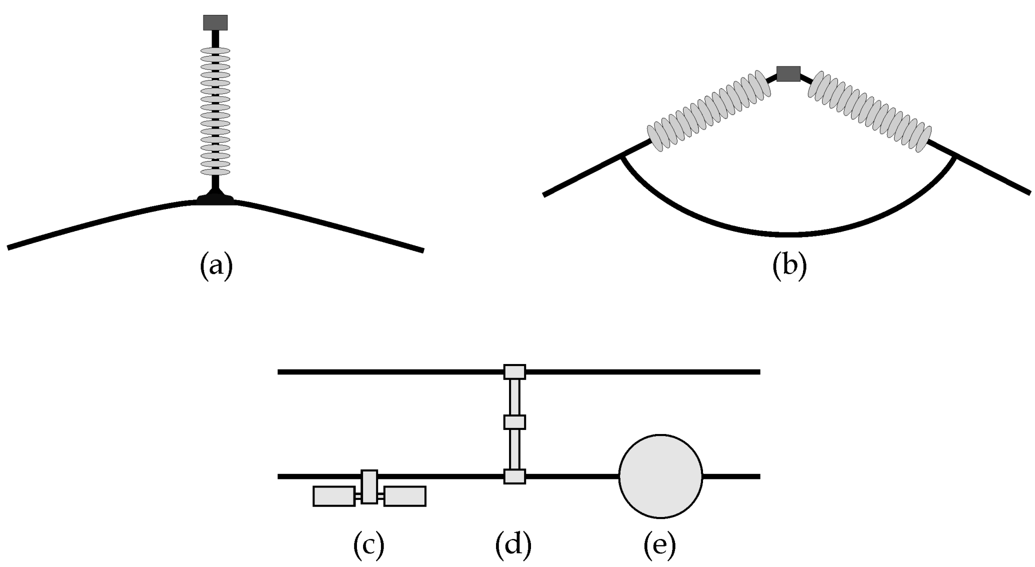


Fig. 1. Obstacles on conductors: (a) suspension insulator, (b) strain insulator, (c) damper, (d) spacer and (e) aircraft warning light.

2.2 Robot Functionality

The design of the robot determines its functionality. In helicopter-assisted inspection the helicopter is flown along the power lines and the camera operator has to track and film the lines with a normal, IR and UV camera. The video footage is then carefully inspected on the ground. This is a very quick method of inspection but tedious for the camera operator and quite inaccurate. That is why the requirements for the automation system are automatic power line tracking, automatic visual inspection and automatic measurement of power line safety distance. Another problem that needs to be solved for these systems to work is also the acquisition of high-quality images, which is very important for visual power line tracking and visual inspection.
Similar problems need to be solved when developing an UAV (Unmanned Aerial Vehicle) for power line inspection. A small helicopter is usually used for the UAV, because it has the ability to hover. The UAV has to be able to autonomously travel along the power lines, find and document faults. It also has to be as energy-independent as possible. The problems

associated with this approach are similar to those of helicopter-assisted inspection, but even more demanding. The key issues are position control, automatic power line tracking, obstacle avoidance, communication, image acquisition, automatic fault detection, measuring power line safety distance and power pick-up from the power line.
Another inspection approach, which has been developed for many years, is the climbing robot. The robot travels suspended from the conductor and has to cross obstacles along the power line, which requires complex robotic mechanisms. The robot functionality should include autonomous traveling along the conductor, automatic visual inspection and at least semi-autonomous obstacle crossing. The main problems associated with this approach are thus robotic mechanism design and construction, the conductor grasping system, the driving system, conductor obstacle detection and recognition, the robot control system, communication, visual inspection, power supply and electromagnetic shielding.

3. Automated Helicopter Inspection

One of the first articles on automating helicopter-assisted inspection (Whitworth et al., 2001) addressed some of the problems, specifically, tracking the power line, especially the poles that need careful inspection, and image acquisition stabilization. A tracking algorithm for power line poles was developed and tested on a scaled laboratory test rig. The initial position of the pole would be obtained with DGPS (Differential Global Positioning System). The pole recognition was done on the basis of two vertical lines and the two horizontal lines of the top cross arm. The reported success rate of the pole recognition algorithm was 65-92% on videos recorded at helicopter inspection, but the image processing rate of 2 to 8 images per second was rather small and the recognition did not work well when background was cluttered. The authors concluded that the concept is feasible, although problems with robustness could arise in real environments with complex backgrounds and varying lighting conditions. Visual tracking of the poles with corner detection and matching was investigated in (Golightly and Jones, 2003). For corner detection the zoom invariant CVK (named by the authors: Cooper, Venkatesh, Kitchen) method described in (Cooper et al., 1993) was proposed. The method was found suitable for corner detection at the tops of the power line poles. Because the method detects multiple matches for one physical corner, detected corners have to be aggregated. Corner matching is then done on two consecutive images, using a basic corner matcher. Relatively good stability of the whole system was reported.
For accurate inspection, the quality of images taken from the helicopter has to be as good as possible. Images taken from an on board camera often get blurred, due to constant vibration and translational movement of the helicopter. In (Jones and Earp, 2001) this problem was thoroughly investigated and minimal optical stabilization requirements defined. Small movements of the helicopter can be compensated by mounting the camera on gyro-stabilized gimbals, which lock the sightline to an inertial reference. Translational helicopter movement can only be compensated with visual tracking of the inspected object. It was found that for sufficient inspection detail, the image blur should not be more than 1% and that the stabilized platform must achieve optical stabilization better than 100-200 μr (micro radians).

4. Inspection with an UAV

Inspection with an UAV is an upgrade of automated helicopter inspection so both concepts have some common problems. An evaluation of using an UAV for power line inspection (Jones and Earp, 1996) indicated that this inspection method could be faster than foot patrol and would yield the same or better accuracy than costly helicopter inspection. It was concluded that the system is feasible from a technical point of view. The concept was further investigated in (Jones, 2005). A small electrically driven rotorcraft, which can pick up energy from power lines, was presented. This vehicle would be equipped with gyro-stabilized cameras, navigation and position regulation, a computer for image and other sensor data processing, a communication link and a system for electric power pick up. Power would be obtained from the power line using a pantograph mechanism. The most research was devoted to the development of a vision system for power line tracking and to image quality assurance. Namely, good power line tracking is important for visual position control and navigation, while image quality is of utmost importance for inspection purposes.

4.1 Position Control

Since power lines have to be inspected from a small distance but must under no circumstances get damaged even in strong wind, position control of the UAV is difficult yet very important. Because conductors have to be in the field of view of the camera almost all the time, determining position of the helicopter visually from the images of the conductors seems very attractive (Campoy et al., 2001, Golightly and Jones, 2005, Jones et al., 2006). Position control is thus closely related to automatic tracking of power lines. The helicopter is a very complex, unstable and nonlinear system with cross couplings. In (Campoy et al., 2001) a Linear Quadratic Gaussian (LQG) controller was chosen for roll and pitch control and a PID controller for yaw control. The controllers were implemented on the basis of measured dynamic characteristics of the helicopter. Because only position of the helicopter could be measured, all other required variables were estimated by the Kalman filter. The robustness was tested when the helicopter was in hover by pulling it with a cable. The regulation worked well in the presence of such external disturbances.

A rotorcraft model and a position control system for a power line inspection robot were also presented in (Jones et al., 2006). A mathematical model of a ducted-fan rotorcraft with the center of gravity above the aircraft center was derived and used for the development of control system. The control was achieved by moving a mass, positioned above the center of gravity, left or right. When the mass is moved, the craft tilts in the same direction and accelerates in that direction. The control system is closely linked with visual tracking of power lines and controls the height and lateral position of the craft to the lines. Lateral position and height are both measured with image analysis.

4.2 Automatic Power Line Tracking

Visual tracking of power lines with an UAV is similar to visual tracking with a helicopter. The only major difference is that the UAV can get closer to the lines. The tracking methods are therefore a little different. Jones and Golightly developed a simple tracking algorithm that could track the power line with three lines based on the Hough Transform (Jones et al., 2006). The main purpose of this tracking algorithm was to provide height and lateral displacement of the vehicle to the control system. The method was tested on a scaled model and was proven to be successful even when the background was cluttered. Another method for visual power line tracking (Campoy et al., 2001) utilized a vector-gradient Hough transform for line detection. Only one line was tracked and simultaneously inspected. The position of the helicopter with regard to the line was determined with stereo vision.

4.3 Obstacle Avoidance

Another problem related to robot mobility is obstacle avoidance and path planning. The space around power lines is usually obstacle free; nevertheless, the robot must be able to avoid obstacles on its way, when it is not controlled by a human operator. A computer vision solution to this problem was proposed (Williams et al., 2001). Positions of the obstacles were determined by optical flow. The obtained positions were used in the path planning algorithm based on the distance transform. The algorithms were tested in a laboratory environment using a test rig with a scaled version of a power line. It was established that the principles used were correct but the method was sensitive to the variations in background, lighting and perspective. An important problem was also the computing power because image analysis demands were high and rapid obstacle detection was required.

4.4 Power Supply

An important characteristic of an inspection vehicle is the duration of its power supply. The longer the craft can stay operational the more lines can be inspected. Current battery technology does not permit long durations of flight for small electrically driven helicopters. Power lines are an abundant source of energy but obtaining that power is far from trivial. A concept of a power line power pick-up device was presented in (Jones, 2007). The power would be acquired by touching two lines of different phases with a special pantograph mechanism (Fig. 2). For this concept to work, line tracking and position control algorithms have to be highly reliable.

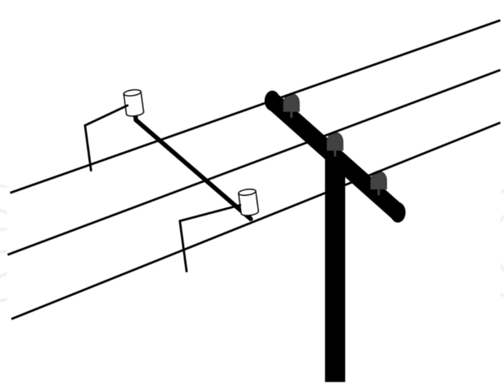


Fig. 2. The proposed pantograph power pick-up mechanism

4.5 Other Problems

A difficult problem that has not been researched thoroughly is automatic power line fault detection. It would be most convenient if the robot would be able to automatically detect faults on-site, so it could re-inspect them more thoroughly. On the other hand, automatic fault detection could be done in the ground station after the inspection, which would be

easier to implement but would not provide detailed information about the defects. A big difficulty with fault detection is the quality of images taken from the UAV. Because of the distance from the line and constant movement of the craft, the quality of images is usually poor, which makes automatic fault detection especially demanding.
A big problem with the UAV concept of inspection is that almost every system on the robot (position control, obstacle avoidance, fault detection and power pick up) depends on visual tracking of power lines, which is not very reliable. Although visual power line tracking was successful in the laboratory, the real environment is much more demanding. Contrast between the lines and the background is usually very low. Lighting varies a great deal and depends on unpredictable weather conditions. The UAV is in constant motion and vibrates, so the images acquired by the robot would be of a poor quality and the faults very difficult to detect even for a human. Unintentional detection of other straight lines on the image, such as other power lines or railroad tracks, would also pose a serious problem.

5. Climbing Robots

An alternative approach to power line inspection is by means of a climbing robot, which can climb on the conductor and has to somehow overcome all various obstacles on the power lines. The main advantage of this concept is the inspection accuracy. Namely, close proximity to the line and low vibrations increase the quality of image acquisition. On the other hand, development of a robot mechanism for overcoming obstacles on the line is extremely difficult. The main research problem with climbing robots is therefore the development of a robot mechanism and a control system for obstacle crossing. The proximity of the conductor also brings problems related to electromagnetic shielding. Sensitive electronics and sensors have to be protected from the electric and magnetic fields of the conductor.

5.1 Robot Mechanisms and Obstacle Traversing

One of the first operational robot mechanisms for power line inspection was the robot presented in (Sawada et al., 1991). The robot consisted of a drive, an arc shaped rail, a guide rail manipulator and a balancer with controller. It could travel on slopes of up to 30º. When the robot would come across an obstacle it would unpack its rail and mount it on the conductor on both sides of the obstacle. Then the drive mechanism would release the conductor and travel on the rail to the other side. The robot was able to negotiate towers and other equipment on overhead ground wires. Not having proper shielding and mechanisms for overcoming obstacles, the proposed robot could not travel on phase conductors.
A more complex robot mechanism, presented in (Tang et al., 2004), had two arms (front arm and rear arm) and a body. Each arm had 4 degrees of freedom and a gripper with a running wheel. The body also had a running wheel with a gripper. When overcoming obstacles, the robot would release the conductor with the front arm, elongate it over the obstacle and grasp the conductor on the other side. Then the body would release and the two arms would move it across the obstacle, where it would grip the conductor again. Finally, the rear arm would move across the obstacle. This robot could overcome all standard obstacles on phase conductors of overhead power lines. However, it could not travel on bundled conductors.

The robot configuration in (Xinglong et al., 2006) had two arms and a special gripper combined with a driving wheel. The specialty of this mechanism is that the gripper could always grasp the conductor, when it was in contact with the running wheel. The gripper presses on the conductor from the left and right side of the wheel. The main disadvantage was that the gripper could not handle large torque, which can easily occur when crossing obstacles. For that reason, a special very effective obstacle crossing strategy that also simplifies the design of the robot was presented (Fig. 3). When the robot would detect an obstacle ahead, it would stop, grasp the conductor with the front arm and move its body under the front arm in order to minimize the torque when crossing the obstacle (Fig. 3(a)). Next, the rear arm would lift the running wheel up and the front arm would rotate the robot around its own axis. Finally, the rear arm would lower the wheel on the conductor (Fig. 3(b)). The same process would then be repeated with the arms' roles changed. Because of this obstacle traversing strategy, the robot arms need only two degrees of freedom, the torques in the joints and on the conductor are small and, consequently, the motors do not need to be as powerful and heavy.

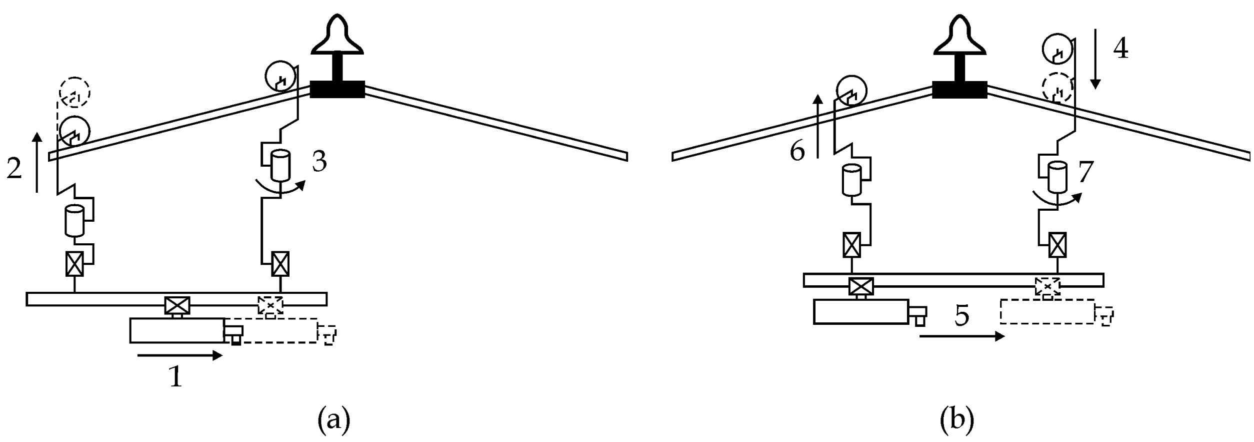


Fig. 3. Obstacle traversing strategy proposed in (Xinglong et al., 2006).

5.2 Robot Control System

The main purpose of the robot control system is to navigate the robot over obstacles on the line. One of the first robot control algorithms for power line inspection was described in (Sawada et al., 1991). A more complex control system, using a distributed expert system that was divided between the robot and the ground station, was described in (Tang et al., 2004). The robot control system would run on an embedded PC/104 based computer, connected to the ground station with a wireless data link and a separate image transmission channel. The robot expert system consisted of an inference engine, knowledge base, static database, external information input module and decision-making module. The inference engine would decide what commands to execute on the basis of sensor information and information in the static database. Sensors would provide information about current position of the robot and the obstacles around it, while the static database would contain data about towers and other obstacles on the line. The robot expert system would plan the path of the robot arms so that the robot would overcome the obstacle successfully. The ground station would be used for monitoring and guiding the robot as well as for detecting faults on the power line from the images sent by the robot. Similar distributed expert system designs were presented in (Ludan et al., 2006).

5.3 Obstacle Detection and Recognition

Obstacle detection is usually done with a proximity sensor, which is simple yet effective but the detection of the obstacle is usually not enough to overcome it. In most cases the type of the obstacle has to be known. In (Zhang et al., 2006) a computer vision method for obstacle recognition and distance measurement was presented. The method determines the obstacle types from the shapes on the image. An ellipse represents a suspension insulator string and two circles left and right of the conductor a strain insulator string. After the obstacle is recognized, its position is also located with a stereo vision. The method was tested on a real power line for which the accuracy of 7 % or better was reported. Another important problem associated with visual obstacle detection and recognition is the elimination of motion blur from the captured images (Fu et al., 2006). Although climbing robot is fixed on the conductor, it also swings under the influence of wind and when traveling along the line.

5.4 Power Supply

Power lines could provide the inspection robot with energy for its operation. Energy from the line could be extracted from the magnetic field of the line. This concept was presented in (Peungsungwal et al., 2001). A magnetic iron core was placed around the conductor. Current induced in the secondary coil around the core was measured at different numbers of windings of the secondary. It was shown that the current reaches its maximum value at a certain number of secondary windings and that the power transferred to the secondary coil increases with the current of the power line.

6. Climbing-Flying Robot

The abovementioned advantageous features of both robot types can be combined. For that reason, we propose a new robot type, i.e. the so-called climbing-flying robot (Fig. 4). The proposed robot would combine a helicopter for flying over the obstacles and a special drive mechanism for traveling on the conductor. During inspection, the robot would travel on the conductor up to an obstacle. Then it would fly off the conductor over the obstacle, land on the other side and continue traveling along the conductor. Traveling on the conductor would be automated, while flying over the obstacles would likely have to be done manually. Some of the problems that would need to be solved are similar to those described in the two previous sections. For instance, power pick-up system, obstacle detection and recognition, and drive mechanism for traveling on the conductor. Besides the advantages that arise from the proposed combination of the two robot types, there are also some specific new problems, which we address in the following.

6.1 Robot design

Design of the climbing-flying robot is much more difficult than design of the flying robot, although not as difficult as design of the climbing robot. When designing the proposed robot one must take into consideration the weight limitations of the helicopter, which are much stricter than for the flying robot. The reason for this is the addition of the drive

mechanism and the electromagnetic shielding, which significantly increase the weight of the robot.
Another major problem is also the weight distribution in the robot. In order to achieve a good degree of stability on the power line, the center of gravity of the robot must be below the conductor. This conflicts with the design of the helicopter, where the majority of the weight is placed directly below the rotor to achieve good maneuverability. The parts of the robot must therefore be carefully positioned to achieve the optimal position of the center of gravity. A coarse distribution of robot parts inside the robot is proposed in Fig. 4.

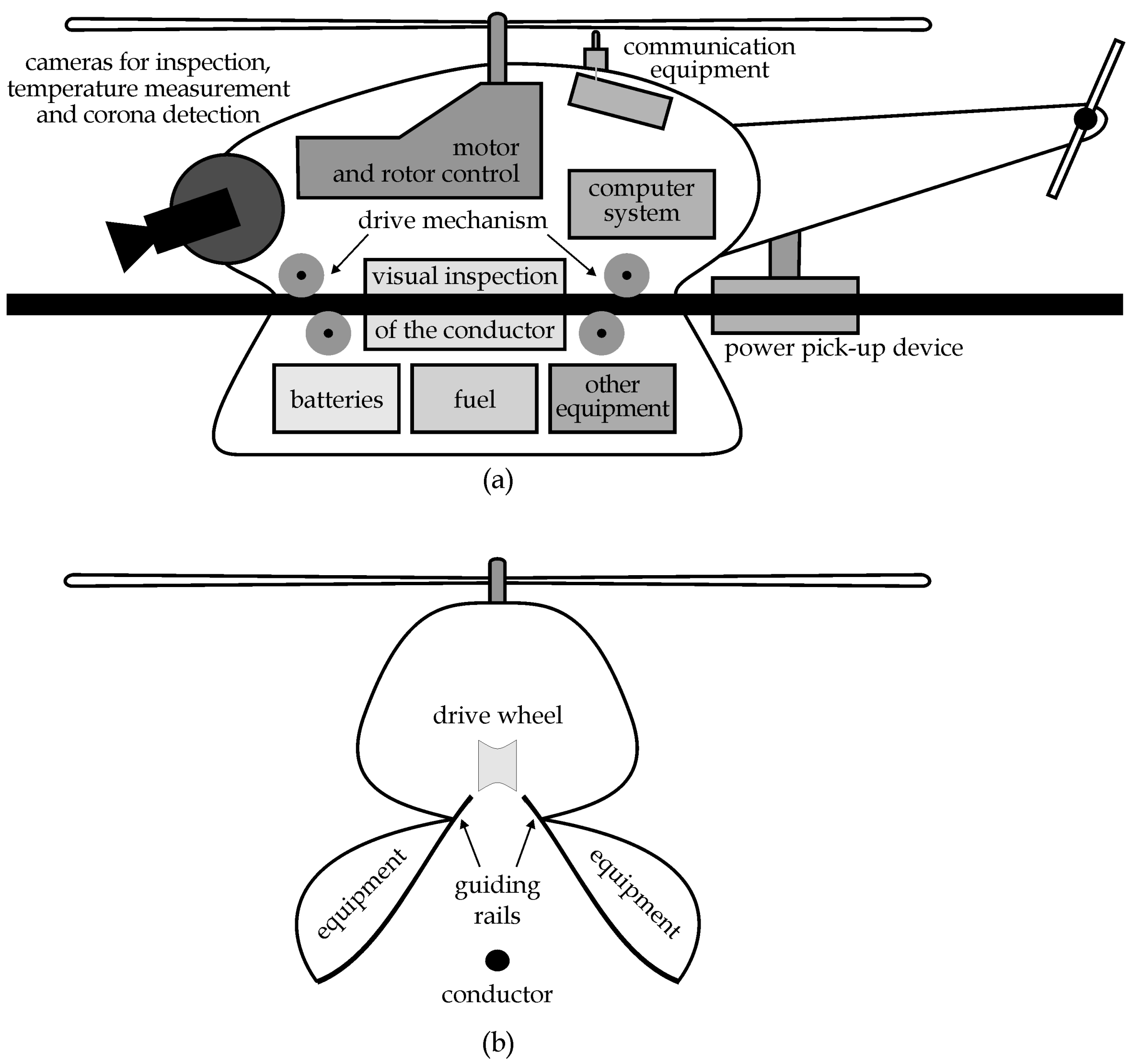


Fig. 4. The proposed robot: (a) An illustration of the proposed climbing-flying robot and its components; (b) a sketch of the robot from the front, showing the rails for easier landing on conductors and equipment placement for stability.

Setting the weight limitation and distribution problems aside, the most important problems of the climbing-flying robot are the design of individual systems, which are the helicopter, drive mechanism, visual inspection system, power pick-up device and communication system. The design of these systems is discussed in the following subsections.

6.2 Helicopter

When choosing the rotor configuration of the helicopter for the climbing-flying robot we have three choices. The most common is the Sikorsky configuration. Ninety percent of all the helicopters in the world are made in this configuration. It is simple to produce, has good maneuverability and sufficient lift. The tandem rotors configuration has worse maneuverability, but produces more lift as there is no power needed for balancing the main rotor torque. This configuration is also more difficult to make and maintain, as it has more moving parts and a more complex design. The coaxial rotors configuration is also more expensive to build and maintain. However it requires less space, while producing the same amount of lift as the other two configurations. This results in a smaller and more maneuverable helicopter for the same payload limitations. In comparison to the Sikorsky configuration the coaxial configuration has better maneuverability but is more expensive and has more frequent maintenance. For the climbing-flying robot the coaxial configuration is therefore the best choice.

6.3 Drive mechanism

The drive mechanism would consist of the front and the rear drive mechanism. Each of the two drive mechanisms would consist of two wheels (Fig. 5). The upper wheel would be the drive wheel while the lower wheel would provide stability for the robot on the power line. The drive wheel would be connected to an electrical motor with a drive chain, whereas the lower support wheel would run freely. The wheels would be made of aluminum and the conductor contact surfaces of the wheels would be covered with conductive rubber to increase traction, damp vibrations and to keep the robot on the same electric potential as the conductor.

Grasping the conductor would be done with the support wheel. At landing the robot would sit down onto the drive wheels with the help of special rails (Fig. 4(b) and Fig. 5). After the robot would be positioned on the drive wheels the support wheels would be moved into position with servomotors. The contact force with the conductor would be applied with springs. Before takeoff, the support wheels would be retracted and the robot would be free to lift off the conductor.

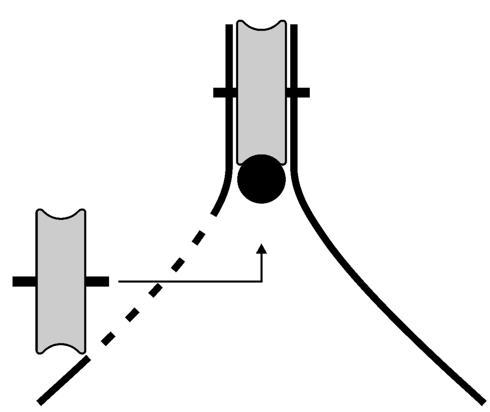


Fig. 5. A part of the proposed drive mechanism. After the robot lands on the conductor the lower wheels grasp the conductor from the sides.

6.4 Visual inspection system

Visual inspection of the conductor would consist of two systems. Visual inspection system at the front of the robot would perform visual inspection of the power line and obstacle detection with a wide angle camera. Visual inspection of the power line would consist of detection of conductor, insulator, supporting tower and other equipment defects. As visual detection of defects on all these different systems would not be very reliable, the conductor would be more accurately inspected with the second visual inspection system, while defects on other equipment would be detected with infrared and ultraviolet cameras, also a part of the front visual inspection system. Infrared cameras would be used to easily detect overheating of any part of the power line equipment. Ultraviolet cameras, on the other hand, would make detection of corona, which is usually a sign of a defect, fairly straightforward.

The second visual inspection system inside the robot would perform a more accurate visual inspection of the conductor. This visual inspection system would consist of three line scan cameras placed around the conductor 120 degrees apart (
Fig. 6(b)). The conductor would be illuminated with two LED based lights for each camera (
Fig. 6(a)). The lights would be placed on both sides of the cameras. This lighting configuration would provide diffuse illumination of the conductor, which would enable efficient visual defect detection. For triggering the line scan cameras an incremental encoder on one of the wheels of the drive mechanism would be used.

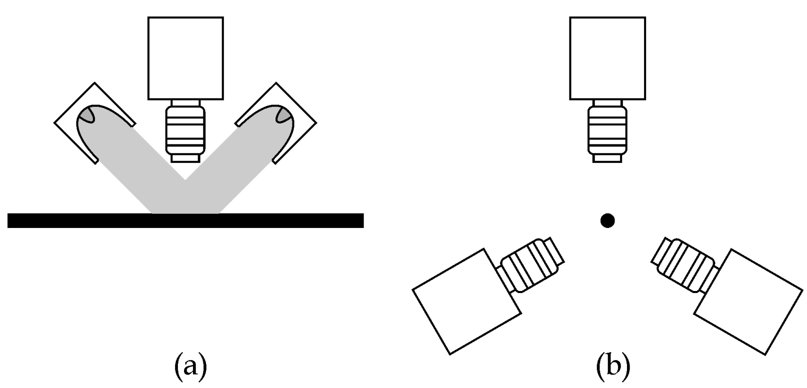


Fig. 6. Conductor visual inspection system. (a) Illumination, camera and conductor configuration for one camera. (b) Camera configuration around the conductor.

6.5 Power pick-up device

The power pick-up device consists of two parts, the toroidal core and the clasping mechanism. The toroidal core (Fig. 7) is made from a ferromagnetic iron core and is split into two halves. On each half is a winding that transforms the energy of the magnetic field in the iron core to electrical energy, which is then further treated with a special converter circuit to obtain a useable voltage to power the systems onboard the robot. The converter must be capable of handling a large range of input voltages as the voltage in the winding changes linearly with the power line current. The clasping mechanism takes care of the closing and opening of the toroidal core after landing and before takeoff (Fig. 8). It is extremely important that the clasping mechanism closes the two halves of the toroidal core as closely together as possible, as even a small slit between the two halves significantly affects the efficiency of the power pick-up device. Its precision is therefore of great importance.

A very important parameter of the power pick-up device is its power to weight ratio. It is crucial that a power pick-up device is as light as possible, as weight is limited on the robot. The power produced by the power pick-up device depends on the power line current and also on the geometry of the toroidal core. An analysis of the power to weight ratio in dependence of the geometry of the power pick-up device has to be performed to determine the feasibility of this device. A preliminary analysis was done in (Katrašnik, 2007). The analysis showed that such a power pick-up device is feasible, as the power to weight ratio of more than 250 W/kg can be achieved for a relatively small 400 A power line current.

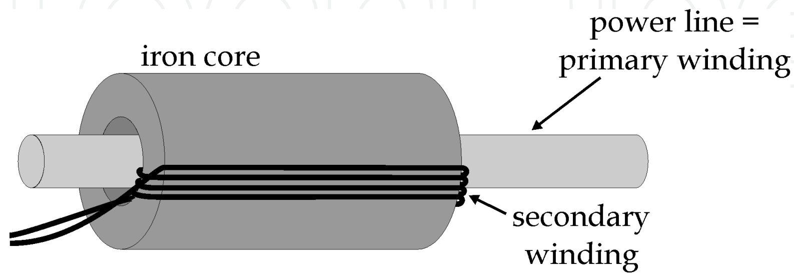


Fig. 7. The power pick-up device.

6.6 Communication

In order to guide the robot over the obstacles effectively the operator needs real-time visual feedback about the robot's surroundings, while the guiding data have to be sent with minimal latency. For this reasons, a reliable high bandwidth wireless data link with very low latency is required. Another requirement, which somehow conflicts with the high bandwidth requirement, is long communication distance that should reach at least 5 kilometers for an efficient operation.

Fig. 8. The power pick-up device with the clasping mechanism. (a) Opened power pick-up device. (b) Closed power pick-up device.

7. Comparison of robot types

Because it is not practically feasible to objectively assess all three robot types, we decided to conduct a subjective scoring of the three inspection concepts according to some important characteristics. Specifically, we selected and weighted four evaluation categories (table I): design and construction requirements (weight 4), inspection quality (weight 3), autonomy at inspection, obstacle avoidance and energy requirements (weight 2), and universality or generality of the inspection principle (weight 1). The three inspection concepts were then ranked in each of the categories, as explained in the following paragraphs, and accordingly assigned the weighted scores (rank × weight).

The climbing robot is definitely the most difficult to design and construct, while the flying robot is the less so. Namely, there are a large number of commercial UAVs available on the market that can well serve the purpose if equipped by the appropriate sensory and computing equipment. The most challenging task for the flying robot is software development. Similar observations can be made for the climbing-flying robot but due to additional components and shielding requirements, this robot would be more difficult to design and construct. The climbing robot ranks last in this the most important category due to a number of reasons. First, complex grippers, drive mechanism and controller are required for effectively crawling on the line. Another problem is the expert system for obstacle detection, recognition and overcoming. Next, the whole body of the robot requires appropriate shielding from the powerful electromagnetic fields.

In terms of inspection quality, the flying robot is the most problematic due lower image quality (vibrations), lower resolution (grater inspection distance) and limited field of view, especially when inspecting the conductors. The latter can be much better inspected by the climbing and flying-climbing robots if using line scan cameras for high-resolution inspection from all sides. Other power line equipment can be efficiently inspected from the conductor by both robots just before crossing the obstacles. However, climbing-flying robot can further inspect the equipment from additional angles when flying over the obstacles and this is why it ranks best in the inspection category.

Autonomy at inspection, obstacle crossing and the terms of energy independence fit into another important category. Developing a flying robot for autonomous inspection, flying and avoiding obstacles is certainly more difficult than making the climbing robot autonomous at inspection and when climbing over the obstacles. In this respect, the climbing-flying robot ranks in between. In terms of energy independence, the climbing and climbing-flying robots can use induction system for power pick-up from the conductor, while the pantograph mechanism proposed for the flying robot is more dangerous, less reliable and more complex.

The last evaluation category deals with the universality of the inspection concept or its flexibility when inspecting different power lines systems. It is very difficult if not impossible to design a robot that would work on all power lines without any modifications. The flying robot is certainly the most flexible in this respect, followed by the climbing-flying robot, which would need adaptations for traveling along different conductors. The less general is certainly the climbing robot as major modifications would be required for adaptation to different conductors and especially to other types of obstacles.

	w	**Climbing**	**Climbing-flying**	**Flying**
Design and construction	4	1 | 4	2 | 8	**3** | 12
Inspection quality	3	2 | 6	**3** | 9	1 | 3
Autonomy	2	**3** | 6	2 | 4	1 | 2
Universality	1	1 | 1	2 | 2	**3** | 3
Total score		17	**23**	20

w = weight, rank | weighted score

Table 1. Robot type comparison

8. Conclusion

The most important decisive factor for choosing the robot type is certainly performance to price ratio. A big portion of the final price is usually the cost of development. The robot performance is a combination of inspection quality, autonomy and universality. We can conclude that the flying robot would likely have the smallest performance to price ratio (table I). Namely, this robot, although universal and easy to design, would offer the lowest inspection quality and low inspection autonomy. The development costs would certainly be very high for the climbing robot but the robot would be much more autonomous and could offer better inspection quality. The latter also holds true for the climbing-flying robot, which would probably not be as autonomous as the climbing robot when crossing obstacles but the cost of development should be much lower.

In conclusion, the power pick-up system and automatic visual inspection are problems that still need to be solved efficiently for the flying robot, while automatic power line tracking and obstacle avoidance need further improvements to become practically feasible. The climbing robot also needs further developments of the power pick-up system, automatic visual inspection, electromagnetic shielding, robot mechanism and the control system. The proposed climbing-flying concept for power line inspection has not been researched yet, offering a number of specific challenges, such as high communication link bandwidth and reliable system for landing on the conductor. Nevertheless, the proposed concept seems feasible from the practical point of view and because good performance to price ration could be obtained.

9. References

Aggarwal, R. K., Johns, A. T., Jayasinghe, J. A. S. B. & Su, W. (2000) An overview of the condition monitoring of overhead lines. *Electric Power Systems Research,* 53**,** 15.

Campoy, P., Garcia, P. J., Barrientos, A., Cerro, J. D., Aguirre, I., Roa, A., Garcia, R. & Muñoz, J. M. (2001) An Stereoscopic Vision System Guiding an Autonomous Helicopter for Overhead Power Cable Inspection. *Proc., Robot Vision: International Workshop RobVis 2001, Auckland, New Zealand.*

Cooper, J., Venkatesh, S. & Kitchen, L. (1993) Early jump-out corner detectors. *IEEE Transactions on Pattern Analysis and Machine Intelligence,* 15**,** 823.

Fu, S., Zhang, Y., Zhao, X., Liang, Z., Hou, Z., Zou, A., Tan, M., Ye, W. & Bo, L. (2006) Motion Deblurring for a Power Transmission Line Inspection Robot. *Computational Intelligence.* Berlin, Springer Berlin / Heidelberg.

Golightly, I. & Jones, D. (2003) Corner detection and matching for visual tracking during power line inspection. *Image and Vision Computing,* 21**,** 827.

Golightly, I. & Jones, D. (2005) Visual control of an unmanned aerial vehicle for power line inspection. *Proc. 12th International Conference on Advanced Robotics (ICAR '05).*

Jones, D. (2005) Power line inspection - a UAV concept. *The IEE Forum on Autonomous Systems 2005 (Ref. No. 2005/11271).*

Jones, D., Golightly, I., Roberts, J. & Usher, K. (2006) Modeling and Control of a Robotic Power Line Inspection Vehicle. *Proc. of IEEE International Conference on Control Applications (CCA '06).*

Jones, D. I. (2007) An experimental power pick-up mechanism for an electrically driven UAV. *Proc. of IEEE International Symposium on Industrial Electronics - ISIE 2007.*

Jones, D. I. & Earp, G. K. (1996) Requirements for aerial inspection of overhead electrical power lines. *Proc. 12th International Conference on Remotely Piloted Vehicles.* Bristol.

Jones, D. I. & Earp, G. K. (2001) Camera sightline pointing requirements for aerial inspection of overhead power lines. *Electric Power Systems Research,* 57**,** 73.

Katrašnik, J. (2007) Robotic Power Line Inspection. *Faculty of Electrical Engineering.* Ljubljana, University of Ljubljana.

Ludan, W., Hongguang, W., Lijin, F. & Mingyang, Z. (2006) Research on Obstacle-navigation Control of a Mobile Robot for Inspection of the Power Transmission Lines Based on Expert System. *Proceedings of the 8th International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines (CLAWAR 2005)* Springer Berlin Heidelberg.

Peungsungwal, S., Pungsiri, B., Chamnongthai, K. & Okuda, M. (2001) Autonomous robot for a power transmission line inspection. *Proc. of the 2001 IEEE International Symposium on Circuits and Systems (ISCAS 2001).*

Sawada, J., Kusumoto, K., Maikawa, Y., Munakata, T. & Ishikawa, Y. (1991) A mobile robot for inspection of power transmission lines. *IEEE Transactions on Power Delivery***,** 309.

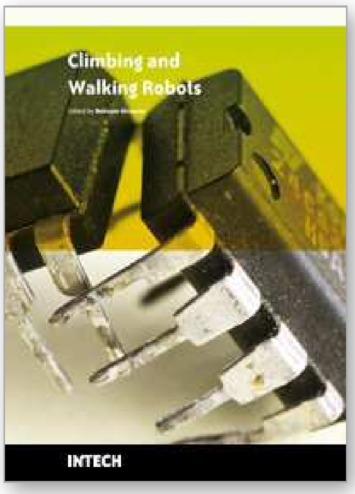
Tang, L., Wang, H. & Fang, L. (2004) Development of an inspection robot control system for 500KV extra-high voltage power transmission lines. *Proc. of SICE 2004 Annual Conference.*

Whitworth, C. C., Duller, A. W. G., Jones, D. I. & Earp, G. K. (2001) Aerial video inspection of overhead power lines. *Power Engineering Journal [see also Power Engineer],* 15**,** 25.

Williams, M., Jones, D. I. & Earp, G. K. (2001) Obstacle avoidance during aerial inspection of power lines. *Aircraft Engineering and Aerospace Technology,* 73**,** 472-479.

Xinglong, Z., Hongguang, W., Lijin, F., Mingyang, Z. & Jiping, Z. (2006) A Novel Running and Gripping Mechanism Design Based on Centroid Adjustment. *Proc. of the 2006 IEEE International Conference on Mechatronics and Automation.*

Zhang, Y., Fu, S., Zhao, X., Liang, Z., Tan, M. & Zhang, Y. (2006) Visual Navigation for a Power Transmission Line Inspection Robot. *Computational Intelligence.* Berlin, Springer Berlin / Heidelberg.



Climbing and Walking Robots
Edited by Behnam Miripour

ISBN 978-953-307-030-8
Hard cover, 508 pages
Publisher InTech
Published online 01, March, 2010
Published in print edition March, 2010

Nowadays robotics is one of the most dynamic fields of scientific researches. The shift of robotics researches from manufacturing to services applications is clear. During the last decades interest in studying climbing and walking robots has been increased. This increasing interest has been in many areas that most important ones of them are: mechanics, electronics, medical engineering, cybernetics, controls, and computers. Today's climbing and walking robots are a combination of manipulative, perceptive, communicative, and cognitive abilities and they are capable of performing many tasks in industrial and non- industrial environments. Surveillance, planetary exploration, emergence rescue operations, reconnaissance, petrochemical applications, construction, entertainment, personal services, intervention in severe environments, transportation, medical and etc are some applications from a very diverse application fields of climbing and walking robots. By great progress in this area of robotics it is anticipated that next generation climbing and walking robots will enhance lives and will change the way the human works, thinks and makes decisions. This book presents the state of the art achievments, recent developments, applications and future challenges of climbing and walking robots. These are presented in 24 chapters by authors throughtot the world The book serves as a reference especially for the researchers who are interested in mobile robots. It also is useful for industrial engineers and graduate students in advanced study.