

INSPECTION OF HIGH VOLTAGE POWER LINES – A NEW APPROACH

M. BÜHRINGER, J. BERCHTOLD, M. BÜCHEL, C. DOLD,
M. BÜTIKOFER, M. FEUERSTEIN
ETH Zürich, 8092 Zürich, Switzerland

W. FISCHER, C. BERMES, R. SIEGWART
*Autonomous System Lab, ETH Zürich,
Tannenstrasse 3, 8092 Zürich, Switzerland*

This paper presents the “Cable Crawler”, a mobile teleoperated robot to inspect high voltage power lines. Its mechanism allows riding on the topmost ground cable of high voltage power lines and crossing a set of mast tips as well as smaller obstacles autonomously and thus is not limited to just move from mast to mast. The robot consists of an aluminium chassis, six propulsion units and two spaces for cameras and other electronic components. Six electrical motors drive independently six rubber-coated rollers, two in a horizontal position to take the weight and four vertical ones. The four vertical rollers are pressed onto the wire by springs, which guarantees slipless propulsion in difficult situations. A Matlab program controls the drives independently. An optical camera is mounted on the prototype, which can rotate 360° and the image can be transmitted wireless to the user’s computer monitor. With a mass of 58 kg and only six drives it consequently follows the industry’s wish to have a robust, easy to maintain and rather cheap solution. Regarding the fields examined by the robot, the project concentrated on the detection of trees growing into proximity of the wires.

Keywords: Field Robot, Mechanism Design, Service Robots, Wheeled Robots

1. Introduction

High voltage lines need to be inspected regularly, at least once a year. At present, this work is done by teams on foot, as well as by helicopter missions. Inspections on foot need a lot of time and in some situations are even impossible due to difficult terrain such as mountains or steep valleys. The helicopter missions are somewhat quicker but very costly, tedious and difficult, especially for the pilot, since he needs to fly at minimum distance to the power lines. The possibility of strong side winds additionally turns this task into a dangerous situation [4].



Figure 1. Common mast tip with ground cable departing on both sides.

The main goal of this project is to develop a device that moves along the wires and traverses the standard mast tip of the Swiss power industry. Figure 1 shows such a mast tip that is widely used in Switzerland and most other European countries. On each side one can see the ground cable leaving the tip towards the next mast. These cables do not transmit power and are installed on top of the other cables to protect from damages caused by lightning. The main difficulty to deal with was to find a mechanism that can move on the sloping wire (also around horizontal angles) and ride over all the different obstacles on top. So far, different research groups have developed several robots that can cross obstacles on the wires [1-3]. Most of these robots use active structures that result in designs with a relatively high number of actuators and sensors – leading to a complex control and resulting in relatively big and expensive devices of slow speed.

In order to realize a robot that is simpler, faster and more robust, the main goal within this work is to realize a vehicle structure with a passive articulation that can just roll over the specified obstacles.

The paper is structured as follows: Section 2 explains the basic mechanical concept. This section is followed by a description of the main challenges within the detailed design and how we solved them – spring system, power transmission, lightweight chassis design and control electronics. In Section 4 we show some test results and provide an outlook on future development and industrial use.

2. Basic mechanical concept

The basic mechanical concept of the robot can be seen in Figure 2. The propulsion is generated both with two horizontal cylinders (2.1) that have their normal force generated by gravity, and by two pairs of vertical cylinders (2.2) that are pressed against each other by a spring system (1). To increase the stability, the payload is mounted at a very low position (4).

When riding on the cable, the arms for the vertical cylinders (3.2) remain at a constant angle towards the central part of the chassis (3.1). As soon as an obstacle is reached, the front arms open and the front vertical propulsion units embrace the obstacle. While opening, the forces generated by the springs (1) will increase and try to manoeuvre the system back into a centre position on the obstacle. The front vertical cylinders may lose direct contact with the obstacle or the ground cable. Since the two side cylinders are in a tapered shape, the cylinder pair always falls back into a centre position. When the rear pair of vertical cylinders reaches the obstacle, the front pair has already passed. The obstacle passing sequence is then similar to the one described for the front pair. More details of the obstacle-passing-sequence can be seen in Figure 5.

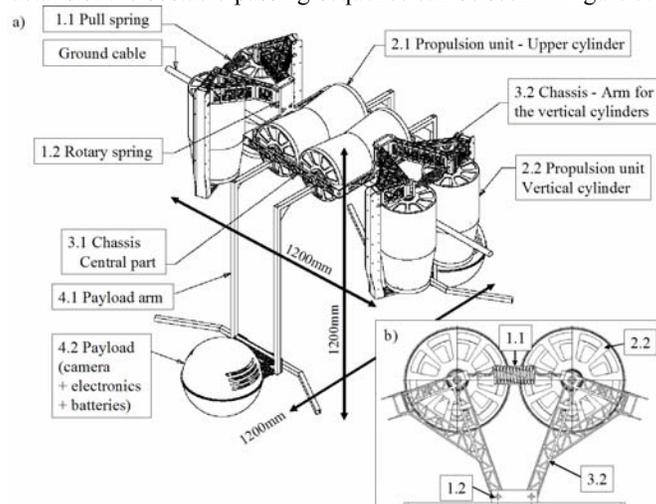


Figure 2. (a) Overall mechanical design with the main assemblies
(b) Top view of the spring system and the vertical propulsion unit.

3. Detailed design

Within the detailed design, the following challenges had to be solved: Dimensioning the spring system, building a lightweight chassis, realizing the torque-transmission in the cylinders, and controlling motors and camera. .

3.1. Spring system

Within the spring system, the main challenge is to design it in a way that it is strong enough to keep the robot stable in all positions and generate enough normal force for the traction in the side cylinders, but yet soft enough to open when passing the mast tips. As it can be seen in Figure 2.b, the spring system consists of one pull-spring (1.1) and two rotary springs (1.2). The two rotary springs are pre-stressed. These springs have a no-force angle of 90° . When mounted to the chassis, these springs have an adjustable pre-stress angle. Since these springs are pointing towards each other, the resulting force is zero and the two arms stay within a centre position. The pull spring is installed to fine tune the normal force – required to generate enough grip for a forward motion without wheel slip.

When such a pair of cylinders encounters an obstacle such as a mast top, which mostly also implies a change of cable direction; these arms are being rotated out of their centre position. The rotary springs then increasingly add force to the arms for the vertical cylinders (3.2) and therefore take back the arms into a centre position. This effect is also used to increase the normal force in order to generate more traction when passing an obstacle.

3.2. Chassis

The chassis consists of a rectangular frame reinforced by a middle beam. This frame is made out of two different kinds of profiles: two lateral ones and two front parts. They are bound using normal screws, which render an easy assembling and disassembling possible. The four front and back movement units are fixed in the centre of both front parts. The middle beam prevents the front parts from bending outside due to the relatively high masses. On each side of this frame a vertical arm with a length of 900 mm is fixed that holds the two spheres with the camera and the electronic units. At the end of these arms there are two sliding bars facing the mast, whose purpose it is to prevent the robot from falling off the mast tip in the instance in which it is in the unstable position directly on top of the tip. Furthermore, they help to push the machine into the right direction in case the wires depart at a horizontal angle from the mast. Thanks to the chosen structure the centre of gravity of the chassis lies 230 mm below the wire.

Since low cost and simplicity were among the most important goals in this project the team tried to find easy ways of production and favoured the use of standard parts as often as possible. All frame parts are water cut out of 10 mm

aluminium. Since the parts are stressed mainly by bending torque, a truss structure, where most of the material is placed as far away from the middle axis as possible, was used to guarantee a high flexural stiffness and a low mass at the same time. The lateral arms were welded using normal 20 mm x 20 mm rectangular aluminium profiles with a wall thickness of 2 mm. Aluminium was chosen because of its low density at comparatively high strength and the low risk of corrosion. All parts add up to an aggregate mass of 6.7 kg, which represents about 11% of the total mass.

3.3. Propulsion unit and torque transmission

All six propulsion cylinders carry their motors inside (Figure 3). Their axes are fixed to the chassis and thus do not turn. The cylinders are pivoted on this axis with two ball bearings. The torque from the actuators (60W, 5Nm) is transmitted with a gear belt. For increasing the torque, an additional reduction of 2:1 is realized with this gear belt.

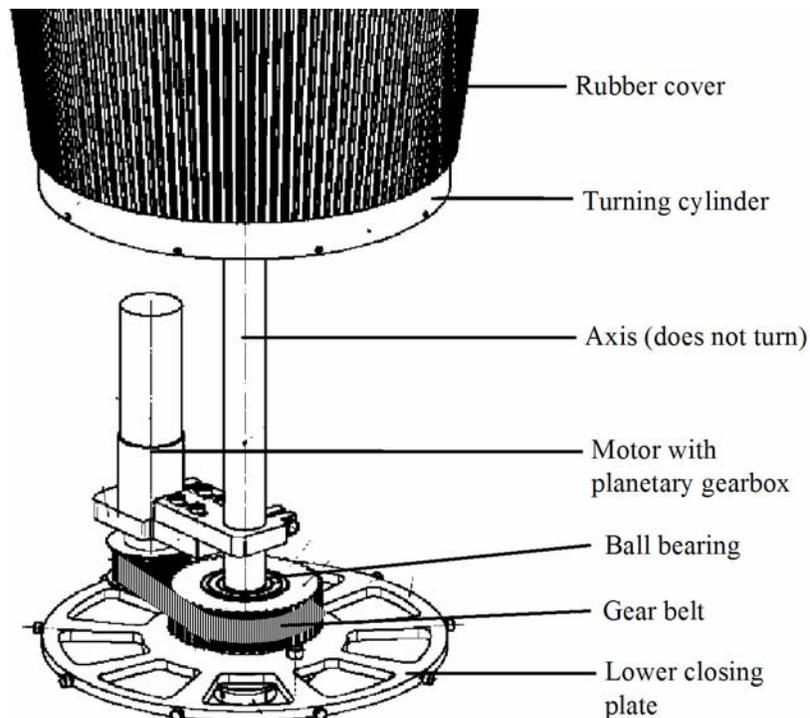


Figure 3. Explosion drawing of side propulsion cylinder with inner motor construction.

3.4. Control of motors and camera

In order to control the robot at distances up to 16 km, a remote control was realized. It consists of two units. One is the base unit, a computer that a user is operating via a graphical user interface. The second unit is a board computer on the robot itself, situated in one of the spheres of the robot. A wireless radio circuit allows controlling velocity and moving direction of each drive. A Matlab program was developed, which sends commands at a frequency of 2.4 GHz to the board computer. This information is then transmitted to the position controller. For the prototype line current is used as power supply. A hardware diagram of the motor control is depicted in Figure 4 (a).

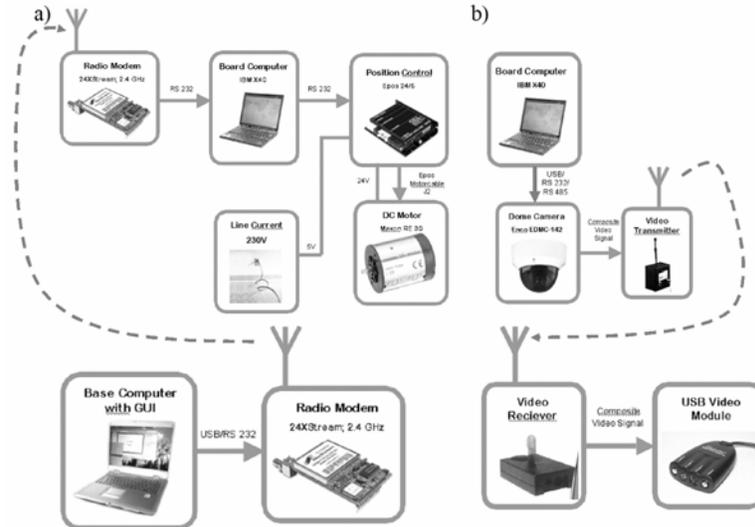


Figure 4. Hardware diagram (a) Motor control (b) camera control

The inspection robot is also equipped with a dome camera with two degrees of freedom. It is possible to rotate around the horizontal and a vertical axis, up to 360° and allows zooming in on a detail of interest. A position control was designed in order to lock the camera on a desired position. The same GUI and radio circuit are used to control the position of the camera with Matlab, as for the motor control. A command line, containing all necessary information for the camera control as well as for the motor control, is sent to the board computer at a rate of 10 Hz. Using a video transmitter, a receiver and a USB video module the video recordings can be seen on-line on the base computer screen. The hardware diagram of the camera control can be seen in Figure 4 (b).

4. Tests

The robot was tested successfully in a laboratory environment. It was shown that the mechanical design could cope with the requirements implied by the mast tip geometry. Especially the motorization of the four vertical cylinders proved to be substantial. With traction on only the two horizontal units, the robot could not traverse the mast tip by itself, due to the obstacle geometry and insufficient friction. Also the rubber coating on the cylinders resulted to be substantial to increase the friction coefficient.

Figure 5 shows the robot crossing a mast tip. Figure 6 shows the entire robot together with a human operator for size comparison.

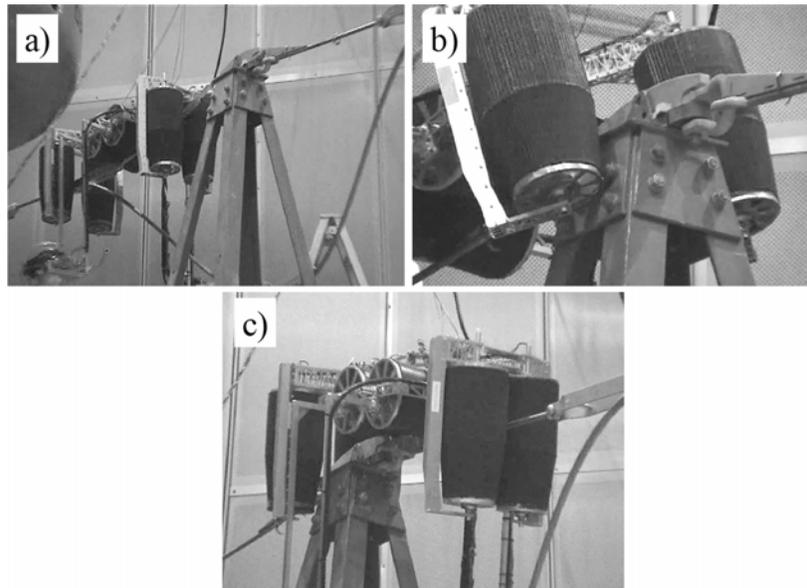


Figure 5. Sequence of passing a mast tip.

5. Conclusion and Outlook

The Cable Crawler presented in this paper illustrates a new approach to robot-performed power line inspections. It could be shown that the required mobility on slightly inclined cables and mast tops can be achieved with a pure passive suspension that does not need additional actuators in the robot structure. Such a relatively simple mechanical structure allows for building cheap and robust devices – as it is wanted by industry.

Future improvements in a final industrial version will mainly stress on the further reduction of mass (currently 58kg), a better transportability to the mast top by just one operator and more robustness against rain or snow. The control software will be implemented on a hardware that is robust enough for any weather conditions. Also some additional application modules such as automatic damage detection will be included.

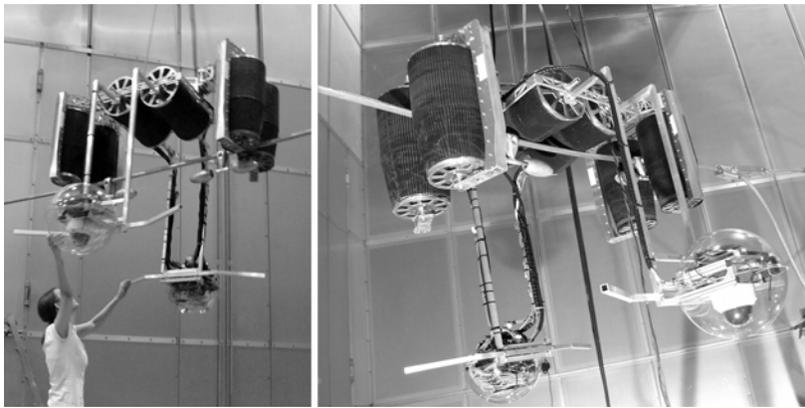


Figure 6. The Cable Crawler in the test environment.

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