INSPECTION ROBOT CAPABLE OF CLEARING OBSTACLES WHILE OPERATING ON A LIVE LINE

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Robotic systems are used in a range of applications to carry out inspection and repair tasks in hostile environments and in otherwise inaccessible locations. Applied robotics has found several niche applications in Hydro-Québec operations. One example of a recently developed robotic solution for power line applications is the LineROVer Technology.

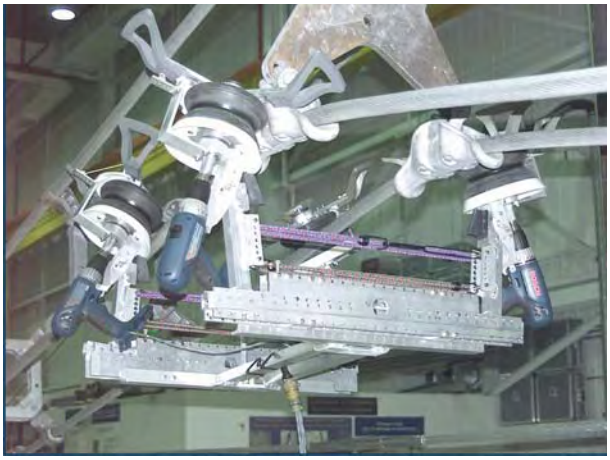

Figure 1: Hydro-Québec's RST-2X Technology

The LineScout robot developed meets this requirement and can clear obstacles as it travels down a line. It can move along several axes, allowing it to adjust its shape in real time to various line configurations and to a wide range of obstacles while remaining as light and compact as possible. The robot's geometry was engineered to give it at least six possible obstacle-clearing sequences, making it versatile in unforeseen situations. The robot can operate on an energized line, has one-day battery life and can be remotely controlled 5 km away. The control approach and electronics allow intuitive human operation of the robot. Moreover, it can operate semi-autonomously, learning to clear obstacles by means of automated sequences.

LINESCOUT TECHNOLOGY: DEVELOPMENT CONTEXT

Robotic technology has been used by electric utilities in many areas (production, transmission and distribution).

Innovation in transmission line maintenance was the subject of an extensive review of the literature in 2003. Innovations include a few robots designed to cross obstacles while operating on a transmission line: the TVA Line Rover, NSI Power Line Inspection System and Sawada's Mobile Robot for Inspection of Power Transmission Lines. A few other university and industrial designs were developed but never got beyond prototyping.

Since early 2002, a team at Hydro-Québec's research institute, IREQ, collaborating closely with Hydro-Québec TransÉnergie's personnel, has been developing two prototype robots for transmission line inspection that are able to move over obstacles while operating on a power line.

RST-2X Technology (Figure 1) is a demonstration prototype with a very simple design that has proven its ability to cross suspension insulator strings and spacer dampers on a four-conductor bundle. A patent is pending for that robot. The second robot, the LineScout Technology, has the more complex but far more versatile design described below.

The Pros and Cons of a Span-by-Span Approach

Since 2000, the LineROVer Technology has proven its worth and efficiency for live-line inspection on transmission networks. Its light weight, from 25 to 35 kg, depending on its configuration, allows it to move along ground wires and conductors of any gauge. The whole system is compact enough to be quickly and easily transported by helicopter to remote areas. Since the technology is fairly simple, no extensive training is needed to make an operator comfortable with its control.

TRANSMISSION NETWORKS: TARGET CAPABILITIES

The first thing to do in developing a technology like the LineScout is to target the part of the network where robotics applications are potentially useful: spans with many obstacles, river/road/distribution-line crossing and all parts of the network with conductor bundles. This means that the technology must work on live lines up to 735 kV. It is also imperative that the LineScout operate on ground wires.

That being settled, the obstacles the robot must be able to cross have to be chosen, weighing the inspection tasks desired against the increased robot complexity, weight and size entailed. Warning spheres (0.76-m diameter) provide a good example of a trade-off decision. However, the decision was taken to clear them given how highly valuable this is for transmission line inspections.

An extensive review was conducted of transmission line components and circuit configurations (bundles, vertical/horizontal circuits, single/double insulator strings). This review is summarized in Figure 2, which shows obstacles classified according to the continuous length to be crossed. For example, two vibration dampers could be seen as one or two obstacles, depending on the distance between them. Since that distance may vary, the robotic platform must have a flexible enough design to suit most situations encountered (Figure 3).

LINESCOUT TECHNOLOGY: THE PLATFORM

A team from IREQ developed the LineScout Technology to meet the objectives above. The name evokes its predecessor, the LineROVer, but also the new possibilities that arise by sending this

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Line Robot

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moving platform equipped with various tools farther along power lines to gather information and collect data. This section presents specifics about platform technology.

Crossing Approach

In order to move efficiently and fairly quickly along parts of spans with no obstacles, a two-wheel design was chosen for the vehicle. Furthermore, having natural rubber wheels of adequate size allows the LineScout to simply roll over simple obstacles such as splices, dampers and various types of clamps.

To clear other types of obstacles, the LineScout uses the sequence schematized in Figure 4. It must first be understood that the LineScout is built around three independent frames: the "Wheel Frame" (dark), the "Arm Frame" (light) and the "Center Frame" (white circle), which links the first two frames together.

In step 1, the LineScout stops in front of the obstacle to clear. Between the wheels but very close to them, are two sets of "Safety Rollers" (two small rectangles), which clamp firmly onto the conductors from below to secure the vehicle.

In step 2, the Arm Frame and Center Frame slide forward and pivot so that the two "Auxiliary Arms" (two vertical rectangles with "Gripper" tips) are located to either side of the obstacle. Note that since the Center Frame supports a fair fraction of the overall weight (e.g., onboard electronics and battery) LineScout's center of gravity is still very close to one of the supporting wheels.

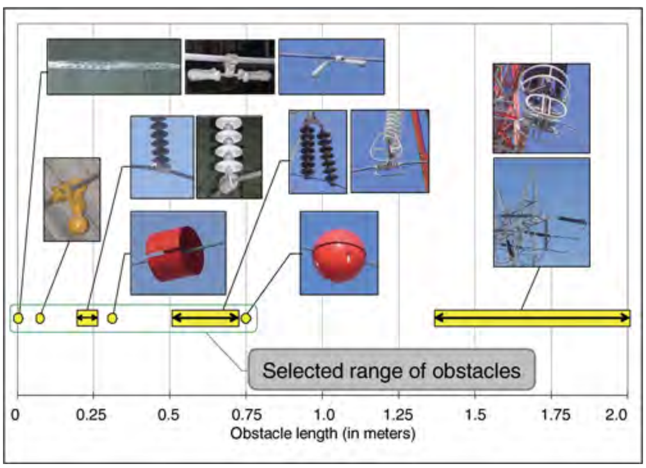

Figure 2: Obstacles classified by length

Figure 3: Sequence of obstacles

Table 1: Design technical specifications

Specification	Value
Line components and environment	
Conductor diameter	12 – 60 mm
Splice diameter	25 – 85 mm
Maximum obstacle length	0.76 m
Maximum conductor temperature	95.0°C
Number of conductor	1 – 4
Maximum slope in span	30°
Ambient operating temperature	0°C – 40°C
Platform	
Weight	100 kg
Length	1.37 m
Height	0.75 m
Traction force	500 N
Linear speed	1.0 m/s
Battery life	5.0 hours
Telecommunication signal range	5.0 km
EMI robustness	735 kV – 1000 A

This minimizes the cantilevered distances, reducing the size of the structure required.

Step 3 shows the platform configuration after two subsequent movements. First, the Auxiliary Arms rise up to the conductor and their Grippers clamp onto it, providing a new set of supports for the vehicle. Then, the Safety Rollers open and a mechanism flips the wheels down below the Wheel Frame.

By again sliding and pivoting beneath the obstacle, the Wheel Frame and the Center Frame now cross to the opposite side, as shown in step 4.

In step 5, as in step 3, the flipping mechanism brings the wheels back onto the conductor, allowing the Safety Rollers to secure their grasp again so that the Auxiliary Arm Grippers can be opened safely. The Auxiliary Arms then return to their initial lowered position.

Step 6 shows the LineScout once the Arm Frame and Center Frame have returned to their initial position. The entire sequence lasts about two minutes. The vehicle is now ready to continue rolling down the line.

One of the main advantages to this approach is the resulting compactness: a vehicle with an overall length of only 1.37 m is able to clear obstacles 0.76 m in diameter. This design still allows a relatively long (0.79-m) wheelbase making the vehicle very stable and able to carry a larger payload. Another key advantage of this approach is that it is neither limited to a specific size of obstacle nor to a specific distance between adjacent obstacles.

For example, Figure 3 shows a set of two torsion dampers followed by an insulators string. It is unlikely that such a set would always have the exact same spacing between obstacles. It was thus deemed necessary that the operator could adjust any crossing sequence to the actual configuration encountered. The numerous, somewhat redundant, degrees of movement are what make such adjustments possible.

Technology Overview

Once the approach was defined, the actual design could start, driven by the goal of obtaining a robust, reliable and fairly lightweight prototype. Time was also a tight constraint since only nine months were allotted before the first functioning prototype had to be demonstrated.