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Date: First version in September 2003, Revised in December 2004

**Technical Report No. : USU-CSOIS-TR-04-08**

Reports are available from http://mechatronics.ece.usu.edu/reports/

# Aerial Surveillance System for Overhead Power Line Inspection

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**Abstract**

Electrical companies routinely inspect their overhead lines by helicopter. Current detailed aerial inspection approach uses trained inspectors who fly aboard helicopters to inspect the lines with binoculars and cameras, while recording the data in a logbook. The procedure is performed while the helicopter hovers over and around power lines and structures, creating an element of danger for the pilot and the inspector. A manned helicopter with automatic video surveillance system will be a promising alternative. Existing automation technology for the power line inspection is described: the concept, the current status, and the key problems. Further, unmanned remotely operated flying robot might be the future of overhead power line inspection.

**Key Words:** Power line inspection, manned helicopter, remotely piloted vehicle, active vision, pattern recognition, vision feedback control.

## I. Introduction

With aging transmission lines already operating at capacity, and the difficulties involved in building new ones, utilities are trying to meet increasing customer demands for reliable power. They must keep existing lines operating at maximum efficiency, which requires stepping up inspection and maintenance. Information on observed or potential overhead line defects is thus of great value.

A wide variety of items need to be inspected for defects, which generally depends on the size of the item and the level of details required [1]:

**1)** Large scale items: sagging spans, leaning poles, broken or slack stay wires, and tree encroachment;

**2)** Medium scale items: equipment mounted on the poles, high voltage and low voltage fuse units, air break switches, anti-climbing guards, and safety notices;

**3)** Small scale items: broken or chipped insulators, discoloration due to corroded joints on conductors, and traces of arcing on fuse gear or switches.

Until now, the inspection of power lines has not evolved along with the high-tech era. Utilities traditionally send their crews out either on foot to walk the lines or in vehicles to drive the lines, with frequent stops to send linemen up towers for closer inspection [2]. An alternative detailed inspection approach uses trained inspectors who fly aboard helicopters to inspect the lines with binoculars and cameras, while recording the data in a log book. The procedure is performed while the helicopter hovers over and around power lines and structures, creating an element of danger for the pilot and the inspector [3].

While the traditional helicopters fly slowly, hover frequently, and maintain precise positions, a new concept using maned helicopter with automatic video surveillance that can typically fly at $50 \sim 60$ mph from mission start to finish, stay $30 \sim 50$ m away from the overhead lines and structures, and complete the inspection at $10 \sim 12$ seconds, as illustrated in Fig. 1, has been proposed to be a promising alternative. Inspections will thus be safer, less stressful to the pilot, and less risky to the system. To acquire appropriate videos (to finish the inspection task) within $10 \sim 12$ seconds for each inspection target brings out problems of strict requirements in the fields of computer vision and control. A primary list of problems are presented in Sec. II with their partial solutions.

Fig. 1. Aerial power line inspection illustration (from News Releases).

Manned helicopter with automatic video surveillance system has been developed or under development. The Avcan helicopter-based aerial patrol system is developed by the Avcan Systems Corp, Canada. The Aerospect precision imaging, a unit of Utah State University Research Foundation, is also developing an image surveillance and inspection system (ISIS) to inspect power lines. Using the ISIS, the helicopter will be able to fly at 55 mph, 300 feet away from the structures, while capturing and storing high resolution images. Besides, the Airborne Inspection System (AIS), developed at the Electric Power Research Institute, can produce video and still images that reveal objects as small as broken insulators, as shown in Fig. 2, while the helicopter is flying at a speed of $70 \sim 90$ mph.

Based on the application scenario, the data to collect during surveillance includes visual information on equipment (insulator status, corrosion, tower and pole conditions), thermal profiles of

Fig. 2. Broken insulator unit (developed at Electric Power Research Institute).

conductor and splices, vegetation and other potential right-of-way incursions, concrete degradation and soil erosion in footings, and other abnormal conditions [4]. Accordingly, typical equipment of a manned helicopter usually consists of:

**1)** Geometric information system (GIS) telling the targets' positions;

**2)** Differential global position system (DGPS) giving readings of the vehicle's motion parameters,

**3)** Active vision system (digital camera) for capturing high resolution video (or plus a digital still camera),

**4)** Sensors for capturing temperature readings.

As one step further, small remotely piloted vehicle (RPV) concept has been proposed and pursued, such as in the EA Technology Ltd, which might become the future of power line inspection. The RPV concept shares the same sensor equipment with the manned helicopter, but has a more strict requirement for safety. Safe operation must be demonstrated continually and unequivocally. Inspection operations must be scheduled in coordination with other air traffics.

## II. Manned Helicopter

Automatic video surveillance of power lines is not as straightforward as it may sound. Particular problems such as:

**1)** Pattern recognition of target locations [5],

**2)** Camera stabilization in compensation of the helicopter's 6 degree-of-freedom (DOF) movement [1],

**3)** Acquiring and maintaining the target in the camera's field of view (FOV) [1],

**4)** Image degradation caused by camera's residual sightline motion [1], [6], [7],

**5)** Data analysis system,

begin to be addressed in the literature and partial solutions are given in the above referenced papers, which are briefly described in the followings.

### *A. Feature Extraction of Target Location*

The first and obvious task of automatic video power line surveillance is to be able to extract the target feature locations such that this visual information can be sent to a visual feedback control loop to generate appropriate control input to the active vision system, the gimbal, to maintain the target in the FOV. The key problem in the pattern recognition arises from the changing perspective of the target. While model-based pattern recognition algorithms might be effective, the feature extraction task is made more difficult by factors such as environmental conditions (light intensity and direction, weather conditions) and the distracting background features (fences, trees, roads). Another inherent requirement for the pattern recognition algorithms is that it must be invariant to the camera's focal length, since the focal length varies widely during the inspection for a clear and closer "look".

A corner based pattern recognition algorithm is presented in [5] for the recognition of the pole-top of the overhead power lines. Recognition algorithms for other specific inspection features need to be developed based on the inspection requirements. Generally, a set of models are needed for the model-based recognition algorithms.

### *B. Camera Stabilization*

"Camera shake" degrades images, which is a general problem affecting any cameras mounted on a moving vehicle. In aerial power line surveillance, the helicopter has a 6 DOF motion. Besides, random disturbance such as the gust is inevitable. The video camera thus needs to be stabilized to accomplish the inspection task. Partial solution to this problem is to mount the camera on a gyro-stabilized gimbals, which lock the sightline of the camera to an inertial reference. In this way, the angular motion of the vehicle is compensated [1].

### *C. Initial Acquiring and Tracking of Target Features*

Initial acquiring of the target locations can be based on the GIS and DGPS, where the GIS provides 3-D locations of the target and the DGPS reads the current positions of the vehicle. Since errors could exist in both the GIS and the DGPS readings, the above initial acquiring method has the chance to fail. In this case, manual control by the operator using a joystick is needed to bring the target in the view. Once the target is in the FOV of the camera, pattern recognition algorithms, with one described early in Sec. II-A, are used to locate the feature locations in consequent images and provide visual information to control the gimbal such that the target to inspect lies around the center of image.

### D. Image Degradation Caused by Sinusoidal Gimbal Motion

Image degradation (blurring) could be caused not only by the motions of the vehicle and the gust, but also by the residual motion of the gimbal. A detailed study of sinusoidal residual gimbal motion is conducted in [6], where it is reported that tolerable motion is of the order of $1\% \sim 2\%$ of the FOV of the camera for both static and dynamic images. Accordingly, optical stabilization of the order of 100 ur is necessary for satisfactory inspection. A further study in [7] shows that the above reported tolerable motion is not guaranteed due to both the helicopter's translational motion and the sinusoidal residual gimbal motion, unless the camera is rotated at a certain rate to compensate for the helicopter's rectilinear motion. The above study will affect the design of the automatic tracking system.

### E. Data Analysis for Defects

Another question is how to deal with the huge amount of visual information collected during the aerial patrol. The digital data can run through pattern recognition softwares, where neural network and fuzzy logic algorithms might be applied, to analyze the data and locate the defects. The above analysis could be performed off line after the aerial patrol with the recorded video, or even on line during the patrol, where multiple digital signal processors might be needed to give the required high computation speed. With the data analysis system, it is possible to build a profile database for each overhead power line, including its more accurate position, some related images, and possible defects or warnings.

## III. Flying Robot

Using the manned helicopter described in Sec. II, it is often necessary to avoid areas where the low-flying helicopter could cause disturbance to people or livestock. In such cases, a small unmanned remotely piloted vehicle, which is equipped with the same or similar sensors as the manned helicopter, could be an answer. British distribution companies in particular are intrigued by this technology, and see its potential to reduce inspection cost and outage frequency in the future [4]. The RPV developed in the EA Technology Ltd is shown in Fig. 3.

Similar to the manned helicopter, the RPV usually has a high resolution CCD camera with a zoom lens mounted in an active gimbal system to stabilize the camera against vehicle movement. Further, it provides the operator a remote pan and tilt control in case the operator wants to interrupt the

Fig. 3. Remotely piloted vehicle (developed at EA Technology Ltd).

automatic surveillance process and inspect specific area manually.

Besides the image processing tasks described in Sec. II, issues such as path planning and obstacle avoidance [8] are necessities for the flying robot to operate safely. Overall speaking, the craft should be operated consistently and predictably before finally takeoff.

## IV. Potential Applicable Theories

### A. Range Identification

As mentioned above, the key problem in the image processing or pattern recognition arises from the changing perspective of the target. While the available patter recognition algorithm is shown to perform well for video sequences of good quality, cancelling/avoiding the perspective effects will surly improve the recognition accuracy and help to maintain the target in the FOV. In the aerial power line surveillance, the motion dynamics of the vehicle (either the manned helicopter or the RPV) and the active gimbal system are known, while the target is stationary. This setup forms exactly a perspective dynamic system, where relative depth information between the target and the camera can be estimated using nonlinear observers proposed in the literature for range identification [9], [10], [11]. After the depth information is identified, the perspective effect can be removed and better pattern recognition results can be achieved. The estimated depth could also be helpful to maintain the vehicle at a reasonable distance from the target, thus being safer.

### B. Iterative Learning Control (ILC)

When the aerial vehicle (especially the RPV) is operating routinely to inspect overhead power lines, in similar environments and for similar targets, the movement of the vehicle near the inspection field (not including the trip between two inspection targets) can be similar unsurprisingly. In this case, ILC theory can be applied to make the vehicle maintain more stabilized, where the gust could be regarded as a source of disturbance, either linear or nonlinear. With the above feature, a RPV will be more reliably controlled. Even for the manned helicopter, the pilot will be relieved of the navigation task partially.

## V. Concluding Remarks

Fundamental prototype of the aerial surveillance system applied to power line inspection is conceptually described. The basic technologies, current status and progress, and possible applicable theories are discussed briefly. In this specific application scenario, issues such as pattern recognition, active vision, and vision feedback control need to be addressed thoroughly to guarantee the vehicle maintain stable and safe, as well as to obtain sufficient inspection coverage and accuracy with the least amount of time.

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