Power Line Maintenance Inspection

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This paper introduces a hardware+software system designed to meet over-head line inspection needs for maintenance purposes, encompassing inspections of assets through video, infra-red or ultra-violet cameras and the environment (right-of-way) based on LiDAR and video. It is intended for airborne use from manned helicopters.

Power Line Maintenance Inspection [PLMI] was designed by Albatroz Engineering to provide integrated, flexible, real-time tools for the inspection of overhead lines (OHL). PLMI should be competitive for all lines above 1kV. Although primarily developed for airborne applications, it has been extended to ground operations using all-terrain vehicles. Extensions to "human wearable" devices, motorcycles or pack animals and unmanned aerial vehicles (UAV) have been envisaged.

Power Line Maintenance Inspection comprehends two segments: a field segment, named PLMI online, and an office segment, named PLMI offline.

1. PLMI online

Inspection systems perform some or all of the following types of inspections:

1. Thermography with deep infra-red cameras to detect mechanical faults on conductive parts,
2. Visual inspection, often supported with high quality photographs or video streams to report physical faults of many types,
3. Corona inspection with ultra-violet cameras to detect the corona effect on conductive and isolating parts[1],
4. Clearance (or "right-of-way") with LiDAR to detect hazardous objects too close to OHL,
5. Environmental inspection, often supported with photographs or video stream to report conditions on the surroundings of power lines
6. Foundation inspections to detect wear and corrosion below ground level,
7. Climbing inspections to detect wear and corrosion above ground level and
8. Ground resistance inspections.

While the first five inspections are non contact procedures that can be performed from an airborne or ground vehicle, the latter three types require people on the ground touching the infrastructure. These three types tend to be carried in longer periods (typically, 5 to 10 years) while the first five are run in shorter periods (typically, 1 to 3 years).

PLMI includes hardware - sensors, computers, containers and fixation parts - and real-time software for the first five types of inspections. PLMI online was built with a modular non-centralized structure, so that each client needs only to acquire the inspection tools not yet available and PLMI will integrate with the existing third party modules. In the sequence it is assumed that helicopters are used for inspections but all modules are functional on ground inspections too. Three PLMI online modules have been developed:

[1] In some territories, ultrasound is used instead of ultra-violet to detect the corona effect

1.1 Digital Recording

The **Airborne Digital Recording System** [ADRS] acquires and performs digital, synchronized recording of inspection data from all sensors associated with the five types of inspections, such as video, infra-red and ultra-violet cameras, LiDAR and audio (Figure 1).

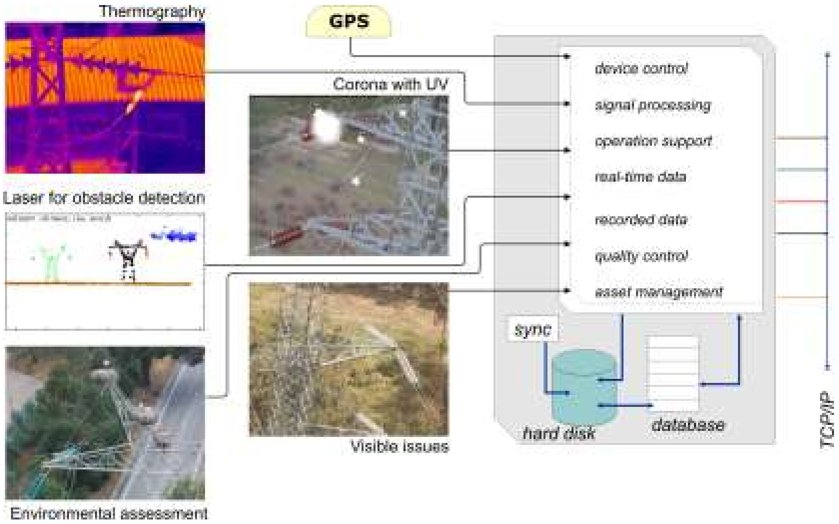

Figure 1 - Airborne Digital Recording System architecture

The **Airborne Digital Recording System** [1] provides device control on each sensor and signal processing capabilities as needed (e.g. compression, thresholds, metadata), operation support tools (e.g. sensor status, remaining disk, inspection configuration and hours, register weather conditions). Inspectors can access both live and recorded data. The system has its own embedded real-time quality control. All recorded data is stamped with a common real time clock reference and with geographical coordinates acquired from GPS (attitude and heading reference sensors can be used for increased accuracy). In this way, every data entry is associated to a specific location and time permitting data retrieval using both types of references. Optionally, inspection data can be linked with asset management databases to associate assets and their corresponding field data.

Video can be acquired from analogue cameras (PAL or NTSC) or digital cameras through Gigabit IP links (with dedicated power or with PoE[2]). Audio is stored associated to the video. Current implementations store up to four video channels and two audio channels. The output is accessible through TCP/IP and the system may be fully autonomous or operated via a web interface accessed with common browsers (see Section 1.3).

For higher reliability, inspection data is stored in a RAID system, to minimise the probability of failure and to support data transfer (see Chapter 2). Figure 2 shows an implementation of **Airborne Digital Recording System** certifiable as a minor modification to Eurocopter Écureuil/A-Star helicopters.

[2] Power over Ethernet: a protocol to supply devices out of the regular data cable.

Figure 2 - ADRS unit: connectors and controls

1.2 Track Clearance

The **Track Clearance** system performs automatic and real time inspection of the line track (right-of-way) featuring obstacle detection, classification and report generation. It is based on the Airborne Sweeping Laser Measurement System [ASLMS] [2] that includes a LiDAR sensor, a fixed video camera[3] and a GPS receiver to estimate location (an optional attitude and heading reference system can be included to improve accuracy and allow the construction of 3D models).

The system is mounted on the exterior of the helicopter (Figure 3) and operates automatically while the airborne inspection team focuses on other inspections. The LiDAR beam sweeps a fixed angle of view (see (a) in Figure 3) and measures the distance between the helicopter and the first obstacle in each direction. At some instant determined by the internal clock (10:18:24, (b) in Figure 3) and some location determined by GPS (40.36...°N, 8.65... °W) the area around the power line is as shown in (b), where the cross section of a high voltage line is apparent. Synchronously, the video camera covering the same angle of view captures the scene (c).

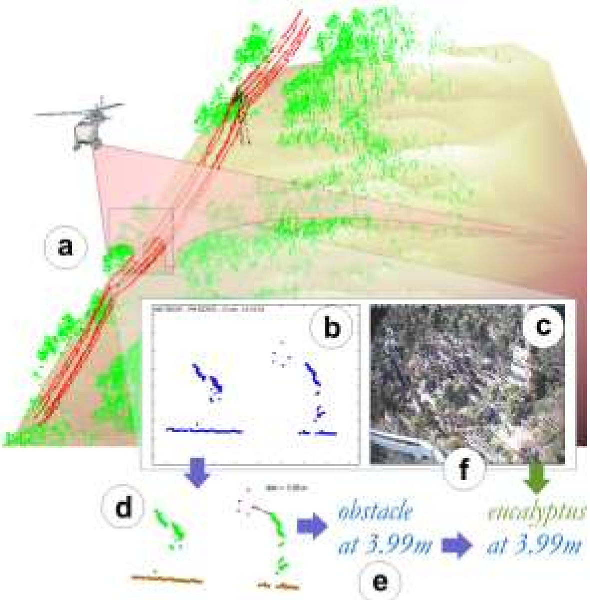

Figure 3 - Track Clearance working principle

[3] Certain applications require a second camera pointing to the ground to take horizontal photos.

In real time, the software classifies the range samples and identifies the OHL (d)[4]. If the safety envelope around the conductors is breached, a vegetation anomaly is computed (d = 3.99m (e)), recorded and highlighted to the operator. From the associated video image, the inspector can identify the obstacle, immediately or at the office: it's a eucalyptus (f).

In addition to clearance anomalies the system can automatically detect towers and keep track of quality control variables, such as velocity over ground (to keep track of density of points and distance between consecutive scans), distance to the line (for safety reasons and quality of inspection), distance to the ground (to keep track of distance between adjacent samples).

The Track Clearance system may be integrated with the ADRS (see previous section) or operate autonomously, in which case it can be a two part system with external sensors (Figure 4) and internal computing or a single external block with only power and data link entering the aircraft cabin.

Figure 4 - ASLMS with a quick-release helicopter mount

1.3 Inspection Interface

The Inspection Interface is a software module that integrates and enhances the operations of the other modules[5]. It uses client-server architecture with a HTTP server mounted over a TCP/IP data link. The interface operates as a web page with multiple "tabs", one for each tool (Figure 5): configuration, video streams (for thermography, video and corona), asset condition, track clearance, maps, reports and mission archive. Multiple users can be operating the interface simultaneously, either to compare results on a common tool or to operate different tools.

[4] The lower dot in the line cross-section has a different colour to denote an optical fibre cable. Since it is non-conductive, clearance rules do not apply to it.

[5] It is possible to operate both Airborne Digital Recording System and Track Clearance without a computer interface since both are fully autonomous, but the inspectors would lose significant insight into the mission.

Figure 5 - Inspection Interface screenshots

The asset condition tool is used to register all points of interest (POI) with time and location references; in one implementation, it involves more than 100 different descriptors and each descriptor has 3 to 10 parameters. Later on during the mission, inspectors can review the descriptors and the synchronous data recorded (*e.g.* video, audio) to assess if it is convenient to return to a given POI. Also, the complexity of the map tools depends on the connection with the geographic information systems.

2. PLMI offline

The office segment contains only software (in some configurations, specialised computers may be required). The data transference from PLMI online to PLMI offline is done through mass storage due to the large size of inspection data sets. The process is illustrated in Figure 6.

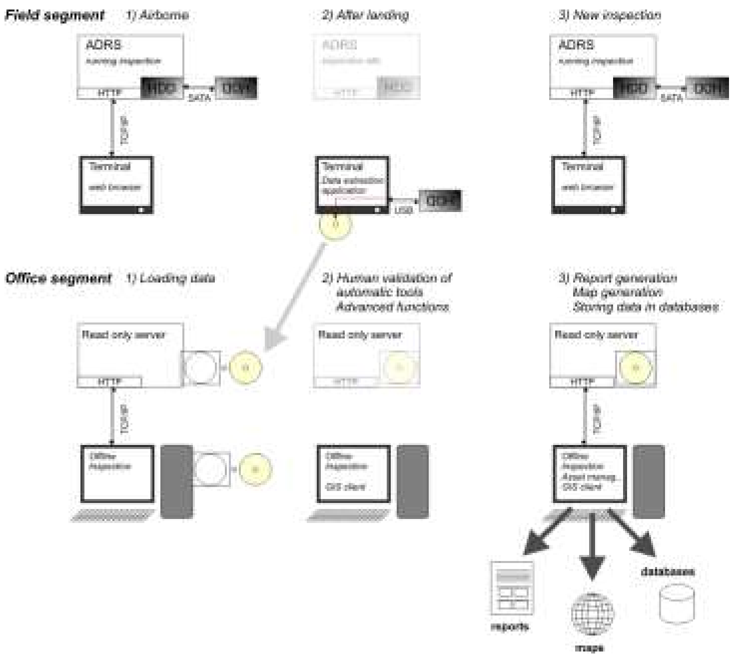

Figure 6 - Field, office segment data transition

Inspection data is recorded in a RAID1 configuration with an internal disk linked to an external disk through SATA interface (1). Once the aircraft has landed data is transferred to a portable computer – often the same unit used in the field as terminal - with a USB cable to transfer data (a typical workday produces about 10Gb of data) (2). At the end of the day, all data is transferred to an optical disk or other mass storage. Meanwhile, inspectors return the external drive to ADRS to restore data and resume inspections (3).

At the office, data is loaded either through a dedicated read-only server or directly at the workstation (1). Then, the inspector processes and validates results (2). In the end, all points of interest are stored in databases while reports and maps are issued to support geographic information systems (GIS), asset management and maintenance teams.

2.1 PLMI server

PLMI offline is organised in a server/client environment. The server runs a database with geographic extensions where all data related to the inspections is stored: sensor data, processed data and reports. Depending on the implementation, this server may also contain databases that reflect the asset management databases and the topology (functional connections) of the grid. It can also link to GIS. The server's main functions are:

- Store inspection data,
- Process time-space queries on inspection, asset, geographic and topological data,
- Provide inspection related information to asset management systems,
- Provide inspection related information to GIS,
- Query asset management systems about assets and their condition,
- Query GIS about location of assets and third party databases.

In addition to the basic information exchange functions, this server will also implement innovative functions such as described in [3].

2.2 PLMI client

The PLMI client application is designed according to the modules implemented in the online segment and the information infrastructure of the grid operator (at the office segment). The following assumes the most comprehensive implementation on both segments.

The specialised inspections based on human analyses are processed autonomously from PLMI, in many cases using third-party software as in the thermography analysis. Then, the PLMI module associates the time and geography reference of any POI with the documents or numbers of the appropriate anomalies. Typically, anomalies are classified with a severity grade; one implementation uses:

A. for critical or non compliant to standards,
B. for serious or standard compliant but in risk of non compliance before next inspections and
C. for moderate; it should be incorporated into the scheduled maintenance effort & budget.

Other authors have proposed more sophisticated and insightful approaches that are under consideration [4].

The track clearance or right of way inspection (see Section 1.3)is repeated at the office to take advantage of the lift of the real-time constraints. This allows for more complex, feature rich and computational intense algorithms. For instance, real-time anomaly detection is based on instant, local data since the location of future towers is unknown whereas in the Offline application the tower-to-tower catenary is modelled and the algorithm can determine sag at different load ratios. Moreover, the classification of anomalies unfolds into many subclasses, taking account regulatory differences among types of roads, constructions, OHL and many others.

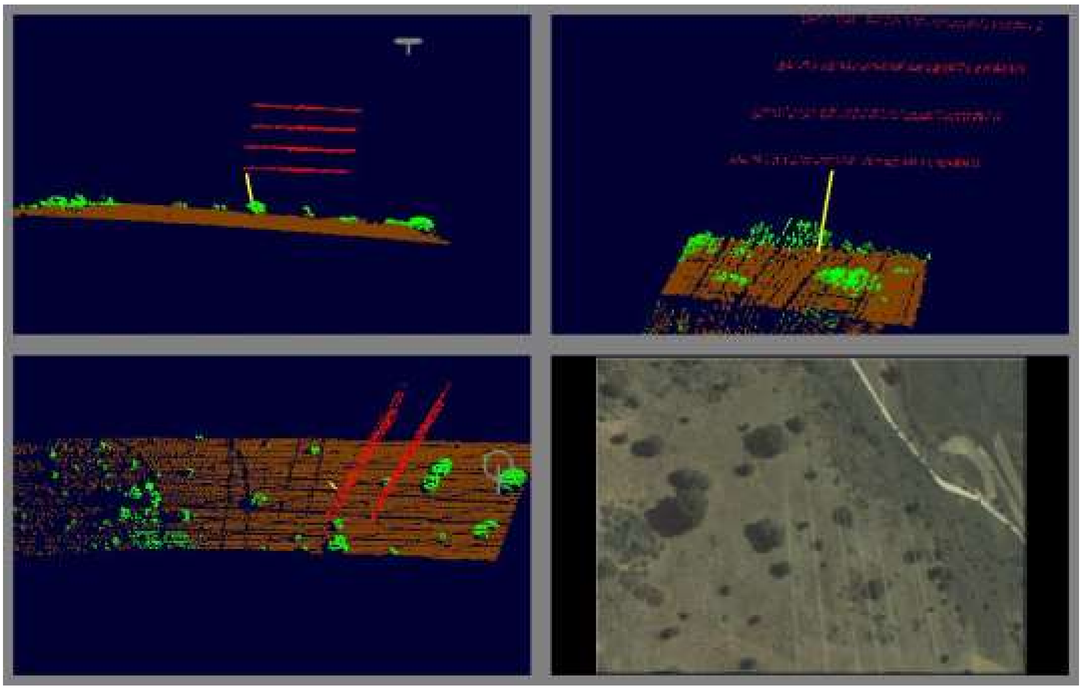

Figure 7 - snapshot of Track Clearance module

This application implements the following functions:

- Load data and transfer to databases (when appropriate),
- View LiDAR data with different geometric arrangements,
- Process range data into 3D models,
- Automatically analyse the 3D models to establish POI (mostly anomalies),
- Interactive interface for manual classification and validation of POI,
- Statistics of the right-of-way in different parameters,
- Generation of outputs for database-systems and files,
- Generation of map outputs for GIS and related formats,
- Generation of quantitative and descriptive reports,
- Query databases (when appropriate) for time or space analogies between POI.

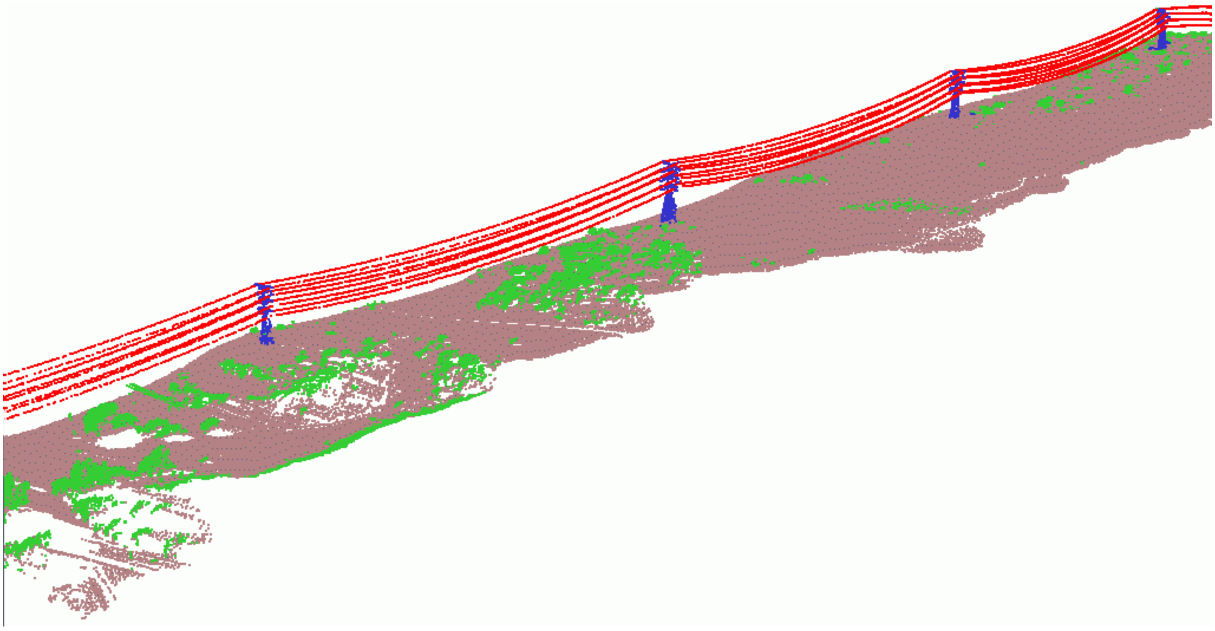

Figure 8 - fraction of a 3D model

The output functions may integrate all POI regardless of their origin. The purpose is to create an integrated, synchronous, current and localised diagnostics of all POI and their severity. shows samples of the Offline Inspection application.

3. PLMI adapted to ground inspections

The need to adapt to ground inspections led to the development of Ground Maintenance Inspection (GMI) [5]. The concept is similar to PLMI, albeit with lower grade sensors. Moreover, the system is easier to operate from the ground vehicle and there is lots of available DC power.

In some applications, GMI can be used to input data directly into the asset database or the GIS as the inspection and maintenance tasks are combined. Currently, GMI includes video recording, track clearance and asset condition features. The data structure is common to PLMI making both systems compatible.

4. Conclusions

The goal of PLMI was to create integrated, flexible, real-time tools for OHL inspections [6]. Integration was the major driver for the economical savings are decisive to implement a thorough inspection routine and, in addition to those, OHL condition is better assessed through simultaneous inspections. The proposed system provides:

- **Flexibility**, since it incorporates existing sensors into PLMI and to adapt to existing inspection practices; it is fit for transmission and distribution lines alike; it can be operated from the ground or airborne; it supplies quantitative, qualitative and multimedia data;
- **Modularity**, to operate different functions or types of inspections autonomously;
- **Integration** and **synchronization**, of multiple sensors from different manufacturers into one single, modern recording system with time and location referencing;
- **Improved insight,** as the analysis of physical phenomena from different simultaneous data streams contributes to overcome each sensors shortcomings;
- **Integration** with information infrastructure associated to asset management and GIS;

- **Real-time tools**, for instant anomaly confirmation; for reporting just after the inspection; for human-technology mutual leverage and for confidence building during learning;
- **Faster analysis and response**, supporting emergency and contingency scenarios;
- **Selective inspection of** geo-referenced issues optimises focus and frequency of inspections.

Specifically, the Track Clearance module introduces the following innovative features:

- Track clearance is integrated with routine inspections,
- Track clearance is performed in real time with instant human validation,
- Early clearance reports are available immediately after the mission.

The experience with PLMI on distribution lines (10kV to 60kV) is reported in [7][6].

5. References

[1] http://www.albatroz-eng.com/solutions/adrs_en.html

[2] http://www.albatroz-eng.com/solutions/aslms_en.html

[3] Francisco Azevedo[1], João Gomes-Mota[2], "A time and space framework for overhead grid maintenance optimisation", [1]Universidade Nova de Lisboa, [2]Albatroz Engineering, Touch Briefings, to be published 2010.

[4] Condition Based Risk Management (CBRM) – Enabling Asset Condition Information to be Central to Corporate Decision Making, David Hughes, EA Technology-UK, CIRED, 18th International Conference on Electricity Distribution, Turin, 6-9 June 2005.

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