AUTONOMOUS INSPECTION IN TRANSMISSION AND DISTRIBUTION POWER LINES - METHODOLOGY FOR IMAGE ACQUISITION BY MEANS OF UNMANNED AIRCRAFT SYSTEM AND ITS TREATMENT AND STORAGE

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ABSTRACT

Brazil has a national integrated electrical system with more than 120,000 kilometers of Overhead Transmission Lines (OHTL), owned by Transmission and Distribution Companies. Current inspection approaches are obsolete and expensive or don't cover all items to be inspected. In spite of having many academic related works, the use of Unmanned Aircraft System (UAS) for inspection remains as a challenge for real purposes because, when a project reaches the phase of implementation, many real constraints difficult the process. To overcome this challenge, Celesc (a Santa Catarina Distribution Company) and the Institute of Studies and Energy Management - INERGE are jointly developing a project whose main objective is the development of an integrated system for autonomous inspection of lines using Unmanned Aircraft System of rotary wings and VTOL capacity, with optical and thermal sensors. This article presents the methodology developed or the analysis of inconsistencies in transmission and distribution lines. The results obtained so far, indicate that the methodology will succeed in OHTL inspection, due to the high quality of the images, allowing for identification of existing problems in the line components, thus significantly increasing the efficiency of inspections, mainly in areas of difficult access.

INTRODUCTION

Inspection of distribution or transmission lines through UAVs has been a persistent goal for companies in several countries, such as China, the United Kingdom and the United States, and for several authors, such as EPRI [1] and Montanbault [2].

The solutions are diverse, because aircrafts with the most varied characteristics (fixed or movable wings, VTOL or catapult capacities, etc.) exist in the market as well as the use of a great variety of optical and thermal sensors. However, this R & D project, focuses not on the platform used, but on its most innovative and relevant aspects: the development of an integrated system (SIGMA) that manages the inspections from the planning to the final disposal of results, after treatment and analysis made by means such as specific software (detailed in another article presented in CIRED 2017).

The project was based on the "mission profile" concept, which is an inspection action on an OHTL specifically defined as part of the annual inspection plan of each of the lines, in which points of interest in a given line stretch, Right of Way, or group of structures, are the target of the sensing conducted by the UAS. The mission incorporates the inspection of the entire line or of different parts of the line, with predetermined objectives, such as inspecting the Right of Way, determining the presence of rust on structures, or broken insulation, both individually and simultaneously, according to Celesc's specific needs and characteristics of the line to be inspected. The UAS can carry out a mission using one of two types of flight: (1) Flight to the Front, where the UAS travels the defined stretch of the mission to a height below the limits accepted by the Aeronautics for uncontrolled flights conducting the sensing of the Right of Way, conductors and structures, in search of inconsistencies such as invasions, high vegetation, soil erosion, chain integrity, etc., and (2) Paired Flight, where the aircraft is oriented to sense details of structures, chains, fittings, splices, etc..

The flights to be carried out by UAS are defined according to the existing rules of Aeronautics ICA 100-40 [3], ANAC RBAC_E 094 [4]. Although the project is currently at the end of the second year of a three-year period, the systems are already perfectly defined, except for the prototyping, UAS integration - sensors and field tests, which are already under development by the supplier company.

DEVELOPMENT

Demands

Celesc's main demands, which guided this project, were:

- extensive distribution lines throughout the territory of Santa Catarina, usually inspected by land, through inspection teams that use binoculars or simple vision in the search and identification of defects or incidents in components;
- locations in regions with diverse topography, coastal, plateau and mountainous conditions, and varied environmental conditions, with predominant pollutants such as coal and saltpeter;
- difficult land inspection in places with hard or dangerous access or indigenous lands, often of unsanitary conditions;

- inspections do not follow a defined pattern, with incidents reported from the inspectors' point of view, making it necessary to conform to the standards defined by the regulatory agency (ANEEL). In this way, there will be a standardization of the inspection criteria and consequent reduction of the times of analysis and diagnosis of possible problems as well as a faster response time;
- optimization of the System's Operation - it is necessary to have an efficient planning of the interventions in the (predictive) lines to optimize the operation of the lines, making the interruption time as short as possible.

Proposed Methodology

To develop an integrated system for autonomous inspection of OHTL based on the use of UAS with Vertical Take-Off and Landing (VTOL) capability through intelligent sensing and image treatment / diagnosis. The design of this system is shown in figure 1, where the flow of collection, analysis, treatment and distribution of data collected (images and videos) is shown.

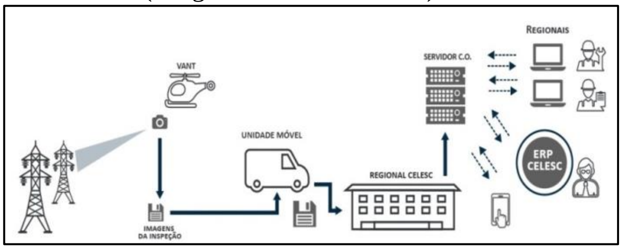

Figure 1: System's Operation

The data is captured by sensors placed on an aircraft and stored in hardware placed on the aircraft that will carry out the missions, controlled by a system installed in a van (the Ground Control Station, ECT) stationed at a predetermined location along the transmission line chosen as pilot for the project (LT 69 kV Usina Garcia - Roçado). In the van we will have two technicians qualified for the operation, a pilot and an observer (ICA 100-40).
After each flight, the data stored in the aircraft is transferred to the equipment installed in the ECT, where the pre-processing of the data will take place. The ECT will move to a Celesc's office (or alternatively a substation) from where the data will be transferred to the Operations Center server, for a second stage of processing, to enable the most accurate analysis and decision making.
The "mission profile" considers:

- an aircraft with VTOL capacity;
- maximum payload capacity (sensors) = 10 kg;
- flight height: between 300 m and 100 m;
- maximum distance from the main axis of the OHTL 100 to 300 meters;
- autonomy - 4 hours max;
- range - 100 km max;
- flight profile - VLOS (online range of sight) or RLOS (range by radio); and
- good weather conditions and efficient links for data transmission.

In the VLOS flight, the pilot maintains direct visual contact with the aircraft (without the support of lenses - except corrective lenses-, or other equipment). In addition the pilot always has all the information on telemetric data and flight images through the navigation system installed in the bow of the aircraft, which will be visualized on screen at the Ground Control Station (ECT). From the Ground Control Station the pilot will be able to intervene in the operation of the aircraft, according to the rules established in ICA 100-40, to eliminate possible failures or operational deficiencies, as well as to deal with adverse situations such as changes in the meteorological conditions (wind, rain, luminosity).

SIGMA System

Inspections comprise various field and office activities and the SIGMA system integrates all these activities for better performance and efficiency. In addition, it provides users with an environment in which all inspection data is available for further analysis and also stored for further inspection.
Figure 2 contains the component diagram illustrating the architecture of the inspection system, integrating the aeronautics modules, inspection management system (SIGMA) and image processing. Flight plans are created in a specific software for aeronautics and exported to be attached to the respective inspection plans created through SIGMA software server module.

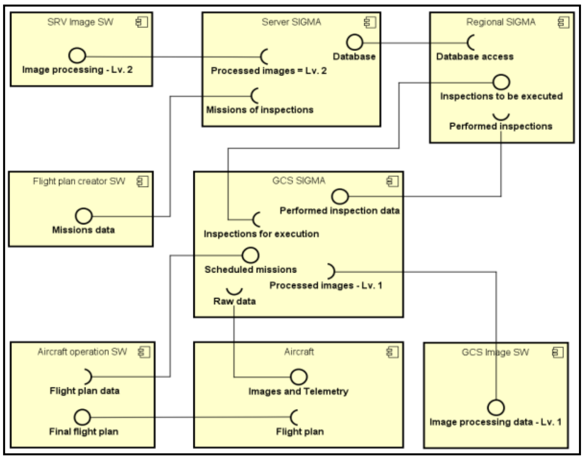

Fig. 2 – Component Diagram of the SIGMA System

The SIGMA system has a module (called "regional") used to send flight plans and field information to conduct inspections as well as to receive mission data. This data transfer is performed between the regional module and another module (called "GCS SIGMA"), executed at the ground control station (GCS). Before taking off, the aircraft is loaded with the flight plans, using the software

"Aircraft Operation SW".

Once the flight has been performed and the images have been acquired, it is necessary to carry out the processing of the images. For this, two modules are used. The first module operates at the ground control station and performs only the analysis of the quality of the images acquired in the field.

The operation of the image processing software is transparent to the user and is done through SIGMA. With this, the field operator performs the so-called first-level analysis. In this analysis, the field operator will decide, supported by software, whether the images are appropriate for second-level analysis or whether a new flight will be required to acquire new images.

The second image processing module operates on the server at Celesc's Operation Center and is intended for detailed automatic analysis of images for nonconformities. The users are able to carry out the second level analysis, in which the results of the automatic image analysis are verified. False positives (false nonconformities) can be manually indicated by the user, and false negatives (real nonconformities) can be discarded.

Figure 3 shows the physical units where the inspection system is operated. Computers 1 and 2 are located in the Operation Center. Computers 3 and 4 are located in the ground control station and are connected to each other via Ethernet network for data transmission, which alternatively can be done via flash drive. The flight plans are loaded into the aircraft by the "Aircraft Operation SW" module, running on computer 4.

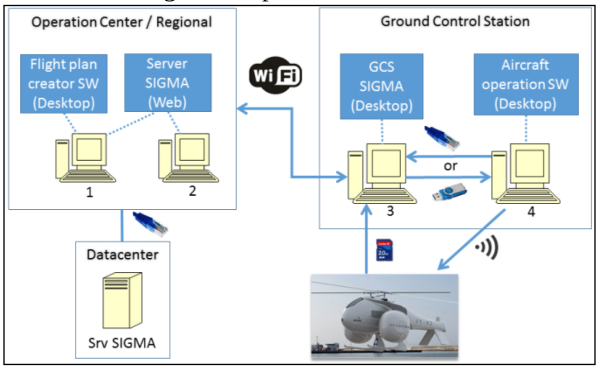

Fig. 3 – Overview of the Data Communication Infrastructure of the Inspection System

During the flight the data is stored on an SD card carried in the aircraft. At the end of the flight, the SD card is inserted into computer 3 and through the SIGMA, the data is downloaded for analysis by the field operator. After the field missions, the data stored in computer 3 is uploaded to the company's datacenter through a Wi-Fi network.

The operation of software on computers 1 and 4 is performed by a person with pilot training (as requested by the aeronautic rules). To operate the software on computers 2 and 3, a person with knowledge in line inspection is required.

Image Treatment

The autonomous inspection of transmission lines using UAS as a methodological tool is relatively recent and has received considerable attention, with several projects being proposed in recent years [5], [6] and [7].

Digital processing of the image plays an essential role, being used as a basis for the recognition and identification of components (intact or not) of transmission lines such as structures, insulators, fittings, conductor cables, Right of Way, etc.

The great variety of components, the lack of standardization, the variation of the clearance under the lines and the adversity of meteorological conditions related to the flight such as wind, humidity, visibility through the atmosphere; which are essential to the stability of the flight; are some characteristics that put to the test the best processing techniques. To overcome this challenge, a software was developed to identify the images collected and the comparison with the images available in an image bank, in order to try to characterize eventual incidents (nonconformities). This analysis starts from the capturing of images by the sensors installed in the aircraft, and their decomposition and treatment, to eliminate distortions and blur, improve the focus, etc. This image acquisition and its decomposition are shown in Figure 4:

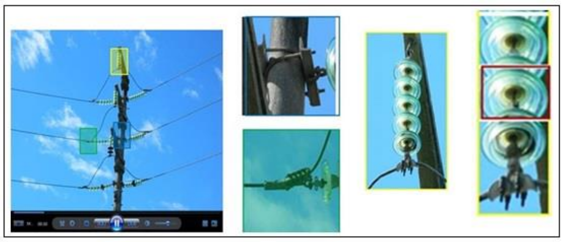

Fig. 4 – Decomposition of Images Taken by Sensors

In the first picture, on the left, a general plan of the top of a structure can be seen with 3 highlighted areas: the vertical chain of insulators, the anchoring clamp and the fittings connecting the crosshead to the structure. These areas are then highlighted so that the database can be compared, and the chain of insulators has the widened focus to detail a particular insulator.

The proposed processing system divides the challenges into two major stages, identification and evaluation.

The first stage identifies the components classified in macro elements (Structures, Right of Way, Buildings, etc.), and components of the line (chains of insulators, hardware, etc.), to finally get to the detailing of components (clamps, bolts, screws, etc.). In the second stage an evaluation of the components, nonconformities or defects found in the first step is carried out through two (2) evaluation functions:

- evaluation of defined nonconformities - identifies recurring defects in components;

- evaluation by history - compares the current image with previous images for changes or degradation of the component.

CONCLUSION

This article shows the main aspects (challenges) encountered in conducting an autonomous inspection in distribution or transmission lines and points out the ways Celesc and INERGE teams have found to solve them.
In the area of Digital Image Processing an automatic process was created to diagnose possible defects or nonconformities before a large volume of data is processed. In the area of Information Technology, a modular system was built with the independence of its main modules, Image Processing, Creation of Flight Plans and Management of Air Missions, in order to ensure the cohesion and non-coupling of the components.
As the main results obtained with this type of inspection, we can mention, amongst others:

- easier access to places where a ground inspection presents difficulties;
- speed in the primary evaluation of the images collected in each mission;
- availability of the images and data for more detailed analysis in the offices;
- standardization of Celesc's inspections, aiming at compliance with ANEEL guidelines.

Although it can be concluded that the demands have been satisfactorily met, it can be foreseen that in the near future, with the technological evolution determined by the increasing interest in the inspection by UAS in world-wide level, besides the use of UAS and sensors sets for inspection related activities, an accelerated development of these components towards the optimization of inspections, such as lighter and more accurate sensors, the use of smaller and lighter platforms with a predictable improvement in the quality of inspections will be possible.

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