SATELLITE IMAGERY AND PRUNING MANAGEMENT: A REVOLUCIONARY APPROACH

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ABSTRACT

This article presents a robust pruning planning and management tool for trees along electric power distribution networks, that results from a R & D project executed by Concert Technologies S.A in partnership with a Brazilian power distribution utility. The main technology of the solution is based on high-resolution satellites images processing, digital analysis and photogrammetry techniques. The major difference of the tool presented here is its ability to determine not only the presence of vegetation in the risk areas, but also the height of the trees identified, eliminating the need for in-situ data collection. In addition, the solution also includes a powerful specialized algorithm that leads to an optimized pruning plan. This algorithm can consider several criteria for generating the pruning plan, such as available budget, pruning costs, service quality indicators, productivity and location of pruning teams, among others. Those plans allow the preventive management of trees, minimizing the need for emergency pruning, with consequent attenuation of the number of interruptions in the electric power supply caused by trees.

KEYWORDS: high-resolution satellite images; remote sensing; photogrammetry; GIS; pruning plan.

INTRODUCTION

Energy utilities faces increasing challenges related to the demands of the sector as well as regulatory standards. The additional pressure from shareholders charging financial results requires that these efforts fit into criteria for resource rationalization, risk mitigation and operational efficiency, forcing utilities to optimize business processes. Within this vision, guaranteeing the continuity of electricity supply services is an essential premise, permeating the whole of the concessionaire in an organized and unique way.

Vegetation is a significant source of disruption to energy utilities, and the consequences of these disruptions on the variables that guide its management, such as quality and service availability, are important and very impacting. In some regions, a quarter to half of all disruptions can be attributed to vegetation. It is so critical issue for the operation of the electric system that some utilities have a vice president responsible only for vegetation management.

Identifying vegetation risk areas can be a costly process. Add to this the fact that scheduling and routing of pruning teams are often sub-optimal, which further increases the cost of vegetation management. Optimize these processes can produce significant benefits in the form of fewer disruptions and reduced costs. In this sense, a system that allows to identify, monitor and organize, in an efficient way, all the relevant data for analysis and modeling of an optimized pruning management plan, aimed at the preventive action of this type of interruption, is extremely relevant for the energy distribution lines maintenance activities.

In general, such system only will be effective in achieve the demands associated with the generating and managing trees pruning plans problem if it is able to address the following requirements:

1. Automatically identify the trees in the risk area of the energy distribution lines and the height of these trees;
2. Eliminate the need for in-situ data collection and all costs associated with registration, inspection and survey;
3. Eliminate corrective maintenance on energy distribution lines due to damage caused by vegetation;
4. Eliminate registration costs associated with the location of the distribution network of interest, using the utility GIS data as input;
5. Plan the pruning schedule, considering factors such as the dates and risks associated with each spot of vegetation identified along the distribution lines, and aiming at minimizing the main costs associated with pruning, the optimum allocation of pruning teams and an improvement of power quality indicators.

In the present project a system capable of addressing all listed requirements have been developed, highlighting as its main innovation factors the ability to determine tree height and generation of an optimized pruning schedule, capable of considering multiple criteria for its composition, such as available budget, pruning costs, productivity and location of pruning teams, quality indicators associated with network segments, among others. The tool enables consistent decision-making, increasing the performance and reliability of the pruning management service, as well as contributing to the energy efficiency of the concessionaire.

This article begins with an overview of the methodology adopted for the solution development, followed by a brief explanation about the main technologies addressed in its construction. Then the presentation of the tool itself, through its main functions, is showed. Finally, examples of results obtained with their use and the relevant conclusions are presented.

METHODOLOGY

The R & D project resulted in specialized software, equipped with all the necessary intelligence to attend to the problem of planning and managing the pruning of trees along the electricity distribution networks. The developed system uses the Geographic Information System (GIS) data to locate the distribution networks, digital processing techniques and high-resolution satellite image analysis to identify the trees within the area considered as risk of touch with the distribution network, digital photogrammetry techniques to discover the height of these trees, and a specific optimization algorithm to select trees for pruning.

In general, the methodology implemented by the system consists of the following procedures:

1. Location of the distribution network in the satellite images: performed through the georeferencing of the utility´s GIS data with the images;
2. Identification of areas with presence of vegetation in satellite images: fulfilled through digital processing and high-resolution satellite image analysis techniques;
3. Identification of vegetation areas within risk areas around distribution lines: identification of the energy distribution network and the trees located in its risk area, as well as its height. Digital photogrammetry techniques are used in this operation;
4. Planning of pruning management: Once the critical areas and vegetation are identified, it is possible to carry out the pruning planning, which culminates in the generation of a pruning schedule that consider the budget constraint and prioritization criteria that deal with "health" indicators of each distribution circuit section. In this activity, factors such as the dates and risks associated with each tree identified along the networks are evaluated and the goal is to minimize the main associated costs such as tree registration, inspection, pruning and post-pruning inspection, as well as the improvement of quality indicators of electricity distribution services.

The following subsections will present technical details related to the main functions developed in the system, namely: identification of the vegetation and its height and generation of pruning schedules.

Identification of vegetation area

To identify vegetation from satellite images, a variety of indexes have already been developed, based on calculations made on the values of color shades of each pixel representative of vegetation regions, which aid in the mapping and identification of these areas (Blackburn, 1998, pp. 657-675).

NDVI (Normalized Difference Vegetation Index) is one of these indexes and allows not only to map vegetation but also to measure its quantity and condition in a given area. The physical principle of NDVI is based on the spectral signature of plants. Green and living plants strongly absorb solar radiation in the red region (0.6 micrometers) to use this radiation as a source of energy in the photosynthesis process. On the other hand, plant cells strongly reflect the near infrared region (0.8 micrometers). The portions absorbed in the red and reflected in the infrared vary according to the conditions of the plants. The greener, nourished, healthy and well supplied of water the plant is, greater the red absorption and infrared reflectance. Thus, the difference between the reflectance of the red and infrared bands will be greater the greener and healthier the vegetation is. The NDVI indicator is calculated according to the equation shown in Figure 1, where Red and NIR are the reflectance in the red and near infrared bands, respectively. From the equation, NDVI values vary from -1 to +1 and for vegetated areas their values vary between 0 and 1.

NDVI - *NormalizedDifferenceVegetationIndex*

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

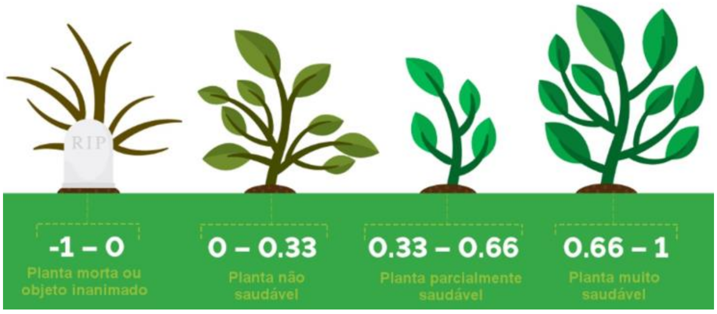


Figure 1. Relationship between NDVI and vegetation health.
(font: https://sentera.com/understanding-ndvi-plant-health/)

In the system developed through this project, vegetation identification implements the calculation of the NDVI factor from satellite images containing the RGB-NIR bands.

Identification of vegetation height

Digital photogrammetry allows the reconstruction of a three-dimensional space, called an object-space, from a non-empty set of two-dimensional images, called image-space. For the transformation to be implemented, in addition to the satellite images collected in stereoscope pair, a set of control points is also required, which are expressed in the object space. Once placed in the image-space, we have all the input parameters for the deduction of the function that maps one system to the other. This is the technology behind tree height determination.

The images and control points, once processed, give rise to the Digital Surface Model (DSM), which represents numerically the terrain relief. For many applications based on remote sensing, it is beneficial or even mandatory to have a Digital Terrain Model (DTM), in addition to the DSM, for the region of interest. However, once object height (DSM) and soil (DTM) information is available, it becomes possible to generate a normalized digital surface model (nDSM), representing the relative height above the ground. Such products can be used to calculate, for example, the height of the forest and therefore the biomass, or the height of the trees, buildings and other man-made structures, and accurately represent the demand of this project for the tree height. Figure 2 pictorially illustrates the numerical information that is obtained through the DSM and DTM.

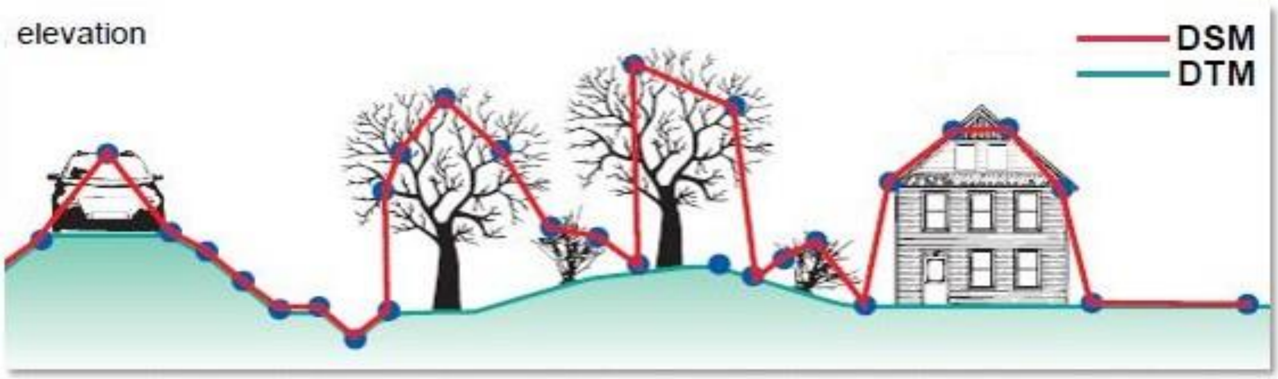


Figure 2. Numerical representation of DSM and DTM.

All the above models can be purchased, as a processing service, from the image suppliers. In this project, we decided for acquire the DSM, whose generation requires specialized software for image processing and the iteration of specialized technicians, and implement a DTM extraction approach, especially suitable for DSMs generated from high-resolution stereo images. The method used can be applied to images of optical sensors with a spatial resolution in the range of 0.5 to 1.0 meters (R. Perko at all, 2015).

Generation of pruning schedules

Once identified the trees present in the risk areas and its height, the pruning schedule can be carried out. This schedule will indicate the optimization to logistics management for prune the trees in risky conditions, resulting in an optimized pruning schedule for the utility.

To do so, the trees whose determined height indicates proximity risk for the distribution network, named trees eligible for pruning, are selected. After that, they are subjected to a specialized algorithm with the objective of maximizing the attendance of the higher priority trees, considering restrictions associated with the available budget and factors indicative of risk (related to grid quality indicators) of the areas where these trees are located. The adoption of such a planning criterion minimizes several of the major costs associated with pruning, such as inspection, planning, survey and pruning, as well as minimizing the costs associated with blackouts due to unplanned shutdowns.

The problem in question was specially designed to meet the existing reality in the utility and was modeled mathematically to allow the generation of optimized pruning schedules. The model and its implementation can generate a day-to-day planning, to a horizon in which it is possible to estimate which trees will be pruned each month. Thus, the optimization module receives as input data a tree list, the associated priority and the month in which they are to be pruned, in addition to budget, costs, productivity and location of pruning teams, and generates as output the date indication for the pruning and responsible team for each one of the selected trees. Figure 3 illustrates this process.

The architecture of the developed system consists of a back-end, where processes associated with database and images load, image analysis and pruning schedules generation are executed, and a front-end, developed with web technology (especially HTML5 and Java Script), from which users make use of the system modules and functions. The main system component modules, namely Map, Image Analysis and Calendars, are described in the following subsections.

Figure 3. Components of optimal pruning planning.

PRUNING MANAGEMENT SYSTEM

Map

The Map Module is intended to provide the system users the possibility of visualizing, in a geo-referenced map and satellite images, all elements of their distribution network that are in the system database; as well as the trees located in the risk area of the network. It presents several functions of support to the visualization, among which we stand out the proximity function. It allows the visualization of the trees that are in the risk areas of the distribution network, highlighted by their proximity to the network. Activating the proximity function causes all the trees in the display to be highlighted in red, yellow or green; meaning that they are very close, approaching or without risk to the distribution network, respectively. Figure 4 presents the system interface with the combined use of the Layer, Mapping, and Proximity support functions.

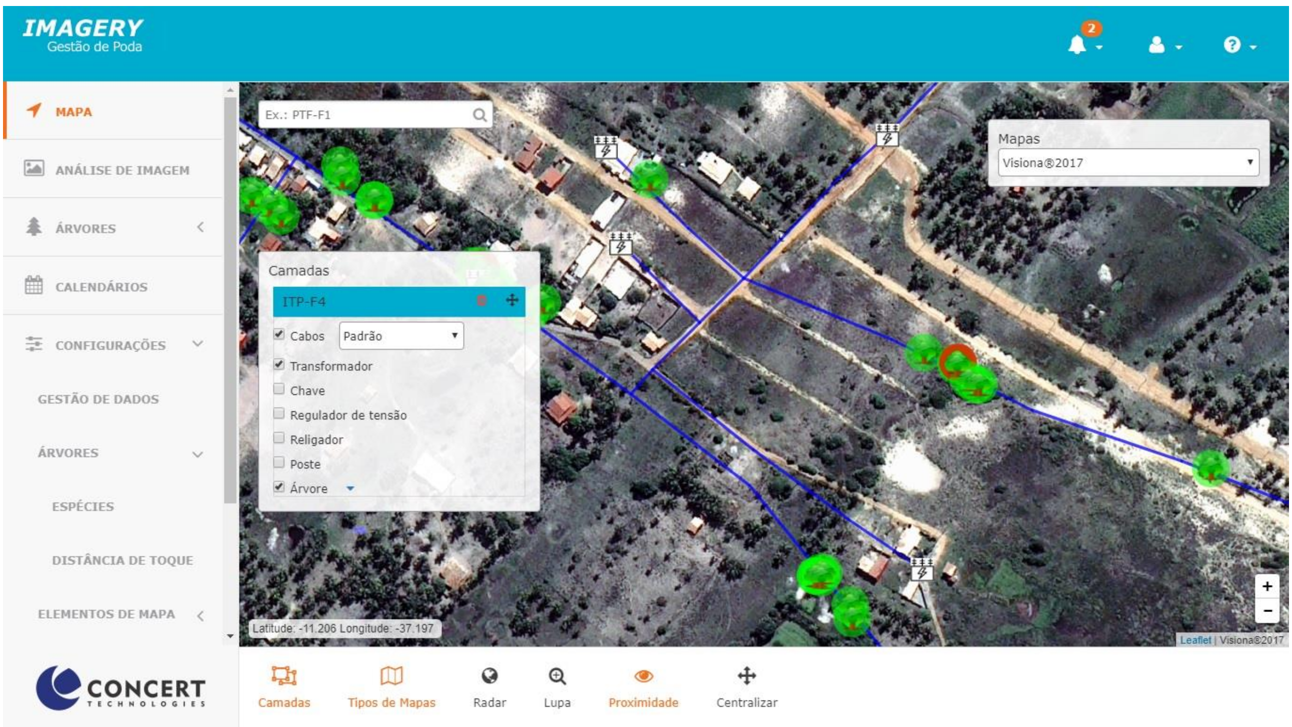


Figure 4. Map Module - Layer Functions, Map Types and Proximity.

Image Analysis

The Image Analysis Module provides system users with the necessary functions to load the acquired satellite images, as well as perform the analysis of these images for trees identification and its height.

All trees with a height greater than or equal to one meter (minimum height resolution of the models) that are located within the risk area of the network are identified and stored in the system database. This process must be performed each time a new image is acquired or the distribution network changes relatively to the inclusion or removal of feeders or line segments.

To perform the image analysis, the user must provide the values for the analysis parameters, which are:

a) Value of NDVI. The closer to one, the healthier the vegetation is;

b) Value of the diameter of the network risk area (in meters), considering that the network is in the middle of that diameter;
c) Value of the difference of height between consecutive pixels to break of individuals when the vegetation is in the form of a stain.

Figure 5 illustrates the image analysis interface. In this example, from the image analysis, 20 trees were in the risk area of the distribution network that permeates the analyzed image area.

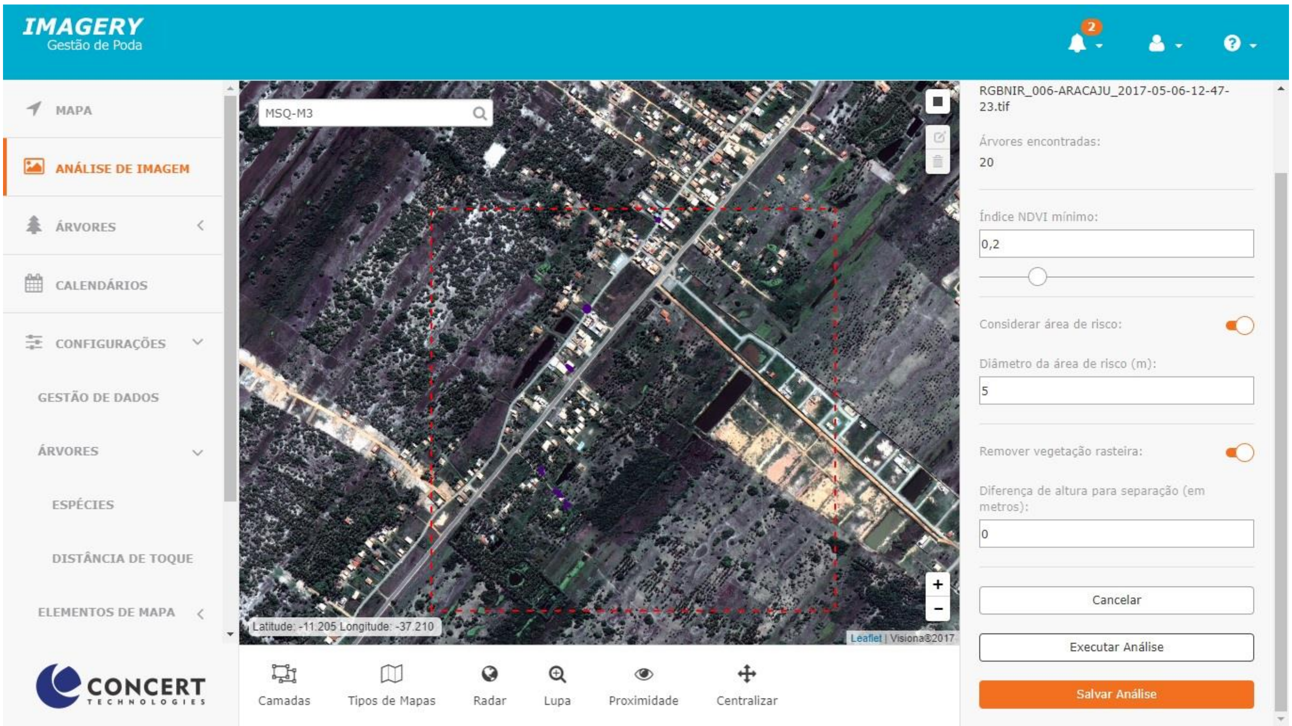
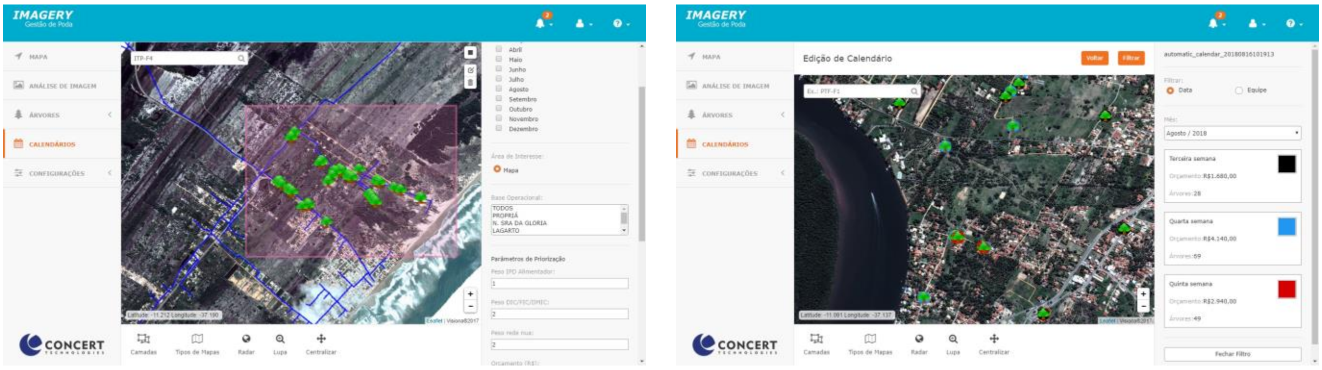


Figure 5. - Image Analysis Module

Calendar

The Calendars Module provides users of the system with the functions associated with pruning calendars, which are: viewing details associated with each existing calendar; export calendars to the labor management system; generation of new calendars and edition of existing and not yet exported calendars, to change dates or team allocated in each pruning.

To create a new pruning calendar, the user must first define the region to which the pruning calendar is to be generated. To do so, it is possible to delimit the area of interest on the map or select the set of feeders or cities. Once the area of interest has been defined, it is necessary to define the calendar coverage period, the operational bases that can be allocated for pruning and other prioritization parameters to be applied during the schedule generation. As the developed system is oriented to the utility's business, the main indicators of service quality and network structure are used to prioritize the pruning to be performed. Figure 6 - Calendars Module - Generation (a) and edition (b) of pruning calendars, illustrates in (a) the parameter setting interface for generating a new pruning calendar and in (b), the editing interface of the pruning calendars, showing the determined pruning filtered by month.



(a) (b)

Figure 6. Calendars Module - Generation (a) and edition (b) of pruning calendars.

The pruning schedules generated by the system are exported to the utility labor management system, from which the dispatch of the teams is carried out.

Field teams, when performing a pruning service, should return to the Pruning Management system some information related to the pruned tree, such as its species and touch distance (distance between the tree and the distribution line) after pruning. From these data, the system can estimate the growth of that tree, inserting it into a new pruning schedule when it again presents a risk to the network.

RESULTS

Area of interest, images and aggregate products

For the present project, satellite images were acquired for an area of interest (AOI), which corresponds to approximately 6,119 km2, encompassing the easement ranges of power networks in Brazil. The images specification and aggregate products purchased for the project are as listed below:

1. Stereoscopic images Pleiades, for an area of 6.119 km2, with nominal spatial resolution of 0.5 meters in the panchromatic band and 2 meters in the multispectral bands (Product Bundle);
2. Digital Surface Models (DSM), for an area of 6.119 km2, with 1 meter of pixel spacing;
3. Digital Terrain Models (DTM), for an area of 1.200 km2, with 1 meter of pixel spacing; these models were used to validate the results obtained from the derivation method implemented in the project;
4. Orthorectified images (R, G, B and IR), for an area of 6.119 km2, with 0.5 meter of spatial resolution;
5. Mosaic of equalized orthoimages for an area of 6.119 km2. The mosaic is used to display the images in the system HMIs.

Figure 7 - Orthorectified image, DSM, DTM and nDSM, presents an example of an image acquired for the project, which covers a small city, and the respective numerical models DSM, DTM and nDSM.

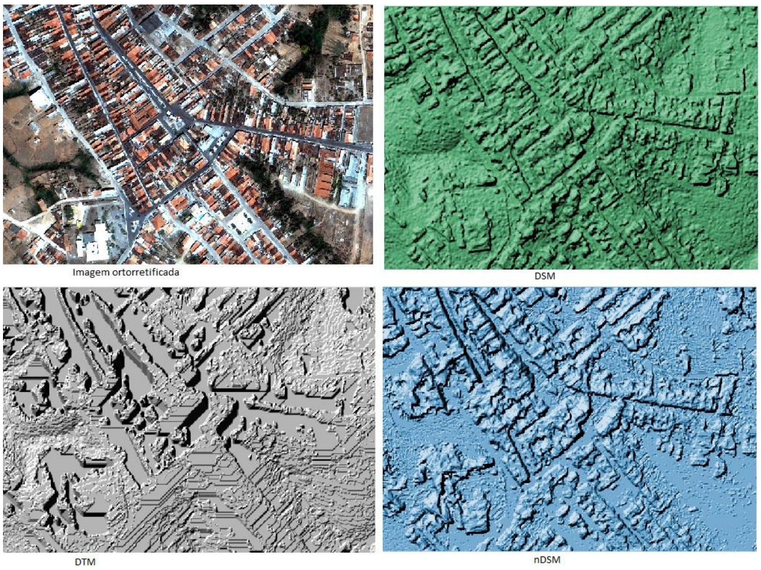


Figure 7. Orthorectified image, DSM, DTM and nDSM example.

Field evaluation

The present field evaluation involved two distribution feeders. Figure 8 - Feeders and identified trees (a) illustrates all trees identified and cataloged in the system based on the satellite image analysis, represented superimposed on the image used in this process. It is observed that only the trees in the risk environment of the feeders were mapped.

A pruning schedule for these feeders was generated using a 40-centimeter touch distance to determine the subset of trees eligible for pruning. Based on the parameters used, the obtained schedule indicated 128 (one hundred and twenty eight) trees for pruning (Figure 8 - Feeders and identified trees (b)). Considering that the indicated budget was not extrapolated, the selected trees includes all the trees located in the risk areas of these feeders, at 40 centimeters or less from the distribution line and therefore needed to be pruned.

Figure 9 presents data collected and recorded through photographs for two cases presented here. For Case 1, a coconut tree, the system indicated the height A = 10 meters and the touch distance DT = 0. In field, it was observed a real height A = 12 meters and DT = 0 - Figure 9 (a). For Case 2, a mango tree, the values indicated by the system and measured in the field were the same: A = 10 meters and DT = 0 - Figure 11 (c). For both cases, the touch distance calculated by the system was accurate, meaning that both trees in fact needed to be pruned.

In Figures 9 (b) and (d) we record the pruning performed, highlighting the post-pruning touch distances for each case, 2.5 and 3.5 meters respectively.

Figure 8. Feeders and identified trees.

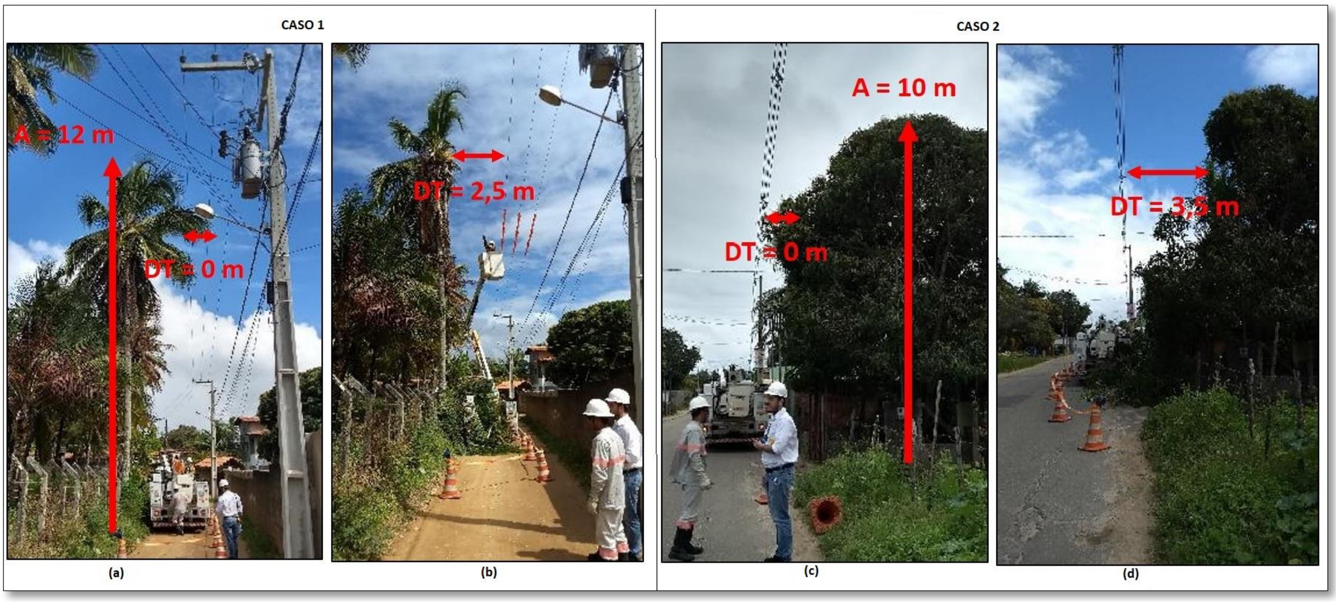


Figure 9. Field validation records.

CONCLUSIONS

The present work has innovated the Energy Distribution Sector by using high-resolution satellite images in conjunction with GIS data to solve the problem of identifying and manage trees in high-risk areas of touch in the distribution network. When analyzing satellite images, it was possible to distinguish vegetation from other objects, to differentiate between grass and shrub trees, to measure tree height and to use GIS data to measure the distance between trees, poles and cables.

The second part of the work involved the development of a pruning management algorithm to optimize pruning activity itself. Once the risk areas were identified, based on the available budget, the locations, productivity and speed of the pruning teams, the risk level desired and the cost of pruning a tree, the algorithm was able to determine a roadmap and schedule optimized for the pruning operations of each team. The algorithm is robust enough to be applied to a neighborhood or an entire city.

Regarding the results obtained, it was verified that, for the coconut trees, the height determined as a function of the satellite images presents a certain imprecision, that because they do not have a central crown, with a sparse canopy. It is believed that this same imprecision will extend to all species of trees that have the same characteristic of canopy. On the other hand, for tree species with dense crowns, as in the case of mango tree, the result obtained by the system proved to be accurate.

Considering that the height of the vegetation is only relevant for the first pruning, and after this pruning, the data observed in the field, especially the post-pruning touch distance, feedback the developed system; and considering that, despite the error in determining the height, the touch distance presented was correct (all trees really needed to be pruned), we can say that the system developed in this R & D project perfectly addresses the problem of pruning management, taking into account all the requirements presented at the beginning of this article, because:

1. Automatically identifies the trees that are in the risk area of the distribution network, as well as the height of these trees;
2. Eliminates the need for on-site data collection and all costs associated with registration, inspection and survey;
3. Allows minimizing or even eliminating corrective maintenance on overhead lines due to damage caused by vegetation;
4. Eliminates registration costs associated with the location of the distribution network of interest;
5. Plan pruning schedule considering the dates and risks associated with each identified tree and ensuring optimum allocation of pruning teams.

Finally, there is currently a considerable constellation of imaging satellites from different operators orbiting the Earth. The technology present in some of these satellites allows the collection of products with spatial resolution of up to 30 centimeters and with high frequency of an area revisit. This context fosters the remote sensing market and increases the competitiveness among the operators, generating reflections on the costs and availability of the images and guaranteeing the feasibility cost versus benefit of the solution.

The creative use of satellite imagery from this work demonstrates how innovative companies to improve operational performance and reduce costs can apply satellite imagery.

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