

# CARTOGRAPHIC FEATURES EXTRACTION METHODOLOGY IN REMOTE SENSING IMAGES AIMING AT THE CARTOGRAPHIC UPDATE OF ALLOTMENTS

Eduardo Soares Nascimento<sup>1</sup>, Allan Alves Lopes Ferreira<sup>1</sup>, Thamires Gil Godoy<sup>1</sup>, Caio Flávio Martinez Fontoura Junior<sup>1</sup>,  
Guilherme Pina Cardim<sup>1</sup>, Pedro Miguel Berardo Duarte Pina<sup>2</sup>, Erivaldo Antonio da Silva<sup>1</sup>.

<sup>1</sup> São Paulo State University (UNESP), Presidente Prudente, São Paulo, Brazil - (e.nascimento, aal.ferreira, thamires.godoy, caio.fontoura, guilherme.cardim, erivaldo.silva)@unesp.br

<sup>2</sup> University of Coimbra, Portugal- ppina@dct.uc.pt

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## ABSTRACT:

The need for updated cartographic products in Brazil is essential for effective planning and project implementation. Outdated maps, which can be up to three decades old, hinder various projects, making it necessary to find alternative methods for semi-automated cartographic updates. This study focuses on the use of orbital images obtained through Remote Sensing, processed using Digital Image Processing and Mathematical Morphology techniques. The methodology aims to extract and detect urban targets (allotments) and update an outdated cartographic database. The results obtained demonstrate the achievement of the established objectives, with the proposed methodology outperforming conventional filtering methods. Statistical validation confirms the effectiveness of post-processing techniques such as inpainting. The automated extraction and processing of features using software tools like MATLAB, CARTOMORPH, and QGIS prove to be an efficient solution for updating outdated maps. Ongoing research and refinement of methods aim to enhance the accuracy and reliability of the methodology, making valuable contributions to the cartographic community and benefiting map users worldwide.

## 1. INTRODUCTION

The identification of earth's surface changes is of crucial importance for Brazilian cartography since it becomes possible to update cartographic products for use in planning (Rodrigues, Silva and Leonardi, 2010). In addition, out-of-date cartographic products in Brazil can reach up to 3 decades at the most varied levels of detail, and because of this, several projects are impaired and even discontinued. Thus, as stated by Silva (2002), a country with vast dimensions needs a solid and updated cartographic base.

Alternatives that allow the cartographic update in a semi-automated way are therefore necessary. One of these alternatives is the use of orbital images obtained by Remote Sensing, processed by hybrid techniques of Digital Image Processing and Mathematical Morphology (MM), which allows the detection and/or extraction of cartographic features (Correia et al., 2005). Therefore, it is possible to update a cartographic product that is outdated, using, for example, vectorization techniques map x image.

The methodology presented by Silva and Leonardi (2009) exclusively uses Mathematical Morphology and the application of conventional filters (Gradient and Sobel) for the identification of racetracks. The authors applied an overlay technique on an existing topographic map that contains the interest feature to determine the detection accuracy. Rodrigues, Silva, and Leonardi (2010) also used mathematical morphology along with Digital Image Processing techniques, supporting the potential use of MM in the field of cartography.

In this article, in conjunction with the aforementioned authors, a methodology for the extraction and detection of urban targets (Allotments) will be addressed. An outdated cartographic database will be updated, unlike the authors Silva and Leonardi

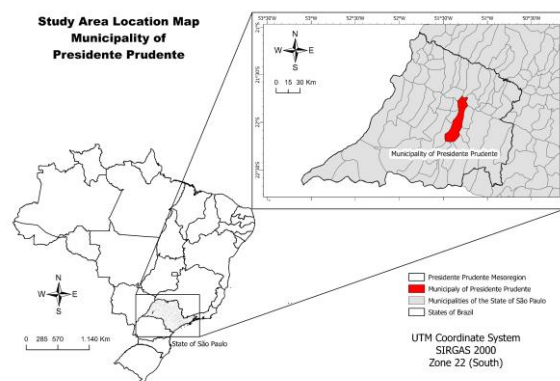
(2009) and Rodrigues, Silva, and Leonardi (2010) that use existing and current maps to overlay their results and evaluate their performance. Thus, this paper presents the results obtained from a semiautomatic routine to road extraction from an allotment in digital images and the updating of it on an outdated cartographic basis.

## 2. OBJECTIVE

To contribute to the process of semi-automation of information extraction from high spatial resolution images, aiming at updating outdated cartographic bases with hybrid techniques of Digital Image Processing and Mathematical Morphology.

## 3. MATERIALS AND METHODS

The study area relates to the allotments situated within the Municipality of Presidente Prudente, located in the interior of the state of São Paulo, as illustrated in Figure 1.



**Figure 1.** Study Area Location Map. Municipality of Presidente Prudente.

Da Costa (2019) mentions that Presidente Prudente underwent rapid urbanization coupled with disorderly growth. These combined factors may result in a hampered mapping of the municipality, possibly due to a lack of resources or the onerous nature of the task. Therefore, considering that the municipality suffers from this disparity, similar to other cities in the state of Sao Paulo, its use as an example is justified.

### 3.1 Materials

To execute the project, several software packages were used: MATLAB R2018b was used together with Image Processing toolbox, QGIS 3.16.15 and CARTOMORPH. The data used consists of a digital image acquired by CBERS 4 satellite and the cartographic base of the state of São Paulo (Geographic and Cartographic Institute - IGC).

### 3.2 Methods

#### 3.2.1 Mathematical Morphology (MM)

Serra (1982) defines mathematical morphology (MM) as a theory for digital image analysis based on set theory, lattice theory, and topology. MM involves structured morphological processing through displacement-invariant operators. Initially developed for binary images, MM has been successfully extended to grayscale and color images. In addition, Soille (2003) defined MM as a theory for the analysis of spatial structures, focused on the analysis of object shape and pattern. The term "morphology" refers to its goal of examining object form, while "mathematical" signifies that the analysis relies on a set of geometric and algebraic theories. As such, MM is not merely a theory, but a powerful technique for image analysis.

Soille (2003) provided a comprehensive exploration of the fundamental principles and techniques of morphological image analysis. MM is a powerful framework that utilizes set theory to process and analyze images, providing an efficient tool for feature enhancement and extraction of structural information.

Soille's book covers the essential aspects of binary and greyscale morphology, as well as geodesic operations, which enable the analysis of shape and connectivity of structures within an image. The author also presents numerous examples of how MM can be applied in several fields, such as medical imaging, remote sensing, and computer vision (Soille, 2003).

#### 3.2.2 Statistical Analysis of cartographic extractions

The evaluation of the results obtained are of fundamental importance because from this analysis it is possible to understand whether that result is reliable or not. For the evaluation, the Cartomorph software developed by Cardim (2015) will be used, in which a set of metrics are used by comparison with a reference image. The metrics used in this work will be the conventional ones: Completeness, Correctness, and Quality.

- Completeness

The first quality metric is known as completeness (Com) and can be defined by Equation 1. It represents the percentage of pixels in the ground-truth image (or reference mask) that the approach has accurately detected. This metric has a value ranging from 0 to 1, with 1 being considered ideal, as it indicates how comprehensive the approach is in terms of detecting pixels.

$$Com = \frac{TP}{TP + FN} \quad (1)$$

TP represents the true positives, which refers to the number of pixels that have been correctly detected. On the other hand, FN represents the false negatives, which are pixels that have not been detected by the approach, in accordance with the ground truth (GT).

- Correctness

The "correctness" (Cor) metric, as defined in Equation 2, represents the percentage of pixels that the method has correctly identified in accordance with the ground truth (GT). The ideal value for this metric is 1, indicating that the method has correctly identified all interest pixels.

$$Cor = \frac{TP}{TP + FP} \quad (2)$$

FP represents false positives, which refers to pixels that have been falsely detected.

- Quality

The final metric is the "quality" (Qua), as defined in Equation 3, which combines the two previous measures and indicates the overall performance of the approach. The ideal value for this metric is 1, which represents the highest level of quality and indicates that the approach has performed exceptionally well.

$$Qua = \frac{TP}{TP + FP + FN} \quad (3)$$

The value of the quality metric can be used to describe the overall performance of the approach, providing a measure of the quality that has been achieved.

#### 3.2.3 Image Georeferencing

Image georeferencing is the process of assigning geographic coordinates to each pixel of a digital image, allowing it to be accurately overlaid onto a geographic map. This enables spatial analysis and informed decision-making based on visual information. Georeferencing can be performed manually or using specialized software, such as ArcGIS and QGIS. This technique is widely applied in diverse fields such as cartography, surveying, agriculture, environmental management, and remote sensing.

The process of image georeferencing involves a geometric transformation that establishes a relationship between image coordinates and the geodesic or geographic coordinates of a map. In doing so, this transformation eliminates any distortions caused during the image formation process by the sensor system, as well as inaccuracies in the platform positioning data (Ladiwig; Silveira; Medeiros, 2015).

#### 3.2.4 Inpainting algorithm proposed by Liang-Jian Deng et al. (2015).

Inpainting is a technique that is used to fill in missing or corrupted parts of an image. In remote sensing, inpainting can be used to improve the quality of images that have missing or

distorted data due to various factors such as cloud cover or sensor malfunction.

One of the main benefits of inpainting in remote sensing is that it can improve the accuracy of image analysis, classification, and interpretation by providing a complete and coherent image. Inpainting techniques can be used to fill in missing data using information from neighboring pixels or other images acquired at different times or wavelengths. This can help to minimize the impact of missing data on subsequent analysis.

According to Figueira et al. (2020), image inpainting aims at repairing the damaged regions of an image and/or even removing some specific objects. This stage of the application of inpainting will serve as a post-processing step, aiming to improve and optimize the results obtained after the application of the proposed methodology.

### 3.2.5 Methodological Flowchart

The sequence developed in this paper, from the extraction of the feature to the cartographic update is presented in Figure 2.

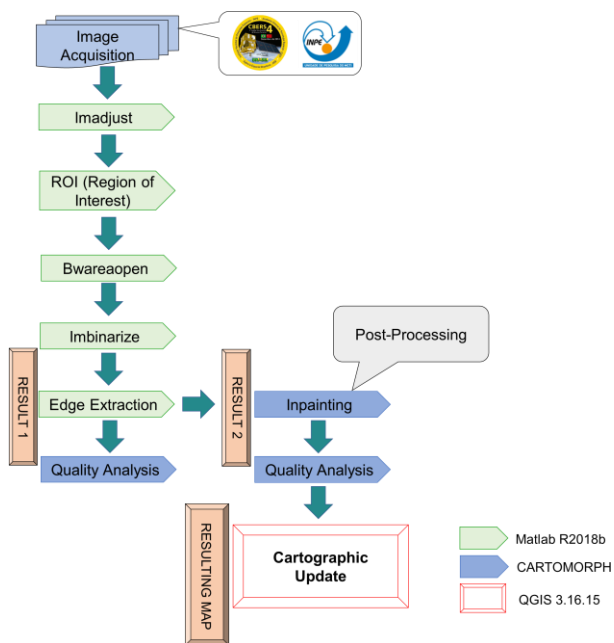


Figure 2. Flowchart

The proposed methodology incorporates a series of morphological operators and image processing techniques to update outdated cartographic products. In this study, three morphological operators, namely *imadjust*, *imbinarize*, and *bwareaopen*, were utilized. The *imadjust* operator is applied to enhance image contrast, thereby improving the visibility of cartographic features. The *imbinarize* operator converts the adjusted image into a binary representation, facilitating subsequent processing steps. The *bwareaopen* operator effectively removes noise and small unwanted objects from the binary image, ensuring the preservation of relevant cartographic elements. These morphological operators are part of a specialized toolbox specifically designed for Mathematical Morphology (MM) applications. This toolbox, available in the MATLAB software platform developed by SDC Information Systems, encompasses a comprehensive set of morphological operators used in mathematical morphology. Additionally, the Region of Interest (ROI) technique is employed to selectively process and analyze specific areas of interest within the image. By applying

this technique, the algorithm detects and extracts relevant cartographic features within the defined ROI. To address partially detected areas, a post-processing technique known as inpainting, as proposed by Liang-Jian Deng et al. (2015), is utilized. The inpainting technique reconstructs missing or discontinuous parts of the cartographic features, ensuring their completeness and accuracy. Lastly, the updated cartographic information obtained from the post-processing stage is superimposed onto the outdated cartographic base. This integration allows for the visualization and comparison of the updated features with the original base, enabling the assessment of the improvements made during the updating process.

## 4. RESULTS AND DISCUSSIONS

The features of interest are the residential allotments Damha Beldelvere (Figure 3a) and the Damha IV (Figure 5a), located in Presidente Prudente -SP.

It is noteworthy that these test areas were chosen since they are not yet included in the cartographic base of the state of São Paulo provided by the Geographic and Cartographic Institute (IGC) database.

The results obtained from the routine application are illustrated in Figure 3.

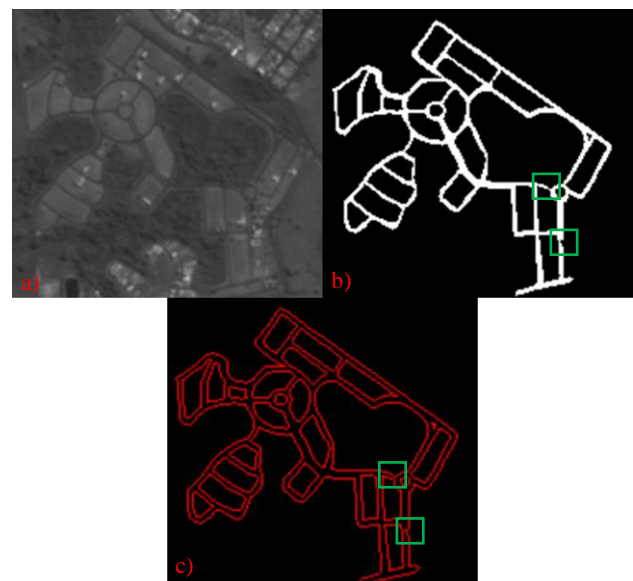
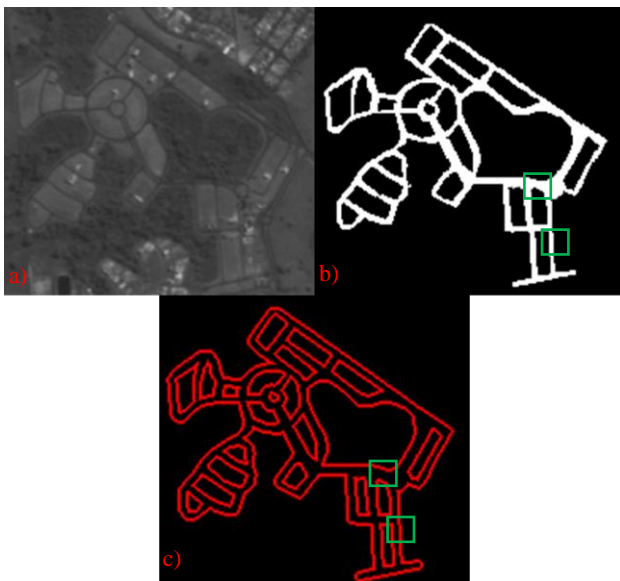


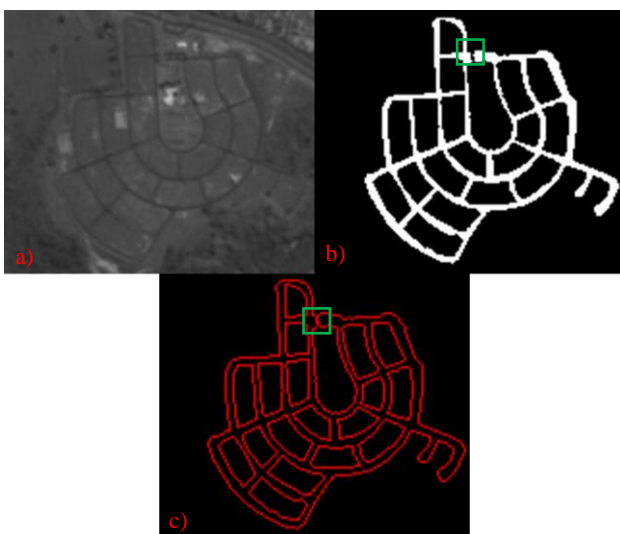
Figure 3. Application of the methodology: Damha Beldelvere allotment. A) original image; b) result of the application of routine; c) contours of the extracted feature.

In Figure 3, the application of the methodology discussed in this article is presented. Visually, items b and c in Figure 3, highlighted in green, showed discontinuities (noise) resulting from the application of the methodology. To improve the results, post-processing was applied to enhance the quality of the extraction. The results of the post-processing (Inpainting) can be seen in Figure 4.



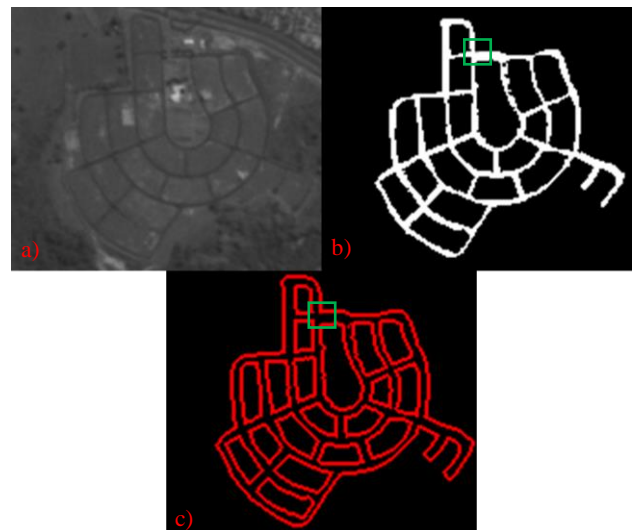
**Figure 4.** Application of the methodology with Inpainting: Damha Beldelvere allotment. A) original image; b) result of the application of routine; c) contours of the extracted feature.

In Figure 4, the green-highlighted area indicates that the discontinuities were reconstructed. A preliminary (visual) analysis suggests that the results improved after reconstruction. Similarly, the routine was applied for the second characteristic (Figure 5).



**Figure 5.** Application of the methodology: Damha IV allotment. A) original image; b) result of the application of routine; c) contours of the extracted feature.

Figure 5 displays the application of the methodology discussed in this article for the second feature of interest. Similar to Figure 3, green-highlighted items b and c in Figure 5 also showed discontinuities (noise) resulting from the methodology's application. Similarly to the previous process depicted in Figure 4, inpainting was used to improve extraction quality. The results of the post-processing (inpainting) can be seen in Figure 6.



**Figure 6.** Application of the methodology with Inpainting: Damha IV allotment. A) original image; b) result of the application of routine; c) contours of the extracted feature.

In Figure 6, items b and c highlighted in green indicate that the discontinuities were reconstructed. A preliminary (visual) analysis suggests that the results improved after reconstruction. To confirm the preliminary visual analyses, a statistical analysis was performed using the operator's correctness, completeness, and quality. The results are shown in Table 1. The values for these metrics range from [0;1], with 1 being regarded as a perfect detection (Wiedemann, 2003).

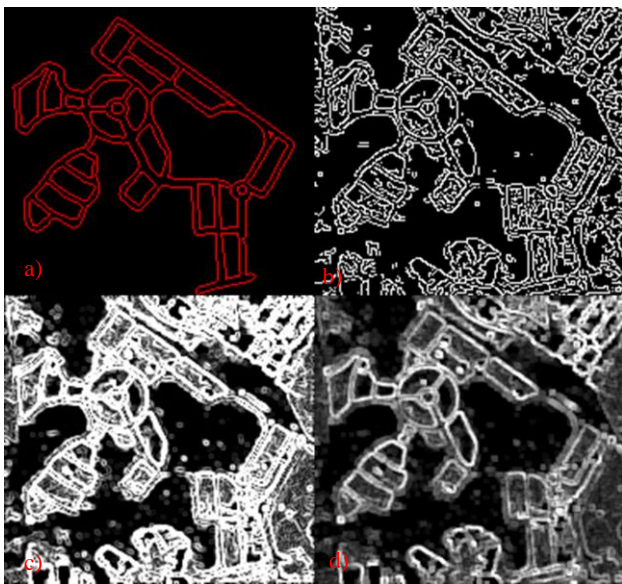
Features	Completeness	Correctness	Quality
Feature 1	0,8665	0,9197	0,8056
<b>Feature 1 with inpainting</b>	0.8676	0.9198	0.8146
Feature 2	0,9424	0,9825	0,9271
<b>Feature 2 with inpainting</b>	0.9513	0.9855	0.9278

**Table 1.** Performance evaluation.

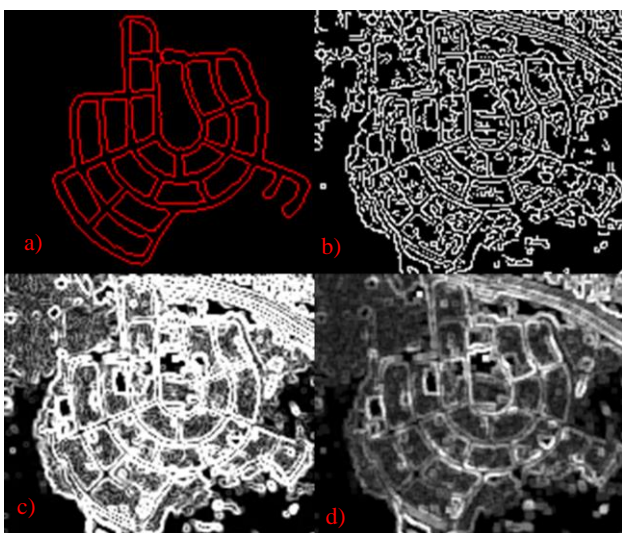
As shown in Table 1, the post-processing (feature with inpainting) step improved the quality of the results, which is in agreement with the preliminary visual analysis, as expected. It is worth noting that even without the inpainting step, the results were satisfactory (above 0.80).

To perform a visual comparison between the methodology proposed in this work and conventional filters, the object of study was subjected to conventional filters such as Canny, Sobel, and Gradient. Below, in Figures 7 and 8, the results of these filters are shown. The results of applying the conventional filters and those of the proposed methodology are presented to facilitate the comparison. In Figure 7, (a), (b), (c), and (d) represent the results for the Damha Beldelvere allotment, while in Figure 8, (a), (b), (c), and (d) correspond to the Damha IV allotment.





**Figure 7.** Damha Beldelvere allotment: Visual comparison of the object of study from the proposed methodology with the application of conventional filters. a) Result of the proposed methodology, b) Canny, c) Sobel, and d) Gradient.

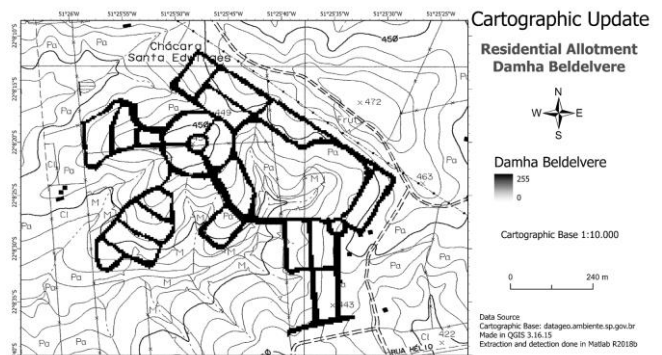


**Figure 8.** Damha IV allotment: Visual comparison of the object of study from the proposed methodology with the application of conventional filters. a) Result of the proposed methodology, b) Canny, c) Sobel, and d) Gradient.

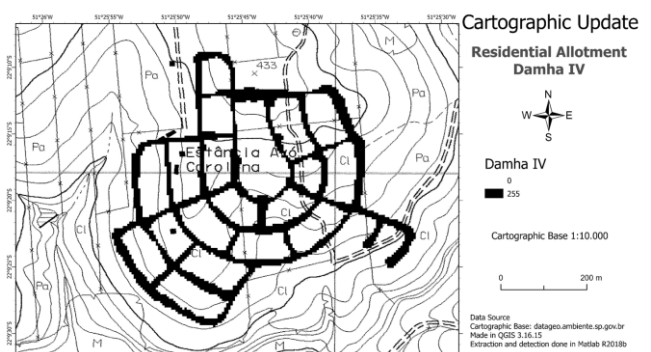
During the visual comparison between the results obtained by the morphological operators and the conventional ones shown in Figures 7 and 8, it is evident that the results obtained conventionally exhibit greater difficulty in accurately delineating the features of interest. The complexity of the scene contributes to this challenge, as the conventional filters tend to produce more segmented outputs. In contrast, the proposed methodology achieves a higher level of visual precision, providing a more accurate representation of the features of interest.

Thus, the feature was updated in an outdated cartographic database using the post-processed results, which not only provided superior statistical values (as shown in Table 1) but also demonstrated the best performance compared to the conventional methods seen in Figures 7 and 8. Therefore, it was understood

that the post-processed results were the most suitable choice for the database update. The updated cartographic database obtained through the methodology is presented in Figures 9 and 10.



**Figure 9.** Result of the cartographic update: Damha Beldelvere allotment.



**Figure 10.** Result of the cartographic update: Damha IV allotment.

The features of interest were inserted into the cartographic database of the state of São Paulo. It is worth noting that this process was performed in QGIS.

## 5. CONCLUSION

From the results obtained, the established objectives were successfully achieved. However, it is important to note that the quality of the data used in the feature extraction/detection process is crucial to obtain accurate and reliable results. It is important to remember that a comparison was made with conventional filtering methods, and the proposed methodology demonstrated superior visual outcomes.

The improved results were statistically validated by Table 1, which showed a significant difference before and after the application of post-processing techniques, such as inpainting, as can be seen in Figures 3 and 5. It should be emphasized that the automated methodology of extracting features from digital images and their processing through appropriate software tools, such as MATLAB, CARTOMORPH, and QGIS, proves to be an effective solution for updating outdated maps.

This work represents part of our continuous effort to enhance the accuracy and reliability of the methodology, aiming for its safe application in cartographic updating processes. Therefore, we are actively conducting further research in new areas and refining our

methods to achieve even better performance. We hope that our ongoing efforts will make valuable contributions to the cartographic community and benefit map users worldwide.

#### ACKNOWLEDGEMENTS

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