Simpósio Nacional de Instrumentação Agropecuária

SIAGRO

São Carlos

Ciência • Tecnologia • Inovação • Mercado

14 a 16 de outubro de 2025 | Embrapa Instrumentação São Carlos - SP

Anais

Editores:

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ISSN 2358-9132

Embrapa Instrumentação

ISSN 2358-9132

Empresa Brasileira de Pesquisa Agropecuária
Embrapa Instrumentação
Ministério da Agricultura, Pecuária e Abastecimento

Simpósio Nacional de Instrumentação Agropecuária 2025

Anais do SIAGRO

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Embrapa Instrumentação
São Carlos, SP
2025

Exemplares desta publicação podem ser adquiridos na:

Embrapa Instrumentação
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Rua XV de Novembro, 1452
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Editoração eletrônica: Valentim Monzane

1ª edição
Publicação digital (2025): PDF

Dados internacionais de catalogação (CIP)
Embrapa Instrumentação

S612 Simpósio Nacional de Instrumentação Agropecuária (5.: 2025 : São Carlos, SP).
Anais do SIAGRO: ciência, inovação e mercado 2025 – São Carlos, SP: Embrapa Instrumentação, 2025.

ISSN 2358-9132

1. Instrumentação agropecuária. 2. Automação de processos agrícolas. 3. Agricultura de precisão. 4. Sensores. 5. Equipamentos agrícolas. 6. Monitoramento. 7. Nanotecnologia. 8. Modelagem. 9. Métodos avançados. 10. Inovação. 11. Tecnologias convergentes. I. Herrmann Junior, P. S. P. II. Azeredo, H. M. C. III. Durigan, M. F. B. IV. Bassoi, L. H. V. Título.

CDD 21 ED 681.763

Vera Viana dos Santos Brandão (CRB – 8/7283)

ESTIMATION OF FOREST METRICS IN INTEGRATED PRODUCTION SYSTEMS USING DIGITAL AERIAL PHOTOGRAMMETRY

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Abstract: The use of remote sensing to estimate forest metrics has proven to be an excellent option for reducing cost and time in forest inventories. In areas with fragmented vegetation, digital aerial photogrammetry (DAP) can be applied, further reducing costs as it uses passive sensors. Therefore, integrated production system areas are good candidates for achieving positive results. We assessed whether DAP via unmanned aerial vehicle (UAV) equipped with an RGB camera is capable of estimating forest metrics such as diameter at breast height (DBH) and height in crop-livestock-forest integration (ICLF) and livestock-forest integration (ILF) systems, composed of native tree species under different management practices. Using height metrics and canopy cover metrics derived from the point cloud, we were able to fit regression models for estimating mean DBH and mean height. The predictive model for mean DBH achieved an R^2 of 0.540 and RMSE of 2.30 cm, while the mean height model presented 0.640 and 1.30 m. We concluded that DAP is capable of estimating forest metrics in ICLF and ILF with low cost.

Keywords: photogrammetry, dendrometry, remote sensing, point cloud

ESTIMATIVA DE MÉTRICAS FLORESTAIS EM SISTEMAS INTEGRADOS DE PRODUÇÃO UTILIZANDO FOTOGRAMETRIA AÉREA DIGITAL

Resumo: O uso de sensoriamento remoto para estimar métricas florestais vem se mostrando uma ótima opção para redução de custo e tempo em inventários florestais. Em áreas com vegetação fragmentada a fotogrametria aérea digital (FAD) pode ser aplicada, reduzindo ainda mais os custos, pois utiliza sensores passivos. Visto isso, áreas de sistemas de integrados de produção são candidatos a obterem bons resultados. Avaliamos se a FAD via aeronave pilotada remotamente (ARP) embarcada com câmera RGB, é capaz de estimar métricas florestais como diâmetro altura do peito (DAP) e altura em áreas de sistemas de integração lavoura-pecuária- floresta (ILPF) e integração pecuária-floresta (IPF), compostos por espécies arbóreas nativas sob diferentes manejos. Utilizando métricas de altura e cobertura de dossel da nuvem de pontos, foi possível ajustar modelos de regressão para a estimativa de DAP médio e altura média. O modelo preditivo de DAP obteve R^2 de 0,540 e RMSE de 2,30 cm, enquanto o da altura apresentou 0,640 e 1,30 m. Foi possível concluir que a DAP é capaz de estimar métricas florestais em áreas de ILPF e IPF com baixo custo.

Palavras-chave: fotogrametria, dendrometria, sensoriamento remoto, nuvem de pontos

1. Introduction

Traditional forest inventories are costly and time-consuming operations, primarily due to field campaigns and logistics (Almeida et al., 2020). To reduce cost and time, the use of remote sensing to estimate forest metrics has proven to be an excellent option. Therefore, the use of digital aerial photogrammetry (DAP) emerges as an alternative, as it uses passive sensors which are cheaper than active sensors (Goodbody et al., 2019; Almeida et al., 2020). Through technological advancements in remotely piloted aircraft (RPA), including lower equipment costs, ease of overflights, higher frequency of high-resolution image acquisition, coupled with the development of image processing techniques, the 3D products derived from DAP have shown satisfactory results in estimating forest metrics across different ecosystems (Goodbody et al., 2019; Cao et al., 2019; Almeida et al., 2020; D'Oliveira et al., 2021; Fu et al., 2021).
The accuracy in estimating forest metrics from 3D products generated by DAP is linked to the quality of the digital terrain model (DTM) produced, as this is used in the normalization of the point cloud (Almeida et al., 2020; D'Oliveira et al., 2021). Studies show that DAP is a suitable option for estimating forest metrics in areas with fragmented vegetation, where the ground is clearly visible, enhancing DTM accuracy (Almeida et al., 2020; Queiroz et al., 2023). Therefore, integrated production system areas such as crop-livestock-forest integration (ICLF) and livestock-forest integration (ILF) are candidates for achieving good results. This is because tree planting lines are implemented in rows separated by forage species. The present study aimed to evaluate the accuracy of the MDT generated through DAP, as well as extract the mean DBH (diameter at breast height) and the mean height through the 3D point cloud, developing prediction models for these variables in integrated production systems, such as ICLF and ILF.

2. Materials and Methods

2.1. Study area

This study was conducted in experimental areas of integrated production systems at Canchim Farm, belonging to the Brazilian Agricultural Research Corporation – Southeast Livestock (EMBRAPA – CPPSE), located at coordinates 7568936.91 m S and 206447.21 m E (UTM) in the municipality of São Carlos, São Paulo. The integrated systems consist of signalgrass pasture (*Urochloa decumbens* Stapf) intercropped with native forest species implemented in December 2007 and January 2008. They comprise planting rows arranged in three-line bands, spaced 22 m apart from the center line, with 2.5 m x 2.5 m spacing between individual trees, resulting in approximately 545 trees/hectare. The integrated systems are subdivided into two types: crop-livestock-forest integration (ICLF), named M (1.20 ha), N (1.90 ha), and G (2.14 ha); and livestock-forest integration (ILF), named K (3.76 ha) and L (4.00 ha). ICLF-M underwent one thinning and ICLF-N underwent two thinnings, resulting in approximately 365 trees/ha and 180 trees/ha, respectively. ICLF-G was not subjected to any management or thinning. ILF-K and ILF-L underwent two thinnings each, resulting in approximately 310 trees/ha each.

2.2. Data collection and processing

First, the forest inventory was conducted between March and April 2022. DBH (cm) and height (m) were measured for all living trees within each of 30 plots, comprising six per area. Then the flights were performed with 85% front and side overlap at 120 m altitude, resulting in a GSD of 4.40 cm. The images processing was performed using Pix4D Mapper 4.8.4 software (Pix4D Incorporation, 2023), including the generation of the orthomosaic, DTM and point cloud. The DTM quality was assessed by comparing 87 field-collected GNSS points with DTM-derived estimates. Then, the point cloud was normalized using the DTM from Pix4D Mapper 4.8.4. Point cloud metrics were extracted using FUSION/LDV 4.61 software (McGaughey, 2024). The regression analysis between the observed metrics in forest inventory and point cloud metrics was conducted in computational environment using the R software, version 4.4.1 (R Core Team, 2024). For selecting the best combination of explanatory variables, Bayesian Information Criterion (BIC), Coefficient of Determination (R^2), and root mean square error (RMSE) values were analyzed. Shapiro-Wilk test (5% significance) assessed residual normality of selected models, while Bartlett's test evaluated homoscedasticity (Legendre & Legendre 2012). Multicollinearity was assessed using Variance Inflation Factor (VIF) (Montgomery, 2012). Predictive capacity of chosen models was evaluated via Monte Carlo cross-validation, with 1,000 random splits into training (80%) and validation (20%) datasets (Picard & Cook, 2012) After selecting prediction models for mean DBH and mean height, the variables that composed each model were rasterized with FUSION/LDV 4.6.1. Finally, the raster calculator in software QGIS 3.28.9 was used to spatialize the studied variables.

3. Results and Discussion

The generated DTM was satisfactory and presented R^2 of 0.985 and RMSE of 0.825 m, adequately representing the terrain reality of the study area. The results in this study were similar to those reported by Almeida et al. (2020), who obtained an R^2 of 0.980 and RMSE of 1.04 m. When generating a DTM from DAP in Brazilian savannah, Queiroz et al. (2023) achieved an adjusted R^2 of 0.990 and RMSE of 4.60 m after cross-validation. These areas are highly fragmented, allowing clear ground visibility, primarily due to their stratification and low canopy height (Ribeiro & Walter, 1998), which enables the creation of highly reliable DTMs (Almeida et al., 2020).

The predictive model for mean DBH presented R^2 of 0.540 and RMSE of 2.30 cm after cross-validation, with two height metrics namely H020 (points above 0.20 m from the ground) and H40 (40% of point cloud points below this threshold). Despite exhibiting a relatively low R^2, the error was also considered low due to the close relationship between DBH and height in planted forests (Fu et al., 2021). In other forest types, additional metrics may be necessary for more accurate DBH estimation. For example, in Atlantic Forest areas, Almeida et al. (2020) achieved R^2 of 0.880 and RMSE of 0.800 cm using six variables, one Fourier transform metric (Amp06), four height metrics (HL3, HL4, HLskew, H01), and one canopy cover metric (CC%Hmean). The Fourier transform captured subtle details of vertical structure (Gonçalves, 2014), while height and cover metrics improved model accuracy. In poplar and metasequoia plantations, Cao et al. (2019) obtained R^2 of 0.570 and RMSE of 5.17 cm using two canopy density metrics (D5, D7) and one canopy volume metric (closed). This error was substantially higher than in the present study, despite Cao et al. (2019) used LiDAR-derived DTM.

The predictive model for mean height presented R^2 of 0.640 and RMSE of 1.30 m, with two height metrics (Hmean and H01) and one canopy cover metric (CCHmode). Hmean indicates the mean height of points, H01 represents the threshold below which 1% of the point cloud lies, while CCHmode represents the total points above the height mode threshold starting at 1.50 m. The model showed poorer fit but lower error when compared to Cao et al. (2019), who achieved R^2 of 0.830 and RMSE of 2.60 m using a model with two height metrics (H25, H95) and one canopy cover metric (D3). Conversely, better-fitting models with lower error were obtained by Almeida et al. (2020), who achieved R^2 of 0.840 and RMSE of 0.900 m, using two Fourier transform metrics (Amp08, Amp25) and four height metrics (HLkurt, H01, H05, H10). Thus, more complex metrics may improve precision and reduce error in estimating mean tree height.

After fitting the predictive models, they were used to spatialize the mean DBH and mean height to the entire study area (Figure 1).

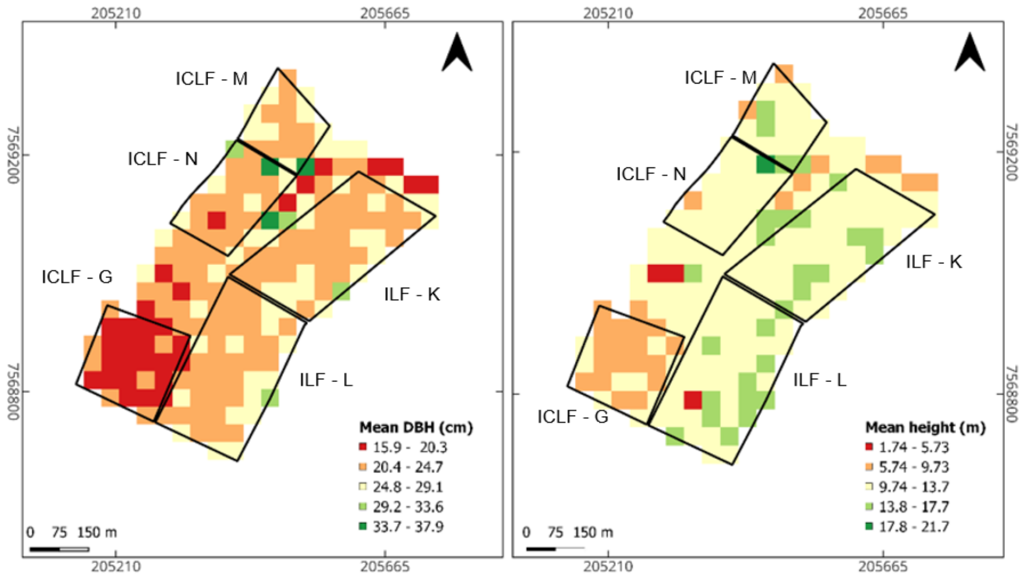

Figure 1. Mean DBH and mean height specialization for the entire study area.

4. Conclusions

DAP proved to be an excellent option for generating products such as DTMs and point clouds in ICLF and ILF areas. Using metrics extracted from the point cloud, it was possible to adjust models for satisfactory estimation of mean DBH and mean height. This method provides forest managers with rapid access to information about the tree component, supporting decision-making regarding the need for forest management interventions, as well as the assessment of previously implemented management practices. As a final product, the spatial mapping of forest metrics enables the observation of growth trends across the area of interest where direct forest metric measurements were not conducted.

In future studies, more sophisticated metrics to increase the R^2 value should be used, such as the Fourier transform, that can captured subtle details of the arboreal vertical structure.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001

References

Almeida, A., Gonçalves, F., Silva, G., Souza, R., Treuhaft, R., Santos, W., Loureiro, D., & Fernandes, M. (2020). Estimating Structure and Biomass of a Secondary Atlantic Forest in Brazil Using Fourier Transforms of Vertical Profiles Derived from UAV Photogrammetry Point Clouds. Remote Sensing, 12(21), 3560.https://doi.org/10.3390/rs12213560

Cao, L., Liu, H., Fu, X., Zhang, Z., Shen, X., & Ruan, H. (2019). Comparison of UAV LiDAR and Digital Aerial Photogrammetry Point Clouds for Estimating Forest Structural

Attributes in Subtropical Planted Forests. *Forests*, 10(2), 145. https://doi.org/10.3390/f10020145
D'Oliveira, M. V. N., Figueiredo, E. O., Almeida, D. R. A., Oliveira, L. C., Silva, C. A., Nelson, B. W., Cunha, R. M., Papa, D. A., Stark, S. C. & Valbuena, R. (2021). Impacts of selective logging on Amazon forest canopy structure and biomass with a LiDAR and photogrammetric survey sequence. *Forest Ecology and Management*, 500, 119648. https://doi.org/10.1016/j.foreco.2021.119648
Fu, X., Zhang, Z., Cao, L., Coops, N. C., Goodbody, T. R. H., Liu, H., Shen, X. & Wu, X. (2021). Assessment of approaches for monitoring forest structure dynamics using bi-temporal digital aerial photogrammetry point clouds. *Remote Sensing of Environment*, 255, 112300. https://doi.org/10.1016/j.rse.2021.112300
Gonçalves, F. G. (2014). *Vertical Structure and Aboveground Biomass of Tropical Forests from Lidar Remote Sensing*. (Doctoral dissertation). Oregon State University. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/1n79h9029
Goodbody, T.R.H., Coops, N.C. & White, J.C. (2019). Digital Aerial Photogrammetry for Updating Area-Based Forest Inventories: A Review of Opportunities, Challenges, and Future Directions. *Current Forestry Reports,* 5, 55–75. https://doi.org/10.1007/s40725-019-00087-2
LEGENDRE, P; LEGENDRE, L. (2012). *Numerical Ecology*. 3. ed. Elsevier.
McGaughey, R. J. (2024). FUSION/LDV: Software for LiDAR Data Analysis and Visualization. Version 4.61. Washington: USDA/Forest Service/PNRS. http://forsys.cfr.washington.edu/fusion/fusionlatest.html
Montgomery, D. C.; Peck, E. A.; Vining, G. G. (2012). *Introduction to linear regression analysis*. 5 ed. Wiley & Sons
Picard, R. R., & Cook, R. D. (2012). Cross-Validation of Regression Models. *Journal of the American Statistical Association*, 79(387), 575–583.https://doi.org/10.2307/2288403
Pix 4D Incorporation. (2023). *Pix4D Mapper*, Version 4.8.4. https://www.pix4d.com/product/pix4dmapper-photogrammetry-software/
Queiroz, R. F. P., d'Oliveira, M. V. N., Rezende, A. V., & de Alencar, P. A. L. (2023). Estimation of Aboveground Biomass Stock in Tropical Savannas Using Photogrammetric Imaging. *Drones*, 7(8), 493. https://doi.org/10.3390/drones7080493
R Core Team (2024). A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/
Ribeiro, J. F., Walter, B. M. T. (1998). Fitofisionomias Do Bioma Cerrado. *In:* Sano, S. M., Almeida, S. P. (eds.). *Cerrado: Ambiente e Flora*. (pp. 89-166). Planaltina: Embrapa Cerrados.