REVISTA DO SEMINÁRIO INTERNACIONAL DE ESTATÍSTICA COM R | **ISSN: 2526-7299**

VOL 5, Nº 2, JULHO DE 2024

VIII SEMINÁRIO INTERNACIONAL DE ESTATÍSTICA COM R - AI IN DATA SCIENCE

OPERATIONALIZING TLS IN FOREST INVENTORIES: THE R PACKAGE FORTLS

Mª José Ginzo Villamayor[1]

Juan Manuel Molina Valero[2]

Adela Martínez Calvo[3]

Manuel Antonio Novo Pérez[4]

Juan Gabriel Álvarez González[3]

Fernando Montes Pita[5]

César Pérez Cruzado[3]

Resumo

A digitalização a laser terrestre (TLS) oferece representações de superfície 3D rápidas, automáticas e detalhadas usando um scanner de fácil utilização. Essa tecnologia é bastante promissora para os Inventários Florestais (FIs). No entanto, sua aplicação operacional é prejudicada pela ausência de algoritmos bem estabelecidos para o processamento de dados de TLS. Para resolver esse problema, apresentamos o FORTLS, um pacote R projetado especificamente para automatizar o processamento de dados de nuvem de pontos TLS para aplicações florestais. O pacote FORTLS permite: (i) Detecção de árvores e estimativa de seu diâmetro à altura do peito (dbh), (ii) Estimativa de diversas variáveis de estande (por exemplo, densidade, área basal, média e altura dominante), (iii) Cálculo de métricas relacionadas aos principais atributos das árvores estimados em FIs no nível do povoamento; e (iv) Otimização do projeto da parcela para integrar os dados do TLS com as medições de campo. O FORTLS funciona de forma eficaz com dados TLS de varredura única, melhorando a eficiência da aquisição de dados, reduzindo o tempo de processamento e aumentando o tamanho das amostras de forma econômica. O pacote também inclui recursos para corrigir problemas de oclusão, o que leva a estimativas aprimoradas das variáveis do estande. Esses recursos facilitam o uso operacional do TLS em FIs, complementados por técnicas de inferência de abordagens baseadas em modelos e assistidas por modelos.

Palavras-chave: Parâmetros de povoamentos florestais; LiDAR; Silvicultura de precisão; Sensoriamento remoto; Tecnologias terrestres.

Abstract

Terrestrial Laser Scanning (TLS) offers rapid, automatic, and detailed 3D surface representations using a user-friendly scanner. This technology holds significant promise for

---

[1] Universidade de Santiago de Compostela (USC) and Centro de Investigación y Tecnología Matemática de Galicia (CITMAGA)

[2] Czech University of Life Sciences Prague (CZU)

[3] Universidade de Santiago de Compostela (USC)

[4] Centro de Investigación y Tecnología Matemática de Galicia (CITMAGA)

[5] Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)

Forest Inventories (FIs). However, its operational application is hindered by the absence of well-established algorithms for processing TLS data. To address this, we introduce FORTLS, an R package specifically designed to automate TLS point cloud data processing for forestry applications. The FORTLS package enables: (i) Detection of trees and estimation of their diameter at breast height (dbh), (ii) Estimation of various stand variables (e.g., density, basal area, mean, and dominant height), (iii) Calculation of metrics related to key tree attributes estimated in FIs at the stand level, and (iv) Optimization of plot design to integrate TLS data with field measurements. FORTLS works effectively with single-scan TLS data, enhancing data acquisition efficiency, reducing processing time, and increasing sample sizes cost-effectively. The package also includes features to correct occlusion issues, leading to improved estimates of stand variables. These capabilities facilitate the operational use of TLS in FIs, complemented by inference techniques from model-based and model-assisted approaches.
Keywords: Forest stands parameters; LiDAR; Precision forestry; Remote sensing; Terrestrial-based-technologies.

Introduction

Forest inventories (FIs) are vital for sustainable forest management and policy development, offering crucial data for global and regional forest resource estimation and monitoring (Tomppo et al., 2010). Technological advancements, particularly in remote and proximal sensing, have significantly improved FIs. Light detection and ranging (LiDAR) systems, such as airborne laser scanning (ALS) and terrestrial laser scanning (TLS), generate 3D point clouds, aiding in estimating tree attributes effectively. ALS is operational for estimating variables like mean height, basal area, and volume at the stand level (White et al., 2016), while TLS provides higher spatial resolution under the canopy, enhancing observations of near-ground vegetation and trunk coverage, crucial for measurements like diameter at breast height (dbh) and stem curves (White et al., 2016).

However, TLS adoption in FIs faces challenges such as high acquisition costs, limited software, and a lack of trained personnel (Liang et al., 2016). Efficient and affordable automation of data processing to extract forest attributes is crucial (White et al., 2016; Liang et al., 2016). While various algorithms and software applications have been developed, they often focus on single trees, involve semi-automatic processing, or are commercially available (Krok et al., 2020). The FORTLS R package addresses these challenges by automating TLS point cloud data processing and estimating forestry variables (Molina-Valero et al., 2021). It detects trees, estimates dbh and other attributes, computes stand-level metrics, and optimizes plot design by combining TLS and field-measured data. Designed to facilitate operational TLS use through a single-scan approach, FORTLS enhances data acquisition efficiency, reduces processing time, and increases sample size without requiring pre-scanning tasks or complex post-processing. A case study in a Pinus sylvestris stand in northern Spain demonstrated FORTLS's potential for operational use in FIs, which could significantly improve the efficiency and accuracy of forest inventories, supporting better forest management and policy-making.

Objective

The FORTLS package enables (i) detection of dbh and other tree attributes, (ii) estimation of stand variables such as height (h), basal area (G), and volume (V), (iii) computation of metrics related to essential tree attributes at the stand level, and (iv) optimization of plot design by integrating TLS data with field-measured data. It also includes features to correct occlusion issues, enhancing the accuracy of stand variable estimates. The current version of FORTLS utilizes single-scan TLS data to facilitate operational use and is designed as easy-to-use open-source software for both scientists and technical users.

Material and Methods

The R package FORTLS (Molina-Valero et al., 2021) was developed to leverage the accessibility of R, a free statistical software (R Core Team, 2021). Initial development stages were described by Molina-Valero et al. (2020), and the first version was released in March 2021. The latest stable version and the most recent development version of FORTLS are available for free from CRAN and GitHub, respectively. To optimize FORTLS, demanding computing processes were enhanced using C++ code with the Rcpp package (Eddelbuettel & Balamuta, 2018) and the RcppEigen package (Bates & Eddelbuettel, 2013), which integrates the Eigen C++ library for matrix calculations. Spatial data operations utilize the raster (Hijmans, 2020) and sp (Bivand et al., 2013) packages. Voronoi polygons are generated using ggvoronoi (Garrett et al., 2021), and large TLS point cloud datasets are handled with the vroom package (Hester & Wickham, 2020). Interactive graphics are created with plotly (Sievert, 2020) and htmlwidgets (Vaidyanathan et al., 2020). Additional packages include progress (Csárdi & FitzJohn, 2019), scales (Wickham & Seidel, 2020), and tidyr (Wickham, 2021) for various specific tasks. This work is based on the stable version 1.0.6 of FORTLS available on CRAN. Key steps in TLS point cloud data processing with FORTLS are outlined, including (i) normalization, (ii) tree detection, and (iii) estimation of metrics and variables at the stand level.

Results

The steps for processing TLS data with FORTLS are outlined below, detailing the various operations and function arguments involved. Finally, the results of TLS data processing using FORTLS are presented for the case study mentioned earlier. Users can install the released version of FORTLS from CRAN or the latest development version from GitHub using the install_github function from the devtools package (Wickham et al., 2021). The functions are designed for two primary uses of TLS data: (1) conservative tree detection, prioritizing accuracy, and (2) computation of metrics and variables related to forest attributes, either (2.1) without field data or (2.2) with field data. The workflow for these functions is illustrated in Figure 6 (Molina-Valero *et* al., 2022). Although the workflow can be executed directly in the current R session, most functions are designed to import data and save results to a specified working directory, defined by the dir.data and dir.result arguments, to facilitate efficient operation. Notably, outputs from previous functions often serve as inputs for subsequent ones, making it advantageous to use the same directory for data and results. A script with a complete workflow example is provided as supplementary material in Molina-Valero et al., 2022.

Discussion

Despite advancements in TLS (terrestrial laser scanning) algorithms and applications for forestry (Krok et al., 2020), TLS is not yet a standard tool in forest inventories (FIs) (Liang et al., 2016). Automation of point cloud processing with user-friendly software is essential (White et al., 2016). The FORTLS R package addresses this by automating TLS point cloud processing for estimating FI variables, detecting trees, and generating metrics at the stand level. It allows for assessment and optimization of plot designs by comparing TLS data with field data. This flexibility sets FORTLS apart from applications like Computree, SimpleForest, AdTree, and TreeGSM, which focus on detailed tree attributes rather than stand-level metrics. FORTLS uses single scans to cover larger areas, viewing TLS as a sampling tool rather than a measurement instrument. This approach is rare, with few comparable applications like 3D Forest and AutoStem™. FORTLS incorporates occlusion correction methods, improving estimates in larger plots, consistent with findings. It evaluates correlations between TLS-derived metrics and forest variables, facilitating model-assisted inference, similar to ABA inference for ALS devices. This enables efficient sampling and demonstrates FORTLS's utility in FIs by increasing sample size cost-effectively without requiring point cloud co-registration or field measurement targets (Liang et al., 2016). Future research should explore more complex study cases, additional metrics, model-assisted methodologies, and enhance computation processes for broader application. FORTLS is available on CRAN and GitHub.

Conclusions

The R package FORTLS is valuable software for processing TLS (terrestrial laser scanning) data for forestry applications. It offers significant advantages by working with single scans and automating data processing, addressing the major challenge of affordability in data acquisition and processing. Initial case studies have shown promising results for conventional variables, with direct estimates and strong correlations between field-derived and TLS-derived metrics and variables. However, its potential for producing model-assisted inferences from these metrics and variables remains to be demonstrated. One of the software's most valuable features is its flexibility, allowing it to adapt to the best possible plot design for each variable and enabling the use of multiple plot designs within a single sampling framework. To fully establish FORTLS as an operational tool in forest inventories, further research involving larger and more complex case studies is needed. Additionally, developing new metrics and variables will enhance its applicability and effectiveness.

References

TOMPPO, E., GSCHWANTNER, T., LAWRENCE, M., MCROBERTS, R.E., GABLER, K., SCHADAUER, K., CIENCIALA, E., 2010. **National forest inventories. Pathways for common reporting**. European Science Foundation 1, 541–553.

WHITE, J.C., COOPS, N.C., WULDER, M.A., VASTARANTA, M., HILKER, T., TOMPALSKI, P., 2016. **Remote sensing technologies for enhancing forest inventories: a review**. Can. J. Rem. Sens. 42 (5), 619–641.

LIANG, X., KANKARE, V., HYYPPÄ, J., WANG, Y., KUKKO, A., HAGGRÉN, H., YU, X., KAARTINEN, H., JAAKKOLA, A., GUAN, F., HOLOPAINEN, M., VASTARANTA, M., 2016. **Terrestrial laser scanning in forest inventories**. ISPRS J. Photogrammetry Remote Sens. 115, 63–77.

MOLINA-VALERO, J.A., MARTÍNEZ-CALVO, A., GINZO-VILLAMAYOR, M.J., NOVO PÉREZ, A.M., ÁLVAREZ-GONZÁLEZ, J.G., MONTES, F., PÉREZ-CRUZADO, C., 2022. **Operationalizing the use of TLS in forest inventories: The R package FORTLS**. Environmental Modelling and Software. 150. 105337

KROK, G., KRASZEWSKI, B., STERÉNCZAK, K., 2020. **Application of terrestrial laser scanning in forest inventory–an overview of selected issues**. For. Res. Pap. 81 (4), 175–194.

MOLINA-VALERO, J.A., GINZO-VILLAMAYOR, M.J., NOVO-PÉREZ, A.M., MARTÍNEZ-CALVO, A., ÁLVAREZ-GONZÁLEZ, J.G., MONTES, F., PÉREZ-CRUZADO, C., 2021. **FORTLS: an R Package for Processing TLS data and Estimating Stand Variables in Forest Inventories".** Environmental Sciences Proceedings 3(38), 1-9.

R CORE TEAM, 2021. **R: A Language and Environment for Statistical Computing**. R Foundation for Statistical Computing, Vienna, Austria.

MOLINA-VALERO, J.A., GINZO-VILLAMAYOR, M.J., NOVO-PÉREZ, M.A., ÁLVAREZ-GONZÁLEZ, J.G., MONTES, F., MARTÍNEZ-CALVO, A., PÉREZ-CRUZADO, C., 2020. **FORTLS: an R package for processing TLS data and estimating stand variables in forest inventories.** Environ. Sci. Proc. 3, 38.

EDDELBUETTEL, D., BALAMUTA, J.J., 2018. **Extending R with C++: a brief introduction to Rcpp.** Am. Statistician 72 (1), 28–36.

BATES, D., EDDELBUETTEL, D., 2013. **Fast and elegant numerical linear algebra using the RcppEigen package.** J. Stat. Software 52 (5), 1–24.

HIJMANS, R.J., 2020. **Raster: Geographic Data Analysis and Modeling. R package version 3.4-5**.

BIVAND, R.S., PEBESMA, E., GOMEZ-RUBIO, V., 2013. **Applied Spatial Data Analysis with R**, vol. 2. Springer, New York.

GARRETT, R.C., NAR, A., FISHER, T.J., 2021. **Ggvoronoi: Voronoi Diagrams and Heatmaps with 'ggplot2. R package version 0.8.4**.

HESTER, J., WICKHAM, H., 2020. **Vroom: Read and Write Rectangular Text Data Quickly. R package version 1.3.2**.

SIEVERT, C., 2020. **Interactive Web-Based Data Visualization with R, Plotly, and Shiny**. CRC Press, ISBN 9781138331457.

VAIDYANATHAN, R., XIE, Y., ALLAIRE, J.J., CHENG, J., SIEVERT, C., RUSSELL, K., 2020. **Htmlwidgets: HTML Widgets for R. R package version 1.5.3**.

CSÁRDI, G., FITZJOHN, R., 2019. **Progress: Terminal Progress Bars. R package version 1.2.2.**

WICKHAM, H., 2021. **Tidyr: Tidy Messy Data. R package version 1.1.3.**

WICKHAM, H., SEIDEL, D., 2020. **Scales: Scale Functions for Visualization. R package version 1.1.1**.

KROK, G., KRASZEWSKI, B., STERÉNCZAK, K., 2020. **Application of terrestrial laser scanning in forest inventory–an overview of selected issues**. For. Res. Pap. 81 (4), 175–194.