Package: CspStandSegmentation (via r-universe)

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Type Package

Title Comparative Shortest Path Forest Stand Segmentation from LiDAR Data

Version 0.2.0

Description Functionality for segmenting individual trees from a forest stand scanned with a close-range (e.g., terrestrial or mobile) laser scanner. The complete workflow from a raw point cloud to a complete tabular forest inventory is provided. The package contains several algorithms for detecting tree bases and a graph-based algorithm to attach all remaining points to these tree bases. It builds heavily on the 'lidR' package. A description of the segmentation algorithm can be found in Larysch et al. (2025) <doi:10.1007/s10342-025-01796-z>.

URL https://github.com/JulFrey/CspStandSegmentation

BugReports https://github.com/JulFrey/CspStandSegmentation/issues

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Imports Rcpp (>= 1.0.5), lidR, dbscan, igraph, foreach, doParallel, magrittr, data.table, sf, terra, RCSF, conicfit, rgl

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Contents

`add_geometry` *Add geometric features to a LAS object*

Description

The function calls a fast cpp multi-core function to calculate eigenvalues for the points in a point cloud based on the k nearest neighbors. Afterwards it adds geometric features like Curvature, Linearity, Planarity, Sphericity, Anisotrophy and Verticlity to the points itself.

Usage

```
add_geometry(las, k = 10L, n_cores = 1)
```

Arguments

las	A LAS object (see lidR::LAS)
k	the k nearest neighbors to use for the eigenvalue calculation
n_cores	The number of CPU cores to use

Details

Details of the metrics can be found in: Hackel, T., Wegner, J.D. & Schindler, K. (2016) Contour Detection in Unstructured 3D Point Clouds. In 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR). Presented at the 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), IEEE, Las Vegas, NV, USA, pp. 1610-1618.

Value

The function returns a single LAS object with the geometric features attached to it in the LAS@data section.

Author(s)

Julian Frey <julian.frey@wwd.uni-freiburg.de>

Examples

```
LASfile <- system.file("extdata", "beech.las", package="CspStandSegmentation")
las <- lidR::readLAS(LASfile, select = "xyz")

las <- add_geometry(las, k = 5, n_cores = 2)
summary(las@data)
```

---

add_las_attributes *Add all las_attributes from las@data to the header of a las element*

Description

The helper function adds all headings from las@data which are not part of lidR:::LASATTRIBUTES to the las header using lidR::add_lasattribute. Only attributes that are included in the header got saved when using lidR::writeLAS, this is a convenient way to add them.

Usage

```
add_las_attributes(las)
```

Arguments

las	an element of lidR::LAS class

Value

the las file with updated header

Author(s)

Julian Frey <julian.frey@wwd.uni-freiburg.de>

Examples

```
file <- system.file("extdata", "beech.las", package="CspStandSegmentation")
las <- lidR::readTLSLAS(file)

las@data$noise <- runif(nrow(las@data))
las@data$noiseZ <- las@data$var1 * las@data$Z

las <- add_las_attributes(las)
```

---

add_voxel_coordinates *Add voxel coordinates to a las file*

Description

Adds the collums x_vox, y_vox and z_vox in the given ressolution to the las element. This is convenient if information has been derived in voxel space and these should be attached to the original points.

Usage

```
add_voxel_coordinates(las, res)
```

Arguments

las	an element of lidR::LAS class
res	voxel ressolution in [m]

Details

Voxel coordinates derived with this function are identical to those derived by lidR::voxelize.

Value

las file with additional voxel coordinates

Author(s)

Julian Frey <julian.frey@wwd.uni-freiburg.de>

Examples

```
file = system.file("extdata", "beech.las", package="CspStandSegmentation")
las = lidR::readTLSLAS(file)

las <- add_voxel_coordinates(las,res = 1)
```

`comparative_shortest_path` *helper function for csp_cost_segemntation*

Description

The function performs a Dijkstra algorithm on a 3D voxel file to assign every voxel to the closest seed point using the igraph package.

Usage

```
comparative_shortest_path(
  vox = vox,
  adjacency_df = adjacency_df,
  seeds,
  v_w = 0,
  l_w = 0,
  s_w = 0,
  N_cores = parallel::detectCores() - 1,
  Voxel_size,
  N_trees = 1
)
```

Arguments

`vox`	a LAS S4 element with XYZ voxel coordinates in the @data slot.
`adjacency_df`	a data.frame with voxel ids (row numbers) in the first column and a neighboring voxel ID in the second column and the weight (distance) in the third column. Might be generated using the dbscan::frNN function (which requires reshaping the data).
`seeds`	seed points for tree positions.
`v_w, l_w, s_w`	weights for verticality, linearity spericity see `csp_cost_segmentation`
`N_cores`	Number of CPU cores for multi-threading
`Voxel_size`	Edge length used to create the voxels. This is only important to gain comparable distance weights on different voxel sizes. Should be greater than 0.
`N_trees`	The number of closest stem locations to add to the point cloud If > 1 the distances will be added as well.

Value

voxels with the TreeID in the data slot

Author(s)

Julian Frey <julian.frey@wwd.uni-freiburg.de>

See Also

csp_cost_segmentation

`csp_cost_segmentation` *Comparative Shortest Path with cost weighting tree segmentation*

Description

Segments single trees from forest point clouds based on tree positions (xyz-coordinates) provided in the map argument.

Usage

```
csp_cost_segmentation(
  las,
  map,
  Voxel_size = 0.3,
  V_w = 0,
  L_w = 0,
  S_w = 0,
  N_cores = 1,
  N_trees = 1
)
```

Arguments

`las`	A lidR LAS S4 object.
`map`	A data.frame, including the columns X, Y, Z, TreeID, with X and Y depicting the location of the trees. Can be generated using CspStandSegmentation::find_base_coordinates_raster
`Voxel_size`	The voxel size (3D resolution) for the routing graph to determine the nearest map location for every point in the point cloud.
`V_w`	verticality weight. Since trunks are vertical structures, routing through voxels with high verticality can be rated 'cheaper.' should be a number between 0 and 1 with 0 meaning no benefit for more vertical structures.
`L_w`	Linearity weight. Similar to V_w but for linearity, higher values indicate a malus for linear shapes (usually branches).
`S_w`	Spericity weight. Similar to V_w but for sphericity, higher values indicate a malus for spherical shapes (usually small branches and leaves).

N_cores	number of CPU cores used for parallel routing using the foreach package.
N_trees	The number of closest stem locations to add to the point cloud

Details

The whole point cloud is voxelized in the given resolution and the center of gravity for the points inside is calculated as voxel coordinate. A graph is build, which connects the voxel coordinates based on a db-scan algorithm. The distances between the voxel coordinates is weighted based on geometric features computed for the points in the voxels. Distances along planar and/or vertical faces like stems are weighted shorter than distances through voxels with high sphericity like leaves and clusters of twigs. This avoids small individuals spreading into the upper canopy. For every voxel center, the weighted distance in the network is calculated to all tree locations from the map argument. The TreeID of the map argument with the shortest distance is assigned to the voxel. All points in the point cloud receive the TreeID from their parent voxel.

Value

Returns a copy of the las point cloud with an additional field for the TreeID.

Author(s)

Julian Frey <julian.frey@wwd.uni-freiburg.de>

See Also

comparative_shortest_path

Examples

```
# read example data

file = system.file("extdata", "beech.las", package="CspStandSegmentation")
las = lidR::readTLSLAS(file)

# Find tree positions as starting points for segmentation
map <- CspStandSegmentation::find_base_coordinates_raster(las)

# segment trees
segmented <- las |>
CspStandSegmentation::add_geometry() |>
CspStandSegmentation::csp_cost_segmentation(map, 1, S_w = 0.5)
```

`eigen_decomposition` *Fast Eigenvalues decomposition for k nearest neighbors using a C++ function*

Description

C++ helper function to compute eigenvalues for geometric feature calculation.

Usage

```
eigen_decomposition(las, k, ncpu = 1L)
```

Arguments

`las`	LAS element
`k`	k nearest neighbors
`ncpu`	number of cpu cores to use

Value

The function returns for every point the 3 eigenvalues and the third element of the third eigenvector. These values are needed to compute planarity, linerity, verticality etc. in the add_geometry function

Author(s)

Julian Frey <julian.frey@iww.uni-freiburg.de>

See Also

add_geometry

`fast_unlist` *helper function to unlist IDs generated by dbscan::frNN*

Description

creates a vector of indices from a nested list created by dbscan::frNN

Usage

```
fast_unlist(list, l)
```

Arguments

`list`	a list element created by dbscan::frNN
`l`	the expected length of the result

Value

Returns a vector with the values in the list.

Author(s)

Julian Frey <julian.frey@iww.uni-freiburg.de>

---

fast_unlist_dist *helper function to unlist distances computed by dbscan::frNN*

Description

extracts the distances from a nested list created by dbscan::frNN

Usage

```
fast_unlist_dist(list, l)
```

Arguments

list	a list element created by dbscan::frNN
l	the expected length of the result

Value

Returns a vector with the values in the list.

Author(s)

Julian Frey <julian.frey@iww.uni-freiburg.de>

---

fds *Farthest Distance Sampling (Farthest Point Sampling)*

Description

This function selects n points from a matrix of points such that the minimum distance between any two points is maximized. This version is memory efficient and can handle large matrices.

Usage

```
fds(mat, n, ret = "idx", scale = FALSE)
```

Arguments

mat	a matrix of points with one row for each point and one column for each dimension, can also be a las object then only XYZ will be used
n	the number of points to select, or if <1 the proportion of points to select
ret	the type of output to return. Options are "idx" (default) to return the indices of the selected points, "mat" to return the selected points.
scale	logical. If TRUE, the dimensions are scaled to have a mean of 0 and a standard deviation of 1 before calculating distances.

Value

a vector of indices or a matrix of points

Examples

```
mat <- matrix(rnorm(1000), ncol = 10)
sample <- fds(mat, 50, ret = "mat")
str(sample)
```

---

find_base_coordinates_geom

Find stem base position using a geometric feature filtering and clustering approach

---

Description

Find stem base position using a geometric feature filtering and clustering approach

Usage

```
find_base_coordinates_geom(
  las,
  zmin = 0.5,
  zmax = 2,
  res = 0.5,
  min_verticality = 0.9,
  min_planarity = 0.5,
  min_cluster_size = NULL
)
```

Arguments

las	an element of lidR::LAS class
zmin	lower search boundary
zmax	upper search boundary
res	cluster search radius
min_verticality	minimum verticality >0 & <1 for a point to be considered a stem point
min_planarity	minimum planarity >0 & <1 for a point to be considered a stem point
min_cluster_size	minimum number of points in the cluster to be considered a tree, if NULL median cluster size is chosen

Value

data.frame with X, Y, Z and TreeID for stem base positions

Author(s)

Julian Frey <julian.frey@wwd.uni-freiburg.de>

Examples

```
# read example data
file = system.file("extdata", "beech.las", package="CspStandSegmentation")
tls = lidR::readTLSLAS(file)

# Find tree positions
map <- CspStandSegmentation::find_base_coordinates_geom(tls)
```

---

find_base_coordinates_raster

Find stem base position using a density raster approach

Description

Find stem base position using a density raster approach

Usage

```
find_base_coordinates_raster(
  las,
  res = 0.1,
  zmin = 0.5,
  zmax = 2,
  q = 0.975,
  eps = 0.2
)
```

Arguments

las	an element of lidR::LAS class
res	raster resolution
zmin	lower search boundary
zmax	upper search boundary
q	quantile of raster density to assign a tree region
eps	search radius to merge base points

Value

data.frame with X, Y, Z and TreeID for stem base positions

Author(s)

Julian Frey <julian.frey@wwd.uni-freiburg.de>

Examples

```
# read example data
file = system.file("extdata", "beech.las", package="CspStandSegmentation")
tls = lidR::readTLSLAS(file)

# Find tree positions
map <- CspStandSegmentation::find_base_coordinates_raster(tls)
```

---

forest_inventory *Function to perform a forest inventory based on a segmented las object (needs to contain TreeID)*

Description

This function estimates a taper curve for evry tree and returns the DBH at 1.3m, its position in XY coordinates, the tree height and the trees 2D projection area.

Usage

```
forest_inventory(
  las,
  slice_min = 0.3,
  slice_max = 4,
  increment = 0.2,
  width = 0.1,
  max_dbh = 1,
  n_cores = 1,
  tree_id_col = "TreeID",
  non_tree_id = 0,
```

```
  use_stem_segmentation = FALSE,
  semantic_colname = NULL,
  stem_semantic_label = NULL
)
```

Arguments

las	lidR las object with the segmented trees
slice_min	the minimum height of a slice for stems to estimate the taper curve
slice_max	the maximum height of a slice for stems to estimate the taper curve
increment	the increment of the slices
width	the width of the slices
max_dbh	the maximum DBH allowed
n_cores	number of cores to use
tree_id_col	Column name for the instance segmantation ID (TreeIDs)
non_tree_id	tree_id_col value for non tree elements (can be a vector of IDs)
use_stem_segmentation	logical whether to use only points classified as stem for DBH estimation
semantic_colname	character name of the semantic segmentation column (only needed if use_stem_segmentation is TRUE)
stem_semantic_label	integer semantic label value for stem points (only needed if use_stem_segmentation is TRUE)

Value

a data.frame with the TreeID, X, Y, DBH, quality_flag, Height and ConvexHullArea

Examples

```
# read example data
file = system.file("extdata", "beech.las", package="CspStandSegmentation")
las = lidR::readTLSLAS(file)

# find tree positions as starting points for segmentation
map <- CspStandSegmentation::find_base_coordinates_raster(las)

# segment trees
segmented <- las |>
  CspStandSegmentation::add_geometry(n_cores = 2) |>
  CspStandSegmentation::csp_cost_segmentation(map, 1, N_cores = 2)

# perform inventory
inventory <- CspStandSegmentation::forest_inventory(segmented, n_cores = 2)
```

`forest_inventory_simple` *Function to perform a forest inventory based on a segmented las object (needs to contain TreeID) This version is a faster but more simplistic approach than forest_inventory() for the DBH estimates*

Description

Function to perform a forest inventory based on a segmented las object (needs to contain TreeID) This version is a faster but more simplistic approach than forest_inventory() for the DBH estimates

Usage

```
forest_inventory_simple(
  las,
  slice_min = 1.2,
  slice_max = 1.4,
  max_dbh = 1,
  n_cores = max(c(1, parallel::detectCores()/2 - 1))
)
```

Arguments

`las`	lidR las object with the segmented trees
`slice_min`	the minimum height of a DBH slice
`slice_max`	the maximum height of a DBH slice
`max_dbh`	the maximum DBH allowed
`n_cores`	number of cores to use

Value

a data.frame with the TreeID, X, Y, DBH, quality_flag, Height and ConvexHullArea

`las_merge` *Makes one las-object from multiple las-objects*

Description

This function merges multiple las objects into one las object. The function checks if all inputs are las-objects and if they have the same CRS. The function will also add a column oci with the original cloud index to each las-object. The function will then rbind all data by the minimum set of columns. If the fill argument is set to False, columns which do not exist in all las objects will be removed. If the fill argument is set to True, missing columns will be filled with NA.

Usage

```
las_merge(..., oci = FALSE, fill = FALSE)
```

Arguments

...	any number of las objects or a list with las objects
oci	add a column with the original cloud index
fill	fill missing columns with NA if it is set to False columns which do not exist in all las-objects will be removed

Value

A single las-object with only the overlapping column name

Examples

```
# number of points per las
n <- 100
las1 <- lidR::LAS(data.frame(X = runif(n), Y = runif(n), Z = runif(n)))
las2 <- lidR::LAS(data.frame(X = runif(n) + 2, Y = runif(n), Z = runif(n)))
las3 <- lidR::LAS(data.frame(X = runif(n) + 4, Y = runif(n), Z = runif(n)))
merged <- las_merge(las1, las2, las3)
lidR::npoints(merged) == (n*3)

lasList <- list(las1,las2,las3)
merged <- las_merge(lasList)
lidR::npoints(merged) == (n*3)
```

---

p_dist *Point distance function*

Description

calculates euclidean distances for n dimensions

Usage

```
p_dist(p1, p2)
```

Arguments

p1	point 1
p2	point 2

Value

the distance between the two points

Examples

```
p_dist(c(0,0), c(3,4))
```

`p_mat_dist` *Point distance function*

Description

calculates euclidean distances for n dimensions between a matrix of points and a single point

Usage

```
p_mat_dist(mat, p)
```

Arguments

`mat`	matrix with points as rows
`p`	point to calculate distances

Value

the distances between every row of mat and p

Examples

```
p_mat_dist(as.matrix(cbind(runif(100),runif(100))), c(3,4))
```

`plot_inventory` *Function to plot the inventory results into a lidR 3d plot of the point cloud*

Description

Function to plot the inventory results into a lidR 3d plot of the point cloud

Usage

```
plot_inventory(plot, inventory, col = NA, cex = 1.5, label_col = "white")
```

Arguments

`plot`	lidR 3d plot
`inventory`	data.frame with the inventory results
`col`	color of the spheres
`cex`	numeric size of the labels
`label_col`	character color of the labels

Value

the plot with the inventory results

Examples

```
# read example data
file = system.file("extdata", "beech.las", package="CspStandSegmentation")
las = lidR::readTLSLAS(file)

# find tree positions as starting points for segmentation
map <- CspStandSegmentation::find_base_coordinates_raster(las)

# segment trees
segmented <- las |>
  CspStandSegmentation::add_geometry(n_cores = 2) |>
  CspStandSegmentation::csp_cost_segmentation(map, 1, N_cores = 2)

# perform inventory
inventory <- CspStandSegmentation::forest_inventory(segmented, n_cores = 2)

# plot the results
## Not run:
x <- lidR::plot(segmented, color = "TreeID")
plot_inventory(x, inventory)

## End(Not run)
```

---

point_center_angle *Returns the angle between the center of the circle and a point in degrees*

Description

Returns the angle between the center of the circle and a point in degrees

Usage

```
point_center_angle(point, circle)
```

Arguments

point	numeric vector of length 2 c(X,Y)
circle	numeric vector of length 3 c(center_X, center_Y, radius)

Value

numeric angle in degrees

point_circle_distance *Helper function to compute distances from a point to the circle*

Description

Helper function to compute distances from a point to the circle

Usage

```
point_circle_distance(point, circle)
```

Arguments

point	numeric vector of length 2 c(X,Y)
circle	numeric vector of length 3 c(center_X, center_Y, radius)

Value

numeric distance from the point to the circle

ransac_circle_fit *RANSAC circle fitting algorithm specially adapted for tree DBH estimation*

Description

This function fits a circle to a set of points using the RANSAC algorithm it maximizes the points that are in the circle and the number of filled 36 degree angle segments Therefore, this function searches for the most complete circle with the highest number of points represented.

Usage

```
ransac_circle_fit(
  data,
  n_iterations = 1000L,
  distance_threshold = 0.01,
  min_inliers = 3L
)
```

Arguments

data	numeric matrix with 2 columns (X, Y) representing the point cloud
n_iterations	integer maximum number of iterations
distance_threshold	numeric maximum distance from a point to the circle to be considered an inlier
min_inliers	integer minimum number of inliers to consider the circle as valid

Value

a list with the following elements: circle: the center coordinates and radius of the circle inliers: number of points within the circles dist threshold angle_segs: number of populated 10deg angular segments of the circle using the distance_threshold n_iter: number of iterations run

---

suppress_cat *Suppress only the cat() output*

Description

Suppress only the cat() output

Usage

```
suppress_cat(f, ...)
```

Arguments

f	function to be called
...	parameters to the function

Value

the return value of the function

---

voxelize_points_mean_attributes *helper function to voxelize a las element*

Description

Calculate voxel mean values for all numeric attributes in the las@data table including the XYZ-coordinates.

Usage

```
voxelize_points_mean_attributes(las, res)
```

Arguments

las	a lidR::LAS element
res	voxel resolution in meter

Value

a las element with XYZ-coordinates as the voxel center and X_gr,Y_gr,Z_gr as the center of gravity (mean point coordinates) as well as all other numeric columns voxel mean values with their original name.

Author(s)

Julian Frey <julian.frey@wwd.uni-freiburg.de>

See Also

voxelize_points

Examples

```
# read example data
file = system.file("extdata", "beech.las", package="CspStandSegmentation")
las = lidR::readTLSLAS(file)
vox <- las |> voxelize_points_mean_attributes(1)
```

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