Package 'stfit'

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Type Package

Title Spatio-Temporal Functional Imputation Tool

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Description A general spatiotemporal satellite image imputation method based on sparse functional data analytic techniques. The imputation method applies and extends the Functional Principal Analysis by Conditional Estimation (PACE). The underlying idea for the proposed procedure is to impute a missing pixel by borrowing information from temporally and spatially contiguous pixels based on the best linear unbiased prediction.

BugReports https://github.com/mingsnu/stfit/issues

License GPL-3

LazyData true

Depends R (>= 3.5.0)

Imports Rcpp, Matrix, doParallel, foreach, abind, fda, raster, rasterVis, RColorBrewer

LinkingTo Rcpp

Suggests testthat, dplyr

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Author Weicheng Zhu [aut, cre]

Maintainer Weicheng Zhu <mingsnu@gmail.com>

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R topics documented:

`stfit-package` *stfit: Spatial-Temporal Functional Imputation Tool*

Description

The stfit package provides functions to impute missing values for a sequence of observed images for the same location using functional data analysis technique

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`ARE` *Absolute relative error*

Description

Absolute relative error

Usage

```
ARE(y, ypred)
```

Arguments

y	vector
ypred	vector

Value

numeric number. A measure of difference between y and ypred.

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epan *Epanicnicov kernel function*

Description

Epanicnicov kernel function

Usage

```
epan(x)
```

Arguments

x	numeric vector

Value

vector

---

getMask *Get image mask*

Description

Get image mask

Usage

```
getMask(object, tol = 0.95)
```

Arguments

object	A numeric matrix. Each row is an row stacked image.
tol	If the percentage of missing values for a pixel over time is greater than this value, this pixel is treated as a mask value.

getMissingLayers *Get missing layer index*

Description

Get missing layer index

Usage

```
getMissingLayers(rst.list)
```

Arguments

rst.list	a RasterStack or RasterBrick object or a list of them

Value

index of the missing layers

landsat106 *Landsat data example*

Description

A dataset containing observation values of a 31x31 pixcels landsat image observed between year 1982 and 2015.

Usage

```
landsat106

landsat2
```

Format

A data frame with 990 rows and 963 columns:

- year year
- doy day of the year
- pixeli pixel value for the i-th pixel of the image

An object of class `tbl_df` (inherits from `tbl`, `data.frame`) with 990 rows and 963 columns.

landsatVis *Data visualization for landsat data*

Description

Data visualization for landsat data

Usage

```
landsatVis(
  mat,
  img.nrow = 31,
  byrow = FALSE,
 colthm = rasterTheme(panel.background = list(col = "black"), region = brewer.pal(9,
    "YlOrRd")),
  ...
)
```

Arguments

mat	A matrix, each row corresponds to a vectorized image pixel values.
img.nrow	number of rows of the image
byrow	logical value indicating whether the pixcel values are stored by row or by column. Default to FALSE
colthm	Color theme for the plot, passing to the par.settings parameter of the levelplot function in the rasterVis package
...	All other options passed to levelplot function in the rasterVis package

Examples

```
landsatVis(landsat106[landsat106$year == 2015, -c(1:2)],
names.attr = as.character(landsat106$doy[landsat106$year == 2015]))
```

lc_cov_1d *Local constant covariance estimation*

Description

Local constant covariance estimation

Usage

```
lc_cov_1d(ids, time, resid, W, t1, t2)
```

Arguments

ids	a vector indicating subject/group ids
time	integer vector of observed time points, the minimum time unit is 1
resid	vector of residual values used for covariance calculation
W	weight vector, it contains both kernel and bandwidth information in general local polynomial estimation setting up
t1	time point 1
t2	time point 2

---

lc_cov_1d_est *Local constant covariance estimation*

Description

Local constant covariance estimation

Usage

```
lc_cov_1d_est(ids, time, resid, W, tt)
```

Arguments

ids	a vector indicating subject/group ids
time	integer vector of observed time points, the minimum time unit is 1
resid	vector of residual values used for covariance calculation
W	weight vector, it contains both kernel and bandwidth information in general local polynomial estimation setting up
tt	time vector

---

llreg *Local linear regression*

Description

Local linear regression

Usage

```
llreg(x, y, x.eval = x, minimum.num.obs = 4, h = 60, Kern = epan)
```

Arguments

x	independent variable
y	response variable
x.eval	dnew data to predict on
minimum.num.obs	minimum number of observations needed to run the regression
h	bandwidth
Kern	Kernel

Value

predicted values at 'x.eval'

---

lpreg *Local Polynomial Regression*

Description

Local Polynomial Regression

Usage

```
lpreg(x, y, x.eval, minimum.num.obs = 4, span = 0.3, ...)
```

Arguments

x	independent variable
y	response variable
x.eval	vector to predict on
minimum.num.obs	minimum number of observations needed to run the regression
span	see 'loess' function
...	other parameters passed to 'loess' function

Value

predicted values at 'x.eval'

meanEst *STFIT Mean Estimation*

Description

The function is used for pixel-wise mean estimation.

Usage

```
meanEst(
  doy,
  mat,
  doyeval = seq(min(doy), max(doy)),
  msk = rep(FALSE, ncol(mat)),
  outlier.tol = 0.5,
  minimum.num.obs = 4,
  cluster = NULL,
  redo = TRUE,
  clipRange = c(-Inf, Inf),
  clipMethod = c("truncate", "nnr"),
  img.nrow = NULL,
  img.ncol = NULL
)
```

Arguments

doy	vector of day of year (DOY) index
mat	data matrix. Each row contains a row stacked image pixel values.
doyeval	a vector of DOY on which to get the mean imputation
msk	an optional logistic vector. TRUE represent the corresponding pixel is always missing.
outlier.tol	the tolerance value in defining an image as outlier. The percent of outlier pixels in an image exceed this value is regarded as outlier image which will not be used in temporal mean estimation.
minimum.num.obs	minimum number of observations needed for mean estimation. Too few observations may lead to big estimation error.
cluster	an optional vector defining clusters of pixels. If NULL, mean estimation is conducted on each pixel, otherwise all pixels from the same cluster are combined for mean estimation.
redo	whether to recalculate the mean estimation if there is an outlier (only redo once).
clipRange	vector of length 2, specifying the minimum and maximum values of the prediction value
clipMethod	"nnr" or "truncate". "nnr" uses average of nearest neighbor pixels to impute; "truncate use the clipRange value to truncate.

img.nrow	number of rows for an image, only used when 'clipMethod' is "nnr"
img.ncol	number of columns for an image, only used when 'clipMethod' is "nnr"

Details

There are several predefined methods for mean estimation: smooth_spline, llreg, lpreg and spreg. User can use opt$get() to check the current registered method and use opt$set() function to set the method. For exmaple, one can run opt$set(smooth_spline) first and then run the meanEst function to use smoothing spline regression for mean eatimation. User can also customize the methods for mean estimation. For example, mean estimation through fourier basis expansion:

```
.X = fda::eval.basis(1:365, fda::create.fourier.basis(rangeval=c(0,365), nbasis=11))
customfun <- function(x, y, x.eval=1:365, minimum.num.obs = 10){
  nonna.idx = !is.na(y)
  if(sum(nonna.idx) < minimum.num.obs)
    return(rep(NA, 365))
 ## lmfit = lm.fit(.X[unlist(lapply(x, function(x) which(x == x.eval))),], y[nonna.idx])
  lmfit = lm.fit(.X[x[nonna.idx],], y[nonna.idx])
  return(.X[x.eval,]
}
stfit::opts_stfit$set(temporal_mean_est = customfun)
```

Value

a list containing the following entries:

- doyeval: same as input doyeval
- meanmat: estimated mean matrix, with number of rows equals length of doyeval and number of columns equal ncol(mat)
- idx: a list of image indexes
  - idx.allmissing: completely missing image indexes,
  - idx.partialmissing: partially observed image indexes,
  - idx.fullyobserved: fully observed image indexes,
  - idx.outlier: outlier image indexes.
- outlier: a list of image outliers information
  - outidx: index of the outlier image
  - outpct: percentage of outlier pixels corresponding to outidx,
  - outlst: a list of the same length as outidx, with each list the missing pixel index.

NMSE *Normalized Mean Square Estimation*

Description

Normalized Mean Square Estimation

Usage

```
NMSE(y, ypred)
```

Arguments

y	vector
ypred	vector

Value

numeric number. A measure of difference between y and ypred.

opts_stfit *Options for stfit*

Description

Options for stfit

Usage

```
opts_stfit
```

Format

An object of class `list` of length 3.

outlier *Image Outlier Detection*

Description

Image Outlier Detection

Usage

```
outlier(mat)
```

Arguments

mat	data matrix. Each row is a row stacked image.

Value

a list containing the following entries:

- outidx: index of the outlier image
- outpct: percentage of outlier pixels corresponding to outidx,
- outlst: a list of the same length as outidx, with each list the missing pixel index.

Examples

```
dfB = landsat106[landsat106$year >= 2000,]
matB = as.matrix(dfB[,-c(1:2)])
outlier(matB)
```

pctMissing *Missing value percentages*

Description

Missing value percentages

Usage

```
pctMissing(x, mc.cores)
```

Arguments

x	A RasterStack object
mc.cores	Numer of cores to use

Value

A vector of percent of missing values for each layer

rmOutlier *Remove outlier*

Description

An outlier is defined as points outside the whiskers of the boxplot over the time domain (DOY).

Usage

```
rmOutlier(rst)
```

Arguments

rst	a *Raster object

Value

a *Raster object

RMSE *Root Mean Square Estimation*

Description

Root Mean Square Estimation

Usage

```
RMSE(y, ypred)
```

Arguments

y	vector
ypred	vecotr

Value

numeric number. A measure of difference between y and ypred.

seffEst *STFIT Spatial Effect Estimation*

Description

STFIT Spatial Effect Estimation

Usage

```
seffEst(
  rmat,
  img.nrow,
  img.ncol,
  h.cov = 2,
  h.sigma2 = 2,
  weight.cov = NULL,
  weight.sigma2 = NULL,
  nnr,
  method = c("lc", "emp"),
  partial.only = TRUE,
  pve = 0.99,
  msk = NULL,
  msk.tol = 0.95,
  var.est = FALSE
)
```

Arguments

rmat	residual matrix
img.nrow	image row dimension
img.ncol	image column dimension
h.cov	bandwidth for spatial covariance estimation; ignored if weight.cov is supplied
h.sigma2	bandwidth for sigma2 estimation
weight.cov	weight matrix for spatial covariance estimation
weight.sigma2	weight vector for spatial variance estimation
nnr	maximum number of nearest neighbor pixels to use for spatial covariance estimation
method	"lc" for local constant covariance estimation and "emp" for empirical covariance estimation
partial.only	calculate the spatical effect for partially observed images only, default is TRUE
pve	percent of variance explained of the selected eigen values. Default is 0.99.
msk	an optional logistic vector. TRUE represent the corresponding pixel is always missing.

msk.tol	if 'msk' is not given, the program will determine the mask using getMask function. If the percentage of missing values for a pixel over time is greater than this
var.est	Whether to estimate the variance of the temporal effect. Default is FALSE.

Value

List of length 3 with entries:

- seff_mat: estimated spatial effect matrix of the same shape as rmat.
- seff_var_mat: estimated spatial effect variance matrix of the same shape as rmat.
- idx: a list of two entries:
  - idx.allmissing: index of the completely missing images.
  - idx.imputed: index of the partially observed images, where spatial effects are estimated.

---

smooth_spline *Smoothing spline regression*

Description

Smoothing spline regression

Usage

```
smooth_spline(x, y, x.eval = x, minimum.num.obs = 4, ...)
```

Arguments

x	independent variable
y	response variable
x.eval	vector to predict on
minimum.num.obs	minimum number of observations needed to run the regression
...	other parameters to be passed to smooth.spline function

Value

predicted values at 'x.eval'

spreg *spline regression*

Description

spline regression

Usage

```
spreg(
  x,
  y,
  x.eval,
  minimum.num.obs = 4,
  basis = c("fourier", "bspline"),
  rangeval = c(min(x.eval) - 1, max(x.eval)),
  nbasis = 11,
  ...
)
```

Arguments

x	independent variable
y	response variable
x.eval	vector to predict on
minimum.num.obs	minimum number of observations needed to run the regression
basis	what basis to use, "fourier" and "bspline" are available
rangeval	see `fda::create.basis`
nbasis	see `fda::create.basis`
...	arguments passed to `fad::create.basis` functions

Value

predicted values at 'x.eval'

stfit_landsat *STFIT for Landsat data*

Description

This function is used for Landsat data imputation, which includes five steps: mean estimation, outlier detection, temporal effect estimation, spatial effect estimation and imputation. In real application, one can use this as a template to create a five steps imputation procedure depending on the real data structure.

Usage

```
stfit_landsat(
  year,
  doy,
  mat,
  img.nrow,
  img.ncol,
  doyeval = 1:365,
  h.tcov = 100,
  h.tsigma2 = 300,
  h.scov = 2,
  h.ssigma2 = 2,
  nnr = 10,
  outlier.action = c("keep", "remove"),
  outlier.tol = 0.2,
  intermediate.save = TRUE,
  intermediate.dir = "./intermediate_output/",
  use.intermediate.result = TRUE,
  teff = TRUE,
  seff = TRUE,
  doy.break = NULL,
  cycle = FALSE,
  t.grid = NULL,
  t.grid.num = 50,
  clipRange = c(0, 1800),
  clipMethod = "nnr",
  var.est = FALSE
)
```

Arguments

year	vecotr of year
doy	vecotr of DOY (day of the year)
mat	a numeric matrix. Each row contains a row stacked image pixel values.
img.nrow	number of rows of the image

img.ncol	number of columns of the image
doyeval	a vector of DOY on which to get the mean and temporal imputation
h.tcov	bandwidth for temporal covariance estimation
h.tsigma2	bandwith for temporal variance estimation
h.scov	bandwidth for spatial covariance estimation
h.ssigma2	bandwidth for spatial variance estimation
nnr	maximum number of nearest neighbor pixels to use for spatial covariance estimation
outlier.action	"keep" to keep outliers; "remove" to replace outliers with imputed values
outlier.tol	The threshold to use to define outlier image. Default is 0.2, i.e. images with more than 20% outlier pixels are treated as outlier image.
intermediate.save	TRUE or FASLE; whether to save the intermediate results including mean, temporal effect and spacial effect imputation resutls. The intermediate results can be useful to avoid duplicating the computation for some imputation steps.
intermediate.dir	directory where to save the intermediate results
use.intermediate.result	whether to use the intermediate results in the 'intermediate.dir' folder. Default is TRUE.
teff	TRUE or FALSE, wheter to calculate the temporal effect. Default is TRUE.
seff	TRUE or FALSE, wheter to calculate the spatial effect. Default is TRUE.
doy.break	a vector of break points for doy where the spatial effect are estimated seperately on each interval. Default is NULL, i.e. the spatial effect is assumed to be the same over doy.
cycle	TRUE or FALSE. When doy.break is specified, whether to combine the first doy.break interval and the last doy.break together for spatial effect estimation.
t.grid	a vector of grid points on which to calculate the temporal covariance function
t.grid.num	number of grid points to use for temporal covariance estimation. Ignored if t.grid is given.
clipRange	passed to meanEst function
clipMethod	passed to meanEst function
var.est	Whether to estimate the variance of the temporal and spatial effects. Default is FALSE.

Value

List of length 4 with entries:

- imat: imputed matrix of mat
- smat: standard error matrix of the same size as mat
- idx: a list of image indexes

  - idx.allmissing: completely missing image indexes,
  - idx.partialmissing: partially observed image indexes,
  - idx.fullyobserved: fully observed image indexes,
  - idx.outlier: outlier image indexes.
- outlier: a list of image outliers information
  - outidx: image index with outlier pixels,
  - outpct: percentage of outlier pixels corresponding to `outidx`,
  - outlst: a list of the same length as `outidx`, with each list the missing pixel index.

Examples

```
library(doParallel)
library(raster)
library(rasterVis)
library(RColorBrewer)
dfB = landsat106[landsat106$year >= 2000,]
matB = as.matrix(dfB[,-c(1:2)])
year = dfB$year
doy = dfB$doy
if(require(doParallel))
  registerDoParallel(1)
res <- stfit_landsat(year, doy, matB, 31, 31, nnr=30,
use.intermediate.result = FALSE, intermediate.save = FALSE, var.est = TRUE)
## visualize the imputed results
idx = c(res$idx$idx.allmissing[150], res$idx$idx.partialmissing[c(30, 60, 90)])
rst_list = list()
for(i in 1:length(idx)){
  rst_list[(i-1)*3+1] = raster(matrix(matB[idx[i],], 31))
  rst_list[(i-1)*3+2] = raster(matrix(res$imat[idx[i],], 31))
  rst_list[(i-1)*3+3] = raster(matrix(res$sdmat[idx[i],], 31))
}
s = stack(rst_list)
levelplot(s, index.cond=list(c(seq(1, 12, 3), seq(2, 12, 3), seq(3, 12, 3))),
          par.setting = rasterTheme(panel.background=list(col="black"),
                                    region = brewer.pal(9, 'YlOrRd')),
          names.attr = c(rbind(paste0("Original ", idx),
                               paste0("Imputed ", idx),
                               paste0("Std. Error ", idx))),
          layout = c(4,3))
```

`teffEst` *STFIT Temporal Effect Estimation*

Description

STFIT Temporal Effect Estimation

Usage

```
teffEst(
  ids,
  doy,
  rmat,
  doyeval = seq(min(doy), max(doy)),
  h.cov = 100,
  h.sigma2 = 300,
  weight.cov = NULL,
  weight.sigma2 = NULL,
  pve = 0.99,
  t.grid = NULL,
  t.grid.num = 50,
  var.est = FALSE
)
```

Arguments

ids	ids for 'group', for data with repeated measurement over years, year is ids; for pixels belong to certain clusters, cluster is ids.
doy	vecotr of DOY (day of the year)
rmat	residual matrix with rows corresponding to doy and columns corresponding to pixel index
doyeval	a vector of DOY on which to get the temporal imputation
h.cov	bandwidth for temporal covariance estimation; ignored if weight.cov is supplied
h.sigma2	bandwidth for temporal variance estimation
weight.cov	weight vector for temporal covariance estimation
weight.sigma2	weight vector for temporal variance estimation
pve	percentage of variance explained; used for number of eigen values selection. Default is 0.99.
t.grid	a vector of grid points on which to calculate the temporal covariance function
t.grid.num	number of grid points to use for temporal covariance estimation. Ignored if t.grid is given.
var.est	Whether to estimate the variance of the temporal effect. Default is FALSE.

Value

List of length 2 with entries:

- teff_array: 3-d array with first dimention 'ids', second dimention 'doy' and third dimention pixel index.
- teff_var_array: same structure as teff_array if var.est is TRUE, otherwise NULL.

weightMatrix *Weight matrix calculation*

Description

Weight matrix calculation

Usage

```
weightMatrix(h)
```

Arguments

h	'bandwith'

Value

a weighting matrix

weightVector *Weight vector calculation*

Description

Weight vector calculation

Usage

```
weightVector(h)
```

Arguments

h	bandwidth, should be positive numbers

Value

a vector

Index