Package 'LSTS'

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Type Package

Title Locally Stationary Time Series

Version 2.1

Description A set of functions that allow stationary analysis and locally stationary time series analysis.

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BugReports https://github.com/pachadotdev/LSTS/issues/

Imports stats, Rdpack, ggplot2, scales, patchwork

RdMacros Rdpack

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Suggests testthat (>= 2.1.0)

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Author Ricardo Olea [aut, cph],
Wilfredo Palma [aut, cph],
Pilar Rubio [aut],
Mauricio Vargas [aut, cre] (<https://orcid.org/0000-0003-1017-7574>)

Maintainer Mauricio Vargas <mavargas11@uc.cl>

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R topics documented:

`block.smooth.periodogram` *Smooth Periodogram by Blocks*

Description

Plots the contour plot of the smoothing periodogram of a time series, by blocks or windows.

Usage

```
block.smooth.periodogram(
  y,
  x = NULL,
  N = NULL,
  S = NULL,
  p = 0.25,
  spar.freq = 0,
  spar.time = 0
)
```

Arguments

`y`	(type: numeric) data vector
`x`	(type: numeric) optional vector, if `x = NULL` then the function uses $(1, \ldots, n)$ where `n` is the length of `y`.
`N`	(type: numeric) value corresponding to the length of the window to compute periodogram. If `N=NULL` then the function will use $N = \text{trunc}(n^{0.8})$, see Dahlhaus and Giraitis (1998) where n is the length of the `y` vector.
`S`	(type: numeric) value corresponding to the lag with which will be taking the blocks or windows to calculate the periodogram.
`p`	(type: numeric) value used if it is desired that `S` is proportional to `N`. By default `p=0.25`, if `S` and `N` are not entered.
`spar.freq`	(type: numeric) smoothing parameter, typically (but not necessarily) in $(0, 1]$.
`spar.time`	(type: numeric) smoothing parameter, typically (but not necessarily) in $(0, 1]$.

Details

The number of windows of the function is $m = \text{trunc}((n - N)/S + 1)$, where trunc truncates de entered value and *n* is the length of the vector `y`. All windows are of the same length `N`, if this value isn't entered by user then is computed as $N = \text{trunc}(n^{0.8})$ (Dahlhaus). `LSTS_spb` computes the periodogram in each of the *M* windows and then smoothes it two times with `smooth.spline` function; the first time using `spar.freq` parameter and the second time with `spar.time`. These windows overlap between them.

Value

A ggplot object.

References

For more information on theoretical foundations and estimation methods see Dahlhaus R, others (1997). "Fitting time series models to nonstationary processes." *The annals of Statistics*, **25**(1), 1–37. Dahlhaus R, Giraitis L (1998). "On the optimal segment length for parameter estimates for locally stationary time series." *Journal of Time Series Analysis*, **19**(6), 629–655.

See Also

`arima.sim`

Examples

```
block.smooth.periodogram(malleco)
```

`Box.Ljung.Test` *Ljung-Box Test Plot*

Description

Plots the p-values Ljung-Box test.

Usage

```
Box.Ljung.Test(z, lag = NULL, main = NULL)
```

Arguments

`z`	(type: numeric) data vector
`lag`	(type: numeric) the number of periods for the autocorrelation
`main`	(type: character) a title for the returned plot

Details

The Ljung-Box test is used to check if exists autocorrelation in a time series. The statistic is

$$q = n(n+2) \cdot \sum_{j=1}^{h} \hat{\rho}(j)^2/(n-j)$$

with *n* the number of observations and $\hat{\rho}(j)$ the autocorrelation coefficient in the sample when the lag is *j*. `LSTS_lbtp` computes q and returns the p-values graph with lag *j*.

Value

A ggplot object.

References

For more information on theoretical foundations and estimation methods see Brockwell PJ, Davis RA, Calder MV (2002). *Introduction to time series and forecasting*, volume 2. Springer. Ljung GM, Box GE (1978). "On a measure of lack of fit in time series models." *Biometrika*, **65**(2), 297–303.

See Also

`periodogram`

Examples

```
Box.Ljung.Test(malleco, lag = 5)
```

---

hessian *Hessian Matrix*

Description

Numerical aproximation of the Hessian of a function.

Usage

```
hessian(f, x0, ...)
```

Arguments

`f`	(type: numeric) name of function that defines log likelihood (or negative of it).
`x0`	(type: numeric) scalar or vector of parameters that give the point at which you want the hessian estimated (usually will be the mle).
`...`	Additional arguments to be passed to the function.

Details

Computes the numerical approximation of the Hessian of `f`, evaluated at `x0`. Usually needs to pass additional parameters (e.g. data). N.B. this uses no numerical sophistication.

Value

An $n \times n$ matrix of 2nd derivatives, where n is the length of `x0`.

See Also

`arima.sim`

Examples

```
# Variance of the maximum likelihood estimator for mu parameter in
# gaussian data
loglik <- function(series, x, sd = 1) {
  -sum(log(dnorm(series, mean = x, sd = sd)))
}
sqrt(c(var(malleco) / length(malleco), diag(solve(hessian(
  f = loglik, x = mean(malleco), series = malleco,
  sd = sd(malleco)
)))))
```

LS.kalman — *Kalman filter for locally stationary processes*

Description

This function run the state-space equations for expansion infinite of moving average in processes LS-ARMA or LS-ARFIMA.

Usage

```
LS.kalman(
  series,
  start,
  order = c(p = 0, q = 0),
  ar.order = NULL,
  ma.order = NULL,
  sd.order = NULL,
  d.order = NULL,
  include.d = FALSE,
  m = NULL
)
```

Arguments

- `series` (type: numeric) univariate time series.
- `start` (type: numeric) numeric vector, initial values for parameters to run the model.
- `order` (type: numeric) vector corresponding to `ARMA` model entered.
- `ar.order` (type: numeric) AR polimonial order.
- `ma.order` (type: numeric) MA polimonial order.
- `sd.order` (type: numeric) polinomial order noise scale factor.
- `d.order` (type: numeric) `d` polinomial order, where `d` is the `ARFIMA` parameter.
- `include.d` (type: numeric) logical argument for `ARFIMA` models. If `include.d=FALSE` then the model is an ARMA process.
- `m` (type: numeric) truncation order of the MA infinity process. By default $m = 0.25n^{0.8}$ where `n` the length of `series`.

Details

The model fit is done using the Whittle likelihood, while the generation of innovations is through Kalman Filter. Details about `ar.order`, `ma.order`, `sd.order` and `d.order` can be viewed in `LS.whittle`.

Value

A list with:

- `residuals` standard residuals.
- `fitted_values` model fitted values.
- `delta` variance prediction error.

References

For more information on theoretical foundations and estimation methods see Brockwell PJ, Davis RA, Calder MV (2002). *Introduction to time series and forecasting*, volume 2. Springer. Palma W (2007). *Long-memory time series: theory and methods*, volume 662. John Wiley \& Sons. Palma W, Olea R, Ferreira G (2013). “Estimation and forecasting of locally stationary processes.” *Journal of Forecasting*, **32**(1), 86–96.

Examples

```
fit_kalman <- LS.kalman(malleco, start(malleco))
```

`LS.summary` *Summary for Locally Stationary Time Series*

Description

Produces a summary of the results to Whittle estimator to Locally Stationary Time Series (`LS.whittle` function).

Usage

```
LS.summary(object)
```

Arguments

`object`	(type: list) the output of `LS.whittle` function

Details

Calls the output from `LS.whittle` and computes the standard error and p-values to provide a detailed summary.

Value

A list with the following components:

`summary`	a resume table with estimate, std. error, z-value and p-value of the model.
`aic`	AIC of the model.
`npar`	number of parameters in the model.

See Also

`LS.whittle`

Examples

```
fit_whittle <- LS.whittle(
  series = malleco, start = c(1, 1, 1, 1),
  order = c(p = 1, q = 0), ar.order = 1, sd.order = 1, N = 180, n.ahead = 10
)
LS.summary(fit_whittle)
```

`LS.whittle` *Whittle estimator to Locally Stationary Time Series*

Description

This function computes Whittle estimator to LS-ARMA and LS-ARFIMA models.

Usage

```
LS.whittle(
  series,
  start,
  order = c(p = 0, q = 0),
  ar.order = NULL,
  ma.order = NULL,
  sd.order = NULL,
  d.order = NULL,
  include.d = FALSE,
  N = NULL,
  S = NULL,
  include.taper = TRUE,
  control = list(),
  lower = -Inf,
  upper = Inf,
  m = NULL,
  n.ahead = 0
)
```

Arguments

`series`	(type: numeric) univariate time series.
`start`	(type: numeric) numeric vector, initial values for parameters to run the model.
`order`	(type: numeric) vector corresponding to `ARMA` model entered.
`ar.order`	(type: numeric) AR polimonial order.
`ma.order`	(type: numeric) MA polimonial order.
`sd.order`	(type: numeric) polinomial order noise scale factor.
`d.order`	(type: numeric) `d` polinomial order, where `d` is the `ARFIMA` parameter.
`include.d`	(type: numeric) logical argument for `ARFIMA` models. If `include.d=FALSE` then the model is an ARMA process.
`N`	(type: numeric) value corresponding to the length of the window to compute periodogram. If `N=NULL` then the function will use $N = \text{trunc}(n^{0.8})$, see Dahlhaus (1998) where n is the length of the `y` vector.
`S`	(type: numeric) value corresponding to the lag with which will go taking the blocks or windows.

include.taper	(type: logical) logical argument that by default is TRUE. See periodogram.
control	(type: list) A list of control parameters. More details in nlminb .
lower	(type: numeric) lower bound, replicated to be as long as start. If unspecified, all parameters are assumed to be lower unconstrained.
upper	(type: numeric) upper bound, replicated to be as long as start. If unspecified, all parameters are assumed to be upper unconstrained.
m	(type: numeric) truncation order of the MA infinity process, by default $m = 0.25n^{0.8}$. Parameter used in LSTS_kalman.
n.ahead	(type: numeric) The number of steps ahead for which prediction is required. By default is zero.

Details

This function estimates the parameters in models: LS-ARMA

$$\Phi(t/T,\, B)\, Y_{t,T} = \Theta(t/T,\, B)\, \sigma(t/T)\, \varepsilon_t$$

and LS-ARFIMA

$$\Phi(t/T,\, B)\, Y_{t,T} = \Theta(t/T,\, B)\, (1-B)^{-d(t/T)}\, \sigma(t/T)\, \varepsilon_t,$$

with infinite moving average expansion

$$Y_{t,T} = \sigma(t/T) \sum_{j=0}^{\infty} \psi(t/T)\, \varepsilon_t,$$

for $t = 1, \ldots, T$, where for $u = t/T \in [0,1]$, $\Phi(u,B) = 1 + \phi_1(u)B + \cdots + \phi_p(u)B^p$ is an autoregressive polynomial, $\Theta(u,B) = 1 + \theta_1(u)B + \cdots + \theta_q(u)B^q$ is a moving average polynomial, $d(u)$ is a long-memory parameter, $\sigma(u)$ is a noise scale factor and $\{\varepsilon_t\}$ is a Gaussian white noise sequence with zero mean and unit variance. This class of models extends the well-known ARMA and ARFIMA process, which is obtained when the components $\Phi(u,B)$, $\Theta(u,B)$, $d(u)$ and $\sigma(u)$ do not depend on u. The evolution of these models can be specified in terms of a general class of functions. For example, let $\{g_j(u)\}$, $j = 1, 2, \ldots$, be a basis for a space of smoothly varying functions and let $d_\theta(u)$ be the time-varying long-memory parameter in model LS-ARFIMA. Then we could write $d_\theta(u)$ in terms of the basis $\{g_j(u) = u^j\}$ as follows $d_\theta(u) = \sum_{j=0}^{k} \alpha_j\, g_j(u)$ for unknown values of k and $\theta = (\alpha_0,\, \alpha_1,\, \ldots,\, \alpha_k)'$. In this situation, estimating θ involves determining k and estimating the coefficients $\alpha_0,\, \alpha_1,\, \ldots,\, \alpha_k$. LS.whittle optimizes LS.whittle.loglik as objective function using nlminb function, for both LS-ARMA (include.d=FALSE) and LS-ARFIMA (include.d=TRUE) models. Also computes Kalman filter with LS.kalman and this values are given in var.coef in the output.

Value

A list with the following components:

coef	The best set of parameters found.
var.coef	covariance matrix approximated for maximum likelihood estimator $\hat{\theta}$ of $\theta := (\theta_1, \ldots, \theta_k)'$. This matrix is approximated by H^{-1}/n, where H is the Hessian matrix $[\partial^2 \ell(\theta)/\partial\theta_i \partial\theta_j]_{i,j=1}^{k}$.

loglik	log-likelihood of coef, calculated with LS.whittle.
aic	Akaike'S 'An Information Criterion', for one fitted model LS-ARMA or LS-ARFIMA. The formula is $-2L + 2k/n$, where L represents the log-likelihood, k represents the number of parameters in the fitted model and n is equal to the length of the series.
series	original time serie.
residuals	standard residuals.
fitted.values	model fitted values.
pred	predictions of the model.
se	the estimated standard errors.
model	A list representing the fitted model.

See Also

nlminb, LS.kalman

Examples

```
# Analysis by blocks of phi and sigma parameters
N <- 200
S <- 100
M <- trunc((length(malleco) - N) / S + 1)
table <- c()
for (j in 1:M) {
  x <- malleco[(1 + S * (j - 1)):(N + S * (j - 1))]
  table <- rbind(table, nlminb(
    start = c(0.65, 0.15), N = N,
    objective = LS.whittle.loglik,
    series = x, order = c(p = 1, q = 0)
  )$par)
}
u <- (N / 2 + S * (1:M - 1)) / length(malleco)
table <- as.data.frame(cbind(u, table))
colnames(table) <- c("u", "phi", "sigma")
# Start parameters
phi <- smooth.spline(table$phi, spar = 1, tol = 0.01)$y
fit.1 <- nls(phi ~ a0 + a1 * u, start = list(a0 = 0.65, a1 = 0.00))
sigma <- smooth.spline(table$sigma, spar = 1)$y
fit.2 <- nls(sigma ~ b0 + b1 * u, start = list(b0 = 0.65, b1 = 0.00))
fit_whittle <- LS.whittle(
  series = malleco, start = c(coef(fit.1), coef(fit.2)), order = c(p = 1, q = 0),
  ar.order = 1, sd.order = 1, N = 180, n.ahead = 10
)
```

`LS.whittle.loglik` *Locally Stationary Whittle log-likelihood Function*

Description

This function computes Whittle estimator for LS-ARMA and LS-ARFIMA models, in data with mean zero. If mean is not zero, then it is subtracted to data.

Usage

```
LS.whittle.loglik(
  x,
  series,
  order = c(p = 0, q = 0),
  ar.order = NULL,
  ma.order = NULL,
  sd.order = NULL,
  d.order = NULL,
  include.d = FALSE,
  N = NULL,
  S = NULL,
  include.taper = TRUE
)
```

Arguments

`x`	(type: numeric) parameter vector.
`series`	(type: numeric) univariate time series.
`order`	(type: numeric) vector corresponding to `ARMA` model entered.
`ar.order`	(type: numeric) AR polimonial order.
`ma.order`	(type: numeric) MA polimonial order.
`sd.order`	(type: numeric) polinomial order noise scale factor.
`d.order`	(type: numeric) `d` polinomial order, where `d` is the `ARFIMA` parameter.
`include.d`	(type: numeric) logical argument for `ARFIMA` models. If `include.d=FALSE` then the model is an ARMA process.
`N`	(type: numeric) value corresponding to the length of the window to compute periodogram. If `N=NULL` then the function will use $N = \text{trunc}(n^{0.8})$, see Dahlhaus (1998) where n is the length of the `y` vector.
`S`	(type: numeric) value corresponding to the lag with which will go taking the blocks or windows.
`include.taper`	(type: logical) logical argument that by default is `TRUE`. See `periodogram`.

Details

The estimation of the time-varying parameters can be carried out by means of the Whittle log-likelihood function proposed by Dahlhaus (1997),

$$L_n(\theta) = \frac{1}{4\pi}\frac{1}{M}\int_{-\pi}^{\pi}\left\{log f_\theta(u_j,\lambda) + \frac{I_N(u_j,\lambda)}{f_\theta(u_j,\lambda)}\right\}d\lambda$$

where M is the number of blocks, N the length of the series per block, $n = S(M-1)+N$, S is the shift from block to block, $u_j = t_j/n$, $t_j = S(j-1)+N/2$, $j = 1,\ldots,M$ and λ the Fourier frequencies in the block ($2\,\pi\,k/N$, $k = 1,\ldots,N$).

References

For more information on theoretical foundations and estimation methods see Brockwell PJ, Davis RA, Calder MV (2002). *Introduction to time series and forecasting*, volume 2. Springer. Palma W, Olea R, others (2010). "An efficient estimator for locally stationary Gaussian long-memory processes." *The Annals of Statistics*, **38**(5), 2958–2997.

See Also

`nlminb`, `LS.kalman`

`LS.whittle.loglik.sd` *Locally Stationary Whittle Log-likelihood sigma*

Description

This function calculates log-likelihood with known θ, through `LS.whittle.loglik` function.

Usage

```
LS.whittle.loglik.sd(
  x,
  series,
  order = c(p = 0, q = 0),
  ar.order = NULL,
  ma.order = NULL,
  sd.order = NULL,
  d.order = NULL,
  include.d = FALSE,
  N = NULL,
  S = NULL,
  include.taper = TRUE,
  theta.par = numeric()
)
```

Arguments

`x`	(type: numeric) parameter vector.
`series`	(type: numeric) univariate time series.
`order`	(type: numeric) vector corresponding to `ARMA` model entered.
`ar.order`	(type: numeric) AR polimonial order.
`ma.order`	(type: numeric) MA polimonial order.
`sd.order`	(type: numeric) polinomial order noise scale factor.
`d.order`	(type: numeric) `d` polinomial order, where `d` is the `ARFIMA` parameter.
`include.d`	(type: numeric) logical argument for `ARFIMA` models. If `include.d=FALSE` then the model is an ARMA process.
`N`	(type: numeric) value corresponding to the length of the window to compute periodogram. If `N=NULL` then the function will use $N = \text{trunc}(n^{0.8})$, see Dahlhaus (1998) where n is the length of the `y` vector.
`S`	(type: numeric) value corresponding to the lag with which will go taking the blocks or windows.
`include.taper`	(type: logical) logical argument that by default is `TRUE`. See `periodogram`.
`theta.par`	(type: numeric) vector with the known parameters of the model.

Details

This function computes `LS.whittle.loglik` with `x` as `x = c(theta.par, x)`.

`LS.whittle.loglik.theta` *Locally Stationary Whittle Log-likelihood theta*

Description

Calculate the log-likelihood with σ known, through `LS.whittle.loglik` function.

Usage

```
LS.whittle.loglik.theta(
  x,
  series,
  order = c(p = 0, q = 0),
  ar.order = NULL,
  ma.order = NULL,
  sd.order = NULL,
  d.order = NULL,
  include.d = FALSE,
  N = NULL,
  S = NULL,
  include.taper = TRUE,
  sd.par = 1
)
```

Arguments

x	(type: numeric) parameter vector.
series	(type: numeric) univariate time series.
order	(type: numeric) vector corresponding to ARMA model entered.
ar.order	(type: numeric) AR polimonial order.
ma.order	(type: numeric) MA polimonial order.
sd.order	(type: numeric) polinomial order noise scale factor.
d.order	(type: numeric) d polinomial order, where d is the ARFIMA parameter.
include.d	(type: numeric) logical argument for ARFIMA models. If include.d=FALSE then the model is an ARMA process.
N	(type: numeric) value corresponding to the length of the window to compute periodogram. If N=NULL then the function will use $N = \text{trunc}(n^{0.8})$, see Dahlhaus (1998) where n is the length of the y vector.
S	(type: numeric) value corresponding to the lag with which will go taking the blocks or windows.
include.taper	(type: logical) logical argument that by default is TRUE. See periodogram.
sd.par	(type: numeric) value corresponding to known variance.

Details

This function computes LS.whittle.loglik with x as x = c(x, sd.par).

---

malleco *Average Araucaria Araucana Tree Ring Width*

Description

A ts object containing average annual ring width measured in milimiters for different Araucaria Araucana trees in the Malleco Region (Chile). The years of observation in this data cover the period 1242-1975.

Format

A time series object with 734 elements

Author(s)

National Oceanic and Atmospheric Administration (NOAA) periodogram *Periodogram function*

Description

This function computes the periodogram from a stationary time serie. Returns the periodogram, its graph and the Fourier frequency.

Usage

```
periodogram(y, plot = TRUE, include.taper = FALSE)
```

Arguments

- `y` (type: numeric) data vector
- `plot` (type: logical) logical argument which allows to plot the periodogram. Defaults to TRUE.
- `include.taper` (type: logical) logical argument which by default is `FALSE`. If `include.taper=TRUE` then `y` is multiplied by $0.5(1 - \cos(2\pi(n-1)/n))$ (cosine bell).

Details

The tapered periodogram it is given by

$$I(\lambda) = \frac{|D_n(\lambda)|^2}{2\pi H_{2,n}(0)}$$

with $D(\lambda) = \sum_{s=0}^{n-1} h\left(\frac{s}{N}\right) y_{s+1} e^{-i\,\lambda\,s}$, $H_{k,n} = \sum_{s=0}^{n-1} h\left(\frac{s}{N}\right)^k e^{-i\,\lambda\,s}$ and λ are Fourier frequencies defined as $2\pi k/n$, with $k = 1, \ldots, n$. The data taper used is the cosine bell function, $h(x) = \frac{1}{2}[1 - \cos(2\pi x)]$. If the series has missing data, these are replaced by the average of the data and n it is corrected by $n-N$, where N is the amount of missing values of serie. The plot of the periodogram is `periodogram` values vs. λ.

Value

A list with with the periodogram and the lambda values.

References

For more information on theoretical foundations and estimation methods see Brockwell PJ, Davis RA, Calder MV (2002). *Introduction to time series and forecasting*, volume 2. Springer. Dahlhaus R, others (1997). “Fitting time series models to nonstationary processes.” *The annals of Statistics*, **25**(1), 1–37.

See Also

`fft`, `Mod`, `smooth.spline`.

Examples

```
# AR(1) simulated
set.seed(1776)
ts.sim <- arima.sim(n = 1000, model = list(order = c(1, 0, 0), ar = 0.7))
per <- periodogram(ts.sim)
per$plot
```

`smooth.periodogram` *Smoothing periodogram*

Description

This function returns the smoothing periodogram of a stationary time serie, its plot and its Fourier frequency.

Usage

```
smooth.periodogram(y, plot = TRUE, spar = 0)
```

Arguments

y	(type: numeric) data vector.
plot	(type: logical) logical argument which allows to plot the periodogram. Defaults to TRUE.
spar	(type: numeric) smoothing parameter, typically (but not necessarily) in $(0, 1]$.

Details

`smooth.periodogram` computes the periodogram from `y` vector and then smooth it with *smoothing spline* method, which basically approximates a curve using a cubic spline (see more details in `smooth.spline`). λ is the Fourier frequency obtained through `periodogram`. It must have caution with the minimum length of `y`, because `smooth.spline` requires the entered vector has at least length 4 and the length of `y` does not equal to the length of the data of the periodogram that `smooth.spline` receives. If it presents problems with tol (**tol**erance), see `smooth.spline`.

Value

A list with with the smooth periodogram and the lambda values

See Also

`smooth.spline`, `periodogram`

Examples

```
# AR(1) simulated
require(ggplot2)
set.seed(1776)
ts.sim <- arima.sim(n = 1000, model = list(order = c(1, 0, 0), ar = 0.7))
per <- periodogram(ts.sim)
aux <- smooth.periodogram(ts.sim, plot = FALSE, spar = .7)
sm_p <- data.frame(x = aux$lambda, y = aux$smooth.periodogram)
sp_d <- data.frame(
  x = aux$lambda,
  y = spectral.density(ar = 0.7, lambda = aux$lambda)
)
g <- per$plot
g +
  geom_line(data = sm_p, aes(x, y), color = "#ff7f0e") +
  geom_line(data = sp_d, aes(x, y), color = "#d31244")
```

`spectral.density` *Spectral Density*

Description

Returns theoretical spectral density evaluated in ARMA and ARFIMA processes.

Usage

```
spectral.density(ar = numeric(), ma = numeric(), d = 0, sd = 1, lambda = NULL)
```

Arguments

`ar`	(type: numeric) AR vector. If the time serie doesn't have AR term then omit it. For more details see the examples.
`ma`	(type: numeric) MA vector. If the time serie doesn't have MA term then omit it. For more details see the examples.
`d`	(type: numeric) Long-memory parameter. If d is zero, then the process is ARMA(p,q).
`sd`	(type: numeric) Noise scale factor, by default is 1.
`lambda`	(type: numeric) λ parameter on which the spectral density is calculated/computed. If `lambda=NULL` then it is considered a sequence between 0 and π.

Details

The spectral density of an ARFIMA(p,d,q) processes is

$$f(\lambda) = \frac{\sigma^2}{2\pi} \cdot \Big(2\,\sin(\lambda/2)\Big)^{-2d} \cdot \frac{\Big|\theta\Big(\exp\Big(-i\lambda\Big)\Big)\Big|^2}{\Big|\phi\Big(\exp\Big(-i\lambda\Big)\Big)\Big|^2}$$

With $-\pi \leq \lambda \leq \pi$ and $-1 < d < 1/2$. $|x|$ is the Mod of x. LSTS_sd returns the values corresponding to $f(\lambda)$. When d is zero, the spectral density corresponds to an ARMA(p,q).

Value

An unnamed vector of numeric class.

References

For more information on theoretical foundations and estimation methods see Brockwell PJ, Davis RA, Calder MV (2002). *Introduction to time series and forecasting*, volume 2. Springer. Palma W (2007). *Long-memory time series: theory and methods*, volume 662. John Wiley \& Sons.

Examples

```
# Spectral Density AR(1)
require(ggplot2)
f <- spectral.density(ar = 0.5, lambda = malleco)
ggplot(data.frame(x = malleco, y = f)) +
  geom_line(aes(x = as.numeric(x), y = as.numeric(y))) +
  labs(x = "Frequency", y = "Spectral Density") +
  theme_minimal()
```

---

ts.diag *Diagnostic Plots for Time Series fits*

Description

Plot time-series diagnostics.

Usage

```
ts.diag(x, lag = 10, band = qnorm(0.975)/sqrt(length(x)))
```

Arguments

x	(type: numeric) residuals of the fitted time series model.
lag	(type: numeric) maximum lag at which to calculate the acf and Ljung-Box test. By default set to 10.
band	(type: numeric) absolute value for bandwidth in the the ACF plot. By default set to 'qnorm(0.975)/sqrt(n)' which approximates to 0.07 for malleco data (n = 734)

Details

This function plot the residuals, the autocorrelation function of the residuals (ACF) and the p-values of the Ljung-Box Test for all lags up to lag.

Value

A ggplot object.

See Also

Box.Ljung.Test

Examples

```
ts.diag(malleco)
```

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