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Description Provides a collection of functions to fit and explore single, multi-component and restricted Frequency Modulated Moebius (FMM) models. ‘FMM’ is a nonlinear parametric regression model capable of fitting non-sinusoidal shapes in rhythmic patterns. Details about the mathematical formulation of ‘FMM’ models can be found in Rueda et al. (2019) <doi:10.1038/s41598-019-54569-1>.

URL https://github.com/alexARC26/FMM

License GPL (>= 2)

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FMM-package

Rhythmic Patterns Modeling by FMM Models

Description

Provides a collection of functions to fit and explore single, multi-component and restricted Frequency Modulated Moebius (FMM) models. 'FMM' is a nonlinear parametric regression model capable of fitting non-sinusoidal shapes in rhythmic patterns.

Details

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For a complete list of functions with individual help pages, use `library(help = "FMM")`.

Author(s)

Adrian Lamela, Itziar Fernandez, Yolanda Larriba, Alejandro Rodriguez, Cristina Rueda

Maintainer: Itziar Fernandez <itziar.fernandez@uva.es>

References

ecgData

Fifth annotated beat (lead MLII) from patient sel100 in 'QT database'

Description
Voltage electric activity data (mV) of the fifth annotated heartbeat for patient sel100 in 'QT database'. 200 samples were collected along 0.8 seconds with a sampling frequency of 250 Hz. Data records correspond to samples from 151248 to 151049 and can be downloaded as text files from 'Physionet' website. Annotated beats were manually revised by experts including R peaks and fiducial marks.

Usage
data(ecgData)

Format
A numeric vector.

Source
'QT database' from 'Physionet' <https://archive.physionet.org/cgi-bin/atm/ATM>

References


Examples
data(ecgData)
str(ecgData)

extractWaves

Individual contribution to the fitted values of each FMM wave

Description
extractWaves extracts individual contribution to the fitted values of each FMM wave.

Usage
extractWaves(objFMM)
Arguments

objFMM: Object of class 'FMM'.

Value

Individual contribution to the fitted values of each FMM wave. It is a list object with as many elements as FMM components have been fitted.

Examples

## Generate example data:
fmm2.data <- generateFMM(M = 0, A = rep(1, 2),
alpha = c(1.5, 3.4), beta = c(0.2, 2.3), omega = c(0.1, 0.2),
plot = FALSE, outvalues = TRUE,
sigmaNoise = 0.5) # add a gaussian noise with sigma = 0.5

## Fit the FMM model with nback = 2 components
## fit is an object of S4 class 'FMM'
fit <- fitFMM(fmm2.data$y, timePoints = fmm2.data$t, nback = 2,
lengthAlphaGrid = 24, lengthOmegaGrid = 10)

## extracts individual contribution of each FMM wave
extractWaves(fit)
Arguments

vData  A numeric vector containing the data to be fitted a FMM model.
nPeriods  A numeric value specifying the number of periods at which vData is observed.
timePoints  A numeric vector containing the time points at which each data of one single period is observed. The default value is NULL, in which case they are equally spaced in range $[0, 2\pi]$. It must be between 0 and $2\pi$.
nback  Number of FMM components to be fitted. Its default value is 1.
betaOmegaRestrictions  An integer vector of length nback indicating which FMM waves are constrained to have equal beta and omega parameters. For example, c(1,1,1,2,2) indicates that $\beta_1=\beta_2=\beta_3$ and $\beta_4=\beta_5$ as well as $\omega_1=\omega_2=\omega_3$ and $\omega_4=\omega_5$. In brief, some waves are restricted to have the same shape. Its default value is the sequence 1:nback to fit the FMM model without restrictions on shape parameters (beta and omega).

maxiter  Maximum number of iterations for the backfitting algorithm. By default, it is set at nback.

stopFunction  Function to check the convergence criterion for the backfitting algorithm (see Details).

lengthAlphaGrid  Precision of the grid of alpha in the search of the best model. If it is increased, more possible values of alpha will be considered, resulting in an increasing in the computation time too. By default, it is set to 48 possible values of alpha, equally spaced between 0 and $2\pi$.

lengthOmegaGrid  Precision of the grid of omega in the search of the best model. If it is increased, more possible values of omega will be considered, resulting in an increasing in the computation time too. By default it is set to 24 possible values of omega, equally spaced between 0 and 1 in a logarithmic way.

numReps  Number of times (alpha, omega) parameters are refined.

showProgress  TRUE to display a progress indicator on the console.

showTime  TRUE to display execution time on the console.

coreMode  TRUE to use parallelized procedure to fit FMM model. Its default value is FALSE. When it is TRUE, the number of cores to be used is equal to 12, or if the machine has less, the number of cores - 1.

restrExactSolution  FALSE to use an approximated algorithm to fit the FMM model with restrictions (default). If TRUE is specified, the exact solution is computed.
Details

Data will be collected over nPeriods periods. When nPeriods > 1 the fitting is carried out by averaging the data collected at each time point across all considered periods. The model is fitting to summarized data. timePoints is a n-length numeric vector where n is the number of different time points per period.

The stopFunction argument can either be the functions alwaysFalse or R2 included in the package or user-defined functions that have the same arguments. The included functions serve for the following:

- alwaysFalse(), its default value, which returns FALSE to force maxIter iterations; and
- R2(vData, pred, prevPred, difMax = 0.001), a function that computes the difference between the explained variability in two consecutive iterations returning TRUE when the convergence criterion is reached. To calculate the explained variability difference, the data and the fitted values from the current and previous iteration are passed as arguments vData, pred and prevPred, respectively. The convergence criterion is fulfilled when the explained variability difference is less than the argument difMax (by default 0.001).

Value

An S4 object of class 'FMM' with information about the fitted model. The object contains the following slots:

@timePoints  The time points as specified by the input argument. It is a numeric vector containing the time points at which each data of one single period is observed.

@data  The data as specified by the input argument. It is a numeric vector containing the data to be fitted a FMM model. Data could be collected over multiple periods.

@summarizedData  When the data has more than one period, a numeric vector containing data averaging the data at each time point across all considered periods.

@nPeriods  A numeric value containing the number of periods in data as specified by the input argument.

@fittedValues  A numeric vector of the fitted values by the FMM model.

@M  A numeric value of the estimated intercept parameter M.

@A  A numeric value or vector of the estimated FMM wave amplitude parameter(s) A.

@alpha  A numeric value or vector of the estimated FMM wave phase translation parameter(s) α.

@beta  A numeric value or vector of the estimated FMM wave skewness parameter(s) β.

@omega  A numeric value or vector of the estimated FMM wave kurtosis parameter(s) ω.

@SSE  A numeric value of the sum of the residual squares values.

@R2  A numeric vector specifying the explained variance by each of the fitted FMM components.

@nIter  A numeric value specifying the number of iterations of the fitting algorithm.

References

FMM-class

Examples

# A monocomponent FMM model is fitted.
FMM_data <- generateFMM(2, 3, 1.5, 2.3, 0.1,
                         from = 0, to = 2*pi, length.out = 100,
                         outvalues = TRUE, sigmaNoise = 0.3, plot = FALSE)
fit <- fitFMM(FMM_data$y, lengthAlphaGrid = 10, lengthOmegaGrid = 10)
summary(fit)

# To see the differences between number of repetitions.
FMM_data <- generateFMM(2, 1, 1.5, 1.1 ,0.14 , outvalues = TRUE, sigmaNoise = 0.15, plot=TRUE)
fit1 <- fitFMM(FMM_data$y, lengthAlphaGrid = 6, lengthOmegaGrid = 3, numReps = 1)
fit2 <- fitFMM(FMM_data$y, lengthAlphaGrid = 6, lengthOmegaGrid = 3, numReps = 6,
               showProgress = FALSE)  # suppress progress messages
getSSE(fit1)
getSSE(fit2)

# Finer resolution grid.
fit3 <- fitFMM(FMM_data$y, lengthAlphaGrid = 10, lengthOmegaGrid = 5, numReps = 1)
getSSE(fit3)

# Two component FMM model with beta and omega restricted
restFMM2w_data <- generateFMM(M = 3, A = c(7, 4), alpha = c(0.5, 5), beta = c(rep(3, 2)),
                              omega = rep(0.05, 2), from = 0, to = 2*pi, length.out = 100,
                              sigmaNoise = 0.3, plot = FALSE)
fit2w.rest <- fitFMM(restFMM2w_data$y, nback = 2, maxiter = 1, numReps = 1,
                     lengthAlphaGrid = 15, lengthOmegaGrid = 10,
                     betaOmegaRestrictions = c(1, 1))
plotFMM(fit2w.rest, components = TRUE)

FMM-class

FMM Class Representation

Description

Class representation for an S4 object of class 'FMM'.

Value

The S4 object of class 'FMM' contains the following slots:

@timePoints The time points as specified by the input argument. It is a numeric vector containing the time points at which each data of one single period is observed.

@data The data as specified by the input argument. It is a numeric vector containing the data to be fitted a FMM model. Data could be collected over multiple periods.

@summarizedData When the data has more than one period, a numeric vector containing data averaging the data at each time point across all considered periods.
@nPeriods A numeric value containing the number of periods in data as specified by the input argument.
@fittedValues A numeric vector of the fitted values by the FMM model.
@M A numeric value of the estimated intercept parameter $M$.
@A A numeric value or vector of the estimated FMM wave amplitude parameter(s) $A$.
@alpha A numeric value or vector of the estimated FMM wave phase translation parameter(s) $\alpha$.
@beta A numeric value or vector of the estimated FMM wave skewness parameter(s) $\beta$.
@omega A numeric value or vector of the estimated FMM wave kurtosis parameter(s) $\omega$.
@SSE A numeric value of the sum of the residual squares values.
@R2 A numeric vector specifying the explained variance by each of the fitted FMM components.
@nIter A numeric value specifying the number of iterations of the fitting algorithm.

Examples

```r
## FMM class
getClass("FMM")
getSlots("FMM")
```

---

### Description

The methods for objects of class ‘FMM’ are:

- `coef` coef method for S4 class ‘FMM’.
- `summary` summary method for S4 class ‘FMM’.
- `fitted` fitted method for S4 class ‘FMM’.
- `resid` resid method for S4 class ‘FMM’.

### Usage

```r
## S4 coef method for signature 'FMM'
coef(object,...)

## S4 summary method for signature 'FMM'
summary(object,...)

## S4 fitted method for signature 'FMM'
fitted(object,...)
```
## S4 resid method for signature 'FMM'
resid(object, ...)

**Arguments**

- `object`: object of class 'FMM'.
- `...`: additional arguments passed to the method.

**Value**

- The function `coef()` returns a list with two components:
  - `M`: A numeric value. The estimated intercept parameter $M$.
  - `wave`: A data.frame with the estimates of each FMM wave parameters. It is organised as one component per row.

- The function `summary()` displays relevant results of the fitting. When it is assigned, this function returns a list with the following components:
  - `coef`: The list returns by the function `coef()`.  
  - `peak.time`: A data.frame with the estimates of the peak and trough times of each wave. It is organised as one component per row.  
  - `resid`: The vector of residuals.  
  - `R.squared`: A numerical value with the R squared of each wave. The total R square is computed as the sum of the contribution of each component.

- The function `fitted()` returns a data.frame with two columns: `timePoints` and `fittedValues`.
- The function `resid()` returns a numeric vector with residuals of the model.

**Examples**

```r
## Generate example data:
fmm2.data <- generateFMM(0, rep(2, 2), c(1.5, 3.4), c(0.2, 2.3), c(0.1, 0.2),
plot = FALSE, outvalues = TRUE,
sigmaNoise = 0.5) # add a gaussian noise with sigma = 0.5

## Fit the FMM model with nback = 2 component
## fit is an object of S4 class 'FMM'
fit <- fitFMM(vData = fmm2.data$y, timePoints = fmm2.data$t, nback = 2,
lengthAlphaGrid = 24, lengthOmegaGrid = 10)

## Extract coefficients of the model:
coef(fit)

## Summarize results:
summary(fit)

## Results on a list:
res <- summary(fit)
res$peak.time # fiducial points
```
## fitted values:
fit.values <- fitted(fit)

## residuals
res <- resid(fit)

generateFMM

Simulating data from FMM models

Description
generateFMM() simulates data from a FMM model defined by parameters $M, A, \alpha, \beta$ and $\omega$.

Usage
generateFMM(
  M,
  A,
  alpha,
  beta,
  omega,
  from = 0,
  to = 2 * pi,
  length.out = 200,
  plot = TRUE,
  outvalues = TRUE,
  sigmaNoise = 0
)

Arguments

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
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<tr>
<td>M</td>
<td>A numeric vector which contains the value of the intercept parameter $M$.</td>
</tr>
<tr>
<td>A</td>
<td>A positive numeric vector which contains the value of the FMM wave amplitude parameter $A$.</td>
</tr>
<tr>
<td>alpha</td>
<td>A numeric vector which contains the value of the FMM wave phase translation parameter $\alpha$.</td>
</tr>
<tr>
<td>beta</td>
<td>A numeric vector which contains the value of the FMM wave skewness parameter $\beta$.</td>
</tr>
<tr>
<td>omega</td>
<td>A numeric vector which contains the value of the FMM wave kurtosis parameter $\omega$. omega parameter must be between 0 and 1.</td>
</tr>
<tr>
<td>from</td>
<td>A numeric value which contains the initial time point of the simulated data. By default, it is 0.</td>
</tr>
<tr>
<td>to</td>
<td>A numeric value which contains the final time point of the simulated data. By default, it is $2\pi$.</td>
</tr>
</tbody>
</table>
generateFMM

length.out  A non-negative number which contains the desired length of the simulation. By default, it is 100.

plot  A logical value indicating whether the simulated data should be drawn on a plot. By default, it is TRUE.

outvalues  A logical value indicating whether the numerical simulation should be return. By default, it is TRUE.

sigmaNoise  A non-negative number which contains the standard deviation of the gaussian noise to be added. Its default value is zero equivalent to a simulation set-up without noise.

Details

To simulate a multicomponent FMM model, arguments A, alpha, beta and omega are vectors of length \( m \), where \( m \) represents the number of FMM waves. With different lengths, the smaller vectors will be replicate until they are the same length as the longest vector.

With sigmaNoise = \( s \), \( s > 0 \), the generateFMM function uses \( \text{rnorm} \) to create the normally distributed noise and adds it to the simulated values.

Value

When outvalues = TRUE a list of with the following components is returned:

- input: a list with the input parameters M, A, alpha, beta and omega.
- t: a numeric vector with the time points at each data is simulated.
- y: a numeric vector with the data simulated.

When plot = TRUE a scatter plot of \( y \) vs \( t \) is drawn.

References


Examples

# Simulate data from a monocomponent FMM model. A plot with the simulated model is shown
generateFMM(M = 2, A = 3, alpha = 1.5, beta = 2.3, omega = 0.1, outvalues = FALSE)

# Add a gaussian noise with standard deviation 0.3. The numeric results are returned
generateFMM(M = 2, A = 3, alpha = 1.5, beta = 2.3, omega = 0.1,
    sigmaNoise = 0.3, plot = FALSE, outvalues = TRUE)

# Simulate data from a multicomponent FMM model with two FMM waves
# both with amplitude parameter = 2
generateFMM(M = 0, A = rep(2, 2), alpha = c(1.5, 3.4), beta = c(0.2, 2.3), omega = c(0.1, 0.2))
getFMMPeaks

Peak and trough times and signal values

Description

getFMMPeaks() is used to estimate peak and trough times and signal values at those times for each component of the model. These parameters result to be useful in multiple applications.

Usage

getFMMPeaks(objFMM, timePointsIn2pi = TRUE)

Arguments

objFMM Object of class 'FMM'
timePointsIn2pi TRUE to return peak and trough times in the $[0, 2\pi]$ interval. When timePointsIn2pi = FALSE the positions of peak and trough times are returned. Its default value is TRUE.

Value

A list with the following components is returned:
tpeakU a numeric vector with the time points at which the peak of each wave is estimated.
tpeakL a numeric vector with the time points at which the trough of each wave is estimated.
ZU a numeric vector with the estimated signal peak values of each wave.
ZL a numeric vector with the estimated signal trough values of each wave.

References


Examples

```r
## Generate example data:
fmm2.data <- generateFMM(0, rep(2, 2), c(1.5, 3.4), c(0.2, 2.3), c(0.1, 0.2),
plot = FALSE, outvalues = TRUE,
sigmaNoise = 0.5) # add a gaussian noise with sigma = 0.5

## Fit the FMM model with nback = 2 components
## fit is an object of S4 class 'FMM'
fit <- fitFMM(fmm2.data$y, timePoints = fmm2.data$t, nback = 2,
```
getS4

lengthAlphaGrid = 24, lengthOmegaGrid = 10
getFMMPeaks(fit, timePointsIn2pi = TRUE)  # times in the [0,2*pi] interval

getS4  General S4 Class Extractor Functions

Description

A collection of functions to extract slots from S4 objects of class 'FMM'.

The extractor functions are:

getTimePoints   Extracts the timePoints slot from a S4 object of class 'FMM'.
data            Extracts the data slot from a S4 object of class 'FMM'.
gSummarizedData Extracts the summarizedData slot from a S4 object of class 'FMM'.
nPeriods        Extracts the nPeriods slot from a S4 object of class 'FMM'.
gFittedValues   Extracts the fittedValues slot from a S4 object of class 'FMM'.
M              Extracts the M slot from a S4 object of class 'FMM'.
A              Extracts the A slot from a S4 object of class 'FMM'.
gAlpha          Extracts the alpha slot from a S4 object of class 'FMM'.
gBeta           Extracts the beta slot from a S4 object of class 'FMM'.
gOmega          Extracts the omega slot from a S4 object of class 'FMM'.
gSSE            Extracts the SSE slot from a S4 object of class 'FMM'.
R2             Extracts the R2 slot from a S4 object of class 'FMM'.
nIter           Extracts the nIter slot from a S4 object of class 'FMM'.

Usage

getM(objFMM)
getOmega(objFMM)
data(objFMM)

Arguments

objFMM         an object of class of class 'FMM'.

Value

Return the content of the corresponding slot.
### mouseGeneExp

**Igap2 gene expression data from mouse liver**

**Description**

Data from High-temporal resolution profiling of mouse liver. Samples were collected every hour for 48 hours from 3-5 mice per time point from liver. Samples were pooled and analyzed using Affymetrix arrays.

**Usage**

```r
data(mouseGeneExp)
```

**Format**

A numeric vector.

**Source**


**References**


**Examples**

```r
data(mouseGeneExp)
str(mouseGeneExp)
```

### neuronalAPTrain

Neuronal AP Train Data simulated with Hodgkin-Huxley model

**Description**

Voltage data in mV simulated with Hodgkin Huxley model (parameters: C=1, gNa=232, gK=45, gL=0.215, vK=-12, vNa=115, vL=10.6, bar(alphaN)=0.95, bar(betaN)=1.3, bar(alphaM)=1, bar(betaM)=1.15, bar(alphaH)=1, bar(betaH)=1) and applied current of 4.5 microA 1 millisecond. The simulation has been done with a modified NeuroDynex Python module.

**Usage**

```r
data(neuronalAPTrain)
```
neuronalSpike

Format
A numeric vector.

Source

References

Examples
```r
data(neuronalAPTrain)
str(neuronalAPTrain)
```

| neuronalSpike | Neuronal Spike Data simulated with Hodgkin-Huxley model |

Description
Voltage data in mV simulated with Hodgkin Huxley model (parameters: \(C=1\), \(g_{Na}=260\), \(g_{K}=30\), \(g_{L}=0.31\), \(v_{K}=-12\), \(v_{Na}=115\), \(v_{L}=10.6\), \(\bar{alpha}_{N}=1.15\), \(\bar{beta}_{N}=0.85\), \(\bar{alpha}_{M}=0.9\), \(\bar{beta}_{M}=1.3\), \(\bar{alpha}_{H}=1\), \(\bar{beta}_{H}=1\)) and applied current of 12 microA 1 millisecond. The simulation has been done with a modified NeuroDynex Python module.

Usage
data(neuronalSpike)

Format
A numeric vector.

Source

References

Examples
data(neuronalSpike)
str(neuronalSpike)
plotFMM

Plot fitted FMM models

Description

plotFMM() is used to plot fitted FMM models. The function can either plot the fitted model against
the data or each of the components of the model separately. Optionally ‘ggplot2’ can be used as
graphic library.

Usage

plotFMM(
  objFMM,
  components = FALSE,
  plotAlongPeriods = FALSE,
  use_ggplot2 = FALSE,
  legendInComponentsPlot = TRUE,
  textExtra = ""
)

Arguments

objFMM Object of class FMM
components A logical value indicating if the centered wave components of the model should
be separately plotted (case where it is TRUE). If FALSE, the default, the fitted
FMM model along with the observed data is plotted.
plotAlongPeriods A logical value indicating if more than one period should be plotted in the plots
by default. Its default value is FALSE.
use_ggplot2 A logical value. If FALSE, the default, R base graphics are used. If TRUE,
'ggplot2' library is used as graphics engine.
legendInComponentsPlot A logical value indicating whether the legend should be plotted in the compo-
ments plot. By defaults it is TRUE.
textExtra A character vector for extra text to be added to the titles of the plots.

Details

plotFMM() can generate two types of plots: the basic plot compares the fitted model against the
original data while the components plot represents separately the centered waves of the model (if
the argument components is TRUE).

The function is also capable of plotting multiple periods if the data has more than one, as is the case
in many applications such as chronobiology. In this case, the argument plotAlongPeriods should be
TRUE. In the case of components plots the value taken by the latter argument is ignored as they are
plotted along just one period.
While, by default, plots are created using base R graphics, 'ggplot2' can also be used for more aesthetic and customizable plots. Optional arguments legendInComponentsPlot and textExtra serve to control, respectively, whether a legend to the components plot should be added and adding extra text to the plot’s title.

**Value**

None if base R graphics are used, a named ggplot2 list if ‘ggplot2’ is used.

**Examples**

```r
# Simulates an scenario in which an FMM model is suitable,
res <- generateFMM(2,3,1.5,2.3,0.1, outvalues = TRUE, sigmaNoise = 0.3, plot=FALSE)
# then a FMM model is fitted to the data.
fit <- fitFMM(res$y, lengthAlphaGrid=20, lengthOmegaGrid=12)
plotFMM(fit)

# Components plot of FMM Model fitted to neuronal data with various optional aesthetics
data("neuronalSpike")
fittedFMM2<-fitFMM(neuronalSpike, nback=2,
 lengthAlphaGrid = 24, lengthOmegaGrid = 10, numReps = 1)
plotFMM(fittedFMM2, components = TRUE)
plotFMM(fittedFMM2, components = TRUE,
 legendInComponentsPlot = FALSE,
 textExtra = "Neuronal Data")

# With ggplot2, customizable plots can be created,
library(ggplot2)
# standard plots
plotFMM(fittedFMM2, use_ggplot2 = TRUE)
# modify x-axis with original timePoints
timePoints <- getTimePoints(fittedFMM2)
nObs <- length(timePoints)
sTimePoints <- round(c(1, nObs*0.25, nObs*0.5, nObs*0.75, nObs))
plotFMM(fittedFMM2, use_ggplot2 = TRUE) +
  scale_x_continuous(breaks = sTimePoints,
                   labels = function(x) round(timePoints[x],2))

# and components plots
plotFMM(fittedFMM2, components = TRUE, use_ggplot2 = TRUE)

# Plot of fitted model to more than one period.
data("mouseGeneExp")
fittedFMM2<-fitFMM(mouseGeneExp, nPeriods = 2,
 lengthAlphaGrid = 20, lengthOmegaGrid = 10)
plotFMM(fittedFMM2, plotAlongPeriods = TRUE)
```

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