Package ‘BayesianAnimalTracker’

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Type Package

Title Bayesian Melding of GPS and DR Path for Animal Tracking

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Depends R (>= 2.10), TrackReconstruction

Description Bayesian melding approach to combine the GPS observations and Dead-Reckoned path for an accurate animal's track, or equivalently, use the GPS observations to correct the Dead-Reckoned path. It can take the measurement errors in the GPS observations into account and provide uncertainty statement about the corrected path. The main calculation can be done by the BMAnimalTrack function.

License GPL (>= 2)

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NeedsCompilation no

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R topics documented:

`as.dataList` *Convert the GPS observations and DR path into a data list*

Description

The data list prepared by this function will be the input to the `BMAnimalTrack` function.

Usage

```
as.dataList(X, Y, Ytime, Xtime=NULL, s2G, timeUnit=1, dUnit=1,
    dMx=NULL, betaOrder=1, scale=TRUE)
```

Arguments

`X`	DR path. The length of it is `T`.
`Y`	GPS observations.
`Ytime`	The time points where the GPS observations are obtained. It has to be a subset of `Xtime`. See details for more.
`Xtime`	The time points where the DR path is obtained. When unspecified taken to be 1:T. See details for more.
`s2G`	The variance of the measurement errors in the GPS observations.
`timeUnit`	Optional. If provided, the working time points become 1:T/timeUnit, which can be used to stablize the estimates of s2H.
`dUnit`	Optional. Distance unit. It can be used to scale `X, Y`.
`dMx`	The design matrix of the parametric bias $h(t)$ in the DR path.
`betaOrder`	Only used when `dMx` is not specified. Decide the degree of the polynomial $h(t) = \sum q = 1^Q \beta_i t^{q-1}$.
`scale`	Logical. Whether to scale the design matrix `dMx`. Recommend to be TRUE.

Details

If `dMx` is not specified. The $h(t)$ is chosen to be polynomial of order `betaOrder`.

For `Xtime` and `Ytime`, they can either be vectors of POSIXlt/POSIXt time points from `strptime` or character or numeric vectors. But they must be POSIXlt/POSIXt time points when the `Xtime` are not regularly spaced. See the example in `Trip1`.

Value

A list of the following values

`XMx`	A matrix with `T` rows. The first column of it is scaled `X`, second column is `1:T/timeUnit` (used in the calculation), and the remaining columns are the scaled design matrix `dMx`.
`glist`	A list with of the data on the GPS time points

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Author(s)

Yang (Seagle) Liu <yang.liu@stat.ubc.ca>

References

Liu, Y., Battaile, B. C., Zidek, J. V., and Trites, A. (2014). Bayesian melding of the Dead-Reckoned path and gps measurements for an accurate and high-resolution path of marine mammals. arXiv preprint arXiv: 1411.6683.

Examples

```
set.seed(1)
#Generating data from our
dlist <- dataSim(T=100, K=10, s2H=1, s2D=0.1, betaVec=c(1))
gpsObs <- dlist$Y
gpsTime <- dlist$Ytime
drPath <- dlist$X
wlist <- as.dataList(drPath, gpsObs, gpsTime, timeUnit=1, s2G=0.01, dUnit=1, betaOrder=1)
#Example continuous in "BMAnimalTrack".
```

BMAnimalTrack — *Bayesian melding bias correction and uncertainty characterization of DR path with GPS observations.*

Description

This is a wrapper function of function `nllh.BB.Phi_XY`, `zSearch`, and `postMar.BB.Eta`. It first estimate the parameters σ_H^2, σ_D^2 by numerical maximizing `nllh.BB.Phi_XY` based on the GPS observations and DR path at the GPS time points. Then the grid of numerical integration of searched by `zSearch`. Finally, the posterior mean and variance of η is computed by `postMar.BB.Eta`. The posterior mean can be used as the corrected path. The posterior credible intervals are also calculated.

Usage

```
BMAnimalTrack(dataList, controlList=BMControl())
```

Arguments

`dataList`	A list produced by `as.dataList`
`controlList`	A list of parameters controls the whole calculation. Details are in `BMControl`

Details

This function carries out the Bayesian inference for the following model proposed in Liu et al.(2014):

$\eta(t)$, the animal's path (one dimensional, northing or easting), is assumed to a Brownian Bridge process with variance parameter σ^2_H.(s2H)

Y, GPS observations observated at a subset of the time points of the path. Conditioning on $\eta(t)$, the GPS observations $Y(t)$ are unbiased iid normal observations of

$$Y(t) = \eta(t) + \epsilon(t)$$

, where the measurment errors $\epsilon(t) iid N(0, \sigma^2_G)$. The σ^2_G (s2G) can be obtained from the manual of the GPS tags and is an input to this model.

X, Dead-Reckoned path, is assumed to be

$$X(t) = \eta(t) + h(t) + \xi(t),$$

where $h(t) = \sum_{q=1}^{Q} d_q(t)\beta_q$ is a parametric function. Users can specify the design matrix $[d_q(t)]$ or take the default polynomial $d_q(t) = t^{q-1}$ and specify the order of it. $\xi(t)$ is a zero-mean Brownian motion process, whose variance parameter is σ^2_D(s2D).

Value

When `controlList$returnParam` is false. Returns a $T * 4$ matrix. T is the number of times points in the path and the four columns of this matrix are:

`Mean`	Posterior mean of η
`Variance`	Posterior variance of η
`CI.lower`	The lower bound of the Bayesian credible intervals
`CI.upper`	The upper bound of the Bayesian credible intervals

When `controlList$returnParam` is true. The empirical Bayesian estimates of σ^2_H, σ^2_D(s2H, s2D) will also be returned.

Note

The current version cannot consider multiple initial values for the numerical maximization nor pass control parameters to the `nlm` used to perform the maximization.

Author(s)

Yang (Seagle) Liu <yang.liu@stat.ubc.ca>

References

Liu, Y., Battaile, B. C., Zidek, J. V., and Trites, A. (2014). Bayesian melding of the Dead-Reckoned path and gps measurements for an accurate and high-resolution path of marine mammals. arXiv preprint arXiv: 1411.6683.

Examples

```
set.seed(1)
#Generating data from our model
dlist <- dataSim(T=100, K=10, s2H=1, s2D=0.1, betaVec=c(1))
gpsObs <- dlist$Y
gpsTime <- dlist$Ytime
drPath <- dlist$X
#Produce the data list required by BMAnimalTrack
wlist <- as.dataList(drPath, gpsObs, gpsTime,
            timeUnit=1, s2G=0.01, dUnit=1, betaOrder=1)
#Calculate the posterior of eta with our Bayesian Melding approach
etaMar <- BMAnimalTrack(wlist, BMControl(print=TRUE))

## Not run:
## A real data example from package TrackReconstruction.
## Example from TrackReconstruction package.
## library(TrackReconstruction)
betas<-Standardize(1,1,-1,1,1,1,-57.8,68.76,-61.8,64.2,
    -70.16,58.08, -10.1,9.55,-9.75,9.72, -9.91,9.43)
#get declination and inclination data for study area
decinc<-c(10.228,65.918)
#data set with 6 associated GPS fixes in the "gpsdata" data set
data(rawdata)
#Perform the Dead-Reckoning of the raw accelerometer and
# magnetometer data
DRoutput<-DeadReckoning(rawdata,betas,decinc,Hz=16,
            RmL=2,DepthHz=1,SpdCalc=3,MaxSpd=3.5)
#prepare GPS data
data(gpsdata02)
#matching time of the GPS and DR
gpsdata <- gpsdata02[gpsdata02$DateTime %in% DRoutput$DateTime, ]
gpsformat<-GPStable(gpsdata)
K <- nrow(gpsformat)
T <- nrow(gpsformat)
#Cut out the periods of DR path with the GPS
DRstart <- min(which(DRoutput$DateTime==gpsformat$DateTime[1]))
DRend <- max(which(DRoutput$DateTime==gpsformat$DateTime[K]))
#Thin the data (Original 16Hz, for now only working with 1Hz)
DRworking <- DRoutput[c(DRstart:DRend)[c(DRstart:DRend)%%16==1], ]

#Calculate the northing in km##
GPSnorthing=c(0, cumsum(gpsformat$DistanceKm[-1]*cos(gpsformat$BearingRad[-T])))
DRnorthing <- (DRworking$Ydim - DRworking$Ydim[1])/1000
#Original unit of DR is in meters

#Data preparation for BM bias correction
ndl <- as.dataList(DRnorthing, GPSnorthing,
    Ytime=gpsformat$DateTime,
    Xtime=DRworking$DateTime,
    s2G=0.0625, timeUnit=60, betaOrder=1)
#Bayesian Melding calculation.
nEtaMar <- BMAnimalTrack(ndl, BMControl(print=TRUE, returnParam=TRUE))
```

```
#Plots.
plot(ndl$XMx[,2], ndl$XMx[,1], type="l", col="blue", ylim=c(0, 2.5))
#uncorrected DR path
points(ndl$glist$Gtime, ndl$glist$Y, col="red", pch=16) #GPS points
lines(ndl$XMx[,2], nEtaMar$etaMar[,1], type="l") #Corrected path
lines(ndl$XMx[,2], nEtaMar$etaMar[,3], type="l", col="grey70") #Lower bound of CI
lines(ndl$XMx[,2], nEtaMar$etaMar[,4], type="l", col="grey70") #Upper bound of CI.

## End(Not run)
```

BMControl *Produce a list of arguements controlling* BMAnimalTrack

---

Description

This function include the defaul values of the parameters controls the BMAnimalTrack function and passes user-specified values into BMAnimalTrack.

Usage

```
BMControl(print = FALSE, zStepSize = 1, logPiTol = 3,
        returnParam = FALSE, CILevel = 0.95, ...)
```

Arguments

print	Logical. Whether to print the progress information to screen.
zStepSize	Positive number. Controls the stepsize in the search of grid points for numerical integratoin. More grid points will be consider with smaller zStepSize.
logPiTol	Positive number. Controls the tolerance the difference between log likelihoods at the grids points and grid center (empirical Bayesian estimates)
returnParam	Logical. Decides whether the empirical Bayesian parameters estimates should be returned.
CILevel	The level of the Bayesian credible interval. Default values i 95%.
...	Other arguments that you would like to pass into the BMAnimalTrack

Value

A list with the above arguments.

Author(s)

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References

Liu, Y., Battaile, B. C., Zidek, J. V., and Trites, A. (2014). Bayesian melding of the Dead-Reckoned path and gps measurements for an accurate and high-resolution path of marine mammals. arXiv preprint arXiv: 1411.6683.

See Also

BMAnimalTrack

Examples

```
set.seed(1)
#Generating data from our
dlist <- dataSim(T=100, K=10, s2H=1, s2D=0.1, betaVec=c(1))
gpsObs <- dlist$Y
gpsTime <- dlist$Ytime
drPath <- dlist$X
wlist <- as.dataList(drPath, gpsObs, gpsTime, timeUnit=1, s2G=0.01,
          dUnit=1, betaOrder=1)
etaMar <- BMAnimalTrack(wlist, BMControl(print=TRUE))
```

---

dataSim *Simulate data to mimic the GPS observations and the DR path.*

Description

Simulate data from our Bayesian melding model with Brownian Bridge and Brownian Motion (See the model description in BMAnimalTrack).

Usage

```
dataSim(T, K, s2H, s2D, s2G=0.01,
   gind=NULL, betaVec=NULL, dMx=NULL, A=0, B=0, scale=TRUE)
```

Arguments

T	Number of time points in the animal's path and DR path.
K	Number of GPS observations.
s2H	Variance parameter for Brownian Bridge.
s2D	Variance parameter for the Brownian motion.
s2G	Variance of the measurement error in the GPS observations.
gind	Optional. The time points where the GPS observations are obtained. Default is randomly generating from 1:T.
betaVec	Coefficients in the function $h(t)$. When unspecified, no parametric bias term is considered.
dMx	Design matrix of dimension T. Default the polynomials.

A	Start point of the path. Default 0.
B	End point of the path. Default 0.
scale	Logical (TRUE of FALSE). Whether to standardize the columns of dMx with scale.

Value

A data list with the following elements:

eta	The simulated path of the animal,
Y	The GPS observations,
Ytime	The time points where the GPS observations are available,
X	Dead-Reckoned path

Author(s)

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References

Liu, Y., Battaile, B. C., Zidek, J. V., and Trites, A. (2014). Bayesian melding of the Dead-Reckoned path and gps measurements for an accurate and high-resolution path of marine mammals. arXiv preprint arXiv: 1411.6683.

Examples

```
set.seed(1)
#Generating data from our
dlist <- dataSim(T=100, K=10, s2H=1, s2D=0.1, betaVec=c(1))
gpsObs <- dlist$Y
gpsTime <- dlist$Ytime
drPath <- dlist$X
wlist <- as.dataList(drPath, gpsObs, gpsTime, timeUnit=1, s2G=0.01, dUnit=1, betaOrder=1)
##Examples continues in function "as.dataList".
```

DegToKM — *Convert between the latitude and longitude in degrees and Northing and Easting in kilometers (KM).*

Description

Based on functions from TrackReconstruction, convert the longitude and latitude degrees into easting and northing in kilometer or vice versa.

Usage

```
DegToKM(gpsformat)
KMToDeg(cPath, iniDeg)
```

Arguments

gpsformat	Output from `GPStable`, including the latitude, longitude in degrees and between GPS great circle distance and Bearing degree, etc.
cPath	A matrix with two columns, the corrected path from `BMAnimalTrack`, first column should be easting in KM and second column should be northing in KM.
iniDeg	The longitude and latitude in degree of the starting point of the path

Details

Please make sure you organize `cPath` and `iniDeg` as the function requires.

Value

`DegToKM` returns a data frame with date-time and the converted easting and northing in km. `KMToDeg` returns a matrix with two columns. The first column is longitude in degree of the corrected path and the second column is the latitude.

Author(s)

Yang (Seagle) Liu <yang.liu@stat.ubc.ca>

References

Liu, Y., Battaile, B. C., Zidek, J. V., and Trites, A. (2014). Bayesian melding of the Dead-Reckoned path and gps measurements for an accurate and high-resolution path of marine mammals. arXiv preprint arXiv: 1411.6683.

See Also

`BMAnimalTrack`, `GPStable`

Examples

```
data(Trip1GPS)
GPSformat <- GPStable(Trip1GPS)
GPSinKM <- DegToKM(GPSformat)
#Convert the degree into kilometers.
GPSdeg <- KMToDeg(GPSinKM[, 2:3], GPSformat[1, c(3, 2)])
#Convert the kilometers back into degrees.
#More comprehensive examples can be found by help(Trip1)
```

`Trip1` *GPS observation and DR path from a foraging trip of northern fur seal*

Description

This foraging trip lasted from 21-Jul-2009 09:30:00 to 28-Jul-2009 09:49:00. It started from and ended at Bogsolof island. This is a thinned version of the full data sets used in Liu et al. (2014a, 2014b). We thinned the original 1Hz DR path into once observation per 10 minutes.

Usage

```
data("Trip1GPS")
data("Trip1DR")
```

Format

`Trip1GPS` is a data frame with 274 observations on the following 3 variables.

`DateTime` Date and time of the observation, character vector

`Latitude` a numeric vector of the latitude observed by GPS

`Longtitude` a numeric vector of the longitude observed by GPS

`Trip1DR` is a data frame with 1187 observations (one observation per 10 minutes plus the points at the GPS observations) with the following variables

`DateTime` Date and time of the observation, character vector

`Xdim` a numeric vector of easting in meters (longitude) from the Dead-Reckoning algorithm

`Ydim` a numeric vector of northing in meters (latitude) from the Dead-Reckoning algorithm

Details

The `Trip1DR` is reconstructed by `TrackReconstruction`. Plots produced from this data set can be found in Liu et al. (2014a, 2014b).

Source

Liu, Y., Battaile, B. C., Zidek, J. V., and Trites, A. (2014a). Bayesian melding of the Dead-Reckoned path and gps measurements for an accurate and high-resolution path of marine mammals. arXiv preprint arXiv: 1411.6683.

Liu, Y., Battaile, B. C., Zidek, J. V., and Trites, A. (2014b). Bias Correction and Uncertainty Characterization of Dead-Reckoned Paths of Marine Mammals. submitted to Animal Bio-telemetery (Proceedings of the 5th Bio-logging Science Symposium).

Examples

```
data(Trip1GPS)
data(Trip1DR)
###Bayesian Melding correction of DR path for this data set.
## Not run:
###Additional File for Animal Bio-telemetry
###Working with a thinned version of Trip 1 data set.
#First install our R package
install.packages("BayesianAnimalTracker")

#Load the package
library(BayesianAnimalTracker)
#Require version 1.1 or higher.

##Load the uncorrected DR path
data(Trip1DR)
  #this result is produced by the TrackReconstruction package

##Load the GPS observations
data(Trip1GPS)

##Processng the GPS observations to get northing and easting in KM
Trip1GPSformat <- GPStable(Trip1GPS)
#GPStable is from TrackReconstruction
Trip1GPSinKM <- DegToKM(Trip1GPSformat)
#Get the northing and easting in km

###Analyze the Northing direction
##Prepare the data list that will be used in our Baysian Melding
ndl <- as.dataList(Trip1DR$Ydim/1000, Trip1GPSinKM$Northing,
                   Ytime=strptime(Trip1GPS$DateTime, "%d-%b-%Y %H:%M:%S"),
                   Xtime=strptime(Trip1DR$DateTime, "%d-%b-%Y %H:%M:%S"),
                   s2G=0.0625, timeUnit=60, betaOrder=1)
#Please notice that the DR is in meter.
#Need to convert it into kilometer.
#Notice here the Xtime is not regularly spaced.
#It must be converted to the dateTime format
#Before further operations.
##The Bayesian Melding to correct bias and qualify uncertianty
nPost <- BMAnimalTrack(ndl, BMControl(print=TRUE, returnParam=TRUE))
#nPost is a list with two components
#first is the parameter estimates of sigma^2_D and sigma^2_H
#second is a matrix of the posterior mean and variance of eta.
#If only eta is needed, you can chagne returnParam into FALSE.

##Plot the results in Easting direction.
##Produce Figure 4 in our paper
nYlim <- c(min(min(ndl$XMx[, 1]),min(nPost$etaMar[,1])),
           max(max(ndl$XMx[, 1]),max(nPost$etaMar[,1])))
#Find the limits in y-axis.
par(mar=c(4, 4, 1, 1))
plot(ndl$XMx[, 2], ndl$XMx[, 1], col="blue",
```

```
xlab="Time (min)", ylab="Northing (KM)",
     type="l", lwd=2, ylim=nYlim)
#Plot the uncorrected DR path
lines(ndl$XMx[, 2], nPost$etaMar[,1], lwd=2)
#Add the posterior mean of eta
#the corrected path from our Bayesian Melding approach
lines(ndl$XMx[, 2], nPost$etaMar[,1] +
1.96*sqrt(nPost$etaMar[,2]), lwd=2, col="grey70")
#Add the upper bound of the 95% credible interval
lines(ndl$XMx[, 2], nPost$etaMar[,1] -
1.96*sqrt(nPost$etaMar[,2]), lwd=2, col="grey70")
#Add the lower bound
legend("topleft", bty="n", legend=c("Posterior Mean",
"95% Credible Interval", "GPS Observations",
"Uncorrected DRA Results"),text.col=c(1, "grey70", 2, 4),
lty=c(1, 1, -1, 1), pch=c(-1, -1, 16, -1),
col=c(1, "grey70", 2, 4))
#Add a legend
points(ndl$glist$Gtime, ndl$g$Y, col="red", pch=16, cex=0.7)
#Add the original GPS observations.


###Analyze the Easting direction
##Prepare the data list that will be used in our Baysian Melding
edl <- as.dataList(Trip1DR$Xdim/1000, Trip1GPSinKM$Easting,
                   Ytime=strptime(Trip1GPS$DateTime, "%d-%b-%Y %H:%M:%S"),
                   Xtime=strptime(Trip1DR$DateTime, "%d-%b-%Y %H:%M:%S"),
                   s2G=0.0625, timeUnit=60, betaOrder=1)

##The Bayesian Melding to correct bias and qualify uncertianty
ePost <- BMAnimalTrack(edl, BMControl(print=TRUE, returnParam=TRUE))
#A list similar to nPost

##Plot the results in Easting direction.
##Produce a plot similar to Figure 4 in our paper
eYlim <- c(min(min(edl$XMx[, 1]),min(ePost$etaMar[,1])),
           max(max(edl$XMx[, 1]),max(ePost$etaMar[,1])))
#Find the limits in y-axis.
par(mar=c(4, 4, 1, 1))
plot(edl$XMx[, 2], edl$XMx[, 1], col="blue",
xlab="Time (min)", ylab="Easting (KM)",
     type="l", lwd=2, ylim=eYlim)
#Plot the uncorrected DR path
lines(edl$XMx[, 2], ePost$etaMar[,1], lwd=2)
#Add the posterior mean of eta
#the corrected path from our Bayesian Melding approach
lines(edl$XMx[, 2], ePost$etaMar[,1] +
1.96*sqrt(ePost$etaMar[,2]), lwd=2, col="grey70")
#Add the upper bound of the 95% credible interval
lines(edl$XMx[, 2], ePost$etaMar[,1] -
1.96*sqrt(ePost$etaMar[,2]), lwd=2, col="grey70")
#Add the lower bound
legend("bottomright", bty="n", legend=c("Posterior Mean",
```

```
"95% Credible Interval", "GPS Observations",
"Uncorrected DRA Results"),text.col=c(1, "grey70", 2, 4),
lty=c(1, 1, -1, 1), pch=c(-1, -1, 16, -1),
col=c(1, "grey70", 2, 4))
#Add a legend
points(edl$glist$Gtime, edl$g$Y, col="red", pch=16, cex=0.7)
#Add the original GPS observations.

###Combine the results in both dimensions,
###and calculate the corrected path in degrees.
cPathInKM <- cbind(ePost$etaMar[,1], nPost$etaMar[,1])
#first column is easting and second column northing in  KM.
cPathInDeg <- KMToDeg(cPathInKM, Trip1GPSformat [1, c(3, 2)])
#Get the longitude and latitude of the starting points
#first longitude and then latitude.

##Produce a plot similar to Figure 2 of Liu et al. (2014b)
plot(cPathInDeg[, ], type="l", lwd=2)
#plot the corrected path
points(Trip1GPSformat [, c(3, 2)], col="red", pch=16)
#add the original GPS observations.



## End(Not run)
```

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