

Package ‘AvInertia’

January 20, 2025

Title Calculate the Inertial Properties of a Flying Bird

Version 0.0.2

Description Tools to compute the center of gravity and moment of inertia tensor of any flying bird. The tools function by modeling a bird as a composite structure of simple geometric objects. This requires detailed morphological measurements of bird specimens although those obtained for the associated paper have been included in the package for use. Refer to the vignettes and supplementary material for detailed information on the package function.

License GPL-3

Encoding UTF-8

LazyData true

RoxygenNote 7.1.1.9000

Imports pracma, readxl, ggplot2, stringr, tidyr, ggthemes, reshape2

Suggests knitr, rmarkdown

VignetteBuilder knitr

Depends R (>= 3.5.0)

URL <https://github.com/charvey23/AvInertia>

BugReports <https://github.com/charvey23/AvInertia/issues>

NeedsCompilation no

Author Christina Harvey [aut, cre] (<<https://orcid.org/0000-0002-2830-0844>>),
Vikram B. Baliga [aut] (<<https://orcid.org/0000-0002-9367-8974>>),
Jasmin C.M. Wong [aut] (<<https://orcid.org/0000-0003-4648-2503>>)

Maintainer Christina Harvey <charveyca@umich.edu>

Repository CRAN

Date/Publication 2022-03-24 15:50:02 UTC

Contents

calc_inertia_conesolid	3
calc_inertia_cylhollow	4
calc_inertia_cylsolid	5
calc_inertia_ellcone	6
calc_inertia_ellcyl	8
calc_inertia_ellipse	9
calc_inertia_platerect	11
calc_inertia_platetri	12
calc_inertia_pyrasolid	13
calc_rot	15
calc_univec	16
clean_pts	16
combine_inertialprop	17
compute_feat_inertia	19
dat_bird_curr	21
dat_bone_curr	22
dat_feat_curr	23
dat_id_curr	23
dat_mat	24
density_optimizer	24
kronecker_delta	26
massprop_birdwing	26
massprop_bones	30
massprop_feathers	31
massprop_head	33
massprop_muscles	34
massprop_neck	36
massprop_pm	37
massprop_restbody	38
massprop_skin	40
massprop_tail	41
massprop_torso	43
orient_feather	45
parallelaxis	47
plot_CGloc	48
rotx	50
store_data	51
structural2VRP_feat	52

`calc_inertia_conesolid`*Moment of inertia tensor of a solid circular cone pyramid*

Description

All outputs are based on an origin at the centered point on the base Reference: <https://apps.dtic.mil/sti/pdfs/AD0274936.pdf>

Usage

```
calc_inertia_conesolid(r, h, m)
```

Arguments

r	radius of the cone base (m)
h	height of the cone (m)
m	mass of the cone (kg)

Value

a 3x3 matrix representing the moment of inertia tensor of a solid circular cone about its center of gravity with z oriented through it's major axis.

CAUTION

Origin of the output tensor is NOT at the center of gravity but at the center of the base.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
```

```

# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

calc_inertia_cylhollow

Moment of inertia tensor of a hollow cylinder

Description

Reference: <https://apps.dtic.mil/sti/pdfs/AD0274936.pdf>

Usage

```
calc_inertia_cylhollow(r_out, r_in, h, m)
```

Arguments

r_out	outer radius of the cylinder (m)
r_in	inner radius of the cylinder (m)
h	height of the cylinder (m)
m	mass of the cylinder (kg)

Value

a 3x3 matrix representing the moment of inertia tensor of a hollow cylinder about its center of gravity with z oriented through its major axis

Author(s)

Christina Harvey

Examples

```

# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

calc_inertia_cylsolid *Moment of inertia tensor of a solid cylinder*

Description

Reference: <https://apps.dtic.mil/sti/pdfs/AD0274936.pdf>

Usage

```
calc_inertia_cylsolid(r, h, m)
```

Arguments

r	radius of the cylinder (m)
h	height of the cylinder (m)
m	mass of the cylinder (kg)

Value

a 3x3 matrix representing the moment of inertia tensor of a solid cylinder about its center of gravity with z oriented through it's major axis

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

Description

Moment of inertia tensor of a solid elliptical cone - end of purple notebook derivation verified in green

Usage

```
calc_inertia_ellcone(A, B, l, m)
```

Arguments

A	half height of the wide base (m)
B	half width of the wide base (m)
l	length of the cone (m)
m	mass of the cone (kg)

Value

a 3x3 matrix representing the moment of inertia tensor of a solid elliptical cone about the center of the wider base with z oriented towards the end.

CAUTION

Origin of the output tensor is NOT at the center of gravity but at the center of the base.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
```

```

dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out,dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

calc_inertia_ellcyl *Moment of inertia tensor of a solid elliptical cylinder Reference: <https://apps.dtic.mil/sti/pdfs/AD0274936.pdf>*

Description

Moment of inertia tensor of a solid elliptical cylinder Reference: <https://apps.dtic.mil/sti/pdfs/AD0274936.pdf>

Usage

```
calc_inertia_ellcyl(a, b, l, m)
```

Arguments

a	half height of the base - oriented along the x axis in torso FOR (z axis in full bird FOR) (m)
b	half width of the base - oriented along the y axis in torso FOR (y axis in full bird FOR) (m)
l	length of the cylinder - oriented along the z axis in torso FOR (x axis in full bird FOR) (m)
m	mass of the cylinder (kg)

Value

a 3x3 matrix representing the moment of inertia tensor of a solid elliptical cylinder about it's center of gravity

Author(s)

Christina Harvey

Examples

```

# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

calc_inertia_ellipse *Moment of inertia tensor of solid ellipse CG or a half ellipse centered on the base*

Description

Reference:<https://apps.dtic.mil/sti/pdfs/AD0274936.pdf>

Usage

```
calc_inertia_ellipse(a, b, c, m)
```

Arguments

a half the height along the x direction (m)

b	half the width along the y direction (m)
c	half the length along the z direction (m)
m	mass of the ellipse (kg)

Value

a 3x3 matrix representing the moment of inertia tensor of a solid ellipse about its center of gravity with the major axes aligned.

CAUTION

Origin is at the center of gravity for a full ellipse or at the center of the base if modeling a half ellipse.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

calc_inertia_platerect

Moment of inertia tensor of a flat rectangular plate - assumes thickness is approximately zero Reference: <https://apps.dtic.mil/sti/pdfs/AD0274936.pdf>

Description

Moment of inertia tensor of a flat rectangular plate - assumes thickness is approximately zero Reference: <https://apps.dtic.mil/sti/pdfs/AD0274936.pdf>

Usage

```
calc_inertia_platerect(w, h, m)
```

Arguments

w	full width of one side of the plate - short edge (m)
h	height of the plate - long edge (m)
m	mass of the plate (kg)

Value

a 3x3 matrix representing the moment of inertia tensor of a flat plate about its center of gravity with z oriented parallel with its long edge (h) and y along its short edge (w)

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
```

```

dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

calc_inertia_platetri *Moment of inertia tensor of a flat triangular plate*

Description

Reference: <https://apps.dtic.mil/dtic/tr/fulltext/u2/a183444.pdf> page 4 equations 2.16-2.20

Usage

```
calc_inertia_platetri(pts, A, rho, t, desired_prop)
```

Arguments

pts	a matrix of the three 3D points that define a point on the triangular plate. Frame of reference: Muscle Origin: VRP each point should be a different row as follows: pt1x, pt1y, pt1z pt2x, pt2y, pt2z pt3x, pt3y, pt3z
A	area of the triangular plate (m)
rho	density of the material (kg/m ³)
t	thickness of the plate (m)
desired_prop	a string containing either "I" or "CG" depending on the desired output

Value

a 3x3 matrix representing the moment of inertia tensor of a flat triangular plate about its center of gravity. Z axis defined as the normal to the input points.

Warning

The input points should be defined in a counterclockwise direction around the plate in the triangular plate frame of reference i.e. all z components should be equal

Author(s)

Christina Harvey

Examples

```

# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

calc_inertia_pyrasolid

*Moment of inertia tensor of a solid square pyramid Reference:
<https://apps.dtic.mil/sti/pdfs/AD0274936.pdf> All outputs are based on
an origin at the centered point on the base*

Description

Moment of inertia tensor of a solid square pyramid Reference: <https://apps.dtic.mil/sti/pdfs/AD0274936.pdf>
All outputs are based on an origin at the centered point on the base

Usage

```
calc_inertia_pyrasolid(w, h, m)
```

Arguments

w	entire width of one side of the pyramid base (m)
h	entire height of the pyramid (m)
m	mass of the pyramid (kg)

Value

a 3x3 matrix representing the moment of inertia tensor of a solid square pyramid about its center of gravity with z oriented through it's major axis.

CAUTION

Origin is NOT at the center of gravity but at the center of the base.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
```

```
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

calc_rot	<i>A 3x3 rotation matrix constructed by projecting the new axes onto the original system. Likely results in rotation about all axes.</i>
----------	--

Description

A 3x3 rotation matrix constructed by projecting the new axes onto the original system. Likely results in rotation about all axes.

Usage

```
calc_rot(z_vector, x_vector)
```

Arguments

z_vector	a 1x3 vector representing the direction for the desired z axis of the new frame of reference. Frame of reference: VRP
x_vector	a 1x3 vector representing the direction for the desired x axis of the new frame of reference. Frame of reference: VRP

Value

a 3x3 matrix representing the rotation matrix that transforms between VRP frame and object frame

Author(s)

Christina Harvey

Examples

```
library(AvInertia)
z_vector = c(0,0,1)
x_vector = c(-1,0,0)

# should return matrix [[-1,0,0];[0,-1,0];[0,0,1]]
calc_rot(z_vector, x_vector)
```

calc_univec	<i>Determine the unit vector of any input vector</i>
-------------	--

Description

Determine the unit vector of any input vector

Usage

```
calc_univec(vector)
```

Arguments

vector any vector or array with only one dimension

Value

the unit vector in the size of the input vector

Author(s)

Christina Harvey

Examples

```
library(AvInertia)

#any random input vector
vector = c(1,2,3)
output_vec = calc_univec(vector)

# if unit vector the magnitude should = 1
pracma::Norm(output_vec)
```

clean_pts	<i>The identified peripheral and joint 3D positions.</i>
-----------	--

Description

A dataset containing the identified peripheral and joint 3D positions for a pigeon BirdID = 20_0300, TestID = 20_03004, FrameID = 317

Usage

```
clean_pts
```


Format

A matrix with 10 rows and 3 columns. Columns represent x, y, and z coordinate respectively:

pt1x, pt1y, pt1z Point on the shoulder joint (m).

pt2x, pt1y, pt2z Point on the elbow joint (m).

pt3x, pt3y, pt3z Point on the wrist joint (m).

pt4x, pt4y, pt4z Point on the end of carpometacarpus (m).

pt6x, pt6y, pt6z Point on the leading edge of the wing in front of the wrist joint (m).

pt8x, pt8y, pt8z Point on tip of most distal primary (m).

pt9x, pt9y, pt9z Point on the tip of the last primary to model as if it is on the end of the carpometacarpus (m).

pt10x, pt10y, pt10z Point on tip of last primary to model as if it was distributed along the carpometacarpus (m).

pt11x, pt11y, pt11z Point on tip of most proximal feather (m).

pt12x, pt12y, pt12z Point on exterior shoulder position (wing root leading edge) (m).

combine_inertialprop *Combine body and wing inertial components.*

Description

Combines data exported from massprop_restbody and massprop_birdwing.

Usage

```
combine_inertialprop(
  curr_torsotail_data,
  left_wing_data,
  right_wing_data,
  dat_id_curr,
  dat_bird_curr,
  symmetric
)
```

Arguments

`curr_torsotail_data` Output dataframe from massprop_restbody.

`left_wing_data` Output dataframe from massprop_birdwing.

`right_wing_data` Output dataframe from massprop_birdwing.

`dat_id_curr` Dataframe related to the current bird wing ID info that must include the following columns:

- speciesSpecies ID code as a string.
- BirdIDBird ID code as a string.
- TestIDTest ID code as a string.
- frameIDVideo frame ID code as a string.

dat_bird_curr Dataframe related to the current bird wing that must include the following columns:

- total_bird_massMass of full bird for the current wing (kg).

symmetric Logical indicating if the input wings are symmetric or not. If True than left_wing_data = right_wing_data.

Value

a dataframe containing all of the inertial properties for each wing component and the full bird about it's center of gravity and the vehicle reference point (VRP)

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

compute_feat_inertia *Compute the inertia of the individual feathers*

Description

Compute the inertia of the individual feathers

Usage

```
compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
```

Arguments

- | | |
|---------------|---|
| dat_mat | Dataframe related to the current species input as a dataframe with the following structure: <ul style="list-style-type: none"> • materialMaterial information. Must include the following: "Cortex", "Medullary" • densityDensity of each material (kg/m³) |
| dat_feat_curr | Dataframe related to the current bird wing feathers input as a dataframe with the following structure: <ul style="list-style-type: none"> • featherFeather ID code. Must be in standard format i.e. 1st primary is "P1", third secondary is "S3", etc. Alula feathers should be grouped and named "alula". • m_fMass of feather in the same row as the appropriate feather ID code (kg) • l_calLength of calamus in the same row as the appropriate feather ID code (m) • l_vaneLength of rachis/vane in the same row as the appropriate feather ID code (m) • w_calWidth (diameter) of calamus in the same row as the appropriate feather ID code (m) • w_vpWidth of proximal vane (average value) in the same row as the appropriate feather ID code (m) • w_vdWidth of distal vane (average value) in the same row as the appropriate feather ID code (m) • vane_angleInterior angle between the rachis and calamus (degrees) <p>NOTE: Alula feathers will be treated as point mass so only the mass of the feathers is required. Other columns can be left blank.</p> |
| dat_bird_curr | Dataframe related to the current bird wing that must include the following columns: <ul style="list-style-type: none"> • barb_radiusRadius of feather barb for current species (m) • barb_distanceDistance between feather barbs for current species (m) |

Value

A list with one entry per flight feather. Each primary feather includes the following variables:

- `I_pria` 3x3 matrix representing the moment of inertia about each feather calamus tip ($\text{kg}\cdot\text{m}^2$).
- `CG_pria` 1x3 vector (x,y,z) representing the center of gravity of the primary feather (m).
- `m_pria` double representing the mass of the primary feather (kg).

Each secondary feather includes the following variables:

- `I_seca` 3x3 matrix representing the moment of inertia about each feather calamus tip ($\text{kg}\cdot\text{m}^2$).
- `CG_seca` 1x3 vector (x,y,z) representing the center of gravity of the primary feather (m).
- `m_seca` double representing the mass of the primary feather (kg).

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

dat_bird_curr	<i>Bird specific morphology dataset</i>
---------------	---

Description

A dataset containing the bird specific morphology data for a pigeon BirdID = 20_0300, TestID = 20_03004, FrameID = 317

Usage

dat_bird_curr

Format

A dataframe with 1 row and 125 variables. Only 29 required for proper operation:

total_bird_mass Mass of full bird for the current wing (kg)
wing_mass Mass of one wing, should be the current wing (kg)
barb_radius Radius of feather barb for current species (m)
barb_distance Distance between feather barbs for current species (m)
brachial_muscle_mass Mass of all muscles in the brachial region of the wing (kg)
antebrachial_muscle_mass Mass of all muscles in the antebrachial region of the wing (kg)
manus_muscle_mass Mass of all muscles in the manus region of the wing (kg)
all_skin_coverts_mass Mass of all skin and covert feathers (kg).
tertiary_mass Mass of tertiary feathers (kg).
extend_neck Logical input defining whether the neck should be modeled as extended or not
head_length Length of the head from base to tip (m)
head_mass Mass of the head (kg)
head_height Height of the head at the base (m)
neck_mass Mass of the neck (kg)
neck_width OPTIONAL: Average width of the stretched neck (m)
neck_length OPTIONAL: Length of the stretched neck (m)
torsotail_length Length from the beginning of the torso to the tip of the tail (m)
torsotail_mass Mass of the torso and tail (kg)
tail_length Length of the tail (m)
tail_mass Mass of the tail (kg)
tail_width Average width of the furled tail (m)
right_leg_mass Mass of the right leg (kg)
left_leg_mass Mass of the left leg (kg)
body_width_max Maximum width of the torso (m)

- body_width_at_leg_insert** Width of the body at the point where the legs are inserted (m).
- x_loc_of_body_max** x coordinate from the VRP in the full bird frame of reference of the maximum body width (m).
- x_loc_leg_insertion** x coordinate from the VRP in the full bird frame of reference of the leg insertion location (m).
- x_loc_TorsotailCoG** x coordinate from the VRP in the full bird frame of reference of the center of gravity of the torso and tail (m).
- z_loc_TorsotailCoG** x coordinate from the VRP in the full bird frame of reference of the the center of gravity of the torso and tail (m).

 dat_bone_curr

Wing bone specific morphology dataset

Description

A dataset containing the wing bone specific data for a pigeon BirdID = 20_0300, TestID = 20_03004, FrameID = 317

Usage

dat_bone_curr

Format

A dataframe with 6 rows and 5 variables:

bone Bone ID code. Must include: "Humerus", "Ulna", "Radius", "Carpometacarpus", "Ulnare" and "Radiale".

bone_mass Mass of bone in the same row as the appropriate bone ID code (kg)

bone_len Length of bone in the same row as the appropriate bone ID code (m)

bone_out_rad Outer radius of bone in the same row as the appropriate bone ID code (m)

bone_in_rad Inner radius of bone in the same row as the appropriate bone ID code (m)

dat_feat_curr *Flight feather specific morphology dataset*

Description

A dataset containing the wing bone specific data for a pigeon BirdID = 20_0300, TestID = 20_03004, FrameID = 317

Usage

dat_feat_curr

Format

A dataframe with 20 rows and 15 variables. Only 8 variables required for proper functioning:

feather Feather ID code. Must be in standard format i.e. 1st primary is "P1", third secondary is "S3", etc. Alula feathers should be grouped and named "alula".

m_f Mass of feather in the same row as the appropriate feather ID code (kg)

l_cal Length of calamus in the same row as the appropriate feather ID code (m)

l_vane Length of rachis/vane in the same row as the appropriate feather ID code (m)

w_cal Width (diameter) of calamus in the same row as the appropriate feather ID code (m)

w_vp Width of proximal vane (average value) in the same row as the appropriate feather ID code (m)

w_vd Width of distal vane (average value) in the same row as the appropriate feather ID code (m)

vane_angle Interior angle between the rachis and calamus (degrees)

dat_id_curr *Identification variables for current configuration*

Description

A dataset containing the identification data for a pigeon BirdID = 20_0300, TestID = 20_03004, FrameID = 317

Usage

dat_id_curr

Format

A dataframe with 1 row and 4 required variables:

species Species ID code as a string

BirdID Bird ID code as a string

TestID Test ID code as a string

frameID Video frame ID code as a string

dat_mat	<i>Material properties.</i>
---------	-----------------------------

Description

A dataset containing the material properties for a pigeon BirdID = 20_0300, TestID = 20_03004, FrameID = 317.

Usage

dat_mat

Format

A dataframe with 20 rows and 15 variables. Only 8 variables required for proper functioning:

material Material information. Must include the following: "Bone","Skin","Muscle","Cortex", "Medullary"

density Density of each material (kg/m³)

density_optimizer	<i>Optimize torso section densities</i>
-------------------	---

Description

Function that is used within an optimization routine to select the appropriate torso section density

Usage

density_optimizer(x, m_body, A, v_ell, CG_body_x, CG_ell, rho_avg)

Arguments

x	a scalar guess at the density of the torso hemi-ellipsoid section (kg/m ³)
m_body	a scalar representing the mass of the full torso
A	a 2x2 matrix representing the mass and volume calculations of the final two torso section
v_ell	a scalar representing the volume of the hemi-ellipsoid
CG_body_x	a scalar representing the position of the center of gravity of the full torso along the x axis with the origin at the VRP
CG_ell	a scalar representing the position of the center of gravity of the hemi-ellipsoid section along the x axis with the origin at the VRP
rho_avg	average density of the full torso

Value

the squared error between the three section densities and the average torso density

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

kronecker_delta	<i>Kroneckerdelta function</i>
-----------------	--------------------------------

Description

Kroneckerdelta function

Usage

```
kronecker_delta(i, j)
```

Arguments

i	a scalar index (usually row of a matrix)
j	a scalar index (usually column of a matrix)

Value

a scalar value. Returns 1 if i and j are equal otherwise returns 0

Author(s)

Christina Harvey

Examples

```
library(AvInertia)

# should return 1
kronecker_delta(1,1)

# should return 0
kronecker_delta(0,1)
```

massprop_birdwing	<i>Calculate the center of gravity and moment of inertia for a halfspan wing.</i>
-------------------	---

Description

Function that reads in anatomical data and returns the moment of inertia tensor and center of gravity of a wing one side of the bird.

Usage

```

massprop_birdwing(
  dat_wingID_curr,
  dat_bird_curr,
  dat_bone_curr,
  dat_feat_curr,
  dat_mat_curr,
  clean_pts,
  feather_inertia,
  plot_var
)

```

Arguments

dat_wingID_curr

Dataframe related to the current bird wing ID info that must include the following columns:

- speciesSpecies ID code as a string.
- BirdIDBird ID code as a string.
- TestIDTest ID code as a string.
- frameIDVideo frame ID code as a string.

dat_bird_curr

Dataframe related to the current bird wing that must include the following columns:

- total_bird_massMass of full bird for the current wing (kg).
- wing_massMass of one wing, should be the current wing (kg).
- barb_radiusRadius of feather barb for current species (m).
- barb_distanceDistance between feather barbs for current species (m).
- brachial_muscle_massMass of all muscles in the brachial region of the wing (kg).
- antebrachial_muscle_massMass of all muscles in the antebrachial region of the wing (kg).
- manus_muscle_massMass of all muscles in the manus region of the wing (kg).
- all_skin_coverts_massMass of all skin and covert feathers (kg).
- tertiary_massMass of tertiary feathers (kg).

dat_bone_curr

Dataframe (6 row x 5 column) related to the current bird wing bones that must include the following columns:

- boneBone ID code. Must include: "Humerus", "Ulna", "Radius", "Carpometacarpus", "Ulnare" and "Radiale".
- bone_massMass of bone in the same row as the appropriate bone ID code (kg).
- bone_lenLength of bone in the same row as the appropriate bone ID code (m).
- bone_out_radOuter radius of bone in the same row as the appropriate bone ID code (m).

	<ul style="list-style-type: none"> • bone_in_rad Inner radius of bone in the same row as the appropriate bone ID code (m).
dat_feat_curr	<p>Dataframe related to the current bird wing feathers input as a dataframe with the following structure:</p> <ul style="list-style-type: none"> • feather Feather ID code. Must be in standard format i.e. 1st primary is "P1", third secondary is "S3", etc. Alula feathers should be grouped and named "alula". • m_f Mass of feather in the same row as the appropriate feather ID code (kg). • l_cal Length of calamus in the same row as the appropriate feather ID code (m). • l_vane Length of rachis/vane in the same row as the appropriate feather ID code (m). • w_cal Width (diameter) of calamus in the same row as the appropriate feather ID code (m). • w_vp Width of proximal vane (average value) in the same row as the appropriate feather ID code (m). • w_vd Width of distal vane (average value) in the same row as the appropriate feather ID code (m). • vane_angle Interior angle between the rachis and calamus (degrees). <p>NOTE: Alula feathers will be treated as point mass so only the mass of the feathers is required. Other columns can be left blank.</p>
dat_mat_curr	<p>Dataframe related to the current species input as a dataframe with the following structure:</p> <ul style="list-style-type: none"> • material Material information. Must include the following: "Bone", "Skin", "Muscle", "Cortex", "Medullary" • density Density of each material (kg/m³).
clean_pts	<p>A data frame of the key positions of the bird as follows:</p> <ul style="list-style-type: none"> • pt1x, pt1y, pt1z Point on the shoulder joint (m). • pt2x, pt2y, pt2z Point on the elbow joint (m). • pt3x, pt3y, pt3z Point on the wrist joint (m). • pt4x, pt4y, pt4z Point on the end of carpometacarpus (m). • pt6x, pt6y, pt6z Point on the leading edge of the wing in front of the wrist joint (m). • pt8x, pt8y, pt8z Point on tip of most distal primary (m). • pt9x, pt9y, pt9z Point on the tip of the last primary to model as if it is on the end of the carpometacarpus (m). • pt10x, pt10y, pt10z Point on tip of last primary to model as if it was distributed along the carpometacarpus (m). • pt11x, pt11y, pt11z Point on tip of most proximal feather (m). • pt12x, pt12y, pt12z Point on exterior shoulder position (wing root leading edge) (m).
feather_inertia	<p>A list with one entry per flight feather. Each primary feather includes the following variables:</p>

- I_{pria} 3x3 matrix representing the moment of inertia about each feather calamus tip ($\text{kg}\cdot\text{m}^2$).
- CG_{pria} 1x3 vector (x,y,z) representing the center of gravity of the primary feather (m).
- m_{pria} double representing the mass of the primary feather (kg).

Each secondary feather includes the following variables:

- I_{seca} 3x3 matrix representing the moment of inertia about each feather calamus tip ($\text{kg}\cdot\text{m}^2$).
- CG_{seca} 1x3 vector (x,y,z) representing the center of gravity of the primary feather (m).
- m_{seca} double representing the mass of the primary feather (kg).

`plot_var` A string that defines the x-axis and y-axis of the output plot. Can either equal "yx" or "yz".

Value

Function returns a dataframe that includes the moment of inertia and center of gravity of one wing about the VRP in the VRP frame and that of each major anatomical group i.e. skin, feathers, bones, muscles.

CAUTION

All points must all have the vehicle reference point (VRP) as their origin and the vehicle major axes as their frame of reference. This is normally selected so that the VRP is in line with the body center of gravity. Ensure the axes used represent a right-handed axis system.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
```

```

dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

massprop_bones	<i>Bone mass properties</i>
----------------	-----------------------------

Description

Calculate the moment of inertia of a bone modeled as a hollow cylinder with two solid end caps

Usage

```
massprop_bones(m, l, r_out, r_in, rho, start, end)
```

Arguments

m	Mass of bone (kg)
l	Length of bone (kg)
r_out	Outer radius of bone (m)
r_in	Inner radius of bone (m)
rho	Density of the bone (kg/m ³)
start	a 1x3 vector (x,y,z) representing the 3D point where bone starts. Points from the VRP to the bone start. Frame of reference: VRP Origin: VRP
end	a 1x3 vector (x,y,z) representing the 3D point where bone ends. Points from the VRP to the bone start. Frame of reference: VRP Origin: VRP

Value

This function returns a list that includes:

- Ia 3x3 matrix representing the moment of inertia tensor of a bone modeled as a hollow cylinder with two solid end caps
- CGa 1x3 vector representing the center of gravity position of a bone modeled as a hollow cylinder with two solid end caps
- ma double that returns the input bone mass

Warning

Parallel axis theorem does not apply between two arbitrary points. One point must be the object's center of gravity.

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

massprop_feathers

Feather mass properties

Description

Calculate the moment of inertia of the feathers within the feather frame of reference.

Usage

```

massprop_feathers(
  m_f,
  l_c,
  l_r_cor,
  w_cal,
  r_b,
  d_b,
  rho_cor,
  rho_med,
  w_vp,
  w_vd,
  angle
)

```

Arguments

m_f	Mass of the entire feather (kg)
l_c	Length of the calamus; start of vane to end of calamus(m)
l_r_cor	Length of rachis; tip to start of vane (m)
w_cal	Width (diameter) of the cortex part of the calamus (m)
r_b	Radius of feather barbs (m)
d_b	Distance between barbs (m)
rho_cor	Density of the cortex (kg/m ³)
rho_med	Density of the medullary (kg/m ³)
w_vp	Width of proximal (closest to body) vane (m)
w_vd	Width of distal (closest to wing tip) vane (m)
angle	Angle between calamus and the vane taken the supplement angle to the interior angle. Negative indicates the feather tip is rotated proximally relative to the start of the feather vane.

Value

a list that includes:

- Ia 3x3 matrix representing the moment of inertia tensor of a simplified feather with the origin at the feather calamus end and within the feather frame of reference
- CGa 1x3 vector representing the center of gravity position of a simplified feather with the origin at the feather calamus end and within the feather frame of reference
- ma double that returns the feather mass

Warning

Parallel axis theorem does not apply between two arbitrary points. One point must be the object's center of gravity.

CAUTION: While computing the variable components of the feather the x axis is the normal of the feather.

Author(s)

Christina Harvey

Examples

```

# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

massprop_head

Head mass properties

Description

Calculate the moment of inertia of a head modeled as a solid cone

Usage

```
massprop_head(m, r, l, start, end)
```

Arguments

m	Mass of head (kg)
r	Maximum head radius (m)
l	Maximum head length (m)
start	a 1x3 vector (x,y,z) representing the 3D point where head starts. Frame of reference: VRP Origin: VRP
end	a 1x3 vector (x,y,z) representing the 3D point where head ends. Frame of reference: VRP Origin: VRP

Value

This function returns a list that includes:

- Ia 3x3 matrix representing the moment of inertia tensor of a head modeled as a solid cone
- CGa 1x3 vector representing the center of gravity position of a head modeled as a solid cone
- ma double that returns the head mass

Warning

Parallel axis theorem does not apply between two arbitrary points. One point must be the object's center of gravity.

Author(s)

Christina Harvey

massprop_muscles *Muscle mass properties*

Description

Calculate the moment of inertia of a muscle modeled as a solid cylinder distributed along the bone length

Usage

```
massprop_muscles(m, rho, l, start, end)
```

Arguments

m	Mass of muscle (kg).
rho	Density of muscle (kg/m ³).
l	Length of the muscle group (m).
start	a 1x3 vector (x,y,z) representing the 3D point where bone starts. Frame of reference: VRP Origin: VRP.
end	a 1x3 vector (x,y,z) representing the 3D point where bone ends. Frame of reference: VRP Origin: VRP.

Value

This function returns a list that includes:

- Ia 3x3 matrix representing the moment of inertia tensor of a muscle modeled as a solid cylinder distributed along the bone length.
- CGa 1x3 vector representing the center of gravity position of a muscle modeled as a solid cylinder distributed along the bone length.
- ma double that returns the input muscle mass.

Warning

Parallel axis theorem does not apply between two arbitrary points. One point must be the object's center of gravity.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

massprop_neck	<i>Neck mass properties</i>
---------------	-----------------------------

Description

Calculate the moment of inertia of a neck modeled as a solid cylinder

Usage

```
massprop_neck(m, r, l, start, end)
```

Arguments

m	Mass of muscle (kg).
r	Radius of the neck (m).
l	Length of the stretched neck (m).
start	a 1x3 vector (x,y,z) representing the 3D point where neck starts. Frame of reference: VRP Origin: VRP.
end	a 1x3 vector (x,y,z) representing the 3D point where neck ends. Frame of reference: VRP Origin: VRP.

Value

This function returns a list that includes:

- Ia 3x3 matrix representing the moment of inertia tensor of a neck modeled as a solid cylinder.
- CGa 1x3 vector representing the center of gravity position of a neck modeled as a solid cylinder.
- ma double that returns the neck mass.

Warning

Parallel axis theorem does not apply between two arbitrary points. One point must be the object's center of gravity.

Author(s)

Christina Harvey

massprop_pm	<i>Point-mass mass properties</i>
-------------	-----------------------------------

Description

Calculate the moment of inertia of any point mass

Usage

```
massprop_pm(m, pt)
```

Arguments

m	Mass of point mass (kg)
pt	a 1x3 vector (x,y,z) representing the location of the point mass. Frame of reference: VRP Origin: VRP

Value

This function returns a list that includes:

- Ia 3x3 matrix representing the moment of inertia tensor of a point mass
- CGa 1x3 vector representing the center of gravity position of a point mass
- ma double that returns the input mass

Warning

Parallel axis theorem does not apply between two arbitrary points. One point must be the object's center of gravity.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
```

```

dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

massprop_restbody	<i>Calculate the center of gravity and moment of inertia for the head, neck, torso and tail.</i>
-------------------	--

Description

Function that reads in anatomical data and returns the moment of inertia tensor and center of gravity for the head, neck, tail and torso.

Usage

```
massprop_restbody(dat_wingID_curr, dat_bird_curr)
```

Arguments

`dat_wingID_curr` Dataframe related to the current bird wing ID info that must include the following columns:

- `species` Species ID code as a string.
- `BirdID` Bird ID code as a string.
- `TestID` Test ID code as a string.
- `frameID` Video frame ID code as a string.

`dat_bird_curr` Dataframe related to the current bird wing that must include the following columns:

- `extend_neck` Logical input defining whether the neck should be modeled as extended or not.
- `head_length` Length of the head from base to tip (m).

- head_mass Mass of the head (kg).
- head_height Height of the head at the base (m).
- neck_mass Mass of the neck (kg).
- neck_width OPTIONAL - Average width of the stretched neck (m).
- neck_length OPTIONAL - Length of the stretched neck (m).
- torsotail_length Length from the beginning of the torso to the tip of the tail (m).
- torsotail_mass Mass of the torso and tail (kg).
- tail_length Length of the tail (m).
- tail_mass Mass of the tail (kg).
- tail_width Average width of the furled tail (m).
- right_leg_mass Mass of the right leg (kg).
- left_leg_mass Mass of the left leg (kg).
- body_width_max Maximum width of the torso (m).
- body_width_at_leg_insert Width of the body at the point where the legs are inserted (m).
- x_loc_of_body_max x coordinate from the VRP in the full bird frame of reference of the maximum body width (m).
- x_loc_leg_insertion x coordinate from the VRP in the full bird frame of reference of the leg insertion location (m).
- x_loc_TorsotailCoGx coordinate from the VRP in the full bird frame of reference of the center of gravity of the torso and tail (m).
- z_loc_TorsotailCoGz coordinate from the VRP in the full bird frame of reference of the the center of gravity of the torso and tail (m).

Value

Function returns a dataframe that includes the moment of inertia and center of gravity of head, neck, torso and tail.

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
```

```

dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

massprop_skin

Calculates the mass properties of skin or tertiaries

Description

Calculate the moment of inertia of skin or tertiaries modeled as a flat triangular plate

Usage

```
massprop_skin(m, rho, pts)
```

Arguments

m	Mass of skin (kg)
rho	Density of skin (kg/m ³)
pts	a 3x3 matrix that represent three points that define the vertices of the triangle. Frame of reference: VRP Origin: VRP Must be numbered in a counterclockwise direction for positive area, otherwise signs will be reversed. each point should be a different of the matrix as follows: <ul style="list-style-type: none"> • pt1x, pt1y, pt1z • pt2x, pt1y, pt2z • pt3x, pt3y, pt3z

Value

This function returns a list that includes: point mass

- Ia 3x3 matrix representing the moment of inertia tensor of skin modeled as a flat triangular plate
- CGa 1x3 vector representing the center of gravity position of skin modeled as a flat triangular plate
- ma double that returns the input skin mass

Warning

Parallel axis theorem does not apply between two arbitrary points. One point must be the object's center of gravity.

Caution: The skin frame of reference assumes that the z axis is normal to the incoming points.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

massprop_tail

Head mass properties

Description

Calculate the moment of inertia of a tail modeled as a solid cone

Usage

```
massprop_tail(m, l, w, start, end)
```

Arguments

m	Mass of muscle (kg)
l	Length of the tail (m)
w	Width of the tail (m)
start	a 1x3 vector (x,y,z) representing the 3D point where head starts. Frame of reference: VRP Origin: VRP
end	a 1x3 vector (x,y,z) representing the 3D point where head ends. Frame of reference: VRP Origin: VRP

Value

This function returns a list that includes:

- Ia 3x3 matrix representing the moment of inertia tensor of a head modeled as a solid cone
- CGa 1x3 vector representing the center of gravity position of a head modeled as a solid cone
- ma double that returns the head mass

Warning

Parallel axis theorem does not apply between two arbitrary points. One point must be the object's center of gravity.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
```

```

dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

massprop_torso

Torso and leg mass properties

Description

Calculate the moment of inertia of a head modeled as a solid cone

Usage

```

massprop_torso(
  m_true,
  m_legs,
  w_max,
  h_max,
  l_bmax,
  w_leg,
  l_leg,
  l_tot,
  CG_true_x,
  CG_true_z,
  start,
  end
)

```

Arguments

m_true	Mass of the torso and legs - no tail (kg)
m_legs	Mass of the legs only (kg)
w_max	Maximum width of the body (m)
h_max	Maximum height of the body (m)
l_bmax	x location of the maximum width of the body (m)

w_leg	width of the body at leg insertion (m)
l_leg	x location of the leg insertion point (m)
l_tot	length of body from clavicle to beginning of the tail (m)
CG_true_x	x location of the CG for the torso and legs, origin is at the VRP, measured positive if aft of the VRP (m)
CG_true_z	z location of the CG for the torso and legs, origin is at the VRP (m)
start	a 1x3 vector (x,y,z) representing the 3D point where torso starts. Frame of reference: VRP Origin: VRP
end	a 1x3 vector (x,y,z) representing the 3D point where tail ends. Frame of reference: VRP Origin: VRP

Value

This function returns a list that includes:

- Ia 3x3 matrix representing the moment of inertia tensor of the torso and leg composite body
- CGa 1x3 vector representing the center of gravity position of the torso and leg composite body
- ma double that returns the mass of the torso and leg composite body

Warning

Parallel axis theorem does not apply between two arbitrary points. One point must be the object's center of gravity.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
```

```

# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out,dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

orient_feather	<i>Determine the feather orientation</i>
----------------	--

Description

Code that returns the orientation of each primary and secondary feather on the wing.

Usage

```
orient_feather(no_pri, no_sec, Pt1, Pt2, Pt3, Pt4, Pt8, Pt9, Pt10, Pt11, Pt12)
```

Arguments

no_pri	a scalar representing the amount of primary feathers.
no_sec	a scalar representing the amount of secondary feathers.
Pt1	a 1x3 vector (x,y,z) representing the point on the shoulder joint (m).
Pt2	a 1x3 vector (x,y,z) representing the point on the elbow joint (m).
Pt3	a 1x3 vector (x,y,z) representing the point on the wrist joint (m).
Pt4	a 1x3 vector (x,y,z) representing the point on the end of carpometacarpus (m).
Pt8	a 1x3 vector (x,y,z) representing the point on tip of most distal primary (m).
Pt9	a 1x3 vector (x,y,z) representing the point on the tip of the last primary to model as if it is on the end of the carpometacarpus (m).
Pt10	1x3 vector (x,y,z) representing the point on tip of last primary to model as if it was distributed along the carpometacarpus (m). Usually the first secondary feather tip.
Pt11	1x3 vector (x,y,z) representing the point on tip of most proximal secondary feather (m).
Pt12	1x3 vector (x,y,z) representing the point on exterior shoulder position (wing root leading edge) (m).

Value

a list called "feather". This contains three matrices.

1. "loc_start" a matrix defining the 3D point where each feather starts. Rows are the different feathers and columns are x, y, z coordinates respectively.
2. "loc_end" a matrix defining the 3D point where each feather end. Rows are the different feathers and columns are x, y, z coordinates respectively.
3. "normal" a matrix that gives the vector that defines the normal to each feather plane. Rows are the different feathers and columns are x, y, z vector directions respectively.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

parallelaxis *Parallel axis theory*

Description

Reads in an initial tensor and an offset to compute the transformed tensor. Will be in the same frame of reference as the input tensor.

Usage

```
parallelaxis(I, offset_vec, m, cg_a)
```

Arguments

I	a 3x3 matrix representing the moment of inertia tensor about the center of gravity of the object (kg-m ²).
offset_vec	a 1x3 vector representing the distance (x,y,z) between the objects CG and the arbitrary pt A (m). Vector should always point from the CG to the arbitrary point A.
m	Mass of the object (kg).
cg_a	If input I is about the CG enter "CG" or if I is about an arbitrary axis enter "A".

Value

a 3x3 matrix representing the transformed moment of inertia tensor after a solid body translation defined by the offset vector.

Author(s)

Christina Harvey

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
```

```

# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

plot_CGloc

Plot the center of gravity of each component

Description

Plot the center of gravity of each component

Usage

```

plot_CGloc(
  clean_pts,
  mass_properties,
  mass_properties_skin,
  mass_properties_bone,
  mass_properties_feathers,
  mass_properties_muscle,
  prop_tertiary1,
  prop_tertiary2,
  plot_var
)

```

Arguments

clean_pts	Dataframe of the key positions of the bird as follows: <ul style="list-style-type: none"> • pt1x, pt1y, pt1z Point on the shoulder joint • pt2x, pt2y, pt2z Point on the elbow joint • pt3x, pt3y, pt3z Point on the wrist joint • pt4x, pt4y, pt4z Point on the end of carpometacarpus • pt6x, pt6y, pt6z Point on the leading edge of the wing in front of the wrist joint
-----------	---

- pt8x, pt8y, pt8zPoint on tip of most distal primary
- pt9x, pt9y, pt9zPoint that defines the end of carpometacarpus
- pt10x, pt10y, pt10zPoint on tip of last primary to model as if on the end of the carpometacarpus
- pt11x, pt11y, pt11zPoint on tip of most proximal feather (wing root trailing edge)
- pt12x, pt12y, pt12zPoint on exterior shoulder position (wing root leading edge)

mass_properties

Dataframe containing the center of gravity and moment of inertia components of the full wing.

mass_properties_skin

Dataframe containing the center of gravity and moment of inertia components of the skin. Formatted with the following columns: "species", "BirdID", "TestID", "FrameID", "prop_type", "component", "value".

mass_properties_bone

Dataframe containing the center of gravity and moment of inertia components of the wing bones. Formatted with the following columns: "species", "BirdID", "TestID", "FrameID", "prop_type", "component", "value".

mass_properties_feathers

Dataframe containing the center of gravity and moment of inertia components of the feathers. Formatted with the following columns: "species", "BirdID", "TestID", "FrameID", "prop_type", "component", "value".

mass_properties_muscle

Dataframe containing the center of gravity and moment of inertia components of the muscles Formatted with the following columns: "species", "BirdID", "TestID", "FrameID", "prop_type", "component", "value".

prop_tertiary1

Dataframe containing the center of gravity and moment of inertia components of the first tertiary group. Formatted with the following columns: "species", "BirdID", "TestID", "FrameID", "prop_type", "component", "value".

prop_tertiary2

Dataframe containing the center of gravity and moment of inertia components of the second tertiary group. Formatted with the following columns: "species", "BirdID", "TestID", "FrameID", "prop_type", "component", "value".

plot_var

Character of either "yx" or "yz". Defines the output axes of the plot.

Value

A plot of the request axes

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
```

```

data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

rotx

A 3x3 rotation matrix allowing rotation about the x-axis. Constructed using a cosine rotation matrix where the rotation angle in degrees is measured counterclockwise allowing positive rotation under the right hand rule.

Description

A 3x3 rotation matrix allowing rotation about the x-axis. Constructed using a cosine rotation matrix where the rotation angle in degrees is measured counterclockwise allowing positive rotation under the right hand rule.

Usage

```
rotx(angle)
```

Arguments

angle a scalar representing the angle to rotate (degrees)

Value

a 3x3 matrix representing the rotation about the x-axis by the given angle

Author(s)

Christina Harvey

Examples

```
library(AvInertia)
angle = 90
# should return matrix [[1,0,0];[0,0,1];[0,1,0]]
rotx(angle)
```

store_data

*Store data from the inertia calculations in long format***Description**

Function to store moment of inertia tensor and center of gravity vector components in long format

Usage

```
store_data(dat_wingID_curr, dat_mass, mass_properties, name)
```

Arguments

dat_wingID_curr

Dataframe related to the current bird wing ID info that must include the following columns:

- speciesSpecies ID code as a string
- BirdIDBird ID code as a string
- TestIDTest ID code as a string
- frameIDVideo frame ID code as a string

dat_mass

Dataframe containing the new MOI and CG data to add to mass_properties as new rows. Must include:

- IMoment of inertia tensor (kg-m²)
- CGCenter of gravity with three location components (m)

mass_properties

Dataframe containing any previously saved data. Must have the following columns: "species", "BirdID", "TestID", "FrameID", "prop_type", "component", "value".

name

Name of the component for which the moment of inertia and center of gravity were computed.

Value

This function returns mass_properties as an updated dataframe with a new row corresponding to the dat_mass information

Examples

```

# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird    = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)

```

structural2VRP_feat *Transform feather specific inertial properties to current position*

Description

Transform feather specific inertial properties to current position

Usage

```
structural2VRP_feat(m_f, I_fCG, CG_start, start, end, normal)
```

Arguments

m_f a scalar representing the mass of the feather (kg)

I_fCG	a 3x3 matrix representing the moment of inertia tensor with the origin at the feather calamus end and within the feather frame of reference
CG_start	a 1x3 vector representing the center of gravity of the feather with the origin at the feather calamus end and within the feather frame of reference
start	a 1x3 vector representing the location of the feather calamus end with the origin at the VRP and within the full bird frame of reference
end	a 1x3 vector representing the location of the feather tip with the origin at the VRP and within the full bird frame of reference
normal	a 1x3 vector representing the normal to the plane of the feather vanes within the full bird frame of reference

Value

a list that includes:

- Ia 3x3 matrix representing the moment of inertia tensor of a simplified feather with the origin at the VRP and within the full bird frame of reference
- CGa 1x3 vector representing the center of gravity position of a simplified feather with the origin at the VRP and within the full bird frame of reference
- ma double that returns the feather mass

Examples

```
# refer to the vignette
library(AvInertia)

# load data
data(dat_id_curr, package = "AvInertia")
data(dat_bird_curr, package = "AvInertia")
data(dat_feat_curr, package = "AvInertia")
data(dat_bone_curr, package = "AvInertia")
data(dat_mat, package = "AvInertia")
data(clean_pts, package = "AvInertia")

# 1. Determine the center of gravity of the bird's torso (including the legs)
dat_torsotail_out = massprop_restbody(dat_id_curr, dat_bird_curr)
# 2. Calculate the inertia of the flight feathers about the tip of the calamus
feather_inertia <- compute_feat_inertia(dat_mat, dat_feat_curr, dat_bird_curr)
# 3. Determine the center of gravity of one of the bird's wings
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = 0)
# Visualize the center of gravity of each wing component in the x and y axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yx")
# or the y and z axis
dat_wing_out      = massprop_birdwing(dat_id_curr, dat_bird_curr,
dat_bone_curr, dat_feat_curr, dat_mat, clean_pts,
feather_inertia, plot_var = "yz")
```

```
# 4. Combine all data and obtain the center of gravity, moment of inertia
# and principal axes of the bird
curr_full_bird = combine_inertialprop(dat_torsotail_out, dat_wing_out,
dat_wing_out, dat_id_curr, dat_bird_curr, symmetric=TRUE)
```

Index

* datasets

- clean_pts, [16](#)
- dat_bird_curr, [21](#)
- dat_bone_curr, [22](#)
- dat_feat_curr, [23](#)
- dat_id_curr, [23](#)
- dat_mat, [24](#)

calc_inertia_conesolid, [3](#)
calc_inertia_cylhollow, [4](#)
calc_inertia_cylsolid, [5](#)
calc_inertia_ellcone, [6](#)
calc_inertia_ellcyl, [8](#)
calc_inertia_ellipse, [9](#)
calc_inertia_platerect, [11](#)
calc_inertia_platetri, [12](#)
calc_inertia_pyrasolid, [13](#)
calc_rot, [15](#)
calc_univec, [16](#)
clean_pts, [16](#)
combine_inertialprop, [17](#)
compute_feat_inertia, [19](#)

dat_bird_curr, [21](#)
dat_bone_curr, [22](#)
dat_feat_curr, [23](#)
dat_id_curr, [23](#)
dat_mat, [24](#)
density_optimizer, [24](#)

kronecker_delta, [26](#)

massprop_birdwing, [26](#)
massprop_bones, [30](#)
massprop_feathers, [31](#)
massprop_head, [33](#)
massprop_muscles, [34](#)
massprop_neck, [36](#)
massprop_pm, [37](#)
massprop_restbody, [38](#)

massprop_skin, [40](#)
massprop_tail, [41](#)
massprop_torso, [43](#)

orient_feather, [45](#)

parallelaxis, [47](#)
plot_CGloc, [48](#)

rotx, [50](#)

store_data, [51](#)
structural2VRP_feat, [52](#)