

SpatialAlgebra

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Chapter 1

Hierarchical Index

1.1 Class Hierarchy

This inheritance list is sorted roughly, but not completely, alphabetically:

SpatialAlgebra::ArticulatedBodyInertia	??
Eigen::Matrix3d	
Rotation	??
SpatialAlgebra::PluckerTransform	??
SpatialAlgebra::RigidBodyInertia	??
SpatialAlgebra::SpatialOperations	??
SpatialAlgebra::SpatialVector	??
SpatialAlgebra::ForceVector	??
SpatialAlgebra::MotionVector	??

Chapter 2

Class Index

2.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

SpatialAlgebra::ArticulatedBodyInertia	
Class representing inertial properties of an articulated body	??
SpatialAlgebra::ForceVector	
Class representing spatial force vectors	??
SpatialAlgebra::MotionVector	
Class representing spatial motion vectors	??
SpatialAlgebra::PluckerTransform	
Class representing spatial coordinate transformations	??
SpatialAlgebra::RigidBodyInertia	
Class representing the inertial properties of a rigid body	??
Rotation	
Class for handling 3D rotations with multiple representations	??
SpatialAlgebra::SpatialOperations	
Static class providing utility operations for spatial vectors and transforms	??
SpatialAlgebra::SpatialVector	
.	??

Chapter 3

File Index

3.1 File List

Here is a list of all documented files with brief descriptions:

include/ ArticulatedBodyInertia.h	
Class representing articulated body inertia properties	??
include/ AxialScrewTransform.h	??
include/ ForceVector.h	
Class representing spatial force vectors	??
include/ MotionVector.h	
Class representing spatial motion vectors	??
include/ PluckerTransform.h	
Class representing coordinate transformations in Plucker coordinates	??
include/ RigidBodyInertia.h	
Class representing rigid body inertia properties	??
include/ Rotation.h	
Class representing 3D rotations with various representations	??
include/ SpatialOperations.h	
Static utility class for spatial algebra operations	??
include/ SpatialUtils.h	
Utility functions for spatial algebra operations	??
include/ SpatialVector.h	??

Chapter 4

Class Documentation

4.1 SpatialAlgebra::ArticulatedBodyInertia Class Reference

Class representing inertial properties of an articulated body.

```
#include <ArticulatedBodyInertia.h>
```

Public Member Functions

- [ArticulatedBodyInertia](#) (const Vector6d &inertia, const Eigen::Matrix3d &h, const Vector6d &M)
Construct articulated body inertia.
- **ArticulatedBodyInertia** ()
Default constructor creating zero inertia.
- const Vector6d & **getInertia** () const
- const Eigen::Matrix3d & **getH** () const
- const Vector6d & **getM** () const
- [ArticulatedBodyInertia operator+](#) (const [ArticulatedBodyInertia](#) &other) const
Add two articulated body inertias.
- [ArticulatedBodyInertia operator+](#) (const [RigidBodyInertia](#) &other) const
Add rigid body inertia to articulated body inertia.
- [ArticulatedBodyInertia operator*](#) (double scalar) const
- [fv apply](#) (const [mv](#) &[mv](#)) const
Apply articulated body inertia to motion vector.
- void **print** () const
Print inertia properties.

4.1.1 Detailed Description

Class representing inertial properties of an articulated body.

Stores and manages generalized inertia matrix components for articulated body dynamics calculations.

4.1.2 Constructor & Destructor Documentation

4.1.2.1 ArticulatedBodyInertia()

```
SpatialAlgebra::ArticulatedBodyInertia::ArticulatedBodyInertia (  
    const Vector6d & inertia,  
    const Eigen::Matrix3d & h,  
    const Vector6d & M)
```

Construct articulated body inertia.

Parameters

<i>inertia</i>	Generalized inertia vector
<i>h</i>	Coupling matrix
<i>M</i>	Mass matrix components

4.1.3 Member Function Documentation

4.1.3.1 `apply()`

```
fv SpatialAlgebra::ArticulatedBodyInertia::apply (
    const mv & mv) const [inline]
```

Apply articulated body inertia to motion vector.

Parameters

<i>mv</i>	Motion vector to apply
-----------	------------------------

Returns

Resulting force vector

4.1.3.2 `operator+()` [1/2]

```
ArticulatedBodyInertia SpatialAlgebra::ArticulatedBodyInertia::operator+ (
    const ArticulatedBodyInertia & other) const [inline]
```

Add two articulated body inertias.

Parameters

<i>other</i>	ArticulatedBodyInertia to add
--------------	---

Returns

Combined [ArticulatedBodyInertia](#)

4.1.3.3 `operator+()` [2/2]

```
ArticulatedBodyInertia SpatialAlgebra::ArticulatedBodyInertia::operator+ (
    const RigidBodyInertia & other) const [inline]
```

Add rigid body inertia to articulated body inertia.

Parameters

<i>other</i>	RigidBodyInertia to add
--------------	---

Returns

Combined [ArticulatedBodyInertia](#)

The documentation for this class was generated from the following file:

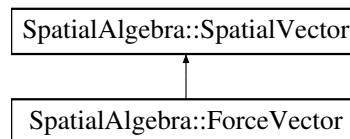
- [include/ArticulatedBodyInertia.h](#)

4.2 SpatialAlgebra::ForceVector Class Reference

Class representing spatial force vectors.

```
#include <ForceVector.h>
```

Inheritance diagram for SpatialAlgebra::ForceVector:



Public Member Functions

- **ForceVector** ()
Default constructor creating zero force.
- [ForceVector](#) (const Vector3d &angular, const Vector3d &linear)
Construct from angular and linear components.
- [ForceVector](#) (const [SpatialVector](#) &other)
Construct from spatial vector.
- Vector3d **getAngular** () const
- Vector3d **getLinear** () const
- [ForceVector](#) **operator+** (const [ForceVector](#) &other) const
- [ForceVector](#) **operator-** (const [ForceVector](#) &other) const
- [ForceVector](#) **operator*** (double scalar) const
- [ForceVector](#) **crossMotion** (const [ForceVector](#) &other) const
- [ForceVector](#) **crossForce** (const [ForceVector](#) &other) const
- double **dot** (const [ForceVector](#) &other) const
- void **print** () const

Public Member Functions inherited from [SpatialAlgebra::SpatialVector](#)

- **SpatialVector** (const Vector3d &angular, const Vector3d &linear)
- **SpatialVector** (const [SpatialVector](#) &other)
- Vector3d **getAngular** () const
- Vector3d **getLinear** () const
- [SpatialVector](#) **operator+** (const [SpatialVector](#) &other) const
- [SpatialVector](#) **operator-** (const [SpatialVector](#) &other) const
- [SpatialVector](#) **operator*** (double scalar) const
- [SpatialVector](#) **crossMotion** (const [SpatialVector](#) &other) const
- [SpatialVector](#) **crossForce** (const [SpatialVector](#) &other) const
- double **dot** (const [SpatialVector](#) &other) const
- void **print** () const

Additional Inherited Members

Protected Attributes inherited from [SpatialAlgebra::SpatialVector](#)

- Vector3d **angular**
- Vector3d **linear**

4.2.1 Detailed Description

Class representing spatial force vectors.

Specialized spatial vector for representing force quantities like torques and linear forces.

4.2.2 Constructor & Destructor Documentation

4.2.2.1 ForceVector() [1/2]

```
SpatialAlgebra::ForceVector::ForceVector (
    const Vector3d & angular,
    const Vector3d & linear)
```

Construct from angular and linear components.

Parameters

<i>angular</i>	Torque component
<i>linear</i>	Force component

4.2.2.2 ForceVector() [2/2]

```
SpatialAlgebra::ForceVector::ForceVector (
    const SpatialVector & other)
```

Construct from spatial vector.

Parameters

<i>other</i>	Spatial vector to convert
--------------	---------------------------

The documentation for this class was generated from the following files:

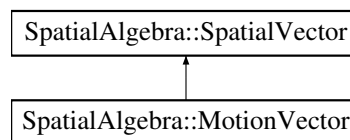
- include/ForceVector.h
- src/ForceVector.cpp

4.3 SpatialAlgebra::MotionVector Class Reference

Class representing spatial motion vectors.

```
#include <MotionVector.h>
```

Inheritance diagram for SpatialAlgebra::MotionVector:



Public Member Functions

- **MotionVector** ()
Default constructor creating zero motion.
- **MotionVector** (const Vector3d &angular, const Vector3d &linear)
Construct from angular and linear components.
- **MotionVector** (const SpatialVector &other)
Construct from spatial vector.
- Vector3d **getAngular** () const
- Vector3d **getLinear** () const
- **MotionVector operator+** (const MotionVector &other) const
- **MotionVector operator-** (const MotionVector &other) const
- **MotionVector operator*** (double scalar) const
- **MotionVector crossMotion** (const MotionVector &other) const
- **MotionVector crossForce** (const MotionVector &other) const
- double **dot** (const MotionVector &other) const
- void **print** () const

Public Member Functions inherited from SpatialAlgebra::SpatialVector

- **SpatialVector** (const Vector3d &angular, const Vector3d &linear)
- **SpatialVector** (const SpatialVector &other)
- Vector3d **getAngular** () const
- Vector3d **getLinear** () const
- **SpatialVector operator+** (const SpatialVector &other) const
- **SpatialVector operator-** (const SpatialVector &other) const
- **SpatialVector operator*** (double scalar) const
- **SpatialVector crossMotion** (const SpatialVector &other) const
- **SpatialVector crossForce** (const SpatialVector &other) const
- double **dot** (const SpatialVector &other) const
- void **print** () const

Additional Inherited Members

Protected Attributes inherited from [SpatialAlgebra::SpatialVector](#)

- Vector3d **angular**
- Vector3d **linear**

4.3.1 Detailed Description

Class representing spatial motion vectors.

Specialized spatial vector for representing motion quantities like angular and linear velocities.

4.3.2 Constructor & Destructor Documentation

4.3.2.1 MotionVector() [1/2]

```
SpatialAlgebra::MotionVector::MotionVector (
    const Vector3d & angular,
    const Vector3d & linear)
```

Construct from angular and linear components.

Parameters

<i>angular</i>	Angular velocity component
<i>linear</i>	Linear velocity component

4.3.2.2 MotionVector() [2/2]

```
SpatialAlgebra::MotionVector::MotionVector (
    const SpatialVector & other)
```

Construct from spatial vector.

Parameters

<i>other</i>	Spatial vector to convert
--------------	---------------------------

The documentation for this class was generated from the following files:

- include/[MotionVector.h](#)
- src/MotionVector.cpp

4.4 SpatialAlgebra::PluckerTransform Class Reference

Class representing spatial coordinate transformations.

```
#include <PluckerTransform.h>
```

Public Member Functions

- [PluckerTransform](#) (const [Rotation](#) &rotation, const [Vector3d](#) &translation)
Construct a Plucker transform.
- [SpatialVector](#) transformMotion (const [SpatialVector](#) &vec) const
Transform a motion vector.
- [SpatialVector](#) transformForce (const [SpatialVector](#) &vec) const
Transform a force vector.
- [SpatialVector](#) inverseTransformMotion (const [SpatialVector](#) &vec) const
Inverse transform a motion vector.
- [SpatialVector](#) inverseTransformForce (const [SpatialVector](#) &vec) const
Inverse transform a force vector.
- [RigidBodyInertia](#) tformRBI (const [RigidBodyInertia](#) &lhat) const
Transform rigid body inertia.
- [RigidBodyInertia](#) invtformRBI (const [RigidBodyInertia](#) &lhat) const
Inverse transform rigid body inertia.
- [ArticulatedBodyInertia](#) tformABI (const [ArticulatedBodyInertia](#) &la) const
- [ArticulatedBodyInertia](#) invtformABI (const [ArticulatedBodyInertia](#) &la) const
- [PluckerTransform](#) **inverse** () const
Compute inverse transform.
- auto **multiply** (const [PluckerTransform](#) &X) const
- auto **apply** (const [fv](#) &v) const
- auto **apply** (const [mv](#) &v) const
- [PluckerTransform](#) **apply** (const [PluckerTransform](#) &X) const
- void **print** () const
Print transform components.
- auto **get** (int &a)
- auto **get** (double &b)

4.4.1 Detailed Description

Class representing spatial coordinate transformations.

Implements rigid body transformations in Plucker coordinates, consisting of rotation and translation components.

4.4.2 Constructor & Destructor Documentation

4.4.2.1 PluckerTransform()

```
PluckerTransform::PluckerTransform (
    const Rotation & rotation,
    const Vector3d & translation)
```

Construct a Plucker transform.

Parameters

<i>rotation</i>	Rotation component
<i>translation</i>	Translation component

4.4.3 Member Function Documentation

4.4.3.1 inverseTransformForce()

```
SpatialVector SpatialAlgebra::PluckerTransform::inverseTransformForce (
    const SpatialVector & vec) const
```

Inverse transform a force vector.

Parameters

<i>vec</i>	Input force vector
------------	--------------------

Returns

Inverse transformed force vector

4.4.3.2 inverseTransformMotion()

```
SpatialVector SpatialAlgebra::PluckerTransform::inverseTransformMotion (
    const SpatialVector & vec) const
```

Inverse transform a motion vector.

Parameters

<i>vec</i>	Input motion vector
------------	---------------------

Returns

Inverse transformed motion vector

4.4.3.3 invtformRBI()

```
RigidBodyInertia SpatialAlgebra::PluckerTransform::invtformRBI (
    const RigidBodyInertia & Ihat) const
```

Inverse transform rigid body inertia.

Parameters

<i>Ihat</i>	Input rigid body inertia
-------------	--------------------------

Returns

Inverse transformed inertia

4.4.3.4 tformRBI()

```
RigidBodyInertia SpatialAlgebra::PluckerTransform::tformRBI (  
    const RigidBodyInertia & Ihat) const
```

Transform rigid body inertia.

Parameters

<i>Ihat</i>	Input rigid body inertia
-------------	--------------------------

Returns

Transformed inertia

4.4.3.5 transformForce()

```
SpatialVector PluckerTransform::transformForce (  
    const SpatialVector & vec) const
```

Transform a force vector.

Parameters

<i>vec</i>	Input force vector
------------	--------------------

Returns

Transformed force vector

4.4.3.6 transformMotion()

```
SpatialVector PluckerTransform::transformMotion (  
    const SpatialVector & vec) const
```

Transform a motion vector.

Parameters

vec	Input motion vector
-----	---------------------

Returns

Transformed motion vector

The documentation for this class was generated from the following files:

- include/[PluckerTransform.h](#)
- src/[PluckerTransform.cpp](#)

4.5 SpatialAlgebra::RigidBodyInertia Class Reference

Class representing the inertial properties of a rigid body.

```
#include <RigidBodyInertia.h>
```

Public Member Functions

- [RigidBodyInertia](#) (double mass, const Vector3d &com, const Vector6d &inertiaMatrixLT)
Construct a rigid body inertia.
- [RigidBodyInertia](#) ()
Default constructor creating zero inertia.
- double **getMass** () const
- const Vector3d & **getCom** () const
- const Vector6d & **getInertiaMatrixLT** () const
- [RigidBodyInertia operator+](#) (const [RigidBodyInertia](#) &other) const
Add two rigid body inertias.
- [RigidBodyInertia operator*](#) (double scalar) const
Scale rigid body inertia.
- [ForceVector apply](#) (const [MotionVector](#) &mv) const
Apply rigid body inertia to motion vector.
- void **print** () const
Print inertia properties.

4.5.1 Detailed Description

Class representing the inertial properties of a rigid body.

Stores and manages mass, center of mass, and rotational inertia matrix for rigid body dynamics calculations.

4.5.2 Constructor & Destructor Documentation

4.5.2.1 RigidBodyInertia()

```
SpatialAlgebra::RigidBodyInertia::RigidBodyInertia (
    double mass,
    const Vector3d & com,
    const Vector6d & inertiaMatrixLT) [inline]
```

Construct a rigid body inertia.

Parameters

<i>mass</i>	Mass of the body
<i>com</i>	Center of mass position
<i>inertiaMatrixLT</i>	Lower triangular part of inertia matrix

4.5.3 Member Function Documentation

4.5.3.1 apply()

```
ForceVector SpatialAlgebra::RigidBodyInertia::apply (
    const MotionVector & mv) const [inline]
```

Apply rigid body inertia to motion vector.

Parameters

<i>mv</i>	Motion vector to apply
-----------	------------------------

Returns

Resulting force vector

Implements: $[I + com \times v; m*v - com \times]$

4.5.3.2 operator*()

```
RigidBodyInertia SpatialAlgebra::RigidBodyInertia::operator* (
    double scalar) const [inline]
```

Scale rigid body inertia.

Parameters

<i>scalar</i>	Scaling factor
---------------	----------------

Returns

Scaled [RigidBodyInertia](#)

4.5.3.3 operator+()

```
RigidBodyInertia SpatialAlgebra::RigidBodyInertia::operator+ (
    const RigidBodyInertia & other) const [inline]
```

Add two rigid body inertias.

Parameters

other	RigidBodyInertia to add
-------	---

Returns

Combined [RigidBodyInertia](#)

The documentation for this class was generated from the following file:

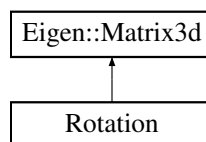
- include/[RigidBodyInertia.h](#)

4.6 Rotation Class Reference

Class for handling 3D rotations with multiple representations.

```
#include <Rotation.h>
```

Inheritance diagram for Rotation:



Public Member Functions

- **Rotation** ()
Default constructor initializing to identity rotation.
- **Rotation** (const Eigen::Matrix3d &matrix)
Construct from 3x3 rotation matrix.
- **Rotation** (const Eigen::AngleAxisd &angleAxis)
Construct from angle-axis representation.
- **Rotation** (const Eigen::Quaterniond &quaternion)
Construct from quaternion representation.
- void **setFromAngleAxis** (const Eigen::AngleAxisd &angleAxis)
Set rotation from angle-axis representation.
- void **setFromQuaternion** (const Eigen::Quaterniond &quaternion)
Set rotation from quaternion representation.
- Eigen::AngleAxisd **toAngleAxis** () const
Convert to angle-axis representation.
- Eigen::Quaterniond **toQuaternion** () const
Convert to quaternion representation.
- **Rotation inverse** () const
Compute inverse rotation.
- **Rotation transpose** () const
Compute matrix transpose.
- **Rotation operator*** (const **Rotation** &other) const
Multiply with another rotation.
- Eigen::Vector3d **operator*** (const Eigen::Vector3d &vector) const
Apply rotation to a vector.

4.6.1 Detailed Description

Class for handling 3D rotations with multiple representations.

Extends Eigen::Matrix3d to provide additional functionality for rotation operations including conversions between different rotation representations.

4.6.2 Constructor & Destructor Documentation

4.6.2.1 Rotation() [1/3]

```
Rotation::Rotation (
    const Eigen::Matrix3d & matrix)
```

Construct from 3x3 rotation matrix.

Parameters

<i>matrix</i>	Input rotation matrix
---------------	-----------------------

4.6.2.2 Rotation() [2/3]

```
Rotation::Rotation (
    const Eigen::AngleAxisd & angleAxis)
```

Construct from angle-axis representation.

Parameters

<i>angleAxis</i>	Angle-axis rotation
------------------	---------------------

4.6.2.3 Rotation() [3/3]

```
Rotation::Rotation (
    const Eigen::Quaterniond & quaternion)
```

Construct from quaternion representation.

Parameters

<i>quaternion</i>	Unit quaternion representing rotation
-------------------	---------------------------------------

4.6.3 Member Function Documentation

4.6.3.1 operator*() [1/2]

```
Eigen::Vector3d Rotation::operator* (
    const Eigen::Vector3d & vector) const
```

Apply rotation to a vector.

Parameters

<i>vector</i>	3D vector to rotate
---------------	---------------------

Returns

Rotated vector

4.6.3.2 operator*() [2/2]

```
Rotation Rotation::operator* (  
    const Rotation & other) const
```

Multiply with another rotation.

Parameters

<i>other</i>	Right-hand side rotation
--------------	--------------------------

Returns

Combined rotation

4.6.3.3 setFromAngleAxis()

```
void Rotation::setFromAngleAxis (  
    const Eigen::AngleAxisd & angleAxis)
```

Set rotation from angle-axis representation.

Parameters

<i>angleAxis</i>	Angle-axis rotation
------------------	---------------------

4.6.3.4 setFromQuaternion()

```
void Rotation::setFromQuaternion (  
    const Eigen::Quaterniond & quaternion)
```

Set rotation from quaternion representation.

Parameters

<i>quaternion</i>	Unit quaternion
-------------------	-----------------

The documentation for this class was generated from the following files:

- include/Rotation.h
- src/Rotation.cpp

4.7 SpatialAlgebra::SpatialOperations Class Reference

Static class providing utility operations for spatial vectors and transforms.

```
#include <SpatialOperations.h>
```

Static Public Member Functions

- static [SpatialVector](#) [crossProductMotion](#) (const [SpatialVector](#) &v1, const [SpatialVector](#) &v2)
Computes the motion cross product between two spatial vectors.
- static [SpatialVector](#) [crossProductForce](#) (const [SpatialVector](#) &v, const [SpatialVector](#) &f)
Computes the force cross product between two spatial vectors.
- static [RigidBodyInertia](#) [transformInertia](#) (const [RigidBodyInertia](#) &inertia, const [PluckerTransform](#) &transform)
Transforms rigid body inertia using a Plucker transform.

4.7.1 Detailed Description

Static class providing utility operations for spatial vectors and transforms.

4.7.2 Member Function Documentation

4.7.2.1 crossProductForce()

```
static SpatialVector SpatialAlgebra::SpatialOperations::crossProductForce (
    const SpatialVector & v,
    const SpatialVector & f) [static]
```

Computes the force cross product between two spatial vectors.

Parameters

<i>v</i>	Force spatial vector
<i>f</i>	Motion spatial vector

Returns

Result of force cross product

4.7.2.2 crossProductMotion()

```
static SpatialVector SpatialAlgebra::SpatialOperations::crossProductMotion (
    const SpatialVector & v1,
    const SpatialVector & v2) [static]
```

Computes the motion cross product between two spatial vectors.

Parameters

<i>v1</i>	First spatial vector
<i>v2</i>	Second spatial vector

Returns

Result of motion cross product

4.7.2.3 transformInertia()

```
static RigidBodyInertia SpatialAlgebra::SpatialOperations::transformInertia (
    const RigidBodyInertia & inertia,
    const PluckerTransform & transform) [static]
```

Transforms rigid body inertia using a Plucker transform.

Parameters

<i>inertia</i>	Input rigid body inertia
<i>transform</i>	Plucker transform to apply

Returns

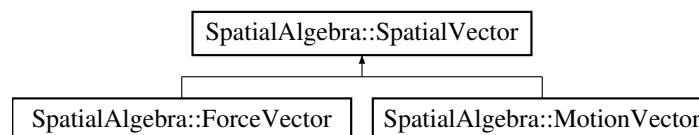
Transformed rigid body inertia

The documentation for this class was generated from the following file:

- include/[SpatialOperations.h](#)

4.8 SpatialAlgebra::SpatialVector Class Reference

Inheritance diagram for SpatialAlgebra::SpatialVector:



Public Member Functions

- **SpatialVector** (const Vector3d &angular, const Vector3d &linear)
- **SpatialVector** (const [SpatialVector](#) &other)
- Vector3d **getAngular** () const
- Vector3d **getLinear** () const
- [SpatialVector](#) **operator+** (const [SpatialVector](#) &other) const
- [SpatialVector](#) **operator-** (const [SpatialVector](#) &other) const
- [SpatialVector](#) **operator*** (double scalar) const
- [SpatialVector](#) **crossMotion** (const [SpatialVector](#) &other) const
- [SpatialVector](#) **crossForce** (const [SpatialVector](#) &other) const
- double **dot** (const [SpatialVector](#) &other) const
- void **print** () const

Protected Attributes

- Vector3d **angular**
- Vector3d **linear**

The documentation for this class was generated from the following files:

- include/SpatialVector.h
- src/SpatialVector.cpp

Chapter 5

File Documentation

5.1 include/ArticulatedBodyInertia.h File Reference

Class representing articulated body inertia properties.

```
#include <array>
#include <iostream>
#include "RigidBodyInertia.h"
#include "SpatialUtils.h"
#include <Eigen/Geometry>
```

Classes

- class [SpatialAlgebra::ArticulatedBodyInertia](#)
Class representing inertial properties of an articulated body.

Typedefs

- using **Vector6d** = Eigen::Matrix<double, 6, 1>
- using **SpatialAlgebra::abi** = [ArticulatedBodyInertia](#)

5.1.1 Detailed Description

Class representing articulated body inertia properties.

5.2 ArticulatedBodyInertia.h

[Go to the documentation of this file.](#)

```

00001 #ifndef ARTIC_BODY_INERTIA_H
00002 #define ARTIC_BODY_INERTIA_H
00003
00009 #include <array>
00010 #include <iostream>
00011 #include "RigidBodyInertia.h"
00012 #include "SpatialUtils.h"
00013 #include <Eigen/Geometry> // Include for RotationMatrix
00014
00015 using Vector6d = Eigen::Matrix<double, 6, 1>;
00016
00017 namespace SpatialAlgebra
00018 {
00025     class ArticulatedBodyInertia
00026     {
00027     private:
00028         Vector6d Inertia;
00029         Eigen::Matrix3d H;
00030         Vector6d M;
00031
00032     public:
00039         ArticulatedBodyInertia(const Vector6d &inertia, const Eigen::Matrix3d &h, const Vector6d &M);
00040
00042         ArticulatedBodyInertia();
00043
00044         // getters
00045         inline const Vector6d &getInertia() const { return Inertia; }
00046         inline const Eigen::Matrix3d &getH() const { return H; }
00047         inline const Vector6d &getM() const { return M; }
00048
00054         inline ArticulatedBodyInertia operator+(const ArticulatedBodyInertia &other) const;
00055
00061         inline ArticulatedBodyInertia operator+(const RigidBodyInertia &other) const;
00062
00063         inline ArticulatedBodyInertia operator*(double scalar) const
00064         {
00065             return ArticulatedBodyInertia(Inertia * scalar, H * scalar, M * scalar);
00066         }
00067
00073         inline fv apply(const mv &mv) const;
00074
00076         inline void print() const;
00077     };
00078
00079     using abi = ArticulatedBodyInertia;
00080
00081 } // namespace SpatialAlgebra
00082
00083 #endif

```

5.3 AxialScrewTransform.h

```

00001

```

5.4 include/ForceVector.h File Reference

Class representing spatial force vectors.

```

#include <iostream>
#include "SpatialVector.h"

```

Classes

- class [SpatialAlgebra::ForceVector](#)
Class representing spatial force vectors.

Typedefs

- using `SpatialAlgebra::fv` = `ForceVector`

5.4.1 Detailed Description

Class representing spatial force vectors.

5.5 ForceVector.h

[Go to the documentation of this file.](#)

```

00001 #ifndef FORCE_VECTOR_H
00002 #define FORCE_VECTOR_H
00003
00009 #include <iostream>
00010
00011 #include "SpatialVector.h"
00012
00013 // Force vector class inherits from SpatialVector
00014 namespace SpatialAlgebra
00015 {
00022     class ForceVector : public SpatialVector
00023     {
00024     public:
00026         ForceVector();
00027
00033         ForceVector(const Vector3d &angular, const Vector3d &linear);
00034
00039         ForceVector(const SpatialVector &other);
00040
00041         // Accessors
00042         Vector3d getAngular() const;
00043         Vector3d getLinear() const;
00044
00045         // Basic operations
00046         ForceVector operator+(const ForceVector &other) const;
00047         ForceVector operator-(const ForceVector &other) const;
00048         ForceVector operator*(double scalar) const;
00049
00050         // Cross-product operations
00051         ForceVector crossMotion(const ForceVector &other) const; // crm equivalent
00052         ForceVector crossForce(const ForceVector &other) const; // crf equivalent
00053
00054         // dot product
00055         double dot(const ForceVector &other) const;
00056
00057         // Printing
00058         void print() const;
00059     };
00060
00061     using fv = ForceVector;
00062
00063 } // namespace SpatialAlgebra
00064
00065 #endif

```

5.6 include/MotionVector.h File Reference

Class representing spatial motion vectors.

```

#include <array>
#include <iostream>
#include "SpatialVector.h"

```

Classes

- class [SpatialAlgebra::MotionVector](#)
Class representing spatial motion vectors.

Typedefs

- using [SpatialAlgebra::mv](#) = [MotionVector](#)

5.6.1 Detailed Description

Class representing spatial motion vectors.

5.7 MotionVector.h

[Go to the documentation of this file.](#)

```

00001 #ifndef MOTION_VECTOR_H
00002 #define MOTION_VECTOR_H
00003
00009 #include <array>
00010 #include <iostream>
00011
00012 #include "SpatialVector.h"
00013
00014 // Motion vector class inherits from SpatialVector
00015
00016 namespace SpatialAlgebra
00017 {
00024     class MotionVector : public SpatialVector
00025     {
00026     public:
00028         MotionVector();
00029
00035         MotionVector(const Vector3d &angular, const Vector3d &linear);
00036
00041         MotionVector(const SpatialVector &other);
00042
00043         // Accessors
00044         Vector3d getAngular() const;
00045         Vector3d getLinear() const;
00046
00047         // Basic operations
00048         MotionVector operator+(const MotionVector &other) const;
00049         MotionVector operator-(const MotionVector &other) const;
00050         MotionVector operator*(double scalar) const;
00051
00052         // Cross-product operations
00053         MotionVector crossMotion(const MotionVector &other) const; // crm equivalent
00054         MotionVector crossForce(const MotionVector &other) const; // crf equivalent
00055
00056         // dot product
00057         double dot(const MotionVector &other) const;
00058
00059         // Printing
00060         void print() const;
00061     };
00062
00063     using mv = MotionVector;
00064
00065 } // namespace SpatialAlgebra
00066
00067 #endif

```

5.8 include/PluckerTransform.h File Reference

Class representing coordinate transformations in Plucker coordinates.

```
#include "SpatialVector.h"
#include "Rotation.h"
#include "ForceVector.h"
#include "MotionVector.h"
#include "RigidBodyInertia.h"
#include "ArticulatedBodyInertia.h"
#include <Eigen/Geometry>
```

Classes

- class [SpatialAlgebra::PluckerTransform](#)
Class representing spatial coordinate transformations.

Typedefs

- using **Vector3d** = Eigen::Matrix<double, 3, 1>
- using **SpatialAlgebra::plux** = [PluckerTransform](#)

5.8.1 Detailed Description

Class representing coordinate transformations in Plucker coordinates.

5.9 PluckerTransform.h

[Go to the documentation of this file.](#)

```
00001 #ifndef PLUCKER_TRANSFORM_H
00002 #define PLUCKER_TRANSFORM_H
00003
00009 #include "SpatialVector.h"
00010 #include "Rotation.h"
00011 #include "ForceVector.h"
00012 #include "MotionVector.h"
00013 #include "RigidBodyInertia.h"
00014 #include "ArticulatedBodyInertia.h"
00015 #include <Eigen/Geometry> // Include for RotationMatrix
00016
00017 using Vector3d = Eigen::Matrix<double, 3, 1>;
00018
00019 namespace SpatialAlgebra
00020 {
00027     class PluckerTransform
00028     {
00029     private:
00030         Rotation rotation;
00031         Vector3d translation;
00032
00033     public:
00039         PluckerTransform(const Rotation &rotation, const Vector3d &translation);
00040
00046         SpatialVector transformMotion(const SpatialVector &vec) const;
00047
00053         SpatialVector transformForce(const SpatialVector &vec) const;
00054
00060         SpatialVector inverseTransformMotion(const SpatialVector &vec) const;
00061
00067         SpatialVector inverseTransformForce(const SpatialVector &vec) const;
```

```

00068
00074     RigidBodyInertia tformRBI(const RigidBodyInertia &Ihat) const;
00075
00081     RigidBodyInertia invtformRBI(const RigidBodyInertia &Ihat) const;
00082
00083     // transform abi
00084     ArticulatedBodyInertia tformABI(const ArticulatedBodyInertia &Ia) const;
00085     ArticulatedBodyInertia invtformABI(const ArticulatedBodyInertia &Ia) const;
00086
00088     PluckerTransform inverse() const;
00089
00090     // multiply by X
00091     // PluckerTransform multiply(const PluckerTransform &X) const;
00092     auto multiply(const PluckerTransform &X) const;
00093
00094     auto apply(const fv& v) const{
00095         return transformMotion(v);
00096     }
00097     auto apply(const mv& v) const{
00098         return transformForce(v);
00099     }
00100
00101     PluckerTransform apply(const PluckerTransform &X) const;
00102
00103     // template <typename T>
00104     // T apply(const T&) const{
00105
00106     // }
00107
00109     void print() const;
00110
00111     // testing
00112     auto get(int &a) { return a; }
00113     auto get(double &b)
00114     {
00115         char c{'c'};
00116         return c;
00117     }
00118 };
00119
00120     using plux = PluckerTransform;
00121
00122 } // namespace SpatialAlgebra
00123
00124 #endif

```

5.10 include/RigidBodyInertia.h File Reference

Class representing rigid body inertia properties.

```

#include <array>
#include <iostream>
#include "SpatialVector.h"
#include "ForceVector.h"
#include "MotionVector.h"
#include <Eigen/Geometry>

```

Classes

- class [SpatialAlgebra::RigidBodyInertia](#)
Class representing the inertial properties of a rigid body.

Typedefs

- using **Vector3d** = Eigen::Matrix<double, 3, 1>
- using **Vector6d** = Eigen::Matrix<double, 6, 1>
- using **SpatialAlgebra::rbi** = [RigidBodyInertia](#)

5.10.1 Detailed Description

Class representing rigid body inertia properties.

5.11 RigidBodyInertia.h

[Go to the documentation of this file.](#)

```

00001 #ifndef RIGID_BODY_INERTIA_H
00002 #define RIGID_BODY_INERTIA_H
00003
00009 #include <array>
00010 #include <iostream>
00011 #include "SpatialVector.h"
00012 #include "ForceVector.h"
00013 #include "MotionVector.h"
00014 #include <Eigen/Geometry> // Include for RotationMatrix
00015
00016 using Vector3d = Eigen::Matrix<double, 3, 1>;
00017 using Vector6d = Eigen::Matrix<double, 6, 1>;
00018
00019 namespace SpatialAlgebra
00020 {
00021     class RigidBodyInertia
00022     {
00023     private:
00024         double mass;
00025         Vector3d com;
00026         Vector6d inertiaMatrixLT;
00027
00028     public:
00029         inline RigidBodyInertia(double mass, const Vector3d &com, const Vector6d &inertiaMatrixLT)
00030             : mass(mass), com(com), inertiaMatrixLT(inertiaMatrixLT) {}
00031
00032         inline RigidBodyInertia()
00033         {
00034             RigidBodyInertia(0.0, {0.0, 0.0, 0.0}, {0.0, 0.0, 0.0, 0.0, 0.0, 0.0});
00035         }
00036
00037         // Getters
00038         inline double getMass() const { return mass; }
00039         inline const Vector3d &getCom() const { return com; }
00040         inline const Vector6d &getInertiaMatrixLT() const { return inertiaMatrixLT; }
00041
00042         inline RigidBodyInertia operator+(const RigidBodyInertia &other) const
00043         {
00044             // const double sumMass = mass + other.mass;
00045             // const Vector3d sumCom = com + other.com;
00046             return RigidBodyInertia(mass + other.mass, com + other.com, inertiaMatrixLT +
00047 other.inertiaMatrixLT);
00048         }
00049
00050         inline RigidBodyInertia operator*(double scalar) const // Changed to pass by value
00051         {
00052             return RigidBodyInertia(mass * scalar, com * scalar, inertiaMatrixLT * scalar);
00053         }
00054
00055         inline ForceVector apply(const MotionVector &mv) const
00056         {
00057             // rbi = [m, com, I_LT], mv = [v, w]
00058             // rbi.apply(mv) = [I + com x v; m*v - com x w]
00059             Vector3d omega = mv.getAngular();
00060             Vector3d v = mv.getLinear();
00061             Vector3d comCrossV = com.cross(v);
00062             Vector3d comCrossOmega = com.cross(omega);
00063             Vector3d Iomega = inertiaMatrixLT.head<3>().cwiseProduct(omega) +
00064 inertiaMatrixLT.tail<3>().cwiseProduct(omega);
00065             Vector3d force = mass * v - comCrossOmega;
00066             Vector3d torque = Iomega + comCrossV;
00067             return ForceVector(torque, force);
00068         }
00069
00070         inline void print() const
00071         {
00072             std::cout << "Mass: " << mass << '\n'
00073 << "Center of mass: " << com.transpose() << '\n'
00074 << "Inertia matrix (LT): " << inertiaMatrixLT.transpose() << std::endl;
00075         }
00076     };
00077 }
00078
00079 #endif

```

```

00106     using rbi = RigidBodyInertia;
00107
00108 } // namespace SpatialAlgebra
00109
00110 #endif

```

5.12 include/Rotation.h File Reference

Class representing 3D rotations with various representations.

```
#include <Eigen/Dense>
```

Classes

- class [Rotation](#)
Class for handling 3D rotations with multiple representations.

5.12.1 Detailed Description

Class representing 3D rotations with various representations.

5.13 Rotation.h

[Go to the documentation of this file.](#)

```

00001 #ifndef ROTATION_H
00002 #define ROTATION_H
00003
00009 #include <Eigen/Dense>
00010
00017 class Rotation : public Eigen::Matrix3d
00018 {
00019 public:
00021     Rotation();
00022
00027     Rotation(const Eigen::Matrix3d &matrix);
00028
00033     Rotation(const Eigen::AngleAxisd &angleAxis);
00034
00039     Rotation(const Eigen::Quaterniond &quaternion);
00040
00045     void setFromAngleAxis(const Eigen::AngleAxisd &angleAxis);
00046
00051     void setFromQuaternion(const Eigen::Quaterniond &quaternion);
00052
00054     Eigen::AngleAxisd toAngleAxis() const;
00055
00057     Eigen::Quaterniond toQuaternion() const;
00058
00060     Rotation inverse() const;
00061
00063     Rotation transpose() const;
00064
00070     Rotation operator*(const Rotation &other) const;
00071
00077     Eigen::Vector3d operator*(const Eigen::Vector3d &vector) const;
00078 };
00079
00080 #endif // ROTATION_H

```

5.14 include/SpatialOperations.h File Reference

Static utility class for spatial algebra operations.

```
#include "SpatialVector.h"
#include "PluckerTransform.h"
#include "RigidBodyInertia.h"
#include <Eigen/Geometry>
```

Classes

- class [SpatialAlgebra::SpatialOperations](#)
Static class providing utility operations for spatial vectors and transforms.

5.14.1 Detailed Description

Static utility class for spatial algebra operations.

5.15 SpatialOperations.h

[Go to the documentation of this file.](#)

```
00001 #ifndef SPATIAL_OPERATIONS_H
00002 #define SPATIAL_OPERATIONS_H
00003
00009 #include "SpatialVector.h"
00010 #include "PluckerTransform.h"
00011 #include "RigidBodyInertia.h"
00012 #include <Eigen/Geometry> // Include for RotationMatrix
00013
00014 namespace SpatialAlgebra {
00015
00019 class SpatialOperations {
00020 public:
00027     static SpatialVector crossProductMotion(const SpatialVector& v1, const SpatialVector& v2);
00028
00035     static SpatialVector crossProductForce(const SpatialVector& v, const SpatialVector& f);
00036
00043     static RigidBodyInertia transformInertia(const RigidBodyInertia& inertia,
00044                                             const PluckerTransform& transform);
00045 };
00046
00047 } // namespace SpatialAlgebra
00048
00049 #endif
```

5.16 include/SpatialUtils.h File Reference

Utility functions for spatial algebra operations.

```
#include "SpatialVector.h"
#include "MotionVector.h"
#include "ForceVector.h"
```

Functions

- Eigen::Matrix3d [SpatialAlgebra::skew](#) (const Eigen::Vector3d &v) noexcept
Creates a 3x3 skew-symmetric matrix from a 3D vector.
- double [SpatialAlgebra::dot](#) (const [SpatialVector](#) &v1, const [SpatialVector](#) &v2) noexcept
Computes the spatial dot product between two spatial vectors.
- double [SpatialAlgebra::dot](#) (const [MotionVector](#) &v1, const [MotionVector](#) &v2) noexcept
Computes the spatial dot product between two motion vectors.
- double [SpatialAlgebra::dot](#) (const [ForceVector](#) &v1, const [ForceVector](#) &v2) noexcept
Computes the spatial dot product between two force vectors.
- double **SpatialAlgebra::dot** (const [MotionVector](#) &v1, const [ForceVector](#) &v2) noexcept
- [ForceVector](#) [SpatialAlgebra::cross](#) (const [MotionVector](#) &v1, const [ForceVector](#) &v2) noexcept
Computes the spatial cross product between a motion vector and a force vector.

5.16.1 Detailed Description

Utility functions for spatial algebra operations.

This file contains various utility functions used in spatial algebra computations, including cross products, dot products, and matrix operations.

5.16.2 Function Documentation

5.16.2.1 cross()

```
ForceVector SpatialAlgebra::cross (
    const MotionVector & v1,
    const ForceVector & v2) [inline], [noexcept]
```

Computes the spatial cross product between a motion vector and a force vector.

Parameters

v1	Motion vector
v2	Force vector

Returns

Resulting force vector

Implements: $\text{crf}(v1, v2) = [w1 \times f1 + v1 \times f2, w1 \times f1]$

5.16.2.2 dot() [1/3]

```
double SpatialAlgebra::dot (
    const ForceVector & v1,
    const ForceVector & v2) [inline], [noexcept]
```

Computes the spatial dot product between two force vectors.

Parameters

<i>v1</i>	First force vector
<i>v2</i>	Second force vector

Returns

Scalar dot product result

5.16.2.3 dot() [2/3]

```
double SpatialAlgebra::dot (
    const MotionVector & v1,
    const MotionVector & v2) [inline], [noexcept]
```

Computes the spatial dot product between two motion vectors.

Parameters

<i>v1</i>	First motion vector
<i>v2</i>	Second motion vector

Returns

Scalar dot product result

5.16.2.4 dot() [3/3]

```
double SpatialAlgebra::dot (
    const SpatialVector & v1,
    const SpatialVector & v2) [inline], [noexcept]
```

Computes the spatial dot product between two spatial vectors.

Parameters

<i>v1</i>	First spatial vector
<i>v2</i>	Second spatial vector

Returns

Scalar dot product result

5.16.2.5 skew()

```
Eigen::Matrix3d SpatialAlgebra::skew (
    const Eigen::Vector3d & v) [inline], [noexcept]
```

Creates a 3x3 skew-symmetric matrix from a 3D vector.

Parameters

v	Input 3D vector
-----	-----------------

Returns

Skew-symmetric matrix representation

The resulting matrix S satisfies $S \cdot x = v \times x$ for any vector x

5.17 SpatialUtils.h

[Go to the documentation of this file.](#)

```

00001 #ifndef SPATIAL_UTILS_H
00002 #define SPATIAL_UTILS_H
00003
00012 #include "SpatialVector.h"
00013 #include "MotionVector.h"
00014 #include "ForceVector.h"
00015
00016 namespace SpatialAlgebra {
00017
00024 inline Eigen::Matrix3d skew(const Eigen::Vector3d& v) noexcept {
00025     Eigen::Matrix3d m;
00026     m << 0, -v(2), v(1),
00027         v(2), 0, -v(0),
00028         -v(1), v(0), 0;
00029     return m;
00030 }
00031
00038 inline double dot(const SpatialVector& v1, const SpatialVector& v2) noexcept {
00039     return v1.getAngular().dot(v2.getAngular()) +
00040         v1.getLinear().dot(v2.getLinear());
00041 }
00042
00049 inline double dot(const MotionVector& v1, const MotionVector& v2) noexcept {
00050     return dot(static_cast<const SpatialVector&>(v1),
00051         static_cast<const SpatialVector&>(v2));
00052 }
00053
00060 inline double dot(const ForceVector& v1, const ForceVector& v2) noexcept {
00061     return dot(static_cast<const SpatialVector&>(v1),
00062         static_cast<const SpatialVector&>(v2));
00063 }
00064
00065 inline double dot(const MotionVector& v1, const ForceVector& v2) noexcept {
00066     return dot(static_cast<const SpatialVector&>(v1),
00067         static_cast<const SpatialVector&>(v2));
00068 }
00069
00077 inline ForceVector cross(const MotionVector& v1, const ForceVector& v2) noexcept {
00078     const Vector3d& w1 = v1.getAngular();
00079     const Vector3d& v1_lin = v1.getLinear();
00080     const Vector3d& f1 = v2.getAngular();
00081     const Vector3d& f2 = v2.getLinear();
00082
00083     return ForceVector(
00084         w1.cross(f1),
00085         w1.cross(f2) + v1_lin.cross(f1)
00086     );
00087 };
00088
00089 } // namespace SpatialAlgebra
00090 #endif // SPATIAL_UTILS_H

```

5.18 SpatialVector.h

```

00001 #ifndef SPATIAL_VECTOR_H
00002 #define SPATIAL_VECTOR_H
00003

```

```

00004 // #include <array>
00005 // #include <iostream>
00006 #include <Eigen/Dense>
00007
00008 using Vector3d = Eigen::Matrix<double, 3, 1>;
00009
00010 namespace SpatialAlgebra
00011 {
00012
00013     class SpatialVector
00014     {
00015     protected:
00016         Vector3d angular; // : Angular velocity/force
00017         Vector3d linear; // v or f: Linear velocity/force
00018
00019     public:
00020         // Constructors
00021         SpatialVector();
00022         SpatialVector(const Vector3d &angular, const Vector3d &linear);
00023
00024         SpatialVector(const SpatialVector &other);
00025
00026         // Accessors
00027         Vector3d getAngular() const;
00028         Vector3d getLinear() const;
00029
00030         // Basic operations
00031         SpatialVector operator+(const SpatialVector &other) const;
00032         SpatialVector operator-(const SpatialVector &other) const;
00033         SpatialVector operator*(double scalar) const;
00034
00035         // Cross-product operations
00036         SpatialVector crossMotion(const SpatialVector &other) const; // crm equivalent
00037         SpatialVector crossForce(const SpatialVector &other) const; // crf equivalent
00038
00039         // dot product
00040         double dot(const SpatialVector &other) const;
00041
00042         // Printing
00043         void print() const;
00044     };
00045
00046 } // namespace SpatialAlgebra
00047 #endif

```

