IK SOLVER

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Chapter 1

6 DOF Manipulator - Inverse Kinematics Solver

1.1 Project Description

1.1.1 Overview

The aim of this project is to design and develop an inverse kinematics solver for a 6-axis Manipulator at ACME Robotics. This implementaion is based on the Kuka-KR 5 Manipulator, however it can provide a solution for any 6 axis manipulator with a sperical wrist configuration. Our software will compute and simulate a trajectory based on the path coordinates provided and will be integrated as a module into a future project over at ACME Robotics.

1.1.2 Method

Our implementation includes three methods, two for solving inverse and forwards kinematics for the manipulator, and one method to store the attributes of the specified robot arm. The solution for inverse kinematics will be calculated and stored as joint angles for each path coordinate provided. The forward kinematics solver will calculate end effector position based on the joint values and robot parameters provided. Denavit Hartenberg representation will be employed for both the inverse and forward kinematics solvers. A two sprint Agile Iterative Process approach and test driven development style is utilized in the making of this project.

Chapter 2

Namespace Index

2.1 Namespace List

Here is a list of all namespaces with brief descriptions:

Chapter 3

Hierarchical Index

3.1 Class Hierarchy

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

Chapter 4

Class Index

4.1 Class List

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

Chapter 5

File Index

5.1 File List

Here is a list of all files with brief descriptions:

Chapter 6

Namespace Documentation

6.1 simulation Namespace Reference

Variables

- category
- list dh_d = [0.25, 0.15, 0.2, 0, 0, 0.1]
- list dh_a = [0, 0, 0, 0, 0, 0]
- list dh_alpha = [-1.5708, 1.5708, 0, -1.5708, 1.5708, 0]
- list dh_theta = [0, 0, 0, 0, 0, 0]
- dh_params = np.stack((dh_d,dh_a,dh_alpha,dh_theta), axis=-1)
- robot = RobotSerial(dh_params)
- abc1 = np.array([[-0.266], [0.031], [0.304]])
- abc2 = np.array([[-0.232], [0.192], [0.357]])
- abc3 = np.array([[-0.076], [0.225], [0.461]])
- abc4 = np.array([[-0.014], [0.262], [0.262]])
- abc5 = np.array([[-0.221], [0.020], [0.482]])
- abc6 = np.array([[-0.266], [0.031], [0.304]])
- xyz1 = np.array([-0.665994, 0.308907, 0.665997])
- xyz2 = np.array([-0.71637, 0.398236, 0.71637])
- xyz3 = np.array([0.0292315, 0.541703, 0.91522])
- xyz4 = np.array([0.158575, 0.957389, 0.50314])
- xyz5 = np.array([-0.35985, 0.225772, 0.924447])
- xyz6 = np.array([-0.666147, 0.308929, 0.666111])
- frame1 = Frame.from_euler_3(xyz1, abc1)
- frame2 = Frame.from_euler_3(xyz2, abc2)
- frame3 = Frame.from_euler_3(xyz3, abc3)
- frame4 = Frame.from_euler_3(xyz4, abc4)
- frame5 = Frame.from_euler_3(xyz5, abc5)
- frame6 = Frame.from_euler_3(xyz6, abc6)
- list frames = [frame1, frame2, frame3, frame4, frame5, frame6]
- trajectory = RobotTrajectory(robot, frames)
- motion

6.1.1 Variable Documentation

6.1.1.1 abc1

```
simulation.abc1 = np.array([[-0.266], [0.031], [0.304]])
```

6.1.1.2 abc2

```
simulation.abc2 = np.array([[-0.232], [0.192], [0.357]])
```

6.1.1.3 abc3

```
simulation.abc3 = np.array([[-0.076], [0.225], [0.461]])
```

6.1.1.4 abc4

```
simulation.abc4 = np.array([[-0.014], [0.262], [0.262]])
```

6.1.1.5 abc5

```
simulation.abc5 = np.array([[-0.221], [0.020], [0.482]])
```

6.1.1.6 abc6

```
simulation.abc6 = np.array([[-0.266], [0.031], [0.304]])
```

6.1.1.7 category

```
simulation.category
```

6.1.1.8 dh_a

```
list simulation.dh_a = [0, 0, 0, 0, 0, 0]
```

6.1.1.9 dh_alpha

```
list simulation.dh_alpha = [-1.5708, 1.5708, 0, -1.5708, 1.5708, 0]
```

6.1.1.10 dh_d

```
list simulation.dh_d = [0.25, 0.15, 0.2, 0, 0, 0.1]
```

6.1.1.11 dh_params

```
simulation.dh_params = np.stack((dh_d,dh_a,dh_alpha,dh_theta), axis=-1)
```

6.1.1.12 dh_theta

```
list simulation.dh_theta = [0, 0, 0, 0, 0, 0]
```

6.1.1.13 frame1

```
simulation.frame1 = Frame.from_euler_3(xyz1, abc1)
```

6.1.1.14 frame2

```
simulation.frame2 = Frame.from_euler_3(xyz2, abc2)
```

6.1.1.15 frame3

```
simulation.frame3 = Frame.from_euler_3(xyz3, abc3)
```

6.1.1.16 frame4

```
simulation.frame4 = Frame.from_euler_3(xyz4, abc4)
```

6.1.1.17 frame5

```
simulation.frame5 = Frame.from_euler_3(xyz5, abc5)
```

6.1.1.18 frame6

```
simulation.frame6 = Frame.from_euler_3(xyz6, abc6)
```

6.1.1.19 frames

```
list simulation.frames = [frame1, frame2, frame3, frame4, frame5, frame6]
```

6.1.1.20 motion

```
simulation.motion
```

6.1.1.21 robot

```
simulation.robot = RobotSerial(dh_params)
```

6.1.1.22 trajectory

```
simulation.trajectory = RobotTrajectory(robot, frames)
```

6.1.1.23 xyz1

```
simulation.xyz1 = np.array([-0.665994, 0.308907, 0.665997])
```

6.1.1.24 xyz2

```
simulation.xyz2 = np.array([-0.71637, 0.398236, 0.71637])
```

6.1.1.25 xyz3

```
simulation.xyz3 = np.array([0.0292315, 0.541703, 0.91522])
```

6.1.1.26 xyz4

```
simulation.xyz4 = np.array([0.158575, 0.957389, 0.50314])
```

6.1.1.27 xyz5

```
simulation.xyz5 = np.array([-0.35985, 0.225772, 0.924447])
```

6.1.1.28 xyz6

```
simulation.xyz6 = np.array([-0.666147, 0.308929, 0.666111])
```

Chapter 7

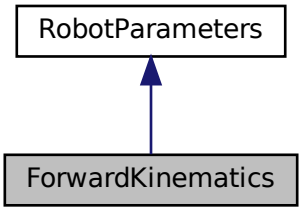
Class Documentation

7.1 ForwardKinematics Class Reference

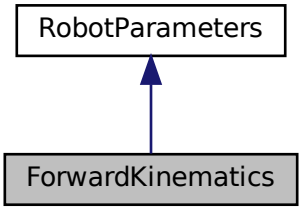
Definition of the Forward Kinematics Class.

`#include <forward_kinematics.hpp>`

Inheritance diagram for ForwardKinematics:



Collaboration diagram for ForwardKinematics:



Public Member Functions

- Eigen::Matrix4d calculate_TF (int i, Eigen::MatrixXd _dh_matrix)

  Calculate the DH transfromation matrix for each joint pair.
- Eigen::Matrix4d solve_fk (Eigen::MatrixXd _dh_matrix)

  Solve the forward kinematics for manipulator.

Public Attributes

- double euler_x
- double euler_y
- double euler_z

7.1.1 Detailed Description

Definition of the Forward Kinematics Class.

7.1.2 Member Function Documentation

7.1.2.1 calculate_TF()

```
Matrix4d ForwardKinematics::calculate_TF (
            int i,
            Eigen::MatrixXd _dh_matrix )
```

Calculate the DH transfromation matrix for each joint pair.

Parameters

i	integer value denoting the row of _dh_matrix to be considered

Returns

Eigen::Matrix<double, 4, 4> Returns the transformation matrix

7.1.2.2 solve_fk()

```
Matrix4d ForwardKinematics::solve_fk (
            Eigen::MatrixXd _dh_matrix )
```

Solve the forward kinematics for manipulator.

Returns

Eigen::Matrix<double, 4, 4> Returns the final Homogeneous transformation matrix

7.1.3 Member Data Documentation

7.1.3.1 euler_x

```
double ForwardKinematics::euler_x
```

7.1.3.2 euler_y

```
double ForwardKinematics::euler_y
```

7.1.3.3 euler_z

```
double ForwardKinematics::euler_z
```

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

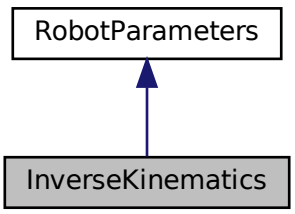
- include/forward_kinematics.hpp
- app/forward_kinematics.cpp

7.2 InverseKinematics Class Reference

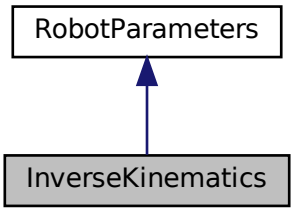
Definition of Inverse Kinematics Class.

```
#include <inverse_kinematics.hpp>
```

Inheritance diagram for InverseKinematics:



Collaboration diagram for InverseKinematics:



Public Member Functions

- InverseKinematics ()

  Construct a new Inverse Kinematics object to assign default values.
- void set_eff_rotation (Eigen::Matrix3d _R_E)

  Sets the end effector rotation matrix.
- Eigen::Matrix3d get_eff_rotation ()

  Gets the end effector rotation matrix.
- Eigen::Vector3d get_eff_position ()

  Gets the end effector position.
- void set_eff_position (Eigen::Vector3d eff_position)

  Sets the end effector position.
- std::vector< double > solve_ik ()

  Method to solve the inverse kinematics of the Manipulator.

Additional Inherited Members

7.2.1 Detailed Description

Definition of Inverse Kinematics Class.

7.2.2 Constructor & Destructor Documentation

7.2.2.1 InverseKinematics()

```
InverseKinematics::InverseKinematics ( )
```

Construct a new Inverse Kinematics object to assign default values.

7.2.3 Member Function Documentation

7.2.3.1 get_eff_position()

```
Eigen::Vector3d InverseKinematics::get_eff_position ( )
```

Gets the end effector position.

Returns

std::vector<double> Returns a vector containing end effector postion

7.2.3.2 get_eff_rotation()

```
Eigen::Matrix3d InverseKinematics::get_eff_rotation ( )
```

Gets the end effector rotation matrix.

Returns

Eigen::Matrix3d Returns End effector rotation matrix

7.2.3.3 set_eff_position()

```
void InverseKinematics::set_eff_position (
            Eigen::Vector3d eff_position )
```

Sets the end effector position.

Parameters

eff_position	Vector containing end effector position

7.2.3.4 set_eff_rotation()

```
void InverseKinematics::set_eff_rotation (
            Eigen::Matrix3d _R_E )
```

Sets the end effector rotation matrix.

Parameters

_R↩ _E	Rotation matrix for end effector with respect to base frame

7.2.3.5 solve_ik()

```
vector< double > InverseKinematics::solve_ik ( )
```

Method to solve the inverse kinematics of the Manipulator.

Returns

std::vector<double>

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

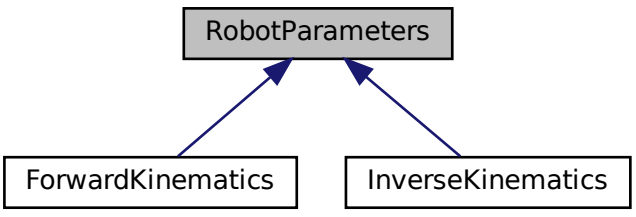
- include/inverse_kinematics.hpp
- app/inverse_kinematics.cpp

7.3 RobotParameters Class Reference

Definition of the Robot Parameter Class.

```
#include <robot_parameters.hpp>
```

Inheritance diagram for RobotParameters:



Public Member Functions

- RobotParameters ()

  Construct a new Robot Parameters object to assign default values.
- void set_dh_parameters ()

  Sets the DH parameters.
- Eigen::MatrixXd get_dh_parameters ()

  Compute the dh parameters matrix.
- std::vector< double > get_robot_angles ()

  Gets the robot angles.
- void set_robot_angles (std::vector< double > robot_angles)

  Sets the robot angles.

Public Attributes

- std::string robot_name

7.3.1 Detailed Description

Definition of the Robot Parameter Class.

7.3.2 Constructor & Destructor Documentation

7.3.2.1 RobotParameters()

```
RobotParameters::RobotParameters ( )
```

Construct a new Robot Parameters object to assign default values.

7.3.3 Member Function Documentation

7.3.3.1 get_dh_parameters()

```
MatrixXd RobotParameters::get_dh_parameters ( )
```

Compute the dh parameters matrix.

Returns

Eigen::MatrixXd Returns DH matrix

7.3.3.2 get_robot_angles()

```
vector< double > RobotParameters::get_robot_angles ( )
```

Gets the robot angles.

Returns

std::vector<double> Returns the robot angles

7.3.3.3 set_dh_parameters()

```
void RobotParameters::set_dh_parameters ( )
```

Sets the DH parameters.

7.3.3.4 set_robot_angles()

```
void RobotParameters::set_robot_angles (
            std::vector< double > robot_angles )
```

Sets the robot angles.

Parameters

robot_angles	Sets the robot angles from the ik solver output

7.3.4 Member Data Documentation

7.3.4.1 robot_name

```
std::string RobotParameters::robot_name
```

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

- include/robot_parameters.hpp
- app/robot_parameters.cpp

Chapter 8

File Documentation

8.1 app/CMakeLists.txt File Reference

Functions

- add_executable (ik_solver main.cpp robot_parameters.cpp forward_kinematics.cpp inverse_kinematics.cpp) include_directories($
- include find_package (PythonLibs REQUIRED) include_directories($

8.1.1 Function Documentation

8.1.1.1 add_executable()

```
add_executable (
            ik_solver main.cpp robot_parameters.cpp forward_kinematics.cpp inverse_kinematics.
cpp )
```

8.1.1.2 find_package()

```
include find_package (
            PythonLibs REQUIRED )
```

8.2 test/CMakeLists.txt File Reference

Functions

- set (GTEST_SHUFFLE 1) add_executable(code_test main.cpp code_test.cpp ../app/robot_parameters.cpp ../app/forward_kinematics.cpp ../app/inverse_kinematics.cpp) target_include_directories(code_test PUBLIC ../vendor/googletest/googletest/include $

8.2.1 Function Documentation

8.2.1.1 set()

```
set (
             GTEST_SHUFFLE 1 )
```

8.3 app/forward_kinematics.cpp File Reference

Program to define the Methods of Forward Kinematics Class.

```
#include "../include/forward_kinematics.hpp"
#include <iostream>
```

Include dependency graph for forward_kinematics.cpp:

8.3.1 Detailed Description

Program to define the Methods of Forward Kinematics Class.

Author

Driver : Tanmay Haldankar (tanmayh@umd.edu), Navigator: Sanchit Kedia (sanchit@terpmail.↩umd.edu), Design Keeper: Qamar Syed (qsyed@umd.edu)

Version

0.12

Date

2022-10-18

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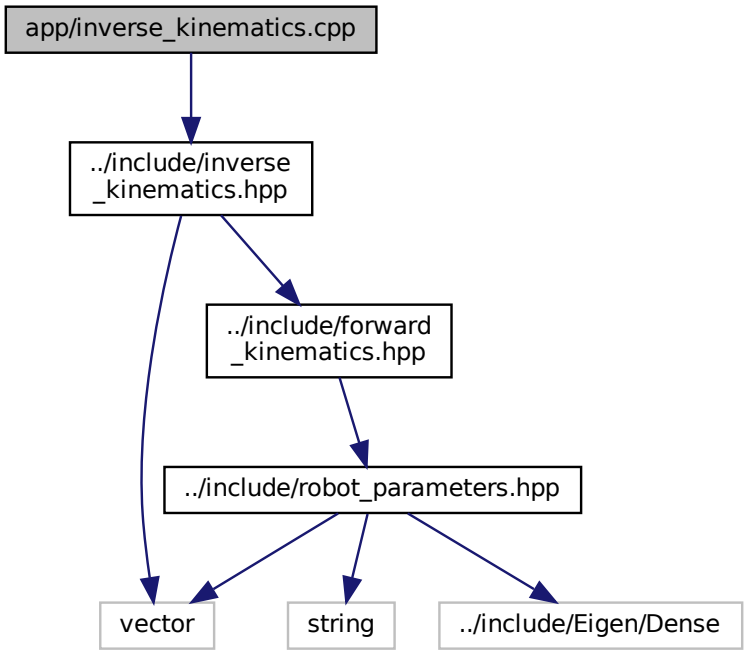
8.4 app/inverse_kinematics.cpp File Reference

```
#include "../include/inverse_kinematics.hpp"
```

Include dependency graph for inverse_kinematics.cpp:

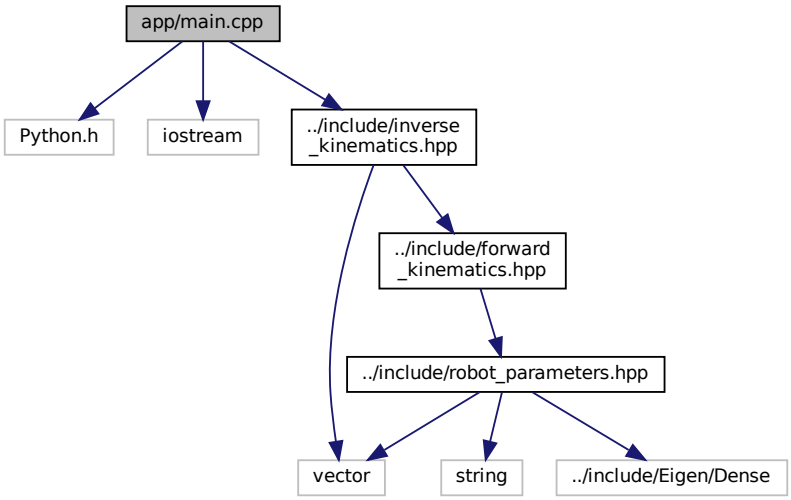


8.5 app/main.cpp File Reference

Program to execute the inverse kinematics and forward kinematics.

```
#include <Python.h>
#include <iostream>
#include "../include/inverse_kinematics.hpp"
```

Include dependency graph for main.cpp:



Functions

- int main ()

  Main Function that calculates the inverse kinematics solution, verifies it by performing forward kinematics and simulates the robot trajectory.

8.5.1 Detailed Description

Program to execute the inverse kinematics and forward kinematics.

Author

Driver : Sanchit Kedia (sanchit@terpmail.umd.edu), Navigator: Tanmay Haldankar (tanmayh@umd.edu), Design Keeper: Qamar Syed (qsyed@umd.edu)

Version

0.2

Date

2022-10-18

Copyright

8.5.2 Function Documentation

8.5.2.1 main()

```
int main ( )
```

Main Function that calculates the inverse kinematics solution, verifies it by performing forward kinematics and simulates the robot trajectory.

Returns

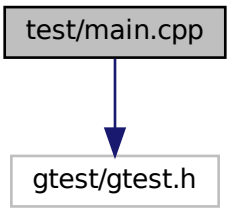
int 0

8.6 test/main.cpp File Reference

Program to use google test for unit testing.

```
#include <gtest/gtest.h>
```

Include dependency graph for main.cpp:



Functions

- int main (int argc, char **argv)

8.6.1 Detailed Description

Program to use google test for unit testing.

Author

Driver : Sanchit Kedia (sanchit@terpmail.umd.edu), Navigator: Tanmay Haldankar (tanmayh@umd.edu), Design Keeper: Qamar Syed (qsyed@umd.edu)

Version

0.1

Date

2022-10-13

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8.6.2 Function Documentation

8.6.2.1 main()

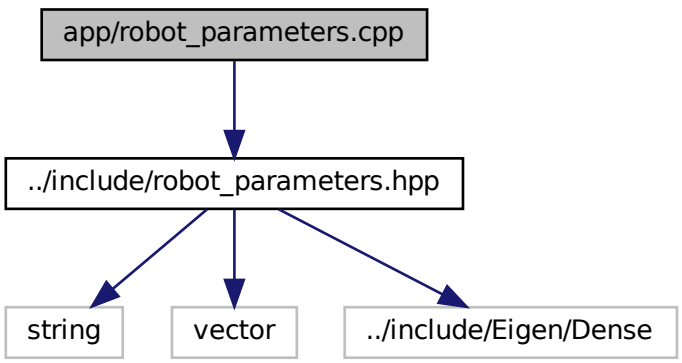
```
int main (
            int argc,
            char ** argv )
```

8.7 app/robot_parameters.cpp File Reference

Program to define the Methods of Robot Parameters Class.

```
#include "../include/robot_parameters.hpp"
```

Include dependency graph for robot_parameters.cpp:



8.7.1 Detailed Description

Program to define the Methods of Robot Parameters Class.

Author

Driver : Sanchit Kedia (sanchit@terpmail.umd.edu), Navigator: Tanmay Haldankar (tanmayh@umd.edu), Design Keeper: Qamar Syed (qsyed@umd.edu)

Version

0.12

Date

2022-10-28

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8.8 app/simulation.py File Reference

Namespaces

- simulation

Variables

- simulation.category
- list simulation.dh_d = [0.25, 0.15, 0.2, 0, 0, 0.1]
- list simulation.dh_a = [0, 0, 0, 0, 0, 0]
- list simulation.dh_alpha = [-1.5708, 1.5708, 0, -1.5708, 1.5708, 0]
- list simulation.dh_theta = [0, 0, 0, 0, 0, 0]
- simulation.dh_params = np.stack((dh_d,dh_a,dh_alpha,dh_theta), axis=-1)
- simulation.robot = RobotSerial(dh_params)
- simulation.abc1 = np.array([[-0.266], [0.031], [0.304]])
- simulation.abc2 = np.array([[-0.232], [0.192], [0.357]])
- simulation.abc3 = np.array([[-0.076], [0.225], [0.461]])
- simulation.abc4 = np.array([[-0.014], [0.262], [0.262]])
- simulation.abc5 = np.array([[-0.221], [0.020], [0.482]])
- simulation.abc6 = np.array([[-0.266], [0.031], [0.304]])
- simulation.xyz1 = np.array([-0.665994, 0.308907, 0.665997])
- simulation.xyz2 = np.array([-0.71637, 0.398236, 0.71637])
- simulation.xyz3 = np.array([0.0292315, 0.541703, 0.91522])
- simulation.xyz4 = np.array([0.158575, 0.957389, 0.50314])
- simulation.xyz5 = np.array([-0.35985, 0.225772, 0.924447])
- simulation.xyz6 = np.array([-0.666147, 0.308929, 0.666111])
- simulation.frame1 = Frame.from_euler_3(xyz1, abc1)
- simulation.frame2 = Frame.from_euler_3(xyz2, abc2)
- simulation.frame3 = Frame.from_euler_3(xyz3, abc3)
- simulation.frame4 = Frame.from_euler_3(xyz4, abc4)
- simulation.frame5 = Frame.from_euler_3(xyz5, abc5)
- simulation.frame6 = Frame.from_euler_3(xyz6, abc6)
- list simulation.frames = [frame1, frame2, frame3, frame4, frame5, frame6]
- simulation.trajectory = RobotTrajectory(robot, frames)
- simulation.motion

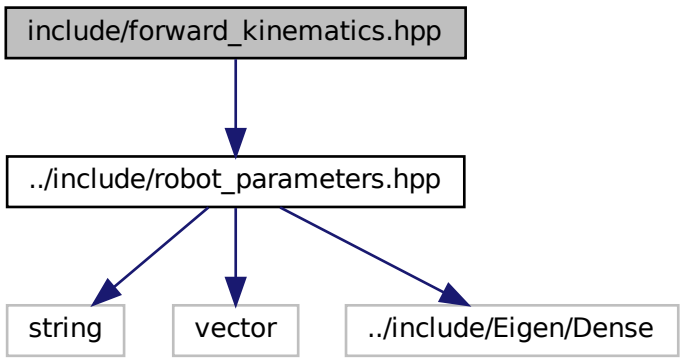
8.9 docs/introduction.txt File Reference

8.10 include/forward_kinematics.hpp File Reference

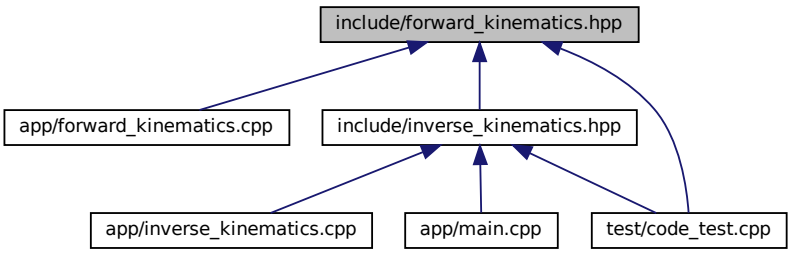
Definition of Forward Kinematics class and Declaration of its Methods.

```
#include "../include/robot_parameters.hpp"
```

Include dependency graph for forward_kinematics.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class ForwardKinematics

  Definition of the Forward Kinematics Class.

8.10.1 Detailed Description

Definition of Forward Kinematics class and Declaration of its Methods.

Author

Driver : Tanmay Haldankar (tanmayh@umd.edu), Navigator: Sanchit Kedia (sanchit@terpmail.umd.edu), Design Keeper: Qamar Syed (qsyed@umd.edu)

Version

0.3

Date

2022-10-28

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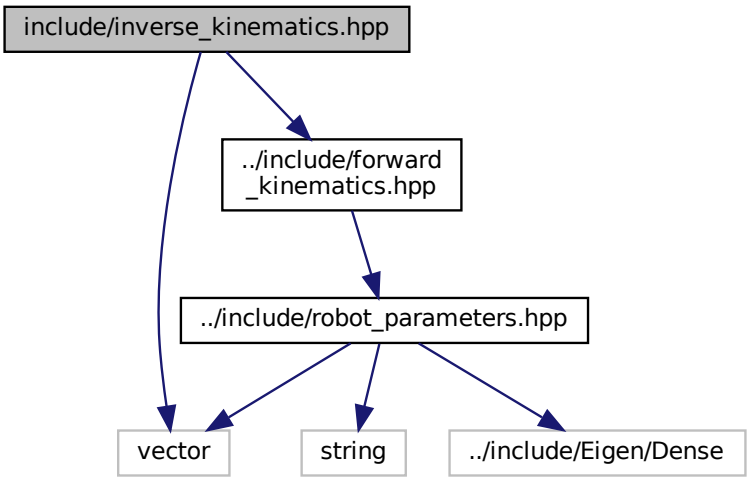
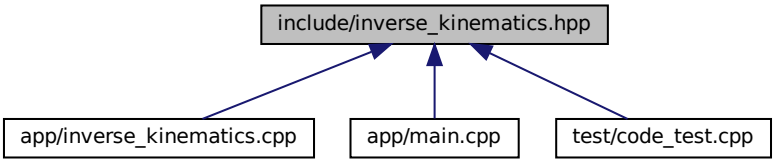
8.11 include/inverse_kinematics.hpp File Reference

```
#include <vector>
#include "../include/forward_kinematics.hpp"
```

Include dependency graph for inverse_kinematics.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class InverseKinematics

  Definition of Inverse Kinematics Class.

8.11.1 Detailed Description

Author

Driver : Sanchit Kedia (sanchit@terpmail.umd.edu), Navigator: Tanmay Haldankar (tanmayh@umd.edu) , Design Keeper: Qamar Syed (qsyed@umd.edu)

Version

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Version

0.3

Date

2022-10-28

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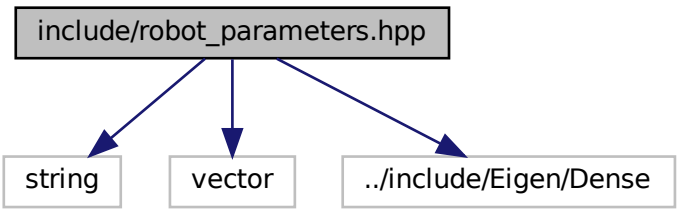
8.12 include/robot_parameters.hpp File Reference

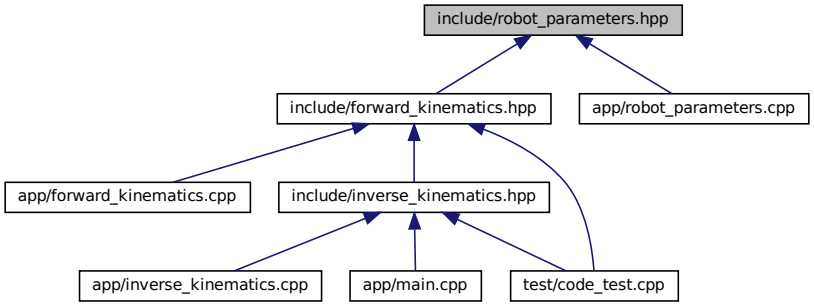
Definition of Robot Parameters class and Declaration of its Methods.

```
#include <string>
#include <vector>
#include "../include/Eigen/Dense"
```

Include dependency graph for robot_parameters.hpp:



This graph shows which files directly or indirectly include this file:



Classes

- class RobotParameters

  Definition of the Robot Parameter Class.

8.12.1 Detailed Description

Definition of Robot Parameters class and Declaration of its Methods.

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Version

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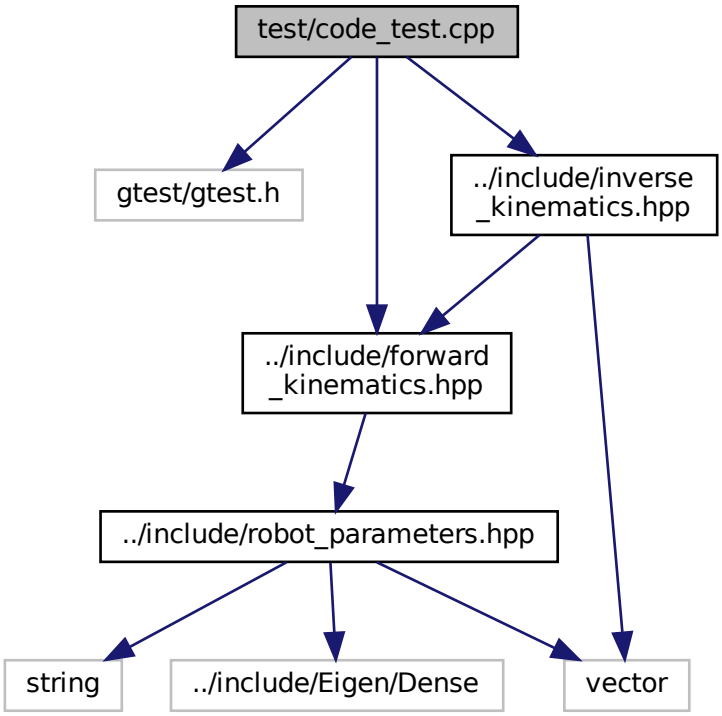
8.13 test/code_test.cpp File Reference

Program to perform unit testing.

```
#include <gtest/gtest.h>
#include "../include/forward_kinematics.hpp"
#include "../include/inverse_kinematics.hpp"
```

Include dependency graph for code_test.cpp:



Functions

- TEST (Robot_Parameters, CheckAngles)

  Construct a new TEST to check if the robot angles vector is empty.
- TEST (Robot_Parameters, CheckDH)

  Construct a new TEST to check the size of the DH Parameters matrix.
- TEST (Robot_Parameters, CheckSetAngles)

  Construct a new TEST to check if the robot angles are being set correctly.
- TEST (Forward_Kinematics, check_calculateTF)

  Construct a new TEST to check the size of the DH transformation matrix.
- TEST (Forward_Kinematics, check_solvefk)

  Construct a new TEST to check the size of final homogeneous transformation matrix.
- TEST (Inverse_Kinematics, Check_solveik)

  Construct a new TEST to check the output of solve_ik function.
- TEST (Inverse_Kinematics, CheckSetIKAngles)

  Construct a new TEST to check the size of end effector Rotation Matrix.
- TEST (Inverse_Kinematics, CheckSetIKPosition)

  Construct a new test to check the size of end effector Position Vector.

8.13.1 Detailed Description

Program to perform unit testing.

Author

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2022-10-15

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8.13.2 Function Documentation

8.13.2.1 TEST() [1/8]

```
TEST (
             Forward_Kinematics ,
             check_calculateTF  )
```

Construct a new TEST to check the size of the DH transformation matrix.

8.13.2.2 TEST() [2/8]

```
TEST (
             Forward_Kinematics ,
             check_solvefk  )
```

Construct a new TEST to check the size of final homogeneous transformation matrix.

8.13.2.3 TEST() [3/8]

```
TEST (
             Inverse_Kinematics ,
             Check_solveik  )
```

Construct a new TEST to check the output of solve_ik function.

8.13.2.4 TEST() [4/8]

```
TEST (
             Inverse_Kinematics ,
             CheckSetIKAngles  )
```

Construct a new TEST to check the size of end effector Rotation Matrix.

8.13.2.5 TEST() [5/8]

```
TEST (
             Inverse_Kinematics ,
             CheckSetIKPosition  )
```

Construct a new test to check the size of end effector Position Vector.

8.13.2.6 TEST() [6/8]

```
TEST (
            Robot_Parameters ,
            CheckAngles  )
```

Construct a new TEST to check if the robot angles vector is empty.

8.13.2.7 TEST() [7/8]

```
TEST (
            Robot_Parameters ,
            CheckDH  )
```

Construct a new TEST to check the size of the DH Parameters matrix.

8.13.2.8 TEST() [8/8]

```
TEST (
            Robot_Parameters ,
            CheckSetAngles  )
```

Construct a new TEST to check if the robot angles are being set correctly.

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