Technische Universität München

Institute for Flight System Dynamics

Rigid Track Position Tracking

–

Doxygen Generated Documentation

Documentation

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Chapter 1

Rigid Track Doxygen Documentation

1.1 Introduction

Rigid Track is a software that provides, combined with an OptiTrack camera, the pose estimation of one object in three dimensional space. This is achieved with only one camera in combination with reflective markers. Those are attached to the object ought to be tracked. The accuracy in the range of millimeters and the high update rate of 100 Hz enable use cases for fast and agile objects. The main application is navigation for drones that rely on high precision position data. Where GPS is not available, e.g. indoors or due to a lacking GPS receiver, this setup substitutes for it. Another use case is the pure pose logging when the drone does not depend on the position, e.g. when it is remote piloted by hand. While this setup contains one OptiTrack Flex 3 camera, every other model of OptiTrack should work, despite not tested. With better camera models, e.g. the Prime Series, even outdoor usage is possible. When the capabilities are not sufficient please refer to OptiTracks Software Motive. But keep in mind that this solution needs at least 3 cameras as Rigid Track works with only one.

1.2 Rigid Track Installation

Start the RigidTrack_setup.exe from the enclosed SD card and follow the instructions given in the installation assistant. Default parameters like installation directory or shortcuts to be created can be chosen. But normally clicking Next and keeping the default values should be sufficient. When the installation is completed a shortcut in the start menu and the desktop can be used to start Rigid Track. The program is then successfully installed in C:/Program Files (x86)/TU Munich FSD/Rigid Track.

1.3 Source Code

The most interesting file for you is main.cpp. It contains the relevant functions for pose estimation. Camera calibration and other functional aspects are also implemented there. The GUI program code is found in RigidTrack.cpp. communication.cpp deals only with communication from main.cpp to the GUI.

Chapter 2

File Index

2.1 File List

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

Chapter 3

File Documentation

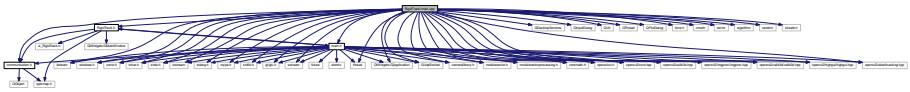
3.1 RigidTrack/main.cpp File Reference

Rigid Track main file that contains most functionallity.

```
#include "RigidTrack.h"
#include "main.h"
#include "communication.h"
#include "cameralibrary.h"
#include "modulevector.h"
#include "modulevectorprocessing.h"
#include "coremath.h"
#include <QtWidgets/QApplication>
#include <QDesktopServices>
#include <QInputDialog>
#include <QUrl>
#include <QThread>
#include <QUdpSocket>
#include <QFileDialog>
#include <opencv\cv.h>
#include "opencv2\core.hpp"
#include "opencv2\calib3d.hpp"
#include <opencv2/imgproc/imgproc.hpp>
#include <opencv2/calib3d/calib3d.hpp>
#include <opencv2/highgui/highgui.hpp>
#include <opencv2\video\tracking.hpp>
#include <fstream>
#include <windows.h>
#include <conio.h>
#include <tchar.h>
#include <stdio.h>
#include <iostream>
#include <stdarg.h>
#include <ctype.h>
#include <stdlib.h>
#include <gl/glu.h>
#include <sstream>
#include <time.h>
#include <cmath>
#include <vector>
#include <algorithm>
```

```
#include <random>
#include <thread>
#include <strsafe.h>
```

Include dependency graph for main.cpp:



Functions

- int main (int argc, char ∗argv[])

  main initialises the GUI and values for the marker position etc
- QPixmap Mat2QPixmap (cv::Mat src)
- void calcBoardCornerPositions (Size boardSize, float squareSize, std::vector< Point3f > &corners)
- void getEulerAngles (Mat &rotCamerMatrix, Vec3d &eulerAngles)
- int startTracking ()
- void startStopCamera ()

  Start or stop the tracking depending on if the camera is currently running or not.
- int setReference ()
- int calibrateCamera ()

  Start the camera calibration routine that computes the camera matrix and distortion coefficients.
- void loadCalibration (int method)
- void testAlgorithms ()
- void projectCoordinateFrame (Mat pictureFrame)
- void setUpUDP ()

  Open the UDP ports for communication.
- void setHeadingOffset (double d)
- void sendDataUDP (cv::Vec3d &Position, cv::Vec3d &Euler)
- void closeUDP ()
- void loadMarkerConfig (int method)
- void drawPositionText (cv::Mat &Picture, cv::Vec3d &Position, cv::Vec3d &Euler, double error)
- void loadCameraPosition ()
- int determineExposure ()
- void determineOrder ()
- int calibrateGround ()

Variables

- commObject commObj

  class that handles the communication from main.cpp to the GUI
- bool safetyEnable = false

  is the safety feature enabled
- bool safety2Enable = false

  is the second receiver enabled
- double safetyBoxLength = 1.5

  length of the safety area cube in meters
- int safetyAngle = 30

  bank and pitch angle protection in degrees

- bool exitRequested = true

  variable if tracking loop should be exited
- int invertZ = 1

  dummy variable to invert Z direction on request
- double frameTime = 0.01

  100 Hz CoSy rate, is later on replaced with the hardware timestamp delivered by the camera
- double timeOld = 0.0

  old time for finite differences velocity calculation. Is later on replaced with the hardware timestamp delivered by the camera
- double timeFirstFrame = 0

  Time stamp of the first frame. This value is then subtracted for every other frame so the time in the log start at zero.
- Vec3d position = Vec3d()

  position vector x,y,z for object position in O-CoSy, unit is meter
- Vec3d eulerAngles = Vec3d()

  Roll Pitch Heading in this order, units in degrees.
- Vec3d positionOld = Vec3d()

  old position in O-CoSy for finite differences velocity calculation
- Vec3d velocity = Vec3d()

  velocity vector of object in o-CoSy in respect to o-CoSy
- Vec3d posRef = Vec3d()

  initial position of object in camera CoSy
- Vec3d eulerRef = Vec3d()

  initial euler angle of object respectivley to camera CoSy
- double headingOffset = 0

  heading offset variable for aligning INS heading with tracking heading
- int intIntensity = 15

  max infrared spot light intensity is 15 1-6 is strobe 7-15 is continuous 13 and 14 are meaningless
- int intExposure = 1

  max is 480 increase if markers are badly visible but should be determined automatically during setReference()
- int intFrameRate = 100

  CoSy rate of camera, maximum is 100 fps.
- int intThreshold = 200

  threshold value for marker detection. If markers are badly visible lower this value but should not be necessary
- Mat Rmat = (cv::Mat_<double>(3, 1) << 0.0, 0.0, 0.0)

  Rotation, translation etc. matrix for PnP results.
- Mat RmatRef = (cv::Mat_<double>(3, 3) << 1., 0., 0., 0., 1., 0., 0., 0., 1.)

  reference rotation matrix from camera CoSy to marker CoSy
- Mat M_CN = cv::Mat_<double>(3, 3)

  rotation matrix from camera to ground, fixed for given camera position
- Mat M_HeadingOffset = cv::Mat_<double>(3, 3)

  rotation matrix that turns the ground system to the INS magnetic heading for alignment
- Mat Rvec = (cv::Mat_<double>(3, 1) << 0.0, 0.0, 0.0)

  rotation vector (axis-angle notation) from camera CoSy to marker CoSy
- Mat Tvec = (cv::Mat_<double>(3, 1) << 0.0, 0.0, 0.0)

  translation vector from camera CoSy to marker CoSy in camera CoSy
- Mat RvecOriginal

  initial values as start values for algorithms and algorithm tests

- Mat TvecOriginal

  initial values as start values for algorithms and algorithm tests
- bool useGuess = true

  set to true and the algorithm uses the last result as starting value
- int methodPNP = 0

  solvePNP algorithm 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP //!< 4 and 1 are the same and not implemented correctly by OpenCV
- int numberMarkers = 4

  number of markers. Is loaded during start up from the marker configuration file
- std::vector< Point3d > list_points3d

  marker positions in marker CoSy
- std::vector< Point2d > list_points2d

  marker positions projected in 2D in camera image CoSy
- std::vector< Point2d > list_points2dOld

  marker positions in previous picture in 2D in camera image CoSy
- std::vector< double > list_points2dDifference

  difference of the old and new 2D marker position to determine the order of the points
- std::vector< Point2d > list_points2dProjected

  3D marker points projected to 2D in camera image CoSy with the algorithm projectPoints
- std::vector< Point2d > list_points2dUnsorted

  marker points in 2D camera image CoSy, sorted with increasing x (camera image CoSy) but not sorted to correspond with list_points3d
- std::vector< Point3d > coordinateFrame

  coordinate visualisazion of marker CoSy
- std::vector< Point2d > coordinateFrameProjected

  marker CoSy projected from 3D to 2D camera image CoSy
- int pointOrderIndices [ ] = { 0, 1, 2, 3 }

  old correspondence from list_points3d and list_points_2d
- int pointOrderIndicesNew [ ] = { 0, 1, 2, 3 }

  new correspondence from list_points3d and list_points_2d
- double currentPointDistance = 5000

  distance from the projected 3D points (hence in 2d) to the real 2d marker positions in camera image CoSy
- double minPointDistance = 5000

  minimum distance from the projected 3D points (hence in 2d) to the real 2d marker positions in camera image CoSy
- int currentMinIndex = 0

  helper variable set to the point order that holds the current minimum point distance
- bool gotOrder = false

  order of the list_points3d and list_points3d already tetermined or not, has to be done once
- bool camera_started = false

  variable thats needed to exit the main while loop
- Mat cameraMatrix

  camera matrix of the camera
- Mat distCoeffs

  distortion coefficients of the camera
- Core::DistortionModel distModel

  distortion model of the camera
- QUdpSocket * udpSocketObject

socket for the communication with receiver 1

- QUdpSocket * udpSocketSafety

  socket for the communication with safety receiver
- QUdpSocket * udpSocketSafety2

  socket for the communication with receiver 3
- QHostAddress IPAdressObject = QHostAddress("127.0.0.1")

  IPv4 adress of receiver 1.
- QHostAddress IPAdressSafety = QHostAddress("192.168.4.1")

  IPv4 adress of safety receiver.
- QHostAddress IPAdressSafety2 = QHostAddress("192.168.4.4")

  IPv4 adress of receiver 2.
- int portObject = 9155

  Port of receiver 1.
- int portSafety = 9155

  Port of the safety receiver.
- int portSafety2 = 9155

  Port of receiver 2.
- QByteArray datagram

  data package that is sent to receiver 1 and 2
- QByteArray data

  data package that's sent to the safety receiver
- const int BACKBUFFER_BITSPERPIXEL = 8

  8 bit per pixel and greyscale image from camera
- std::string strBuf

  buffer that holds the strings that are sent to the Qt GUI
- std::stringstream ss

  stream that sends the strBuf buffer to the Qt GUI
- QString logFileName

  Filename for the logfiles.
- std::string logName

  Filename for the logfiles as standard string.
- SYSTEMTIME logDate

  Systemtime struct that saves the current date and time thats needed for the log file name creation.
- std::ofstream logfile

  file handler for writing the log file

3.1.1 Detailed Description

Rigid Track main file that contains most functionallity.
This file contains allmost all functional code for pose estimation, calibration and so on. The GUI related part is in RigidTrack.cpp and the communication from main.cpp to GUI is done with the commObj class from communication.cpp.

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Version

1.0

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3.1.2 Function Documentation

calcBoardCornerPositions()

```
void calcBoardCornerPositions (
              Size boardSize,
              float squareSize,
              std::vector< Point3f > & corners )
```

Calculate the chess board corner positions, used for the camera calibration.

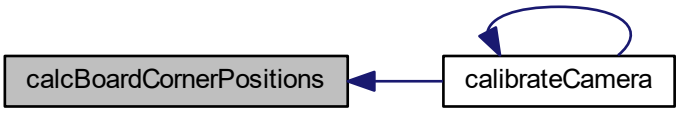
Parameters

in	*boardSize*	denotes how many squares are in each direction.
in	*squareSize*	is the square length in millimeters.
out	*corners*	returns the square corners in millimeters.

Definition at line 238 of file main.cpp.

```
239 {
240     corners.clear();
241
242     for (int i = 0; i < boardSize.height; ++i)
243         for (int j = 0; j < boardSize.width; ++j)
244             corners.push_back(Point3f(float(j*squareSize), float(i*squareSize), 0));
245 }
```

Here is the caller graph for this function:



calibrateGround()

```
int calibrateGround ( )
```

Get the pose of the camera w.r.t the ground calibration frame. This frame sets the navigation frame for later results. The pose is averaged over 200 samples and then saved in the file referenceData.xml. This routine is basically the same as setReference.
Definition at line 1581 of file main.cpp.

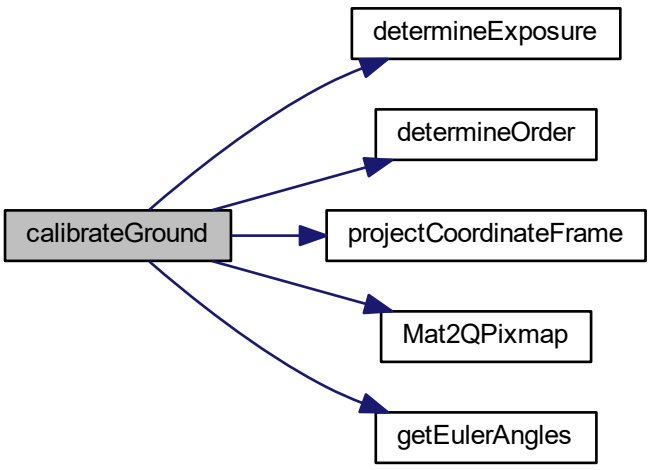
```
1582 {
1583     //! initialize the variables with starting values
```

```
1584     gotOrder = false;
1585     posRef = 0;
1586     eulerRef = 0;
1587     RmatRef = 0;
1588     Rvec = RvecOriginal;
1589     Tvec = TvecOriginal;
1590 
1591     determineExposure();
1592 
1593     ss.str("");
1594     commObj.addLog("Started ground calibration");
1595 
1596     CameraLibrary_EnableDevelopment();
1597     //! Initialize Camera SDK ==--
1598     CameraLibrary::CameraManager::X();
1599 
1600     //! At this point the Camera SDK is actively looking for all connected cameras and will initialize
1601     //! them on it's own.
1602 
1603     //! Get a connected camera ================-----
1604     CameraManager::X().WaitForInitialization();
1605     Camera *camera = CameraManager::X().GetCamera();
1606 
1607     //! If no device connected, pop a message box and exit ==--
1608     if (camera == 0)
1609     {
1610         commObj.addLog("No camera found!");
1611         return 1;
1612     }
1613 
1614     //! Determine camera resolution to size application window ==----
1615     int cameraWidth = camera->Width();
1616     int cameraHeight = camera->Height();
1617     camera->GetDistortionModel(distModel);
1618     cv::Mat matFrame(cv::Size(cameraWidth, cameraHeight), CV_8UC1);
1619 
1620     //! Set camera mode to precision mode, it directly provides marker coordinates
1621     camera->SetVideoType(Core::PrecisionMode);
1622 
1623     //! Start camera output ==--
1624     camera->Start();
1625 
1626     //! Turn on some overlay text so it's clear things are     ===---
1627     //! working even if there is nothing in the camera's view. ===---
1628     //! Set some other parameters as well of the camera
1629     camera->SetTextOverlay(true);
1630     camera->SetFrameRate(intFrameRate);
1631     camera->SetIntensity(intIntensity);
1632     camera->SetIRFilter(true);
1633     camera->SetContinuousIR(false);
1634     camera->SetHighPowerMode(false);
1635 
1636     //! sample some frames and calculate the position and attitude. then average those values and use that
    as zero position
1637     int numberSamples = 0;
1638     int numberToSample = 200;
1639     double projectionError = 0;
1640 
1641     while (numberSamples < numberToSample)
1642     {
1643         //! Fetch a new frame from the camera ===---
1644         Frame *frame = camera->GetFrame();
1645 
1646         if (frame)
1647         {
1648             //! Ok, we've received a new frame, lets do something
1649             //! with it.
1650             if (frame->ObjectCount() == numberMarkers)
1651             {
1652                 //!for(int i=0; i<frame->ObjectCount(); i++)
1653                 for (int i = 0; i < numberMarkers; i++)
1654                 {
1655                     cObject *obj = frame->Object(i);
1656                     list_points2dUnsorted[i] = cv::Point2d(obj->X(), obj->Y());
1657                 }
1658 
1659                 if (gotOrder == false)
1660                 {
1661                     determineOrder();
1662                 }
1663 
1664                 //! sort the 2d points with the correct indices as found in the preceeding order
```

```
      determination algorithm
1665                for (int w = 0; w < numberMarkers; w++)
1666                {
1667                    list_points2d[w] = list_points2dUnsorted[
      pointOrderIndices[w]];
1668                }
1669                list_points2dOld = list_points2dUnsorted;
1670
1671                //!Compute the pose from the 3D-2D corresponses
1672                solvePnP(list_points3d, list_points2d,
      cameraMatrix, distCoeffs, Rvec, Tvec, useGuess,
      methodPNP);
1673
1674                //! project the marker 3d points with the solution into the camera image CoSy and calculate
       difference to true camera image
1675                projectPoints(list_points3d, Rvec, Tvec,
      cameraMatrix, distCoeffs, list_points2dProjected);
1676                projectionError = norm(list_points2dProjected,
      list_points2d);
1677
1678                if (projectionError > 3)
1679                {
1680                    commObj.addLog("Reprojection error is bigger than 3 pixel. Correct marker
       configuration loaded?\nMarker position measured precisely?");
1681                    frame->Release();
1682                    return 1;
1683                }
1684
1685                double maxValue = 0;
1686                double minValue = 0;
1687                minMaxLoc(Tvec.at<double>(2), &minValue, &maxValue);
1688
1689                if (maxValue > 10000 || minValue < 0)
1690                {
1691
1692
1693                    commObj.addLog("Negative z distance, thats not possible. Start the set zero
       routine again and check marker configurations.");
1694                    frame->Release();
1695                    return 1;
1696                }
1697
1698                if (norm(positionOld) - norm(Tvec) < 0.05)   //!<Iterative Method needs time
       to converge to solution
1699                {
1700                    add(posRef, Tvec, posRef);
1701                    add(eulerRef, Rvec, eulerRef); //!< That are not the values of yaw,
       roll and pitch yet! Rodriguez has to be called first.
1702                    numberSamples++;    //!<-- one sample more :D
1703                    commObj.progressUpdate(numberSamples * 100 / numberToSample);
1704                }
1705                positionOld = Tvec;
1706
1707                Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
1708                for (int i = 0; i < numberMarkers; i++)
1709                {
1710                    circle(cFrame, Point(list_points2d[i].x,
      list_points2d[i].y), 6, Scalar(0, 225, 0), 3);
1711                }
1712                projectCoordinateFrame(cFrame);
1713                projectPoints(list_points3d, Rvec, Tvec,
      cameraMatrix, distCoeffs, list_points2d);
1714                for (int i = 0; i < numberMarkers; i++)
1715                {
1716                    circle(cFrame, Point(list_points2d[i].x,
      list_points2d[i].y), 3, Scalar(225, 0, 0), 3);
1717                }
1718
1719                QPixmap QPFrame;
1720                QPFrame = Mat2QPixmap(cFrame);
1721                commObj.changeImage(QPFrame);
1722                QCoreApplication::processEvents();
1723
1724            }
1725            frame->Release();
1726        }
1727    }
1728    //! Release camera ==--
1729    camera->Release();
1730
1731    //!Divide by the number of samples to get the mean of the reference position
1732    divide(posRef, numberToSample, posRef);
```

```
1733     divide(eulerRef, numberToSample, eulerRef); //!< eulerRef is here in Axis Angle
       notation
1734
1735     Rodrigues(eulerRef, RmatRef);                //!< axis angle to rotation matrix
1736
1737     getEulerAngles(RmatRef, eulerRef); //!<  rotation matrix to euler
1738     ss.str("");
1739     ss << "RmatRef is:\n";
1740     ss << RmatRef << "\n";
1741     ss << "Reference Position is:\n";
1742     ss << posRef << "[mm] \n";
1743     ss << "Reference Euler angles are:\n";
1744     ss << eulerRef << "[deg] \n";
1745
1746     //! Save the obtained calibration coefficients in a file for later use
1747     QString fileName = QFileDialog::getSaveFileName(nullptr, "Save ground calibration file", "
       referenceData.xml", "Calibration File (*.xml);;All Files (*)");
1748     FileStorage fs(fileName.toUtf8().constData(), FileStorage::WRITE);
1749     fs << "M_NC" << RmatRef;
1750     fs << "eulerRef" << eulerRef;
1751     strBuf = fs.releaseAndGetString();
1752     commObj.changeStatus(QString::fromStdString(strBuf));
1753     commObj.addLog("Saved ground calibration!");
1754     commObj.progressUpdate(0);
1755     return 0;
1756 }
```

Here is the call graph for this function:



closeUDP()

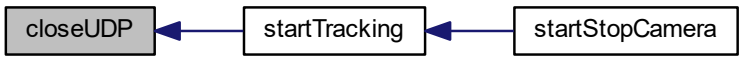
```
void closeUDP ( )
```

Close the UDP ports again to release network interfaces etc. If this is not done the network resources are still occupied and the program can't exit properly.
Definition at line 1191 of file main.cpp.

```
1192 {
1193     //! check if the socket is open and if yes close it
1194     if (udpSocketObject->isOpen())
1195     {
```

```
1196         udpSocketObject->close();
1197     }
1198
1199     if (udpSocketSafety->isOpen())
1200     {
1201         udpSocketSafety->close();
1202     }
1203
1204     if (udpSocketSafety2->isOpen())
1205     {
1206         udpSocketSafety2->close();
1207     }
1208     commObj.addLog("Closed all UDP ports.");
1209 }
```

Here is the caller graph for this function:



determineExposure()

```
int determineExposure ( )
```

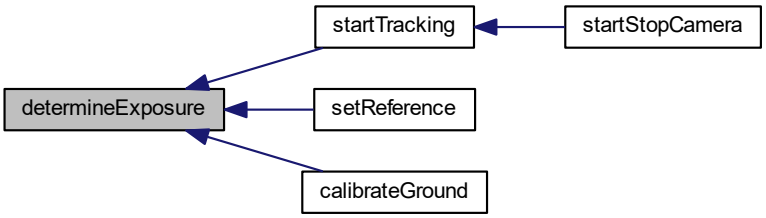
Get the optimal exposure for the camera. For that find the minimum and maximum exposure were the right number of markers are detected. Then the mean of those two values is used as exposure.
Definition at line 1380 of file main.cpp.

```
1381 {
1382     //! For OptiTrack Ethernet cameras, it's important to enable development mode if you
1383     //! want to stop execution for an extended time while debugging without disconnecting
1384     //! the Ethernet devices.  Lets do that now:
1385
1386     CameraLibrary_EnableDevelopment();
1387
1388     //! Initialize Camera SDK ==--
1389     CameraLibrary::CameraManager::X();
1390
1391     //! At this point the Camera SDK is actively looking for all connected cameras and will initialize
1392     //! them on it's own.
1393
1394     //! Get a connected camera ==================----
1395     CameraManager::X().WaitForInitialization();
1396     Camera *camera = CameraManager::X().GetCamera();
1397
1398     //! If no device connected, pop a message box and exit ==--
1399     if (camera == 0)
1400     {
1401         commObj.addLog("No camera found!");
1402         return 1;
1403     }
1404
1405     //! Determine camera resolution to size application window ==----
1406     int cameraWidth = camera->Width();
1407     int cameraHeight = camera->Height();
1408
1409     camera->SetVideoType(Core::PrecisionMode);  //! set the camera mode to precision mode, it used
     greyscale imformation for marker property calculations
1410
1411                                                 //! Start camera output ==--
1412     camera->Start();
1413
1414     //! Turn on some overlay text so it's clear things are     ==--
1415     //! working even if there is nothing in the camera's view. ==--
```

```
1416     camera->SetTextOverlay(true);
1417     camera->SetExposure(intExposure);    //! set the camera exposure
1418     camera->SetIntensity(intIntensity); //! set the camera infrared LED intensity
1419     camera->SetFrameRate(intFrameRate); //! set the camera framerate to 100 Hz
1420     camera->SetIRFilter(true);  //! enable the filter that blocks visible light and only passes infrared
     light
1421     camera->SetHighPowerMode(true); //! enable high power mode of the leds
1422     camera->SetContinuousIR(false); //! enable continuous LED light
1423     camera->SetThreshold(intThreshold); //! set threshold for marker detection
1424
1425     //!set exposure such that num markers are visible
1426     int numberObjects = 0;  //! Number of objects (markers) found in the current picture with the given
     exposure
1427     int minExposure = 1;    //! exposure when objects detected the first time is numberMarkers
1428     int maxExposure = 480;  //! exposure when objects detected is first time numberMarkers+1
1429     intExposure = minExposure;   //! set the exposure to the smallest value possible
1430     int numberTries = 0;    //! if the markers arent found after numberTries then there might be no markers
     at all in the real world
1431
1432                             //! Determine minimum exposure, hence when are numberMarkers objects detected
1433     camera->SetExposure(intExposure);
1434     while (numberObjects != numberMarkers && numberTries < 48)
1435     {
1436         //! get a new camera frame
1437         Frame *frame = camera->GetFrame();
1438         if (frame) //! frame received
1439         {
1440             numberObjects = frame->ObjectCount();   //! how many objects are detected in the image
1441             if (numberObjects == numberMarkers) { minExposure =
    intExposure; frame->Release(); break; } //! if the right amount if markers is found, exit while
     loop
1442             //! not the right amount of markers was found so increase the exposure and try again
1443             numberTries++;
1444             intExposure += 10;
1445             camera->SetExposure(intExposure);
1446             ss.str("");
1447             ss << "Exposure: " << intExposure << "\t";
1448             ss << "Objects found: " << numberObjects;
1449             commObj.addLog(QString::fromStdString(ss.str()));
1450             frame->Release();
1451         }
1452     }
1453
1454     //! Now determine maximum exposure, hence when are numberMarkers+1 objects detected
1455     numberTries = 0;    //! if the markers arent found after numberTries then there might be no markers at
     all in the real world
1456     intExposure = maxExposure;
1457     camera->SetExposure(intExposure);
1458     numberObjects = 0;
1459     while (numberObjects != numberMarkers && numberTries < 48)
1460     {
1461         Frame *frame = camera->GetFrame();
1462         if (frame)
1463         {
1464             numberObjects = frame->ObjectCount(); //! how many objects are detected in the image
1465             if (numberObjects == numberMarkers) { maxExposure =
    intExposure; frame->Release(); break; } //! if the right amount if markers is found, exit while
     loop
1466
1467             //! not the right amount of markers was found so decrease the exposure and try again
1468             intExposure -= 10;
1469             numberTries++;
1470             camera->SetExposure(intExposure);
1471             ss.str("");
1472             ss << "Exposure: " << intExposure << "\t";
1473             ss << "Objects found: " << numberObjects;
1474             commObj.addLog(QString::fromStdString(ss.str()));
1475             frame->Release();
1476         }
1477     }
1478
1479     //! set the exposure to the mean of min and max exposure determined
1480     camera->SetExposure((minExposure + maxExposure) / 2.0);
1481
1482     //! and now check if the correct amount of markers is detected with that new value
1483     while (1)
1484     {
1485         Frame *frame = camera->GetFrame();
1486         if (frame)
1487         {
1488             numberObjects = frame->ObjectCount(); //! how many objects are detected in the image
1489             if (numberObjects != numberMarkers) //! are all markers and not more or less
```

```
      detected in the image
1490              {
1491                  frame->Release();
1492                  commObj.addLog("Was not able to detect the right amount of markers.");
1493                  //! Release camera ===-
1494                  camera->Release();
1495                  return 1;
1496              }
1497              else  //! all markers and not more or less are found
1498              {
1499                  frame->Release();
1500                  intExposure = (minExposure + maxExposure) / 2.0;
1501                  commObj.addLog("Found the correct number of markers.");
1502                  commObj.addLog("Exposure set to:");
1503                  commObj.addLog(QString::number(intExposure));
1504                  break;
1505              }
1506          }
1507      }
1508
1509      camera->Release();
1510      return 0;
1511
1512 }
```

Here is the caller graph for this function:



determineOrder()

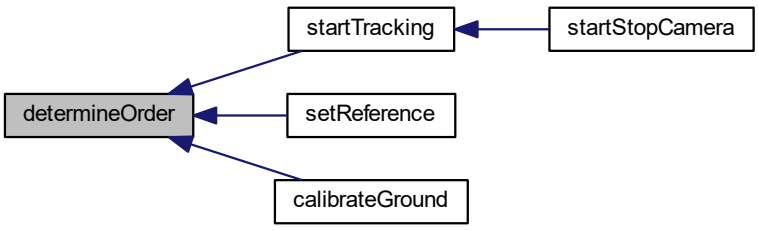
`void determineOrder ( )`

Compute the order of the marker points in 2D so they are the same as in the 3D array. Hence marker 1 must be in first place for both, list_points2d and list_points3d.
Definition at line 1516 of file main.cpp.

```
1517 {
1518     //! determine the 3D-2D correspondences that are crucial for the PnP algorithm
1519     //! Try every possible correspondence and solve PnP
1520     //! Then project the 3D marker points into the 2D camera image and check the difference
1521     //! between projected points and points as seen by the camera
1522     //! the corresponce with the smallest difference is probably the correct one
1523
1524         //! the difference between true 2D points and projected points is super big
1525     minPointDistance = 5000;
1526     std::sort(pointOrderIndices, pointOrderIndices + 4);
1527
1528     //! now try every possible permutation of correspondence
1529     do {
1530         //! reset the starting values for solvePnP
1531         Rvec = RvecOriginal;
1532         Tvec = TvecOriginal;
1533
1534         //! sort the 2d points with the current permutation
1535         for (int m = 0; m < numberMarkers; m++)
1536         {
```

```
1537            list_points2d[m] = list_points2dUnsorted[
    pointOrderIndices[m]];
1538        }
1539
1540        //! Call solve PNP with P3P since its more robust and sufficient for start value determination
1541        solvePnP(list_points3d, list_points2d,
    cameraMatrix, distCoeffs, Rvec, Tvec, useGuess, SOLVEPNP_P3P);
1542
1543        //! set the current difference of all point correspondences to zero
1544        currentPointDistance = 0;
1545
1546        //! project the 3D points with the solvePnP solution onto 2D
1547        projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2dProjected);
1548
1549        //! now compute the absolute difference (error)
1550        for (int n = 0; n < numberMarkers; n++)
1551        {
1552            currentPointDistance += norm(list_points2d[n] -
    list_points2dProjected[n]);
1553        }
1554
1555        //! if the difference with the current permutation is smaller than the smallest value till now
1556        //! it is probably the more correct permutation
1557        if (currentPointDistance < minPointDistance)
1558        {
1559            minPointDistance = currentPointDistance;    //!< set the
     smallest value of difference to the current one
1560            for (int b = 0; b < numberMarkers; b++)    //!< now safe the better permutation
1561            {
1562                pointOrderIndicesNew[b] = pointOrderIndices[b];
1563            }
1564        }
1565
1566
1567    }
1568    //! try every permutation
1569    while (std::next_permutation(pointOrderIndices,
    pointOrderIndices + 4));
1570
1571    //! now that the correct order is found assign it to the indices array
1572    for (int w = 0; w < numberMarkers; w++)
1573    {
1574        pointOrderIndices[w] = pointOrderIndicesNew[w];
1575    }
1576    gotOrder = true;
1577 }
```

Here is the caller graph for this function:



drawPositionText()

```
void drawPositionText (
            cv::Mat & Picture,
```

```
cv::Vec3d & Position,
cv::Vec3d & Euler,
double error )
```

Draw the position, attitude and reprojection error in the picture.

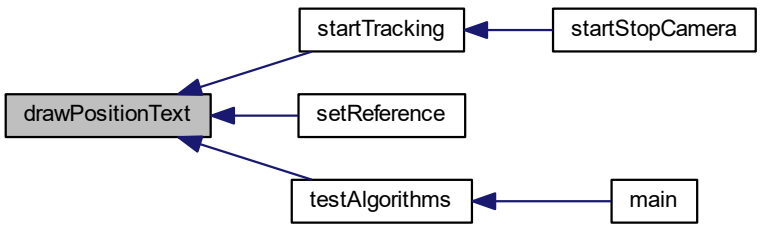
Parameters

in	*Picture*	is the camera image in OpenCV matrix format.
in	*Position*	is the position of the tracked object in navigation CoSy.
in	*Euler*	are the Euler angles with respect to the navigation frame.
in	*error*	is the reprojection error of the pose estimation.

Definition at line 1333 of file main.cpp.

```
1334 {
1335     ss.str("");
1336     ss << "X: " << Position[0] << " m";
1337     putText(Picture, ss.str(), cv::Point(200, 440), 1, 1, cv::Scalar(255, 255, 255));
1338
1339     ss.str("");
1340     ss << "Y: " << Position[1] << " m";
1341     putText(Picture, ss.str(), cv::Point(200, 455), 1, 1, cv::Scalar(255, 255, 255));
1342
1343     ss.str("");
1344     ss << "Z: " << Position[2] << " m";
1345     putText(Picture, ss.str(), cv::Point(200, 470), 1, 1, cv::Scalar(255, 255, 255));
1346
1347     ss.str("");
1348     ss << "Heading: " << Euler[2]*180/3.1415 << " deg";
1349     putText(Picture, ss.str(), cv::Point(350, 440), 1, 1, cv::Scalar(255, 255, 255));
1350
1351     ss.str("");
1352     ss << "Pitch: " << Euler[1] * 180 / 3.1415 << " deg";
1353     putText(Picture, ss.str(), cv::Point(350, 455), 1, 1, cv::Scalar(255, 255, 255));
1354
1355     ss.str("");
1356     ss << "Roll: " << Euler[0] * 180 / 3.1415 << " deg";
1357     putText(Picture, ss.str(), cv::Point(350, 470), 1, 1, cv::Scalar(255, 255, 255));
1358
1359     ss.str("");
1360     ss << "Error: " << error << " px";
1361     putText(Picture, ss.str(), cv::Point(10, 470), 1, 1, cv::Scalar(255, 255, 255));
1362 }
```

Here is the caller graph for this function:



getEulerAngles()

```
void getEulerAngles (
              Mat & rotCamerMatrix,
              Vec3d & eulerAngles )
```

As explained Euler angles can be extracted from an ordinary rotation matrix. As the OpenCV documentation states the embedded function decomposeProjectionMatrix decomposes a projection matrix into a rotation matrix, camera matrix and Euler angles. But in Rigid Track rotCamerMatrix is always only a pure rotation matrix and the camera matrix equals the unit matrix. Get the euler angles from a rotation matrix

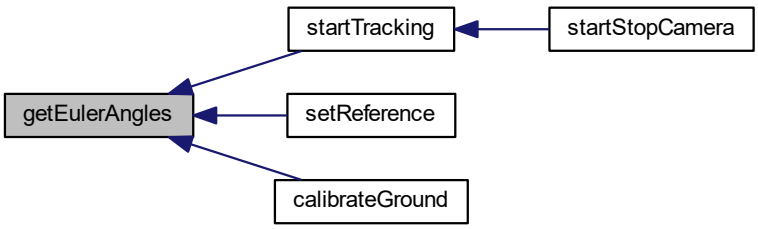
Parameters

in	*rotCamerMatrix*	is a projection matrix, here normally only the extrinsic values.
out	*eulerAngles*	contains the Euler angles that result in the same rotation matrix as rotCamerMatrix.

Definition at line 256 of file main.cpp.

```
256                                                         {
257
258     Mat cameraMatrix, rotMatrix, transVect, rotMatrixX, rotMatrixY, rotMatrixZ;
259     double* _r = rotCamerMatrix.ptr<double>();
260     double projMatrix[12] = { _r[0],_r[1],_r[2],0,
261         _r[3],_r[4],_r[5],0,
262         _r[6],_r[7],_r[8],0 };
263
264     decomposeProjectionMatrix(Mat(3, 4, CV_64FC1, projMatrix),
265         cameraMatrix,
266         rotMatrix,
267         transVect,
268         rotMatrixX,
269         rotMatrixY,
270         rotMatrixZ,
271         eulerAngles);
272 }
```

Here is the caller graph for this function:



loadCalibration()

```
void loadCalibration (
              int method )
```

Load a previously saved camera calibration from a file.

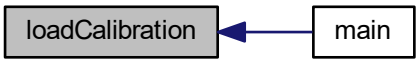
Parameters

in	*method*	whether or not load the camera calibration from calibration.xml. If ==0 then yes, if != 0 then let the user select a different file.

Definition at line 941 of file main.cpp.

```
941                                 {
942
943     QString fileName;
944     if (method == 0)
945     {
946         fileName = "calibration.xml";
947     }
948     else
949     {
950         fileName = QFileDialog::getOpenFileName(nullptr, "Choose a previous saved calibration file", "", "
      Calibration Files (*.xml);;All Files (*)");
951         if (fileName.length() == 0)
952         {
953             fileName = "calibration.xml";
954         }
955     }
956     FileStorage fs;
957     fs.open(fileName.toUtf8().constData(), FileStorage::READ);
958     fs["CameraMatrix"] >> cameraMatrix;
959     fs["DistCoeff"] >> distCoeffs;
960     commObj.addLog("Loaded calibration from file:");
961     commObj.addLog(fileName);
962     ss.str("");
963     ss << "\nCamera Matrix is" << "\n" << cameraMatrix << "\n";
964     ss << "\nDistortion Coefficients are" << "\n" << distCoeffs << "\n";
965     commObj.addLog(QString::fromStdString(ss.str()));
966 }
```

Here is the caller graph for this function:



loadCameraPosition()

```
void loadCameraPosition ( )
```

Load the rotation matrix from camera CoSy to ground CoSy It is determined during calibrateGround() and stays the same once the camera is mounted and fixed.
Definition at line 1366 of file main.cpp.

```
1367 {
1368     //! Open the referenceData.xml that contains the rotation from camera CoSy to ground CoSy
1369     FileStorage fs;
1370     fs.open("referenceData.xml", FileStorage::READ);
1371     fs["M_NC"] >> M_CN;
1372     fs["M_NC"] >> RmatRef;
1373     fs["posRef"] >> posRef;
1374     fs["eulerRef"] >> eulerRef;
1375     commObj.addLog("Loaded reference pose.");
1376 }
```

Here is the caller graph for this function:

loadMarkerConfig()

```
void loadMarkerConfig (
            int method )
```

Load a marker configuration from file. This file has to be created by hand, use the standard marker configuration file as template.

Parameters

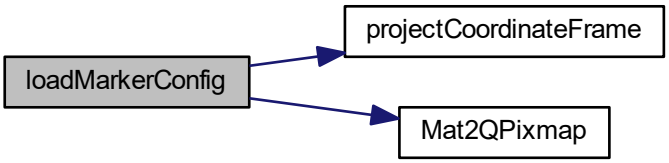
in	*method*	whether or not load the configuration from the markerStandard.xml. If ==0 load it, if != 0 let the user select a different file.

Definition at line 1213 of file main.cpp.

```
1214 {
1215     QString fileName;
1216     //! during start up of the programm load the standard marker configuration
1217     if (method == 0)
1218     {
1219         //! open the standard marker configuration file
1220         FileStorage fs;
1221         fs.open("markerStandard.xml", FileStorage::READ);
1222
1223         //! copy the values to the respective variables
1224         fs["numberMarkers"] >> numberMarkers;
1225
1226         //! inizialise vectors with correct length depending on the number of markers
1227         list_points3d = std::vector<Point3d>(numberMarkers);
1228         list_points2d = std::vector<Point2d>(numberMarkers);
1229         list_points2dOld = std::vector<Point2d>(numberMarkers);
1230         list_points2dDifference = std::vector<double>(
      numberMarkers);
1231         list_points2dProjected = std::vector<Point2d>(
      numberMarkers);
1232         list_points2dUnsorted = std::vector<Point2d>(
      numberMarkers);
1233
1234         //! save the marker locations in the points3d vector
1235         fs["list_points3d"] >> list_points3d;
1236         fs.release();
1237         commObj.addLog("Loaded marker configuration from file:");
1238         commObj.addLog(fileName);
1239
1240
1241
1242     }
1243     else
1244     {
1245         //! if the load marker configuration button was clicked show a open file dialog
1246         fileName = QFileDialog::getOpenFileName(nullptr, "Choose a previous saved marker configuration file
      ", "", "marker configuratio files (*.xml);;All Files (*)");
1247
1248         //! was cancel or abort clicked
1249         if (fileName.length() == 0)
```

```
1250         {
1251             //! if yes load the standard marker configuration
1252             fileName = "markerStandard.xml";
1253         }
1254 
1255         //! open the selected marker configuration file
1256         FileStorage fs;
1257         fs.open(fileName.toUtf8().constData(), FileStorage::READ);
1258 
1259         //! copy the values to the respective variables
1260         fs["numberMarkers"] >> numberMarkers;
1261 
1262         //! inizialise vectors with correct length depending on the number of markers
1263         list_points3d = std::vector<Point3d>(numberMarkers);
1264         list_points2d = std::vector<Point2d>(numberMarkers);
1265         list_points2dOld = std::vector<Point2d>(numberMarkers);
1266         list_points2dDifference = std::vector<double>(numberMarkers);
1267         list_points2dProjected = std::vector<Point2d>(numberMarkers);
1268         list_points2dUnsorted = std::vector<Point2d>(numberMarkers);
1269 
1270         //! save the marker locations in the points3d vector
1271         fs["list_points3d"] >> list_points3d;
1272         fs.release();
1273         commObj.addLog("Loaded marker configuration from file:");
1274         commObj.addLog(fileName);
1275 
1276     }
1277 
1278     //! Print out the number of markers and their position to the GUI
1279     ss.str("");
1280     ss << "Number of Markers: " << numberMarkers << "\n";
1281     ss << "Marker 3D Points X,Y and Z [mm]: \n";
1282     for (int i = 0; i < numberMarkers; i++)
1283     {
1284         ss << "Marker " << i + 1 << ":\t" << list_points3d[i].x << "\t" << list_points3d[i].y << "\t" <<
    list_points3d[i].z << "\n";
1285     }
1286     commObj.addLog(QString::fromStdString(ss.str()));
1287 
1288     //! check if P3P algorithm can be enabled, it needs exactly 4 marker points to work
1289     if (numberMarkers == 4)
1290     {
1291         //! if P3P is possible, let the user choose which algorithm he wants but keep iterative active
1292         methodPNP = 0;
1293         commObj.enableP3P(true);
1294     }
1295     else
1296     {
1297         //! More (or less) marker than 4 loaded, P3P is not possible, hence user cant select P3P in GUI
1298         methodPNP = 0;
1299         commObj.enableP3P(false);
1300         commObj.addLog("P3P algorithm disabled, only works with 4 markers.");
1301     }
1302 
1303     //! now display the marker configuration in the camera view
1304     Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
1305 
1306     //! Set the camera pose parallel to the marker coordinate system
1307     Tvec.at<double>(0) = 0;
1308     Tvec.at<double>(1) = 0;
1309     Tvec.at<double>(2) = 4500;
1310     Rvec.at<double>(0) = 0 * 3.141592653589 / 180.0;
1311     Rvec.at<double>(1) = 0 * 3.141592653589 / 180.0;
1312     Rvec.at<double>(2) = -90. * 3.141592653589 / 180.0;
1313 
1314     projectPoints(list_points3d, Rvec, Tvec, cameraMatrix,
    distCoeffs, list_points2dProjected);
1315     for (int i = 0; i < numberMarkers; i++)
1316     {
1317         circle(cFrame, Point(list_points2dProjected[i].x, list_points2dProjected[i].y), 3, Scalar(255, 0, 0
    ), 3);
1318     }
1319 
1320     projectCoordinateFrame(cFrame);
1321     QPixmap QPFrame;
1322     QPFrame = Mat2QPixmap(cFrame);
1323     commObj.changeImage(QPFrame);
1324     QCoreApplication::processEvents();
1325 
1326 }
```

Here is the call graph for this function:



Here is the caller graph for this function:

main()

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

main initialises the GUI and values for the marker position etc
Both function arguments are not used. After initializing the QApplication and GUI the Rigid Track version and build date is added to the message log. In the next lines Tvec and Rvec are set to start values and the coordinate frame thats shown during tracking is created.After setting position, velocity and Euler angles to default values a heading offset of zero degrees is set. Then the calibrated camera pose, camera calibration and standard marker configuration are loaded.Finally the solvePnP algorithm is tested with test_Algorithm(). Now the programm is fully loaded and waits for events. First the GUI is set up with Signals and Slots, see Qt docu for how that works. Then some variables are initialized with arbitrary values. At last calibration and marker configuration etc. are loaded from xml files.

Parameters

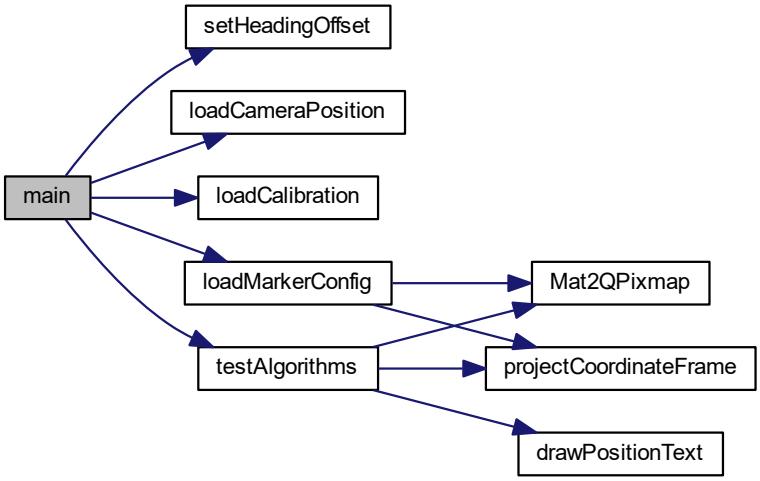
in	*argc*	is not used.
in	*argv*	is also not used.

Definition at line 165 of file main.cpp.

```
166 {
167     QApplication a(argc, argv);
168     RigidTrack w;
169     w.show();   //!< show the GUI
```

```
170     //! connect the Qt slots and signals for event handling
171     QObject::connect(&commObj, SIGNAL(statusChanged(QString)), &w, SLOT(setStatus(QString)),
    Qt::DirectConnection);
172     QObject::connect(&commObj, SIGNAL(imageChanged(QPixmap)), &w, SLOT(setImage(QPixmap)),
    Qt::DirectConnection);
173     QObject::connect(&commObj, SIGNAL(logAdded(QString)), &w, SLOT(setLog(QString)),
    Qt::DirectConnection);
174     QObject::connect(&commObj, SIGNAL(logCleared()), &w, SLOT(clearLog(QString)),
    Qt::DirectConnection);
175     QObject::connect(&commObj, SIGNAL(P3Penabled(bool)), &w, SLOT(enableP3P(bool)),
    Qt::DirectConnection);
176     QObject::connect(&commObj, SIGNAL(progressUpdated(int)), &w, SLOT(progressUpdate(int)),
    Qt::DirectConnection);
177
178     commObj.addLog("RigidTrack Version:");
179     commObj.addLog(QString::number(_MSC_FULL_VER));
180     commObj.addLog("Built on:");
181     commObj.addLog(QString(__DATE__));
182
183     //! initial guesses for position and rotation, important for Iterative Method!
184     Tvec.at<double>(0) = 45;
185     Tvec.at<double>(1) = 45;
186     Tvec.at<double>(2) = 4500;
187     Rvec.at<double>(0) = 0 * 3.141592653589 / 180.0;
188     Rvec.at<double>(1) = 0 * 3.141592653589 / 180.0;
189     Rvec.at<double>(2) = -45 * 3.141592653589 / 180.0;
190
191     //! Points that make up the marker CoSy axis system, hence one line in each axis direction
192     coordinateFrame = std::vector<Point3d>(4);
193     coordinateFrameProjected = std::vector<Point2d>(4);
194     coordinateFrame[0] = cv::Point3d(0, 0, 0);
195     coordinateFrame[1] = cv::Point3d(300, 0, 0);
196     coordinateFrame[2] = cv::Point3d(0, 300, 0);
197     coordinateFrame[3] = cv::Point3d(0, 0, 300);
198
199     position[0] = 1.1234;     //!< set position initial values
200     position[1] = 1.2345;     //!< set position initial values
201     position[2] = 1.3456;     //!< set position initial values
202
203     velocity[0] = 0.123;    //!< set velocity initial values
204     velocity[1] = 0.234;    //!< set velocity initial values
205     velocity[2] = 0.345;    //!< set velocity initial values
206
207     eulerAngles[0] = 1.002;  //!< set initial euler angles to arbitrary values for testing
208     eulerAngles[1] = 1.003;  //!< set initial euler angles to arbitrary values for testing
209     eulerAngles[2] = 1.004;  //!< set initial euler angles to arbitrary values for testing
210
211     setHeadingOffset(0.0); //!< set the heading offset to 0
212
213     ss.precision(4); //!< outputs in the log etc are limited to 3 decimal values
214
215     loadCameraPosition(); //!< load the rotation matrix from camera CoSy to ground CoSy
216     loadCalibration(0); //!< load the calibration file with the camera intrinsics
217     loadMarkerConfig(0); //!< load the standard marker configuration
218     testAlgorithms(); //!< test the algorithms and their accuracy
219
220     return a.exec();
221 }
```

Here is the call graph for this function:



Mat2QPixmap()

```
QPixmap Mat2QPixmap (
            cv::Mat src )
```

Convert an opencv matrix that represents a picture to a Qt Pixmap object for the GUI.

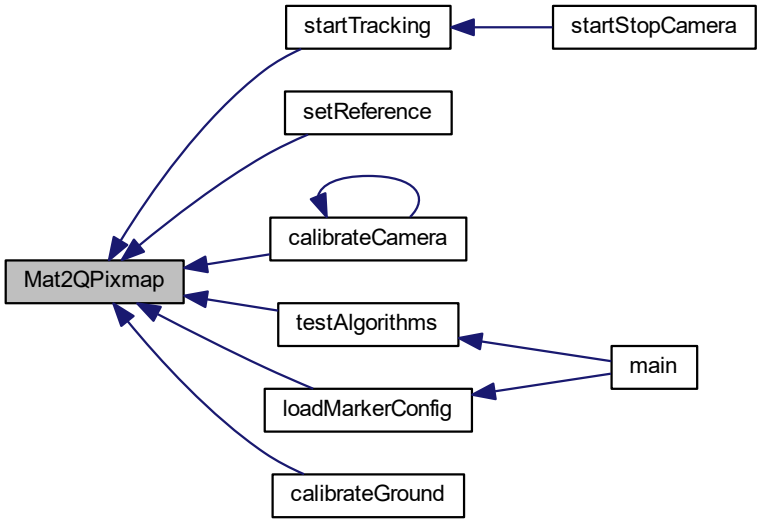
Parameters

in	*src*	is the camera image represented as OpenCV matrix.

Definition at line 225 of file main.cpp.

```
226 {
227     QImage dest((const uchar *)src.data, src.cols, src.rows, src.step, QImage::Format_RGB888);
228     dest.bits(); //! enforce deep copy, see documentation
229                  //! of QImage::QImage ( const uchar * data, int width, int height, Format format )
230     QPixmap pixmapDest = QPixmap::fromImage(dest);
231     return pixmapDest;
232 }
```

Here is the caller graph for this function:



projectCoordinateFrame()

```
void projectCoordinateFrame (
            Mat pictureFrame )
```

Project the coordinate CoSy origin and axis direction of the marker CoSy with the rotation and translation of the object for visualization.

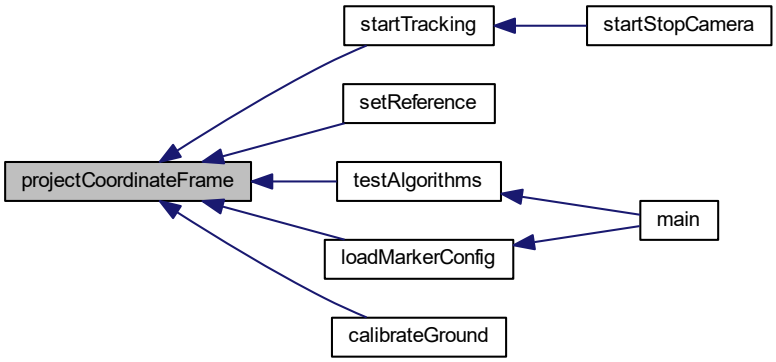
Parameters

in	*pictureFrame*	the image in which the CoSy frame should be pasted.

Definition at line 1099 of file main.cpp.

```
1100 {
1101     projectPoints(coordinateFrame, Rvec, Tvec,
      cameraMatrix, distCoeffs, coordinateFrameProjected);
1102     line(pictureFrame, coordinateFrameProjected[0],
      coordinateFrameProjected[3], Scalar(0, 0, 255), 2); //!<z-axis
1103     line(pictureFrame, coordinateFrameProjected[0],
      coordinateFrameProjected[1], Scalar(255, 0, 0), 2); //!<x-axis
1104     line(pictureFrame, coordinateFrameProjected[0],
      coordinateFrameProjected[2], Scalar(0, 255, 0), 2); //!<y-axis
1105 }
```

Here is the caller graph for this function:



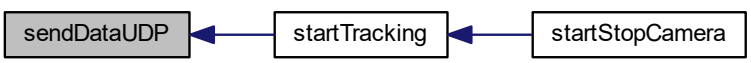
sendDataUDP()

```
void sendDataUDP (
                cv::Vec3d & Position,
                cv::Vec3d & Euler )
```

Send the position and attitude over UDP to every receiver, the safety receiver is handled on its own in the startTracking function because its send rate is less than 100 Hz.
Definition at line 1172 of file main.cpp.

```
1173 {
1174     datagram.clear();
1175     QDataStream out(&datagram, QIODevice::WriteOnly);
1176     out.setVersion(QDataStream::Qt_4_3);
1177     out << (float)Position[0] << (float)Position[1] << (float)Position[2];
1178     out << (float)Euler[0] << (float)Euler[1] << (float)Euler[2]; //! Roll Pitch Heading
1179     udpSocketObject->writeDatagram(datagram,
      IPAdressObject, portObject);
1180
1181     //! if second receiver is activated send it also the tracking data
1182     if (safety2Enable)
1183     {
1184         udpSocketSafety2->writeDatagram(datagram,
      IPAdressSafety2, portSafety2);
1185     }
1186
1187 }
```

Here is the caller graph for this function:



setHeadingOffset()

```
void setHeadingOffset (
              double d )
```

Add a heading offset to the attitude for the case it is wanted by the user.

Parameters

in	*d*	denotes heading offset in degrees.

Definition at line 1140 of file main.cpp.

```
1141 {
1142     headingOffset = d;
1143     d = d * 3.141592653589 / 180.0; //! Convert heading offset from degrees to rad
1144
1145     //! Calculate rotation about x axis
1146     Mat R_x = (Mat_<double>(3, 3) <<
1147         1, 0, 0,
1148         0, 1, 0,
1149         0, 0, 1
1150         );
1151
1152     //! Calculate rotation about y axis
1153     Mat R_y = (Mat_<double>(3, 3) <<
1154         1, 0, 0,
1155         0, 1, 0,
1156         0, 0, 1
1157         );
1158
1159     //! Calculate rotation about z axis
1160     Mat R_z = (Mat_<double>(3, 3) <<
1161         cos(d), -sin(d), 0,
1162         sin(d), cos(d), 0,
1163         0, 0, 1);
1164
1165
1166     //! Combined rotation matrix
1167     M_HeadingOffset = R_z * R_y * R_x;
1168 }
```

Here is the caller graph for this function:

setReference()

```
int setReference ( )
```

Determine the initial position of the object that serves as reference point or as ground frame origin. Computes the pose 200 times and then averages it. The position and attitude are from now on used as navigation CoSy.
Definition at line 613 of file main.cpp.

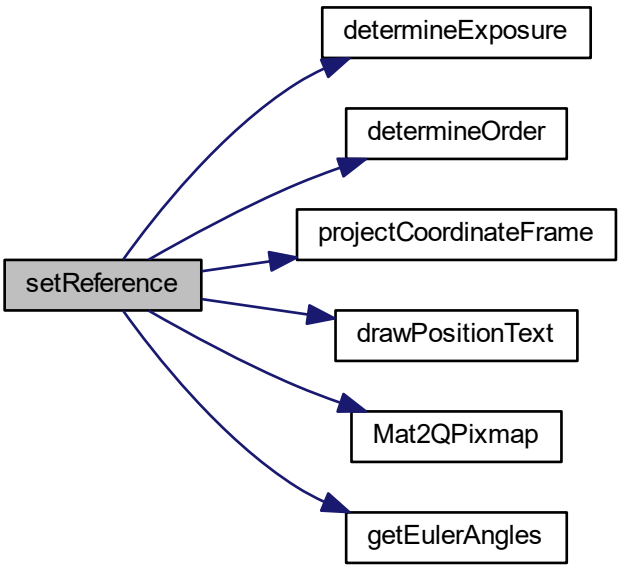
```
614 {
615     //! initialize the variables with starting values
```

```
616     gotOrder = false;
617     posRef = 0;
618     eulerRef = 0;
619     RmatRef = 0;
620     Rvec = RvecOriginal;
621     Tvec = TvecOriginal;
622 
623     determineExposure();
624 
625     ss.str("");
626     commObj.addLog("Started reference coordinate determination.");
627 
628     CameraLibrary_EnableDevelopment();
629     //! Initialize Camera SDK ==--
630     CameraLibrary::CameraManager::X();
631 
632     //! At this point the Camera SDK is actively looking for all connected cameras and will initialize
633     //! them on it's own.
634 
635     //! Get a connected camera ==================---
636     CameraManager::X().WaitForInitialization();
637     Camera *camera = CameraManager::X().GetCamera();
638 
639     //! If no device connected, pop a message box and exit ===-
640     if (camera == 0)
641     {
642         commObj.addLog("No camera found!");
643         return 1;
644     }
645 
646     //! Determine camera resolution to size application window ==----
647     int cameraWidth = camera->Width();
648     int cameraHeight = camera->Height();
649     camera->GetDistortionModel(distModel);
650     cv::Mat matFrame(cv::Size(cameraWidth, cameraHeight), CV_8UC1);
651 
652     //! Set camera mode to precision mode, it directly provides marker coordinates
653     camera->SetVideoType(Core::PrecisionMode);
654 
655     //! Start camera output ===-
656     camera->Start();
657 
658     //! Turn on some overlay text so it's clear things are     ===---
659     //! working even if there is nothing in the camera's view. ===---
660     //! Set some other parameters as well of the camera
661     camera->SetTextOverlay(true);
662     camera->SetFrameRate(intFrameRate);
663     camera->SetIntensity(intIntensity);
664     camera->SetIRFilter(true);
665     camera->SetContinuousIR(false);
666     camera->SetHighPowerMode(false);
667 
668     //! sample some frames and calculate the position and attitude. then average those values and use that
    as zero position
669     int numberSamples = 0;
670     int numberToSample = 200;
671     double projectionError = 0; //!< difference between the marker points as seen by the camera and the
    projected marker points with Rvec and Tvec
672 
673     while (numberSamples < numberToSample)
674     {
675         //! Fetch a new frame from the camera ===---
676         Frame *frame = camera->GetFrame();
677 
678         if (frame)
679         {
680             //! Ok, we've received a new frame, lets do something
681             //! with it.
682             if (frame->ObjectCount() == numberMarkers)
683             {
684                 //!for(int i=0; i<frame->ObjectCount(); i++)
685                 for (int i = 0; i < numberMarkers; i++)
686                 {
687                     cObject *obj = frame->Object(i);
688                     list_points2dUnsorted[i] = cv::Point2d(obj->X(), obj->Y());
689                 }
690 
691                 if (gotOrder == false)
692                 {
693                     determineOrder();
694                 }
695 
```

```
696                 //! sort the 2d points with the correct indices as found in the preceeding order
     determination algorithm
697                 for (int w = 0; w < numberMarkers; w++)
698                 {
699                     list_points2d[w] = list_points2dUnsorted[
    pointOrderIndices[w]];
700                 }
701                 list_points2dOld = list_points2dUnsorted;
702 
703                 //!Compute the pose from the 3D-2D corresponses
704                 solvePnP(list_points3d, list_points2d,
    cameraMatrix, distCoeffs, Rvec, Tvec, useGuess,
    methodPNP);
705 
706                 //! project the marker 3d points with the solution into the camera image CoSy and calculate
     difference to true camera image
707                 projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2dProjected);
708                 projectionError = norm(list_points2dProjected,
    list_points2d);
709 
710                 double maxValue = 0;
711                 double minValue = 0;
712                 minMaxLoc(Tvec.at<double>(2), &minValue, &maxValue);
713 
714                 if (maxValue > 10000 || minValue < 0)
715                 {
716                     ss.str("");
717                     ss << "Negative z distance, thats not possible. Start the set zero routine again or
     restart Programm.";
718                     commObj.addLog(QString::fromStdString(ss.str()));
719                     frame->Release();
720                     return 1;
721                 }
722 
723                 if (projectionError > 5)
724                 {
725                     commObj.addLog("Reprojection error is bigger than 5 pixel. Correct marker
     configuration loaded?\nMarker position measured precisely?");
726                     frame->Release();
727                     return 1;
728                 }
729 
730                 if (norm(positionOld) - norm(Tvec) < 0.05)   //!<Iterative Method needs time
     to converge to solution
731                 {
732                     add(posRef, Tvec, posRef);
733                     add(eulerRef, Rvec, eulerRef); //!< That are not the values of yaw,
     roll and pitch yet! Rodriguez has to be called first.
734                     numberSamples++;    //!<  one sample more :D
735                     commObj.progressUpdate(numberSamples * 100 / numberToSample);
736                 }
737                 positionOld = Tvec;
738 
739                 Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
740                 for (int i = 0; i < numberMarkers; i++)
741                 {
742                     circle(cFrame, Point(list_points2d[i].x,
    list_points2d[i].y), 6, Scalar(0, 225, 0), 3);
743                 }
744                 projectCoordinateFrame(cFrame);
745                 projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2d);
746                 for (int i = 0; i < numberMarkers; i++)
747                 {
748                     circle(cFrame, Point(list_points2d[i].x,
    list_points2d[i].y), 3, Scalar(225, 0, 0), 3);
749                 }
750                 drawPositionText(cFrame, position,
    eulerAngles, projectionError);
751 
752                 QPixmap QPFrame;
753                 QPFrame = Mat2QPixmap(cFrame);
754                 commObj.changeImage(QPFrame);
755                 QCoreApplication::processEvents();
756 
757             }
758             frame->Release();
759         }
760     }
761     //! Release camera ==--
762     camera->Release();
```

```
763
764     //!Divide by the number of samples to get the mean of the reference position
765     divide(posRef, numberToSample, posRef);
766     divide(eulerRef, numberToSample, eulerRef); //!< eulerRef is here in Axis Angle
        notation
767
768     Rodrigues(eulerRef, RmatRef);               //!< axis angle to rotation matrix
769     //!-- Euler Angles, finally
770     getEulerAngles(RmatRef, eulerRef); //!<  rotation matrix to euler
771     ss.str("");
772     ss << "RmatRef is:\n";
773     ss << RmatRef << "\n";
774     ss << "Reference Position is:\n";
775     ss << posRef << "[mm] \n";
776     ss << "Reference Euler Angles are:\n";
777     ss << eulerRef << "[deg] \n";
778
779     //! compute the difference between last obtained TVec and the average Value
780     //! When it is large the iterative method has not converged properly so it is advised to start the
        setReference() function once again
781     double error = norm(posRef) - norm(Tvec);
782     if (error > 5.0)
783     {
784         ss << "Caution, distance between reference position and last position is: " << error << "\n Start
        the set zero routine once again.";
785     }
786     commObj.addLog(QString::fromStdString(ss.str()));
787     commObj.progressUpdate(0);
788     return 0;
789 }
```

Here is the call graph for this function:



startTracking()

```
int startTracking ( )
```

Start the loop that fetches frames, computes the position etc and sends it to other computers. This function is the core of this program, hence the pose estimation is done here.
Definition at line 276 of file main.cpp.

```
276                     {
277
278
279     gotOrder = false; //! The order of points, hence which entry in list_points3d corresponds to
        which in list_points2d is not calculated yet
280     Rvec = RvecOriginal; //! Use the value of Rvec that was set in main() as starting value
        for the solvePnP algorithm
281     Tvec = TvecOriginal; //! Use the value of Tvec that was set in main() as starting value
        for the solvePnP algorithm
282     GetLocalTime(&logDate);  //! Get the current date and time to name the log file
283
284     //! Concat the log file name as followed. The file is saved in the folder /logs in the Rigid Track
        installation folder
285     logFileName = "./logs/positionLog_" + QString::number(logDate.wDay) + "_" +
    QString::number(logDate.wMonth) + "_" + QString::number(logDate.wYear);
286     logFileName += "_" + QString::number(logDate.wHour) + "_" + QString::number(
    logDate.wMinute) + "_" + QString::number(logDate.wSecond) + ".txt";
287     logName = logFileName.toStdString(); //! Convert the QString to a standard string
288
289     determineExposure(); //! Get the exposure where the right amount of markers is
        detected
290
291     //! For OptiTrack Ethernet cameras, it's important to enable development mode if you
292     //! want to stop execution for an extended time while debugging without disconnecting
293     //! the Ethernet devices.  Lets do that now:
294
295     CameraLibrary_EnableDevelopment();
296     CameraLibrary::CameraManager::X(); //! Initialize Camera SDK
297
298     //! At this point the Camera SDK is actively looking for all connected cameras and will initialize
299     //! them on it's own
300
301     //! Get a connected camera
302     CameraManager::X().WaitForInitialization();
303     Camera *camera = CameraManager::X().GetCamera();
304
305     //! If no camera can be found, inform user in message log and exit function
306     if (camera == 0)
307     {
308         commObj.addLog("No camera found!");
309         return 1;
310     }
311
312     //! Determine camera resolution to size application window
313     int cameraWidth = camera->Width();
314     int cameraHeight = camera->Height();
315
316     camera->SetVideoType(Core::PrecisionMode);  //! Set the camera mode to precision mode, it used
        greyscale imformation for marker property calculations
317
318     camera->Start(); //! Start camera output
319
320     //! Turn on some overlay text so it's clear things are
321     //! working even if there is nothing in the camera's view
322     camera->SetTextOverlay(true);
323     camera->SetExposure(intExposure);    //! Set the camera exposure
324     camera->SetIntensity(intIntensity); //! Set the camera infrared LED intensity
325     camera->SetFrameRate(intFrameRate); //! Set the camera framerate to 100 Hz
326     camera->SetIRFilter(true);  //! Enable the filter that blocks visible light and only passes infrared
        light
327     camera->SetHighPowerMode(true); //! Enable high power mode of the LEDs
328     camera->SetContinuousIR(false); //! Disable continuous LED light
329     camera->SetThreshold(intThreshold); //! Set threshold for marker detection
330
331     //! Create a new matrix that stores the grayscale picture from the camera
332     Mat matFrame = Mat::zeros(cv::Size(cameraWidth, cameraHeight), CV_8UC1);
333     QPixmap QPFrame; //! QPixmap is the corresponding Qt class that saves images
334     //! Matrix that stores the colored picture, hence marker points, coordinate frame and reprojected
        points
335     Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
336
337     int v = 0;  //! Helper variable used to kick safety switch
338     //! Variables for the min and max values that are needed for sanity checks
339     double maxValue = 0;
340     double minValue = 0;
341     int framesDropped = 0; //! Ff a marker is not visible or accuracy is bad increase this counter
342     double projectionError = 0; //! Equals the quality of the tracking
```

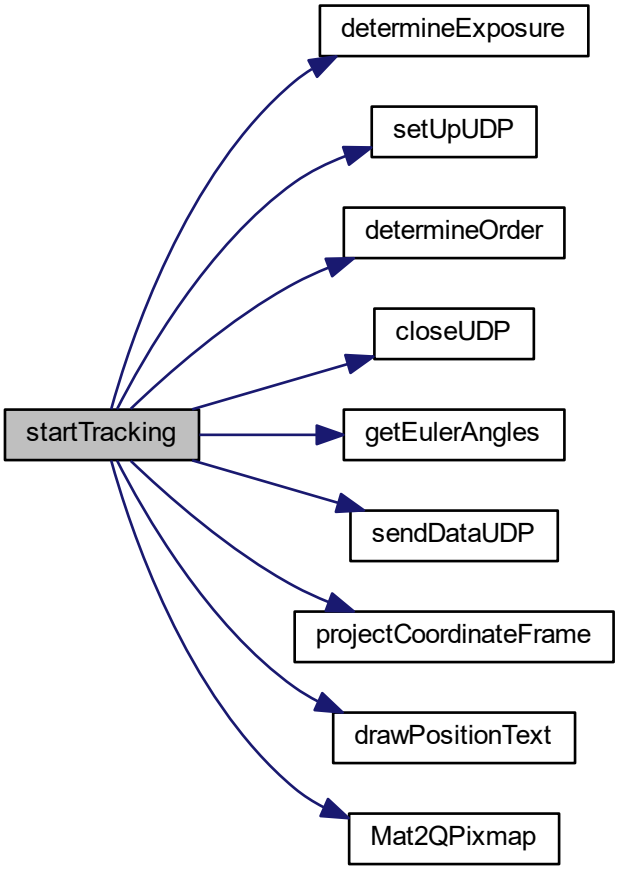
```
343
344     setUpUDP(); //! Open sockets and ports for UDP communication
345
346     if (safetyEnable) //! If the safety feature is enabled send the starting message
347     {
348         //! Send enable message, hence send a 9 and then a 1
349         data.setNum((int)(9));
350         udpSocketSafety->write(data);
351         data.setNum((int)(1));
352         udpSocketSafety->write(data);
353     }
354
355     //! Fetch a new frame from the camera
356     bool gotTime = false; //! Get the timestamp of the first frame. This time is subtracted from every
    subseeding frame so the time starts at 0 in the logs
357     while (!gotTime) //! While no new frame is received loop
358     {
359         Frame *frame = camera->GetFrame(); //! Get a new camera frame
360         if (frame)  //! There is actually a new frame
361         {
362             timeFirstFrame = frame->TimeStamp(); //! Get the time stamp for the first frame.
    It is subtracted for the following frames
363             frame->Release();   //! Release the frame so the camera can continue
364             gotTime = true; //! Exit the while loop
365         }
366     }
367
368     //! Now enter the main loop that processes each frame and computes the pose, sends it and logs stuff
369     while (!exitRequested) //! Check if the user has not pressed "Stop Tracking" yet
370     {
371
372         Frame *frame = camera->GetFrame(); //! Fetch a new frame from the camera
373
374         if (frame) //! Did we got a new frame or does the camera still need more time
375         {
376             framesDropped++; //! Increase by one, if everything is okay it is decreased at the end of the
    loop again
377
378             //! Only use this frame it the right number of markers is found in the picture
379             if (frame->ObjectCount() == numberMarkers)
380             {
381                 //! Get the marker points in 2D in the camera image frame and store them in the
    list_points2dUnsorted vector
382                 //! The order of points that come from the camera corresponds to the Y coordinate
383                 for (int i = 0; i < numberMarkers; i++)
384                 {
385                     cObject *obj = frame->Object(i);
386                     list_points2dUnsorted[i] = cv::Point2d(obj->X(), obj->Y());
387                 }
388
389                 if (gotOrder == false) //! Was the order already determined? This is false for the
    first frame and from then on true
390                 {
391                     determineOrder(); //! Now compute the order
392                 }
393
394                 //! Sort the 2d points with the correct indices as found in the preceeding order
    determination algorithm
395                 for (int w = 0; w < numberMarkers; w++)
396                 {
397                     list_points2d[w] = list_points2dUnsorted[
  pointOrderIndices[w]]; //! pointOrderIndices was calculated in determineOrder()
398                 }
399
400                 //! The first time the 2D-3D corresspondence was determined with gotOrder was okay.
401                 //! But this order can change as the object moves and the marker objects appear in a
402                 //! different order in the frame->Object() array.
403                 //! The solution is that: When a marker point (in the camera image, hence in 2D) was at
404                 //! a position then it wont move that much from one frame to the other.
405                 //! So for the new frame we take a marker object and check which marker was closest this
    point
406                 //! in the old image frame? This is probably the same (true) marker. And we do that for
    every other marker as well.
407                 //! When tracking is good and no frames are dropped because of missing markers this should
    work every frame.
408                 for (int j = 0; j < numberMarkers; j++)
409                 {
410                     minPointDistance = 5000; //! The sum of point distances is set to
    something unrealistic large
411                     for (int k = 0; k < numberMarkers; k++)
412                     {
413                         //! Calculate N_2 norm of unsorted points minus old points
```

```
414                         currentPointDistance = norm(
    list_points2dUnsorted[pointOrderIndices[j]] -
    list_points2dOld[k]);
415                         //! If the norm is smaller than minPointDistance the correspondence is more likely
     to be correct
416                         if (currentPointDistance <
    minPointDistance)
417                         {
418                             //! Update the array that saves the new point order
419                             minPointDistance =
    currentPointDistance;
420                             pointOrderIndicesNew[j] = k;
421                         }
422                     }
423                 }
424 
425                 //! Now the new order is found, set the point order to the new value
426                 for (int k = 0; k < numberMarkers; k++)
427                 {
428                     pointOrderIndices[k] = pointOrderIndicesNew[k];
429                     list_points2d[k] = list_points2dUnsorted[
    pointOrderIndices[k]];
430                 }
431 
432                 //! Save the unsorted position of the marker points for the next loop
433                 list_points2dOld = list_points2dUnsorted;
434 
435                 //!Compute the object pose from the 3D-2D corresponses
436                 solvePnP(list_points3d, list_points2d,
    cameraMatrix, distCoeffs, Rvec, Tvec, useGuess,
    methodPNP);
437 
438                 //! Project the marker 3d points with the solution into the camera image CoSy and calculate
     difference to true camera image
439                 projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2dProjected);
440                 projectionError = norm(list_points2dProjected,
    list_points2d); //! Difference of true pose and found pose
441 
442                 //! Increase the framesDropped variable if accuracy of tracking is too bad
443                 if (projectionError > 5)
444                 {
445                     framesDropped++;
446                 }
447                 else
448                 {
449                     framesDropped = 0;  //! Set number of subsequent frames dropped to zero because error
     is small enough and no marker was missing
450                 }
451 
452                 //! Get the min and max values from TVec for sanity check
453                 minMaxLoc(Tvec.at<double>(2), &minValue, &maxValue);
454 
455                 //! Sanity check of values. negative z means the marker CoSy is behind the camera, that's
     not possible.
456                 if (minValue < 0)
457                 {
458                     commObj.addLog("Negative z distance, that is not possible. Start the set zero
     routine again or restart Program.");
459                     frame->Release(); //! Release the frame so the camera can move on
460                     camera->Release(); //! Release the camera
461                     closeUDP(); //! Close all UDP connections so the programm can be closed later
     on and no resources are locked
462                     return 1; //! Exit the function
463                 }
464 
465                 //! Next step is the transformation from camera CoSy to navigation CoSy
466                 //! Compute the relative object position from the reference position to the current one
467                 //! given in the camera CoSy: \f$ T_C^{NM} = Tvec - Tvec_{Ref} \f$
468                 subtract(Tvec, posRef, position);
469 
470                 //! Transform the position from the camera CoSy to the navigation CoSy with INS alligned
     heading and convert from [mm] to [m]
471                 //! \f$ T_N^{NM} = M_{NC} \times T_C^{NM} \f$
472                 Mat V = 0.001 * M_HeadingOffset * M_CN.t() * (Mat)
    position;
473                 position = V;   //! Position is the result of the preceeding calculation
474                 position[2] *= invertZ;  //! Invert Z if check box in GUI is activated,
     hence height above ground is considered
475 
476                 //! Realtive angle between reference orientation and current orientation
477                 Rodrigues(Rvec, Rmat);  //! Convert axis angle respresentation to ordinary rotation
```

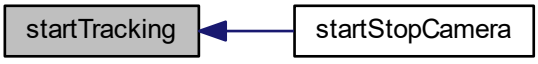
```
    matrix
478
479                 //! The difference of the reference rotation and the current rotation
480                 //! \f$ R_{ NM } = M_{ NC } \times R_{ CM } \f$
481                 Rmat = RmatRef.t() *Rmat;
482
483                 //! Euler Angles, finally
484                 getEulerAngles(Rmat, eulerAngles); //! Get the euler angles
    from the rotation matrix
485                 eulerAngles[2] += headingOffset; //! Add the heading offset to the
    heading angle
486
487                 //! Compute the velocity with finite differences. Only use is the log file. It is done here
    because the more precise time stamp can be used
488                 frameTime = frame->TimeStamp() - timeOld;   //! Time between the old frame
    and the current frame
489                 timeOld = frame->TimeStamp();    //! Set the old frame time to the current  one
490                 velocity[0] = (position[0] - positionOld[0]) /
    frameTime; //! Calculate the x velocity with finite differences
491                 velocity[1] = (position[1] - positionOld[1]) /
    frameTime; //! Calculate the y velocity with finite differences
492                 velocity[2] = (position[2] - positionOld[2]) /
    frameTime; //! Calculate the z velocity with finite differences
493                 positionOld = position;  //! Set the old position to the current one for
    next frame velocity calcuation
494
495                 eulerAngles[0] = eulerAngles[0] * -3.141592653589 / 180.0; //!
    Convert the Euler angles from degrees to rad
496                 eulerAngles[1] = eulerAngles[1] * -3.141592653589 / 180.0;
497                 eulerAngles[2] = eulerAngles[2] * 3.141592653589 / 180.0;
498
499                 //! Send position and Euler angles over WiFi with 100 Hz
500                 sendDataUDP(position, eulerAngles);
501
502                 //! Save the values in a log file, values are:
503                 //! Time sinc tracking started  Position    Euler Angles    Velocity
504                 logfile.open(logName, std::ios::app); //! Open the log file, the folder is
    RigidTrackInstallationFolder/logs
505                 logfile << frame->TimeStamp() - timeFirstFrame << ";" <<
    position[0] << ";" << position[1] << ";" << position[2] << ";";
506                 logfile << eulerAngles[0] << ";" <<
    eulerAngles[1] << ";" << eulerAngles[2] << ";";
507                 logfile << velocity[0] << ";" << velocity[1] << ";" <<
    velocity[2] << "\n";
508                 logfile.close(); //! Close the file to save values
509             }
510
511             //! Check if the position and euler angles are below the allowed value, if yes send OKAY signal
    (1), if not send shutdown signal (0)
512             //! Absolute x, y and z position in navigation CoSy must be smaller than the allowed distance
513             if (safetyEnable)
514             {
515                 if ((abs(position[0]) < safetyBoxLength && abs(position[1]) <
    safetyBoxLength && abs(position[2]) < safetyBoxLength))
516                 {
517                     //! Absolute Euler angles must be smaller than allowed value. Heading is not considered

518                     if ((abs(eulerAngles[0]) < safetyAngle && abs(eulerAngles[1]) <
    safetyAngle))
519                     {
520                         //! Send the OKAY signal to the desired computer every 5th time
521                         if (v == 5) {
522                             data.setNum((int)(1));
523                             udpSocketSafety->write(data); //! Send the 1
524                             v = 0; //! reset the counter that is needed for decimation to every 5th time
    step
525                         }
526                     }
527                     //! The euler angles of the object exceeded the allowed euler angles, send the shutdown
    signal (0)
528                     else
529                     {
530                         data.setNum((int)(0));  //! Send the shutdown signal, a 0
531                         udpSocketSafety->write(data);
532                         commObj.addLog("Object exceeded allowed Euler angles, shutdown signal sent."
    ); //! Inform the user
533
534                     }
535                 }
536                 //! The position of the object exceeded the allowed position, shut the object down
537                 else
538                 {
```

```
539                     data.setNum((int)(0));  //! Send the shutdown signal, a 0
540                     udpSocketSafety->write(data);
541                     commObj.addLog("Object left allowed area, shutdown signal sent."); //! Inform
     the user
542 
543                 }
544             }
545 
546             //! Inform the user if tracking system is disturbed (marker lost or so) or error was too big
547             if (framesDropped > 10)
548             {
549                 if (safetyEnable) //! Also send the shutdown signal
550                 {
551                     data.setNum((int)(0));  //! Send the shutdown signal, a 0
552                     udpSocketSafety->write(data);
553                 }
554                 commObj.addLog("Lost marker points or precision was bad!"); //! Inform the user
555                 framesDropped = 0;
556             }
557 
558             //! Rasterize the frame so it can be shown in the GUI
559             frame->Rasterize(cameraWidth, cameraHeight, matFrame.step,
    BACKBUFFER_BITSPERPIXEL, matFrame.data);
560 
561             //! Convert the frame from greyscale as it comes from the camera to rgb color
562             cvtColor(matFrame, cFrame, COLOR_GRAY2RGB);
563 
564             //! Project (draw) the marker CoSy origin into 2D and save it in the cFrame image
565             projectCoordinateFrame(cFrame);
566 
567             //! Project the marker points from 3D to the camera image frame (2d) with the computed pose
568             projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2d);
569             for (int i = 0; i < numberMarkers; i++)
570             {
571                 //! Draw a circle around the projected points so the result can be better compared to the
     real marker position
572                 //! In the resulting picture those are the red dots
573                 circle(cFrame, Point(list_points2d[i].x,
    list_points2d[i].y), 3, Scalar(225, 0, 0), 3);
574             }
575 
576             //! Write the current position, attitude and error values as text in the frame
577             drawPositionText(cFrame, position, eulerAngles, projectionError);
578 
579             //! Send the new camera picture to the GUI and call the GUI processing routine
580             QPixmap QPFrame;
581             QPFrame = Mat2QPixmap(cFrame);
582             commObj.changeImage(QPFrame); //! Update the picture in the GUI
583             QCoreApplication::processEvents(); //! Give Qt time to handle everything
584 
585             //! Release the camera frame to fetch the new one
586             frame->Release();
587         }
588     }
589 
590     //! User choose to stop the tracking, clean things up
591     closeUDP(); //! Close the UDP connections so resources are deallocated
592     camera->Release();  //! Release camera
593     return 0;
594 }
```

Here is the call graph for this function:



Here is the caller graph for this function:



testAlgorithms()

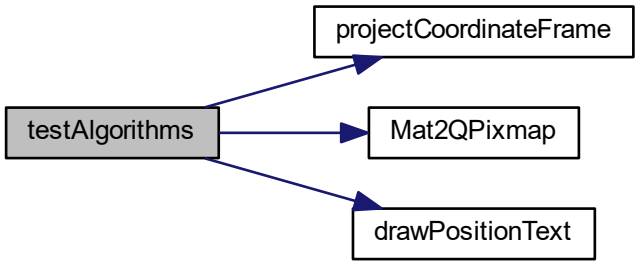
```
void testAlgorithms ( )
```

Project some points from 3D to 2D and then check the accuracy of the algorithms. Mainly to generate something that can be shown in the camera view so the user knows everything loaded correctly.
Definition at line 970 of file main.cpp.

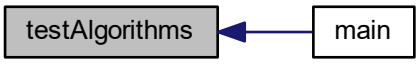
```
971 {
972
973     int _methodPNP;
974
975     std::vector<Point2d> noise(numberMarkers);
976
977     RvecOriginal = Rvec;
978     TvecOriginal = Tvec;
979
980     projectPoints(list_points3d, Rvec, Tvec, cameraMatrix,
    distCoeffs, list_points2dProjected);
981
982     ss.str("");
983     ss << "Unsorted Points 2D Projected \n";
984     ss << list_points2dProjected << "\n";
985     commObj.addLog(QString::fromStdString(ss.str()));
986
987     Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
988     for (int i = 0; i < numberMarkers; i++)
989     {
990         circle(cFrame, Point(list_points2dProjected[i].x, list_points2dProjected[i].y), 6, Scalar(0, 255, 0
    ), 3);
991     }
992
993     projectCoordinateFrame(cFrame);
994
995     ss.str("");
996     ss << "=====================================================\n";
997     ss << "================= Projected Points ==================\n";
998     ss << list_points2dProjected << "\n";
999
1000     randn(noise, 0, 0.5);
1001     add(list_points2dProjected, noise, list_points2dProjected);
1002
1003     ss << "================ With Noise Points ==================\n";
1004     ss << list_points2dProjected << "\n";
1005     commObj.addLog(QString::fromStdString(ss.str()));
1006
1007
1008     bool useGuess = true;
1009     _methodPNP = 0; //!< 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP  //!< not used
1010
1011     solvePnP(list_points3d, list_points2dProjected, cameraMatrix,
    distCoeffs, Rvec, Tvec, useGuess, _methodPNP);
1012
1013     ss.str("");
1014     ss << "=====================================================\n";
1015     ss << "==================== Iterative ======================\n";
1016     ss << "rvec: " << "\n";
1017     ss << Rvec << "\n";
1018     ss << "tvec: " << "\n";
1019     ss << Tvec << "\n";
1020
1021     commObj.addLog(QString::fromStdString(ss.str()));
1022
1023     _methodPNP = 1; //!< 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP UPnP not used
1024     Rvec = cv::Mat::zeros(3, 1, CV_64F);
1025     Tvec = cv::Mat::zeros(3, 1, CV_64F);
1026     solvePnP(list_points3d, list_points2dProjected, cameraMatrix,
    distCoeffs, Rvec, Tvec, useGuess, _methodPNP);
1027
1028     ss.str("");
1029     ss << "=====================================================\n";
1030     ss << "====================    EPNP    ====================\n";
1031     ss << "rvec: " << "\n";
1032     ss << Rvec << "\n";
1033     ss << "tvec: " << "\n";
1034     ss << Tvec << "\n";
1035
1036     projectPoints(list_points3d, Rvec, Tvec, cameraMatrix,
    distCoeffs, list_points2dProjected);
1037     for (int i = 0; i < numberMarkers; i++)
1038     {
1039         circle(cFrame, Point(list_points2dProjected[i].x, list_points2dProjected[i].y), 3, Scalar(255, 0, 0
    ), 3);
1040     }
1041     QPixmap QPFrame;
```

```
1042     QPFrame = Mat2QPixmap(cFrame);
1043     commObj.changeImage(QPFrame);
1044     QCoreApplication::processEvents();
1045     commObj.addLog(QString::fromStdString(ss.str()));
1046     if (numberMarkers == 4)
1047     {
1048         _methodPNP = 2; //!< 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP  //!< not used
1049         Rvec = cv::Mat::zeros(3, 1, CV_64F);
1050         Tvec = cv::Mat::zeros(3, 1, CV_64F);
1051         solvePnP(list_points3d, list_points2dProjected,
     cameraMatrix, distCoeffs, Rvec, Tvec, useGuess, _methodPNP);
1052
1053         ss.str("");
1054         ss << "=========================================================\n";
1055         ss << "====================     P3P    ====================\n";
1056         ss << "rvec: " << "\n";
1057         ss << Rvec << "\n";
1058         ss << "tvec: " << "\n";
1059         ss << Tvec << "\n";
1060
1061         projectPoints(list_points3d, Rvec, Tvec, cameraMatrix,
     distCoeffs, list_points2dProjected);
1062         for (int i = 0; i < numberMarkers; i++)
1063         {
1064             circle(cFrame, Point(list_points2dProjected[i].x, list_points2dProjected[i].y), 3, Scalar(255,
     0, 0), 3);
1065         }
1066         double projectionError = norm(list_points2dProjected, list_points2d);
1067         putText(cFrame, "Testing Algorithms Finished", cv::Point(5, 420), 1, 1, cv::Scalar(255, 255, 255));
1068         drawPositionText(cFrame, position, eulerAngles, projectionError)
     ;
1069
1070         QPixmap QPFrame;
1071         QPFrame = Mat2QPixmap(cFrame);
1072         commObj.changeImage(QPFrame);
1073         QCoreApplication::processEvents();
1074         commObj.addLog(QString::fromStdString(ss.str()));
1075     }
1076
1077     _methodPNP = 4; //!< 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP  //!< not used
1078     Rvec = cv::Mat::zeros(3, 1, CV_64F);
1079     Tvec = cv::Mat::zeros(3, 1, CV_64F);
1080     solvePnP(list_points3d, list_points2dProjected, cameraMatrix,
     distCoeffs, Rvec, Tvec, useGuess, _methodPNP);
1081
1082     ss.str("");
1083     ss << "=========================================================\n";
1084     ss << "====================    UPNP    ====================\n";
1085     ss << "rvec: " << "\n";
1086     ss << Rvec << "\n";
1087     ss << "tvec: " << "\n";
1088     ss << Tvec << "\n";
1089
1090     commObj.addLog(QString::fromStdString(ss.str()));
1091
1092     Rvec = RvecOriginal;
1093     Tvec = TvecOriginal;
1094
1095 }
```

Here is the call graph for this function:



Here is the caller graph for this function:



3.1.3 Variable Documentation

commObj

`commObject commObj`
class that handles the communication from main.cpp to the GUI
Now declare variables that are used across the main.cpp file. Basically almost every variable used is declared here.
Definition at line 68 of file main.cpp.

Rmat

`Mat Rmat = (cv::Mat_<double>(3, 1) << 0.0, 0.0, 0.0)`
Rotation, translation etc. matrix for PnP results.
rotation matrix from camera CoSy to marker CoSy
Definition at line 95 of file main.cpp.

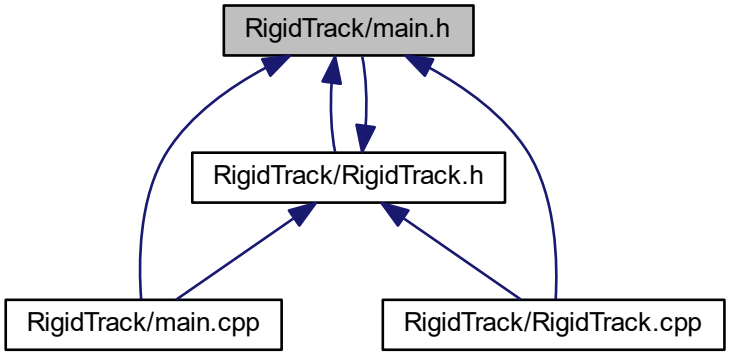
3.2 RigidTrack/main.h File Reference

Header file for main.cpp.

```
#include <fstream>
#include <windows.h>
#include <conio.h>
#include <tchar.h>
#include <stdio.h>
#include <iostream>
#include <stdarg.h>
#include <ctype.h>
#include <stdlib.h>
#include <gl/glu.h>
#include <sstream>
#include <thread>
#include <future>
#include <atomic>
#include "communication.h"
#include "RigidTrack.h"
#include <QtWidgets/QApplication>
#include <QUdpSocket>
#include "cameralibrary.h"
#include "modulevector.h"
#include "modulevectorprocessing.h"
#include "coremath.h"
#include <opencv\cv.h>
#include "opencv2\core.hpp"
#include "opencv2\calib3d.hpp"
#include <opencv2/imgproc/imgproc.hpp>
#include <opencv2/calib3d/calib3d.hpp>
#include <opencv2/highgui/highgui.hpp>
#include <opencv2\video\tracking.hpp>
```

Include dependency graph for main.h:

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



Functions

- int startTracking ()
- void startStopCamera ()

  Start or stop the tracking depending on if the camera is currently running or not.
- int setReference ()
- int calibrateCamera ()

  Start the camera calibration routine that computes the camera matrix and distortion coefficients.
- void loadCalibration (int method)
- void testAlgorithms ()
- void projectCoordinateFrame (Mat pictureFrame)
- void setUpUDP ()

  Open the UDP ports for communication.
- void setHeadingOffset (double d)
- void sendDataUDP (cv::Vec3d &Position, cv::Vec3d &Euler)
- void closeUDP ()
- void loadMarkerConfig (int method)
- void drawPositionText (cv::Mat &Picture, cv::Vec3d &Position, cv::Vec3d &Euler, double error)
- void loadCameraPosition ()
- int determineExposure ()
- void determineOrder ()
- int calibrateGround ()

Variables

- int methodPNP

  solvePNP algorithm 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP ///!< 4 and 1 are the same and not implemented correctly by OpenCV
- bool safetyEnable

  is the safety feature enabled

- bool safety2Enable
  is the second receiver enabled
- double safetyBoxLength
  length of the safety area cube in meters
- int safetyAngle
  bank and pitch angle protection in degrees
- QHostAddress IPAdressObject
  IPv4 adress of receiver 1.
- QHostAddress IPAdressSafety
  IPv4 adress of safety receiver.
- QHostAddress IPAdressSafety2
  IPv4 adress of receiver 2.
- int portObject
  Port of receiver 1.
- int portSafety
  Port of the safety receiver.
- int portSafety2
  Port of receiver 2.
- int invertZ
  dummy variable to invert Z direction on request
- commObject commObj
  class that handles the communication from main.cpp to the GUI

3.2.1 Detailed Description

Header file for main.cpp.

Author

Florian J.T. Wachter

Version

1.0

Date

April, 8th 2017

3.2.2 Function Documentation

calibrateGround()

```
int calibrateGround ( )
```

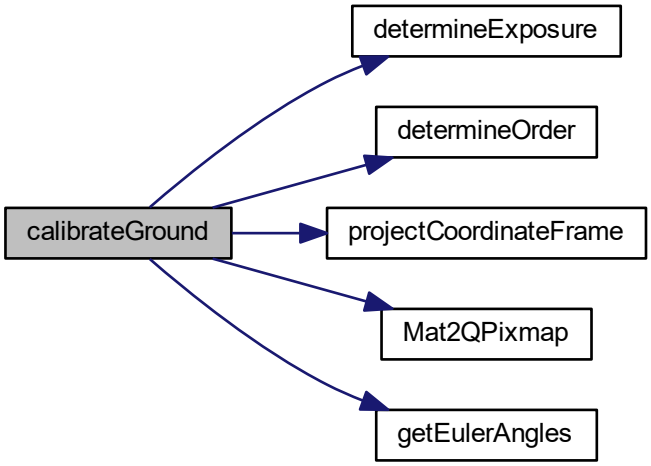
Get the pose of the camera w.r.t the ground calibration frame. This frame sets the navigation frame for later results. The pose is averaged over 200 samples and then saved in the file referenceData.xml. This routine is basically the same as setReference.
Definition at line 1581 of file main.cpp.

```
1582 {
1583     //! initialize the variables with starting values
1584     gotOrder = false;
1585     posRef = 0;
1586     eulerRef = 0;
1587     RmatRef = 0;
1588     Rvec = RvecOriginal;
1589     Tvec = TvecOriginal;
1590 
1591     determineExposure();
1592 
1593     ss.str("");
1594     commObj.addLog("Started ground calibration");
1595 
1596     CameraLibrary_EnableDevelopment();
1597     //! Initialize Camera SDK ==--
1598     CameraLibrary::CameraManager::X();
1599 
1600     //! At this point the Camera SDK is actively looking for all connected cameras and will initialize
1601     //! them on it's own.
1602 
1603     //! Get a connected camera ==================---
1604     CameraManager::X().WaitForInitialization();
1605     Camera *camera = CameraManager::X().GetCamera();
1606 
1607     //! If no device connected, pop a message box and exit ==--
1608     if (camera == 0)
1609     {
1610         commObj.addLog("No camera found!");
1611         return 1;
1612     }
1613 
1614     //! Determine camera resolution to size application window ==----
1615     int cameraWidth = camera->Width();
1616     int cameraHeight = camera->Height();
1617     camera->GetDistortionModel(distModel);
1618     cv::Mat matFrame(cv::Size(cameraWidth, cameraHeight), CV_8UC1);
1619 
1620     //! Set camera mode to precision mode, it directly provides marker coordinates
1621     camera->SetVideoType(Core::PrecisionMode);
1622 
1623     //! Start camera output ===--
1624     camera->Start();
1625 
1626     //! Turn on some overlay text so it's clear things are     ===---
1627     //! working even if there is nothing in the camera's view. ===---
1628     //! Set some other parameters as well of the camera
1629     camera->SetTextOverlay(true);
1630     camera->SetFrameRate(intFrameRate);
1631     camera->SetIntensity(intIntensity);
1632     camera->SetIRFilter(true);
1633     camera->SetContinuousIR(false);
1634     camera->SetHighPowerMode(false);
1635 
1636     //! sample some frames and calculate the position and attitude. then average those values and use that
    as zero position
1637     int numberSamples = 0;
1638     int numberToSample = 200;
1639     double projectionError = 0;
1640 
1641     while (numberSamples < numberToSample)
1642     {
1643         //! Fetch a new frame from the camera ===---
1644         Frame *frame = camera->GetFrame();
1645 
1646         if (frame)
1647         {
1648             //! Ok, we've received a new frame, lets do something
1649             //! with it.
1650             if (frame->ObjectCount() == numberMarkers)
1651             {
1652                 //!for(int i=0; i<frame->ObjectCount(); i++)
1653                 for (int i = 0; i < numberMarkers; i++)
1654                 {
1655                     cObject *obj = frame->Object(i);
1656                     list_points2dUnsorted[i] = cv::Point2d(obj->X(), obj->Y());
1657                 }
1658 
1659                 if (gotOrder == false)
1660                 {
1661                     determineOrder();
1662                 }
```

```
1663
1664                //! sort the 2d points with the correct indices as found in the preceeding order
     determination algorithm
1665                for (int w = 0; w < numberMarkers; w++)
1666                {
1667                    list_points2d[w] = list_points2dUnsorted[
    pointOrderIndices[w]];
1668                }
1669                list_points2dOld = list_points2dUnsorted;
1670
1671                //!Compute the pose from the 3D-2D corresponses
1672                solvePnP(list_points3d, list_points2d,
    cameraMatrix, distCoeffs, Rvec, Tvec, useGuess,
    methodPNP);
1673
1674                //! project the marker 3d points with the solution into the camera image CoSy and calculate
     difference to true camera image
1675                projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2dProjected);
1676                projectionError = norm(list_points2dProjected,
    list_points2d);
1677
1678                if (projectionError > 3)
1679                {
1680                    commObj.addLog("Reprojection error is bigger than 3 pixel. Correct marker
     configuration loaded?\nMarker position measured precisely?");
1681                    frame->Release();
1682                    return 1;
1683                }
1684
1685                double maxValue = 0;
1686                double minValue = 0;
1687                minMaxLoc(Tvec.at<double>(2), &minValue, &maxValue);
1688
1689                if (maxValue > 10000 || minValue < 0)
1690                {
1691
1692
1693                    commObj.addLog("Negative z distance, thats not possible. Start the set zero
     routine again and check marker configurations.");
1694                    frame->Release();
1695                    return 1;
1696                }
1697
1698                if (norm(positionOld) - norm(Tvec) < 0.05)   //!<Iterative Method needs time
     to converge to solution
1699                {
1700                    add(posRef, Tvec, posRef);
1701                    add(eulerRef, Rvec, eulerRef); //!< That are not the values of yaw,
     roll and pitch yet! Rodriguez has to be called first.
1702                    numberSamples++;    //!<-- one sample more :D
1703                    commObj.progressUpdate(numberSamples * 100 / numberToSample);
1704                }
1705                positionOld = Tvec;
1706
1707                Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
1708                for (int i = 0; i < numberMarkers; i++)
1709                {
1710                    circle(cFrame, Point(list_points2d[i].x,
    list_points2d[i].y), 6, Scalar(0, 225, 0), 3);
1711                }
1712                projectCoordinateFrame(cFrame);
1713                projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2d);
1714                for (int i = 0; i < numberMarkers; i++)
1715                {
1716                    circle(cFrame, Point(list_points2d[i].x,
    list_points2d[i].y), 3, Scalar(225, 0, 0), 3);
1717                }
1718
1719                QPixmap QPFrame;
1720                QPFrame = Mat2QPixmap(cFrame);
1721                commObj.changeImage(QPFrame);
1722                QCoreApplication::processEvents();
1723
1724            }
1725            frame->Release();
1726        }
1727    }
1728    //! Release camera ==--
1729    camera->Release();
1730
```

```
1731     //!Divide by the number of samples to get the mean of the reference position
1732     divide(posRef, numberToSample, posRef);
1733     divide(eulerRef, numberToSample, eulerRef); //!< eulerRef is here in Axis Angle
       notation
1734
1735     Rodrigues(eulerRef, RmatRef);               //!< axis angle to rotation matrix
1736
1737     getEulerAngles(RmatRef, eulerRef); //!<  rotation matrix to euler
1738     ss.str("");
1739     ss << "RmatRef is:\n";
1740     ss << RmatRef << "\n";
1741     ss << "Reference Position is:\n";
1742     ss << posRef << "[mm] \n";
1743     ss << "Reference Euler angles are:\n";
1744     ss << eulerRef << "[deg] \n";
1745
1746     //! Save the obtained calibration coefficients in a file for later use
1747     QString fileName = QFileDialog::getSaveFileName(nullptr, "Save ground calibration file", "
       referenceData.xml", "Calibration File (*.xml);;All Files (*)");
1748     FileStorage fs(fileName.toUtf8().constData(), FileStorage::WRITE);
1749     fs << "M_NC" << RmatRef;
1750     fs << "eulerRef" << eulerRef;
1751     strBuf = fs.releaseAndGetString();
1752     commObj.changeStatus(QString::fromStdString(strBuf));
1753     commObj.addLog("Saved ground calibration!");
1754     commObj.progressUpdate(0);
1755     return 0;
1756 }
```

Here is the call graph for this function:



closeUDP()

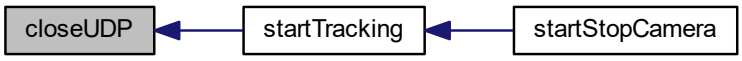
```
void closeUDP ( )
```

Close the UDP ports again to release network interfaces etc. If this is not done the network resources are still occupied and the program can't exit properly.
Definition at line 1191 of file main.cpp.

```
1192 {
1193     //! check if the socket is open and if yes close it
```

```
1194     if (udpSocketObject->isOpen())
1195     {
1196         udpSocketObject->close();
1197     }
1198
1199     if (udpSocketSafety->isOpen())
1200     {
1201         udpSocketSafety->close();
1202     }
1203
1204     if (udpSocketSafety2->isOpen())
1205     {
1206         udpSocketSafety2->close();
1207     }
1208     commObj.addLog("Closed all UDP ports.");
1209 }
```

Here is the caller graph for this function:



determineExposure()

```
int determineExposure ( )
```

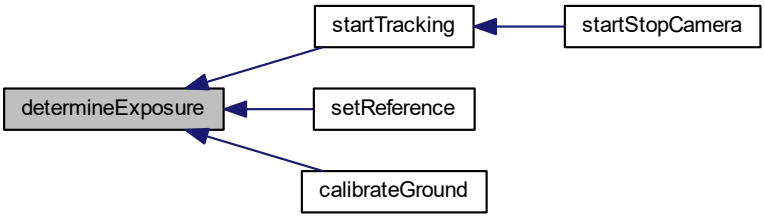
Get the optimal exposure for the camera. For that find the minimum and maximum exposure were the right number of markers are detected. Then the mean of those two values is used as exposure.
Definition at line 1380 of file main.cpp.

```
1381 {
1382     //! For OptiTrack Ethernet cameras, it's important to enable development mode if you
1383     //! want to stop execution for an extended time while debugging without disconnecting
1384     //! the Ethernet devices.  Lets do that now:
1385
1386     CameraLibrary_EnableDevelopment();
1387
1388     //! Initialize Camera SDK ==--
1389     CameraLibrary::CameraManager::X();
1390
1391     //! At this point the Camera SDK is actively looking for all connected cameras and will initialize
1392     //! them on it's own.
1393
1394     //! Get a connected camera ==================----
1395     CameraManager::X().WaitForInitialization();
1396     Camera *camera = CameraManager::X().GetCamera();
1397
1398     //! If no device connected, pop a message box and exit ==--
1399     if (camera == 0)
1400     {
1401         commObj.addLog("No camera found!");
1402         return 1;
1403     }
1404
1405     //! Determine camera resolution to size application window ==----
1406     int cameraWidth = camera->Width();
1407     int cameraHeight = camera->Height();
1408
1409     camera->SetVideoType(Core::PrecisionMode);  //! set the camera mode to precision mode, it used
     greyscale imformation for marker property calculations
1410
1411                                             //! Start camera output ==--
1412     camera->Start();
1413
```

```
1414    //! Turn on some overlay text so it's clear things are     ===---
1415    //! working even if there is nothing in the camera's view. ===---
1416    camera->SetTextOverlay(true);
1417    camera->SetExposure(intExposure);    //! set the camera exposure
1418    camera->SetIntensity(intIntensity); //! set the camera infrared LED intensity
1419    camera->SetFrameRate(intFrameRate); //! set the camera framerate to 100 Hz
1420    camera->SetIRFilter(true);  //! enable the filter that blocks visible light and only passes infrared
      light
1421    camera->SetHighPowerMode(true); //! enable high power mode of the leds
1422    camera->SetContinuousIR(false); //! enable continuous LED light
1423    camera->SetThreshold(intThreshold); //! set threshold for marker detection
1424
1425    //!set exposure such that num markers are visible
1426    int numberObjects = 0;  //! Number of objects (markers) found in the current picture with the given
      exposure
1427    int minExposure = 1;    //! exposure when objects detected the first time is numberMarkers
1428    int maxExposure = 480;  //! exposure when objects detected is first time numberMarkers+1
1429    intExposure = minExposure;   //! set the exposure to the smallest value possible
1430    int numberTries = 0;    //! if the markers arent found after numberTries then there might be no markers
      at all in the real world
1431
1432                            //! Determine minimum exposure, hence when are numberMarkers objects detected
1433    camera->SetExposure(intExposure);
1434    while (numberObjects != numberMarkers && numberTries < 48)
1435    {
1436        //! get a new camera frame
1437        Frame *frame = camera->GetFrame();
1438        if (frame) //! frame received
1439        {
1440            numberObjects = frame->ObjectCount();   //! how many objects are detected in the image
1441            if (numberObjects == numberMarkers) { minExposure =
      intExposure; frame->Release(); break; } //! if the right amount if markers is found, exit while
      loop
1442            //! not the right amount of markers was found so increase the exposure and try again
1443            numberTries++;
1444            intExposure += 10;
1445            camera->SetExposure(intExposure);
1446            ss.str("");
1447            ss << "Exposure: " << intExposure << "\t";
1448            ss << "Objects found: " << numberObjects;
1449            commObj.addLog(QString::fromStdString(ss.str()));
1450            frame->Release();
1451        }
1452    }
1453
1454    //! Now determine maximum exposure, hence when are numberMarkers+1 objects detected
1455    numberTries = 0;    //! if the markers arent found after numberTries then there might be no markers at
      all in the real world
1456    intExposure = maxExposure;
1457    camera->SetExposure(intExposure);
1458    numberObjects = 0;
1459    while (numberObjects != numberMarkers && numberTries < 48)
1460    {
1461        Frame *frame = camera->GetFrame();
1462        if (frame)
1463        {
1464            numberObjects = frame->ObjectCount(); //! how many objects are detected in the image
1465            if (numberObjects == numberMarkers) { maxExposure =
      intExposure; frame->Release(); break; } //! if the right amount if markers is found, exit while
      loop
1466
1467            //! not the right amount of markers was found so decrease the exposure and try again
1468            intExposure -= 10;
1469            numberTries++;
1470            camera->SetExposure(intExposure);
1471            ss.str("");
1472            ss << "Exposure: " << intExposure << "\t";
1473            ss << "Objects found: " << numberObjects;
1474            commObj.addLog(QString::fromStdString(ss.str()));
1475            frame->Release();
1476        }
1477    }
1478
1479    //! set the exposure to the mean of min and max exposure determined
1480    camera->SetExposure((minExposure + maxExposure) / 2.0);
1481
1482    //! and now check if the correct amount of markers is detected with that new value
1483    while (1)
1484    {
1485        Frame *frame = camera->GetFrame();
1486        if (frame)
1487        {
```

```
1488            numberObjects = frame->ObjectCount(); //! how many objects are detected in the image
1489            if (numberObjects != numberMarkers) //! are all markers and not more or less
    detected in the image
1490            {
1491                frame->Release();
1492                commObj.addLog("Was not able to detect the right amount of markers.");
1493                //! Release camera ===-
1494                camera->Release();
1495                return 1;
1496            }
1497            else  //! all markers and not more or less are found
1498            {
1499                frame->Release();
1500                intExposure = (minExposure + maxExposure) / 2.0;
1501                commObj.addLog("Found the correct number of markers.");
1502                commObj.addLog("Exposure set to:");
1503                commObj.addLog(QString::number(intExposure));
1504                break;
1505            }
1506        }
1507    }
1508
1509    camera->Release();
1510    return 0;
1511
1512 }
```

Here is the caller graph for this function:



determineOrder()

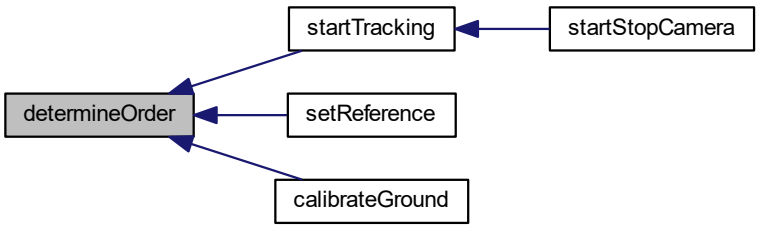
`void determineOrder ( )`

Compute the order of the marker points in 2D so they are the same as in the 3D array. Hence marker 1 must be in first place for both, list_points2d and list_points3d.
Definition at line 1516 of file main.cpp.

```
1517 {
1518     //! determine the 3D-2D correspondences that are crucial for the PnP algorithm
1519     //! Try every possible correspondence and solve PnP
1520     //! Then project the 3D marker points into the 2D camera image and check the difference
1521     //! between projected points and points as seen by the camera
1522     //! the corresponce with the smallest difference is probably the correct one
1523
1524         //! the difference between true 2D points and projected points is super big
1525     minPointDistance = 5000;
1526     std::sort(pointOrderIndices, pointOrderIndices + 4);
1527
1528     //! now try every possible permutation of correspondence
1529     do {
1530         //! reset the starting values for solvePnP
1531         Rvec = RvecOriginal;
1532         Tvec = TvecOriginal;
1533
1534         //! sort the 2d points with the current permutation
```

```
1535         for (int m = 0; m < numberMarkers; m++)
1536         {
1537             list_points2d[m] = list_points2dUnsorted[
     pointOrderIndices[m]];
1538         }
1539 
1540         //! Call solve PNP with P3P since its more robust and sufficient for start value determination
1541         solvePnP(list_points3d, list_points2d,
     cameraMatrix, distCoeffs, Rvec, Tvec, useGuess, SOLVEPNP_P3P);
1542 
1543         //! set the current difference of all point correspondences to zero
1544         currentPointDistance = 0;
1545 
1546         //! project the 3D points with the solvePnP solution onto 2D
1547         projectPoints(list_points3d, Rvec, Tvec,
     cameraMatrix, distCoeffs, list_points2dProjected);
1548 
1549         //! now compute the absolute difference (error)
1550         for (int n = 0; n < numberMarkers; n++)
1551         {
1552             currentPointDistance += norm(list_points2d[n] -
     list_points2dProjected[n]);
1553         }
1554 
1555         //! if the difference with the current permutation is smaller than the smallest value till now
1556         //! it is probably the more correct permutation
1557         if (currentPointDistance < minPointDistance)
1558         {
1559             minPointDistance = currentPointDistance;    //!< set the
      smallest value of difference to the current one
1560             for (int b = 0; b < numberMarkers; b++)    //!< now safe the better permutation
1561             {
1562                 pointOrderIndicesNew[b] = pointOrderIndices[b];
1563             }
1564         }
1565 
1566 
1567     }
1568     //! try every permutation
1569     while (std::next_permutation(pointOrderIndices,
     pointOrderIndices + 4));
1570 
1571     //! now that the correct order is found assign it to the indices array
1572     for (int w = 0; w < numberMarkers; w++)
1573     {
1574         pointOrderIndices[w] = pointOrderIndicesNew[w];
1575     }
1576     gotOrder = true;
1577 }
```

Here is the caller graph for this function:



drawPositionText()

```
void drawPositionText (
              cv::Mat & Picture,
              cv::Vec3d & Position,
              cv::Vec3d & Euler,
              double error )
```

Draw the position, attitude and reprojection error in the picture.

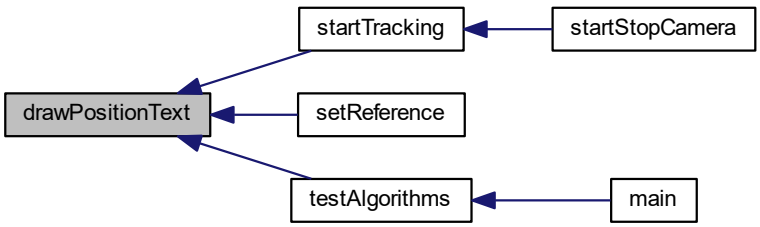
Parameters

in	*Picture*	is the camera image in OpenCV matrix format.
in	*Position*	is the position of the tracked object in navigation CoSy.
in	*Euler*	are the Euler angles with respect to the navigation frame.
in	*error*	is the reprojection error of the pose estimation.

Definition at line 1333 of file main.cpp.

```
1334 {
1335     ss.str("");
1336     ss << "X: " << Position[0] << " m";
1337     putText(Picture, ss.str(), cv::Point(200, 440), 1, 1, cv::Scalar(255, 255, 255));
1338
1339     ss.str("");
1340     ss << "Y: " << Position[1] << " m";
1341     putText(Picture, ss.str(), cv::Point(200, 455), 1, 1, cv::Scalar(255, 255, 255));
1342
1343     ss.str("");
1344     ss << "Z: " << Position[2] << " m";
1345     putText(Picture, ss.str(), cv::Point(200, 470), 1, 1, cv::Scalar(255, 255, 255));
1346
1347     ss.str("");
1348     ss << "Heading: " << Euler[2]*180/3.1415 << " deg";
1349     putText(Picture, ss.str(), cv::Point(350, 440), 1, 1, cv::Scalar(255, 255, 255));
1350
1351     ss.str("");
1352     ss << "Pitch: " << Euler[1] * 180 / 3.1415 << " deg";
1353     putText(Picture, ss.str(), cv::Point(350, 455), 1, 1, cv::Scalar(255, 255, 255));
1354
1355     ss.str("");
1356     ss << "Roll: " << Euler[0] * 180 / 3.1415 << " deg";
1357     putText(Picture, ss.str(), cv::Point(350, 470), 1, 1, cv::Scalar(255, 255, 255));
1358
1359     ss.str("");
1360     ss << "Error: " << error << " px";
1361     putText(Picture, ss.str(), cv::Point(10, 470), 1, 1, cv::Scalar(255, 255, 255));
1362 }
```

Here is the caller graph for this function:



loadCalibration()

```
void loadCalibration (
            int method )
```

Load a previously saved camera calibration from a file.

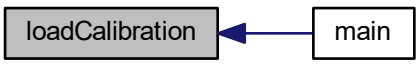
Parameters

in	*method*	whether or not load the camera calibration from calibration.xml. If ==0 then yes, if != 0 then let the user select a different file.

Definition at line 941 of file main.cpp.

```
941                                 {
942
943     QString fileName;
944     if (method == 0)
945     {
946         fileName = "calibration.xml";
947     }
948     else
949     {
950         fileName = QFileDialog::getOpenFileName(nullptr, "Choose a previous saved calibration file", "", "
      Calibration Files (*.xml);;All Files (*)");
951         if (fileName.length() == 0)
952         {
953             fileName = "calibration.xml";
954         }
955     }
956     FileStorage fs;
957     fs.open(fileName.toUtf8().constData(), FileStorage::READ);
958     fs["CameraMatrix"] >> cameraMatrix;
959     fs["DistCoeff"] >> distCoeffs;
960     commObj.addLog("Loaded calibration from file:");
961     commObj.addLog(fileName);
962     ss.str("");
963     ss << "\nCamera Matrix is" << "\n" << cameraMatrix << "\n";
964     ss << "\nDistortion Coefficients are" << "\n" << distCoeffs << "\n";
965     commObj.addLog(QString::fromStdString(ss.str()));
966 }
```

Here is the caller graph for this function:



loadCameraPosition()

```
void loadCameraPosition ( )
```

Load the rotation matrix from camera CoSy to ground CoSy It is determined during calibrateGround() and stays the same once the camera is mounted and fixed.
Definition at line 1366 of file main.cpp.

```
1367 {
1368     //! Open the referenceData.xml that contains the rotation from camera CoSy to ground CoSy
1369     FileStorage fs;
```

```
1370     fs.open("referenceData.xml", FileStorage::READ);
1371     fs["M_NC"] >> M_CN;
1372     fs["M_NC"] >> RmatRef;
1373     fs["posRef"] >> posRef;
1374     fs["eulerRef"] >> eulerRef;
1375     commObj.addLog("Loaded reference pose.");
1376 }
```

Here is the caller graph for this function:

loadMarkerConfig()

```
void loadMarkerConfig (
                int method )
```

Load a marker configuration from file. This file has to be created by hand, use the standard marker configuration file as template.

Parameters

in	*method*	whether or not load the configuration from the markerStandard.xml. If ==0 load it, if != 0 let the user select a different file.

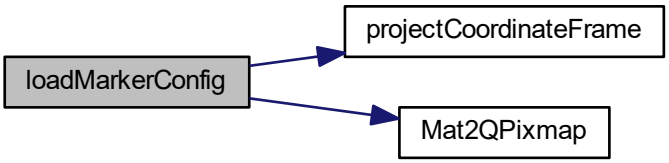
Definition at line 1213 of file main.cpp.

```
1214 {
1215     QString fileName;
1216     //! during start up of the programm load the standard marker configuration
1217     if (method == 0)
1218     {
1219         //! open the standard marker configuration file
1220         FileStorage fs;
1221         fs.open("markerStandard.xml", FileStorage::READ);
1222 
1223         //! copy the values to the respective variables
1224         fs["numberMarkers"] >> numberMarkers;
1225 
1226         //! inizialise vectors with correct length depending on the number of markers
1227         list_points3d = std::vector<Point3d>(numberMarkers);
1228         list_points2d = std::vector<Point2d>(numberMarkers);
1229         list_points2dOld = std::vector<Point2d>(numberMarkers);
1230         list_points2dDifference = std::vector<double>(
     numberMarkers);
1231         list_points2dProjected = std::vector<Point2d>(
     numberMarkers);
1232         list_points2dUnsorted = std::vector<Point2d>(
     numberMarkers);
1233 
1234         //! save the marker locations in the points3d vector
1235         fs["list_points3d"] >> list_points3d;
1236         fs.release();
1237         commObj.addLog("Loaded marker configuration from file:");
1238         commObj.addLog(fileName);
1239 
1240 
1241 
```

```
1242     }
1243     else
1244     {
1245         //! if the load marker configuration button was clicked show a open file dialog
1246         fileName = QFileDialog::getOpenFileName(nullptr, "Choose a previous saved marker configuration file
      ", "", "marker configuratio files (*.xml);;All Files (*)");
1247 
1248         //! was cancel or abort clicked
1249         if (fileName.length() == 0)
1250         {
1251             //! if yes load the standard marker configuration
1252             fileName = "markerStandard.xml";
1253         }
1254 
1255         //! open the selected marker configuration file
1256         FileStorage fs;
1257         fs.open(fileName.toUtf8().constData(), FileStorage::READ);
1258 
1259         //! copy the values to the respective variables
1260         fs["numberMarkers"] >> numberMarkers;
1261 
1262         //! inizialise vectors with correct length depending on the number of markers
1263         list_points3d = std::vector<Point3d>(numberMarkers);
1264         list_points2d = std::vector<Point2d>(numberMarkers);
1265         list_points2dOld = std::vector<Point2d>(numberMarkers);
1266         list_points2dDifference = std::vector<double>(numberMarkers);
1267         list_points2dProjected = std::vector<Point2d>(numberMarkers);
1268         list_points2dUnsorted = std::vector<Point2d>(numberMarkers);
1269 
1270         //! save the marker locations in the points3d vector
1271         fs["list_points3d"] >> list_points3d;
1272         fs.release();
1273         commObj.addLog("Loaded marker configuration from file:");
1274         commObj.addLog(fileName);
1275 
1276     }
1277 
1278     //! Print out the number of markers and their position to the GUI
1279     ss.str("");
1280     ss << "Number of Markers: " << numberMarkers << "\n";
1281     ss << "Marker 3D Points X,Y and Z [mm]: \n";
1282     for (int i = 0; i < numberMarkers; i++)
1283     {
1284         ss << "Marker " << i + 1 << ":\t" << list_points3d[i].x << "\t" << list_points3d[i].y << "\t" <<
      list_points3d[i].z << "\n";
1285     }
1286     commObj.addLog(QString::fromStdString(ss.str()));
1287 
1288     //! check if P3P algorithm can be enabled, it needs exactly 4 marker points to work
1289     if (numberMarkers == 4)
1290     {
1291         //! if P3P is possible, let the user choose which algorithm he wants but keep iterative active
1292         methodPNP = 0;
1293         commObj.enableP3P(true);
1294     }
1295     else
1296     {
1297         //! More (or less) marker than 4 loaded, P3P is not possible, hence user cant select P3P in GUI
1298         methodPNP = 0;
1299         commObj.enableP3P(false);
1300         commObj.addLog("P3P algorithm disabled, only works with 4 markers.");
1301     }
1302 
1303     //! now display the marker configuration in the camera view
1304     Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
1305 
1306     //! Set the camera pose parallel to the marker coordinate system
1307     Tvec.at<double>(0) = 0;
1308     Tvec.at<double>(1) = 0;
1309     Tvec.at<double>(2) = 4500;
1310     Rvec.at<double>(0) = 0 * 3.141592653589 / 180.0;
1311     Rvec.at<double>(1) = 0 * 3.141592653589 / 180.0;
1312     Rvec.at<double>(2) = -90. * 3.141592653589 / 180.0;
1313 
1314     projectPoints(list_points3d, Rvec, Tvec, cameraMatrix,
      distCoeffs, list_points2dProjected);
1315     for (int i = 0; i < numberMarkers; i++)
1316     {
1317         circle(cFrame, Point(list_points2dProjected[i].x, list_points2dProjected[i].y), 3, Scalar(255, 0, 0
      ), 3);
1318     }
1319 
```

```
1320     projectCoordinateFrame(cFrame);
1321     QPixmap QPFrame;
1322     QPFrame = Mat2QPixmap(cFrame);
1323     commObj.changeImage(QPFrame);
1324     QCoreApplication::processEvents();
1325
1326 }
```

Here is the call graph for this function:



Here is the caller graph for this function:

projectCoordinateFrame()

```
void projectCoordinateFrame (
              Mat pictureFrame )
```

Project the coordinate CoSy origin and axis direction of the marker CoSy with the rotation and translation of the object for visualization.

Parameters

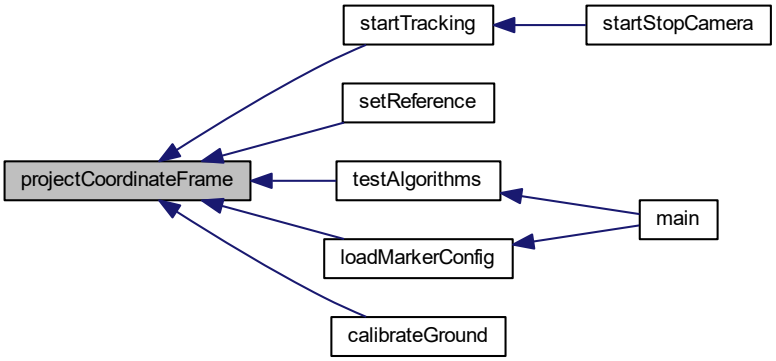
in	*pictureFrame*	the image in which the CoSy frame should be pasted.

Definition at line 1099 of file main.cpp.

```
1100 {
1101     projectPoints(coordinateFrame, Rvec, Tvec,
      cameraMatrix, distCoeffs, coordinateFrameProjected);
1102     line(pictureFrame, coordinateFrameProjected[0],
      coordinateFrameProjected[3], Scalar(0, 0, 255), 2); //!<z-axis
1103     line(pictureFrame, coordinateFrameProjected[0],
      coordinateFrameProjected[1], Scalar(255, 0, 0), 2); //!<x-axis
1104     line(pictureFrame, coordinateFrameProjected[0],
      coordinateFrameProjected[2], Scalar(0, 255, 0), 2); //!<y-axis
```

```
1105 }
```

Here is the caller graph for this function:



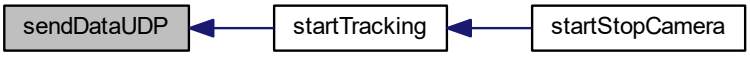
sendDataUDP()

```
void sendDataUDP (
                cv::Vec3d & Position,
                cv::Vec3d & Euler )
```

Send the position and attitude over UDP to every receiver, the safety receiver is handled on its own in the startTracking function because its send rate is less than 100 Hz.
Definition at line 1172 of file main.cpp.

```
1173 {
1174     datagram.clear();
1175     QDataStream out(&datagram, QIODevice::WriteOnly);
1176     out.setVersion(QDataStream::Qt_4_3);
1177     out << (float)Position[0] << (float)Position[1] << (float)Position[2];
1178     out << (float)Euler[0] << (float)Euler[1] << (float)Euler[2]; //! Roll Pitch Heading
1179     udpSocketObject->writeDatagram(datagram,
      IPAdressObject, portObject);
1180
1181     //! if second receiver is activated send it also the tracking data
1182     if (safety2Enable)
1183     {
1184         udpSocketSafety2->writeDatagram(datagram,
      IPAdressSafety2, portSafety2);
1185     }
1186
1187 }
```

Here is the caller graph for this function:



setHeadingOffset()

```
void setHeadingOffset (
                double d )
```

Add a heading offset to the attitude for the case it is wanted by the user.

Parameters

in	*d*	denotes heading offset in degrees.

Definition at line 1140 of file main.cpp.

```
1141 {
1142     headingOffset = d;
1143     d = d * 3.141592653589 / 180.0; //! Convert heading offset from degrees to rad
1144
1145     //! Calculate rotation about x axis
1146     Mat R_x = (Mat_<double>(3, 3) <<
1147         1, 0, 0,
1148         0, 1, 0,
1149         0, 0, 1
1150         );
1151
1152     //! Calculate rotation about y axis
1153     Mat R_y = (Mat_<double>(3, 3) <<
1154         1, 0, 0,
1155         0, 1, 0,
1156         0, 0, 1
1157         );
1158
1159     //! Calculate rotation about z axis
1160     Mat R_z = (Mat_<double>(3, 3) <<
1161         cos(d), -sin(d), 0,
1162         sin(d), cos(d), 0,
1163         0, 0, 1);
1164
1165
1166     //! Combined rotation matrix
1167     M_HeadingOffset = R_z * R_y * R_x;
1168 }
```

Here is the caller graph for this function:

setReference()

```
int setReference ( )
```

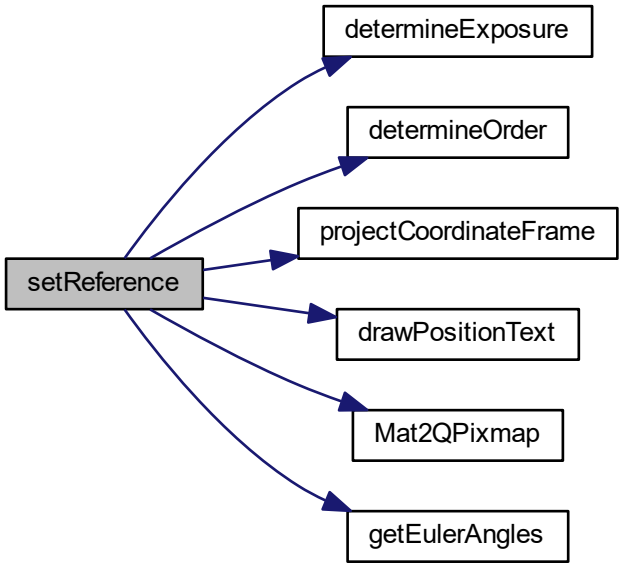
Determine the initial position of the object that serves as reference point or as ground frame origin. Computes the pose 200 times and then averages it. The position and attitude are from now on used as navigation CoSy.
Definition at line 613 of file main.cpp.

```
614 {
615     //! initialize the variables with starting values
616     gotOrder = false;
617     posRef = 0;
618     eulerRef = 0;
619     RmatRef = 0;
620     Rvec = RvecOriginal;
621     Tvec = TvecOriginal;
622 
623     determineExposure();
624 
625     ss.str("");
626     commObj.addLog("Started reference coordinate determination.");
627 
628     CameraLibrary_EnableDevelopment();
629     //! Initialize Camera SDK ==--
630     CameraLibrary::CameraManager::X();
631 
632     //! At this point the Camera SDK is actively looking for all connected cameras and will initialize
633     //! them on it's own.
634 
635     //! Get a connected camera =================----
636     CameraManager::X().WaitForInitialization();
637     Camera *camera = CameraManager::X().GetCamera();
638 
639     //! If no device connected, pop a message box and exit ===-
640     if (camera == 0)
641     {
642         commObj.addLog("No camera found!");
643         return 1;
644     }
645 
646     //! Determine camera resolution to size application window ======
647     int cameraWidth = camera->Width();
648     int cameraHeight = camera->Height();
649     camera->GetDistortionModel(distModel);
650     cv::Mat matFrame(cv::Size(cameraWidth, cameraHeight), CV_8UC1);
651 
652     //! Set camera mode to precision mode, it directly provides marker coordinates
653     camera->SetVideoType(Core::PrecisionMode);
654 
655     //! Start camera output ==--
656     camera->Start();
657 
658     //! Turn on some overlay text so it's clear things are     ===---
659     //! working even if there is nothing in the camera's view. ===---
660     //! Set some other parameters as well of the camera
661     camera->SetTextOverlay(true);
662     camera->SetFrameRate(intFrameRate);
663     camera->SetIntensity(intIntensity);
664     camera->SetIRFilter(true);
665     camera->SetContinuousIR(false);
666     camera->SetHighPowerMode(false);
667 
668     //! sample some frames and calculate the position and attitude. then average those values and use that
    as zero position
669     int numberSamples = 0;
670     int numberToSample = 200;
671     double projectionError = 0; //!< difference between the marker points as seen by the camera and the
    projected marker points with Rvec and Tvec
672 
673     while (numberSamples < numberToSample)
674     {
675         //! Fetch a new frame from the camera ===---
676         Frame *frame = camera->GetFrame();
677 
678         if (frame)
679         {
680             //! Ok, we've received a new frame, lets do something
681             //! with it.
682             if (frame->ObjectCount() == numberMarkers)
683             {
684                 //!for(int i=0; i<frame->ObjectCount(); i++)
685                 for (int i = 0; i < numberMarkers; i++)
686                 {
687                     cObject *obj = frame->Object(i);
688                     list_points2dUnsorted[i] = cv::Point2d(obj->X(), obj->Y());
689                 }
690 
691                 if (gotOrder == false)
692                 {
693                     determineOrder();
```

```
694                 }
695
696                 //! sort the 2d points with the correct indices as found in the preceeding order
     determination algorithm
697                 for (int w = 0; w < numberMarkers; w++)
698                 {
699                     list_points2d[w] = list_points2dUnsorted[
    pointOrderIndices[w]];
700                 }
701                 list_points2dOld = list_points2dUnsorted;
702
703                 //!Compute the pose from the 3D-2D corresponses
704                 solvePnP(list_points3d, list_points2d,
    cameraMatrix, distCoeffs, Rvec, Tvec, useGuess,
    methodPNP);
705
706                 //! project the marker 3d points with the solution into the camera image CoSy and calculate
     difference to true camera image
707                 projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2dProjected);
708                 projectionError = norm(list_points2dProjected,
    list_points2d);
709
710                 double maxValue = 0;
711                 double minValue = 0;
712                 minMaxLoc(Tvec.at<double>(2), &minValue, &maxValue);
713
714                 if (maxValue > 10000 || minValue < 0)
715                 {
716                     ss.str("");
717                     ss << "Negative z distance, thats not possible. Start the set zero routine again or
     restart Programm.";
718                     commObj.addLog(QString::fromStdString(ss.str()));
719                     frame->Release();
720                     return 1;
721                 }
722
723                 if (projectionError > 5)
724                 {
725                     commObj.addLog("Reprojection error is bigger than 5 pixel. Correct marker
     configuration loaded?\nMarker position measured precisely?");
726                     frame->Release();
727                     return 1;
728                 }
729
730                 if (norm(positionOld) - norm(Tvec) < 0.05)   //!<Iterative Method needs time
     to converge to solution
731                 {
732                     add(posRef, Tvec, posRef);
733                     add(eulerRef, Rvec, eulerRef); //!< That are not the values of yaw,
     roll and pitch yet! Rodriguez has to be called first.
734                     numberSamples++;    //!<  one sample more :D
735                     commObj.progressUpdate(numberSamples * 100 / numberToSample);
736                 }
737                 positionOld = Tvec;
738
739                 Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
740                 for (int i = 0; i < numberMarkers; i++)
741                 {
742                     circle(cFrame, Point(list_points2d[i].x,
    list_points2d[i].y), 6, Scalar(0, 225, 0), 3);
743                 }
744                 projectCoordinateFrame(cFrame);
745                 projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2d);
746                 for (int i = 0; i < numberMarkers; i++)
747                 {
748                     circle(cFrame, Point(list_points2d[i].x,
    list_points2d[i].y), 3, Scalar(225, 0, 0), 3);
749                 }
750                 drawPositionText(cFrame, position,
    eulerAngles, projectionError);
751
752                 QPixmap QPFrame;
753                 QPFrame = Mat2QPixmap(cFrame);
754                 commObj.changeImage(QPFrame);
755                 QCoreApplication::processEvents();
756
757             }
758             frame->Release();
759         }
760     }
```

```
761     //! Release camera ==--
762     camera->Release();
763 
764     //!Divide by the number of samples to get the mean of the reference position
765     divide(posRef, numberToSample, posRef);
766     divide(eulerRef, numberToSample, eulerRef); //!< eulerRef is here in Axis Angle
        notation
767 
768     Rodrigues(eulerRef, RmatRef);               //!< axis angle to rotation matrix
769     //!-- Euler Angles, finally
770     getEulerAngles(RmatRef, eulerRef); //!<  rotation matrix to euler
771     ss.str("");
772     ss << "RmatRef is:\n";
773     ss << RmatRef << "\n";
774     ss << "Reference Position is:\n";
775     ss << posRef << "[mm] \n";
776     ss << "Reference Euler Angles are:\n";
777     ss << eulerRef << "[deg] \n";
778 
779     //! compute the difference between last obtained TVec and the average Value
780     //! When it is large the iterative method has not converged properly so it is advised to start the
        setReference() function once again
781     double error = norm(posRef) - norm(Tvec);
782     if (error > 5.0)
783     {
784         ss << "Caution, distance between reference position and last position is: " << error << "\n Start
        the set zero routine once again.";
785     }
786     commObj.addLog(QString::fromStdString(ss.str()));
787     commObj.progressUpdate(0);
788     return 0;
789 }
```

Here is the call graph for this function:



startTracking()

```
int startTracking ( )
```

Start the loop that fetches frames, computes the position etc and sends it to other computers. This function is the core of this program, hence the pose estimation is done here.
Definition at line 276 of file main.cpp.

```
276                     {
277
278
279     gotOrder = false; //! The order of points, hence which entry in list_points3d corresponds to
        which in list_points2d is not calculated yet
280     Rvec = RvecOriginal; //! Use the value of Rvec that was set in main() as starting value
        for the solvePnP algorithm
281     Tvec = TvecOriginal; //! Use the value of Tvec that was set in main() as starting value
        for the solvePnP algorithm
282     GetLocalTime(&logDate);  //! Get the current date and time to name the log file
283
284     //! Concat the log file name as followed. The file is saved in the folder /logs in the Rigid Track
        installation folder
285     logFileName = "./logs/positionLog_" + QString::number(logDate.wDay) + "_" +
        QString::number(logDate.wMonth) + "_" + QString::number(logDate.wYear);
286     logFileName += "_" + QString::number(logDate.wHour) + "_" + QString::number(
        logDate.wMinute) + "_" + QString::number(logDate.wSecond) + ".txt";
287     logName = logFileName.toStdString(); //! Convert the QString to a standard string
288
289     determineExposure(); //! Get the exposure where the right amount of markers is
        detected
290
291     //! For OptiTrack Ethernet cameras, it's important to enable development mode if you
292     //! want to stop execution for an extended time while debugging without disconnecting
293     //! the Ethernet devices.  Lets do that now:
294
295     CameraLibrary_EnableDevelopment();
296     CameraLibrary::CameraManager::X(); //! Initialize Camera SDK
297
298     //! At this point the Camera SDK is actively looking for all connected cameras and will initialize
299     //! them on it's own
300
301     //! Get a connected camera
302     CameraManager::X().WaitForInitialization();
303     Camera *camera = CameraManager::X().GetCamera();
304
305     //! If no camera can be found, inform user in message log and exit function
306     if (camera == 0)
307     {
308         commObj.addLog("No camera found!");
309         return 1;
310     }
311
312     //! Determine camera resolution to size application window
313     int cameraWidth = camera->Width();
314     int cameraHeight = camera->Height();
315
316     camera->SetVideoType(Core::PrecisionMode);  //! Set the camera mode to precision mode, it used
        greyscale imformation for marker property calculations
317
318     camera->Start(); //! Start camera output
319
320     //! Turn on some overlay text so it's clear things are
321     //! working even if there is nothing in the camera's view
322     camera->SetTextOverlay(true);
323     camera->SetExposure(intExposure);    //! Set the camera exposure
324     camera->SetIntensity(intIntensity); //! Set the camera infrared LED intensity
325     camera->SetFrameRate(intFrameRate); //! Set the camera framerate to 100 Hz
326     camera->SetIRFilter(true);  //! Enable the filter that blocks visible light and only passes infrared
        light
327     camera->SetHighPowerMode(true); //! Enable high power mode of the LEDs
328     camera->SetContinuousIR(false); //! Disable continuous LED light
329     camera->SetThreshold(intThreshold); //! Set threshold for marker detection
330
331     //! Create a new matrix that stores the grayscale picture from the camera
332     Mat matFrame = Mat::zeros(cv::Size(cameraWidth, cameraHeight), CV_8UC1);
333     QPixmap QPFrame; //! QPixmap is the corresponding Qt class that saves images
334     //! Matrix that stores the colored picture, hence marker points, coordinate frame and reprojected
        points
335     Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
336
337     int v = 0;  //! Helper variable used to kick safety switch
338     //! Variables for the min and max values that are needed for sanity checks
339     double maxValue = 0;
340     double minValue = 0;
341     int framesDropped = 0; //! Ff a marker is not visible or accuracy is bad increase this counter
342     double projectionError = 0; //! Equals the quality of the tracking
```

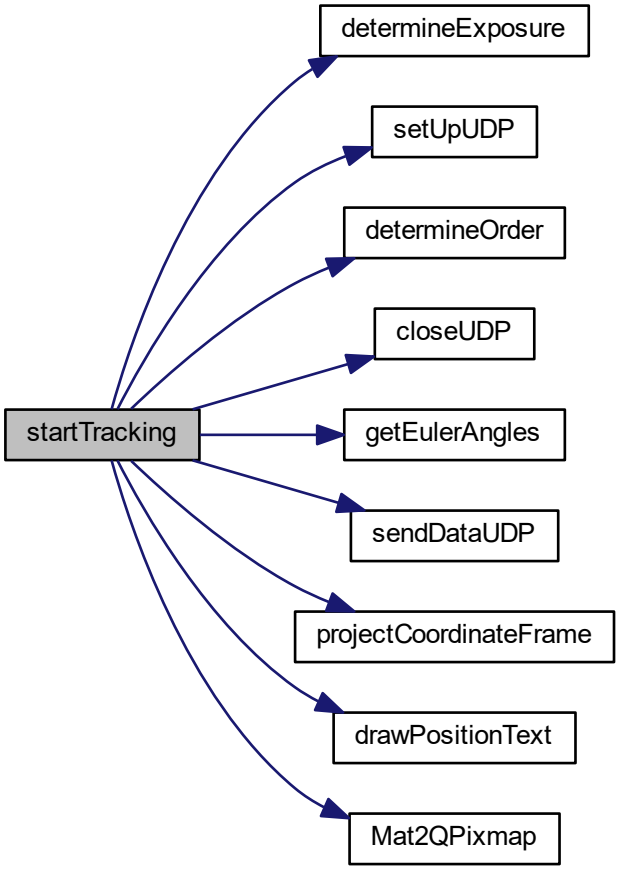
```
343
344     setUpUDP(); //! Open sockets and ports for UDP communication
345
346     if (safetyEnable) //! If the safety feature is enabled send the starting message
347     {
348         //! Send enable message, hence send a 9 and then a 1
349         data.setNum((int)(9));
350         udpSocketSafety->write(data);
351         data.setNum((int)(1));
352         udpSocketSafety->write(data);
353     }
354
355     //! Fetch a new frame from the camera
356     bool gotTime = false; //! Get the timestamp of the first frame. This time is subtracted from every
    subseeding frame so the time starts at 0 in the logs
357     while (!gotTime) //! While no new frame is received loop
358     {
359         Frame *frame = camera->GetFrame(); //! Get a new camera frame
360         if (frame)  //! There is actually a new frame
361         {
362             timeFirstFrame = frame->TimeStamp(); //! Get the time stamp for the first frame.
    It is subtracted for the following frames
363             frame->Release();   //! Release the frame so the camera can continue
364             gotTime = true; //! Exit the while loop
365         }
366     }
367
368     //! Now enter the main loop that processes each frame and computes the pose, sends it and logs stuff
369     while (!exitRequested) //! Check if the user has not pressed "Stop Tracking" yet
370     {
371
372         Frame *frame = camera->GetFrame(); //! Fetch a new frame from the camera
373
374         if (frame) //! Did we got a new frame or does the camera still need more time
375         {
376             framesDropped++; //! Increase by one, if everything is okay it is decreased at the end of the
    loop again
377
378             //! Only use this frame it the right number of markers is found in the picture
379             if (frame->ObjectCount() == numberMarkers)
380             {
381                 //! Get the marker points in 2D in the camera image frame and store them in the
    list_points2dUnsorted vector
382                 //! The order of points that come from the camera corresponds to the Y coordinate
383                 for (int i = 0; i < numberMarkers; i++)
384                 {
385                     cObject *obj = frame->Object(i);
386                     list_points2dUnsorted[i] = cv::Point2d(obj->X(), obj->Y());
387                 }
388
389                 if (gotOrder == false) //! Was the order already determined? This is false for the
    first frame and from then on true
390                 {
391                     determineOrder(); //! Now compute the order
392                 }
393
394                 //! Sort the 2d points with the correct indices as found in the preceeding order
    determination algorithm
395                 for (int w = 0; w < numberMarkers; w++)
396                 {
397                     list_points2d[w] = list_points2dUnsorted[
  pointOrderIndices[w]]; //! pointOrderIndices was calculated in determineOrder()
398                 }
399
400                 //! The first time the 2D-3D corresspondence was determined with gotOrder was okay.
401                 //! But this order can change as the object moves and the marker objects appear in a
402                 //! different order in the frame->Object() array.
403                 //! The solution is that: When a marker point (in the camera image, hence in 2D) was at
404                 //! a position then it wont move that much from one frame to the other.
405                 //! So for the new frame we take a marker object and check which marker was closest this
    point
406                 //! in the old image frame? This is probably the same (true) marker. And we do that for
    every other marker as well.
407                 //! When tracking is good and no frames are dropped because of missing markers this should
    work every frame.
408                 for (int j = 0; j < numberMarkers; j++)
409                 {
410                     minPointDistance = 5000; //! The sum of point distances is set to
    something unrealistic large
411                     for (int k = 0; k < numberMarkers; k++)
412                     {
413                         //! Calculate N_2 norm of unsorted points minus old points
```

```
414                         currentPointDistance = norm(
    list_points2dUnsorted[pointOrderIndices[j]] -
    list_points2dOld[k]);
415                         //! If the norm is smaller than minPointDistance the correspondence is more likely
     to be correct
416                         if (currentPointDistance <
    minPointDistance)
417                         {
418                             //! Update the array that saves the new point order
419                             minPointDistance =
    currentPointDistance;
420                             pointOrderIndicesNew[j] = k;
421                         }
422                     }
423                 }
424 
425                 //! Now the new order is found, set the point order to the new value
426                 for (int k = 0; k < numberMarkers; k++)
427                 {
428                     pointOrderIndices[k] = pointOrderIndicesNew[k];
429                     list_points2d[k] = list_points2dUnsorted[
    pointOrderIndices[k]];
430                 }
431 
432                 //! Save the unsorted position of the marker points for the next loop
433                 list_points2dOld = list_points2dUnsorted;
434 
435                 //!Compute the object pose from the 3D-2D corresponses
436                 solvePnP(list_points3d, list_points2d,
    cameraMatrix, distCoeffs, Rvec, Tvec, useGuess,
    methodPNP);
437 
438                 //! Project the marker 3d points with the solution into the camera image CoSy and calculate
     difference to true camera image
439                 projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2dProjected);
440                 projectionError = norm(list_points2dProjected,
    list_points2d); //! Difference of true pose and found pose
441 
442                 //! Increase the framesDropped variable if accuracy of tracking is too bad
443                 if (projectionError > 5)
444                 {
445                     framesDropped++;
446                 }
447                 else
448                 {
449                     framesDropped = 0;  //! Set number of subsequent frames dropped to zero because error
     is small enough and no marker was missing
450                 }
451 
452                 //! Get the min and max values from TVec for sanity check
453                 minMaxLoc(Tvec.at<double>(2), &minValue, &maxValue);
454 
455                 //! Sanity check of values. negative z means the marker CoSy is behind the camera, that's
     not possible.
456                 if (minValue < 0)
457                 {
458                     commObj.addLog("Negative z distance, that is not possible. Start the set zero
     routine again or restart Program.");
459                     frame->Release(); //! Release the frame so the camera can move on
460                     camera->Release(); //! Release the camera
461                     closeUDP(); //! Close all UDP connections so the programm can be closed later
     on and no resources are locked
462                     return 1; //! Exit the function
463                 }
464 
465                 //! Next step is the transformation from camera CoSy to navigation CoSy
466                 //! Compute the relative object position from the reference position to the current one
467                 //! given in the camera CoSy: \f$ T_C^{NM} = Tvec - Tvec_{Ref} \f$
468                 subtract(Tvec, posRef, position);
469 
470                 //! Transform the position from the camera CoSy to the navigation CoSy with INS alligned
     heading and convert from [mm] to [m]
471                 //! \f$ T_N^{NM} = M_{NC} \times T_C^{NM} \f$
472                 Mat V = 0.001 * M_HeadingOffset * M_CN.t() * (Mat)
    position;
473                 position = V;   //! Position is the result of the preceeding calculation
474                 position[2] *= invertZ;  //! Invert Z if check box in GUI is activated,
     hence height above ground is considered
475 
476                 //! Realtive angle between reference orientation and current orientation
477                 Rodrigues(Rvec, Rmat);  //! Convert axis angle respresentation to ordinary rotation
```

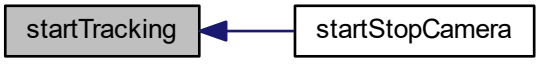
```
matrix
478
479                 //! The difference of the reference rotation and the current rotation
480                 //! \f$ R_{ NM } = M_{ NC } \times R_{ CM } \f$
481                 Rmat = RmatRef.t() *Rmat;
482
483                 //! Euler Angles, finally
484                 getEulerAngles(Rmat, eulerAngles); //! Get the euler angles
    from the rotation matrix
485                 eulerAngles[2] += headingOffset; //! Add the heading offset to the
    heading angle
486
487                 //! Compute the velocity with finite differences. Only use is the log file. It is done here
    because the more precise time stamp can be used
488                 frameTime = frame->TimeStamp() - timeOld;   //! Time between the old frame
    and the current frame
489                 timeOld = frame->TimeStamp();    //! Set the old frame time to the current  one
490                 velocity[0] = (position[0] - positionOld[0]) /
    frameTime; //! Calculate the x velocity with finite differences
491                 velocity[1] = (position[1] - positionOld[1]) /
    frameTime; //! Calculate the y velocity with finite differences
492                 velocity[2] = (position[2] - positionOld[2]) /
    frameTime; //! Calculate the z velocity with finite differences
493                 positionOld = position;  //! Set the old position to the current one for
    next frame velocity calcuation
494
495                 eulerAngles[0] = eulerAngles[0] * -3.141592653589 / 180.0; //!
    Convert the Euler angles from degrees to rad
496                 eulerAngles[1] = eulerAngles[1] * -3.141592653589 / 180.0;
497                 eulerAngles[2] = eulerAngles[2] * 3.141592653589 / 180.0;
498
499                 //! Send position and Euler angles over WiFi with 100 Hz
500                 sendDataUDP(position, eulerAngles);
501
502                 //! Save the values in a log file, values are:
503                 //! Time sinc tracking started  Position    Euler Angles    Velocity
504                 logfile.open(logName, std::ios::app); //! Open the log file, the folder is
    RigidTrackInstallationFolder/logs
505                 logfile << frame->TimeStamp() - timeFirstFrame << ";" <<
    position[0] << ";" << position[1] << ";" << position[2] << ";";
506                 logfile << eulerAngles[0] << ";" <<
    eulerAngles[1] << ";" << eulerAngles[2] << ";";
507                 logfile << velocity[0] << ";" << velocity[1] << ";" <<
    velocity[2] << "\n";
508                 logfile.close(); //! Close the file to save values
509             }
510
511             //! Check if the position and euler angles are below the allowed value, if yes send OKAY signal
    (1), if not send shutdown signal (0)
512             //! Absolute x, y and z position in navigation CoSy must be smaller than the allowed distance
513             if (safetyEnable)
514             {
515                 if ((abs(position[0]) < safetyBoxLength && abs(position[1]) <
    safetyBoxLength && abs(position[2]) < safetyBoxLength))
516                 {
517                     //! Absolute Euler angles must be smaller than allowed value. Heading is not considered

518                     if ((abs(eulerAngles[0]) < safetyAngle && abs(eulerAngles[1]) <
    safetyAngle))
519                     {
520                         //! Send the OKAY signal to the desired computer every 5th time
521                         if (v == 5) {
522                             data.setNum((int)(1));
523                             udpSocketSafety->write(data); //! Send the 1
524                             v = 0; //! reset the counter that is needed for decimation to every 5th time
    step
525                         }
526                     }
527                     //! The euler angles of the object exceeded the allowed euler angles, send the shutdown
    signal (0)
528                     else
529                     {
530                         data.setNum((int)(0));  //! Send the shutdown signal, a 0
531                         udpSocketSafety->write(data);
532                         commObj.addLog("Object exceeded allowed Euler angles, shutdown signal sent."
    ); //! Inform the user
533
534                     }
535                 }
536                 //! The position of the object exceeded the allowed position, shut the object down
537                 else
538                 {
```

```
539                     data.setNum((int)(0));  //! Send the shutdown signal, a 0
540                     udpSocketSafety->write(data);
541                     commObj.addLog("Object left allowed area, shutdown signal sent."); //! Inform
     the user
542 
543                 }
544             }
545 
546             //! Inform the user if tracking system is disturbed (marker lost or so) or error was too big
547             if (framesDropped > 10)
548             {
549                 if (safetyEnable) //! Also send the shutdown signal
550                 {
551                     data.setNum((int)(0));  //! Send the shutdown signal, a 0
552                     udpSocketSafety->write(data);
553                 }
554                 commObj.addLog("Lost marker points or precision was bad!"); //! Inform the user
555                 framesDropped = 0;
556             }
557 
558             //! Rasterize the frame so it can be shown in the GUI
559             frame->Rasterize(cameraWidth, cameraHeight, matFrame.step,
    BACKBUFFER_BITSPERPIXEL, matFrame.data);
560 
561             //! Convert the frame from greyscale as it comes from the camera to rgb color
562             cvtColor(matFrame, cFrame, COLOR_GRAY2RGB);
563 
564             //! Project (draw) the marker CoSy origin into 2D and save it in the cFrame image
565             projectCoordinateFrame(cFrame);
566 
567             //! Project the marker points from 3D to the camera image frame (2d) with the computed pose
568             projectPoints(list_points3d, Rvec, Tvec,
    cameraMatrix, distCoeffs, list_points2d);
569             for (int i = 0; i < numberMarkers; i++)
570             {
571                 //! Draw a circle around the projected points so the result can be better compared to the
     real marker position
572                 //! In the resulting picture those are the red dots
573                 circle(cFrame, Point(list_points2d[i].x,
    list_points2d[i].y), 3, Scalar(225, 0, 0), 3);
574             }
575 
576             //! Write the current position, attitude and error values as text in the frame
577             drawPositionText(cFrame, position, eulerAngles, projectionError);
578 
579             //! Send the new camera picture to the GUI and call the GUI processing routine
580             QPixmap QPFrame;
581             QPFrame = Mat2QPixmap(cFrame);
582             commObj.changeImage(QPFrame); //! Update the picture in the GUI
583             QCoreApplication::processEvents(); //! Give Qt time to handle everything
584 
585             //! Release the camera frame to fetch the new one
586             frame->Release();
587         }
588     }
589 
590     //! User choose to stop the tracking, clean things up
591     closeUDP(); //! Close the UDP connections so resources are deallocated
592     camera->Release();  //! Release camera
593     return 0;
594 }
```

Here is the call graph for this function:



Here is the caller graph for this function:



testAlgorithms()

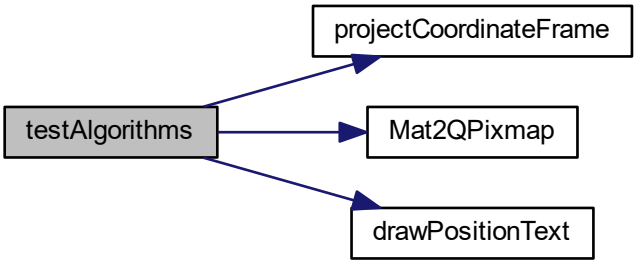
```
void testAlgorithms ( )
```

Project some points from 3D to 2D and then check the accuracy of the algorithms. Mainly to generate something that can be shown in the camera view so the user knows everything loaded correctly.
Definition at line 970 of file main.cpp.

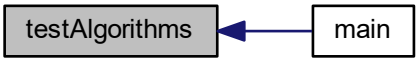
```
971 {
972
973     int _methodPNP;
974
975     std::vector<Point2d> noise(numberMarkers);
976
977     RvecOriginal = Rvec;
978     TvecOriginal = Tvec;
979
980     projectPoints(list_points3d, Rvec, Tvec, cameraMatrix,
    distCoeffs, list_points2dProjected);
981
982     ss.str("");
983     ss << "Unsorted Points 2D Projected \n";
984     ss << list_points2dProjected << "\n";
985     commObj.addLog(QString::fromStdString(ss.str()));
986
987     Mat cFrame(480, 640, CV_8UC3, Scalar(0, 0, 0));
988     for (int i = 0; i < numberMarkers; i++)
989     {
990         circle(cFrame, Point(list_points2dProjected[i].x, list_points2dProjected[i].y), 6, Scalar(0, 255, 0
    ), 3);
991     }
992
993     projectCoordinateFrame(cFrame);
994
995     ss.str("");
996     ss << "=====================================================\n";
997     ss << "================= Projected Points ==================\n";
998     ss << list_points2dProjected << "\n";
999
1000     randn(noise, 0, 0.5);
1001     add(list_points2dProjected, noise, list_points2dProjected);
1002
1003     ss << "================ With Noise Points ==================\n";
1004     ss << list_points2dProjected << "\n";
1005     commObj.addLog(QString::fromStdString(ss.str()));
1006
1007
1008     bool useGuess = true;
1009     _methodPNP = 0; //!< 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP  //!< not used
1010
1011     solvePnP(list_points3d, list_points2dProjected, cameraMatrix,
    distCoeffs, Rvec, Tvec, useGuess, _methodPNP);
1012
1013     ss.str("");
1014     ss << "=====================================================\n";
1015     ss << "==================== Iterative ======================\n";
1016     ss << "rvec: " << "\n";
1017     ss << Rvec << "\n";
1018     ss << "tvec: " << "\n";
1019     ss << Tvec << "\n";
1020
1021     commObj.addLog(QString::fromStdString(ss.str()));
1022
1023     _methodPNP = 1; //!< 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP UPnP not used
1024     Rvec = cv::Mat::zeros(3, 1, CV_64F);
1025     Tvec = cv::Mat::zeros(3, 1, CV_64F);
1026     solvePnP(list_points3d, list_points2dProjected, cameraMatrix,
    distCoeffs, Rvec, Tvec, useGuess, _methodPNP);
1027
1028     ss.str("");
1029     ss << "=====================================================\n";
1030     ss << "====================    EPNP    ====================\n";
1031     ss << "rvec: " << "\n";
1032     ss << Rvec << "\n";
1033     ss << "tvec: " << "\n";
1034     ss << Tvec << "\n";
1035
1036     projectPoints(list_points3d, Rvec, Tvec, cameraMatrix,
    distCoeffs, list_points2dProjected);
1037     for (int i = 0; i < numberMarkers; i++)
1038     {
1039         circle(cFrame, Point(list_points2dProjected[i].x, list_points2dProjected[i].y), 3, Scalar(255, 0, 0
    ), 3);
1040     }
1041     QPixmap QPFrame;
```

```
1042     QPFrame = Mat2QPixmap(cFrame);
1043     commObj.changeImage(QPFrame);
1044     QCoreApplication::processEvents();
1045     commObj.addLog(QString::fromStdString(ss.str()));
1046     if (numberMarkers == 4)
1047     {
1048         _methodPNP = 2; //!< 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP  //!< not used
1049         Rvec = cv::Mat::zeros(3, 1, CV_64F);
1050         Tvec = cv::Mat::zeros(3, 1, CV_64F);
1051         solvePnP(list_points3d, list_points2dProjected,
     cameraMatrix, distCoeffs, Rvec, Tvec, useGuess, _methodPNP);
1052
1053         ss.str("");
1054         ss << "=========================================================\n";
1055         ss << "====================     P3P    ====================\n";
1056         ss << "rvec: " << "\n";
1057         ss << Rvec << "\n";
1058         ss << "tvec: " << "\n";
1059         ss << Tvec << "\n";
1060
1061         projectPoints(list_points3d, Rvec, Tvec, cameraMatrix,
     distCoeffs, list_points2dProjected);
1062         for (int i = 0; i < numberMarkers; i++)
1063         {
1064             circle(cFrame, Point(list_points2dProjected[i].x, list_points2dProjected[i].y), 3, Scalar(255,
     0, 0), 3);
1065         }
1066         double projectionError = norm(list_points2dProjected, list_points2d);
1067         putText(cFrame, "Testing Algorithms Finished", cv::Point(5, 420), 1, 1, cv::Scalar(255, 255, 255));
1068         drawPositionText(cFrame, position, eulerAngles, projectionError)
     ;
1069
1070         QPixmap QPFrame;
1071         QPFrame = Mat2QPixmap(cFrame);
1072         commObj.changeImage(QPFrame);
1073         QCoreApplication::processEvents();
1074         commObj.addLog(QString::fromStdString(ss.str()));
1075     }
1076
1077     _methodPNP = 4; //!< 0 = iterative 1 = EPNP 2 = P3P 4 = UPNP  //!< not used
1078     Rvec = cv::Mat::zeros(3, 1, CV_64F);
1079     Tvec = cv::Mat::zeros(3, 1, CV_64F);
1080     solvePnP(list_points3d, list_points2dProjected, cameraMatrix,
     distCoeffs, Rvec, Tvec, useGuess, _methodPNP);
1081
1082     ss.str("");
1083     ss << "=========================================================\n";
1084     ss << "====================    UPNP    ====================\n";
1085     ss << "rvec: " << "\n";
1086     ss << Rvec << "\n";
1087     ss << "tvec: " << "\n";
1088     ss << Tvec << "\n";
1089
1090     commObj.addLog(QString::fromStdString(ss.str()));
1091
1092     Rvec = RvecOriginal;
1093     Tvec = TvecOriginal;
1094
1095 }
```

Here is the call graph for this function:



Here is the caller graph for this function:



3.2.3 Variable Documentation

commObj

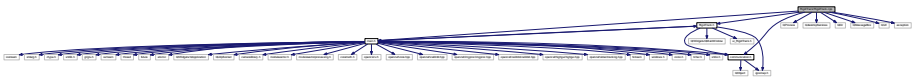
`commObject commObj`
class that handles the communication from main.cpp to the GUI
Now declare variables that are used across the main.cpp file. Basically almost every variable used is declared here.
Definition at line 68 of file main.cpp.

3.3 RigidTrack/RigidTrack.cpp File Reference

Rigid Track GUI source that contains functions for GUI events.

```
#include "RigidTrack.h"
#include <QProcess>
#include <QdesktopServices>
#include <QDir>
#include <QMessageBox>
#include <QUrl>
#include "main.h"
```

```
#include "communication.h"
#include <exception>
```
Include dependency graph for RigidTrack.cpp:



3.3.1 Detailed Description

Rigid Track GUI source that contains functions for GUI events.

Author

Florian J.T. Wachter

Version

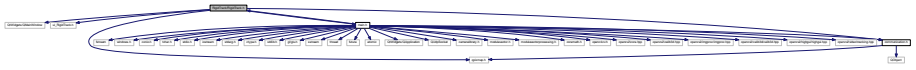
1.0

Date

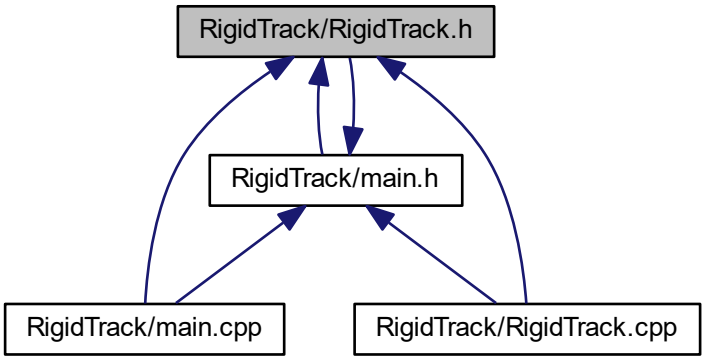
April, 8th 2017

3.4 RigidTrack/RigidTrack.h File Reference

Rigid Track GUI source header with Qt Signals and Slots.
```
#include <QtWidgets/QMainWindow>
#include "ui_RigidTrack.h"
#include <qpixmap.h>
#include "main.h"
#include "communication.h"
```
Include dependency graph for RigidTrack.h:



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



3.4.1 Detailed Description

Rigid Track GUI source header with Qt Signals and Slots.

Author

Florian J.T. Wachter

Version

1.0

Date

April, 8th 2017