

# Visual-Based Navigation

## Solution Exercise Sheet 2

### Topic: Camera Models, Optimization, Calibration

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May 6, 2021

## Part 1: Camera Models

The tests evaluate the functionality of the implemented projection and unprojection function of a Pinhole, Extended Unified, Double Sphere and Kannala-Brandt camera.

## Part 2: Optimization

The major difference between the Ceres curve fitting and the robust curve fitting is that the data in robust curve fitting can have outliers. Also, the result is expected to be more accurate in this case.

## Part 3: Camera calibration

The calibration.cpp has the following CLI argument options:

```
app.add_option("--show-gui", show_gui, "Show GUI"); // Default value is true since
the following is set: bool show_gui = true;
app.add_option("--dataset-path", dataset_path, "Dataset path")->required();
app.add_option(
    "--cam-model", cam_model,
    "Camera model. Possible values: pinhole, ds, eucm, kb4. Default: ds.");
```

Attached is the optimization for the different cameras. After inspecting the output of the program, one can see that a quantitative measure that could be used to determine how well the camera models fit the lenses could be time. The pinhole camera takes much longer than eucm here.

```
//
//
// Pinhole
//
//
```

```
Solver Summary (v 2.0.0-eigen-(3.3.8)-lapack-suitesparse-(5.8.1)
-cxsparse-(3.2.0)-acceleratesparse-eigen-sparse-no-openmp)
```

	Original	Reduced
Parameter blocks	56	55
Parameters	394	387
Residual blocks	12442	12442
Residuals	24884	24884

Minimizer TRUST\_REGION

Sparse linear algebra library SUITE\_SPARSE  
Trust region strategy LEVENBERG\_MARQUARDT

	Given	Used
Linear solver	SPARSE_NORMAL_CHOLESKY	SPARSE_NORMAL_CHOLESKY
Threads	8	8
Linear solver ordering	AUTOMATIC	55

Cost:

Initial	1.795667e+07
Final	1.565735e+05
Change	1.780009e+07

Minimizer iterations 16

Successful steps 16

Unsuccessful steps 0

Time (in seconds):

Preprocessor	0.004467
Residual only evaluation	0.022954 (16)
Jacobian & residual evaluation	0.171202 (16)
Linear solver	0.120713 (16)
Minimizer	0.345600
Postprocessor	0.000277
Total	0.350344

Termination: CONVERGENCE (Function tolerance reached.)

|cost\_change|/cost: 4.470407e-13 <= 1.000000e-12)

```
{
  "value0": {
    "cam.T_i_c": [
      {
        "px": 0.0,
        "py": 0.0,
        "pz": 0.0,
        "qx": 0.0,
        "qy": 0.0,
        "qz": 0.0,
        "qw": 1.0
      },
      {
        "px": 0.1096022011910519,
        "py": -0.00010490093800120144,
        "pz": 0.0037399994879116149,
        "qx": 0.004551532451585768,
        "qy": -0.032244636905271999,
        "qz": 0.002769193435207044,
        "qw": 0.8439081474448701
      }
    ],
    "cam.intrinsics": [
      {
        "cam_type": "pinhole",
        "fx": 546.2147265243003,
        "fy": 551.5811403375211,
        "cx": 399.08840396381728,
        "cy": 208.3716194535161,
        "p1": 0.0,
        "p2": 0.0,
        "p3": 0.0,

```

```

        "p4": 0.0,
        "width": 752,
        "height": 480
    },
    {
        "cam_type": "pinhole",
        "fx": 547.2084840431953,
        "fy": 550.3778802227101,
        "cx": 368.8628350844427,
        "cy": 215.16199227351897,
        "p1": 0.0,
        "p2": 0.0,
        "p3": 0.0,
        "p4": 0.0,
        "width": 752,
        "height": 480
    }
]
}

//
//
// ds
//
//

```

Solver Summary (v 2.0.0-eigen-(3.3.8)-lapack-suitesparse-(5.8.1)  
-cxsparse-(3.2.0)-acceleratesparse-eigensparse-no\_openmp)

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Minimizer TRUST\_REGION

Sparse linear algebra library SUITE\_SPARSE  
Trust region strategy LEVENBERG\_MARQUARDT

	Given	Used
Linear solver	SPARSE_NORMAL_CHOLESKY	SPARSE_NORMAL_CHOLESKY
Threads	8	8
Linear solver ordering	AUTOMATIC	55

Cost:

Initial	5.353182e+06
Final	1.627482e+02
Change	5.353019e+06

Minimizer iterations	15
Successful steps	13
Unsuccessful steps	2

Time (in seconds):

Preprocessor	0.004379
--------------	----------

Residual only evaluation	0.020993 (15)
Jacobian & residual evaluation	0.136768 (13)
Linear solver	0.111169 (15)

Minimizer	0.293896
Postprocessor	0.000266
Total	0.298542

Termination: CONVERGENCE (Parameter tolerance reached.  
Relative step\_norm: 6.569590e-09 <= 1.000000e-08.)

```
{
  "value0": {
    "cam.T_i_c": [
      {
        "px": 0.0,
        "py": 0.0,
        "pz": 0.0,
        "qx": 0.0,
        "qy": 0.0,
        "qz": 0.0,
        "qw": 1.0
      },
      {
        "px": 0.11002674958797228,
        "py": -0.00028913779863995844,
        "pz": 0.00024662505011367346,
        "qx": 0.007794704594611823,
        "qy": 0.000688166258356226,
        "qz": 0.0011789947963589724,
        "qw": 1.0941709537072655
      }
    ],
    "cam.intrinsics": [
      {
        "cam_type": "ds",
        "fx": 351.0372831661496,
        "fy": 350.007455547103,
        "cx": 365.8880973558662,
        "cy": 249.3457383677667,
        "p1": -0.2385312818382275,
        "p2": 0.5678694844862202,
        "p3": 0.0,
        "p4": 0.0,
        "width": 752,
        "height": 480
      },
      {
        "cam_type": "ds",
        "fx": 362.95328868234437,
        "fy": 361.8568553536517,
        "cx": 379.35501913939779,
        "cy": 256.0392416758326,
        "p1": -0.2106378372763585,
        "p2": 0.5776109411828488,
        "p3": 0.0,
        "p4": 0.0,
        "width": 752,
        "height": 480
      }
    ]
  }
}
```

```
//
//
// Eucm
//
//
```

Solver Summary (v 2.0.0-eigen-(3.3.8)-lapack-suitesparse-(5.8.1)  
-cxsparse-(3.2.0)-acceleratesparse-eigensparse-no\_openmp)

	Original	Reduced
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Minimizer TRUST\_REGION

Sparse linear algebra library SUITE\_SPARSE  
Trust region strategy LEVENBERG\_MARQUARDT

	Given	Used
Linear solver	SPARSE_NORMAL_CHOLESKY	SPARSE_NORMAL_CHOLESKY
Threads	8	8
Linear solver ordering	AUTOMATIC	55

Cost:  
Initial 5.353182e+06  
Final 1.627604e+02  
Change 5.353019e+06

Minimizer iterations 7  
Successful steps 7  
Unsuccessful steps 0

Time (in seconds):  
Preprocessor 0.004566

Residual only evaluation 0.012308 (7)  
Jacobian & residual evaluation 0.084586 (7)  
Linear solver 0.056756 (7)  
Minimizer 0.167365

Postprocessor 0.000246  
Total 0.172177

Termination: CONVERGENCE (Parameter tolerance reached.  
Relative step\_norm: 2.762217e-09 <= 1.000000e-08.)

```
{
  "value0": {
    "cam.T_i_c": [
      {
        "px": 0.0,
        "py": 0.0,
        "pz": 0.0,
        "qx": 0.0,
        "qy": 0.0,
        "qz": 0.0,
        "qw": 1.0
      },
      {

```

```

        "px": 0.11002631814679428,
        "py": -0.0002890896514591288,
        "pz": 0.0002461811323400604,
        "qx": 0.007904698851113038,
        "qy": 0.0006990805238899349,
        "qz": 0.001195571007016388,
        "qw": 1.1096211493375517
    }
],
"cam.intrinsics": [
    {
        "cam_type": "eucm",
        "fx": 460.97949862323,
        "fy": 459.62650954895715,
        "cx": 365.8867492138882,
        "cy": 249.34648625409748,
        "p1": 0.5916648148564965,
        "p2": 1.1241125279514093,
        "p3": 0.0,
        "p4": 0.0,
        "width": 752,
        "height": 480
    },
    {
        "cam_type": "eucm",
        "fx": 459.7960643312798,
        "fy": 458.40630957479729,
        "cx": 379.35442499619367,
        "cy": 256.0400996521874,
        "p1": 0.6060839019058487,
        "p2": 1.0883509178352487,
        "p3": 0.0,
        "p4": 0.0,
        "width": 752,
        "height": 480
    }
]
}

//
//
// KB4
//
//

```

Solver Summary (v 2.0.0-eigen-(3.3.8)-lapack-suitesparse-(5.8.1)-cxsparse-(3.2.0)  
-acceleratesparse-eigensparse-no\_openmp)

	Original	Reduced
Parameter blocks	56	55
Parameters	394	387
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Residuals	24884	24884

Minimizer TRUST\_REGION

Sparse linear algebra library SUITE\_SPARSE  
Trust region strategy LEVENBERG\_MARQUARDT

Given

Used

Linear solver	SPARSE_NORMAL_CHOLESKY	SPARSE_NORMAL_CHOLESKY
Threads	8	8
Linear solver ordering	AUTOMATIC	55

Cost:

Initial	5.788049e+06
Final	1.619844e+02
Change	5.787887e+06

Minimizer iterations 8

Successful steps 8

Unsuccessful steps 0

Time (in seconds):

Preprocessor	0.004868
Residual only evaluation	0.012564 (8)
Jacobian & residual evaluation	0.093858 (8)
Linear solver	0.064144 (8)
Minimizer	0.186043
Postprocessor	0.000265
Total	0.191176

Termination: CONVERGENCE (Parameter tolerance reached.)

Relative step\_norm: 3.226535e-10 <= 1.000000e-08.)

```
{
  "value0": {
    "cam.T_i_c": [
      {
        "px": 0.0,
        "py": 0.0,
        "pz": 0.0,
        "qx": 0.0,
        "qy": 0.0,
        "qz": 0.0,
        "qw": 1.0
      },
      {
        "px": 0.11002263076694959,
        "py": -0.00028831176610493863,
        "pz": 0.0002519373753888693,
        "qx": 0.011172419721255964,
        "qy": 0.0009885625429539632,
        "qz": 0.0016880082763027446,
        "qw": 1.566995437615639
      }
    ],
    "cam.intrinsics": [
      {
        "cam_type": "kb4",
        "fx": 461.15819008649006,
        "fy": 459.8080285199655,
        "cx": 365.89723868110846,
        "cy": 249.3549232937617,
        "p1": -0.0045930500460662029,
        "p2": 0.027532419780777828,
        "p3": -0.036977648915392718,
        "p4": 0.018610202935460276,
        "width": 752,

```

```

    "height": 480
  },
  {
    "cam_type": "kb4",
    "fx": 459.7448068650903,
    "fy": 458.3535053476159,
    "cx": 379.3639615166875,
    "cy": 256.0435255171945,
    "p1": 0.004549588328067598,
    "p2": 0.0024854920535080928,
    "p3": -0.010601351994912112,
    "p4": 0.01078104332617372,
    "width": 752,
    "height": 480
  }
]
}
}
}

```