

## Calibration results

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### Normalized Residuals

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Reprojection error (cam0): mean 0.288721159215, median 0.256573072985, std: 0.215098904217  
Reprojection error (cam1): mean 0.322194009023, median 0.295594637366, std: 0.24042540133  
Gyroscope error (imu0): mean 1.46173908788, median 1.38509777945, std: 0.693832227885  
Accelerometer error (imu0): mean 1.08077534718, median 0.99151991984, std: 0.672610875185  
Gyroscope error (imu1): mean 1.45768002478, median 1.38412080621, std: 0.67706139949  
Accelerometer error (imu1): mean 0.9938733237, median 0.903150124432, std: 0.574574932187  
Gyroscope error (imu2): mean 1.411074616, median 1.32748916228, std: 0.685051260906  
Accelerometer error (imu2): mean 1.04037393433, median 0.955390680864, std: 0.590478715116  
Gyroscope error (imu3): mean 1.51269696723, median 1.42654072575, std: 0.780217537602  
Accelerometer error (imu3): mean 1.08991861477, median 0.990224347408, std: 0.652444487868

### Residuals

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Reprojection error (cam0) [px]: mean 0.288721159215, median 0.256573072985, std: 0.215098904217  
Reprojection error (cam1) [px]: mean 0.322194009023, median 0.295594637366, std: 0.24042540133  
Gyroscope error (imu0) [rad/s]: mean 0.00280276248018, median 0.0026558091795, std: 0.00133036528  
Accelerometer error (imu0) [m/s^2]: mean 0.0519233092694, median 0.0476352422168, std: 0.032314007  
Gyroscope error (imu1) [rad/s]: mean 0.00279497956609, median 0.002653935915, std: 0.001298208622  
Accelerometer error (imu1) [m/s^2]: mean 0.0477483059694, median 0.0433897232669, std: 0.027604101  
Gyroscope error (imu2) [rad/s]: mean 0.00270561759158, median 0.00254534947292, std: 0.0013135285  
Accelerometer error (imu2) [m/s^2]: mean 0.0499823184247, median 0.0458994979163, std: 0.028368160  
Gyroscope error (imu3) [rad/s]: mean 0.00290046995307, median 0.00273527256385, std: 0.0014960018  
Accelerometer error (imu3) [m/s^2]: mean 0.0523625760535, median 0.0475729994868, std: 0.031345160

### Transformation (cam0):

-----

T\_ci: (imu0 to cam0):  
[[-0.99987545 0.01531 0.0038332 0.09357779]  
[-0.01531016 -0.99988279 -0.00001215 0.00965728]  
[ 0.00383257 -0.00007083 0.99999265 -0.00158094]  
[ 0. 0. 0. 1. ]]

T\_ic: (cam0 to imu0):

```
[ 0.      0.      0.      1.    ]]
```

timeshift cam0 to imu0: [s] ( $t_{imu} = t_{cam} + \text{shift}$ )  
-0.008922152649677474

Transformation (cam1):

-----  
T\_ci: (imu0 to cam1):

```
[[-0.99988918  0.0148572 -0.00094212  0.00368267]  
 [-0.0148606 -0.99988268  0.00371296  0.00796682]  
 [-0.00088685  0.00372655  0.99999266 -0.00133201]  
 [ 0.          0.          0.          1.        ]]
```

T\_ic: (cam1 to imu0):

```
[[-0.99988918 -0.0148606 -0.00088685  0.00379947]  
 [ 0.0148572 -0.99988268  0.00372655  0.00791613]  
 [-0.00094212  0.00371296  0.99999266  0.00130589]  
 [ 0.          0.          0.          1.        ]]
```

timeshift cam1 to imu0: [s] ( $t_{imu} = t_{cam} + \text{shift}$ )  
-0.008963187315341372

Baselines:

-----  
Baseline (cam0 to cam1):

```
[[ 0.9999885  0.00045301 -0.00477531 -0.08990597]  
 [-0.00043522  0.99999296  0.0037268 -0.00164377]  
 [ 0.00477697 -0.00372468  0.99998165 -0.00016215]  
 [ 0.          0.          0.          1.        ]]
```

baseline norm: 0.08992113712750682 [m]

Gravity vector in target coords: [m/s<sup>2</sup>]

```
[ 0.0584574  0.00827899 -9.80637227]
```

cam0

-----

Camera model: pinhole

Focal length: [714.0155155095808, 716.5436873123501]

Principal point: [389.58301567508346, 279.0643166030217]

Distortion model: radtan

Distortion coefficients: [0.20455888191405258, -0.5256185051219774, -0.0020612586844235836, -0.0004

Type: checkerboard

Rows

Count: 5

Distance: 0.12 [m]

Cols

Count: 8

Distance: 0.12 [m]

cam1

-----

Camera model: pinhole

Focal length: [715.9917039075483, 718.501526994542]

Principal point: [360.60620662077366, 201.69659951558137]

Distortion model: radtan

Distortion coefficients: [0.20737147244731943, -0.5315451315262139, -0.003939382327651133, 0.00033

Type: checkerboard

Rows

Count: 5

Distance: 0.12 [m]

Cols

Count: 8

Distance: 0.12 [m]

IMU configuration

=====

IMU0:

Accelerometer:

Noise density: 0.00224

Noise density (discrete): 0.0480426477205

Random walk: 7.53e-05

Gyroscope:

Noise density: 8.94e-05

Noise density (discrete): 0.0019174163867

Random walk: 2.66e-05

T\_i\_b

[[1. 0. 0. 0.]

[0. 1. 0. 0.]

[0. 0. 1. 0.]

[0. 0. 0. 1.]]

time offset with respect to IMU0: 0.0 [s]

Gyroscope:

M:

[[ 1.00159607 0. 0. ]

[ 0.00063203 1.00055581 0. ]

[-0.00551191 0.00283214 1.00062474]]

A [(rad/s)/(m/s^2)]:

[[ -0.00003112 0.00017375 0.00040171]

[ -0.0003096 0.00005346 0.000036 ]

[ -0.00002698 -0.00007111 0.0001036 ]]

C\_gyro\_i:

[[ 0.99999839 -0.00062465 0.00168513]

[ 0.00061523 0.9999842 0.00558758]

[-0.00168859 -0.00558653 0.99998297]]

Accelerometer:

M:

[[ 1.00200437 0. 0. ]

[ 0.00159025 1.00567212 0. ]

[-0.00189312 -0.0071806 1.00504068]]

IMU1:

-----

Model: scale-misalignment

Update rate: 460.0

Random walk: 7.53e-05  
Gyroscope:  
Noise density: 8.94e-05  
Noise density (discrete): 0.0019174163867  
Random walk: 2.66e-05  
T\_i\_b  
[[-0.99998103 0.00517758 -0.00333646 0.08859576]  
[-0.00514865 -0.99994957 -0.00862207 -0.00139737]  
[-0.00338093 -0.00860472 0.99995726 0.00016911]  
[ 0. 0. 0. 1. ]]

time offset with respect to IMU0: 0.0 [s]

Gyroscope:

M:

[[ 1.00085184 0. 0. ]  
[-0.00080125 0.99562322 0. ]  
[-0.00011602 0.0028861 0.99317244]]

A [(rad/s)/(m/s^2)]:

[[ -0.00008476 0.00016758 -0.00042561]  
[ -0.00029168 0.00001283 -0.00001055]  
[ 0.00003028 0.00008272 0.00011591]]

C\_gyro\_i:

[[ 0.99999481 -0.00171564 0.00272617]  
[ 0.00172325 0.99999462 -0.00279176]  
[-0.00272136 0.00279645 0.99999239]]

Accelerometer:

M:

[[ 1.000658 0. 0. ]  
[ 0.00154793 1.00532047 0. ]  
[-0.0035431 0.00673658 1.0048592 ]]

IMU2:

-----  
Model: scale-misalignment

Update rate: 460.0

Accelerometer:

Noise density: 0.00224

Noise density (discrete): 0.0480426477205

Noise density (discrete): 0.0019174163867

Random walk: 2.66e-05

T\_i\_b

```
[[ 0.99987453 -0.01344225 0.00838002 -0.00020117]
 [ 0.01348046 0.99989892 -0.00452029 0.01406235]
 [-0.00831841 0.00463269 0.99995467 0.00004206]
 [ 0.         0.         0.         1.        ]]
```

time offset with respect to IMU0: 0.0 [s]

Gyroscope:

M:

```
[[ 0.99923901 0.         0.         ]
 [ 0.00197601 0.99492285 0.         ]
 [-0.00221291 -0.00584495 0.99863564]]
```

A [(rad/s)/(m/s^2)]:

```
[[ -0.00004136 0.0001812 0.00043866]
 [ -0.00031307 0.00003205 0.00001691]
 [ -0.00003925 -0.0000837 0.00013695]]
```

C\_gyro\_i:

```
[[ 0.99999898 0.00018132 -0.00141918]
 [ -0.00017982 0.99999943 0.00105338]
 [ 0.00141937 -0.00105313 0.99999844]]
```

Accelerometer:

M:

```
[[ 1.00169209 0.         0.         ]
 [ 0.00162732 1.00485291 0.         ]
 [ 0.00101031 -0.00735471 1.0011397 ]]
```

IMU3:

-----  
Model: scale-misalignment

Update rate: 460.0

Accelerometer:

Noise density: 0.00224

Noise density (discrete): 0.0480426477205

Random walk: 7.53e-05

Gyroscope:

Noise density: 8.94e-05

```
[[ -0.99996109 0.00817504 0.00331388 0.08889938]
 [ -0.00819298 -0.99995167 -0.00543508 0.01244829]
 [ 0.00326929 -0.00546202 0.99997974 0.00032372]
 [ 0.         0.         0.         1.        ]]
```

time offset with respect to IMU0: 0.0 [s]

Gyroscope:

M:

```
[[ 1.0054344 0.         0.         ]
 [-0.0020802 1.00037762 0.         ]
 [ 0.00348791 -0.00272574 1.00042586]]
```

A [(rad/s)/(m/s<sup>2</sup>)]:

```
[[ -0.00005366 0.00018979 -0.00036642]
 [ -0.00029379 0.00003688 -0.00001589]
 [ 0.00003571 0.00007255 0.00012958]]
```

C\_gyro\_i:

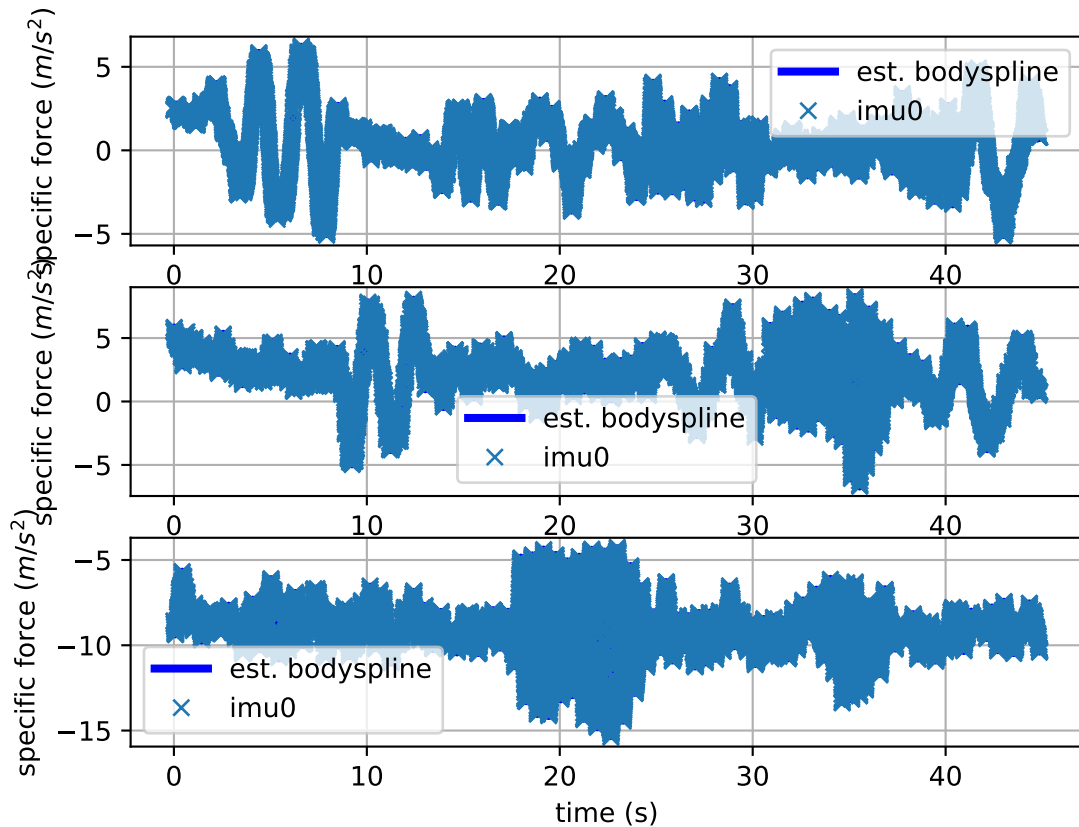
```
[[ 0.99999755 -0.00219424 -0.00028642]
 [ 0.00219307 0.9999894  -0.00404768]
 [ 0.0002953  0.00404704 0.99999177]]
```

Accelerometer:

M:

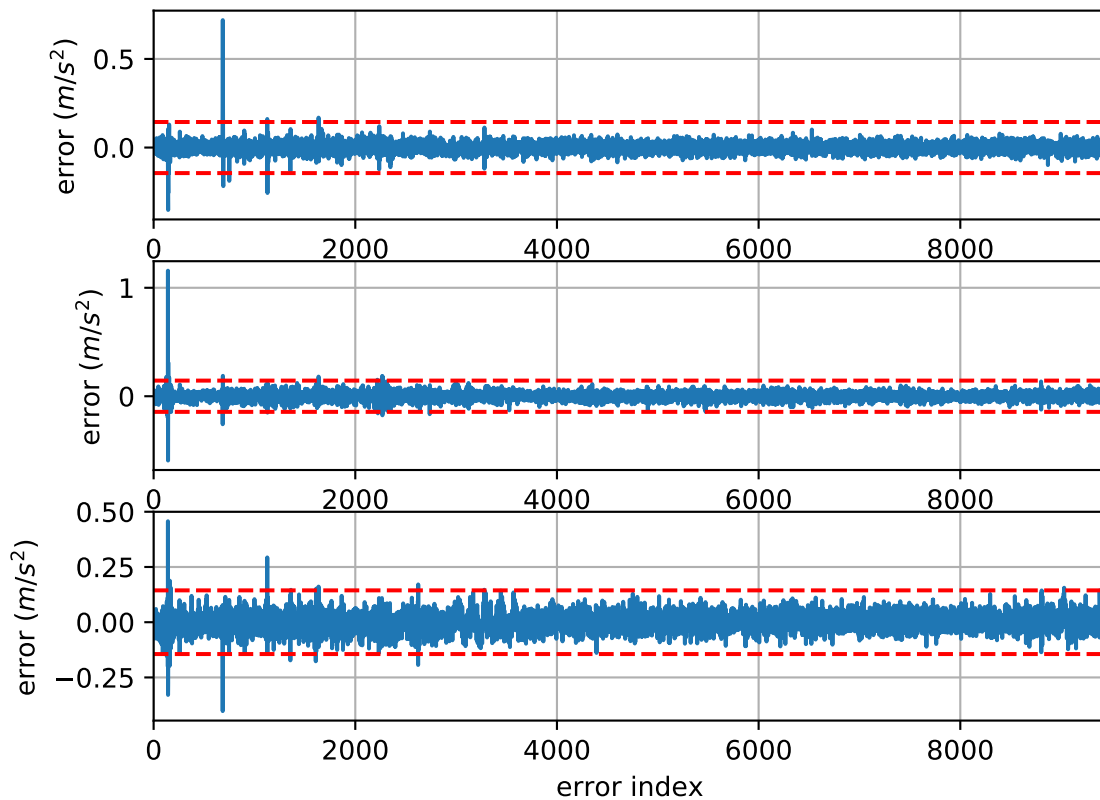
```
[[ 1.00050423 0.         0.         ]
 [ 0.00161436 1.00374656 0.         ]
 [-0.00011382 0.00512601 1.00382725]]
```

Comparison of predicted and measured specific force (imu0 frame)

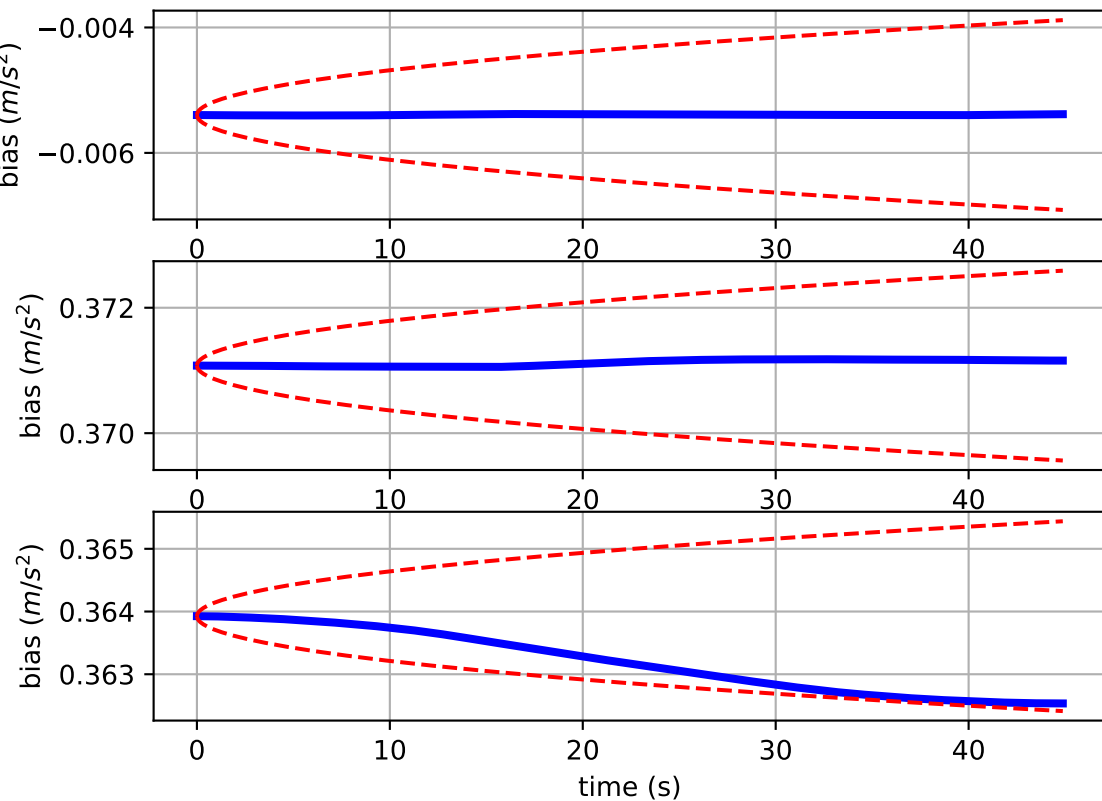




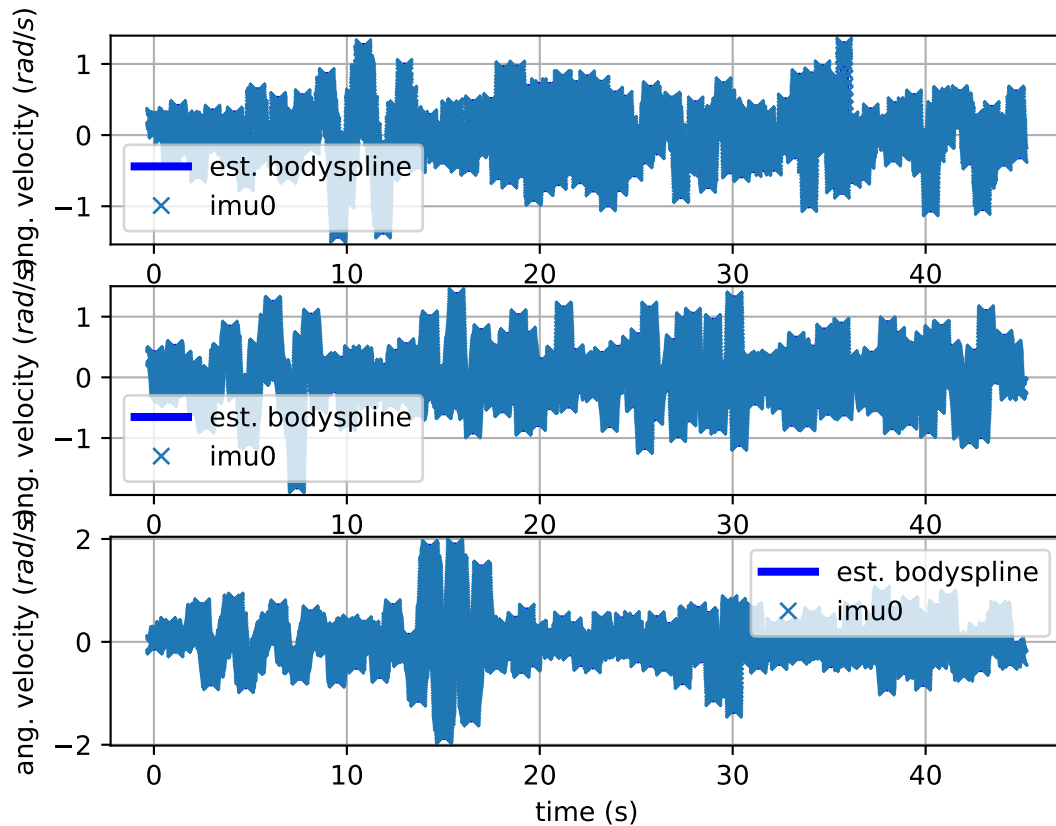
imu0: acceleration error



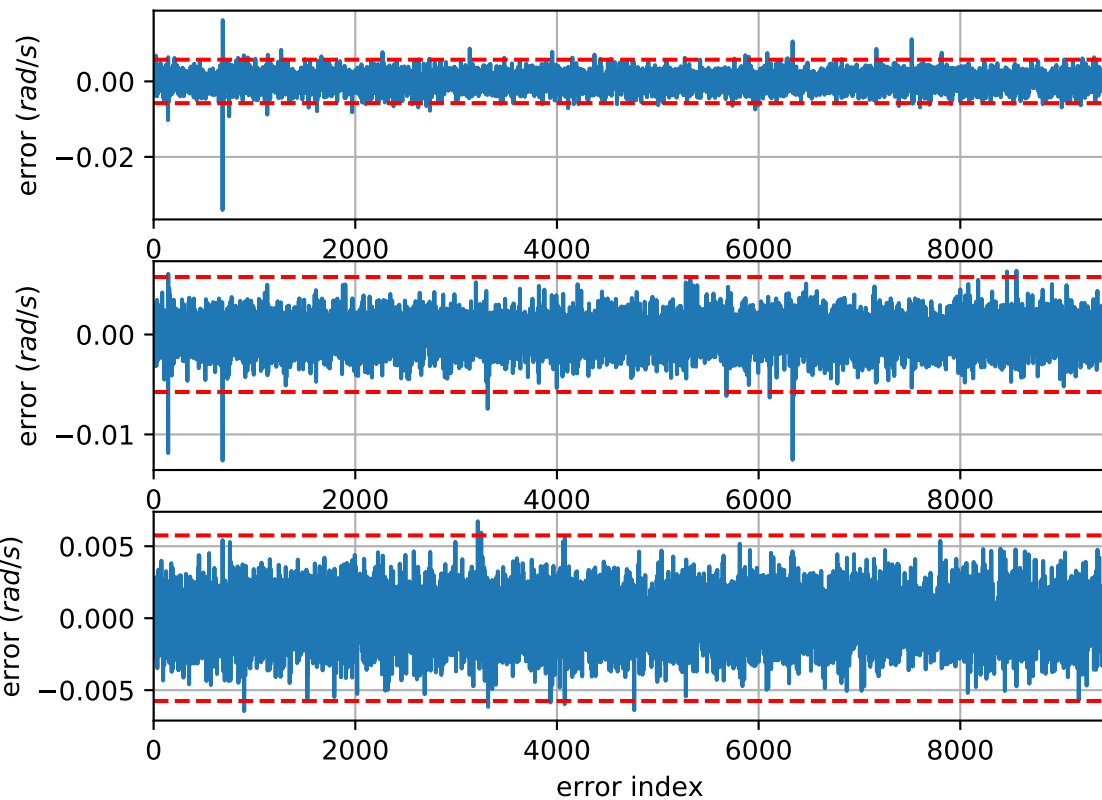
imu0: estimated accelerometer bias (imu frame)



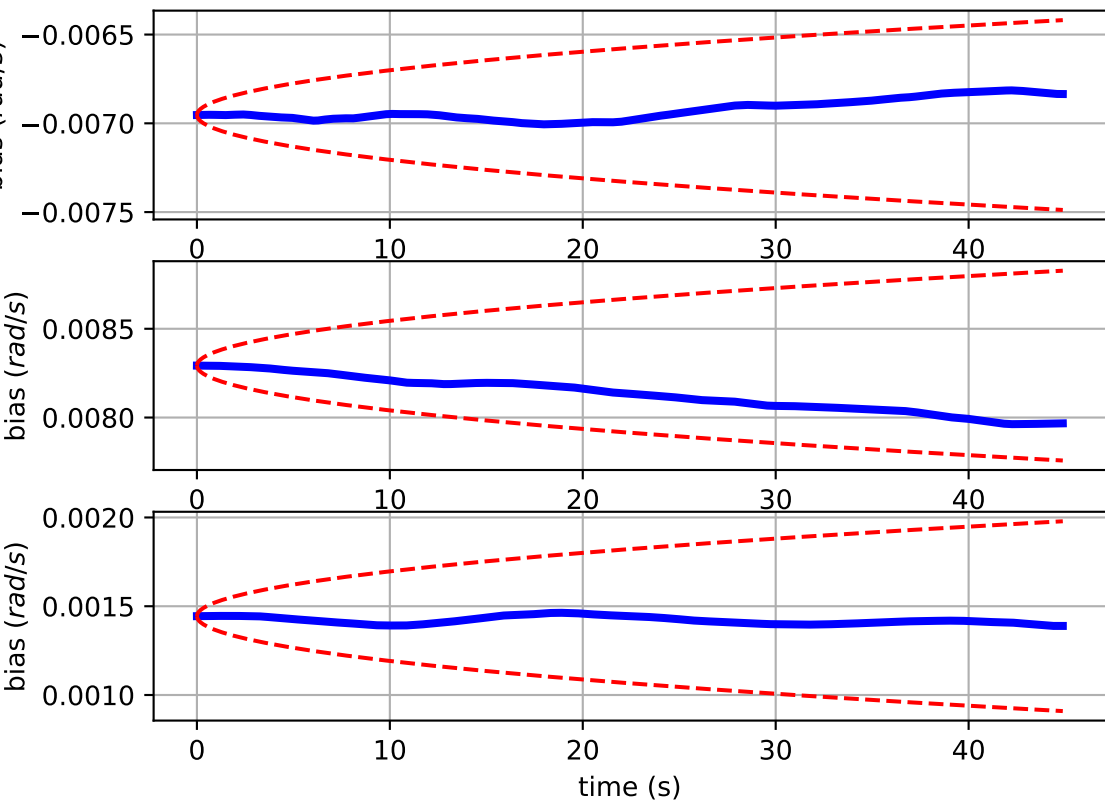
Comparison of predicted and measured angular velocities (body frame)



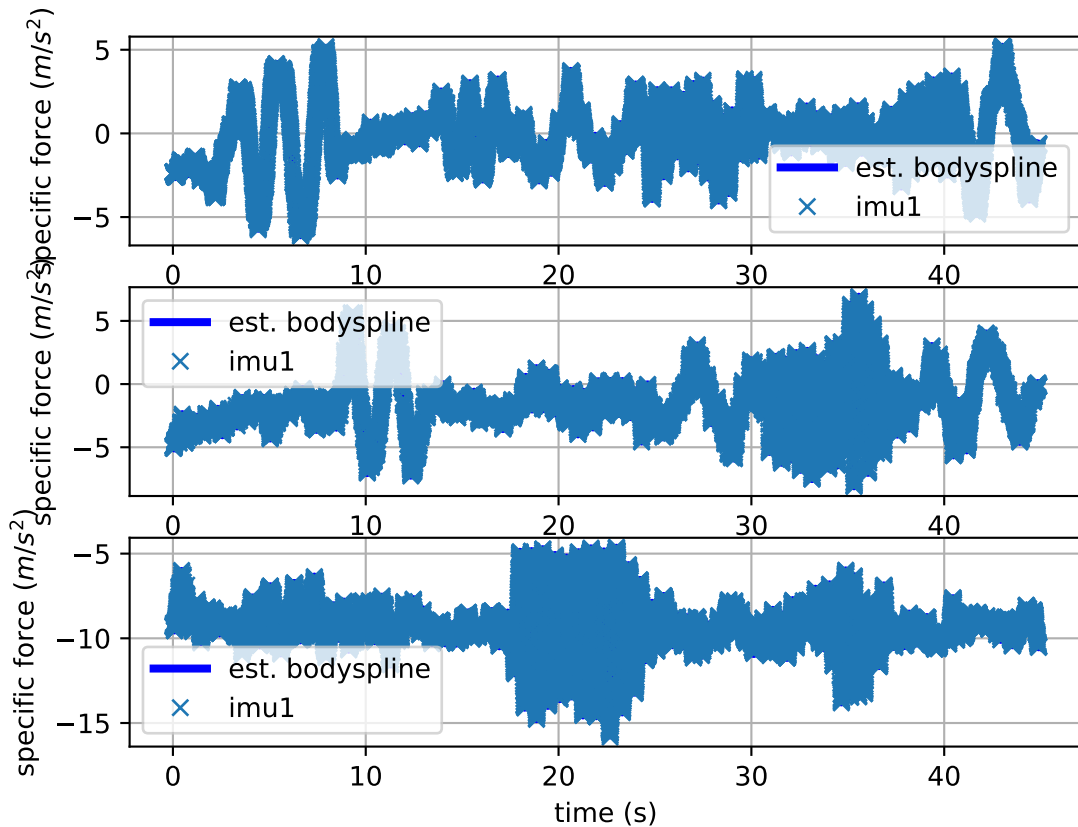
imu0: angular velocities error



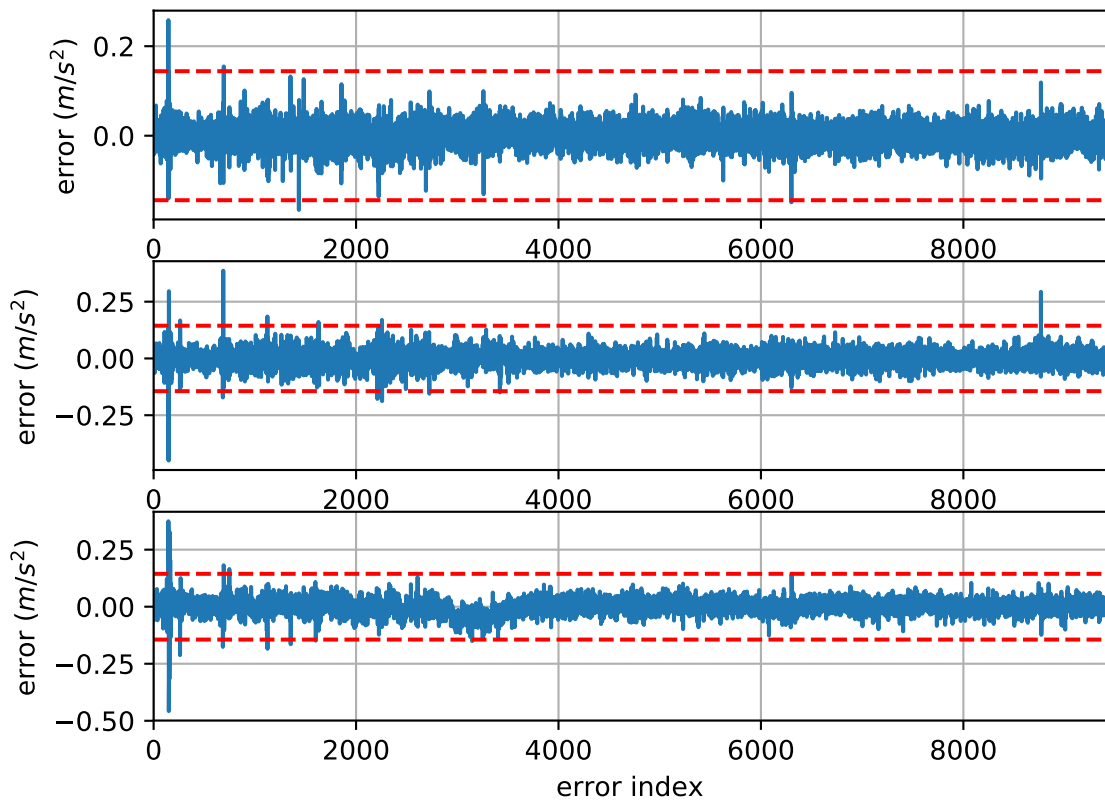
imu0: estimated gyro bias (imu frame)



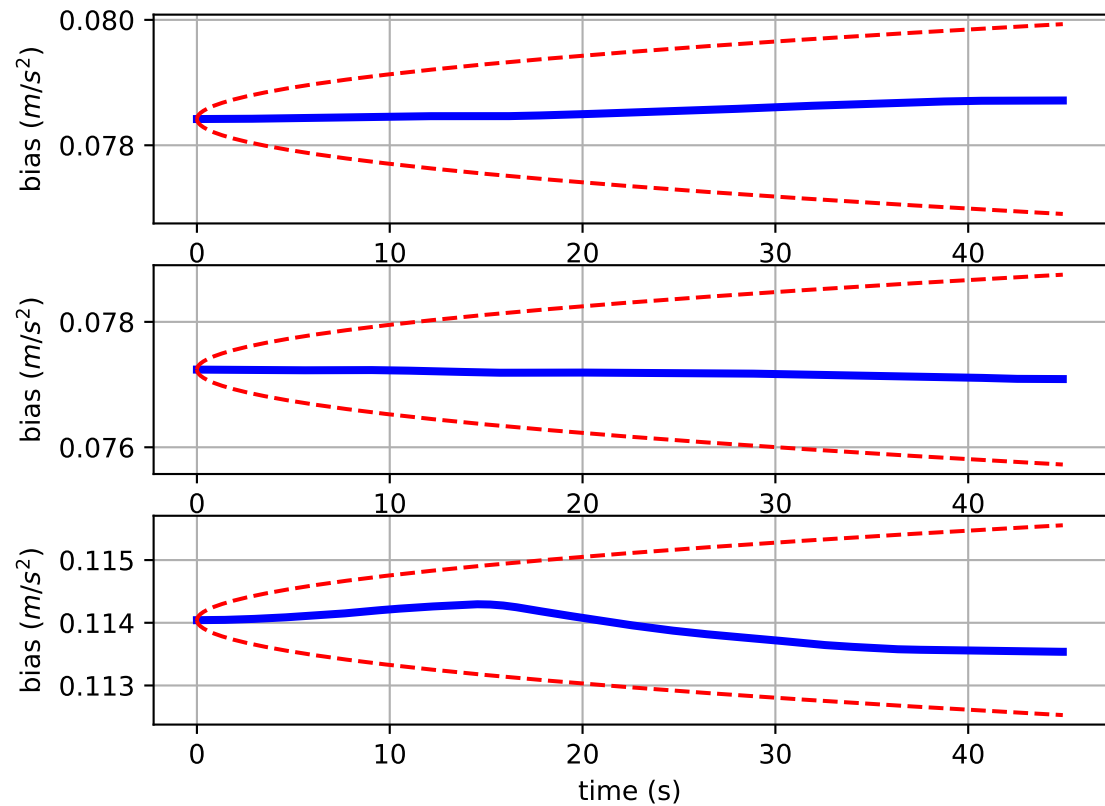
Comparison of predicted and measured specific force (imu0 frame)



imu1: acceleration error

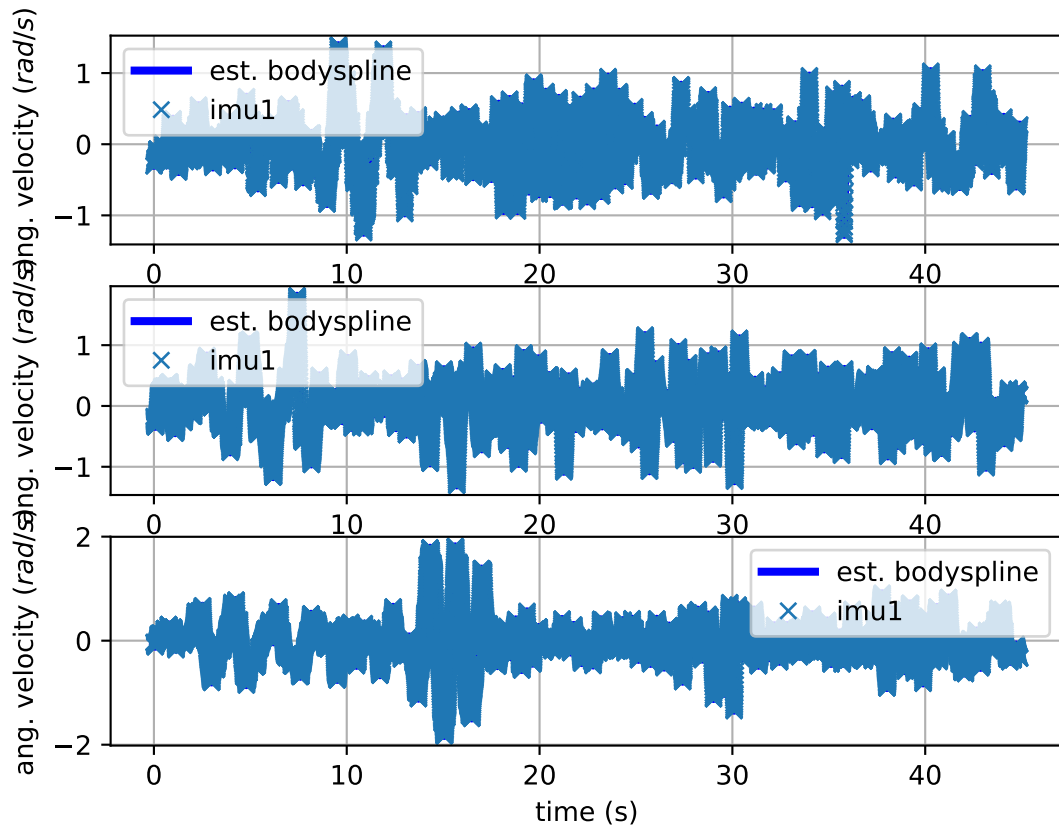


imu1: estimated accelerometer bias (imu frame)

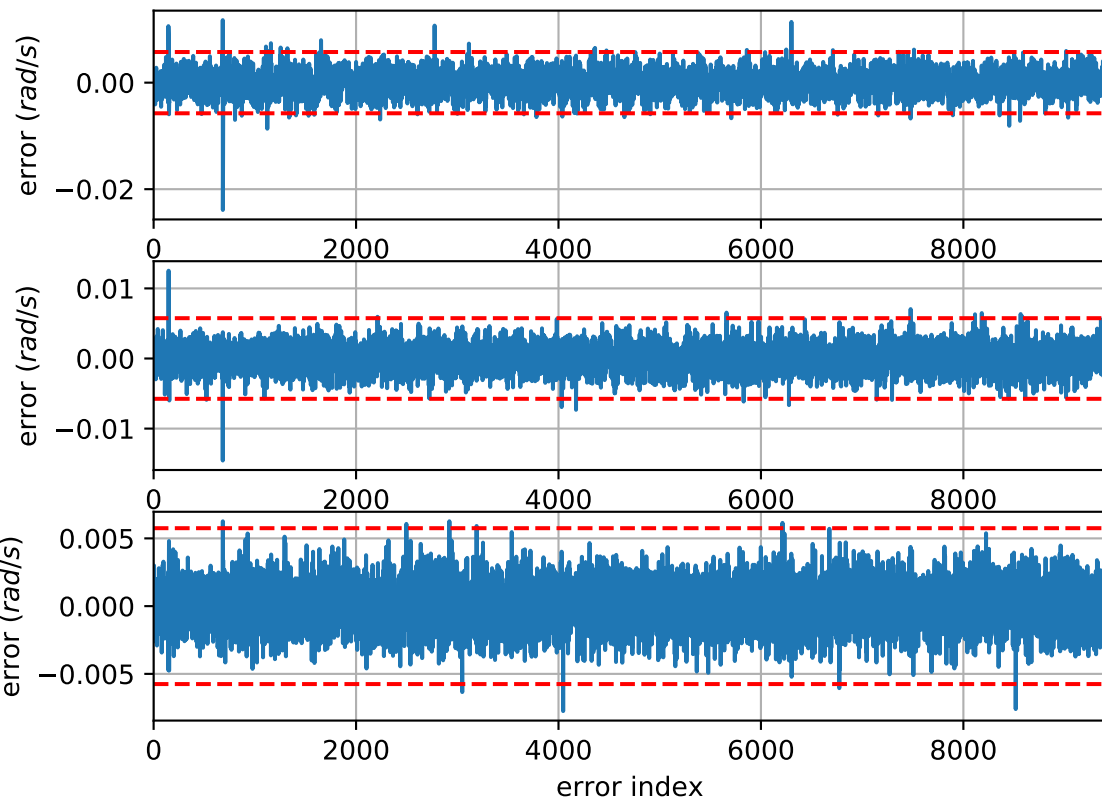




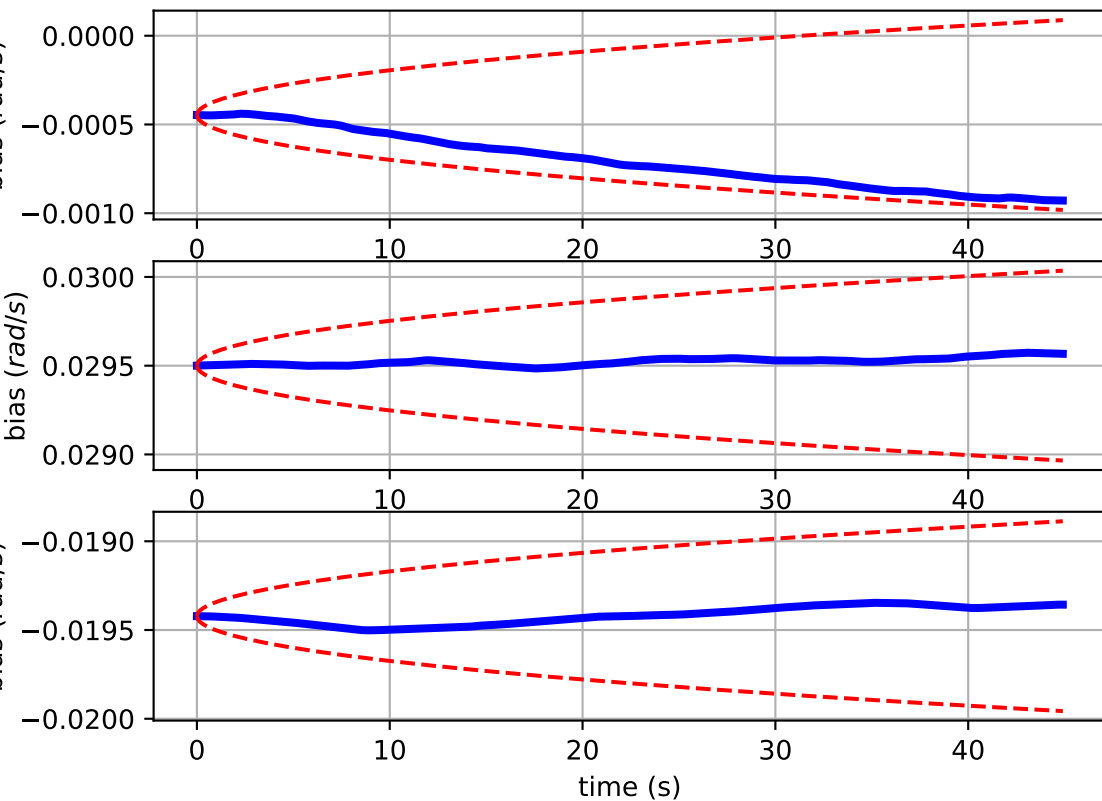
# Comparison of predicted and measured angular velocities (body frame)



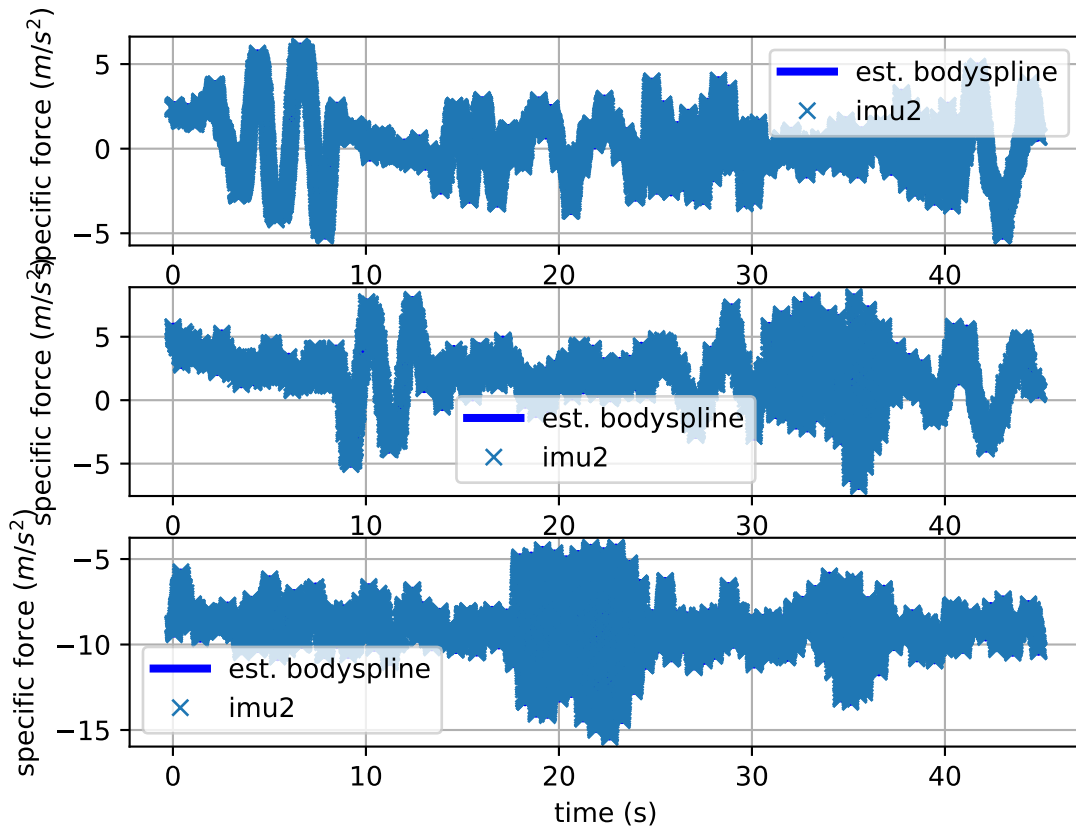
imu1: angular velocities error



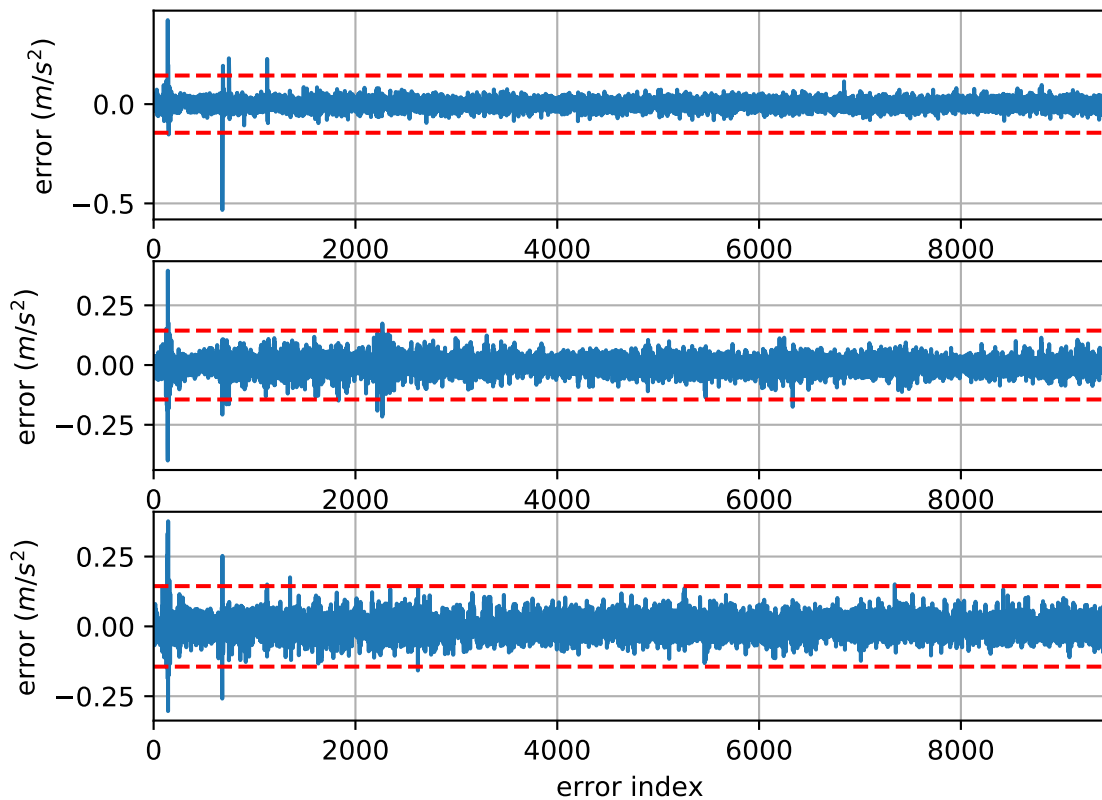
imu1: estimated gyro bias (imu frame)



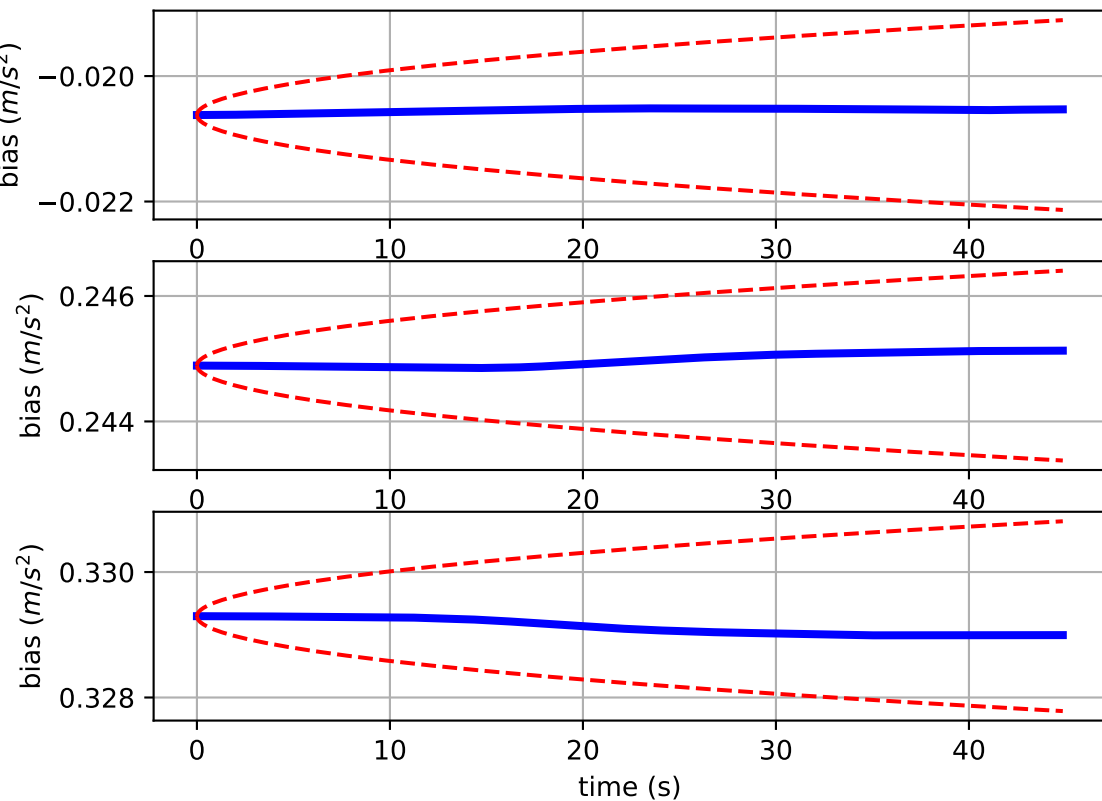
Comparison of predicted and measured specific force (imu0 frame)



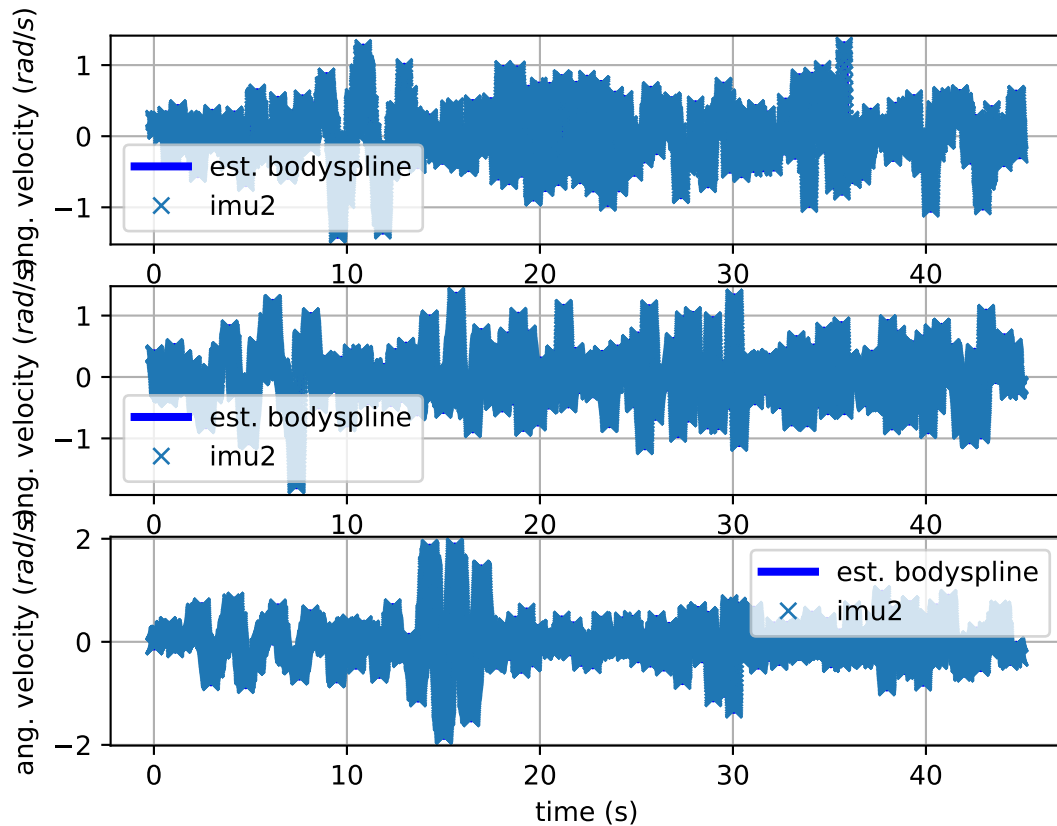
imu2: acceleration error



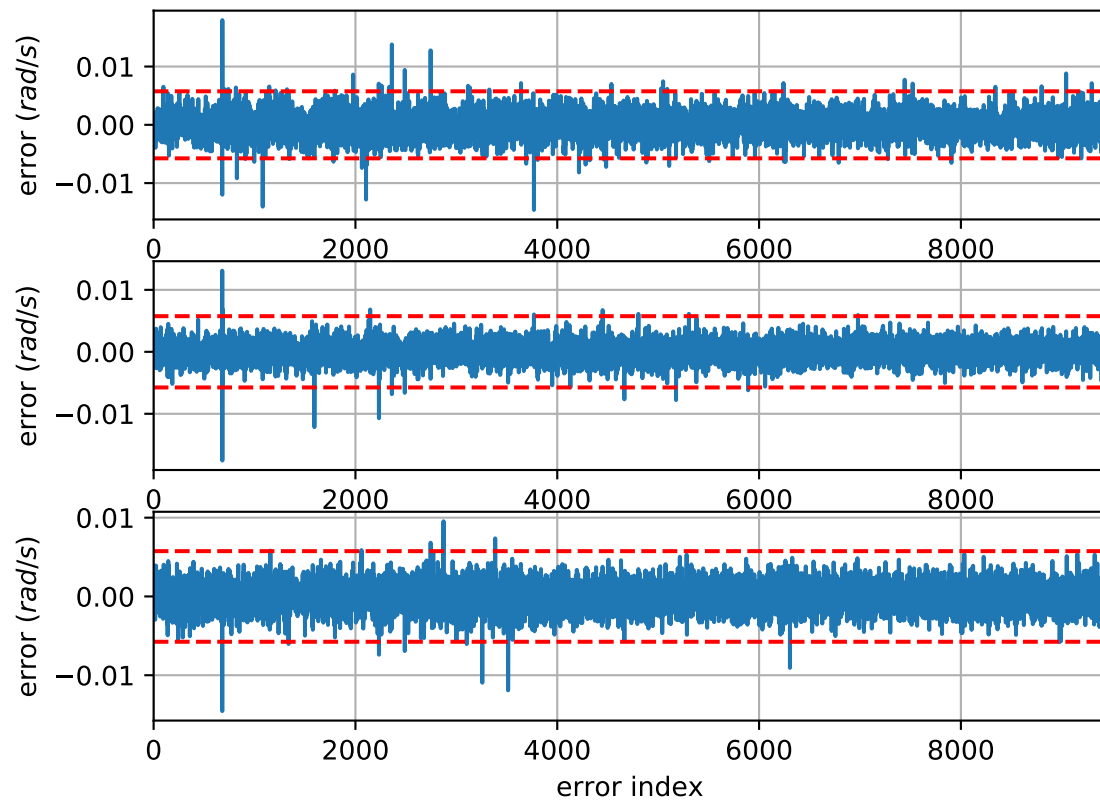
imu2: estimated accelerometer bias (imu frame)



Comparison of predicted and measured angular velocities (body frame)

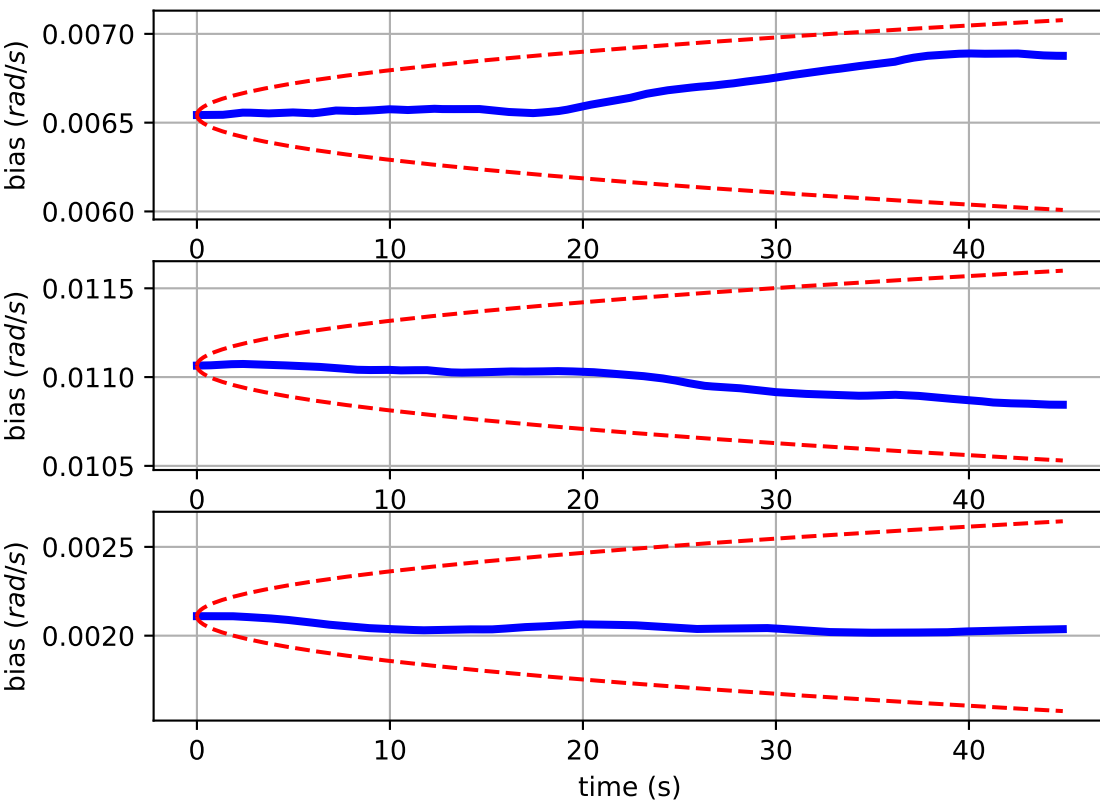


imu2: angular velocities error

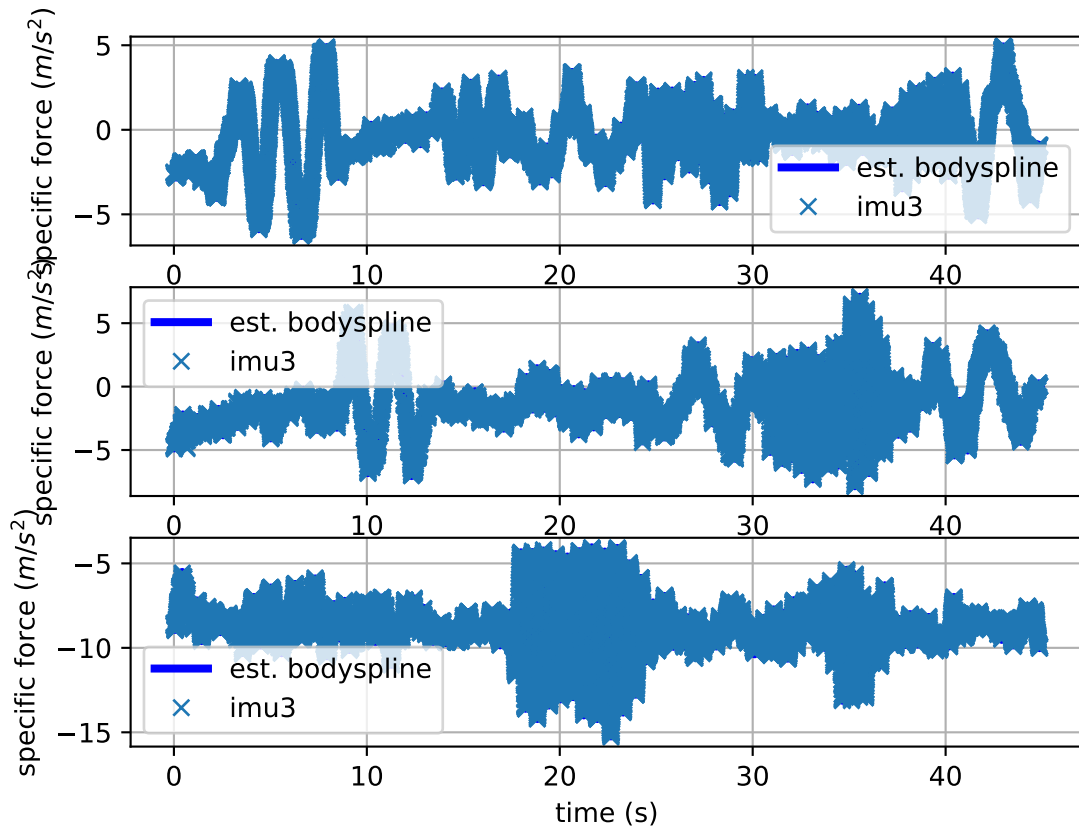




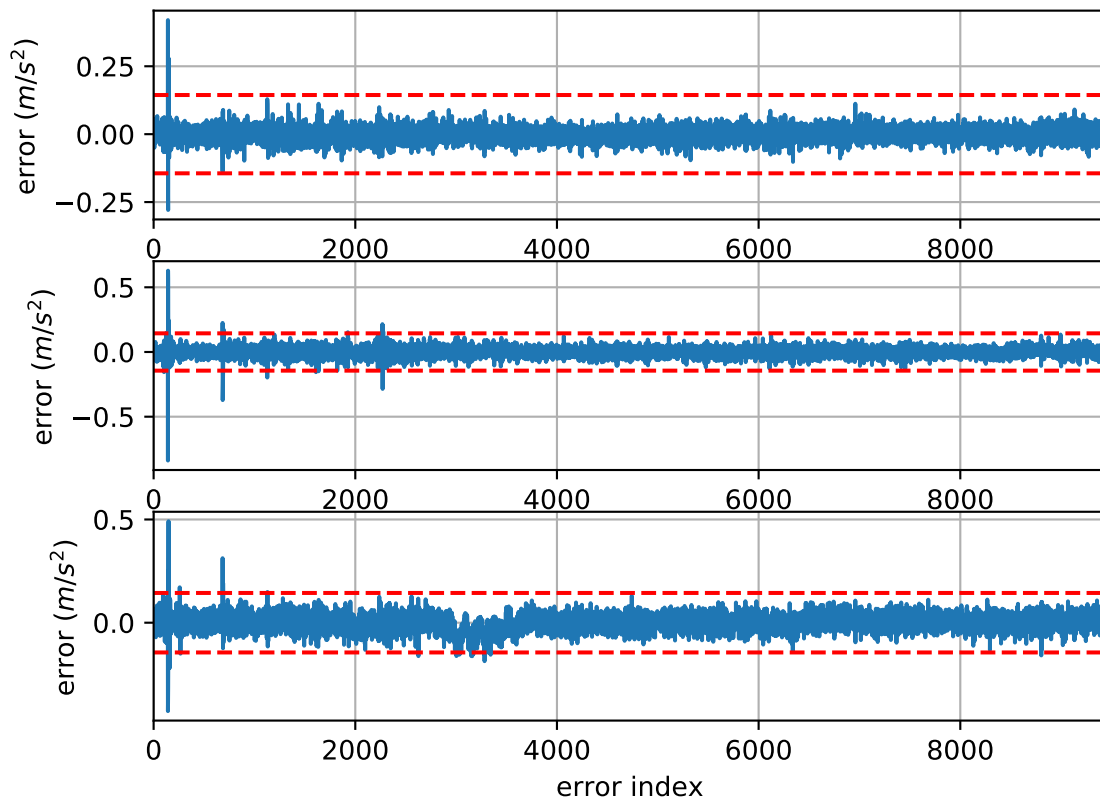
imu2: estimated gyro bias (imu frame)



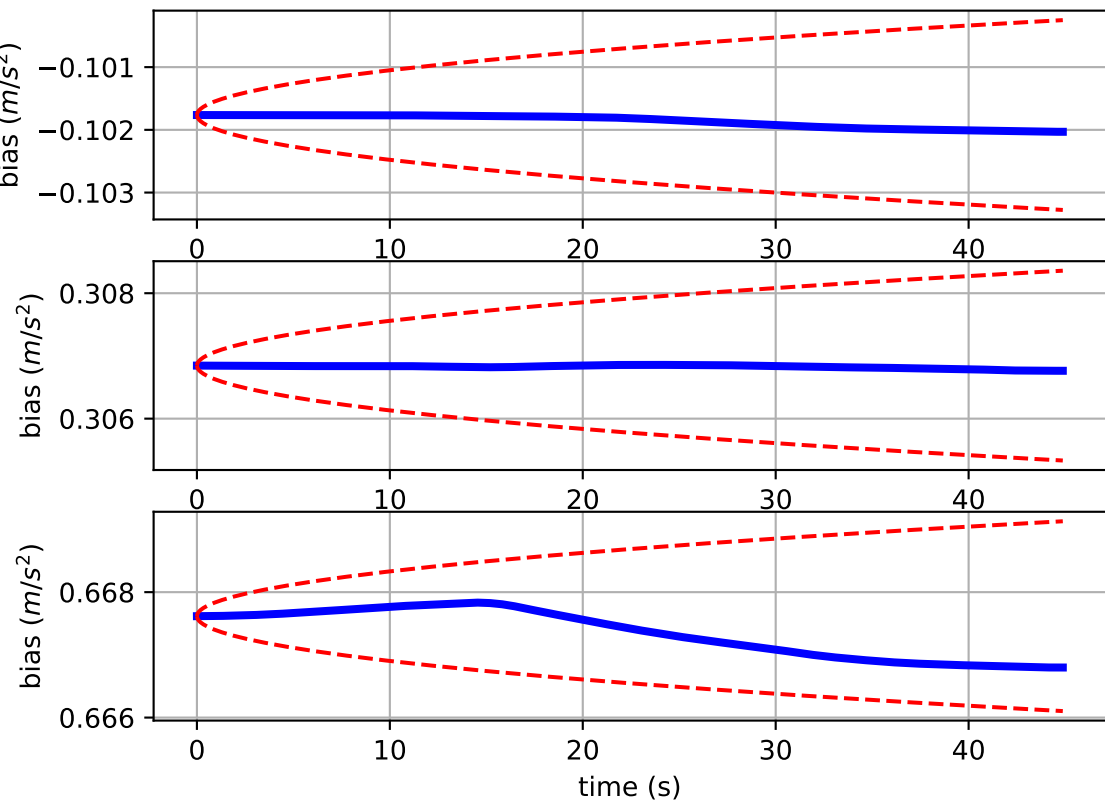
Comparison of predicted and measured specific force (imu0 frame)



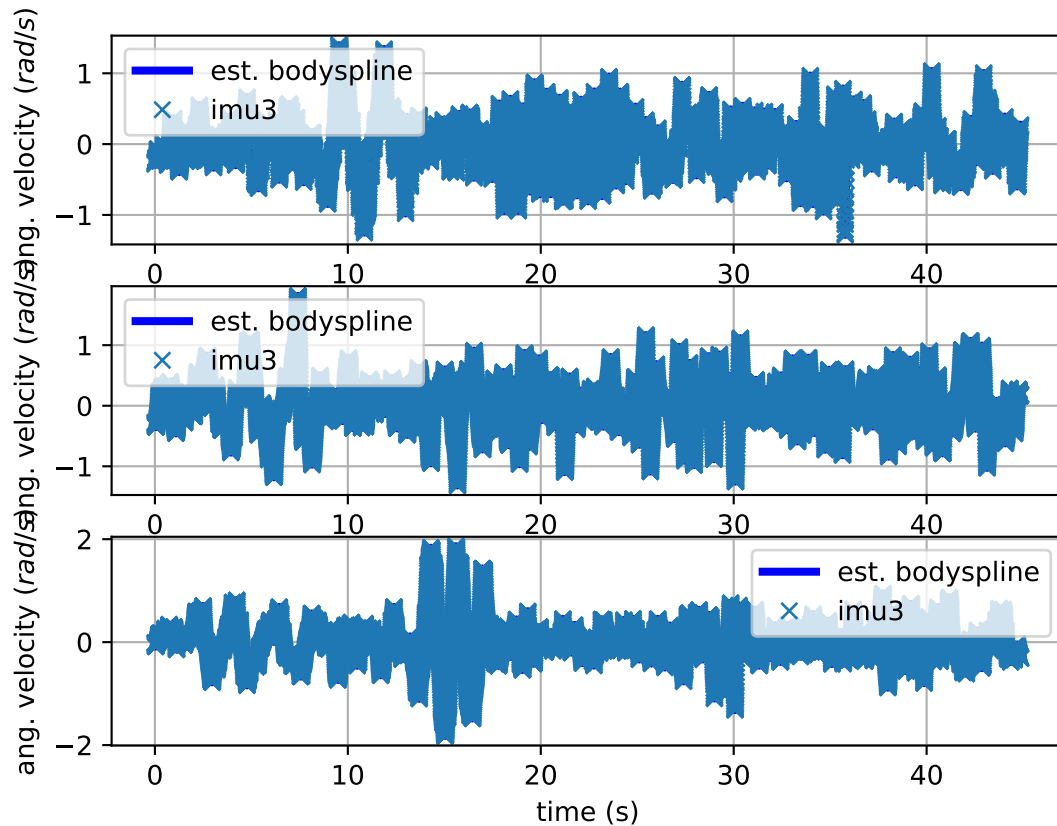
imu3: acceleration error



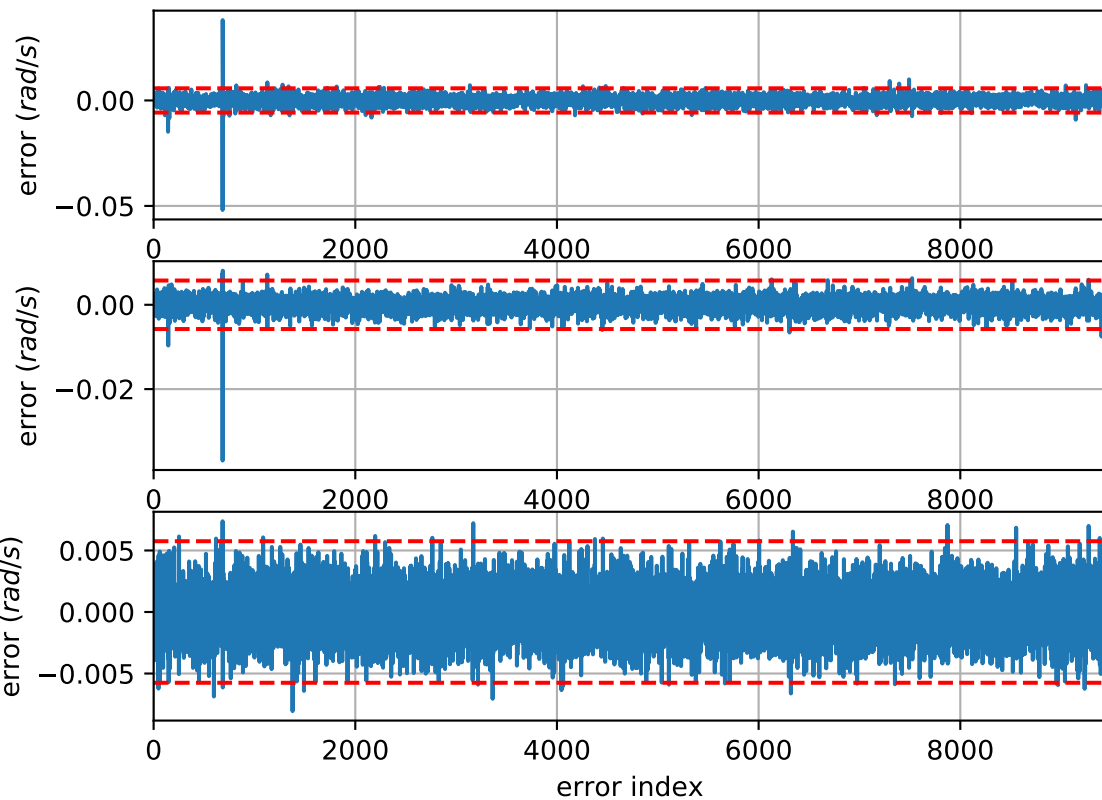
imu3: estimated accelerometer bias (imu frame)



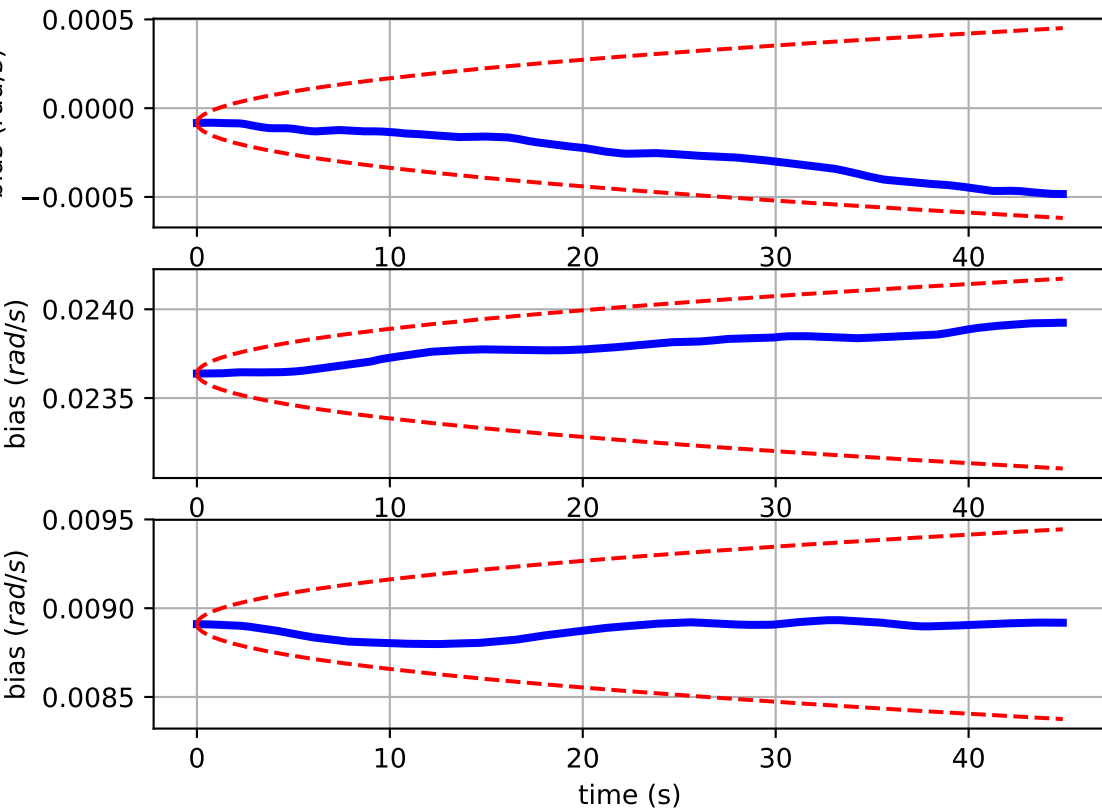
# Comparison of predicted and measured angular velocities (body frame)



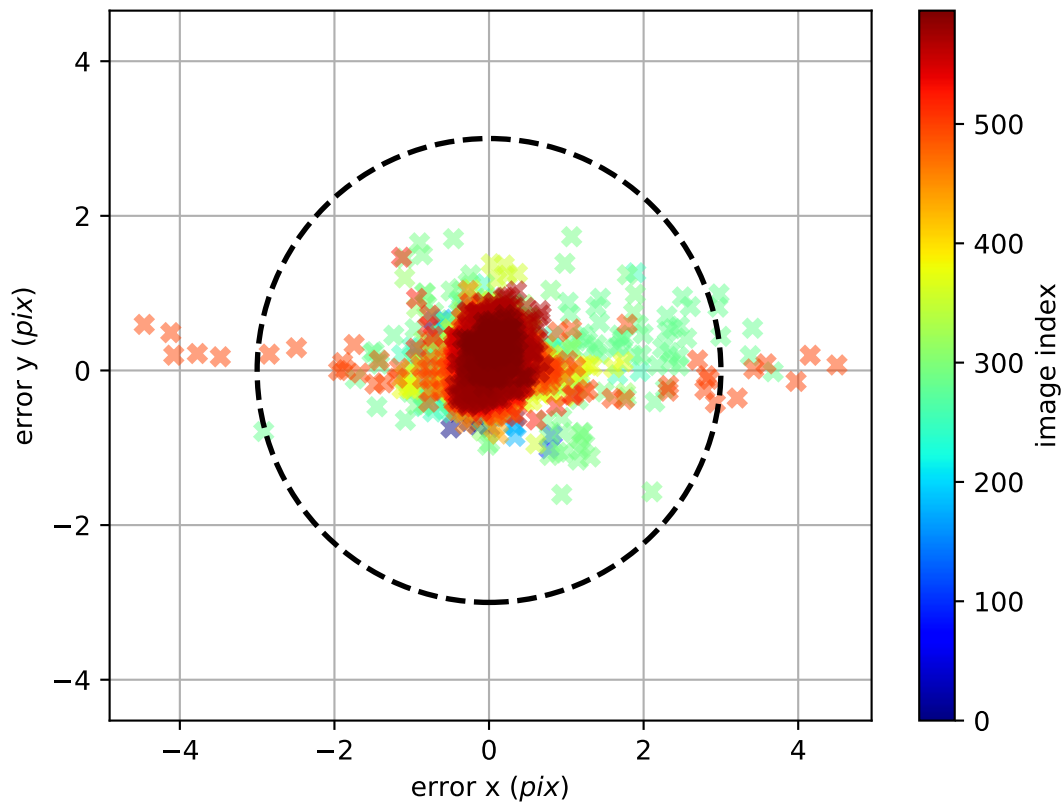
imu3: angular velocities error



imu3: estimated gyro bias (imu frame)



cam0: reprojection errors





cam1: reprojection errors

