# worksheet_tutorial_02_with_output

May 30, 2022

Integrierte Navigation - Tutorial 2: Micro Electro Mechanical Systems (MEMS)

## 1 Description of the task

In this tutorial you'll be thought to post-process inertial measurement data. The lowest accuracy you'll get when you process data as they are. There are ways to get more accurate soltions (e.g. calibration of the IMU and Zero Velocity updates).

We provied necessary sensors so you could make your own measurements and evaluations in small groups. You should learn the complete workflow.

In the* moodle cours* you will find a guidance, how you connect the Arduino with the MPU and how you can receive and store data for further processing.

After installation from hardware and software as well as data acquisition there are severeal subtasks you have to do throughout the notebook. These tasks should help you to capture the complete workflow.

The notebook shows the workflow from data import, bias calculation and integration of the measured values to visualization and table length calculation.

Subasks are built into the individual sections. A large part of the source code is already given, which is to be supplemented by you. In task 7 you have a free hand to calculate your individual table length and to compare different sensor configurations.

## 2 Importing necessary modules

[ ]:
```
import numpy as np
import matplotlib.pyplot as plt
import prepare_data
import mems
```

## 3 Tasks

### 3.1 Data Upload

The recorded measurement data in an ASCII-file must be uploaded in your personal Google Drive and your jupither notebook needs to be access to your Google Drive. 1. Google Drive - upload your file via drag and drop. 2. Google Colaboratory - click on the folder icon on the left and then on the the Google Drive folder icon. 3. Google Colaboratory - allow the access in the pop up

window. 4. Google Colaboratory - navigate to your uploaded file in the file explorer left. 5. Google Colaboratory - click on the three point next to your file and copy the file path. This you will need for Task 2.

#### 3.1.1 Task 1

Do the upload according to the instructions above or use the jupiter notenbook offline.

### 3.2 Import data

After the upload, we have to load the data in the notebook. It is practically to store all data in one array. The values for time, acceleration and turn rates seperated in differend collums and for each timestamp in seperate rows.

> ***Note:*** The timestamp is not unixtime, rather it is the time in milliseconds from the beginning of the script.

#### 3.2.1 Task 2

Programm the code for the import of your measurement data:

> ***Tipp:*** Change the [...] to your own values.
>
> ***Tipp:*** For that purpose you can use the function `loadtxt` from the `numpy` library.

[ ]:
```
# location = '...your file path from task 1 point 5...'
# data = np.loadtxt(location, delimiter='...', skiprows=...)
# data[:,0] = TIME | data[:,1] = ACC_X | data[:,2] = ACC_Y | data[:,3] = ACC_Z␣
↪| data[:,4] = GYR_X | data[:,5] = GYR_Y | data[:,6] = GYR_Z
files = ["data_track_01.csv",
         "data_track_02.csv",
         "data_track_03.csv",
         "data_track_04.csv",
         "data_track_05.csv",
         "data_track_06.csv",
         "data_track_07.csv",
         "data_track_08.csv",
         "data_track_09.csv",
         "data_track_10.csv",
         "data_track_12.csv",
         "data_track_13.csv",
         "data_turntable_01.csv",
         "data_turntable_02.csv",
         "data_turntable_03.csv",
         "data_turntable_04.csv",
         "data_turntable_05.csv",
         "data_turntable_06.csv",
         "data_turntable_07.csv",
         "data_turntable_08.csv",
         "data_turntable_09.csv",
```

```
        "data_turntable_10.csv",
        "data_turntable_11.csv",
        "data_turntable_12.csv"]
measurements = []
for filename in files:
    measurements.append(mems.import_data(filename))
```

### 3.3 Bias determination

After the import of the data, we have to determin the bias from a small dataset of the first values of the measurement. For that purpose you made the short initialisation break (approx. 10 to 20 sconds) in front of the movement along the table edge.

#### 3.3.1 Task 3

Programm the code for the bias determination of your measurement data:

> ***Tipp:*** Change the [...] to your own values.
>
> ***Tipp:*** The `numpy` library has also for that task an easy solution.

[ ]:
```
# value = ...
# bias = np.array([np.mean(data[1:value,1]), np.mean(data[1:value,2]), ... ])
# bias[:,0] = ACC_X | bias[:,1] = ACC_Y | bias[:,2] = ACC_Z | bias[:,3] = GYR_X␣
 ↪| bias[:,4] = GYR_Y | bias[:,5] = GYR_Z
# Acceleration in [m/s^2]
# Turning rates in [°/s]

stationary_parts = [{"before": {"start": 15, "end": 710}, "after": {"start":␣
 ↪1125, "end": 1654}},
                    {"before": {"start": 7, "end": 597}, "after": {"start":␣
 ↪973, "end": 1320}},
                    {"before": {"start": 11, "end": 485}, "after": {"start":␣
 ↪923, "end": 1691}},
                    {"before": {"start": 7, "end": 522}, "after": {"start":␣
 ↪772, "end": 1467}},
                    {"before": {"start": 7, "end": 250}, "after": {"start":␣
 ↪821, "end": 1321}},
                    {"before": {"start": 16, "end": 300}, "after": {"start":␣
 ↪939, "end": 1391}},
                    {"before": {"start": 16, "end": 509}, "after": {"start":␣
 ↪1438, "end": 2041}},
                    {"before": {"start": 34, "end": 548}, "after": {"start":␣
 ↪1914, "end": 2338}},
                    {"before": {"start": 14, "end": 556}, "after": {"start":␣
 ↪1535, "end": 2229}},
                    {"before": {"start": 23, "end": 432}, "after": {"start":␣
 ↪1931, "end": 2294}},
```

```
                    {"before": {"start": 17, "end": 576}, "after": {"start":␣
↪1658, "end": 1999}},
                    {"before": {"start": 23, "end": 392}, "after": {"start":␣
↪1503, "end": 2348}},
                    {"before": {"start": 452, "end": 2574}, "after": {"start":␣
↪5262, "end": 5583}},
                    {"before": {"start": 38, "end": 1427}, "after": {"start":␣
↪3621, "end": 3802}},
                    {"before": {"start": 24, "end": 768}, "after": {"start":␣
↪2365, "end": 2840}},
                    {"before": {"start": 17, "end": 589}, "after": {"start":␣
↪2250, "end": 2406}},
                    {"before": {"start": 12, "end": 617}, "after": {"start":␣
↪1642, "end": 1879}},
                    {"before": {"start": 21, "end": 1967}, "after": {"start":␣
↪2901, "end": 3004}},
                    {"before": {"start": 7, "end": 140}, "after": {"start":␣
↪1405, "end": 1645}},
                    {"before": {"start": 4, "end": 213}, "after": {"start":␣
↪1249, "end": 1304}},
                    {"before": {"start": 10, "end": 818}, "after": {"start":␣
↪1762, "end": 1834}},
                    {"before": {"start": 9, "end": 389}, "after": {"start":␣
↪1760, "end": 1820}},
                    {"before": {"start": 6, "end": 354}, "after": {"start":␣
↪1245, "end": 1346}},
                    {"before": {"start": 6, "end": 202}, "after": {"start":␣
↪1158, "end": 1406}}]

accelerometer_all = []
gyroscope_all = []
timestamps_all = []
accelerometer_bias_all = []
gyroscope_bias_all = []
accelerometer_without_bias_all = []
gyroscope_without_bias_all = []

# Put Measurement-data into data-streams for gyroscope and accelerometer
for measurement_id, data in enumerate(measurements):
    accelerometer = {"x": [], "y": [], "z": []}
    gyroscope = {"x": [], "y": [], "z": []}
    timestamps = []
    for sensor_info in data:
        timestamps.append(sensor_info[0]/1000)
        for j, e in enumerate(["x", "y", "z"]):
            accelerometer[e].append(sensor_info[j+1])
```

```
            gyroscope[e].append(sensor_info[j+4])

    # Determine the biases before and after the movement for the accelerometer
    accelerometer_bias = {"before": {"x": 0.0, "y": 0.0, "z": 0.0},
                          "after": {"x": 0.0, "y": 0.0, "z": 0.0}}
    for i in ["before", "after"]:
        for xyz in ["x", "y", "z"]:
            accelerometer_bias[i][xyz] = mems.calc_offset(accelerometer[xyz],
                                                          ␣
↪stationary_parts[measurement_id][i]["start"],
                                                          ␣
↪stationary_parts[measurement_id][i]["end"])

    # Determine the biases before and after the movement for the gyroscope
    gyroscope_bias = {"before": {"x": 0.0, "y": 0.0, "z": 0.0},
                      "after": {"x": 0.0, "y": 0.0, "z": 0.0}}
    for i in ["before", "after"]:
        for xyz in ["x", "y", "z"]:
            gyroscope_bias[i][xyz] = mems.calc_offset(gyroscope[xyz],
                                                      ␣
↪stationary_parts[measurement_id][i]["start"],
                                                      ␣
↪stationary_parts[measurement_id][i]["end"])

    accelerometer_without_bias = {"x": [], "y": [], "z": []}
    gyroscope_without_bias = {"x": [], "y": [], "z": []}

    for xyz in ["x", "y", "z"]:
        accelerometer_without_bias[xyz] = mems.
↪remove_bias_advanced(accelerometer[xyz],
                                                              ␣
↪accelerometer_bias["before"][xyz],
                                                              ␣
↪accelerometer_bias["after"][xyz],
                                                              ␣
↪stationary_parts[measurement_id]["before"]["end"],
                                                              ␣
↪stationary_parts[measurement_id]["after"]["start"])
        gyroscope_without_bias[xyz] = mems.remove_bias_advanced(gyroscope[xyz],
                                                                ␣
↪gyroscope_bias["before"][xyz],
                                                                ␣
↪gyroscope_bias["after"][xyz],
                                                                ␣
↪stationary_parts[measurement_id]["before"]["end"],
```

```
↪stationary_parts[measurement_id]["after"]["start"])

    accelerometer_all.append(accelerometer)
    gyroscope_all.append(gyroscope)
    timestamps_all.append(timestamps)
    accelerometer_bias_all.append(accelerometer_bias)
    gyroscope_bias_all.append(gyroscope_bias)
    accelerometer_without_bias_all.append(accelerometer_without_bias)
    gyroscope_without_bias_all.append(gyroscope_without_bias)

# print("Biases of the Accelerometer:")
# for i in accelerometer_bias_all:
#     print(f'before: {i["before"]["x"]:15.10f} {i["before"]["y"]:15.10f}
↪{i["before"]["z"]:15.10f}    after: {i["after"]["x"]:15.10f}
↪{i["after"]["y"]:15.10f} {i["after"]["z"]:15.10f}')

# print("Biases of the Gyroscope:")
# for i in gyroscope_bias_all:
#     print(f'before: {i["before"]["x"]:15.10f} {i["before"]["y"]:15.10f}
↪{i["before"]["z"]:15.10f}    after: {i["after"]["x"]:15.10f}
↪{i["after"]["y"]:15.10f} {i["after"]["z"]:15.10f}')
```

## 3.4 Integration of acceleration

### 3.4.1 Velocity

Now we are going to integrate the accelerations to velocity by the given formula:

Formula for velocity:

$$v_i = v_0 + a_i * \Delta t$$

With: * $v_i$: velocity in $[m/s]$ * $v_0$: initial velocity $[m/s]$ * $a_i$: acceleration in $[m/s^2]$ * $\Delta t$: time difference to previous measurement $_{i-1}$ in $[s]$

### 3.4.2 Position

Formula for position:

$$s_i = s_0 + 0.5 * a_i * \Delta t^2 + v_0 * \Delta t$$

With: * $s_i$: distance $[m]$ * $s_0$: initial position $[m]$ * $a_i$: acceleration in $[m/s^2]$ * $\Delta t$: time difference to previous measurement $_{i-1}$ in $[s]$ * $v_0$: initial velocity $[m/s]$

### 3.4.3 Task 4

Programm the code for the integration of acceleration to velocity and positions by the formulaes above:

***Tipp:*** Change the [...] to your own values.

***Tipp:*** For this task with many iterations, `loops` makes your live easier.

[ ]:
```
"""
x_v = np.zeros((3, len(data[:,0])))
x_d = np.zeros((3, len(data[:,0])))

for i in range(1, len(data[:,0])):
    dt = ...

    # velocity [m/s]
    x_v[0,i] = ...
    x_v[1,i] = ...
    x_v[2,i] = ...

    # distances [m]
    x_d[0,i] = ...
    x_d[1,i] = ...
    x_d[2,i] = ...
"""
velocity_all = []
velocity_without_bias_all = []
position_all = []

for measurement_id, e in enumerate(timestamps_all):
    velocity_all.append(mems.
 ↪calc_velocity(accelerometer_without_bias_all[measurement_id], e))

    # Determine offset of velocity before and after movement
    velocity_offset = {"before": {"x": 0.0, "y": 0.0, "z": 0.0},
                       "after": {"x": 0.0, "y": 0.0, "z": 0.0}}
    for i in ["before", "after"]:
        for xyz in ["x", "y", "z"]:
            velocity_offset[i][xyz] = mems.
 ↪calc_offset(velocity_all[measurement_id][xyz],
                                                          ␣
 ↪stationary_parts[measurement_id][i]["start"],
                                                          ␣
 ↪stationary_parts[measurement_id][i]["end"])

    # Remove offset of velocity before and after movement
    velocity_without_bias = {"x": [], "y": [], "z": []}
    for xyz in ["x", "y", "z"]:
        velocity_without_bias[xyz] = mems.
 ↪remove_bias_advanced(velocity_all[measurement_id][xyz],
```

```
                                                                        ␣
↪velocity_offset["before"][xyz],
                                                                        ␣
↪velocity_offset["after"][xyz],
                                                                        ␣
↪stationary_parts[measurement_id]["before"]["end"],
                                                                        ␣
↪stationary_parts[measurement_id]["after"]["start"])
    velocity_without_bias_all.append(velocity_without_bias)

    # Calculate the position
    position_all.append(mems.
↪calc_position(accelerometer_without_bias_all[measurement_id], e,␣
↪velocity_without_bias))
```

### 3.5 Integration of turn rates

Next, we are going to intgrate the turn rates to angles with the formula for rotation angle:

$$r_i = r_{i-1} + \omega_i * \Delta t$$

With: * $r_i$: rotation angle * $\Delta t$: time difference to previous measurement $_{i-1}$ in $[s]$ * $\omega_i$: rotation rate

#### 3.5.1 Task 5

Programm the code for the integration of turn rates to angles by the formulaes above:

> ***Tipp:*** Change the [...] to your own values.
>
> ***Tipp:*** Also `loops` saves lifetime for this task.

[ ]:
```
# euler = np.zeros((3, len(data[:,0])))

# for i in range(1, len(data[:,0])):
#     dt = ...

#     # degree [°]
#     euler[0,i] = ... # phi
#     euler[1,i] = ... # theta
#     euler[2,i] = ... # psi

rotation_all = []

for measurement_id, e in enumerate(timestamps_all):
    rotation_all.append(mems.
↪calc_rotation(gyroscope_without_bias_all[measurement_id], e))
```

```
trajectory_all = []

for measurement_id, e in enumerate(timestamps_all):
    trajectory_all.append(mems.calc_trajectory(position_all[measurement_id],␣
 ↪rotation_all[measurement_id]))
```

## 3.6 Data visualisation

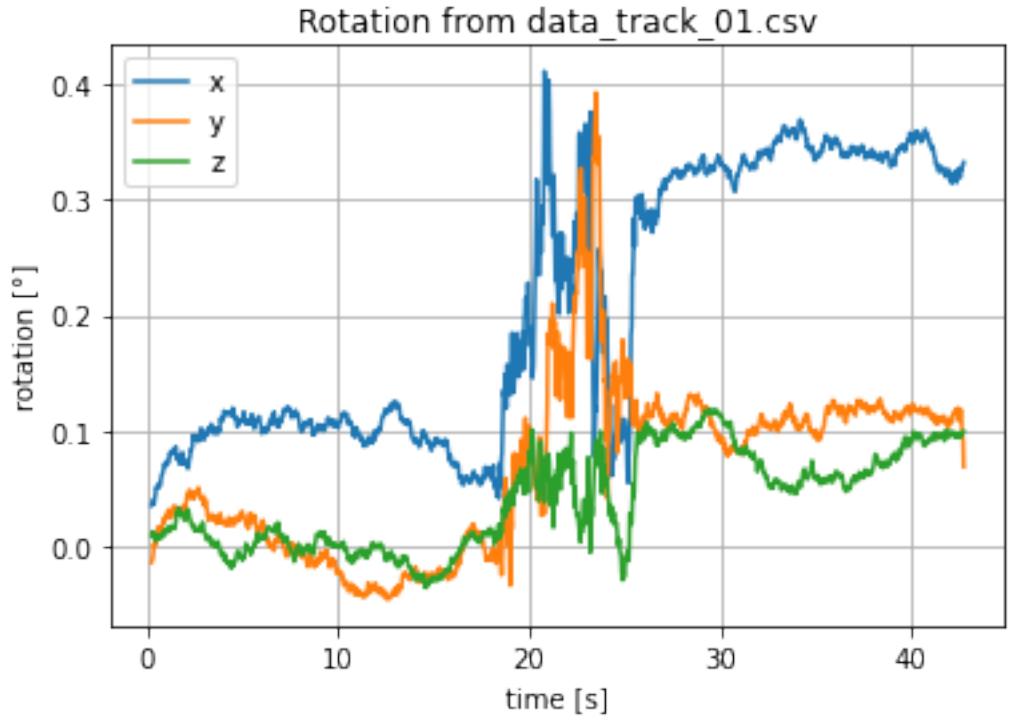
### 3.6.1 Task 6

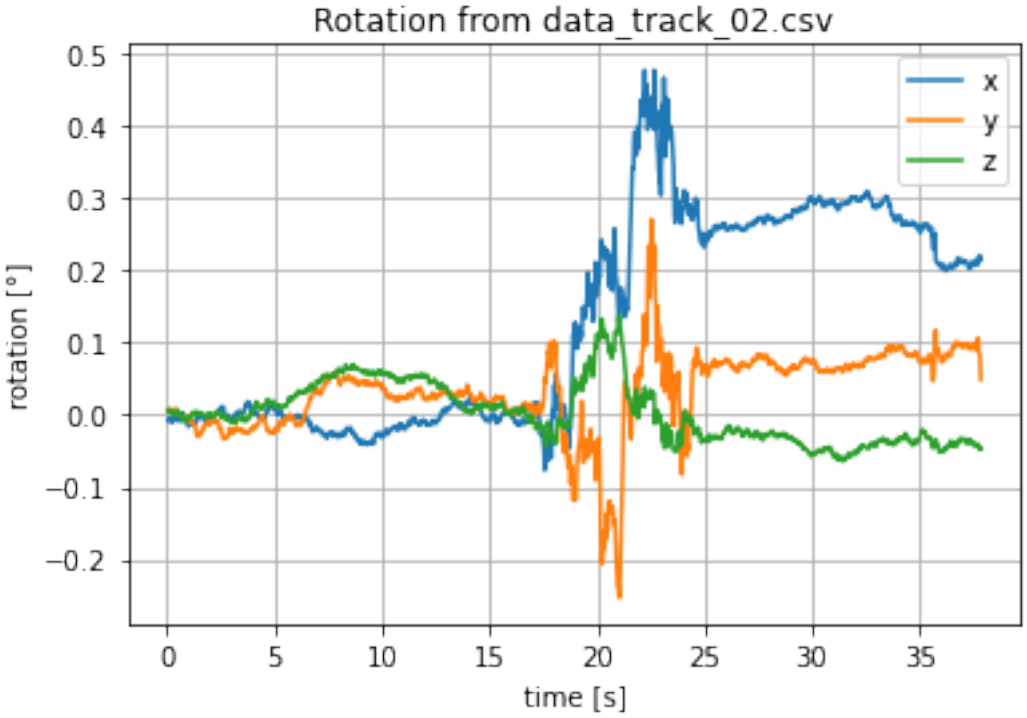
Programm the code for the visualisation of your results. Make three seperate plots for the velocities, the positions and the turn rates. The plots should contain a title, axis labels and a legend.

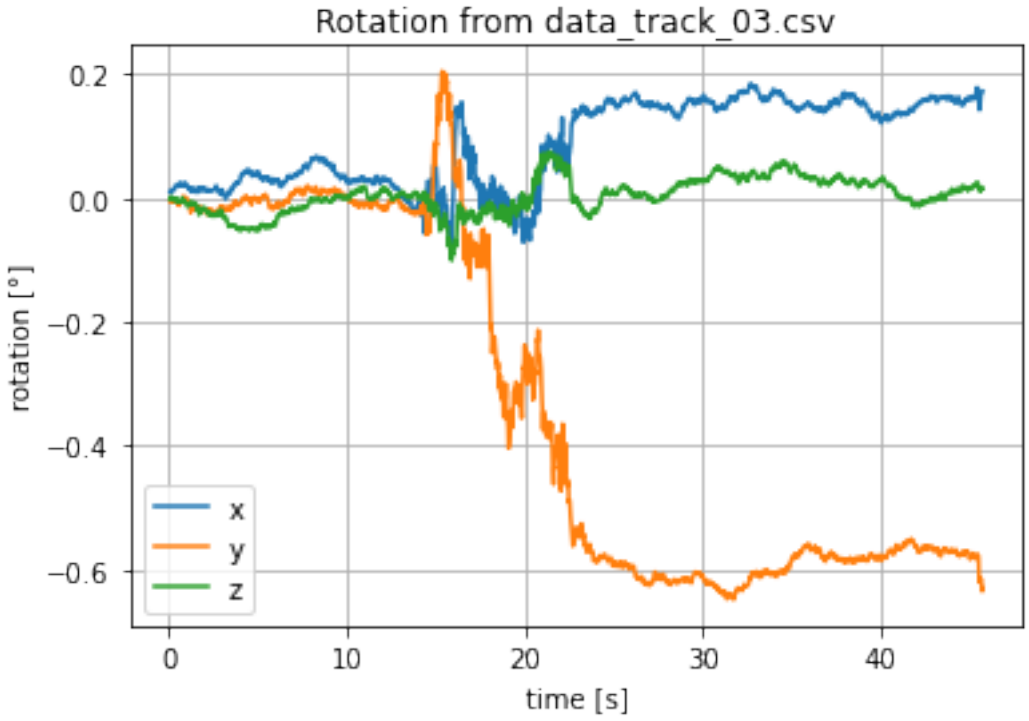
> ***Tipp:*** Change the […] to your own values and adapt it for the following plots.
>
> ***Tipp:*** The library `matplotlib` can be used to create fancy plots.

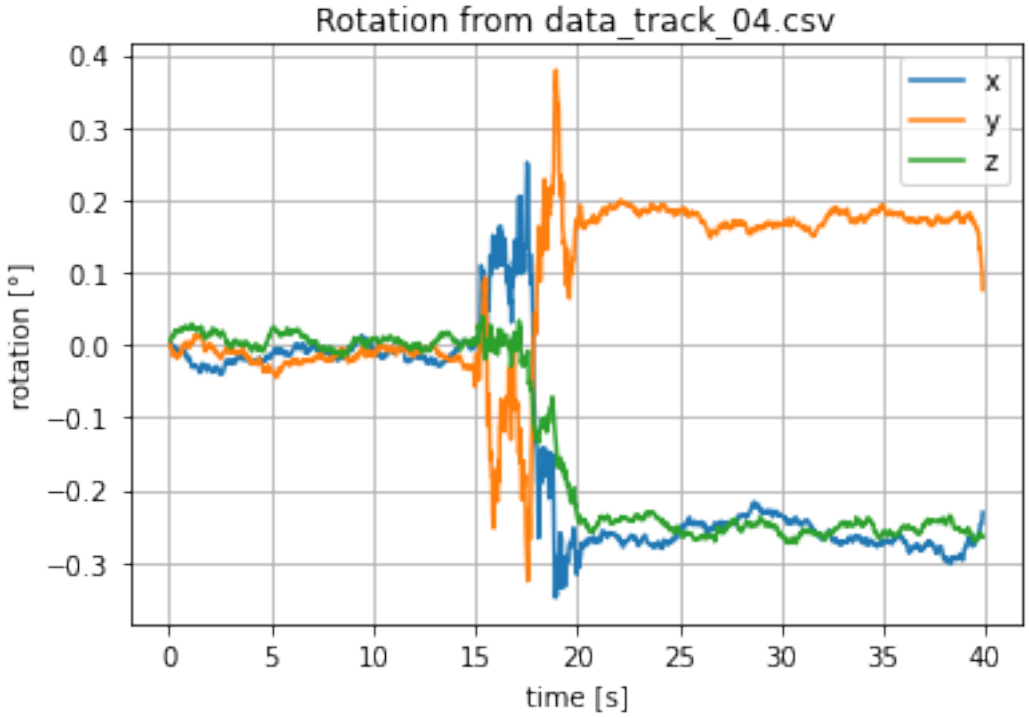
### 3.6.2 Angles

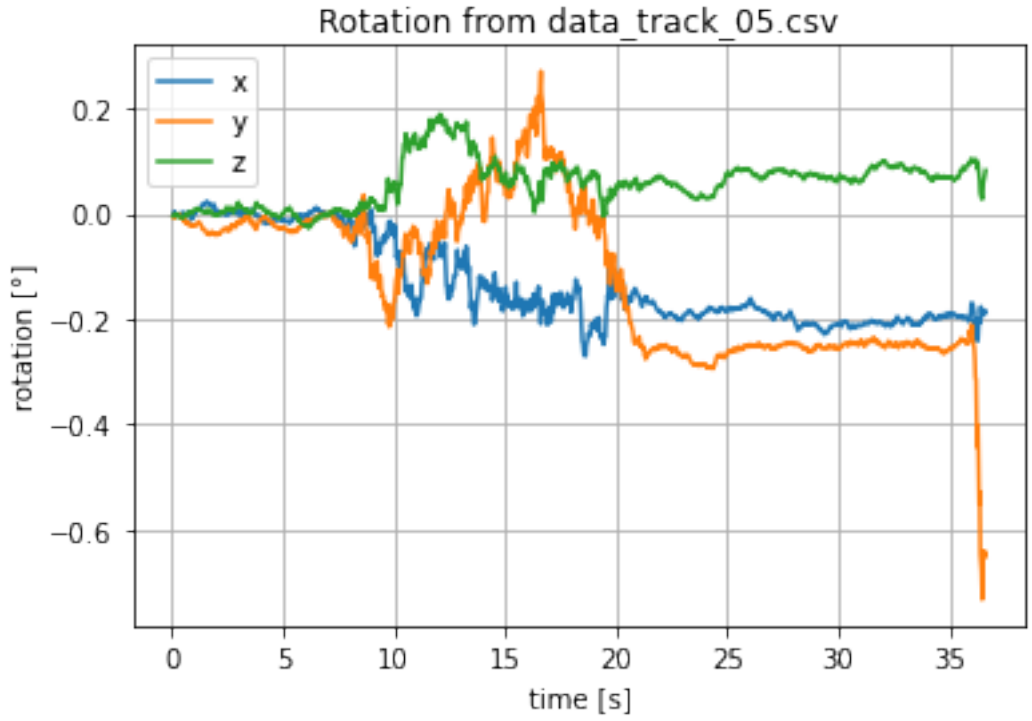
[ ]:
```
# plt.plot(data[:,0]/1000, euler[0,:], label='phi')
# plt.plot(...)
# plt.plot(...)
# plt.title('...')
# plt.xlabel('...')
# plt.ylabel('...')
# plt.legend()
# plt.grid()
# plt.show()

for measurement_id, e in enumerate(timestamps_all):
    mems.plot_results([rotation_all[measurement_id]["x"],␣
 ↪rotation_all[measurement_id]["y"], rotation_all[measurement_id]["z"]],
                      f'Rotation from {files[measurement_id]}',
                      "time [s]",
                      "rotation [°]",
                      ["x", "y", "z"],
                      e)
```

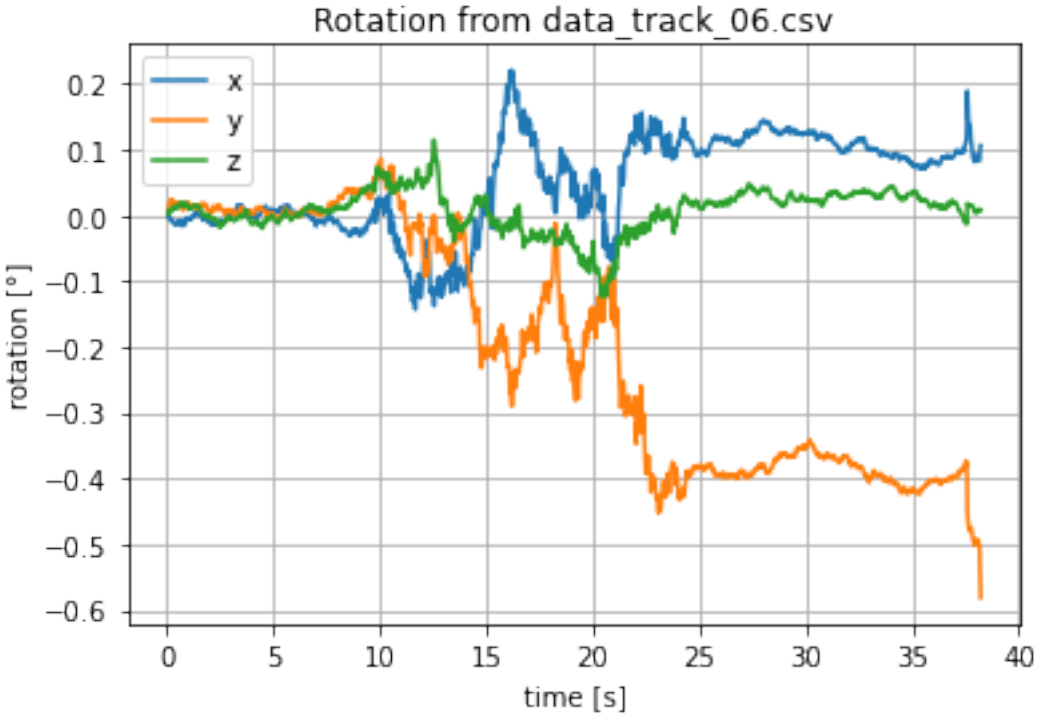

Rotation from data_track_01.csv
x
y
z
rotation [°]
time [s]
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40

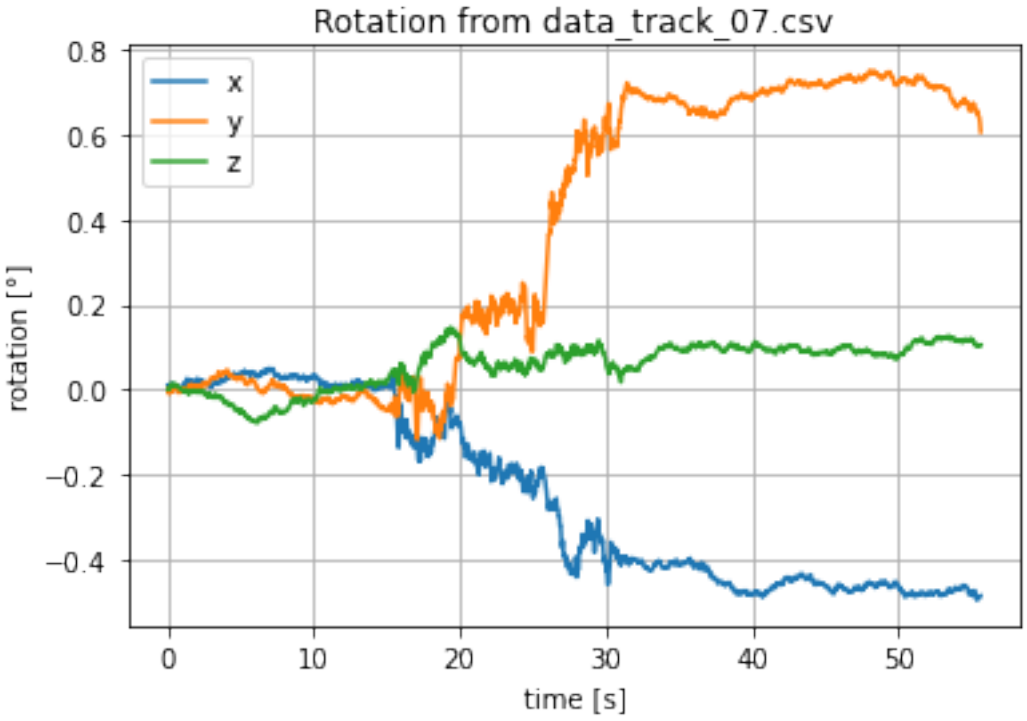

Rotation from data_track_02.csv
x
y
z
rotation [°]
time [s]
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
0
5
10
15
20
25
30
35

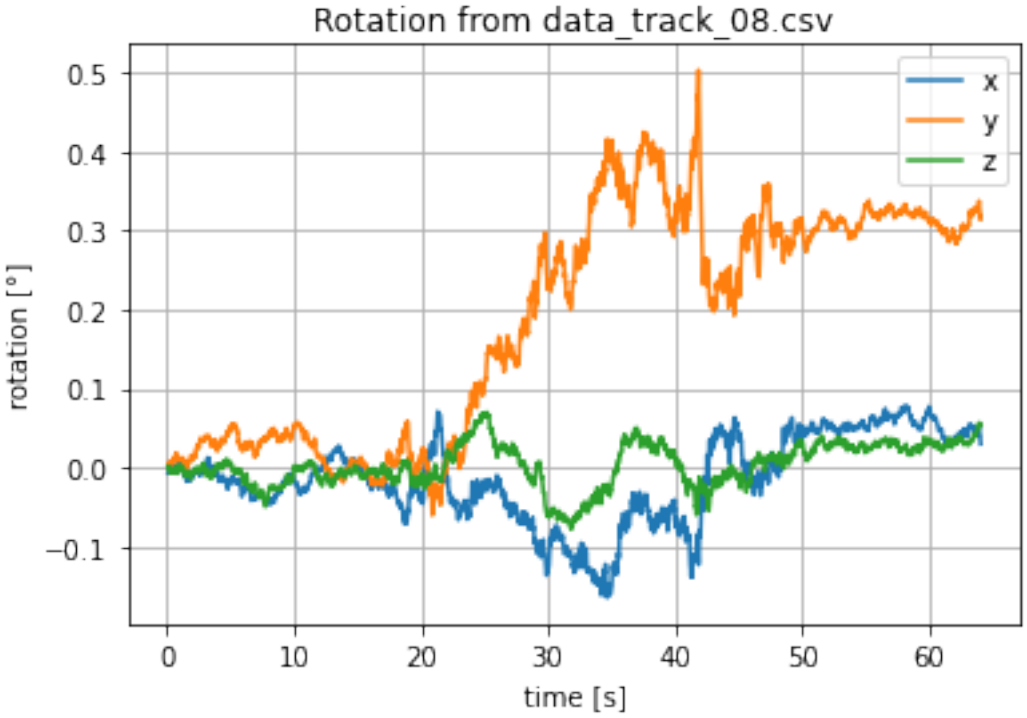

Rotation from data_track_03.csv
rotation [°]
time [s]
x
y
z
0.2
0.0
−0.2
−0.4
−0.6
0
10
20
30
40

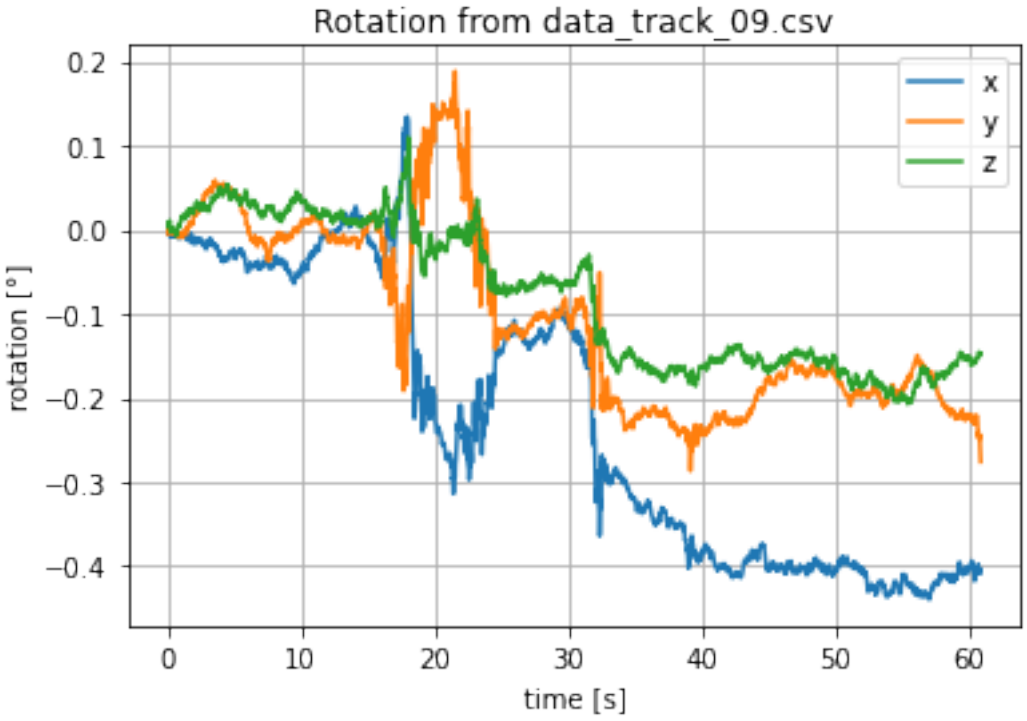

Rotation from data_track_04.csv
rotation [°]
time [s]
x
y
z
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0
5
10
15
20
25
30
35
40

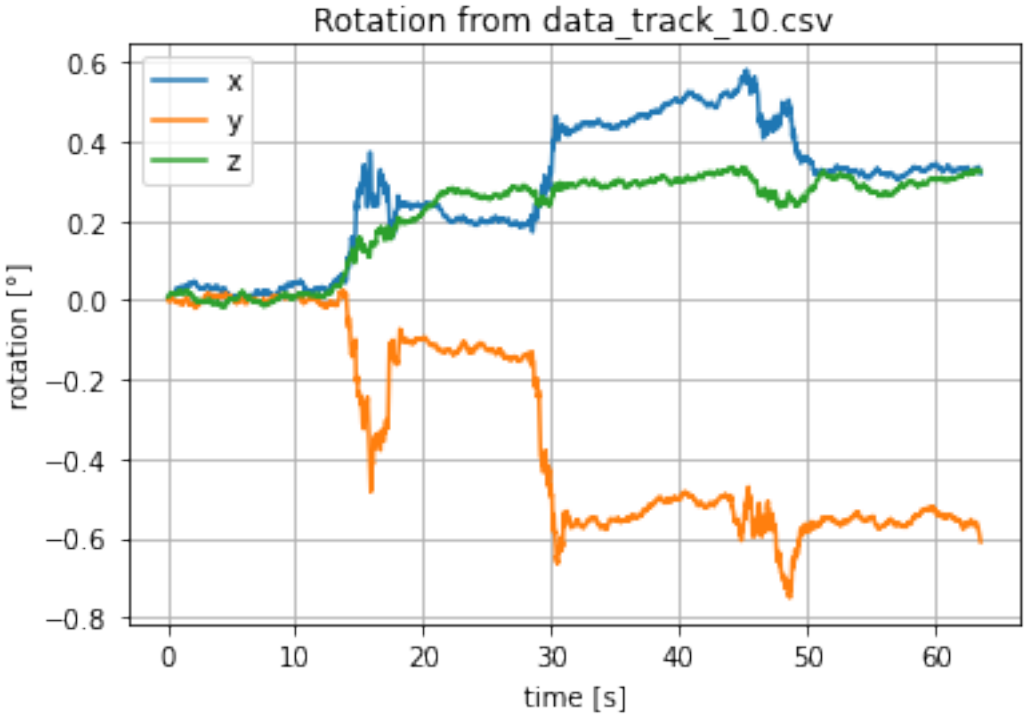

Rotation from data_track_05.csv
x
y
z
0.2
0.0
−0.2
−0.4
−0.6
rotation [°]
0
5
10
15
20
25
30
35
time [s]

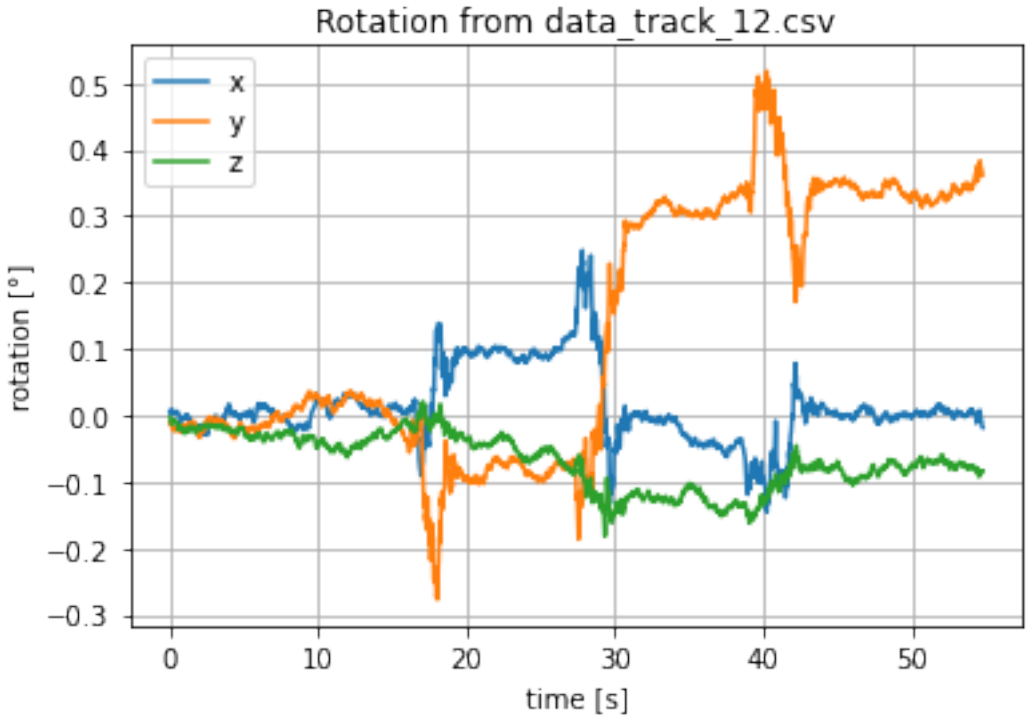

Rotation from data_track_06.csv
x
y
z
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
rotation [°]
0
5
10
15
20
25
30
35
40
time [s]

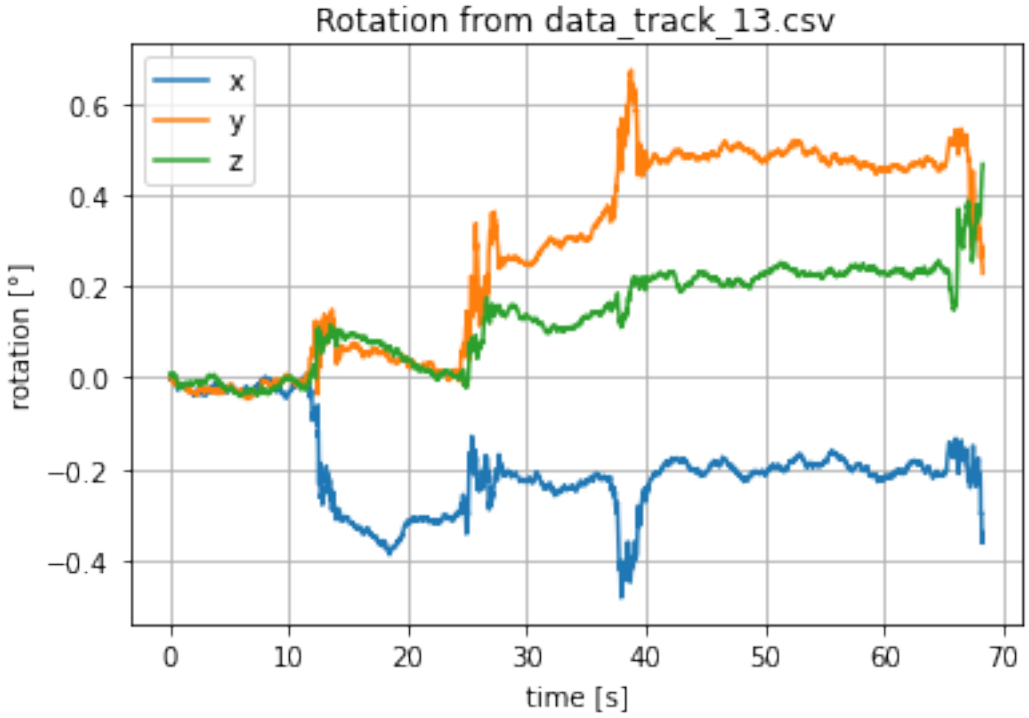

Rotation from data_track_07.csv
x
y
z
rotation [°]
time [s]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0
10
20
30
40
50

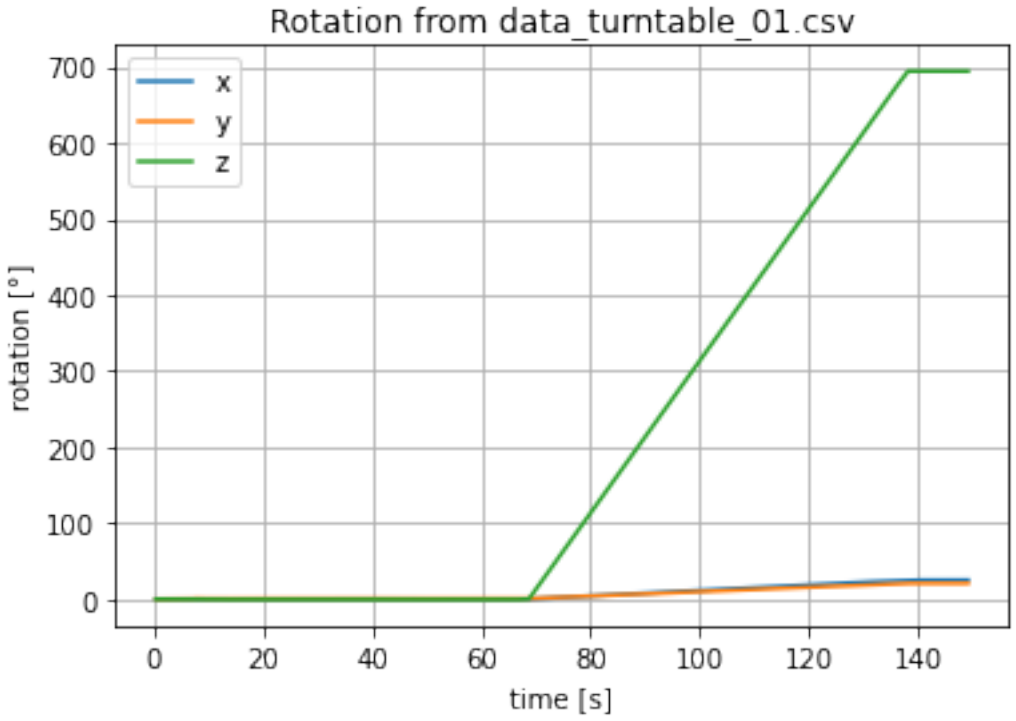

Rotation from data_track_08.csv
x
y
z
rotation [°]
time [s]
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
0
10
20
30
40
50
60

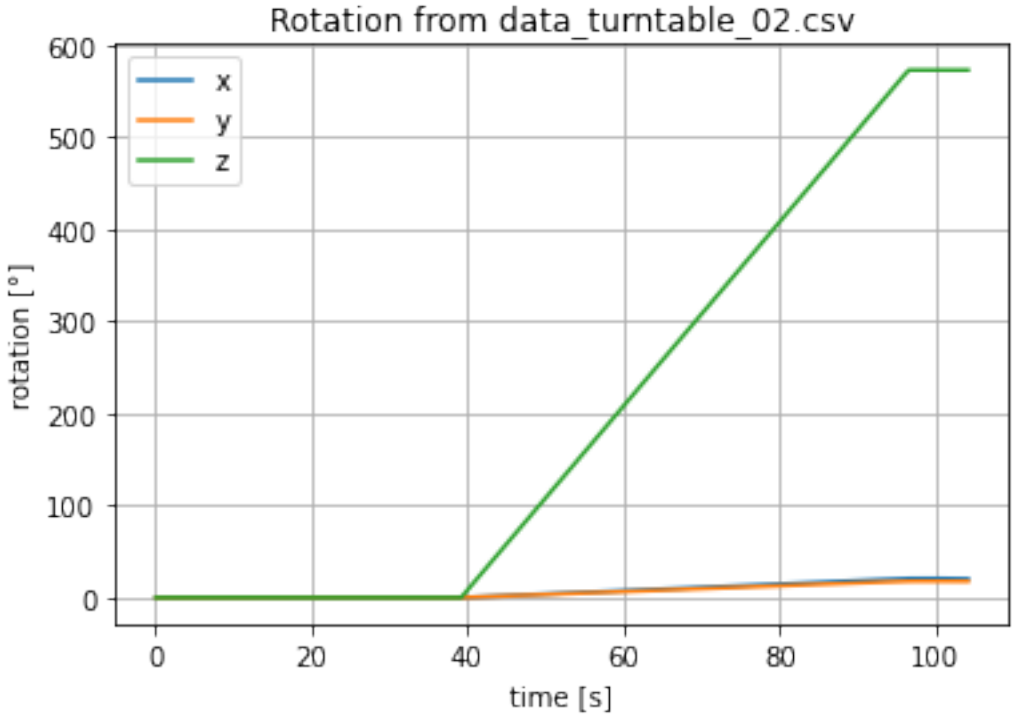

Rotation from data_track_09.csv
x
y
z
rotation [°]
time [s]
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
0
10
20
30
40
50
60

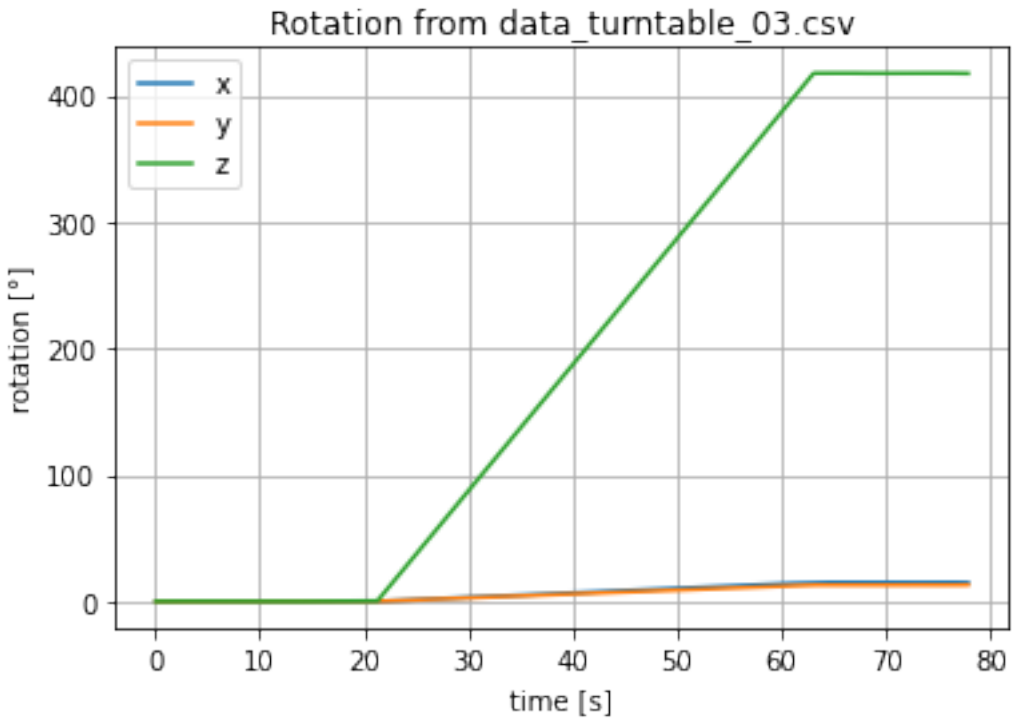

Rotation from data_track_10.csv
x
y
z
rotation [°]
time [s]
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
10
20
30
40
50
60

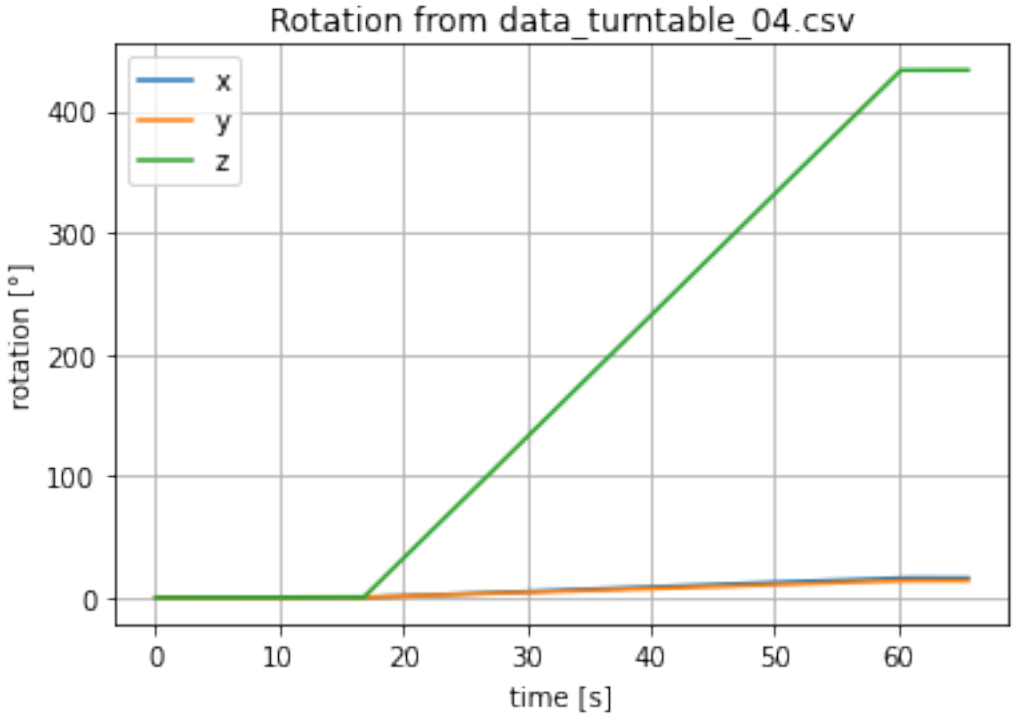

Rotation from data_track_12.csv
x
y
z
rotation [°]
time [s]
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0
10
20
30
40
50

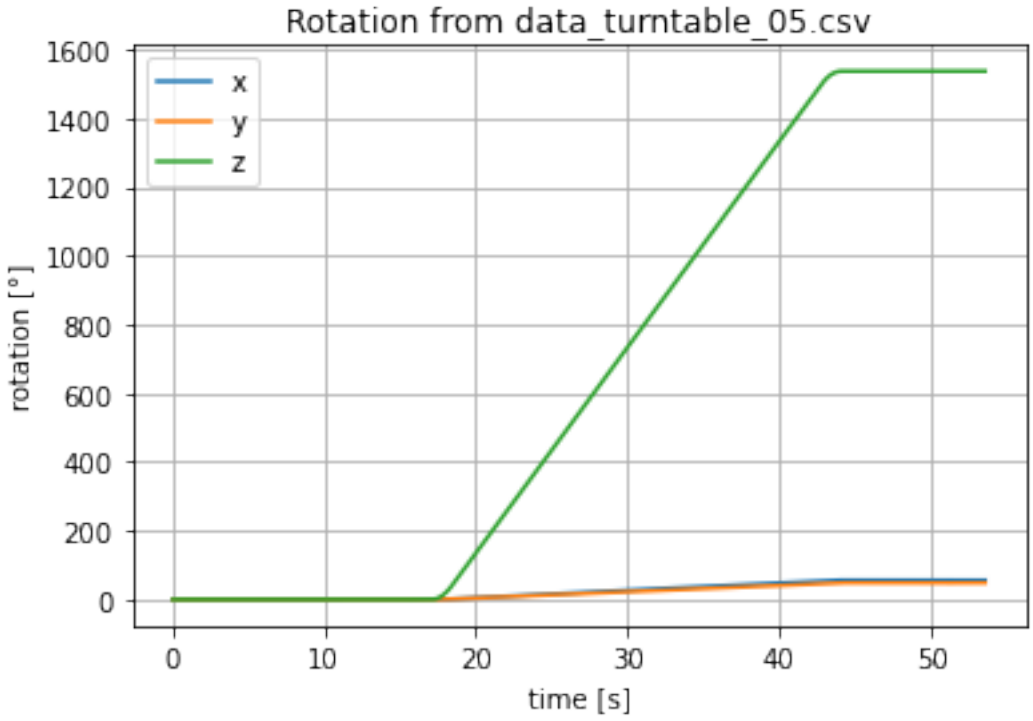

Rotation from data_track_13.csv
x
y
z
rotation [°]
time [s]
0.6
0.4
0.2
0.0
−0.2
−0.4
0
10
20
30
40
50
60
70

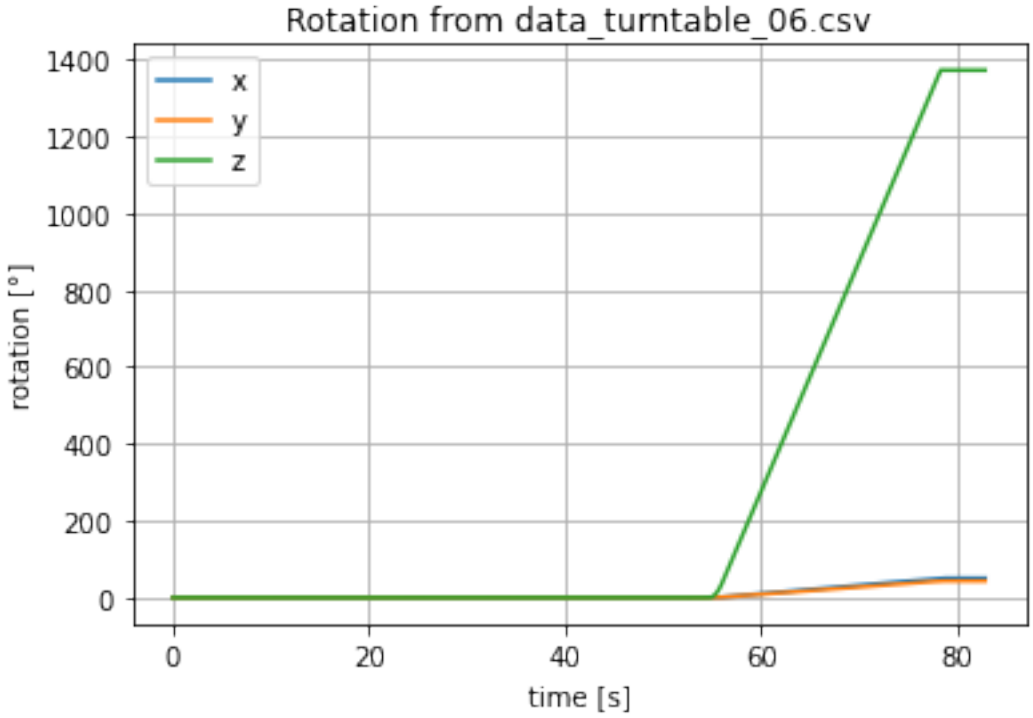

Rotation from data_turntable_01.csv
x
y
z
rotation [°]
time [s]
0
100
200
300
400
500
600
700
0
20
40
60
80
100
120
140

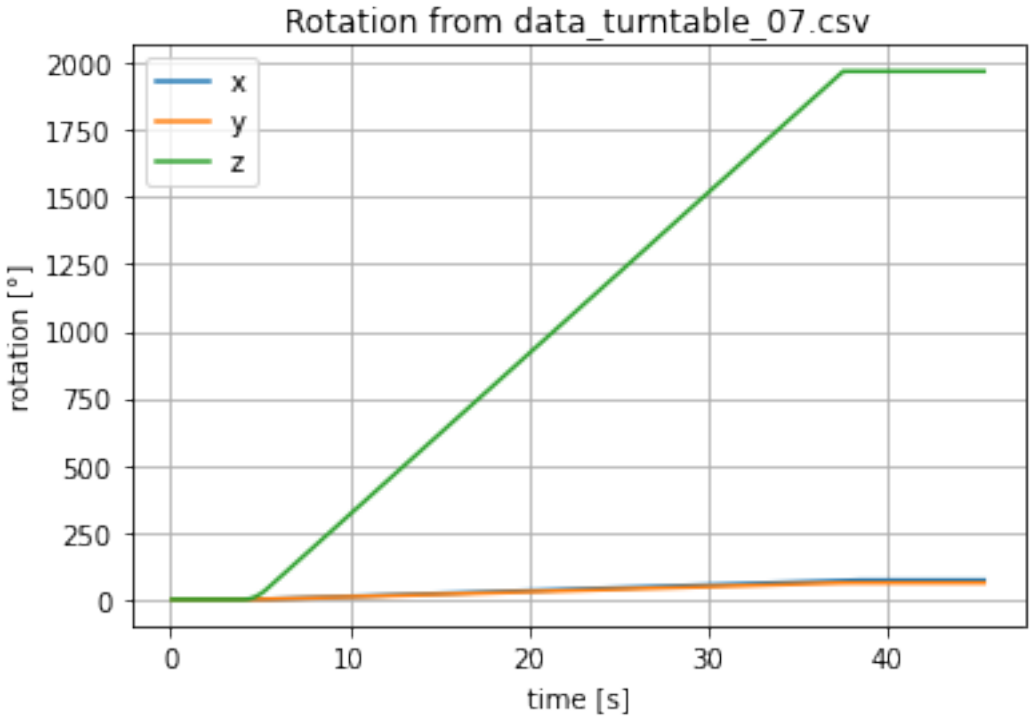

Rotation from data_turntable_02.csv
x
y
z
rotation [°]
time [s]
0
100
200
300
400
500
600
0
20
40
60
80
100

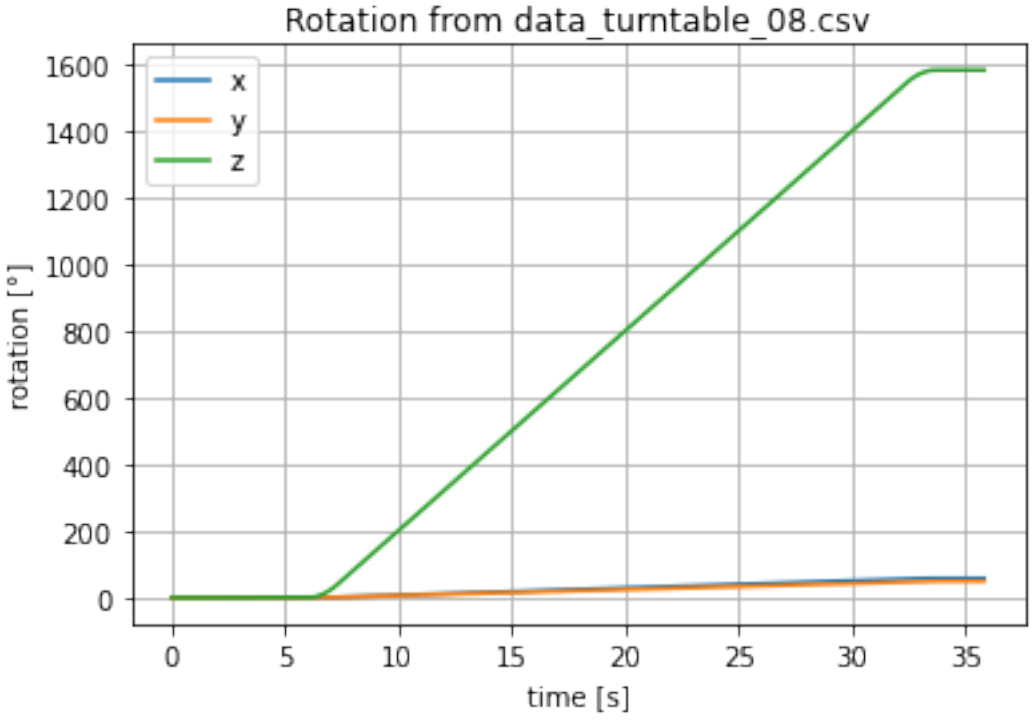

Rotation from data_turntable_03.csv
x
y
z
rotation [°]
time [s]
0
100
200
300
400
0
10
20
30
40
50
60
70
80

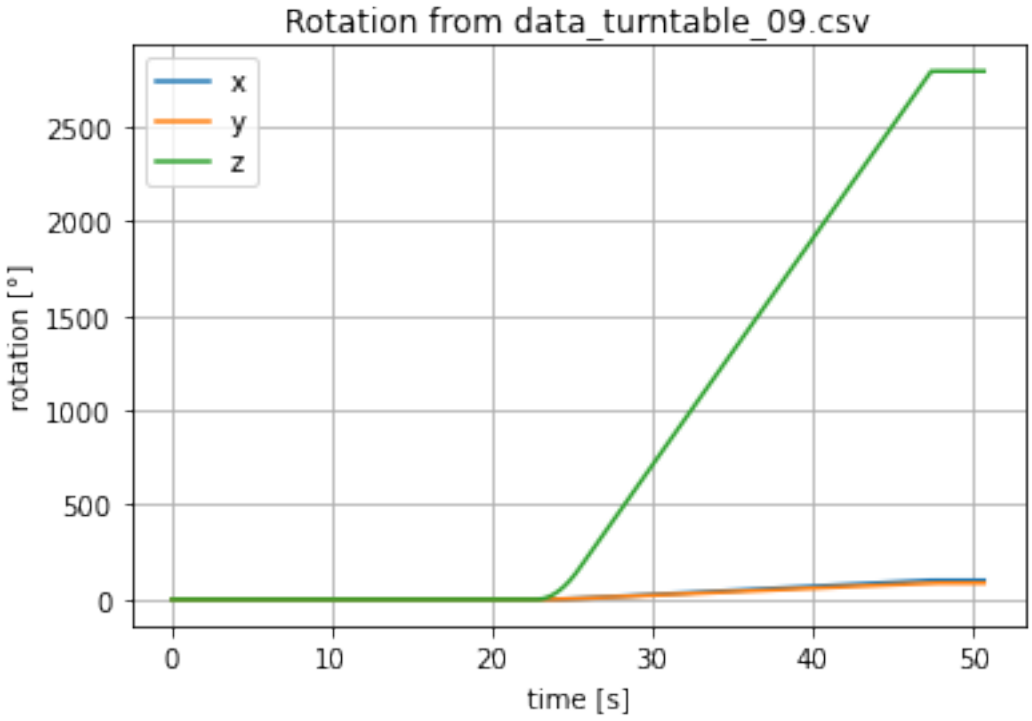

Rotation from data_turntable_04.csv
x
y
z
rotation [°]
time [s]
0
100
200
300
400
0
10
20
30
40
50
60

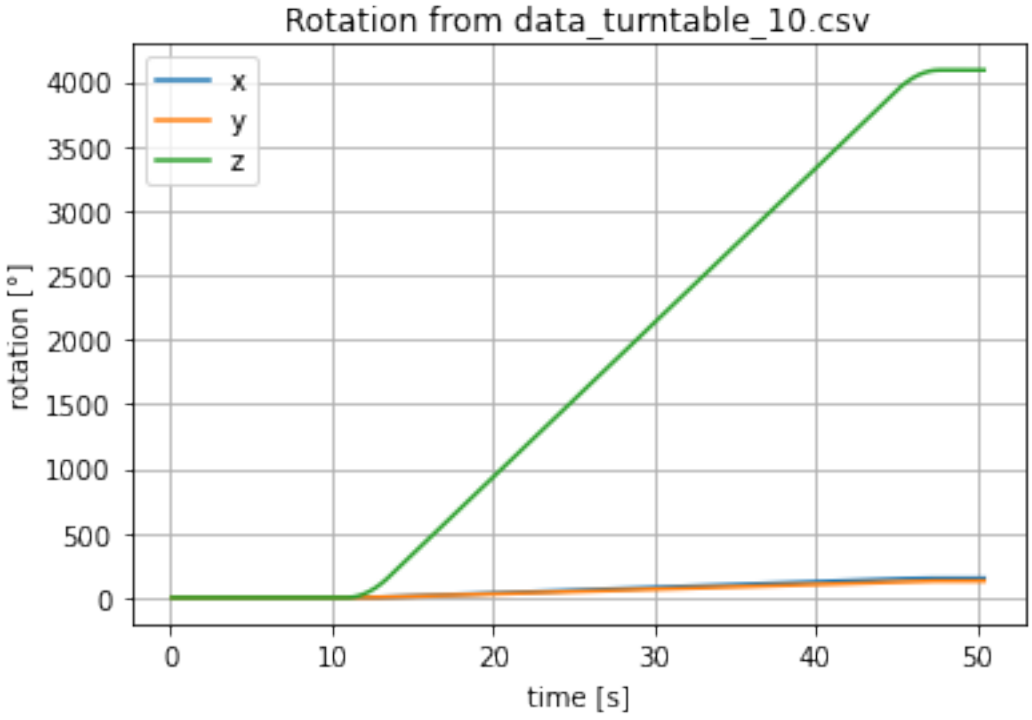

Rotation from data_turntable_05.csv
x
y
z
rotation [°]
time [s]
0
200
400
600
800
1000
1200
1400
1600
0
10
20
30
40
50

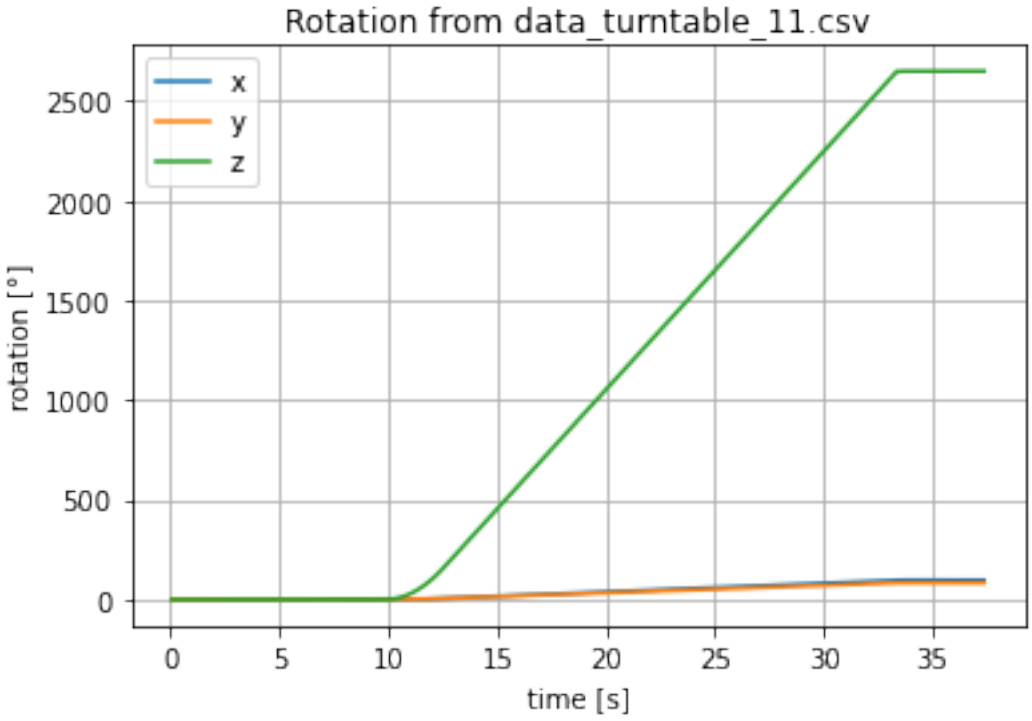

Rotation from data_turntable_06.csv
x
y
z
rotation [°]
time [s]
0
200
400
600
800
1000
1200
1400
0
20
40
60
80

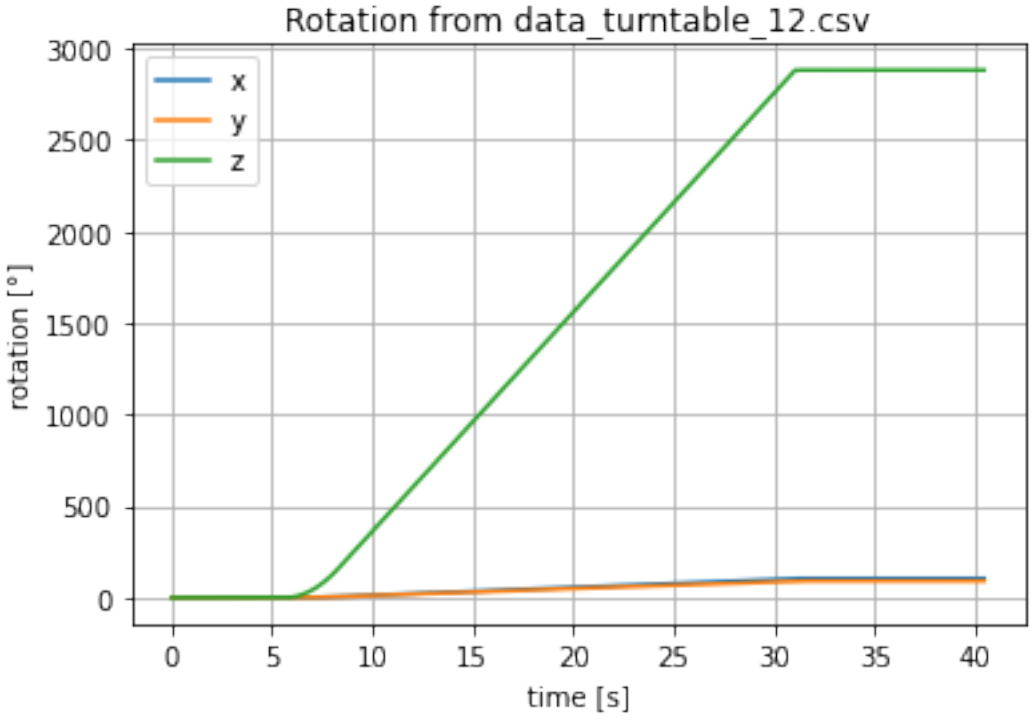

Rotation from data_turntable_07.csv
x
y
z
rotation [°]
time [s]
0
250
500
750
1000
1250
1500
1750
2000
0
10
20
30
40


Rotation from data_turntable_08.csv
x
y
z
rotation [°]
time [s]
0
200
400
600
800
1000
1200
1400
1600
0
5
10
15
20
25
30
35


Rotation from data_turntable_09.csv
x
y
z
rotation [°]
2500
2000
1500
1000
500
0
0
10
20
30
40
50
time [s]

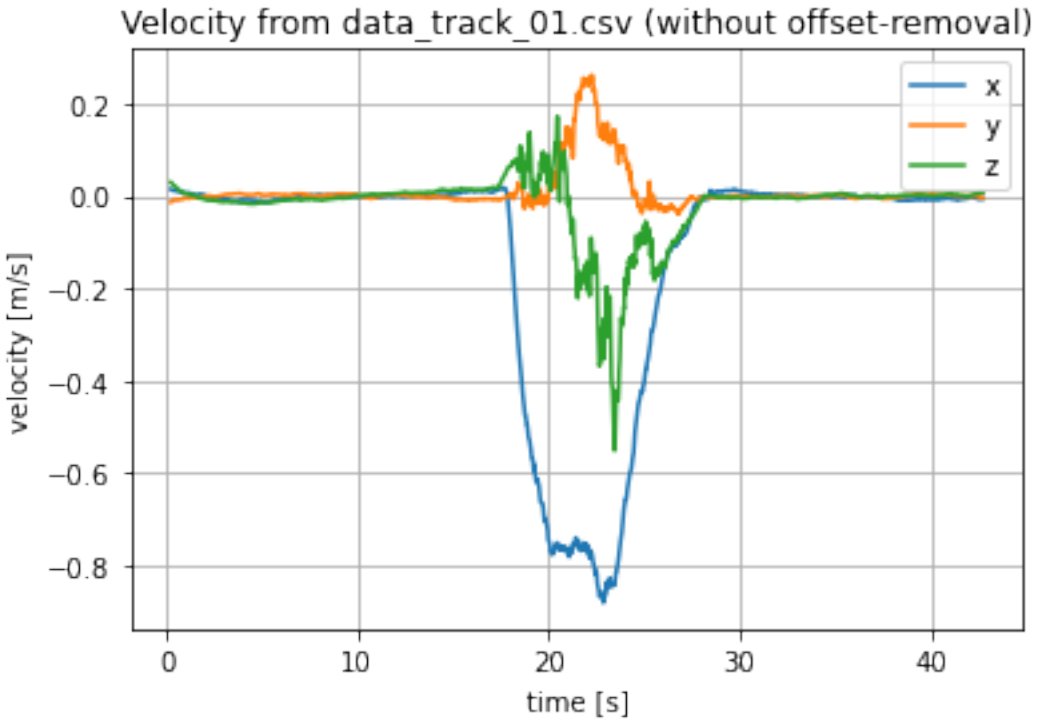

Rotation from data_turntable_10.csv
x
y
z
rotation [°]
4000
3500
3000
2500
2000
1500
1000
500
0
0
10
20
30
40
50
time [s]

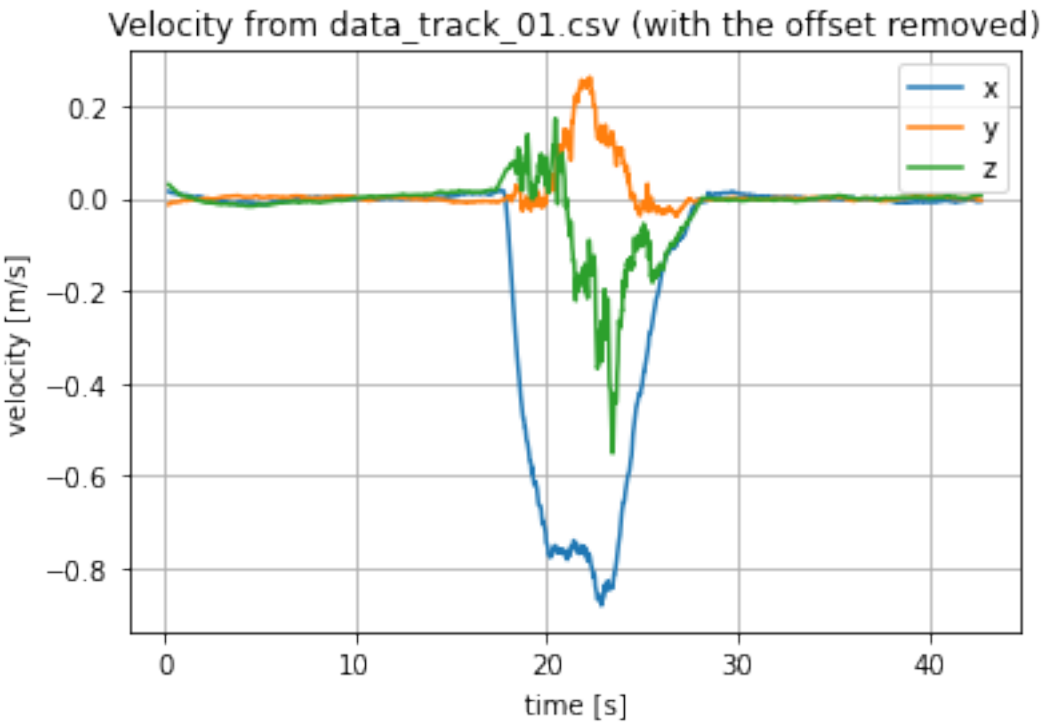

Rotation from data_turntable_11.csv
x
y
z
rotation [°]
time [s]
0
500
1000
1500
2000
2500
0
5
10
15
20
25
30
35

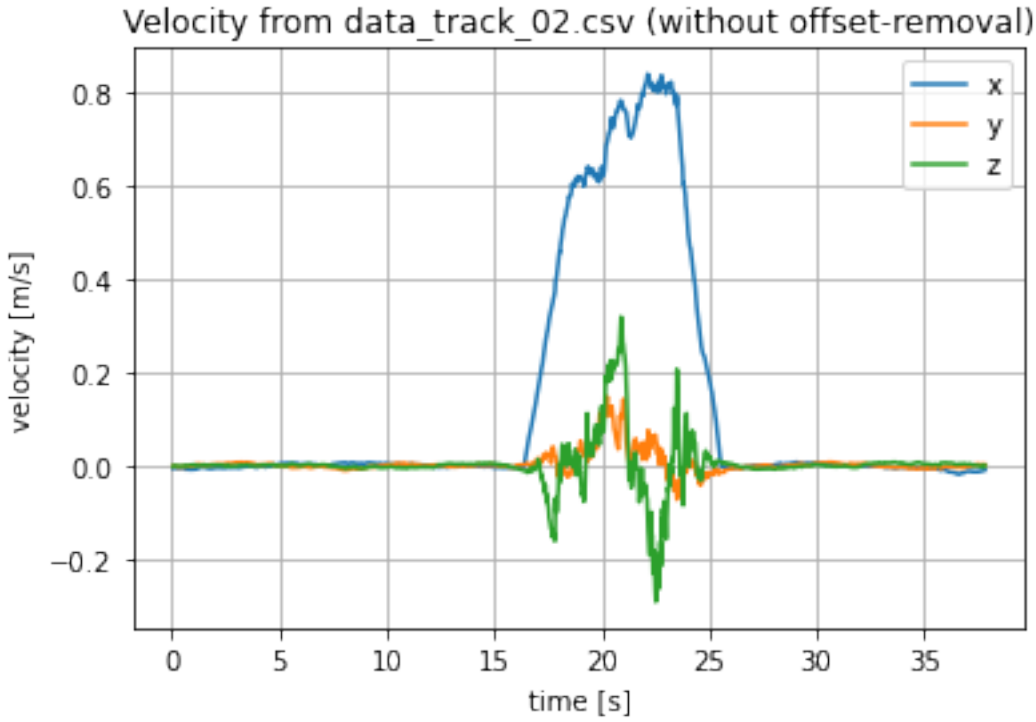

Rotation from data_turntable_12.csv
x
y
z
rotation [°]
time [s]
0
500
1000
1500
2000
2500
3000
0
5
10
15
20
25
30
35
40

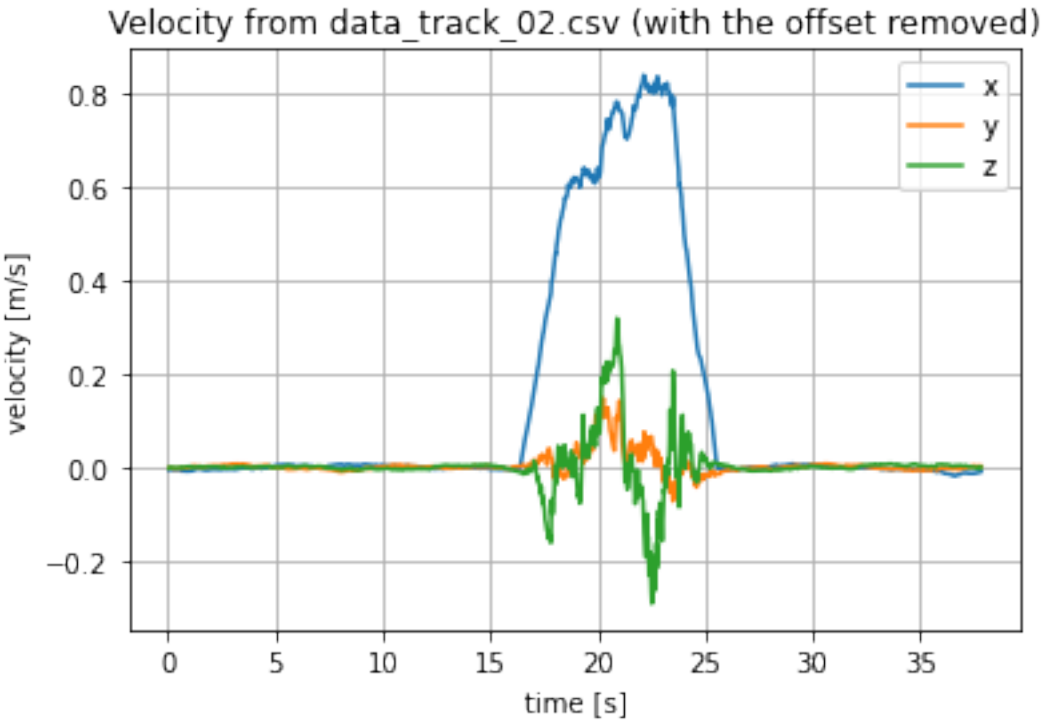
### 3.6.3 Velocity

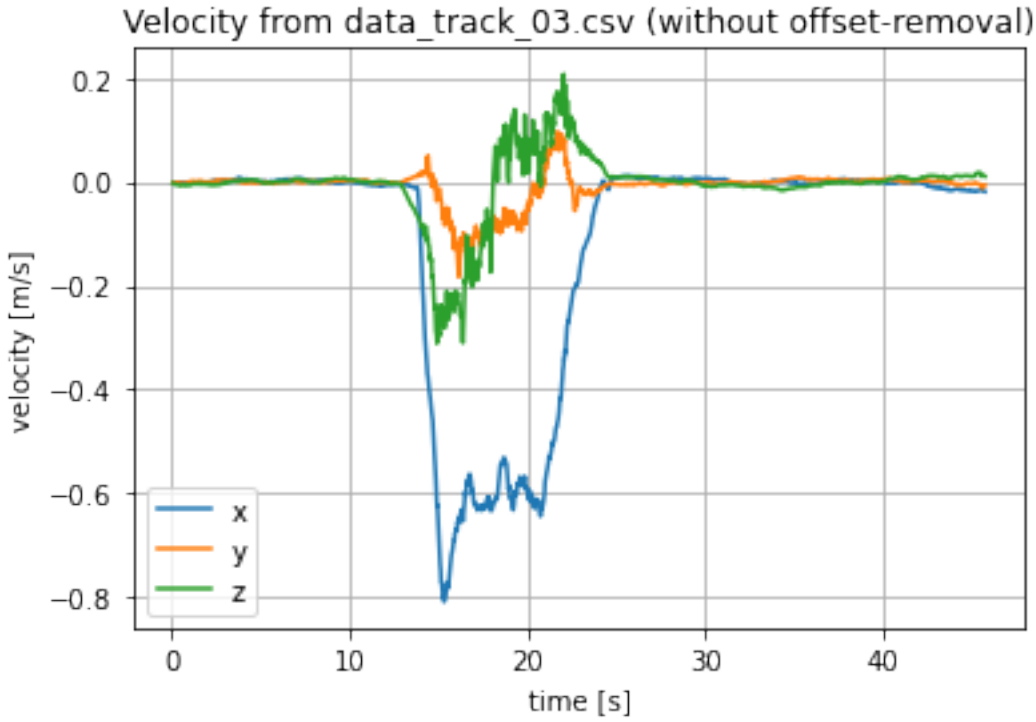
```
[ ]: for measurement_id, e in enumerate(timestamps_all):
        mems.plot_results([velocity_all[measurement_id]["x"],␣
     ↪velocity_all[measurement_id]["y"], velocity_all[measurement_id]["z"]],
                          f'Velocity from {files[measurement_id]} (without␣
     ↪offset-removal)',
                          "time [s]",
                          "velocity [m/s]",
                          ["x", "y", "z"],
                          e)
        mems.plot_results([velocity_without_bias_all[measurement_id]["x"],␣
     ↪velocity_without_bias_all[measurement_id]["y"],␣
     ↪velocity_without_bias_all[measurement_id]["z"]],
                          f'Velocity from {files[measurement_id]} (with the offset␣
     ↪removed)',
                          "time [s]",
                          "velocity [m/s]",
                          ["x", "y", "z"],
                          e)
```

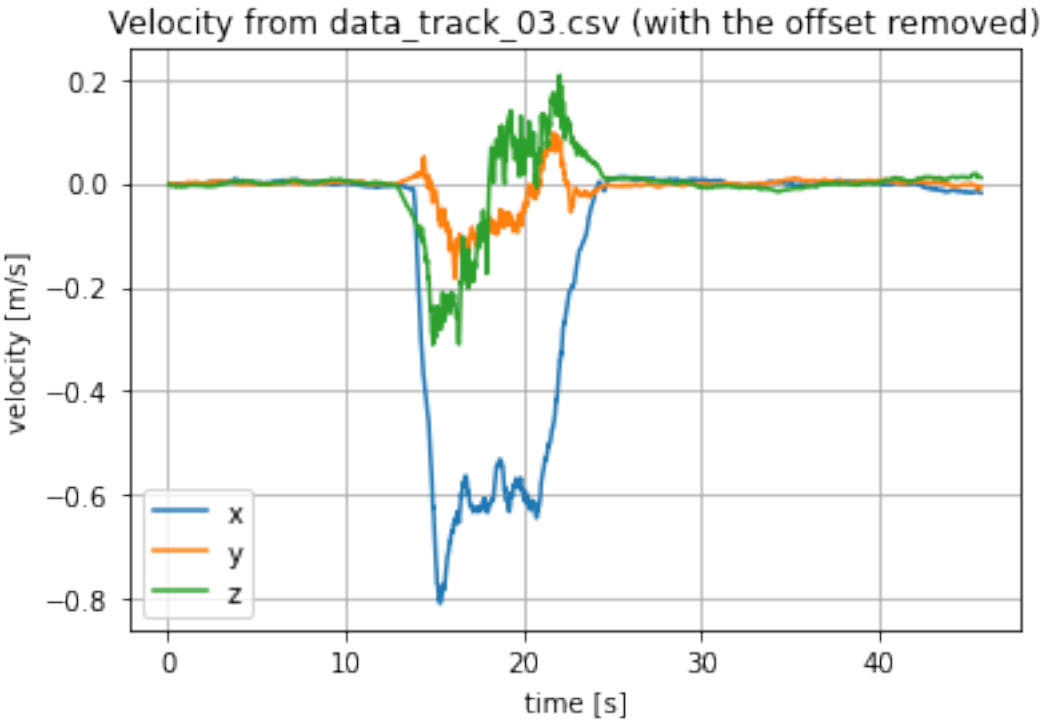


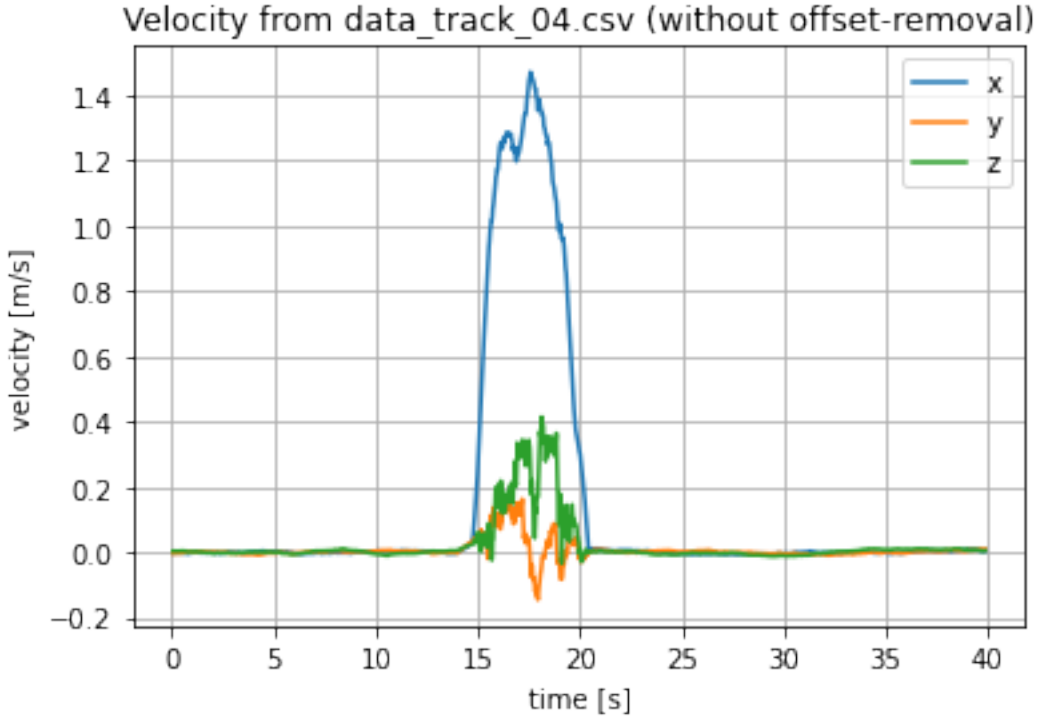

Velocity from data_track_01.csv (with the offset removed)
x
y
z
0.2
0.0
−0.2
−0.4
−0.6
−0.8
velocity [m/s]
0
10
20
30
40
time [s]

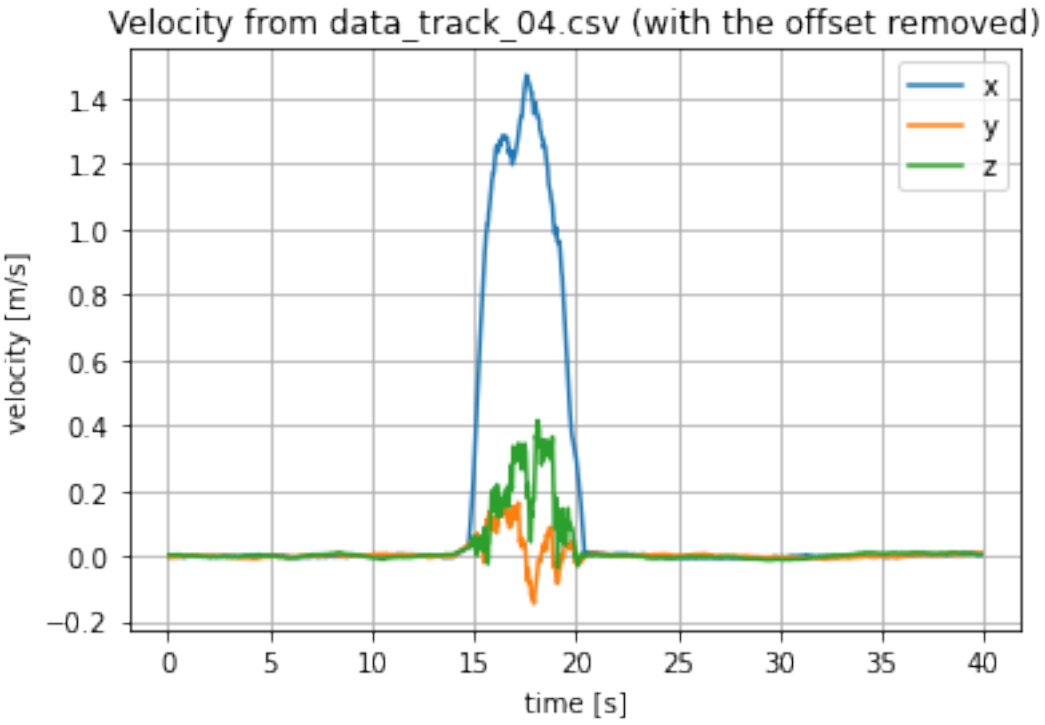

Velocity from data_track_02.csv (without offset-removal)
x
y
z
0.8
0.6
0.4
0.2
0.0
−0.2
velocity [m/s]
0
5
10
15
20
25
30
35
time [s]

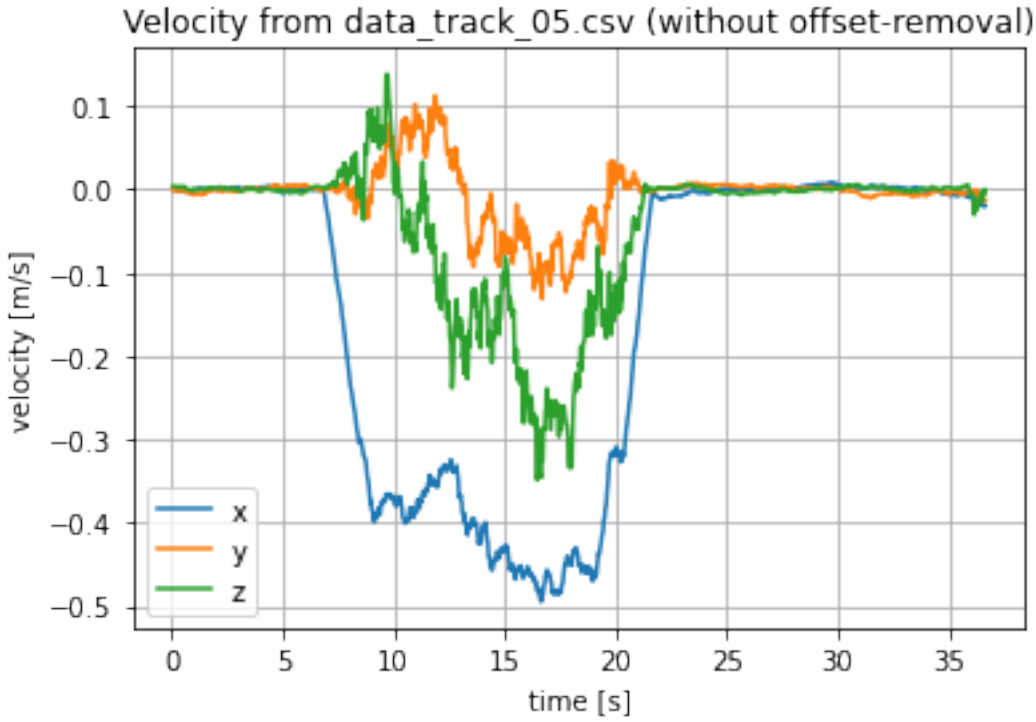

Velocity from data_track_02.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.8
0.6
0.4
0.2
0.0
−0.2
0
5
10
15
20
25
30
35

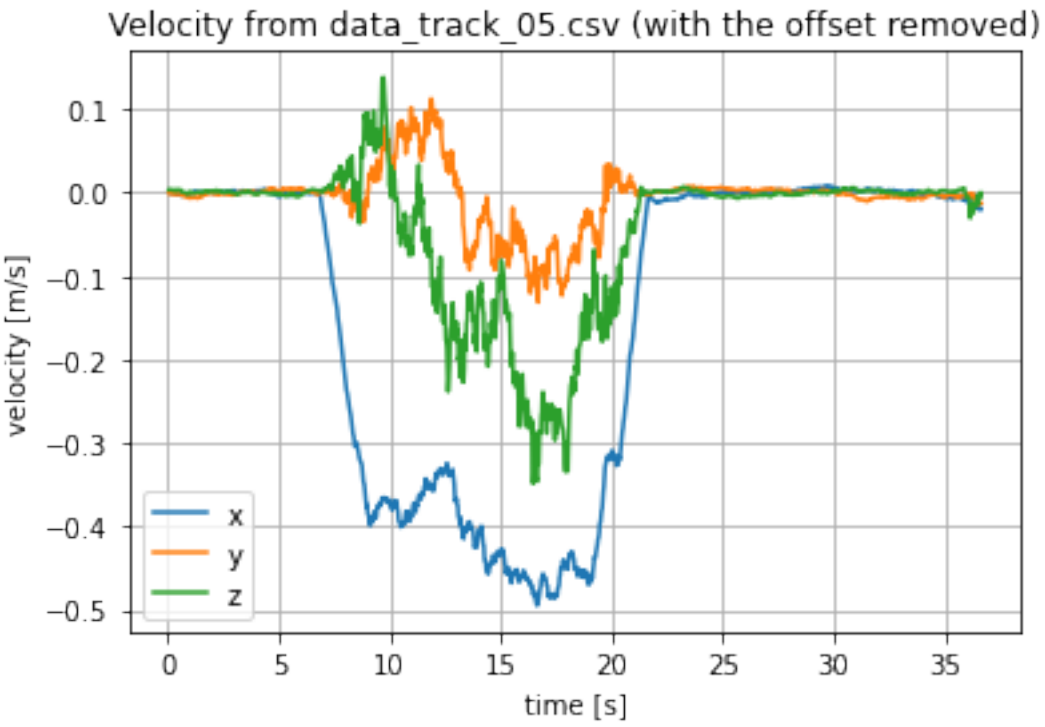

Velocity from data_track_03.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
10
20
30
40

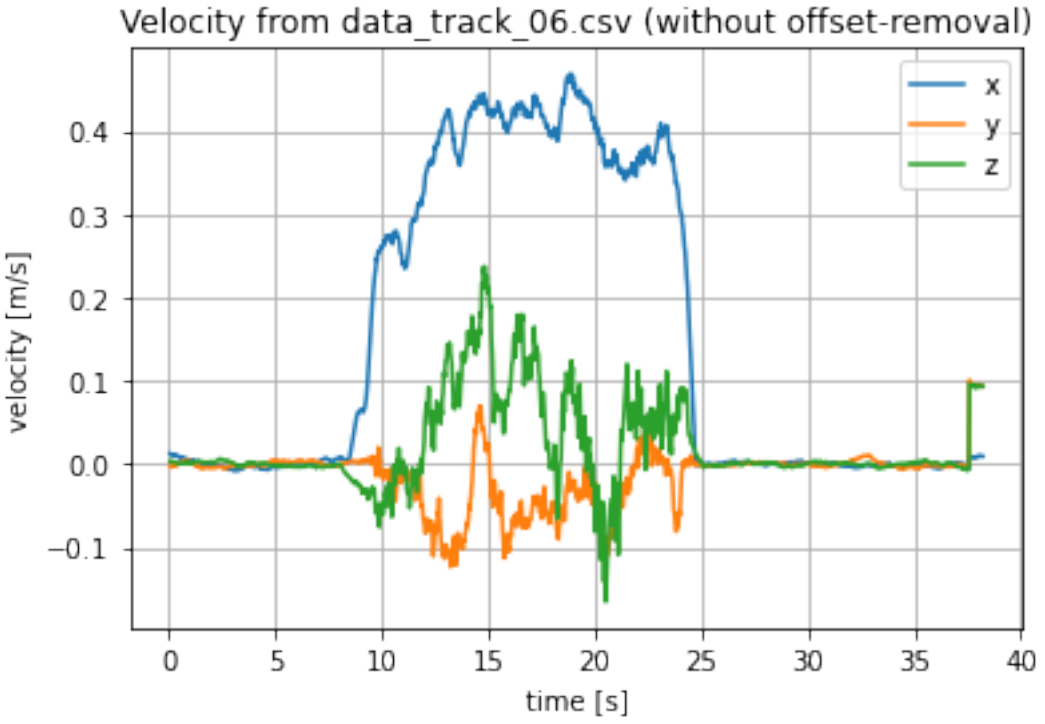

Velocity from data_track_03.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
10
20
30
40

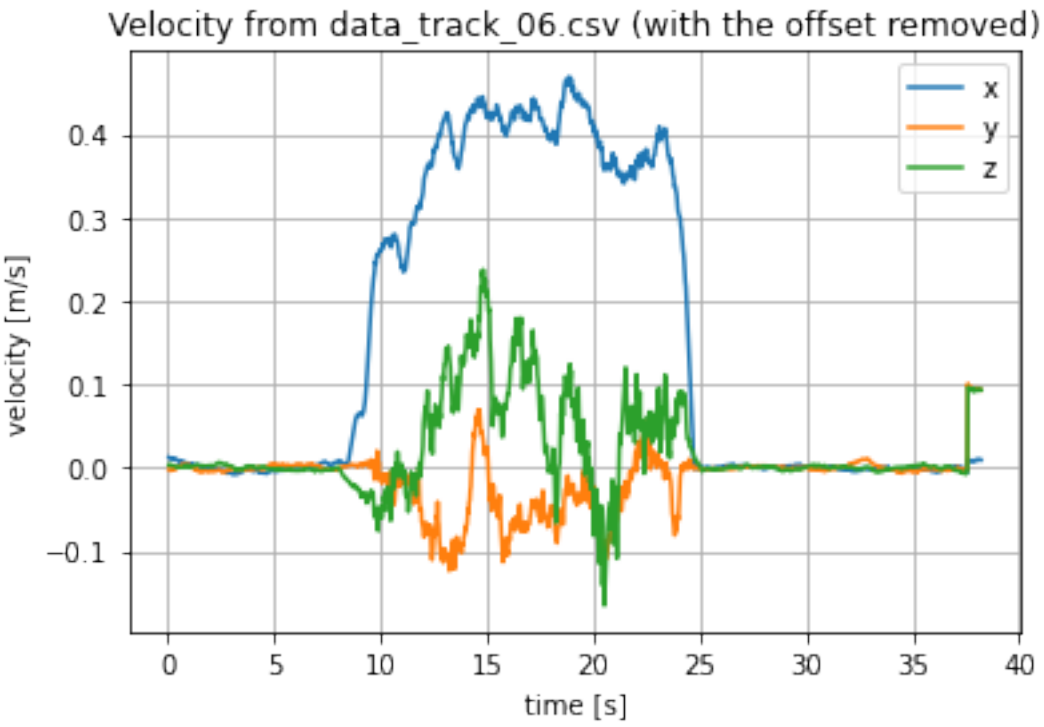

Velocity from data_track_04.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0
5
10
15
20
25
30
35
40

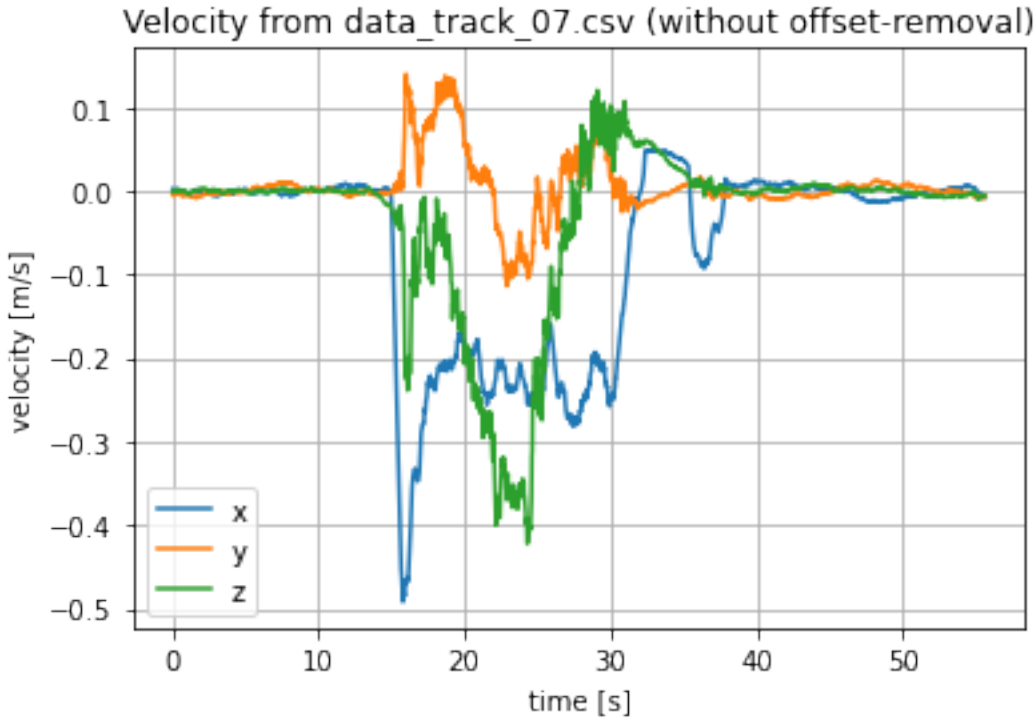

Velocity from data_track_04.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0
5
10
15
20
25
30
35
40

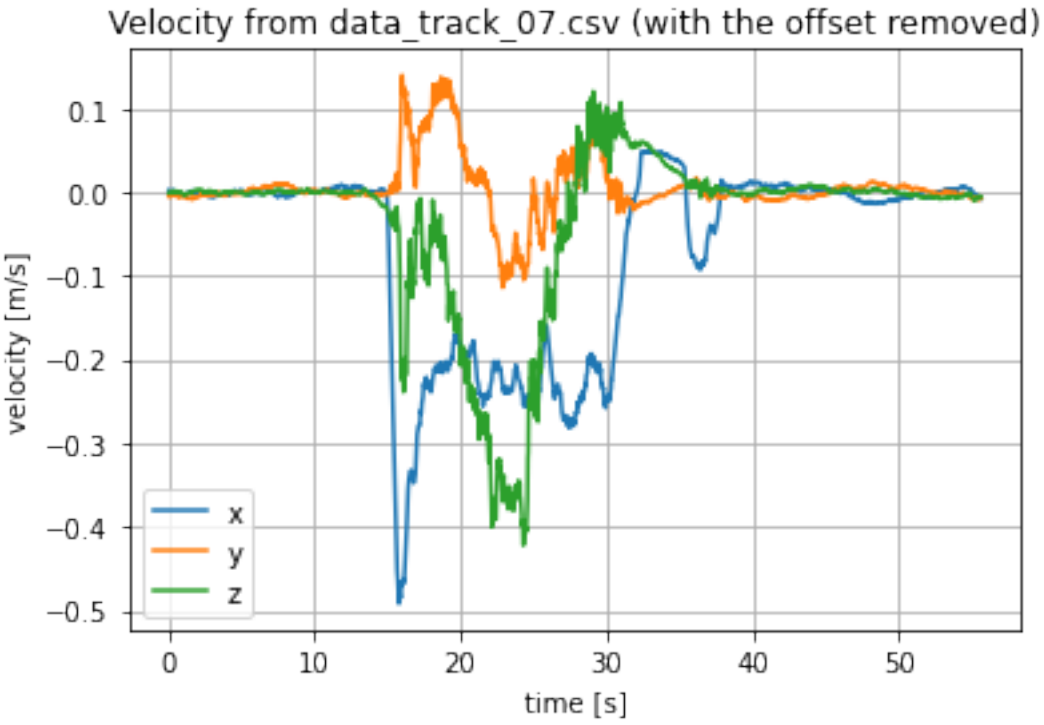

Velocity from data_track_05.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
0
5
10
15
20
25
30
35

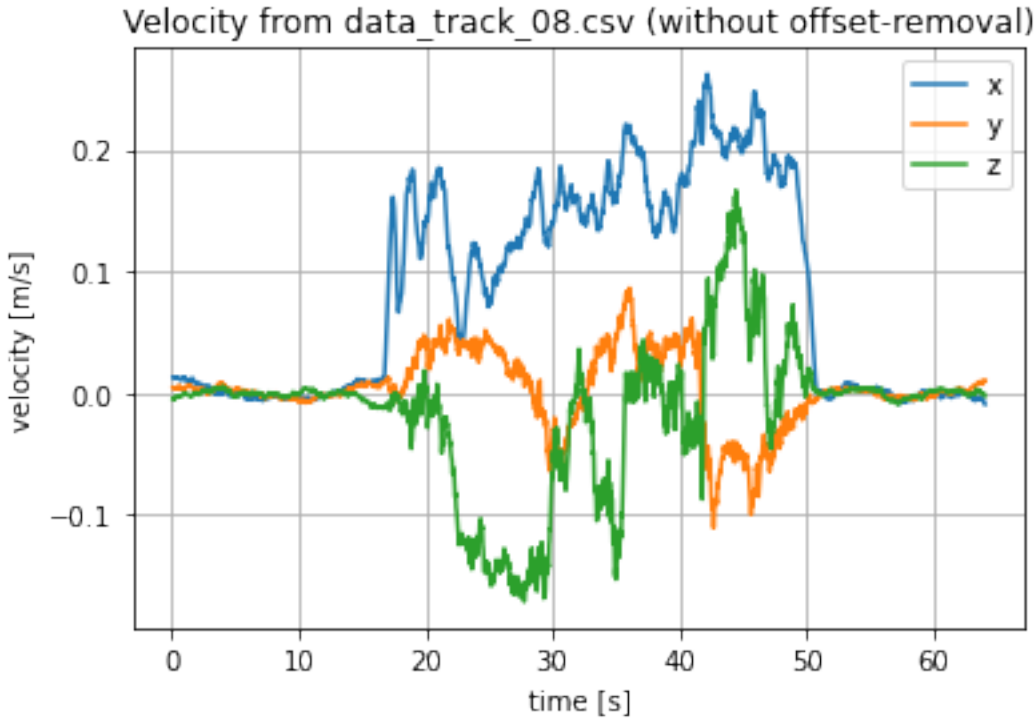

Velocity from data_track_05.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
0
5
10
15
20
25
30
35

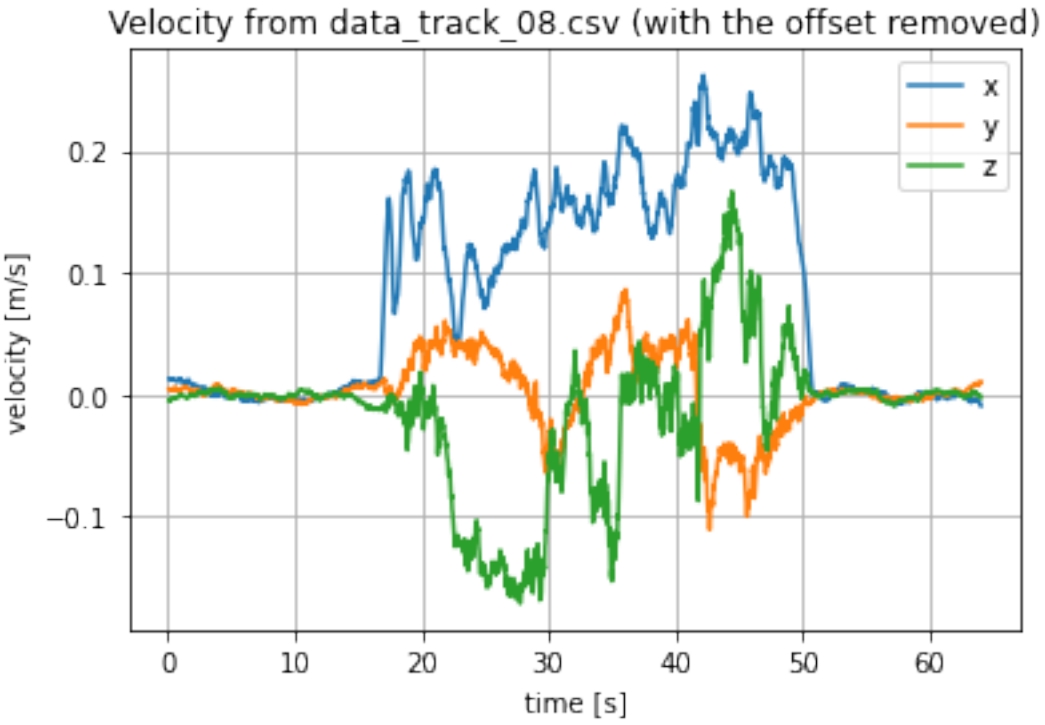

Velocity from data_track_06.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.4
0.3
0.2
0.1
0.0
−0.1
0
5
10
15
20
25
30
35
40

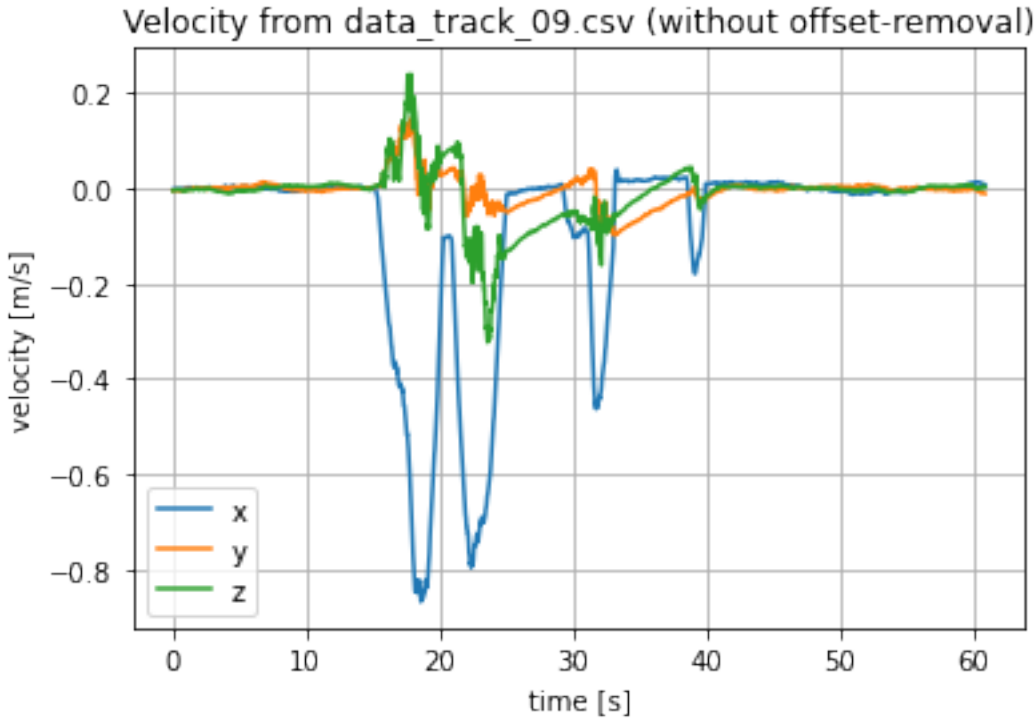

Velocity from data_track_06.csv (with the offset removed)
x
y
z
velocity [m/s]
0.4
0.3
0.2
0.1
0.0
−0.1
0
5
10
15
20
25
30
35
40
time [s]

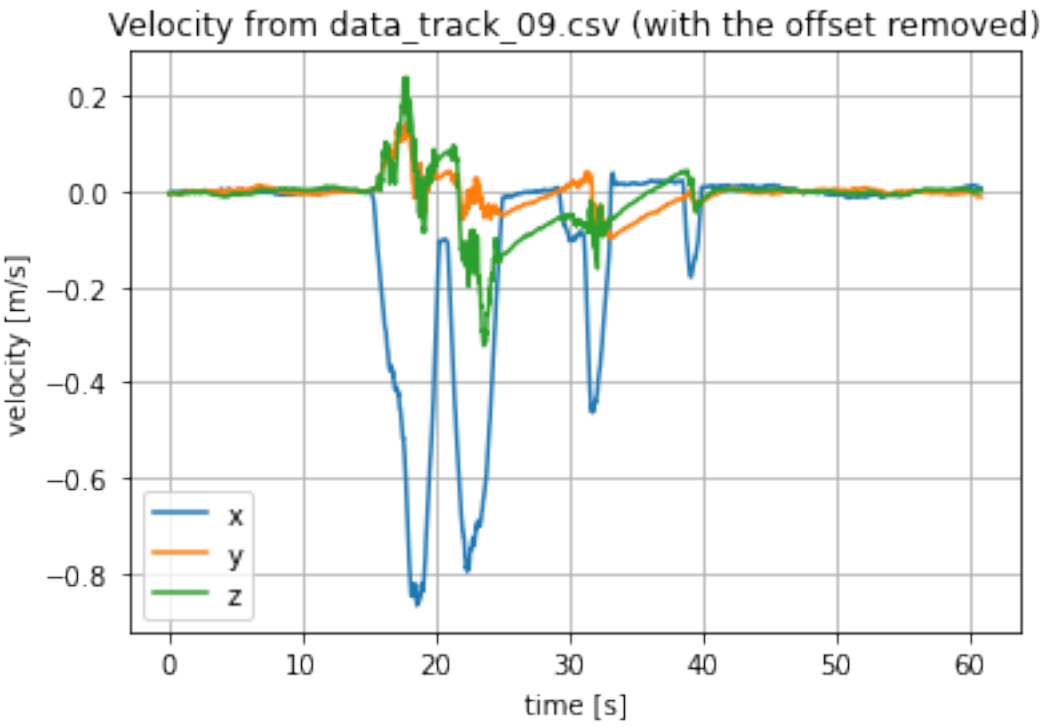

Velocity from data_track_07.csv (without offset-removal)
x
y
z
velocity [m/s]
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
0
10
20
30
40
50
time [s]

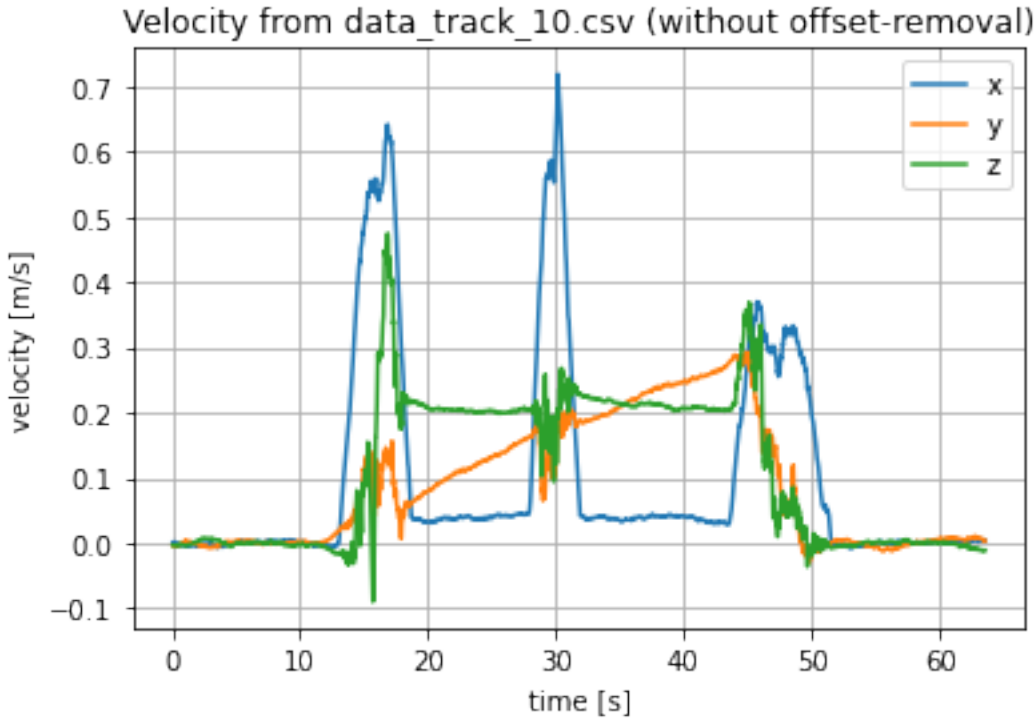

Velocity from data_track_07.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
0
10
20
30
40
50

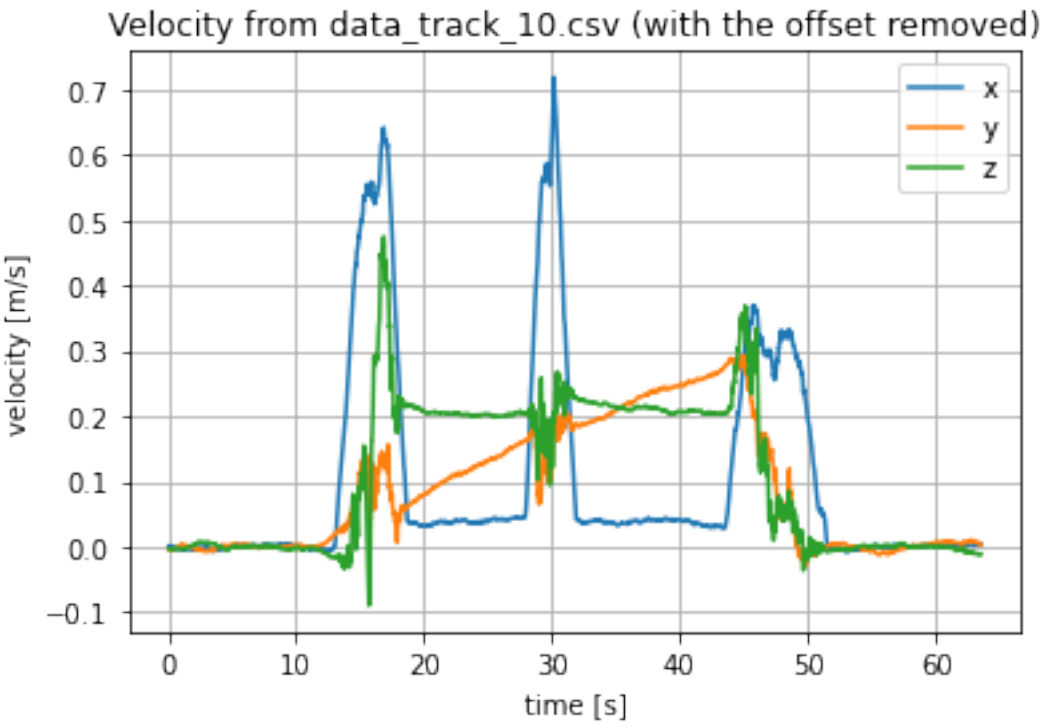

Velocity from data_track_08.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.2
0.1
0.0
−0.1
0
10
20
30
40
50
60

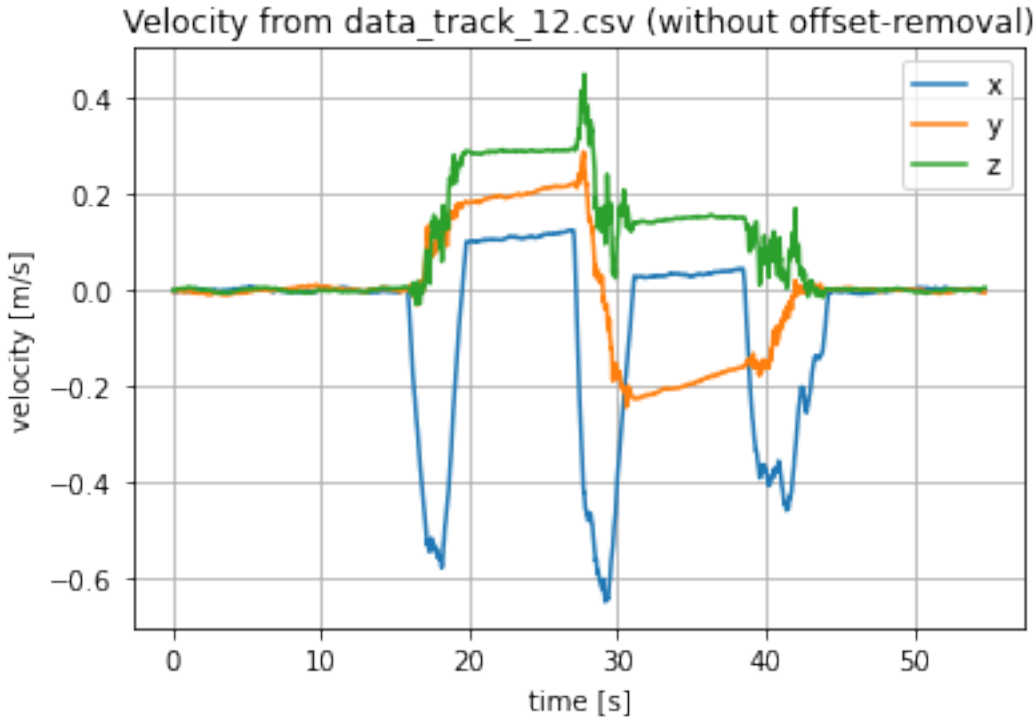

Velocity from data_track_08.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.2
0.1
0.0
−0.1
0
10
20
30
40
50
60

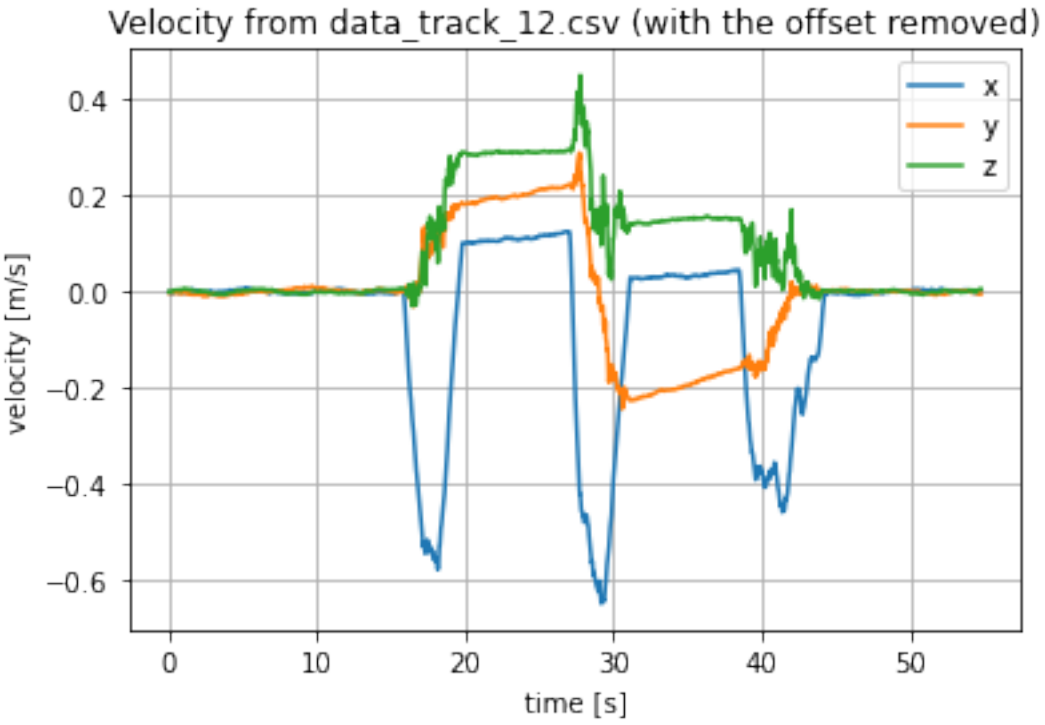

Velocity from data_track_09.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
10
20
30
40
50
60

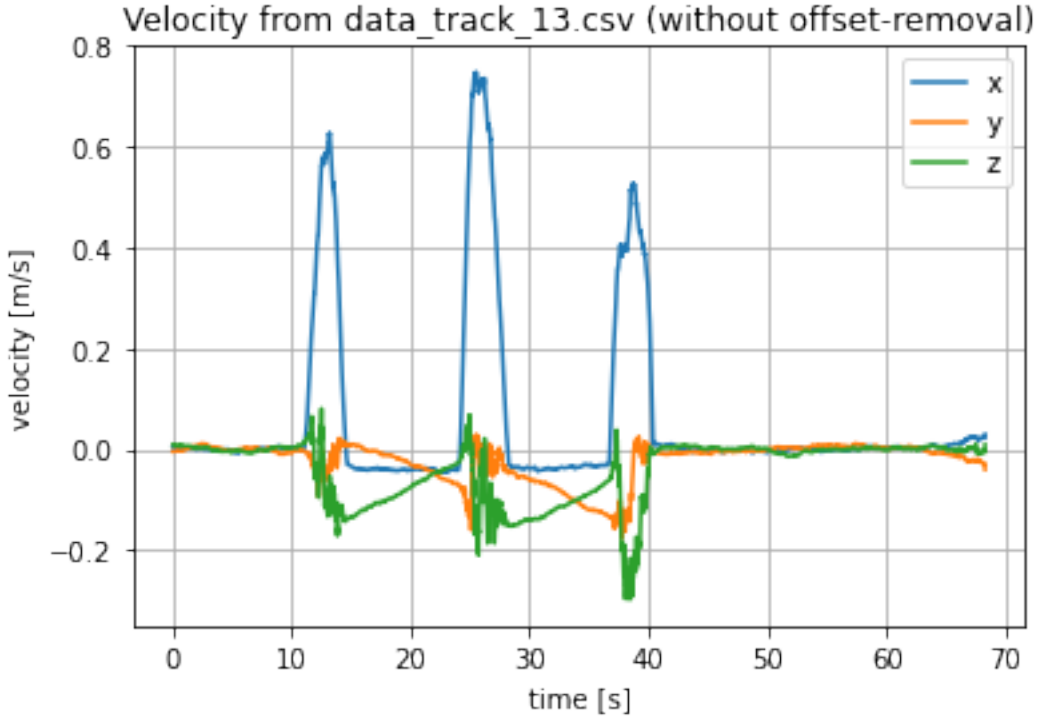

Velocity from data_track_09.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
10
20
30
40
50
60

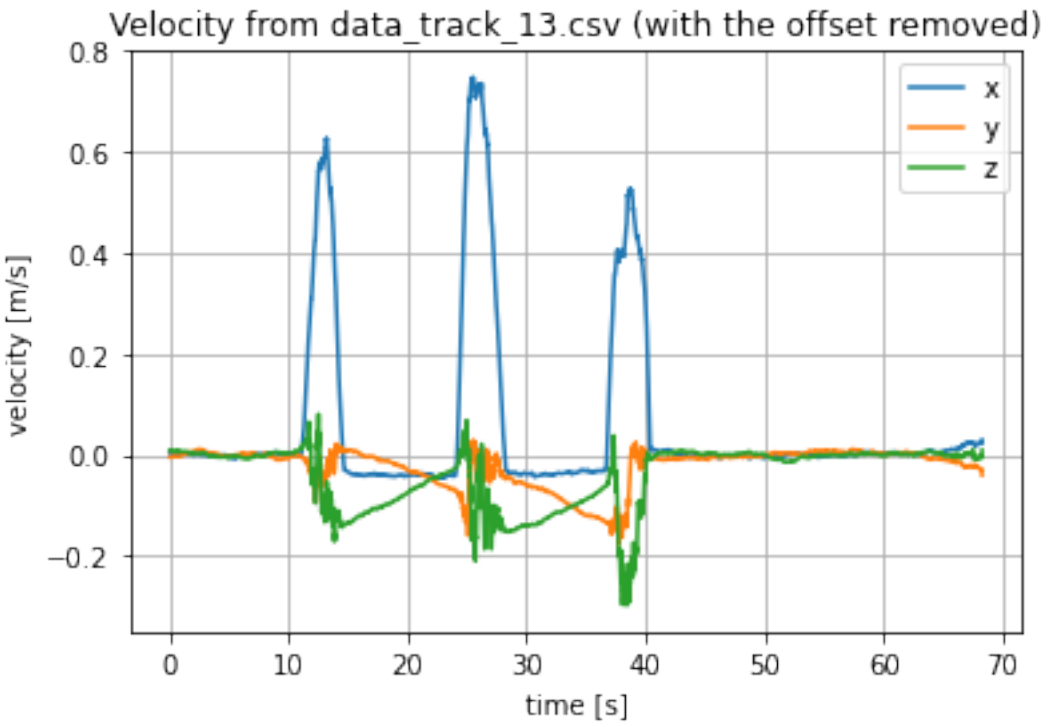

Velocity from data_track_10.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
0
10
20
30
40
50
60

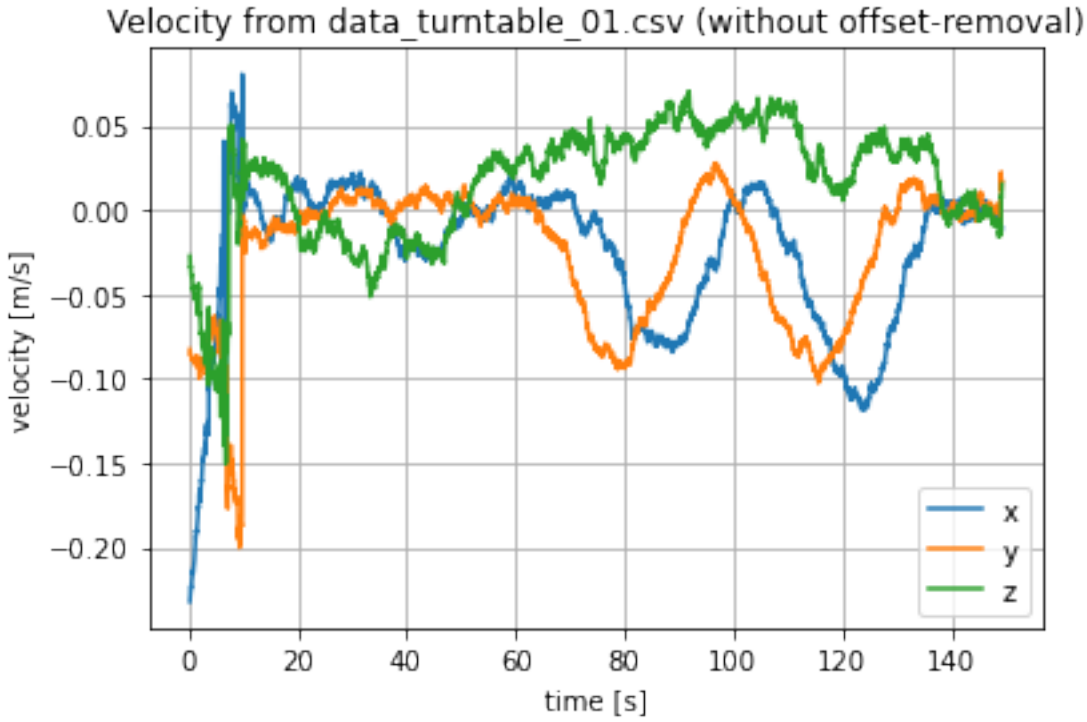

Velocity from data_track_10.csv (with the offset removed)
x
y
z
velocity [m/s]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
0
10
20
30
40
50
60
time [s]

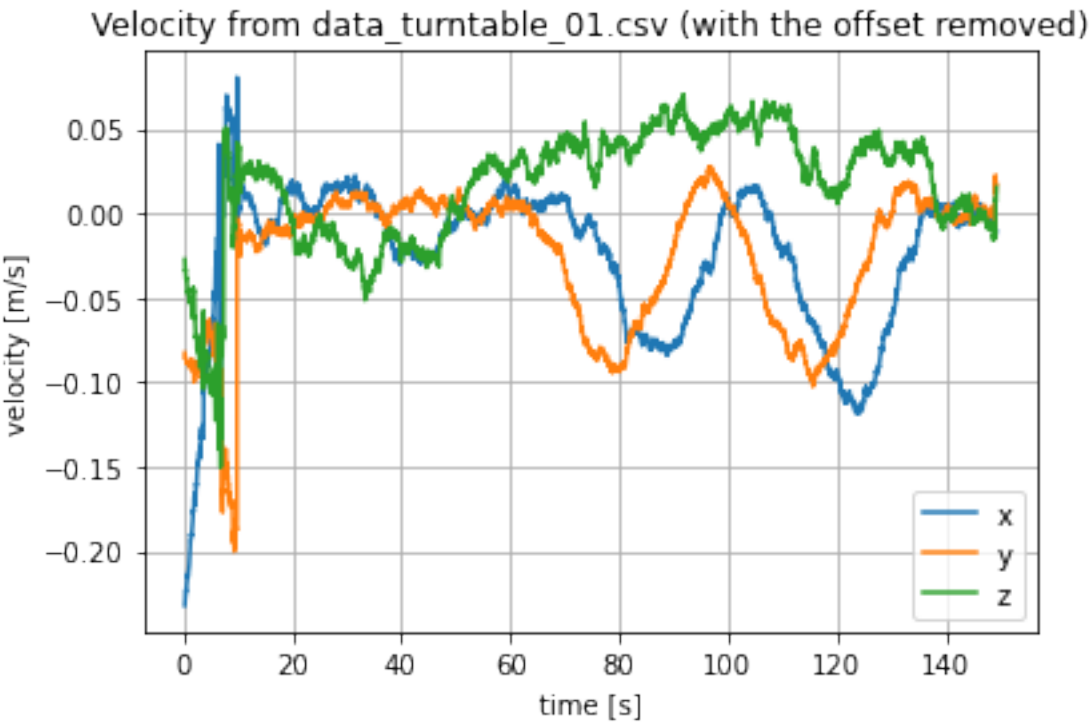

Velocity from data_track_12.csv (without offset-removal)
x
y
z
velocity [m/s]
0.4
0.2
0.0
−0.2
−0.4
−0.6
0
10
20
30
40
50
time [s]

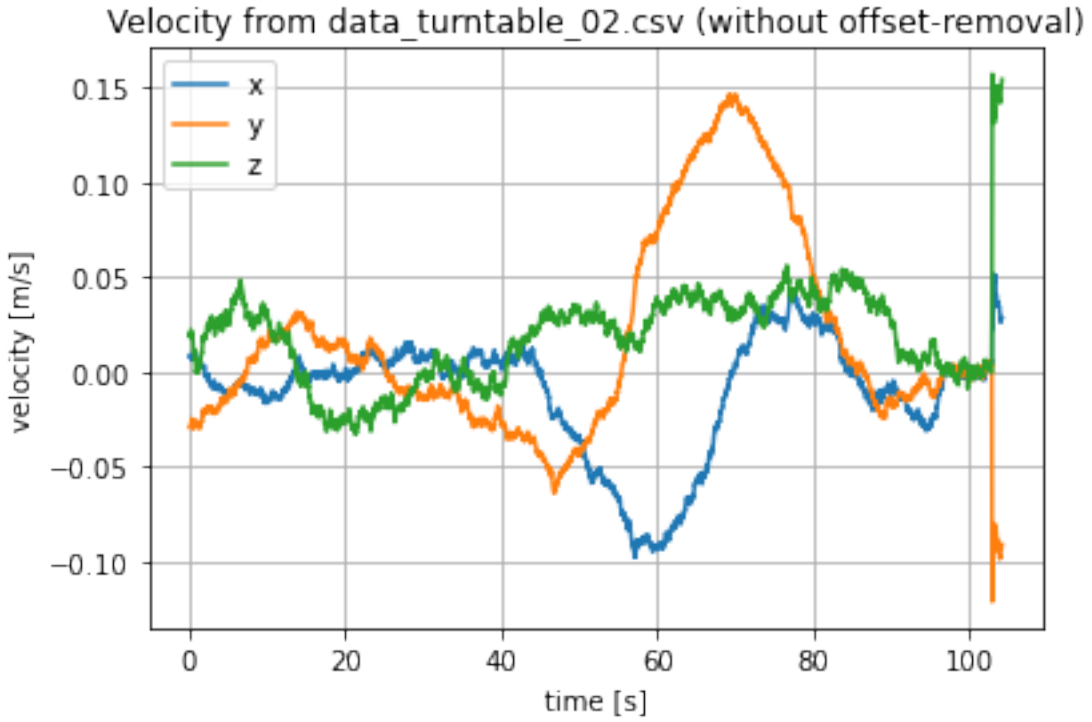

Velocity from data_track_12.csv (with the offset removed)
x
y
z
velocity [m/s]
0.4
0.2
0.0
−0.2
−0.4
−0.6
0
10
20
30
40
50
time [s]

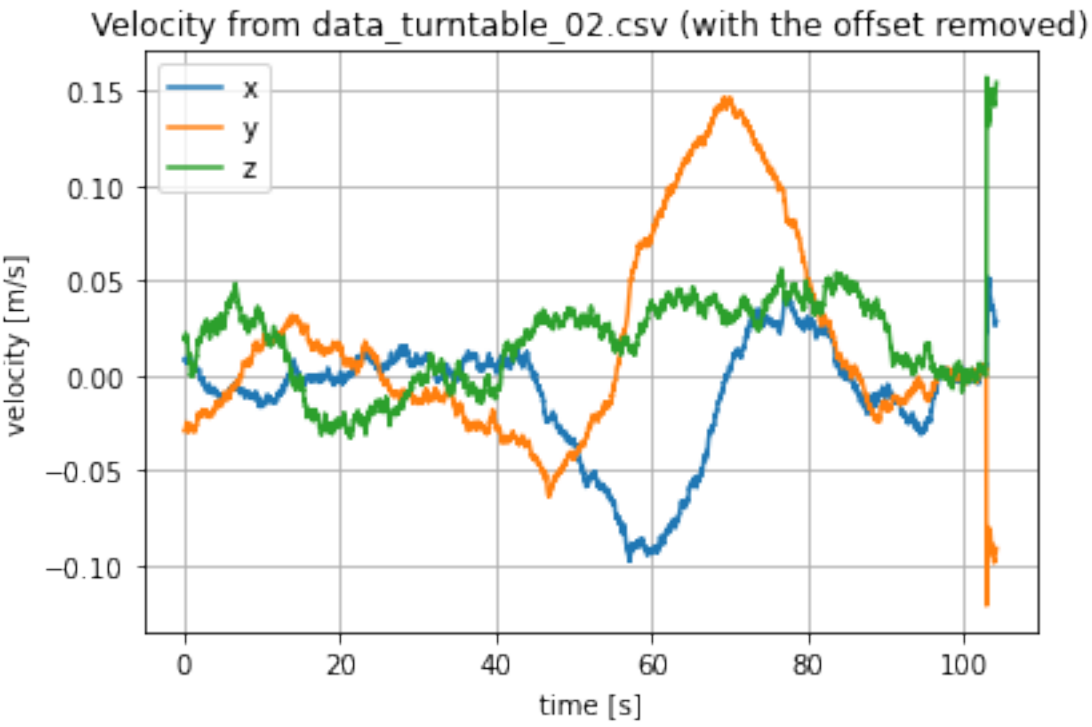

Velocity from data_track_13.csv (without offset-removal)
x
y
z
velocity [m/s]
0.8
0.6
0.4
0.2
0.0
−0.2
0
10
20
30
40
50
60
70
time [s]

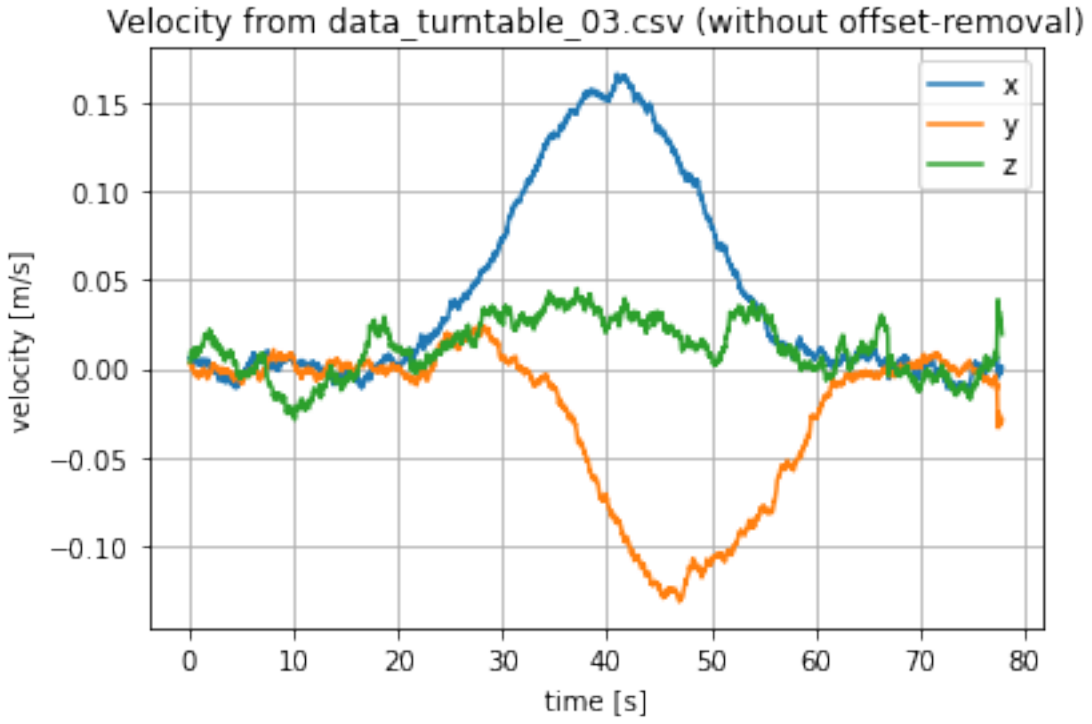

Velocity from data_track_13.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.8
0.6
0.4
0.2
0.0
−0.2
0
10
20
30
40
50
60
70

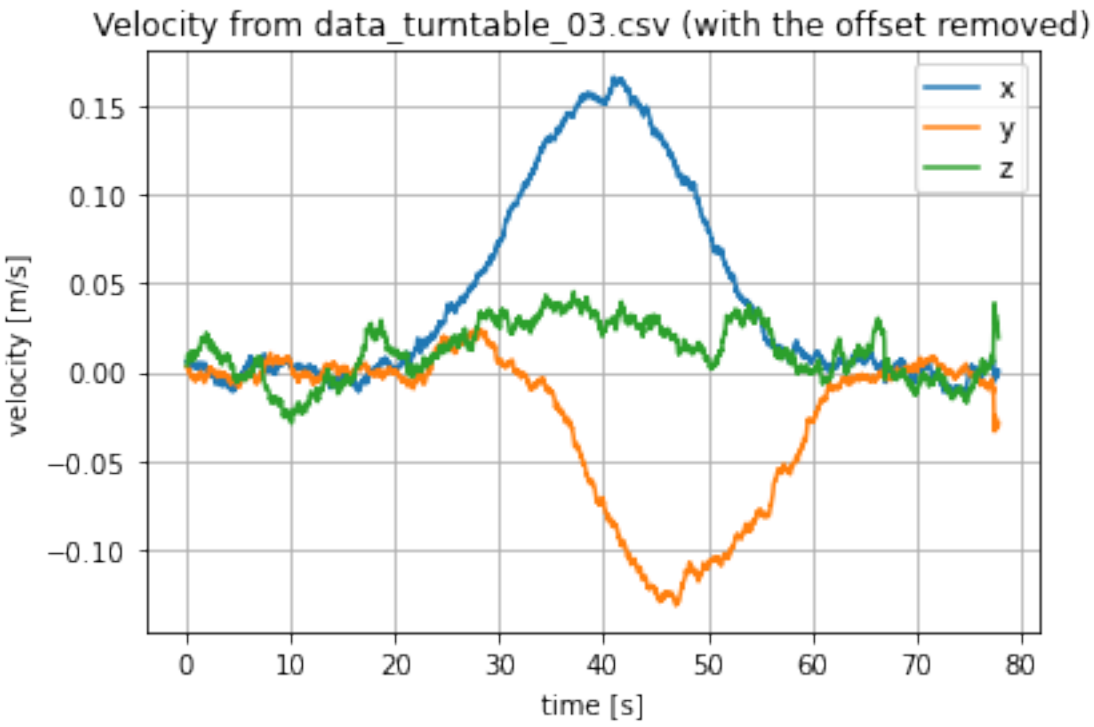

Velocity from data_turntable_01.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.05
0.00
−0.05
−0.10
−0.15
−0.20
0
20
40
60
80
100
120
140

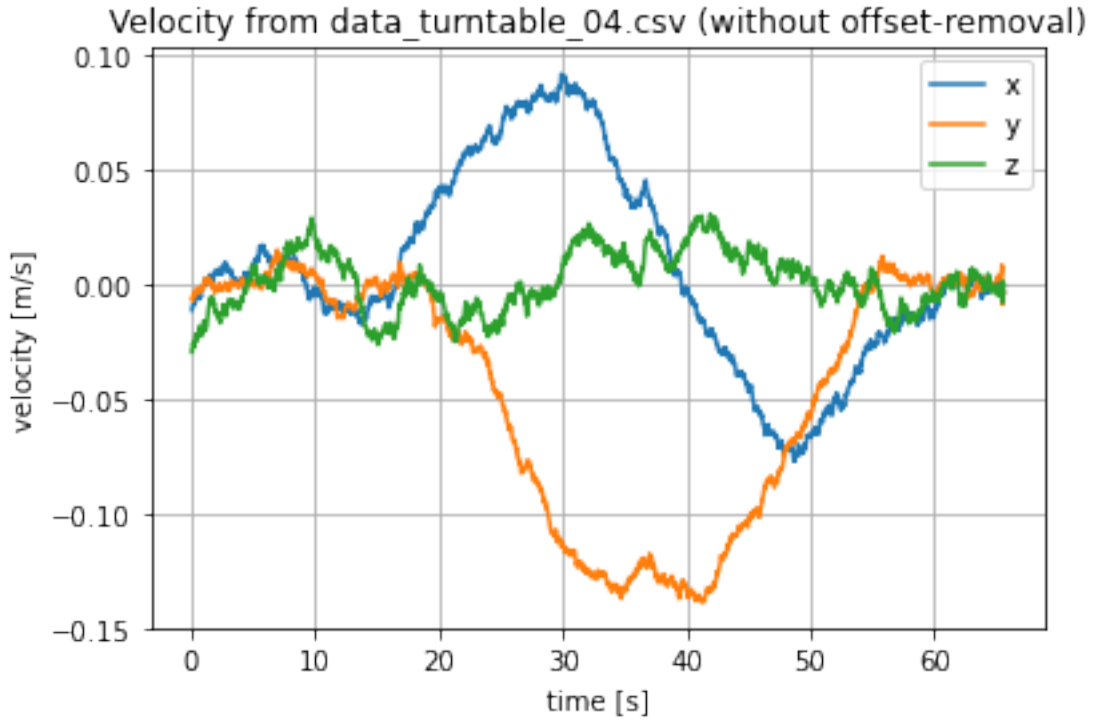

Velocity from data_turntable_01.csv (with the offset removed)
velocity [m/s]
0.05
0.00
−0.05
−0.10
−0.15
−0.20
0
20
40
60
80
100
120
140
time [s]
x
y
z

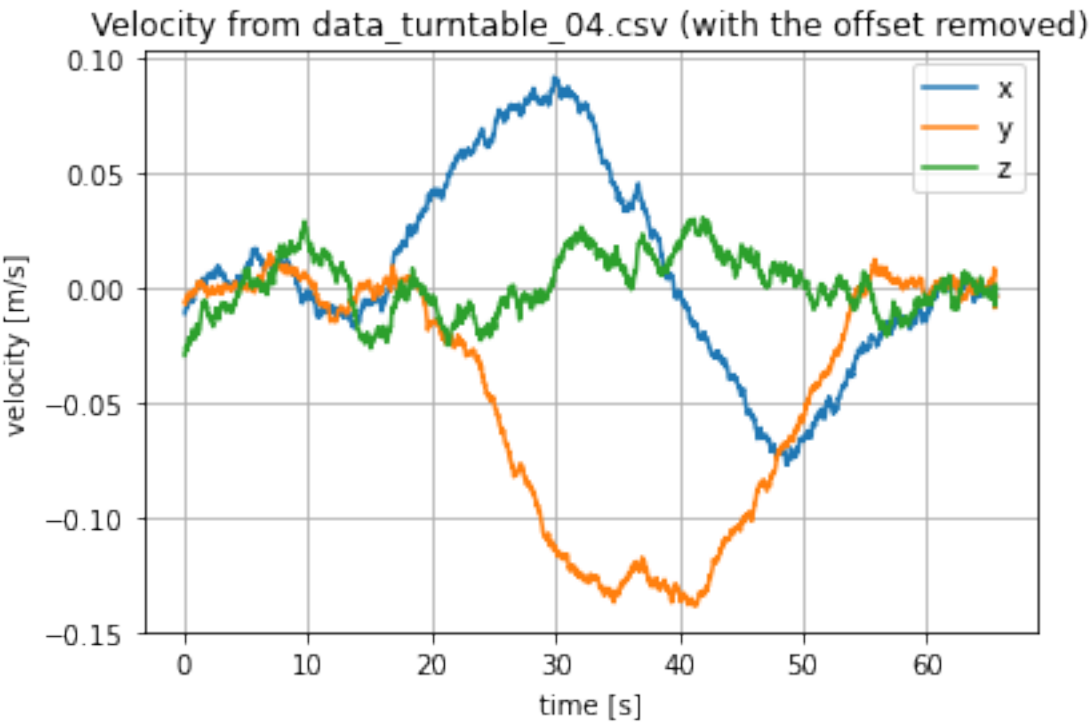

Velocity from data_turntable_02.csv (without offset-removal)
velocity [m/s]
0.15
0.10
0.05
0.00
−0.05
−0.10
0
20
40
60
80
100
time [s]
x
y
z

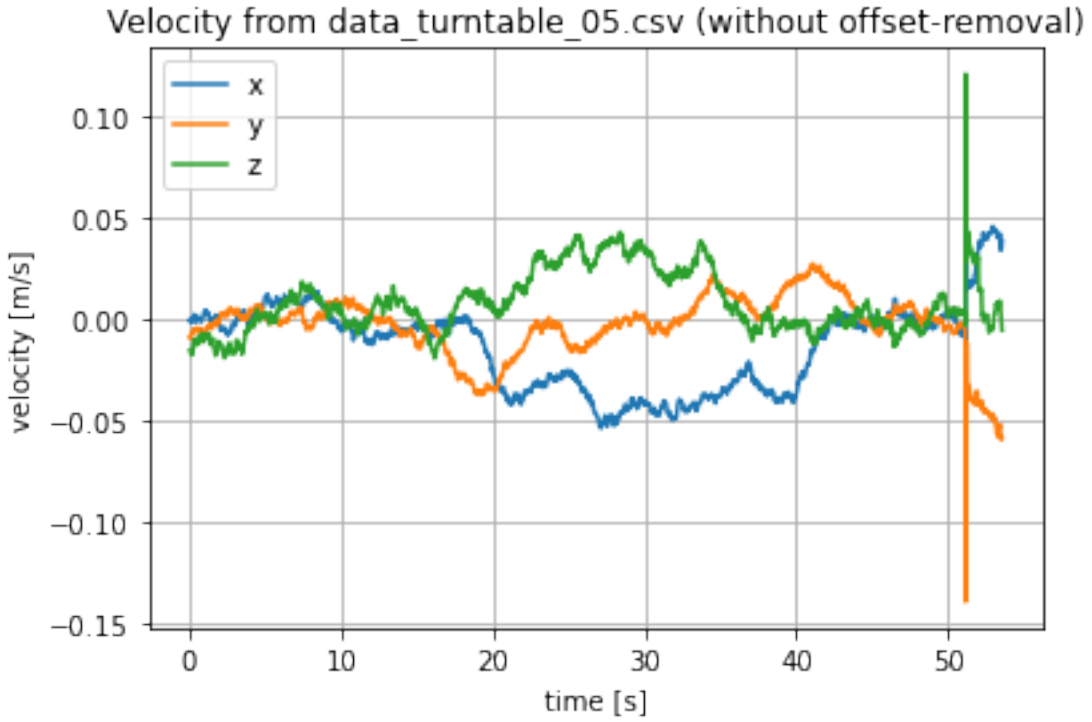

Velocity from data_turntable_02.csv (with the offset removed)
x
y
z
0.15
0.10
0.05
0.00
−0.05
−0.10
velocity [m/s]
0
20
40
60
80
100
time [s]

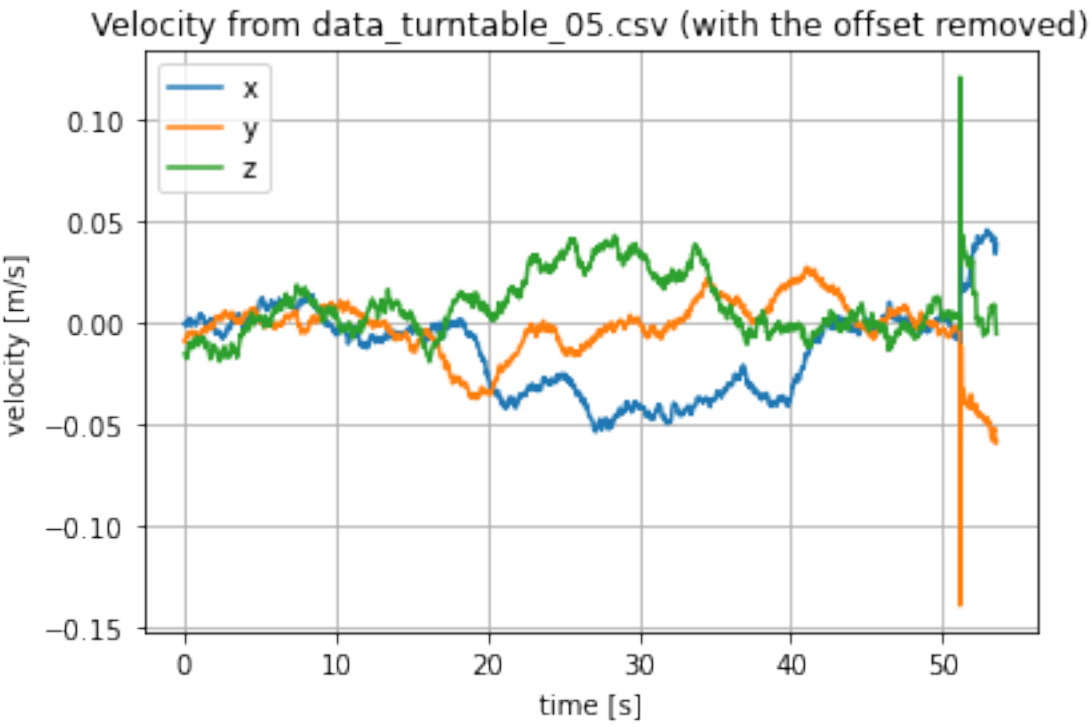

Velocity from data_turntable_03.csv (without offset-removal)
x
y
z
0.15
0.10
0.05
0.00
−0.05
−0.10
velocity [m/s]
0
10
20
30
40
50
60
70
80
time [s]

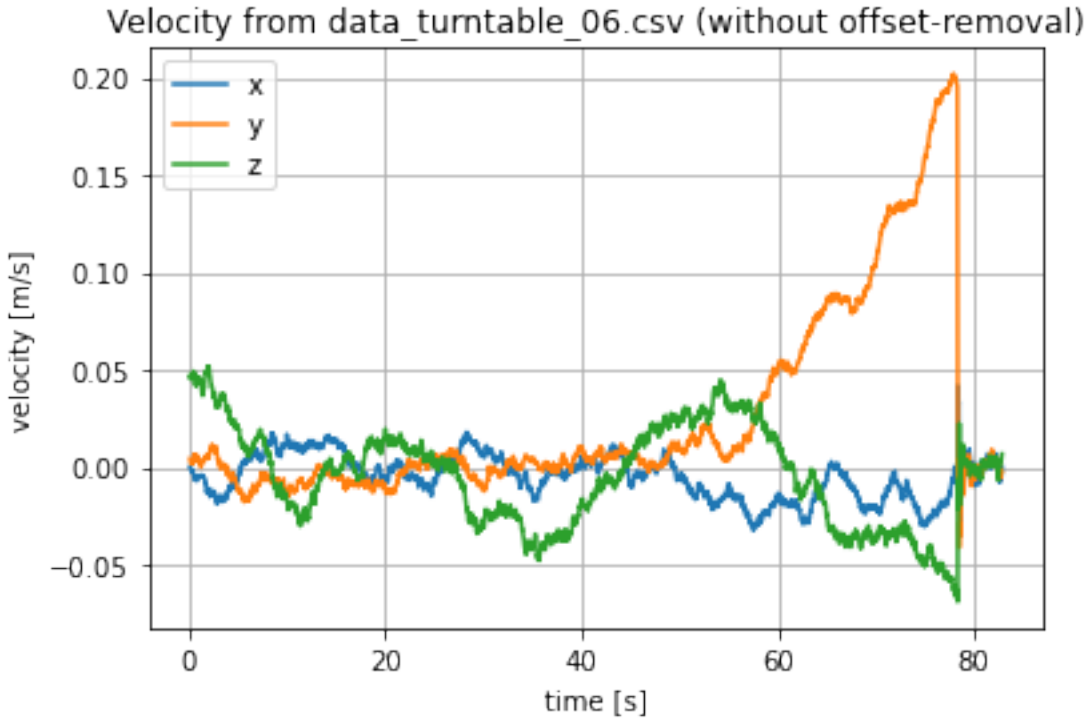

Velocity from data_turntable_03.csv (with the offset removed)
x
y
z
velocity [m/s]
0.15
0.10
0.05
0.00
−0.05
−0.10
0
10
20
30
40
50
60
70
80
time [s]

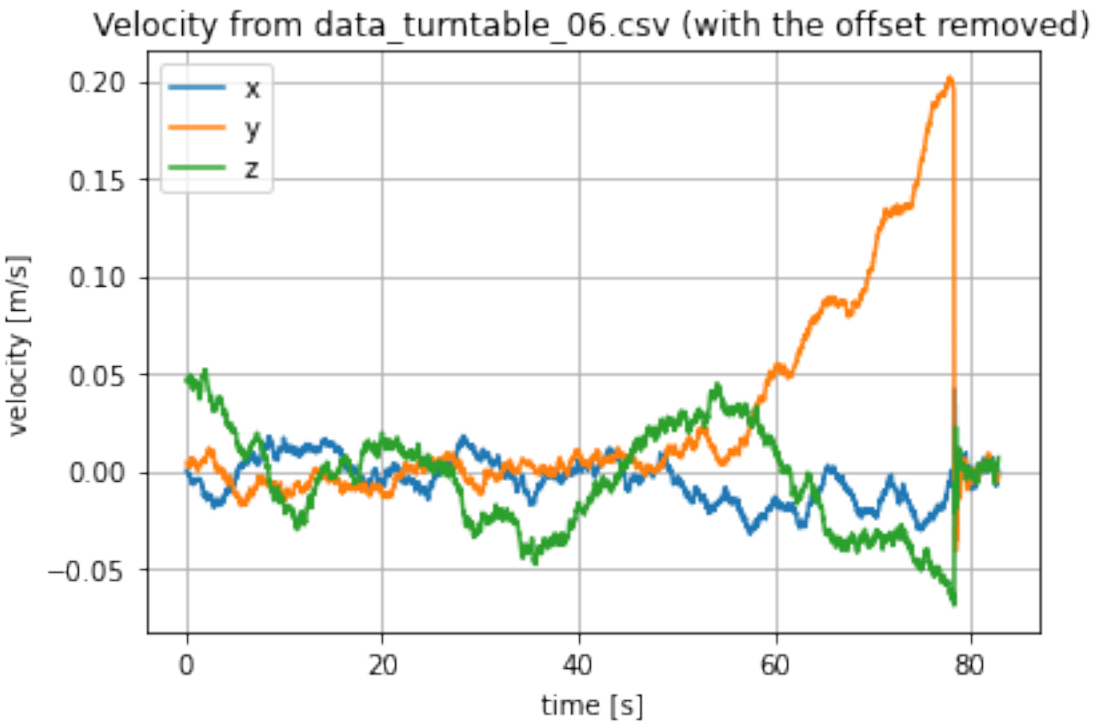

Velocity from data_turntable_04.csv (without offset-removal)
x
y
z
velocity [m/s]
0.10
0.05
0.00
−0.05
−0.10
−0.15
0
10
20
30
40
50
60
time [s]

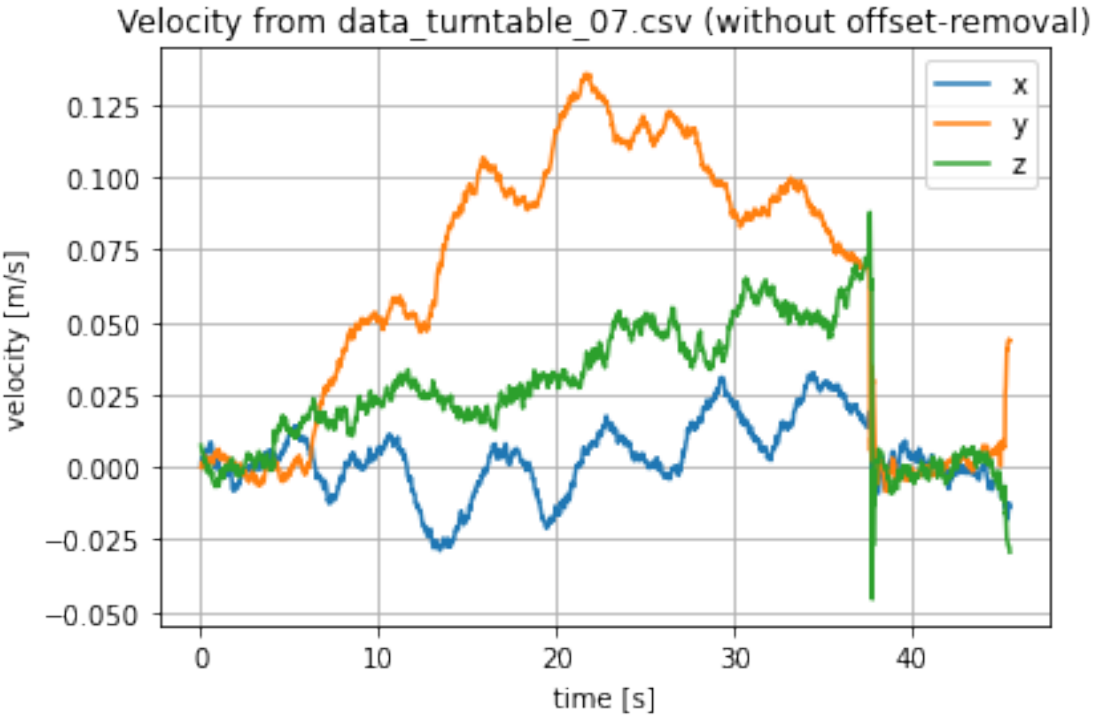

Velocity from data_turntable_04.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.10
0.05
0.00
−0.05
−0.10
−0.15
0
10
20
30
40
50
60

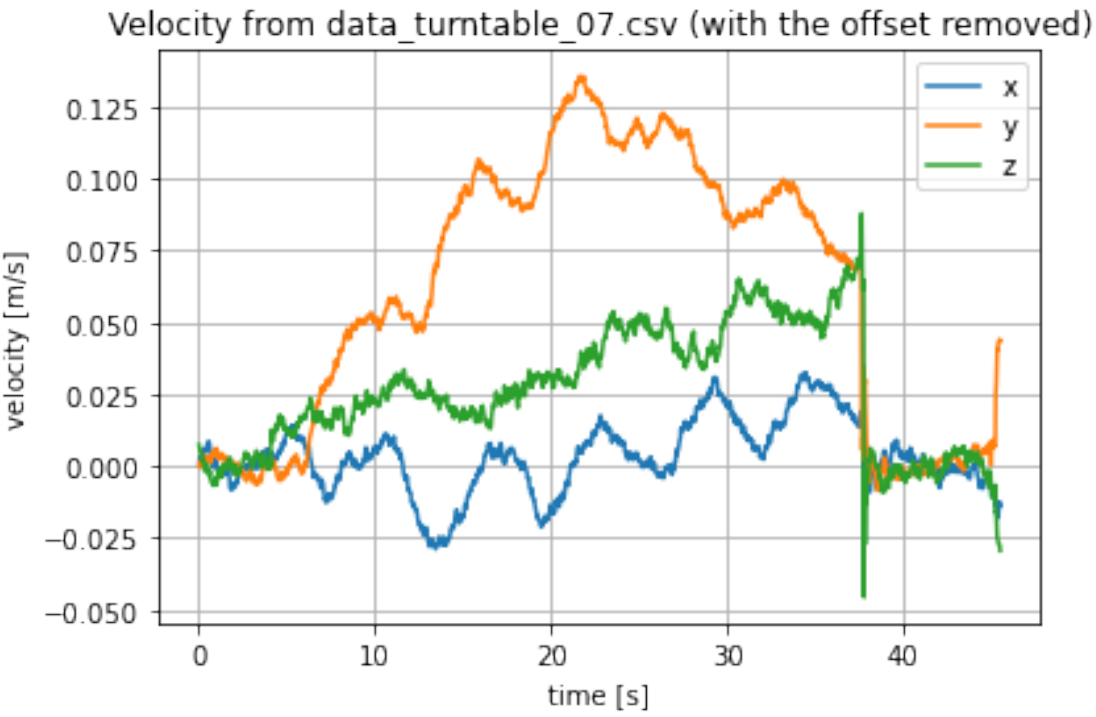

Velocity from data_turntable_05.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.10
0.05
0.00
−0.05
−0.10
−0.15
0
10
20
30
40
50

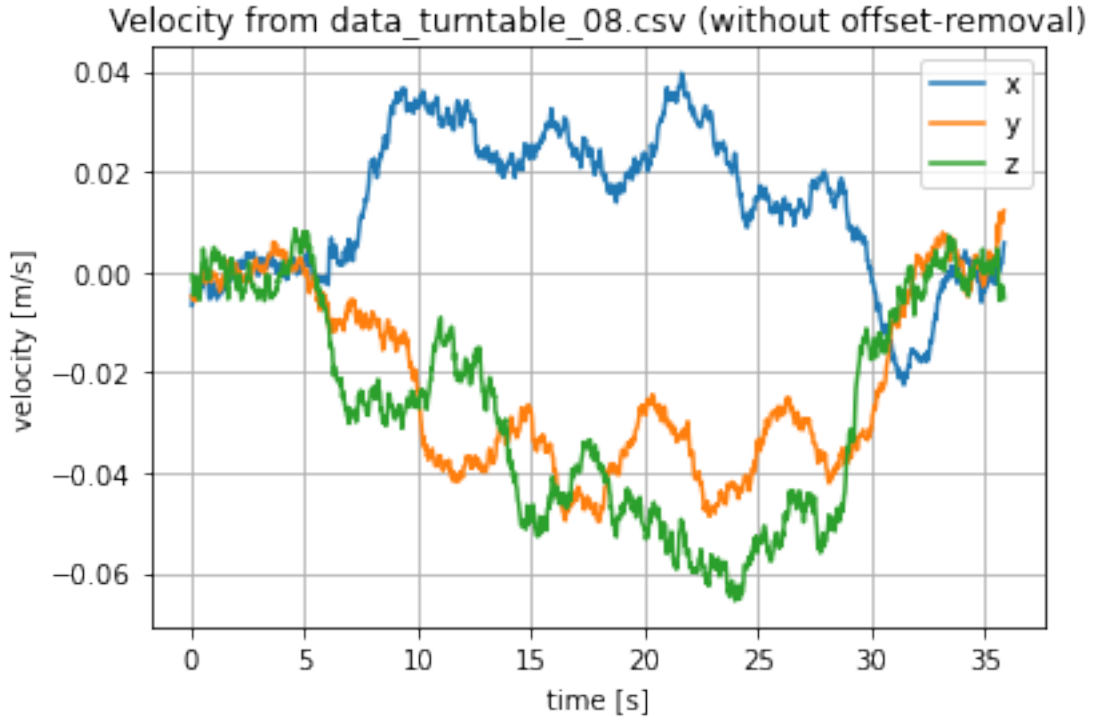

Velocity from data_turntable_05.csv (with the offset removed)
x
y
z
0.10
0.05
0.00
−0.05
−0.10
−0.15
velocity [m/s]
0
10
20
30
40
50
time [s]

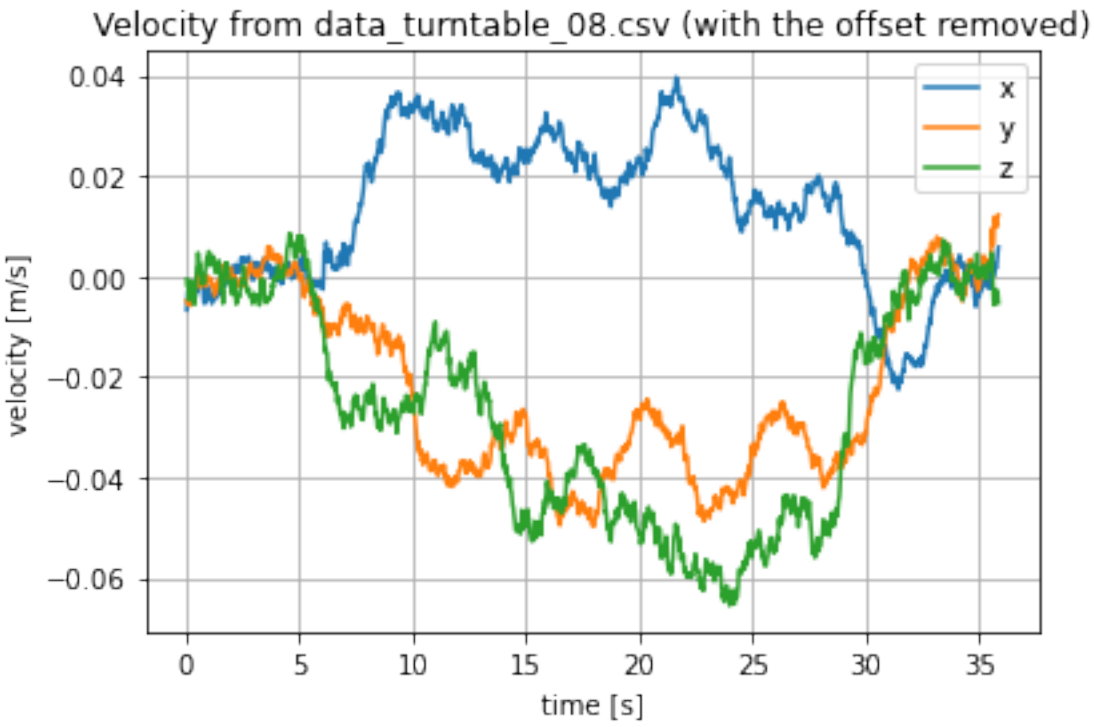

Velocity from data_turntable_06.csv (without offset-removal)
x
y
z
0.20
0.15
0.10
0.05
0.00
−0.05
velocity [m/s]
0
20
40
60
80
time [s]

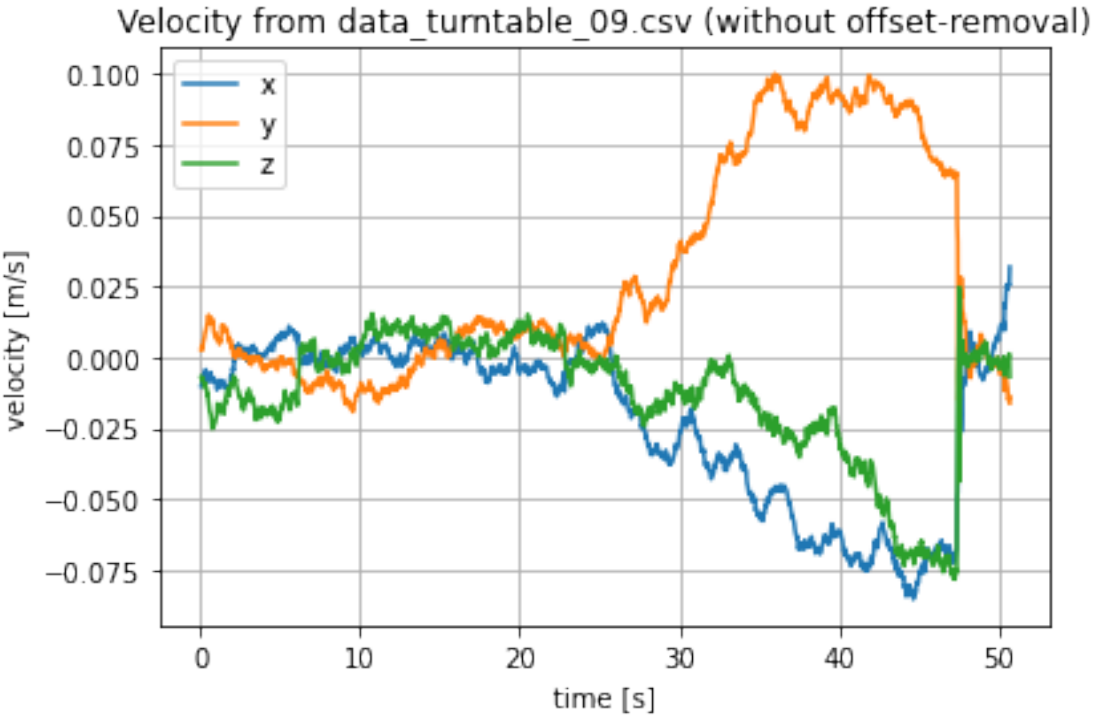

Velocity from data_turntable_06.csv (with the offset removed)
x
y
z
0.20
0.15
0.10
0.05
0.00
−0.05
velocity [m/s]
0
20
40
60
80
time [s]

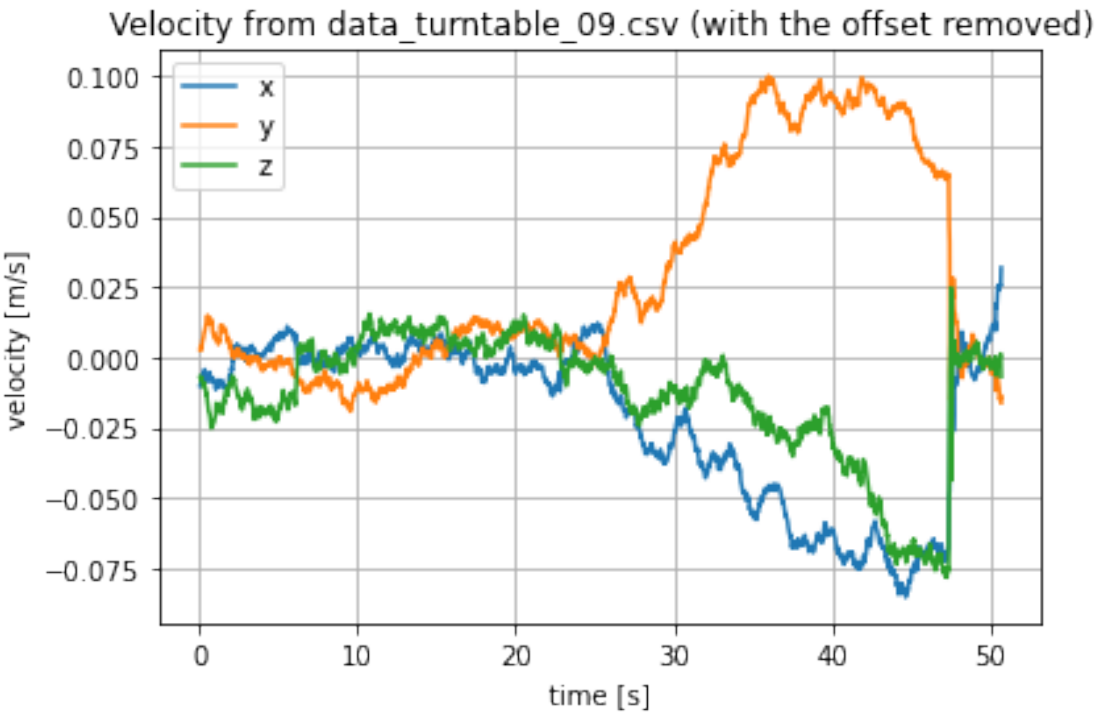

Velocity from data_turntable_07.csv (without offset-removal)
x
y
z
0.125
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
velocity [m/s]
0
10
20
30
40
time [s]

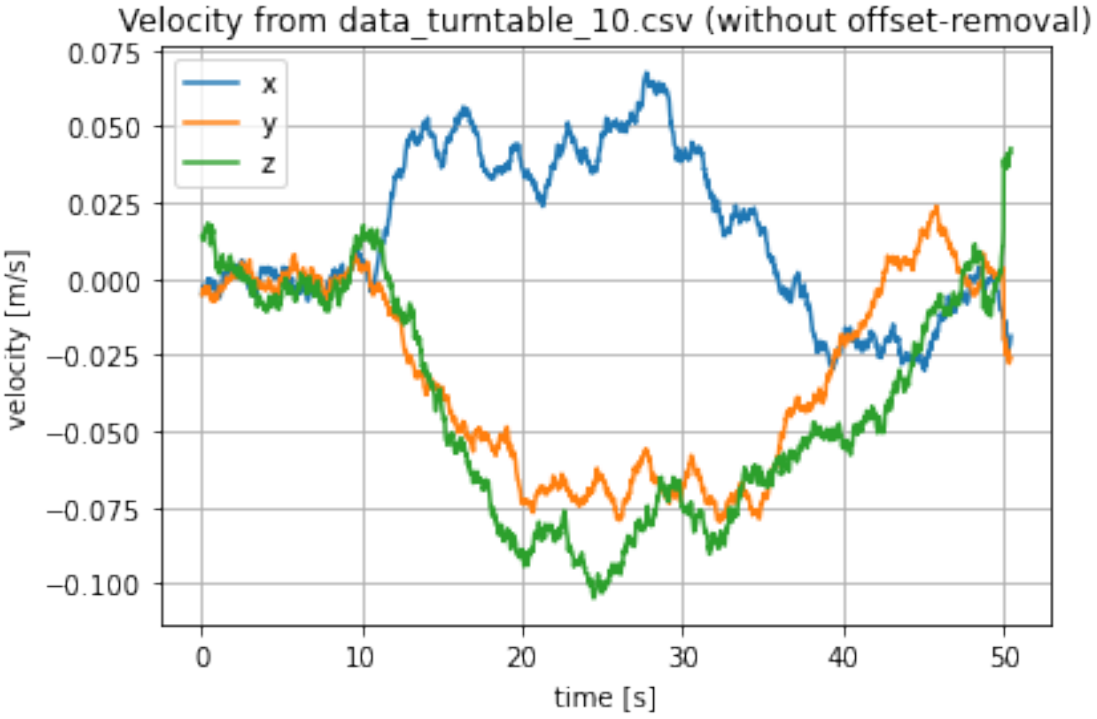

Velocity from data_turntable_07.csv (with the offset removed)
x
y
z
0.125
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
velocity [m/s]
0
10
20
30
40
time [s]

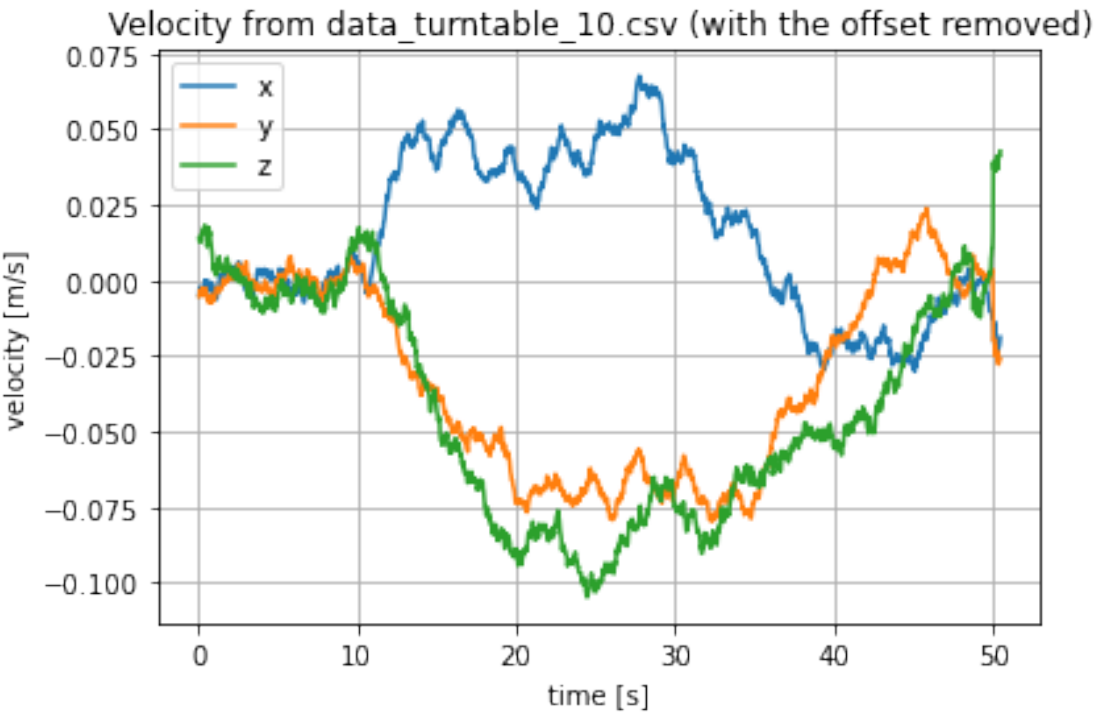

Velocity from data_turntable_08.csv (without offset-removal)
x
y
z
0.04
0.02
0.00
−0.02
−0.04
−0.06
velocity [m/s]
0
5
10
15
20
25
30
35
time [s]

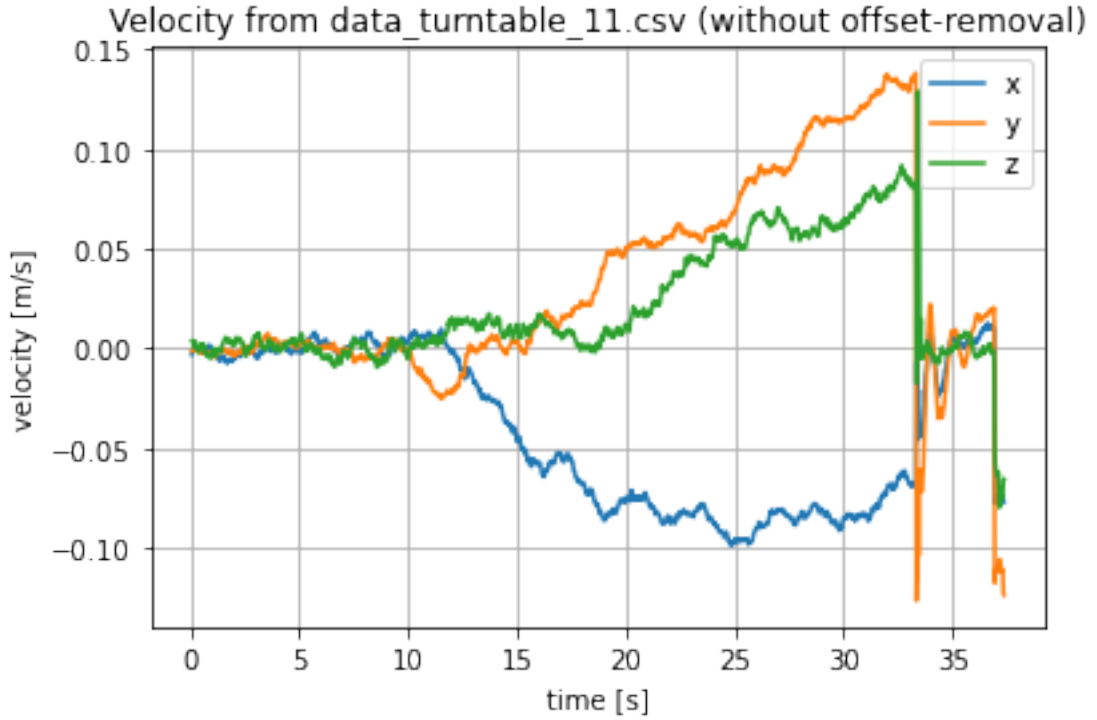

Velocity from data_turntable_08.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.04
0.02
0.00
−0.02
−0.04
−0.06
0
5
10
15
20
25
30
35

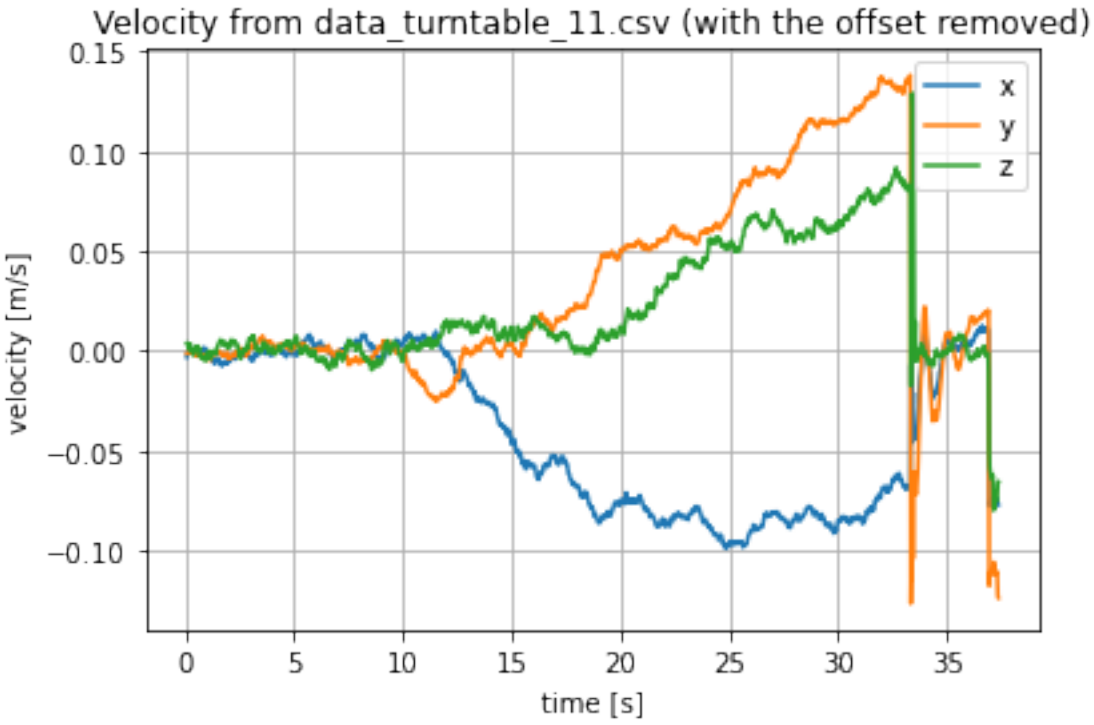

Velocity from data_turntable_09.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
0
10
20
30
40
50

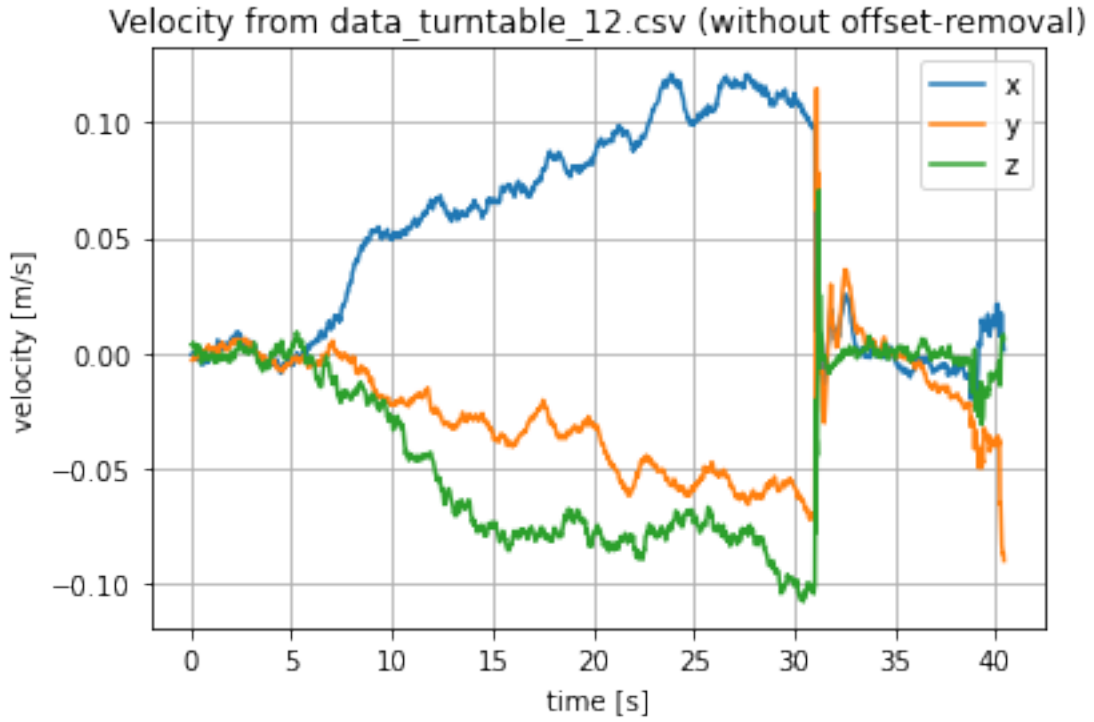

Velocity from data_turntable_09.csv (with the offset removed)
x
y
z
velocity [m/s]
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
0
10
20
30
40
50
time [s]

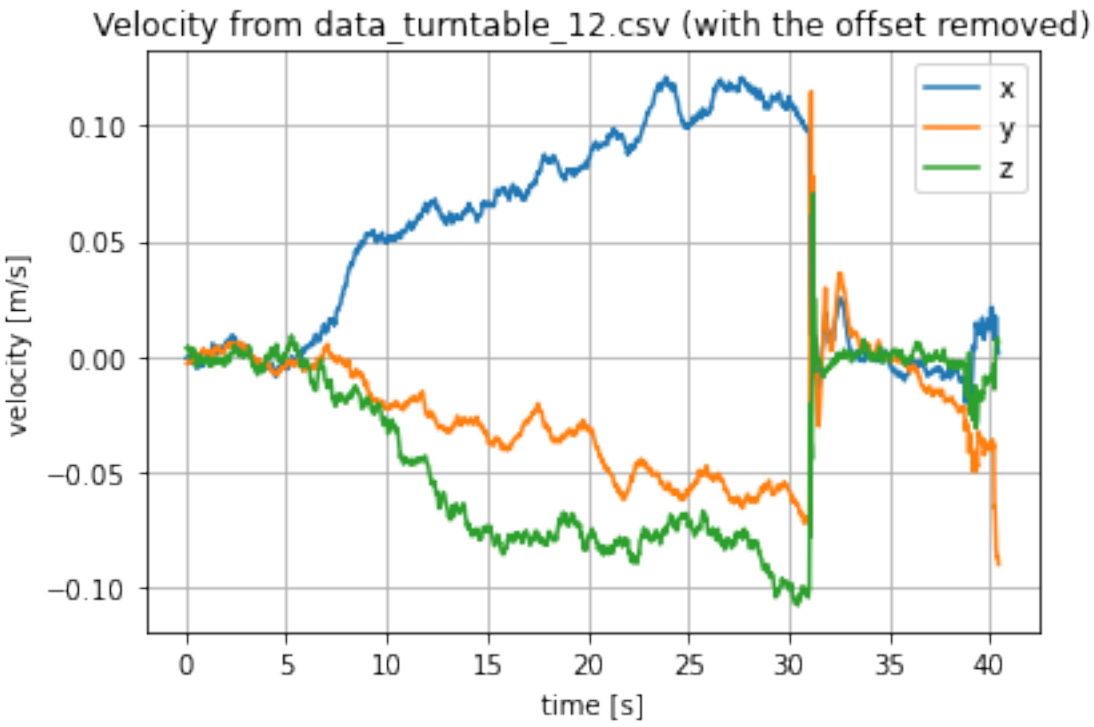

Velocity from data_turntable_10.csv (without offset-removal)
x
y
z
velocity [m/s]
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
−0.100
0
10
20
30
40
50
time [s]


Velocity from data_turntable_10.csv (with the offset removed)
x
y
z
velocity [m/s]
time [s]
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
−0.100
0
10
20
30
40
50


Velocity from data_turntable_11.csv (without offset-removal)
x
y
z
velocity [m/s]
time [s]
0.15
0.10
0.05
0.00
−0.05
−0.10
0
5
10
15
20
25
30
35

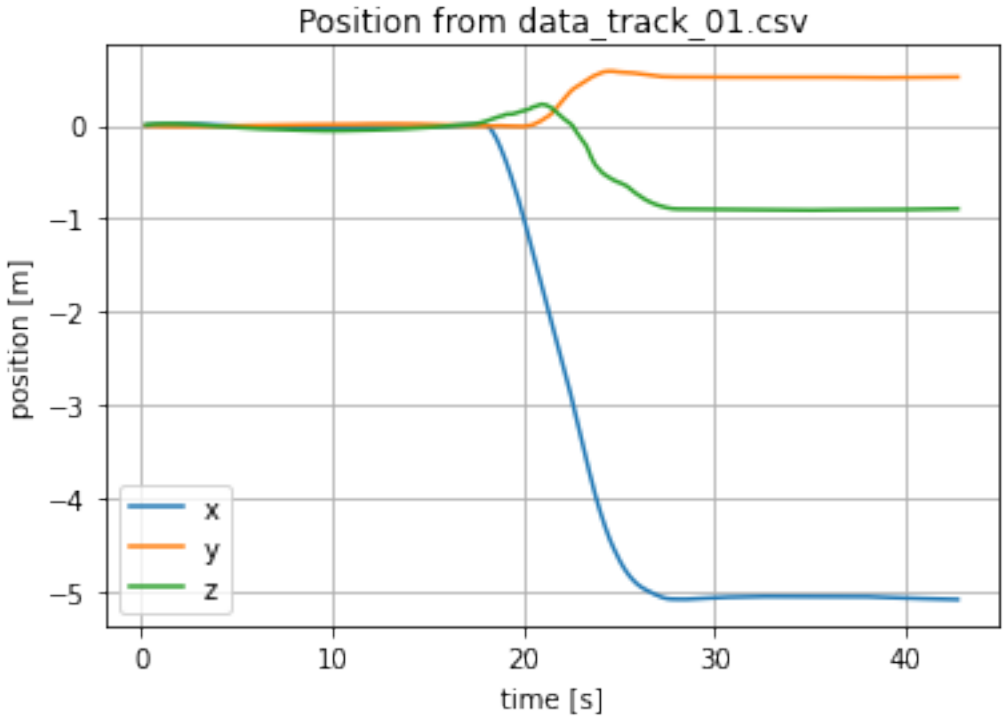

Velocity from data_turntable_11.csv (with the offset removed)
velocity [m/s]
time [s]
x
y
z
0.15
0.10
0.05
0.00
−0.05
−0.10
0
5
10
15
20
25
30
35

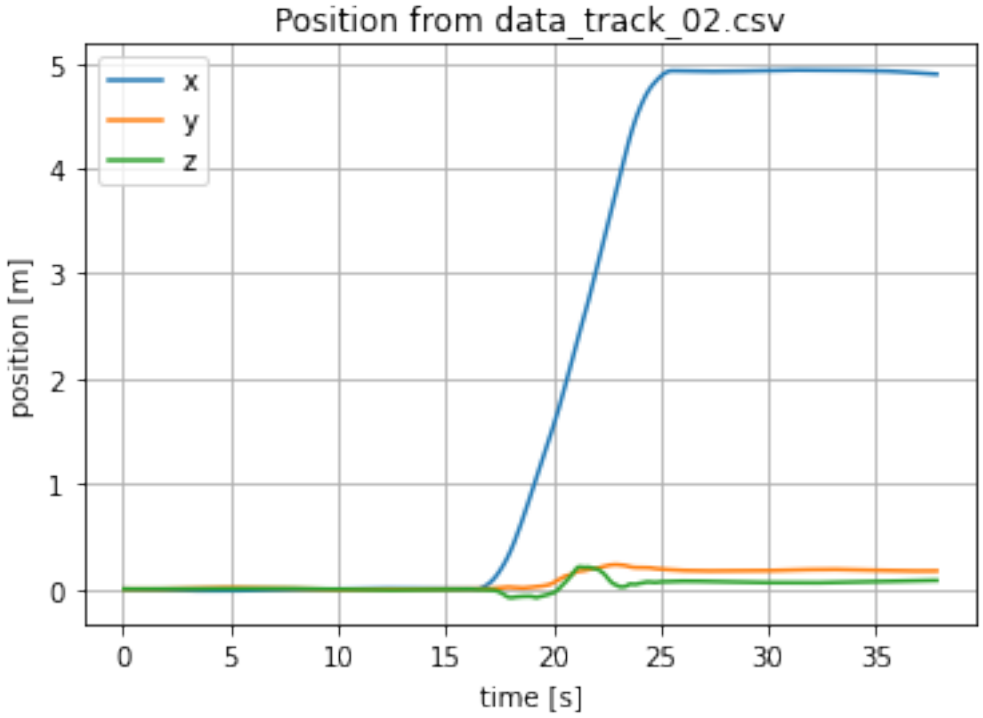

Velocity from data_turntable_12.csv (without offset-removal)
velocity [m/s]
time [s]
x
y
z
0.10
0.05
0.00
−0.05
−0.10
0
5
10
15
20
25
30
35
40

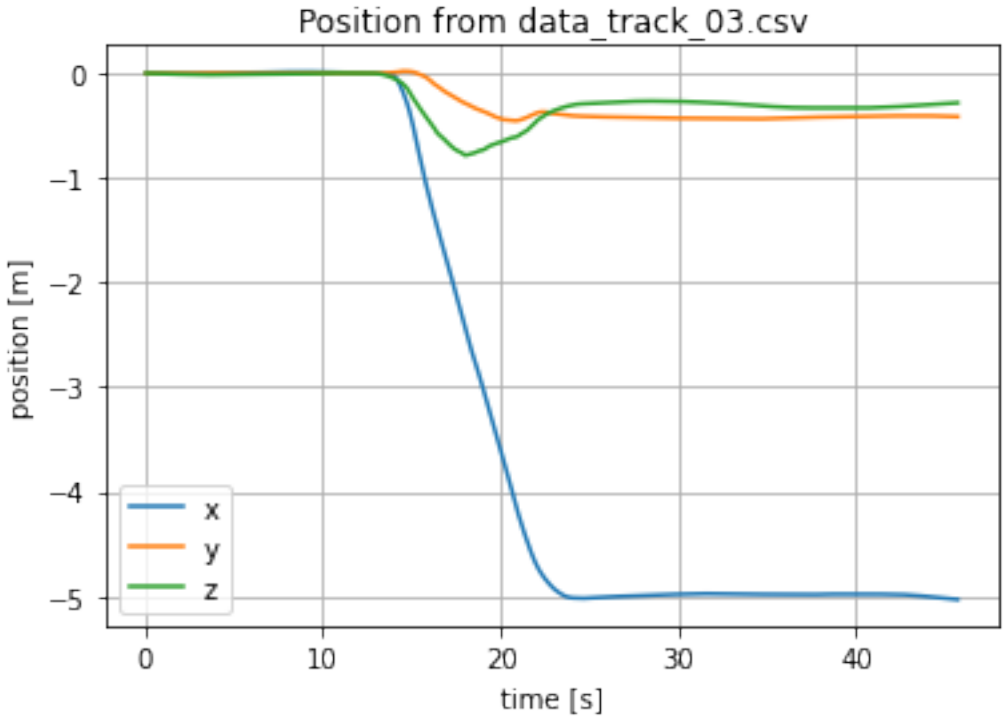


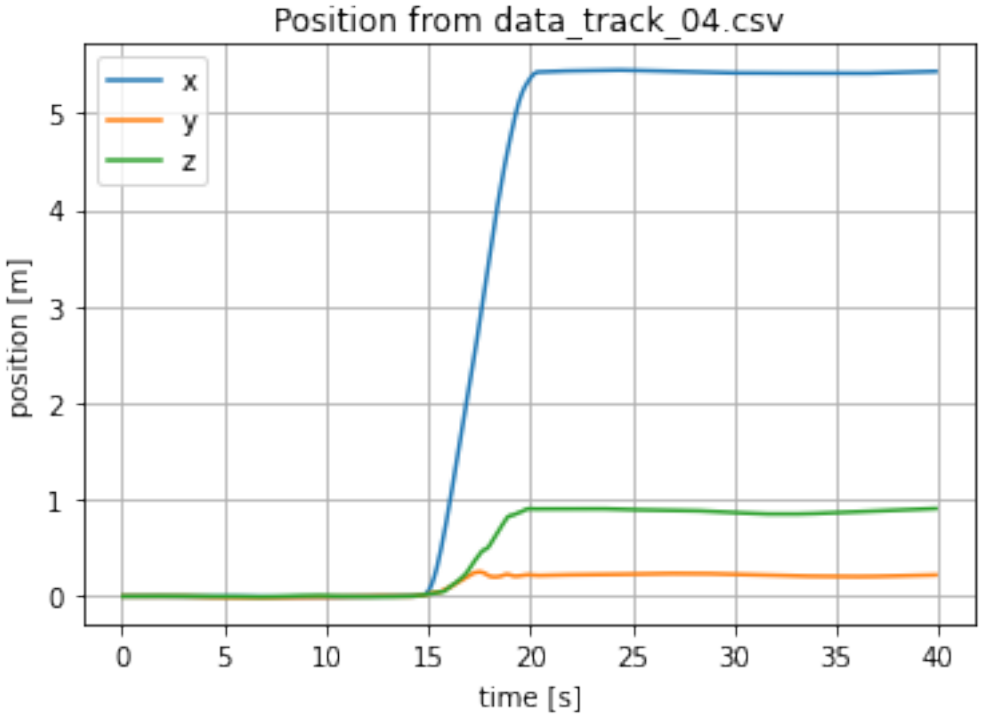

### 3.6.4 Position

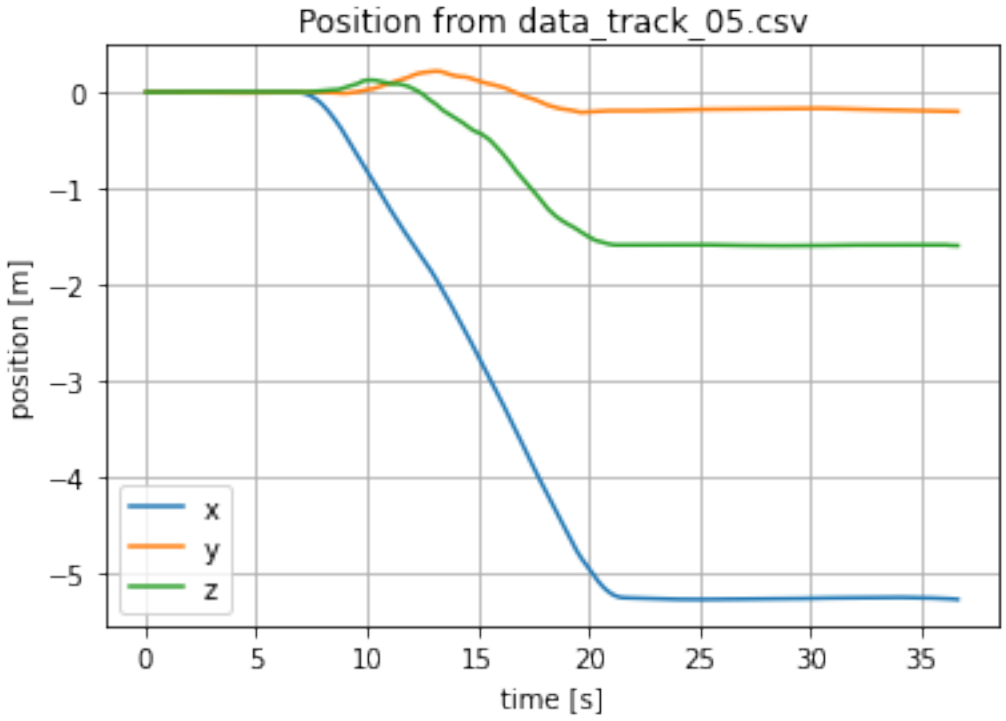
[ ]:
```
for measurement_id, e in enumerate(timestamps_all):
    mems.plot_results([position_all[measurement_id]["x"],␣
 ↪position_all[measurement_id]["y"], position_all[measurement_id]["z"]],
                      f'Position from {files[measurement_id]}',
                      "time [s]",
                      "position [m]",
                      ["x", "y", "z"],
                      e)
```

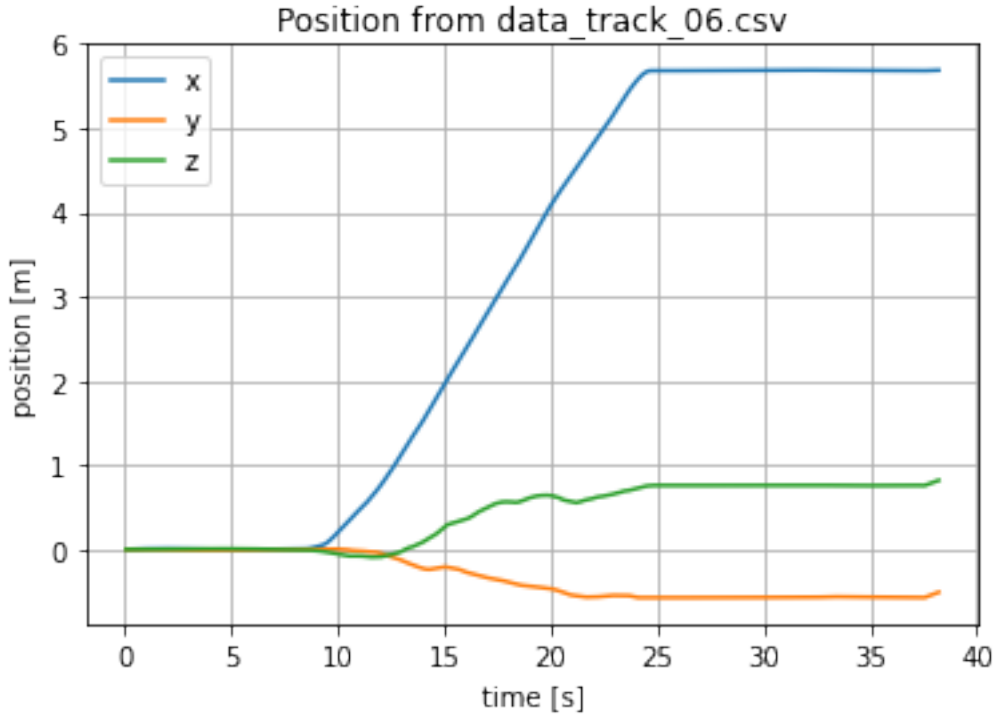

Position from data_track_01.csv
position [m]
time [s]
x
y
z
0
−1
−2
−3
−4
−5
0
10
20
30
40

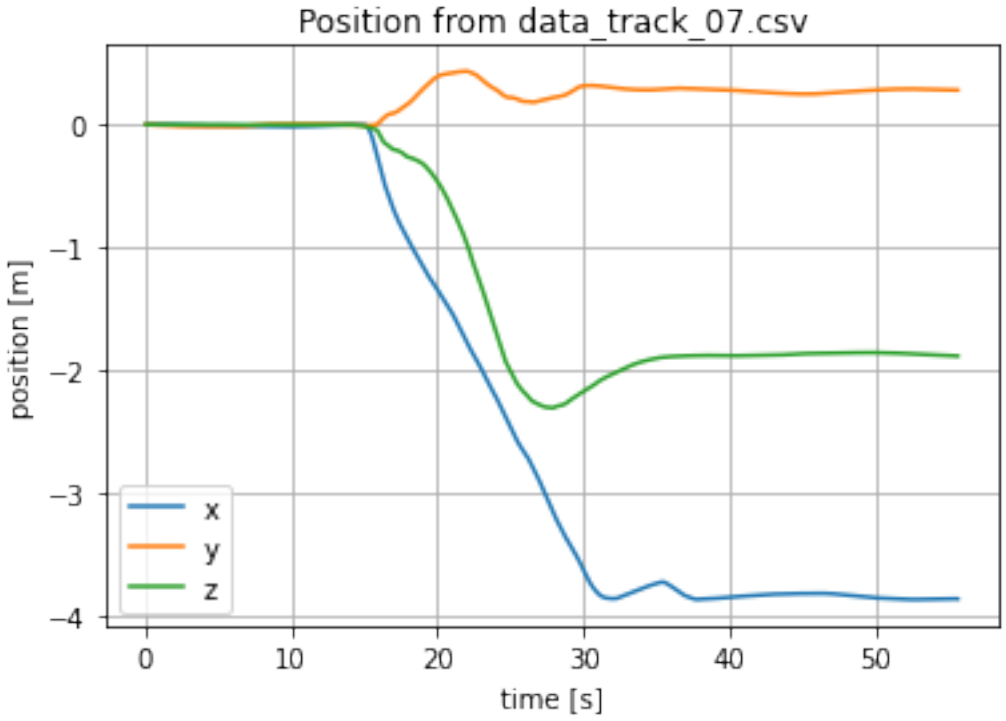

Position from data_track_02.csv
position [m]
time [s]
x
y
z
5
4
3
2
1
0
0
5
10
15
20
25
30
35

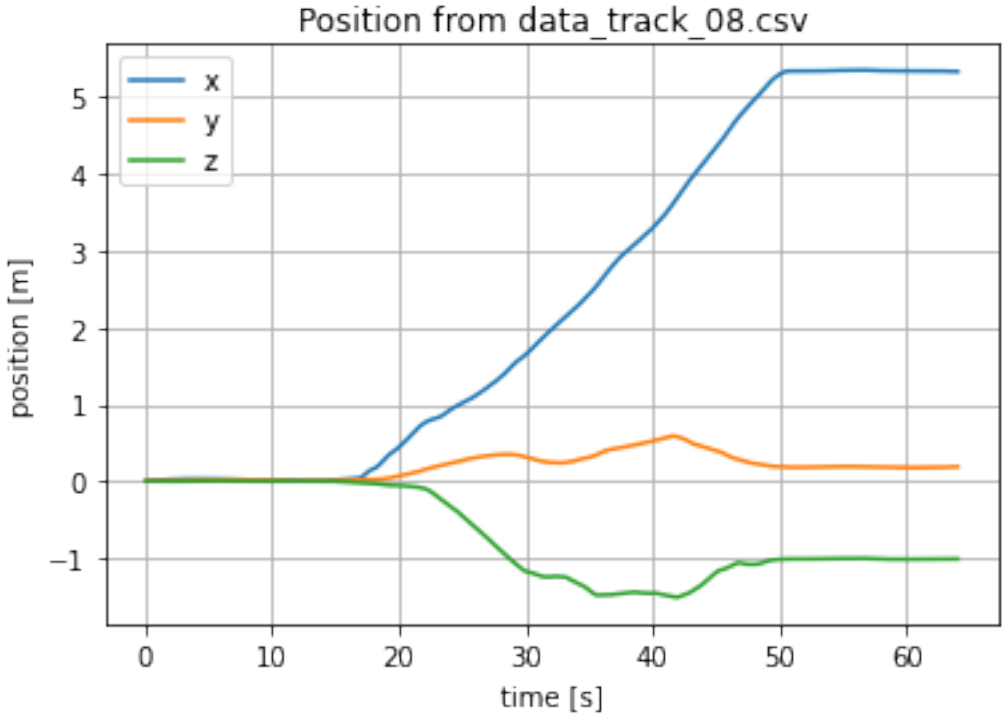

Position from data_track_03.csv
position [m]
time [s]
x
y
z
0
−1
−2
−3
−4
−5
0
10
20
30
40

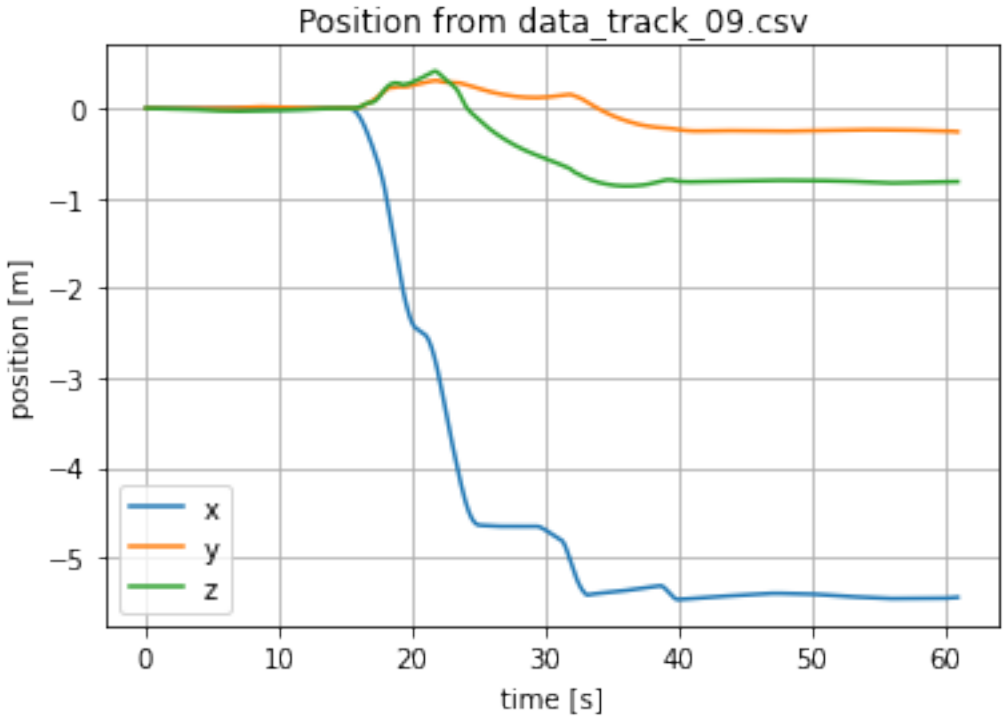

Position from data_track_04.csv
position [m]
time [s]
x
y
z
0
1
2
3
4
5
0
5
10
15
20
25
30
35
40

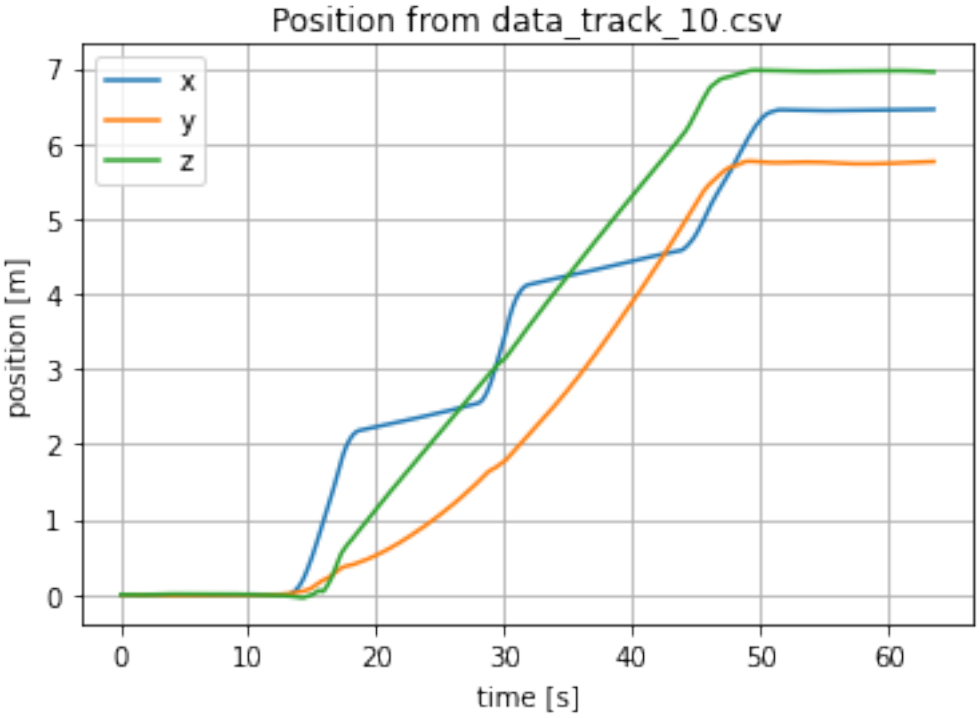

Position from data_track_05.csv
position [m]
time [s]
x
y
z
0
−1
−2
−3
−4
−5
0
5
10
15
20
25
30
35

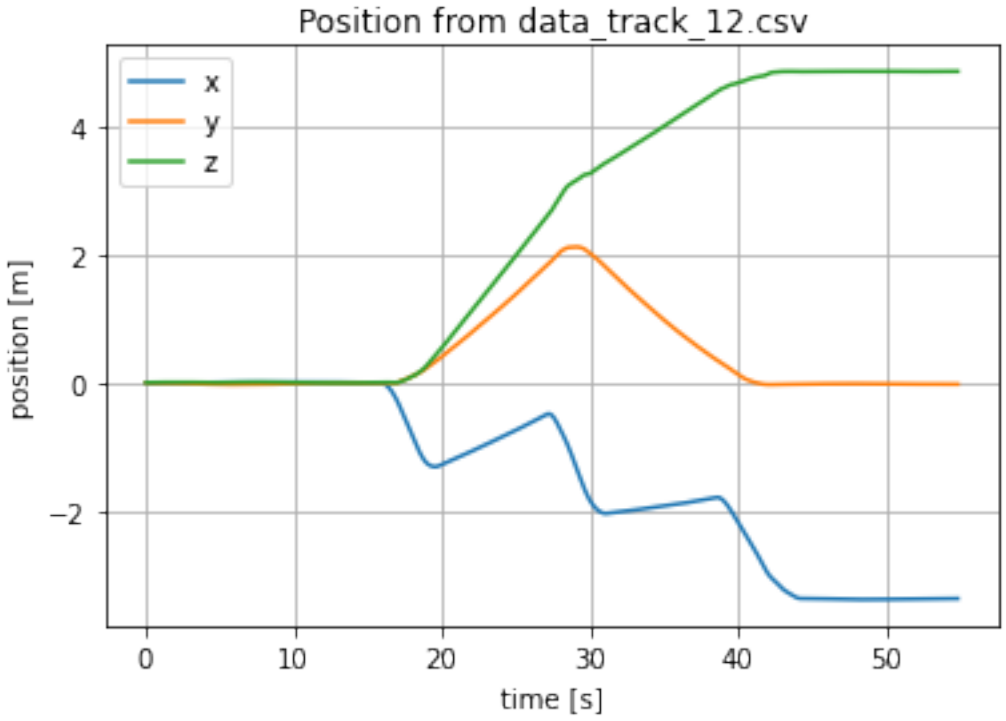

Position from data_track_06.csv
position [m]
time [s]
x
y
z
6
5
4
3
2
1
0
0
5
10
15
20
25
30
35
40

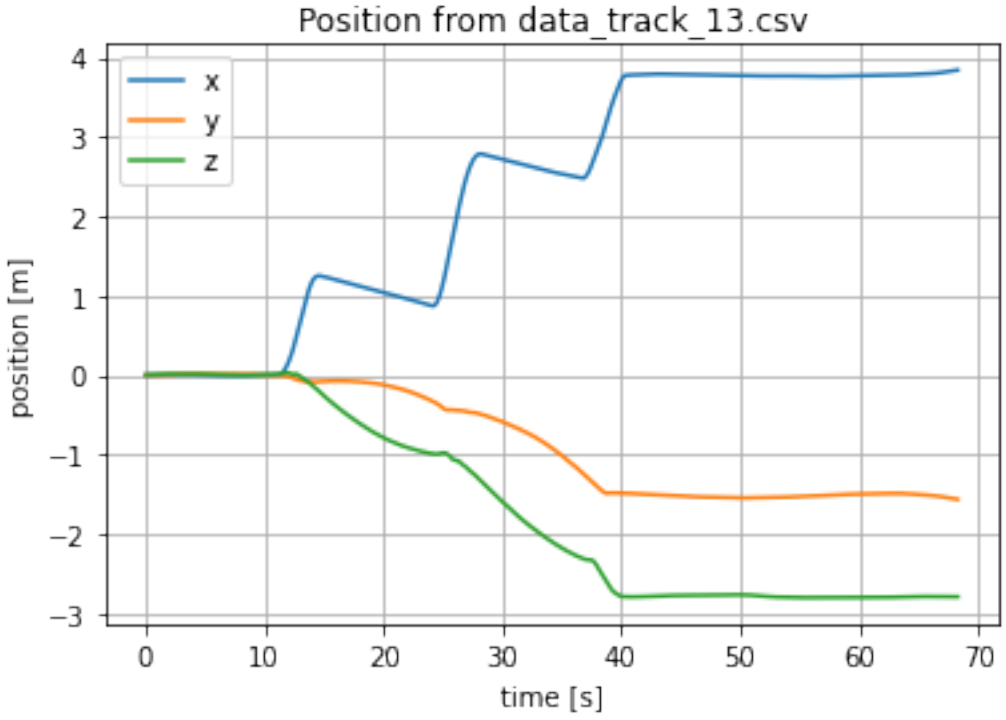

Position from data_track_07.csv
position [m]
time [s]
x
y
z
0
−1
−2
−3
−4
0
10
20
30
40
50

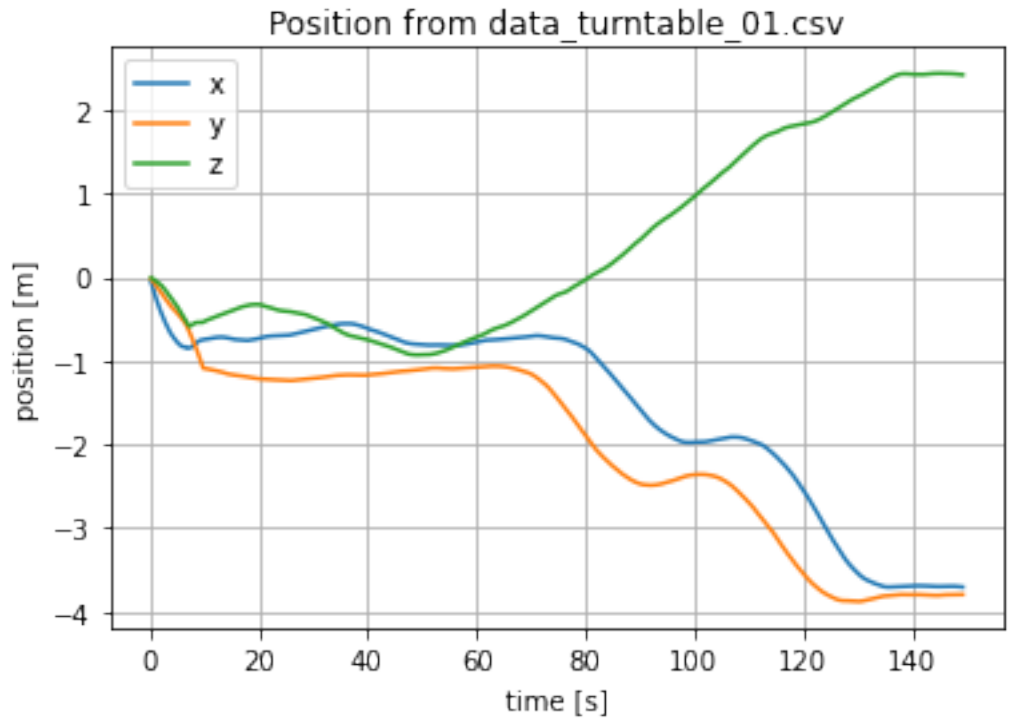

Position from data_track_08.csv
position [m]
time [s]
x
y
z
5
4
3
2
1
0
−1
0
10
20
30
40
50
60

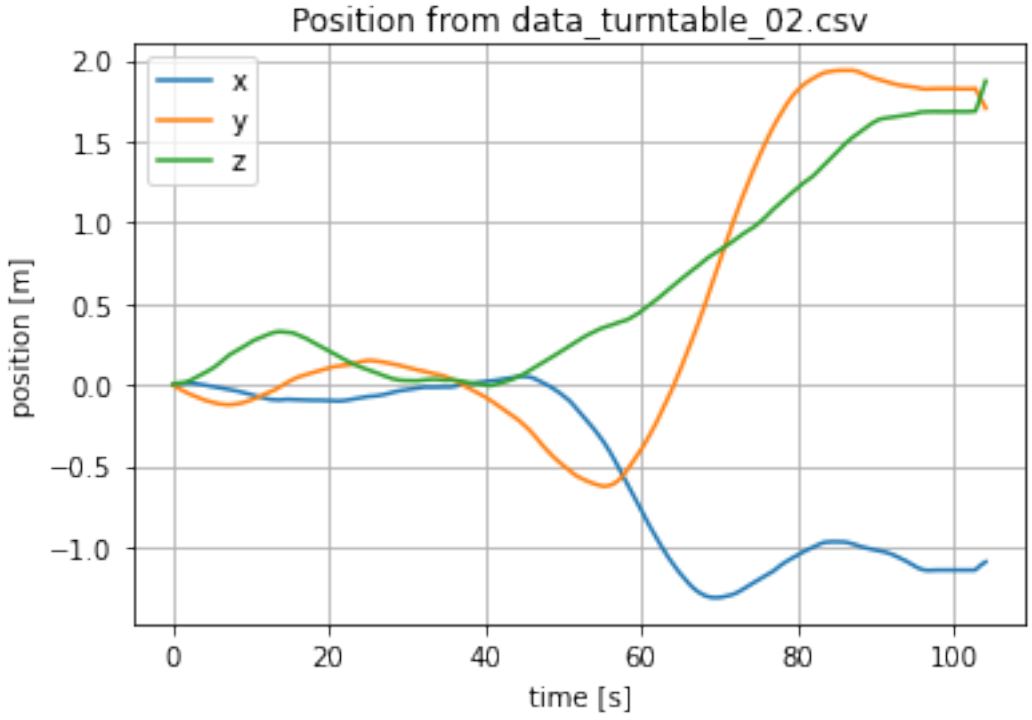

Position from data_track_09.csv
position [m]
time [s]
x
y
z
0
−1
−2
−3
−4
−5
0
10
20
30
40
50
60

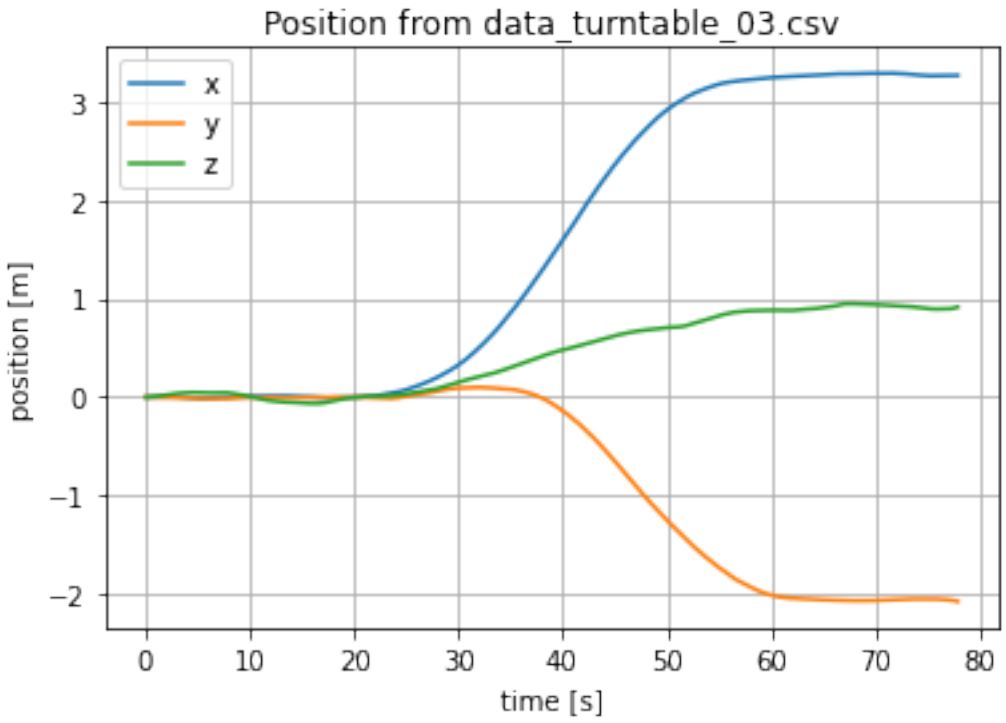

Position from data_track_10.csv
position [m]
time [s]
x
y
z
7
6
5
4
3
2
1
0
0
10
20
30
40
50
60

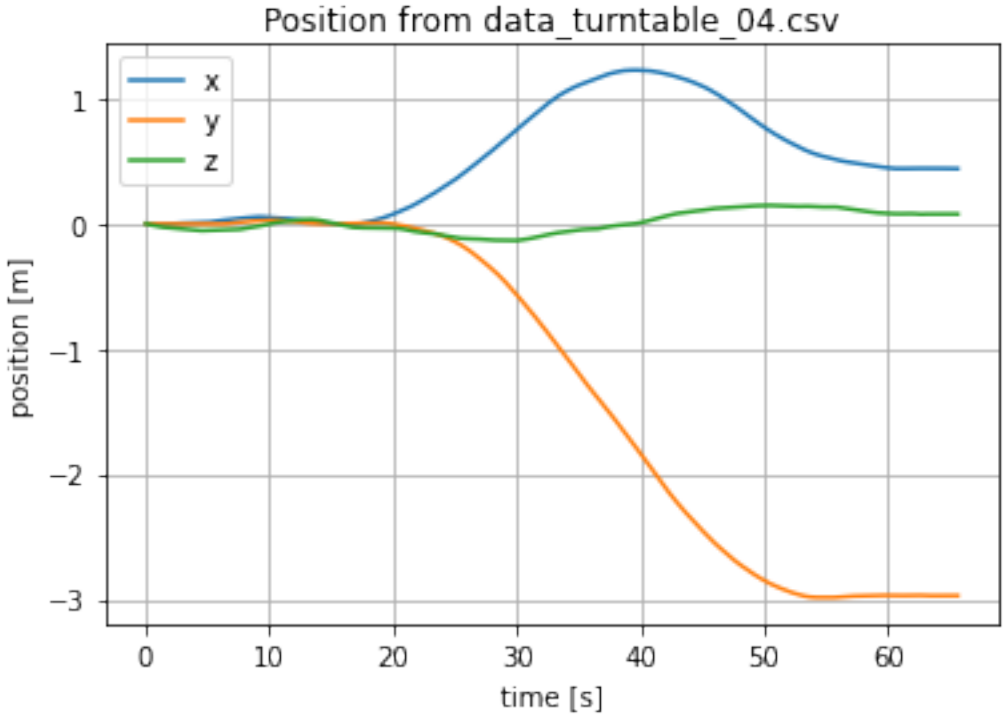

Position from data_track_12.csv
x
y
z
position [m]
time [s]
4
2
0
−2
0
10
20
30
40
50

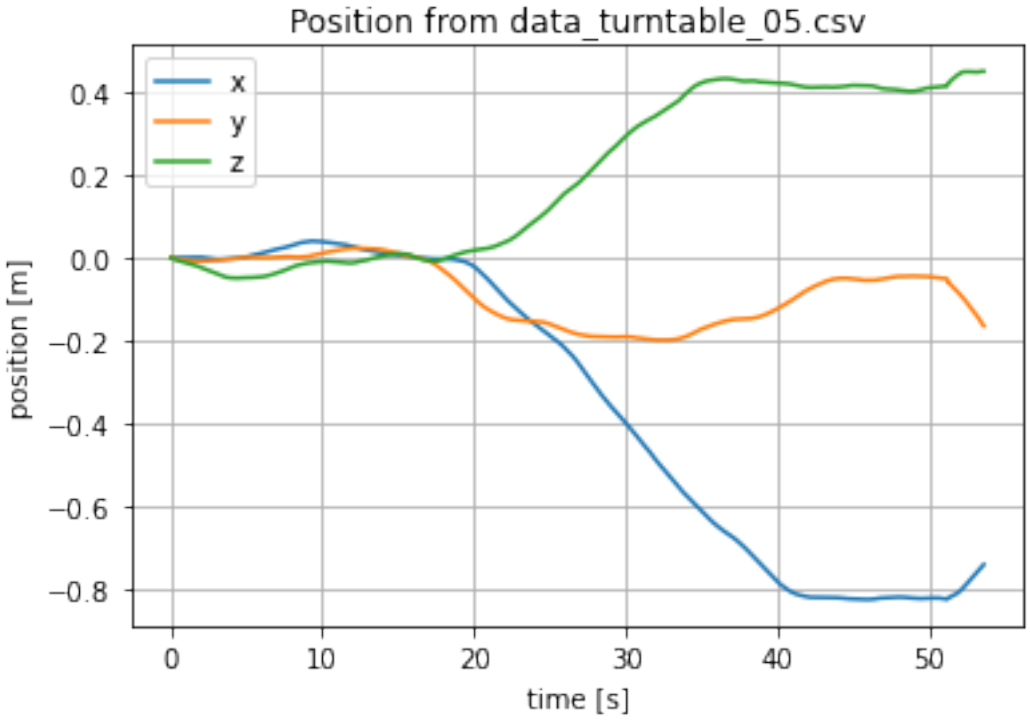

Position from data_track_13.csv
x
y
z
position [m]
time [s]
4
3
2
1
0
−1
−2
−3
0
10
20
30
40
50
60
70

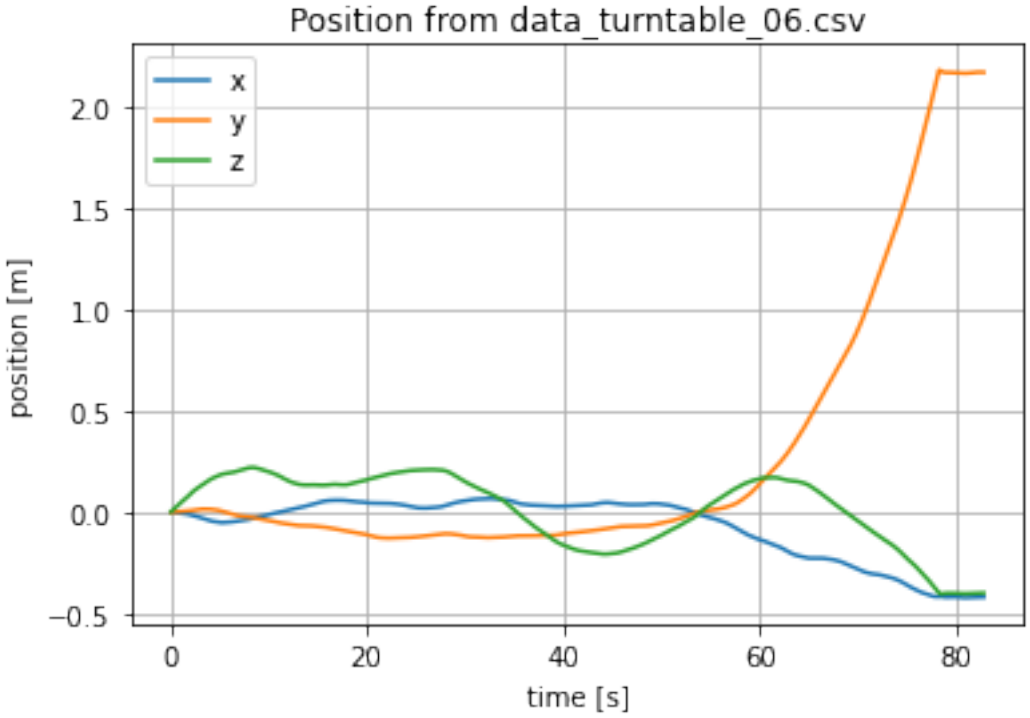

Position from data_turntable_01.csv
x
y
z
position [m]
time [s]
2
1
0
−1
−2
−3
−4
0
20
40
60
80
100
120
140

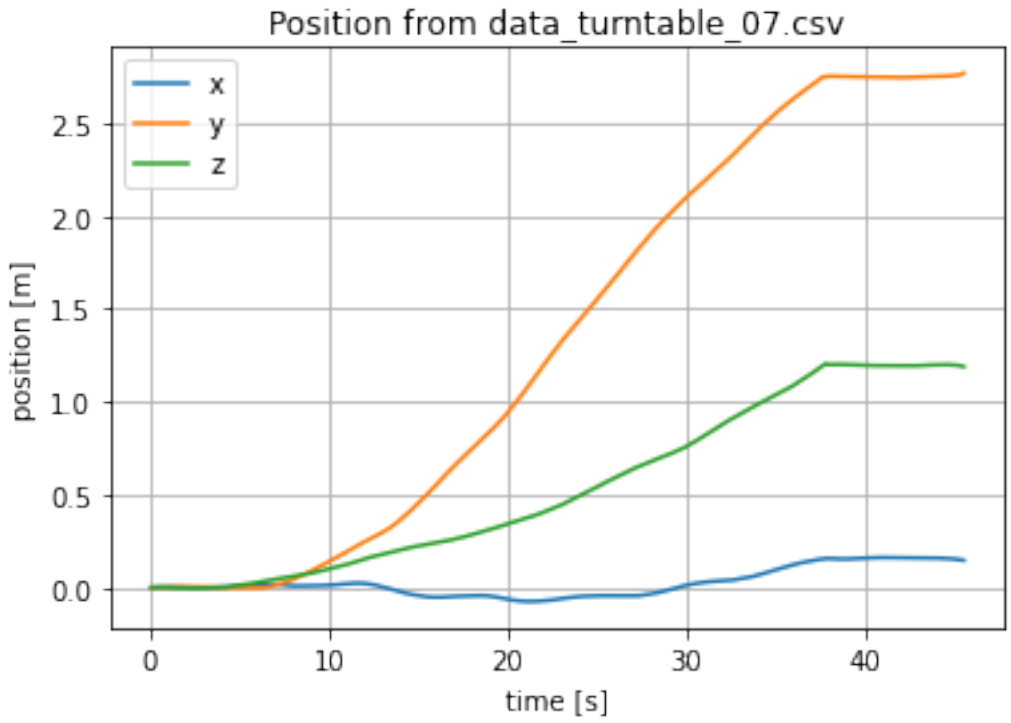

Position from data_turntable_02.csv
x
y
z
position [m]
time [s]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
0
20
40
60
80
100

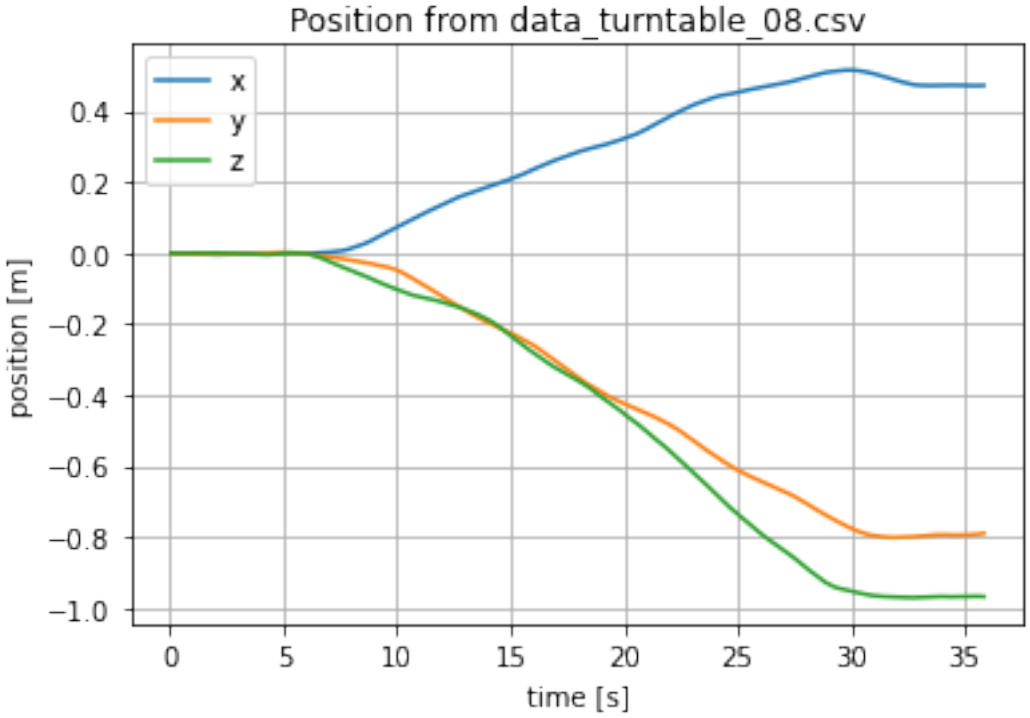

Position from data_turntable_03.csv
x
y
z
position [m]
time [s]
3
2
1
0
−1
−2
0
10
20
30
40
50
60
70
80

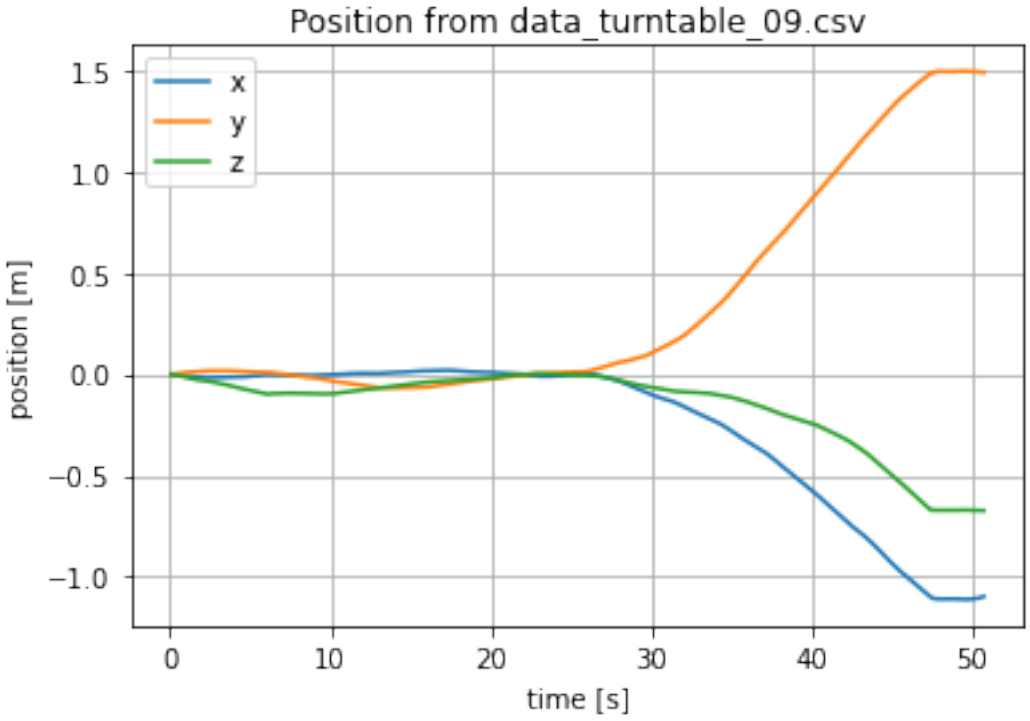

Position from data_turntable_04.csv
x
y
z
position [m]
time [s]
1
0
−1
−2
−3
0
10
20
30
40
50
60

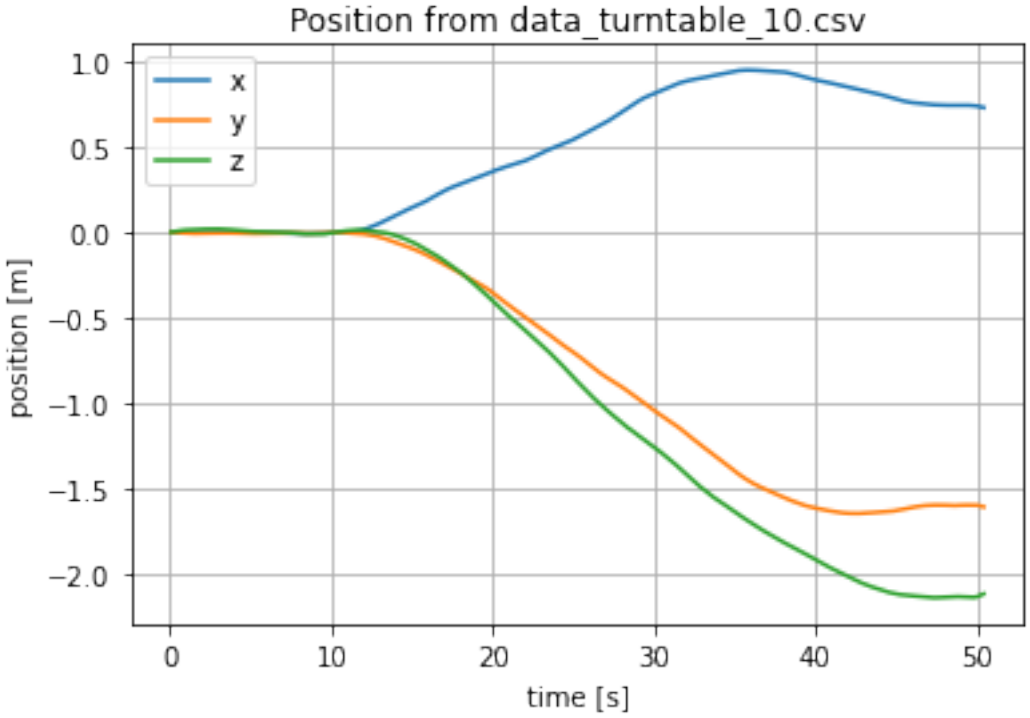

Position from data_turntable_05.csv
x
y
z
position [m]
time [s]
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
10
20
30
40
50

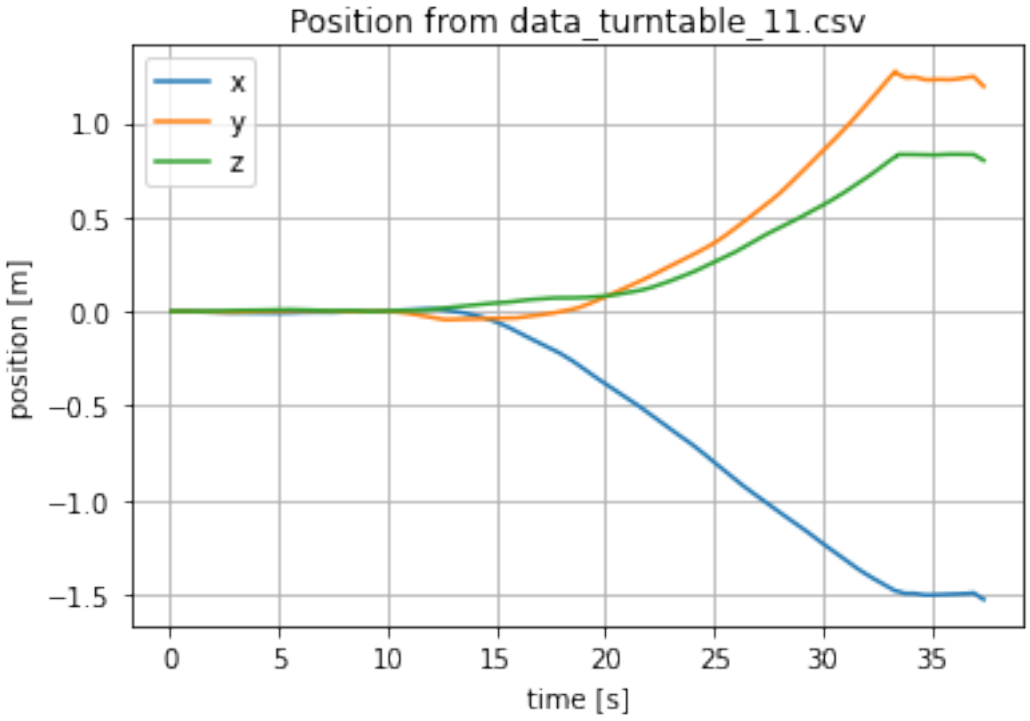

Position from data_turntable_06.csv
x
y
z
position [m]
time [s]
2.0
1.5
1.0
0.5
0.0
−0.5
0
20
40
60
80

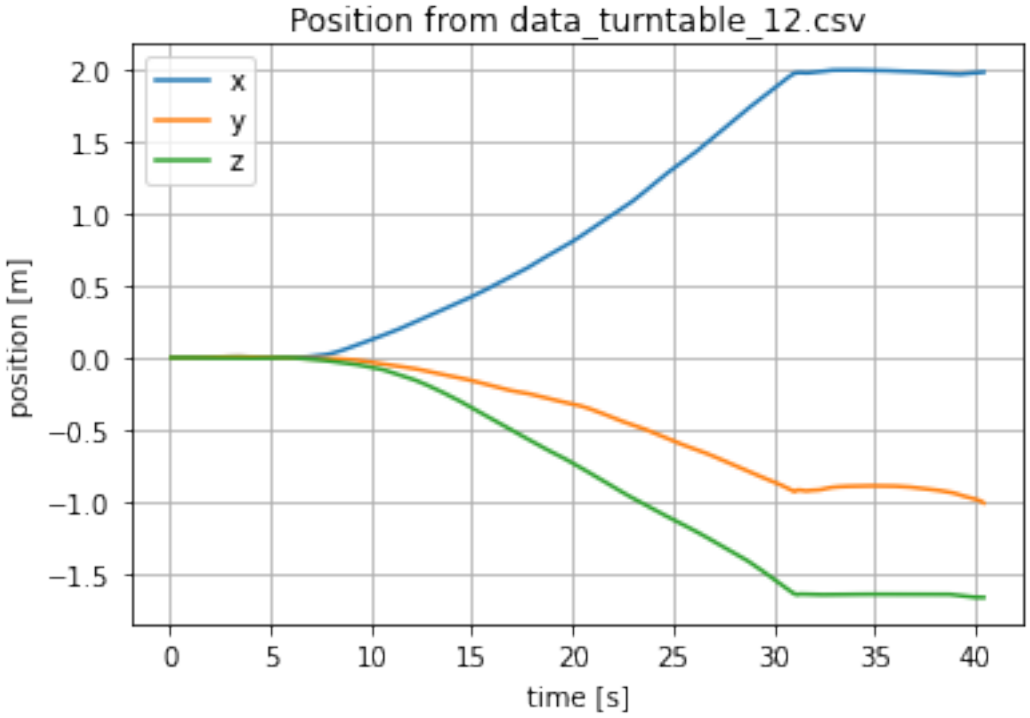

Position from data_turntable_07.csv
x
y
z
position [m]
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
time [s]


Position from data_turntable_08.csv
x
y
z
position [m]
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0
5
10
15
20
25
30
35
time [s]


Position from data_turntable_09.csv
x
y
z
position [m]
time [s]
1.5
1.0
0.5
0.0
−0.5
−1.0
0
10
20
30
40
50

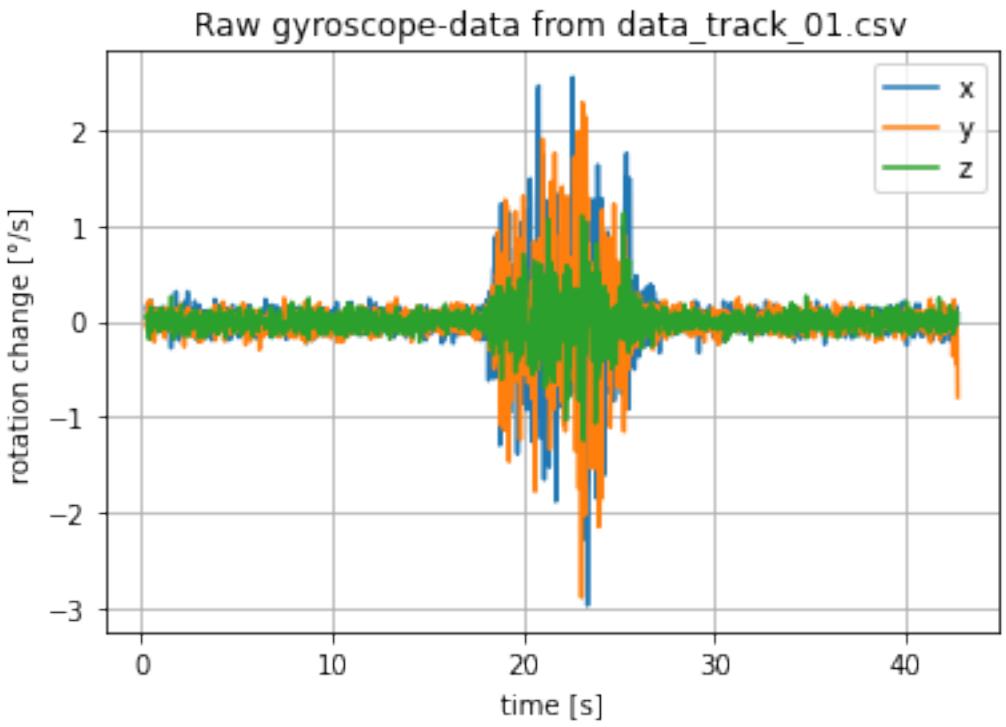

Position from data_turntable_10.csv
x
y
z
position [m]
time [s]
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0
10
20
30
40
50

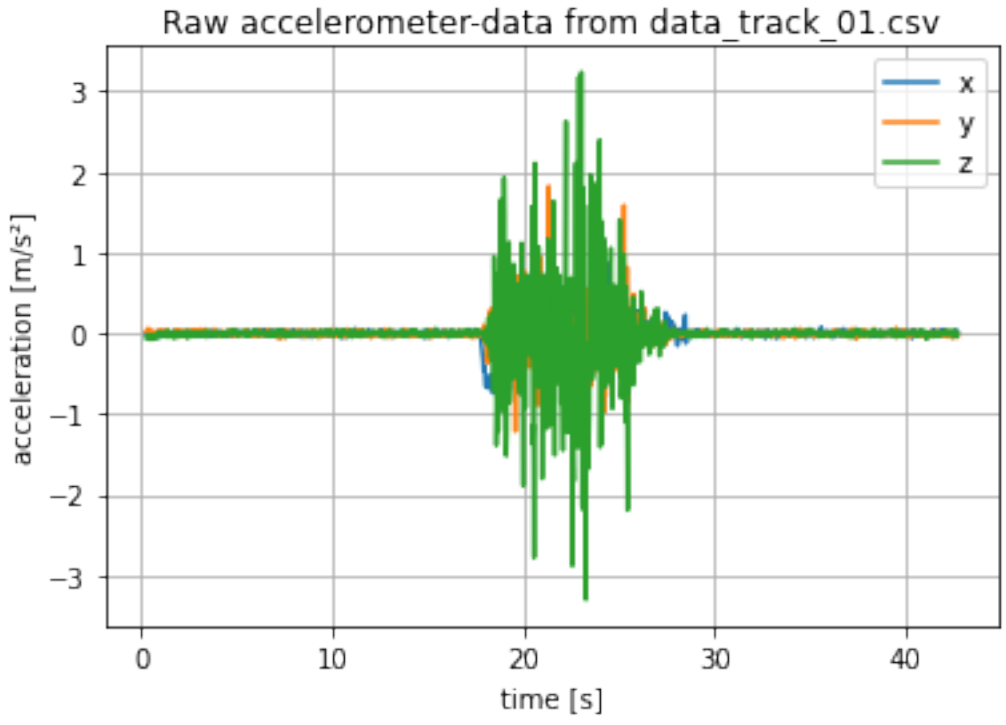

Position from data_turntable_11.csv
x
y
z
position [m]
time [s]
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
5
10
15
20
25
30
35

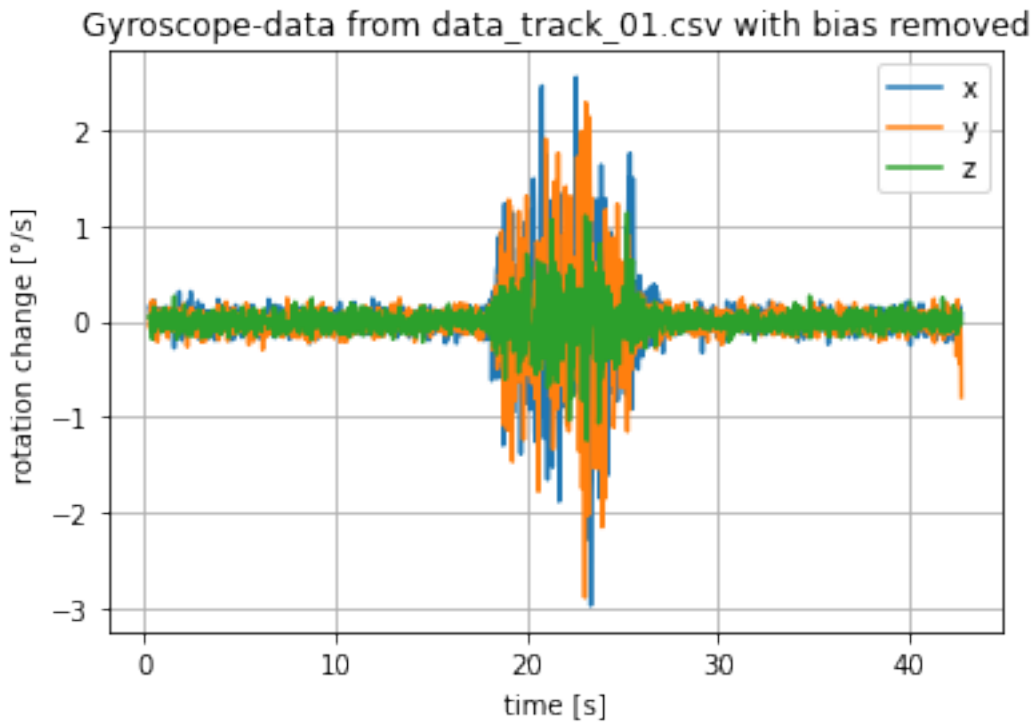

Position from data_turntable_12.csv
x
y
z
position [m]
time [s]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
5
10
15
20
25
30
35
40

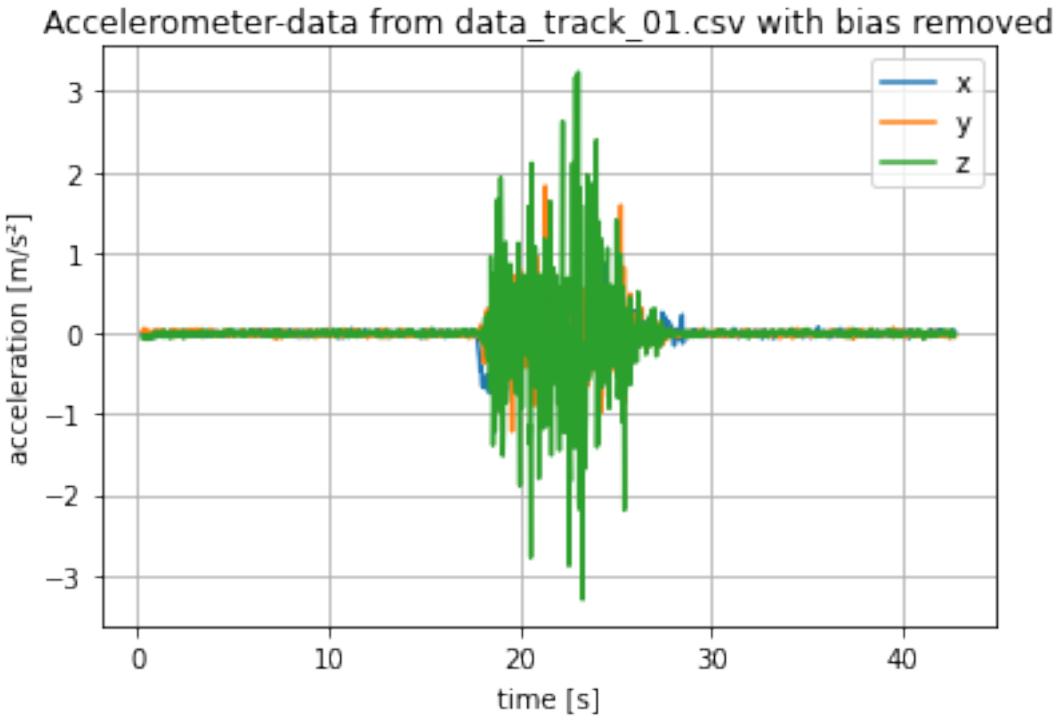
### 3.6.5 Other plots

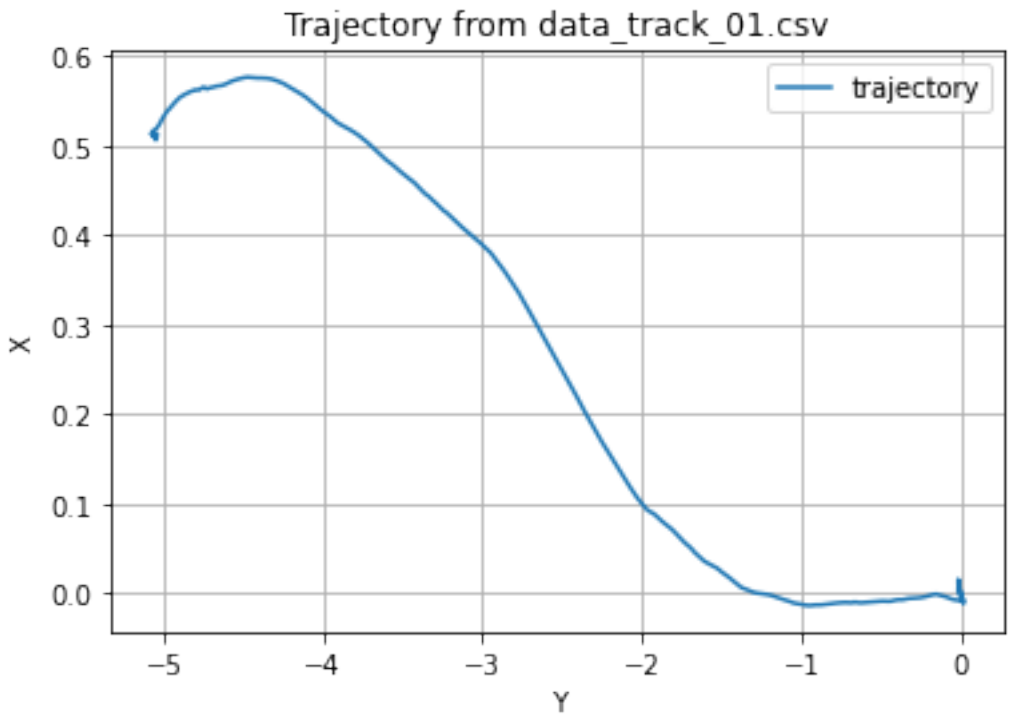
```
[ ]: for measurement_id, e in enumerate(timestamps_all):
        mems.plot_results([gyroscope_all[measurement_id]["x"],␣
     ↪gyroscope_all[measurement_id]["y"], gyroscope_all[measurement_id]["z"]],
                          f'Raw gyroscope-data from {files[measurement_id]}',
                          "time [s]",
                          "rotation change [°/s]",
                          ["x", "y", "z"],
                          e)
        mems.plot_results([accelerometer_all[measurement_id]["x"],␣
     ↪accelerometer_all[measurement_id]["y"],␣
     ↪accelerometer_all[measurement_id]["z"]],
                          f'Raw accelerometer-data from {files[measurement_id]}',
                          "time [s]",
                          "acceleration [m/s²]",
                          ["x", "y", "z"],
                          e)
        mems.plot_results([gyroscope_without_bias_all[measurement_id]["x"],␣
     ↪gyroscope_without_bias_all[measurement_id]["y"],␣
     ↪gyroscope_without_bias_all[measurement_id]["z"]],
                          f'Gyroscope-data from {files[measurement_id]} with bias␣
     ↪removed',
                          "time [s]",
                          "rotation change [°/s]",
                          ["x", "y", "z"],
                          e)
        mems.plot_results([accelerometer_without_bias_all[measurement_id]["x"],␣
     ↪accelerometer_without_bias_all[measurement_id]["y"],␣
     ↪accelerometer_without_bias_all[measurement_id]["z"]],
                          f'Accelerometer-data from {files[measurement_id]} with bias␣
     ↪removed',
                          "time [s]",
                          "acceleration [m/s²]",
                          ["x", "y", "z"],
                          e)
        mems.plot_results([trajectory_all[measurement_id]["x"]],
                          f'Trajectory from {files[measurement_id]}',
                          "Y",
                          "X",
                          ["trajectory"],
                          trajectory_all[measurement_id]["y"])
```

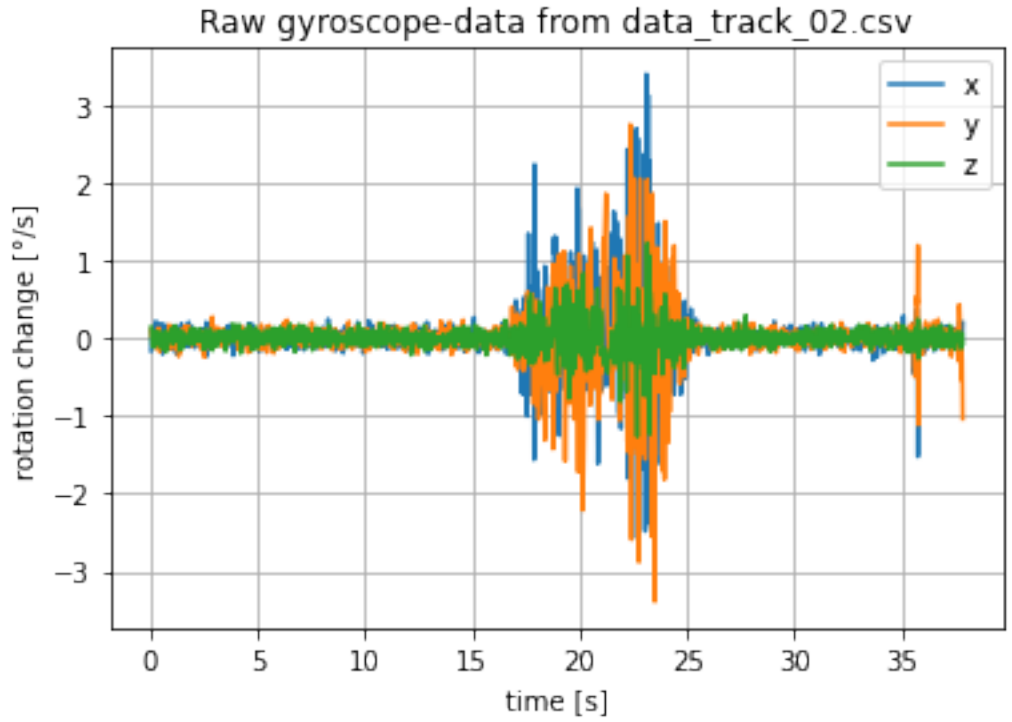

Raw gyroscope-data from data_track_01.csv
rotation change [°/s]
time [s]
x
y
z
2
1
0
−1
−2
−3
0
10
20
30
40

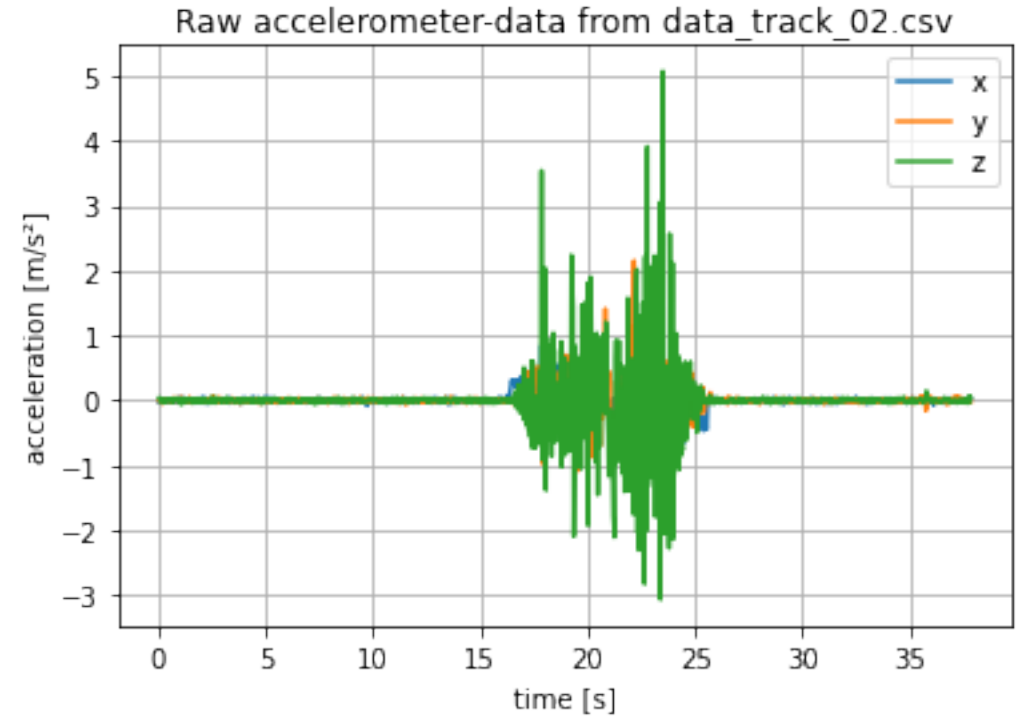

Raw accelerometer-data from data_track_01.csv
acceleration [m/s²]
time [s]
x
y
z
3
2
1
0
−1
−2
−3
0
10
20
30
40

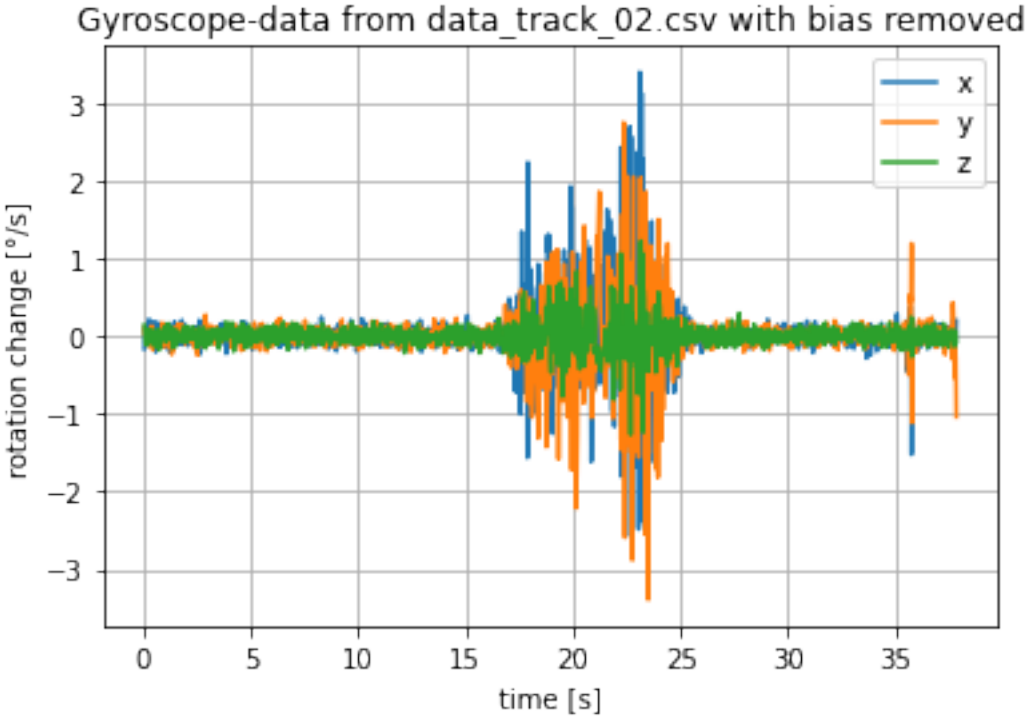

Gyroscope-data from data_track_01.csv with bias removed
x
y
z
rotation change [°/s]
2
1
0
−1
−2
−3
0
10
20
30
40
time [s]

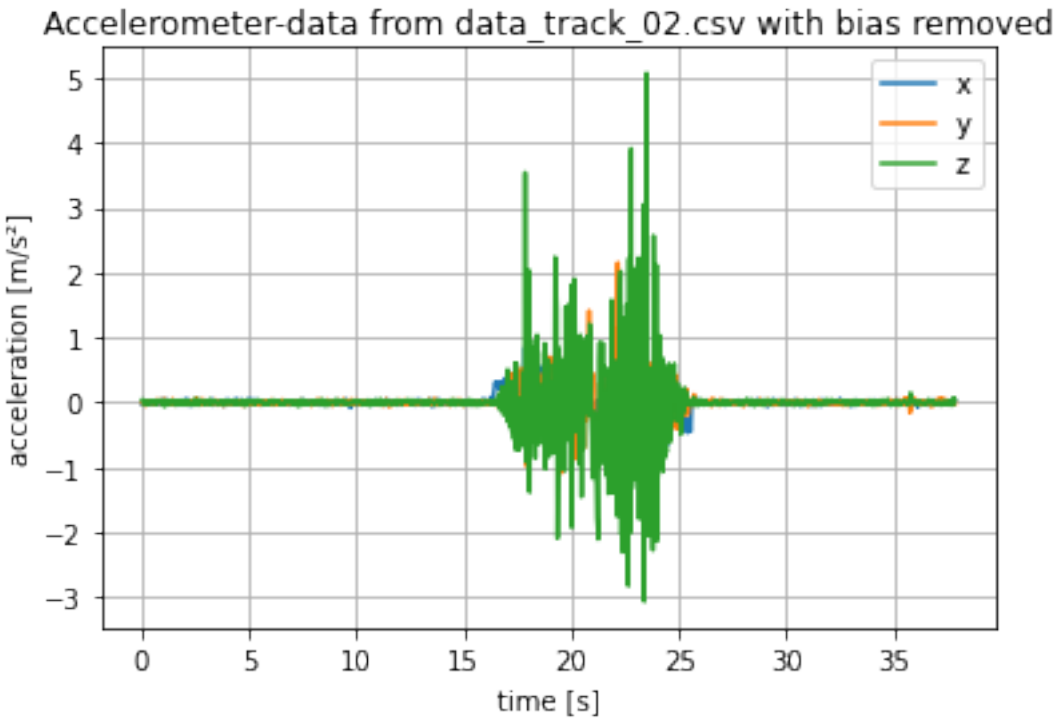

Accelerometer-data from data_track_01.csv with bias removed
x
y
z
acceleration [m/s²]
3
2
1
0
−1
−2
−3
0
10
20
30
40
time [s]

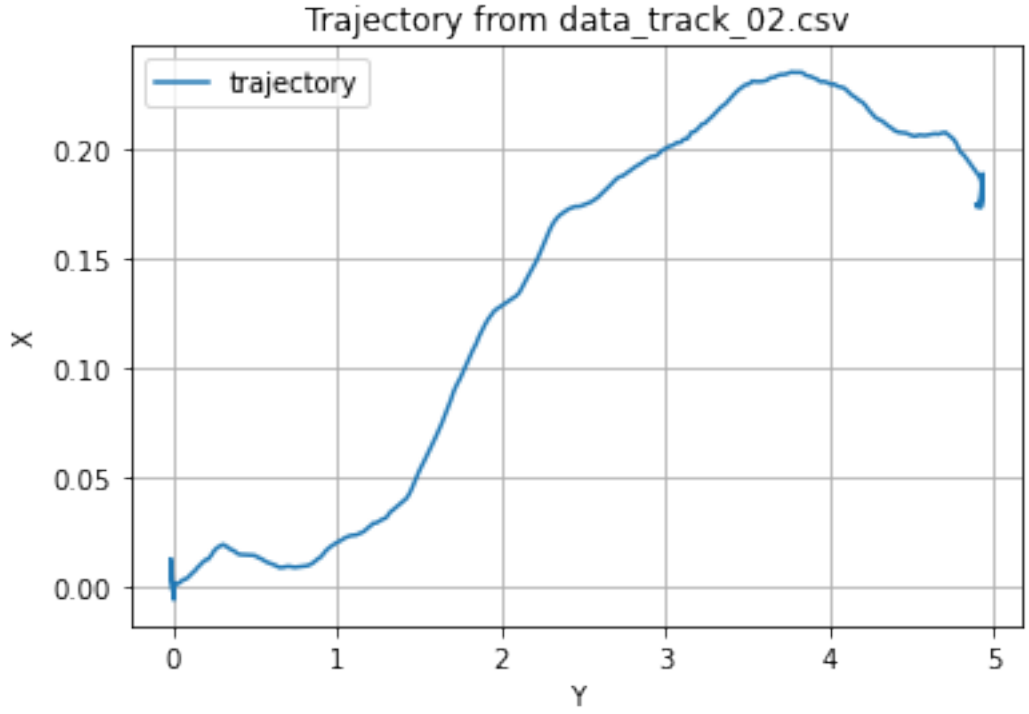

Trajectory from data_track_01.csv
trajectory
X
Y
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−5
−4
−3
−2
−1
0

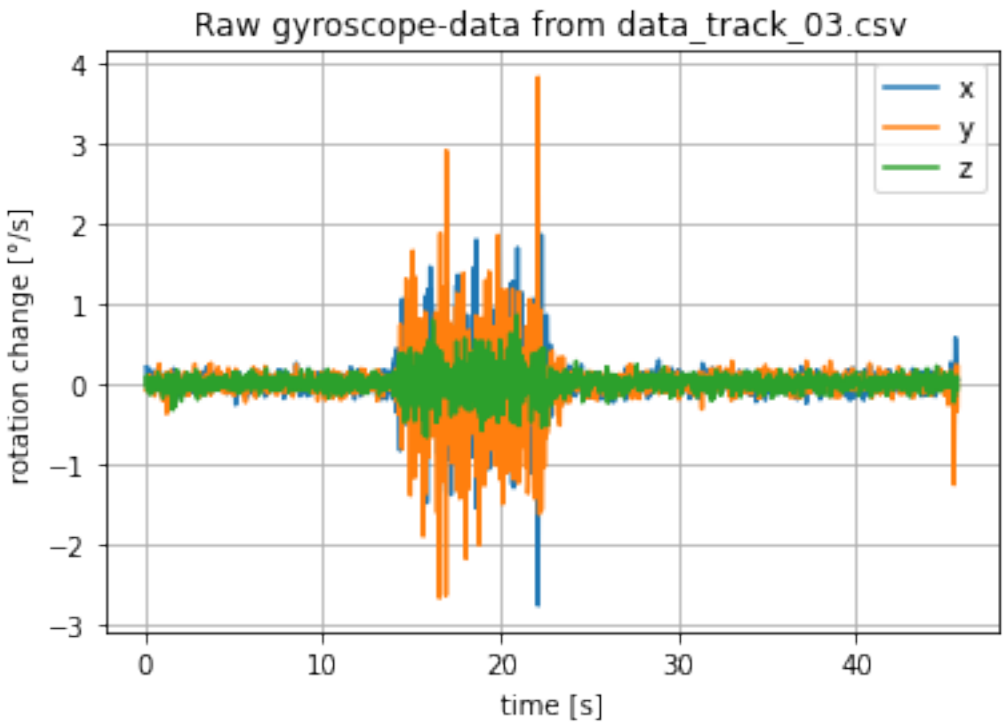

Raw gyroscope-data from data_track_02.csv
x
y
z
rotation change [°/s]
time [s]
3
2
1
0
−1
−2
−3
0
5
10
15
20
25
30
35

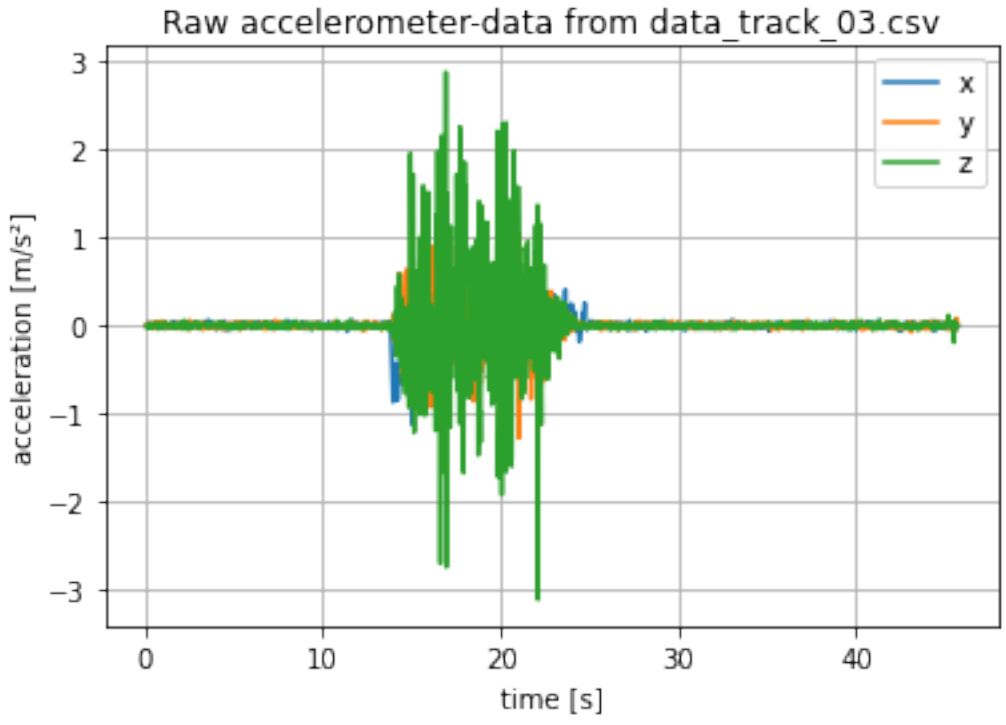

Raw accelerometer-data from data_track_02.csv
x
y
z
acceleration [m/s²]
time [s]

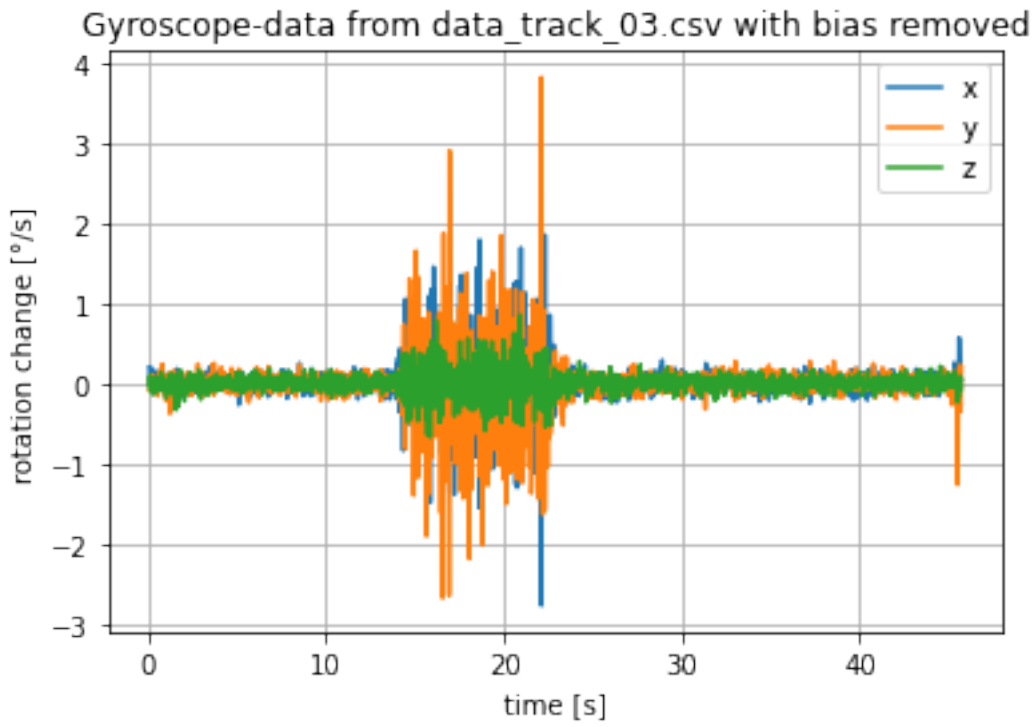

Gyroscope-data from data_track_02.csv with bias removed
x
y
z
rotation change [°/s]
time [s]

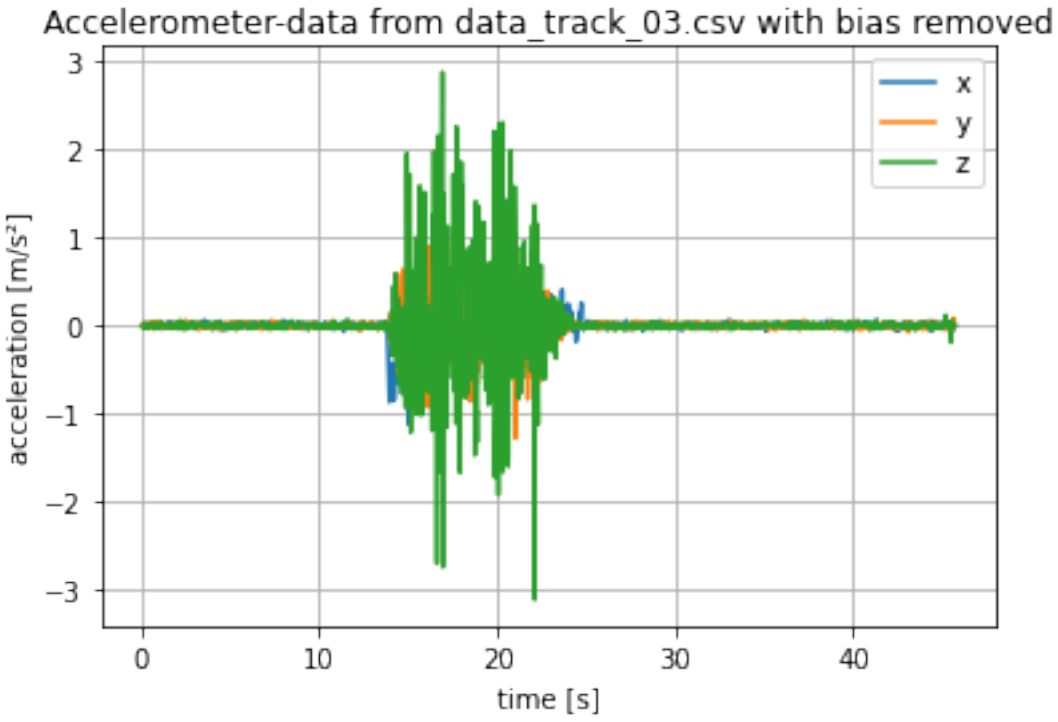

Accelerometer-data from data_track_02.csv with bias removed
x
y
z
acceleration [m/s²]
time [s]
5
4
3
2
1
0
−1
−2
−3
0
5
10
15
20
25
30
35

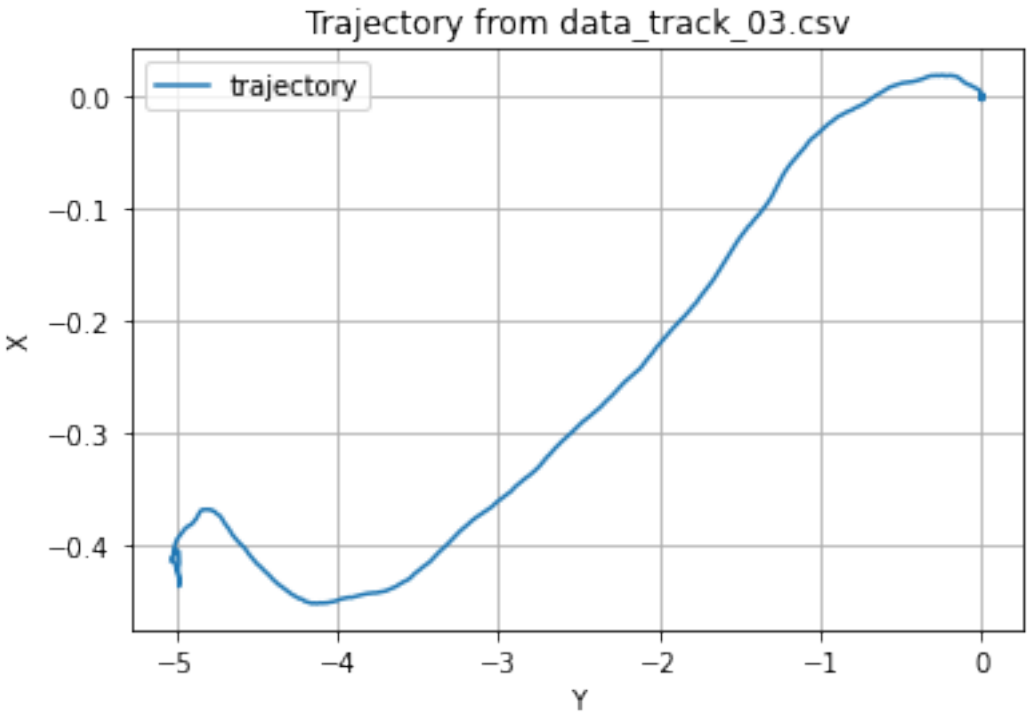

Trajectory from data_track_02.csv
trajectory
X
Y
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5

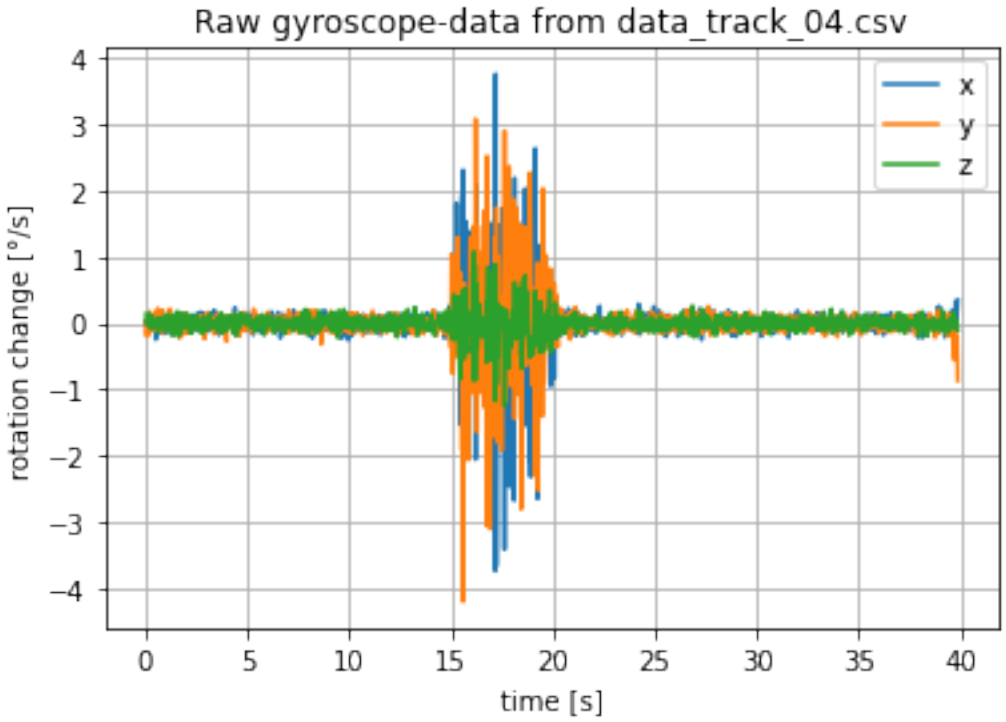

Raw gyroscope-data from data_track_03.csv
rotation change [°/s]
time [s]
x
y
z
4
3
2
1
0
−1
−2
−3
0
10
20
30
40

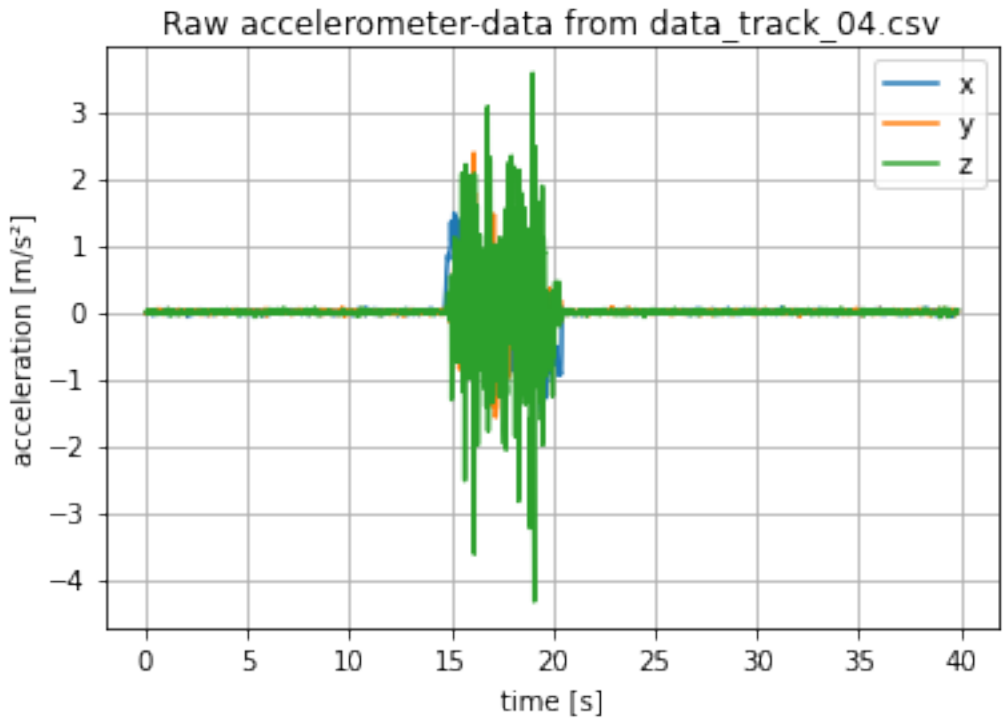

Raw accelerometer-data from data_track_03.csv
acceleration [m/s²]
time [s]
x
y
z
3
2
1
0
−1
−2
−3
0
10
20
30
40

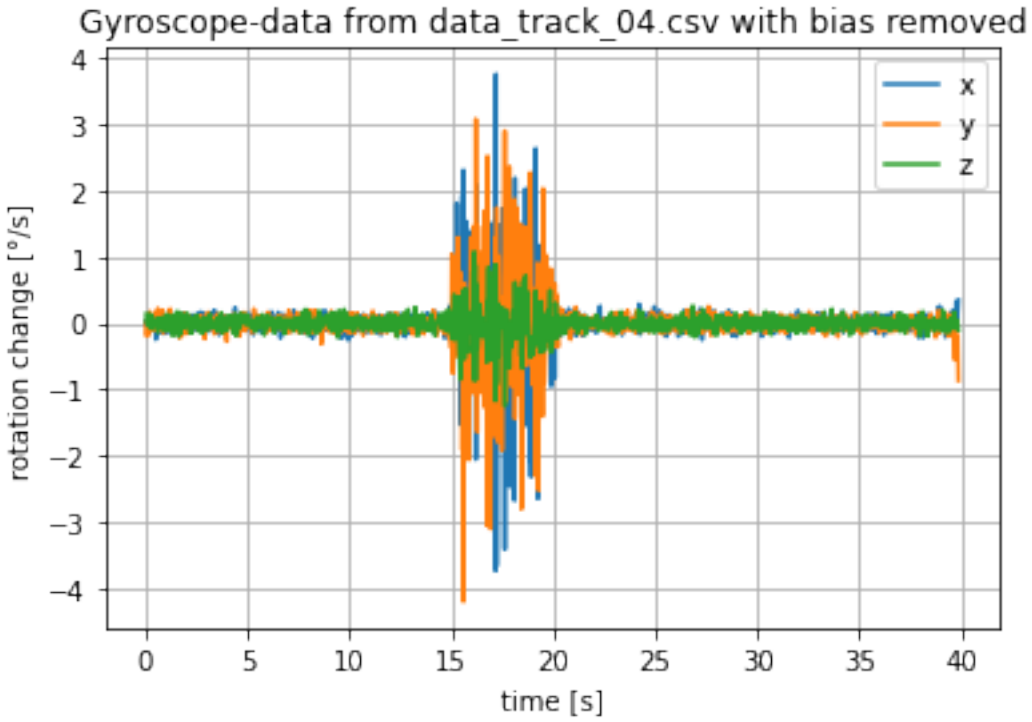

Gyroscope-data from data_track_03.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
4
3
2
1
0
−1
−2
−3
0
10
20
30
40

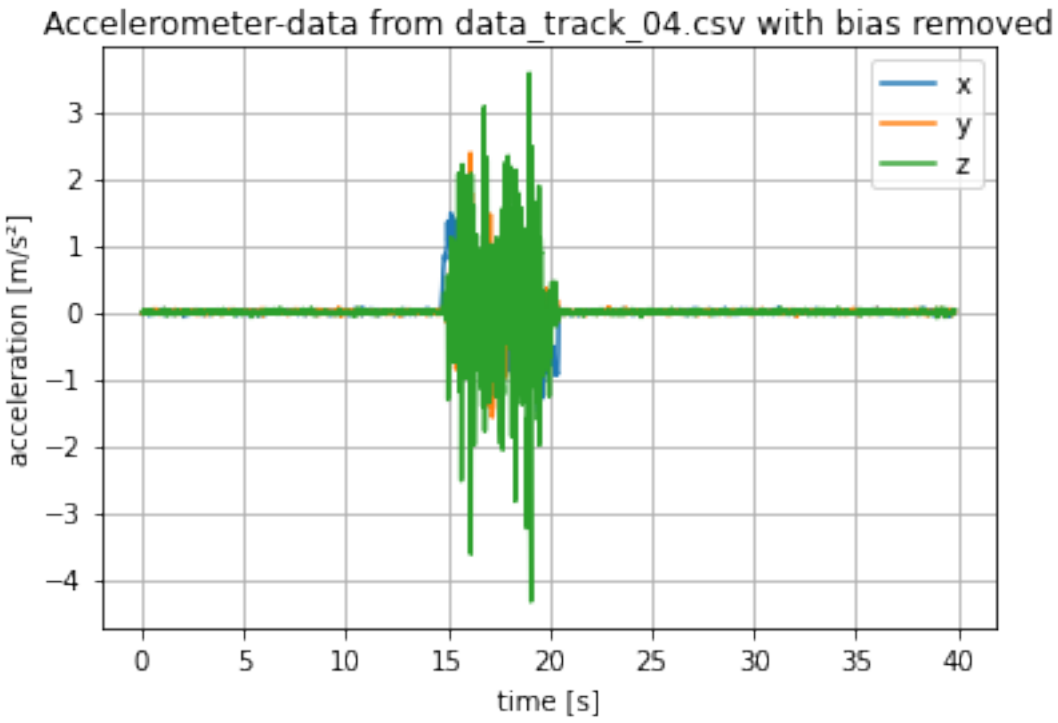

Accelerometer-data from data_track_03.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
3
2
1
0
−1
−2
−3
0
10
20
30
40

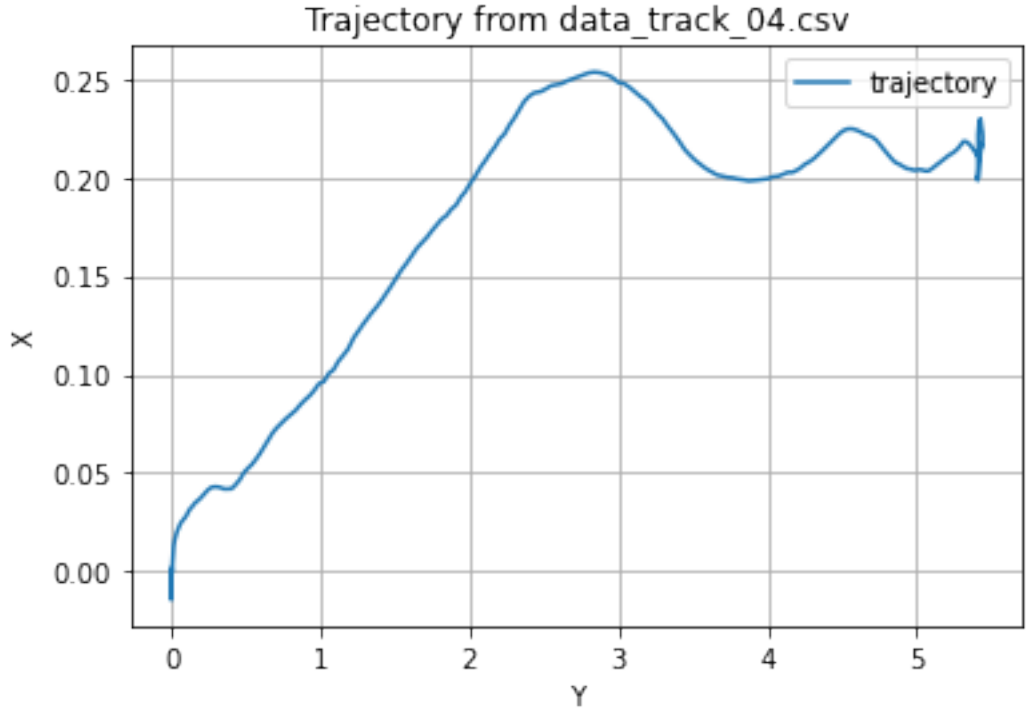

Trajectory from data_track_03.csv
trajectory
0.0
−0.1
−0.2
−0.3
−0.4
X
−5
−4
−3
−2
−1
0
Y

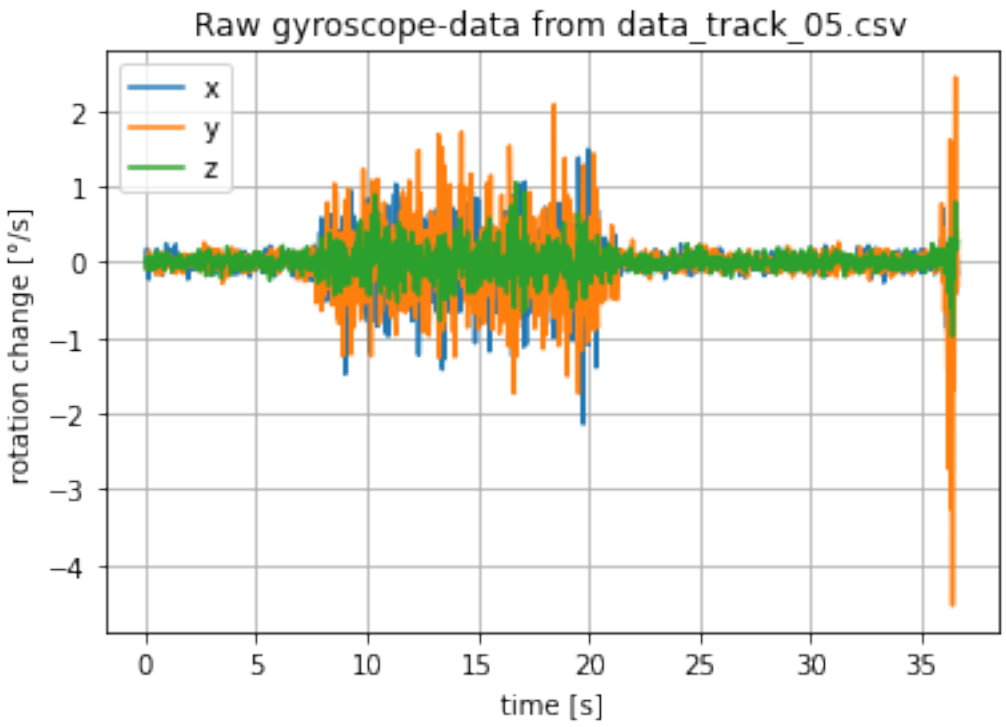

Raw gyroscope-data from data_track_04.csv
x
y
z
4
3
2
1
0
−1
−2
−3
−4
rotation change [°/s]
0
5
10
15
20
25
30
35
40
time [s]

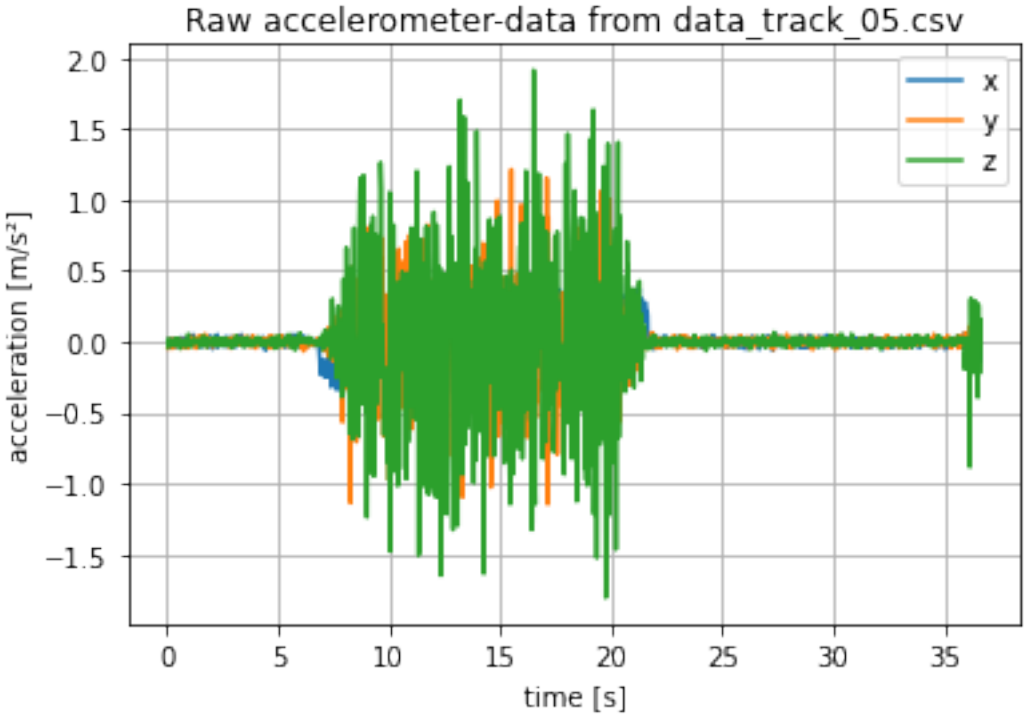

Raw accelerometer-data from data_track_04.csv
x
y
z
acceleration [m/s²]
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40
time [s]

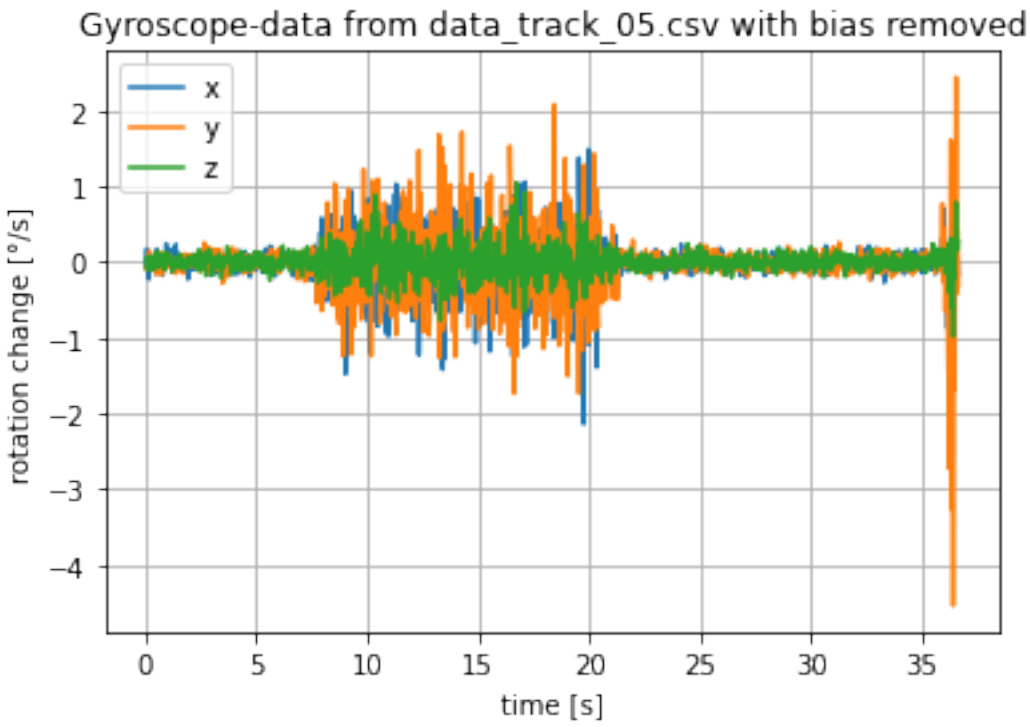

Gyroscope-data from data_track_04.csv with bias removed
x
y
z
rotation change [°/s]
4
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40
time [s]

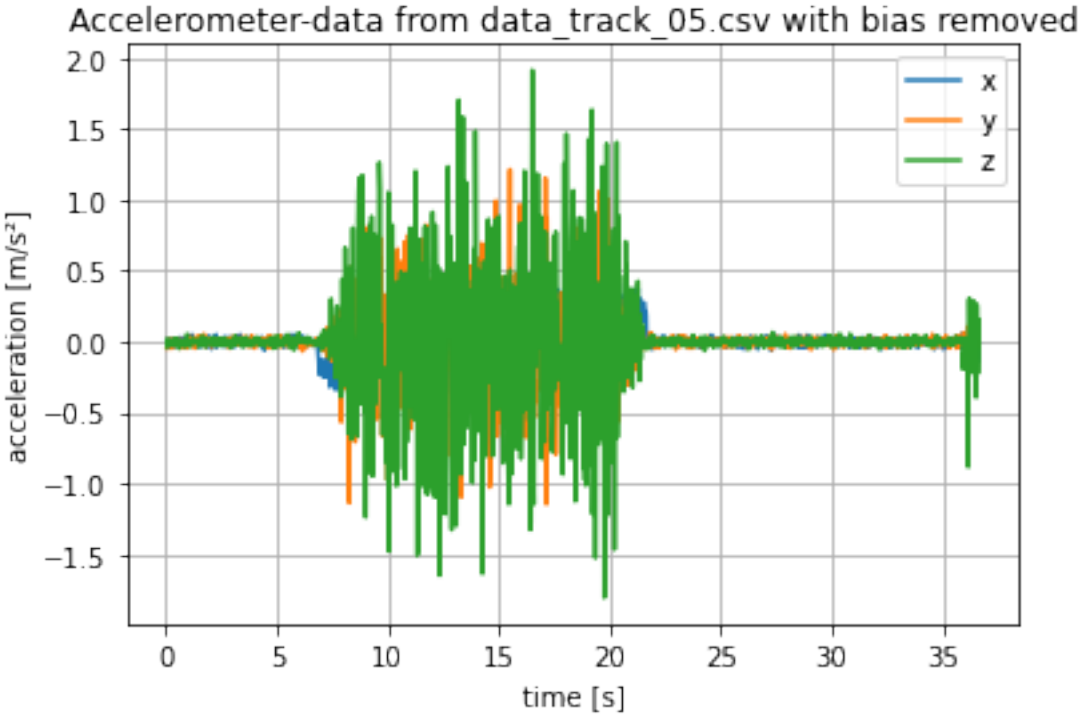

Accelerometer-data from data_track_04.csv with bias removed
x
y
z
acceleration [m/s²]
time [s]
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40

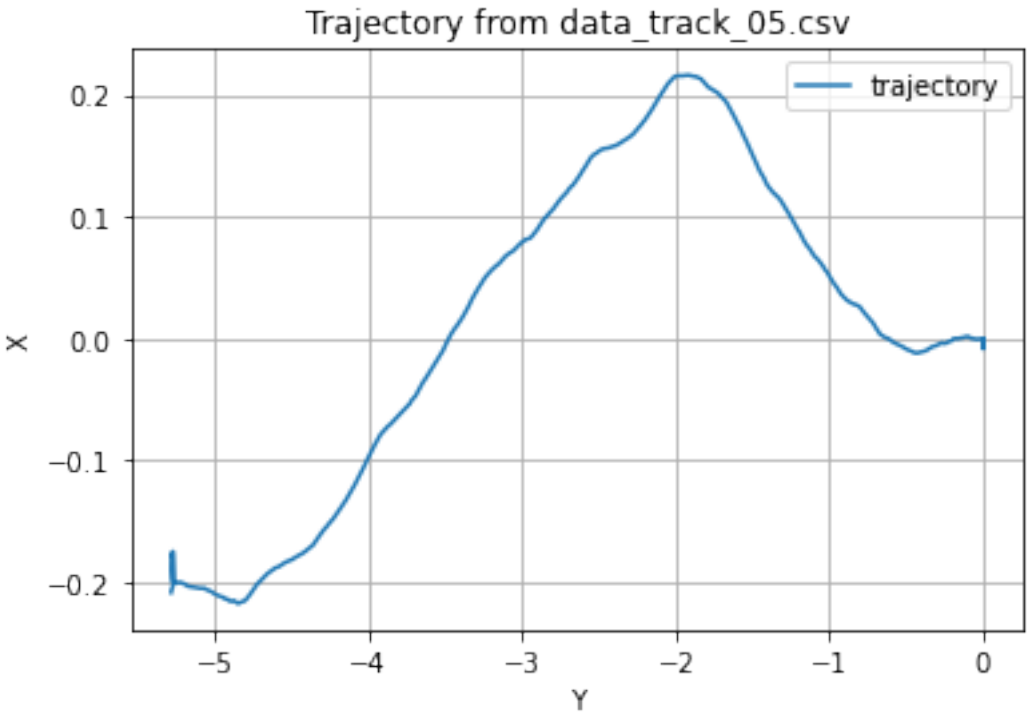

Trajectory from data_track_04.csv
trajectory
X
Y
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5

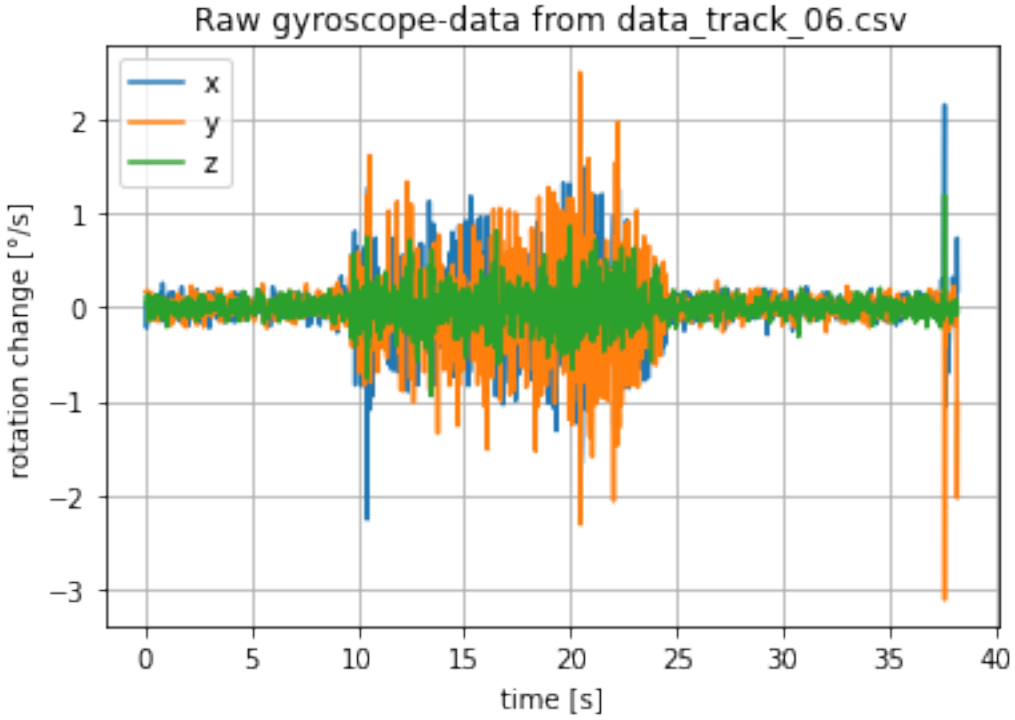

Raw gyroscope-data from data_track_05.csv
x
y
z
rotation change [°/s]
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
time [s]

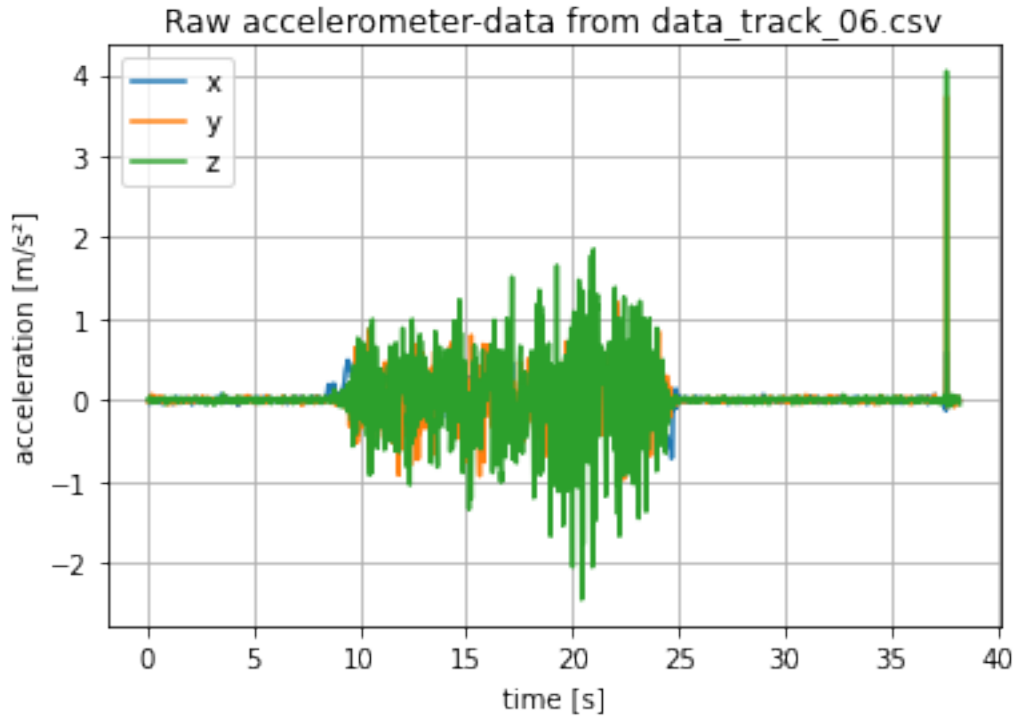

Raw accelerometer-data from data_track_05.csv
x
y
z
acceleration [m/s²]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
5
10
15
20
25
30
35
time [s]

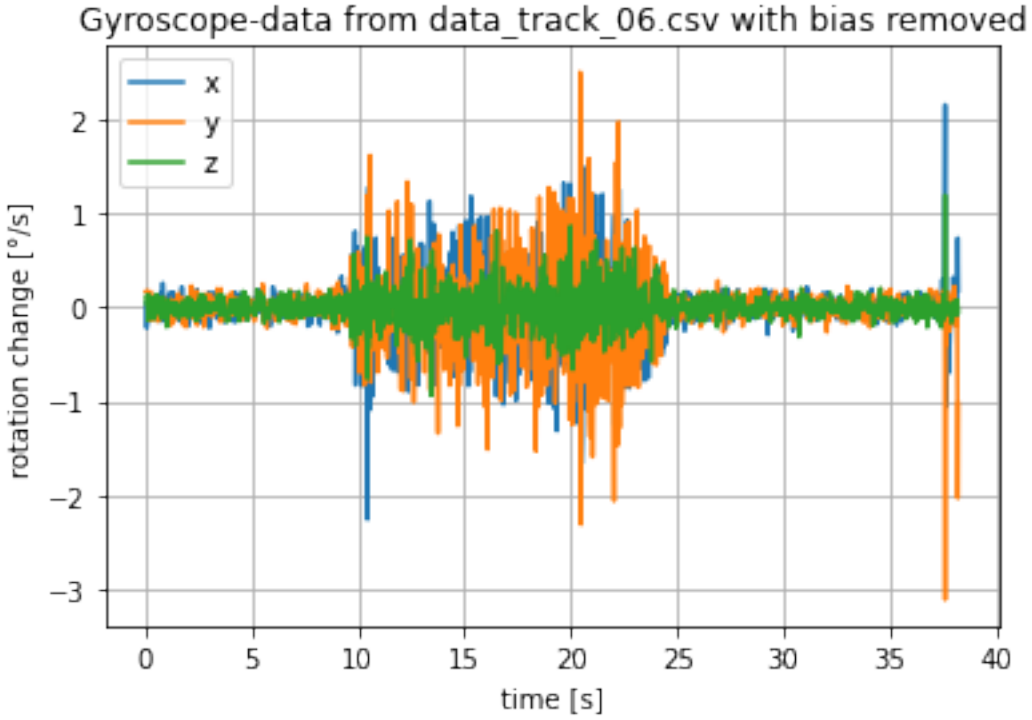

Gyroscope-data from data_track_05.csv with bias removed
x
y
z
rotation change [°/s]
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
time [s]

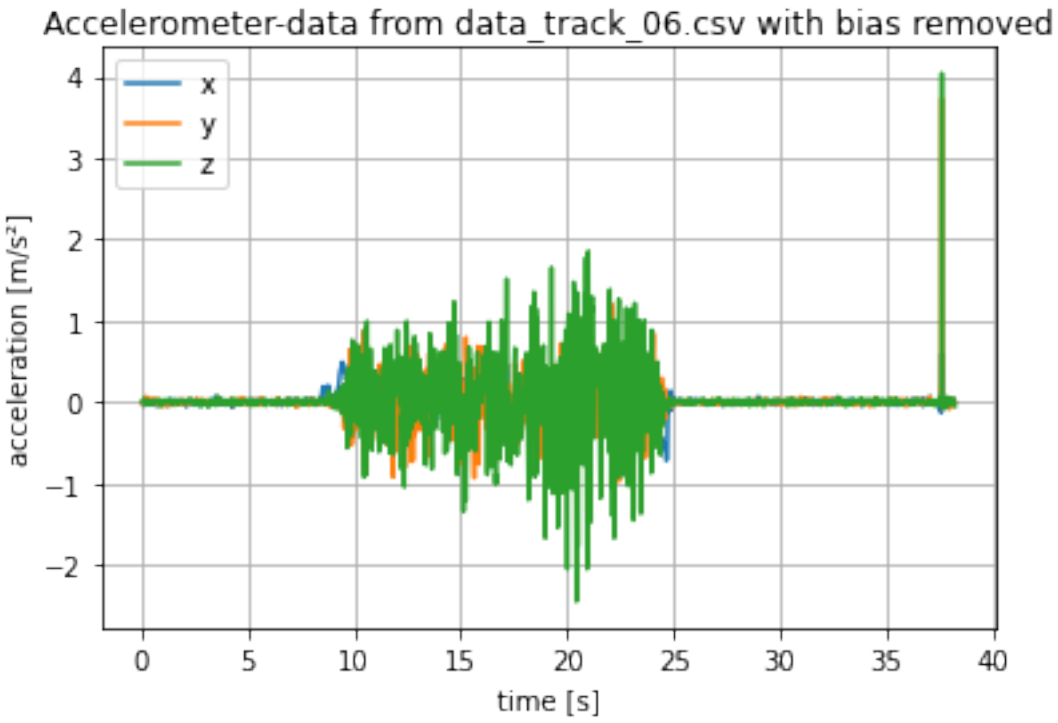

Accelerometer-data from data_track_05.csv with bias removed
x
y
z
acceleration [m/s²]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
5
10
15
20
25
30
35
time [s]

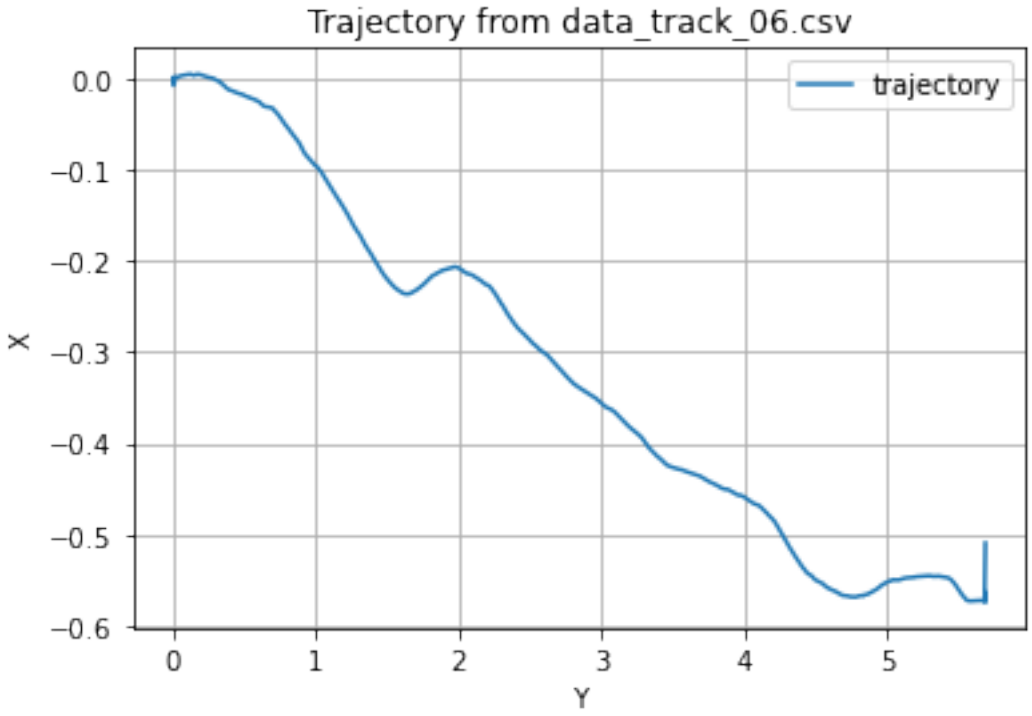

Trajectory from data_track_05.csv
trajectory
X
Y
0.2
0.1
0.0
−0.1
−0.2
−5
−4
−3
−2
−1
0

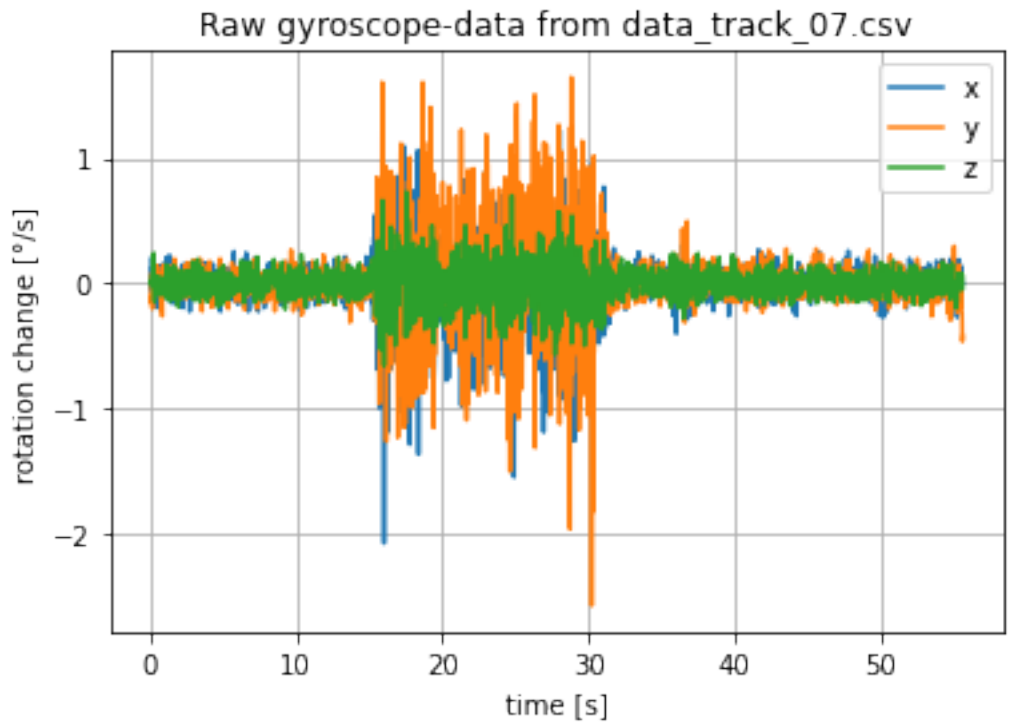

Raw gyroscope-data from data_track_06.csv
x
y
z
rotation change [°/s]
time [s]
2
1
0
−1
−2
−3
0
5
10
15
20
25
30
35
40

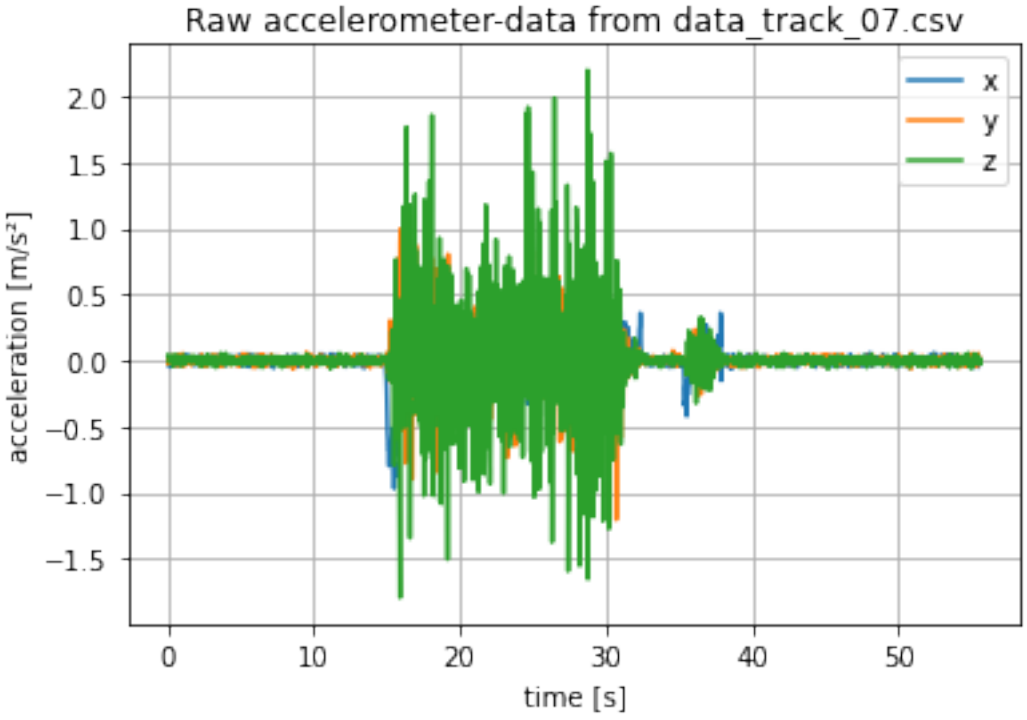

Raw accelerometer-data from data_track_06.csv
x
y
z
acceleration [m/s²]
time [s]

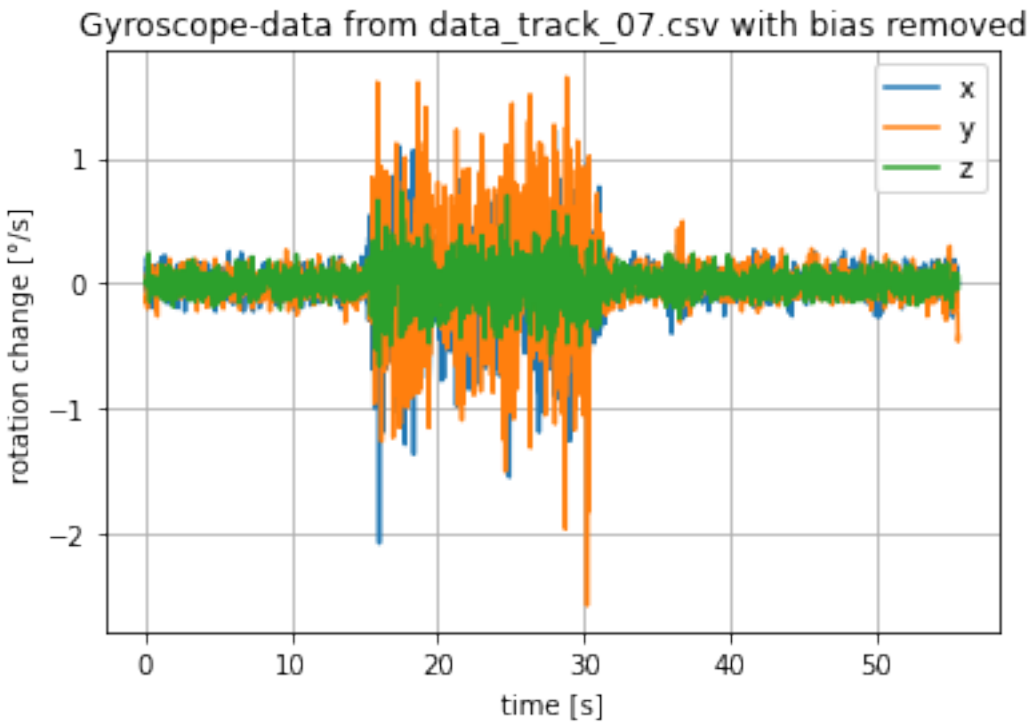

Gyroscope-data from data_track_06.csv with bias removed
x
y
z
rotation change [°/s]
time [s]

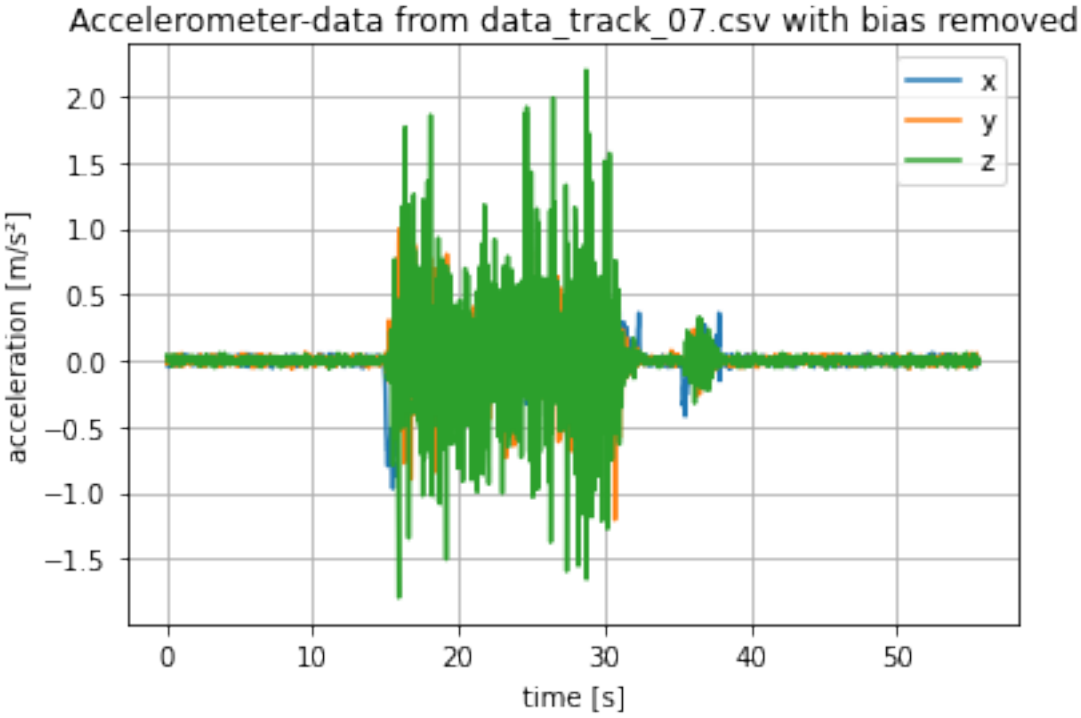

Accelerometer-data from data_track_06.csv with bias removed
x
y
z
acceleration [m/s²]
time [s]
4
3
2
1
0
−1
−2
0
5
10
15
20
25
30
35
40

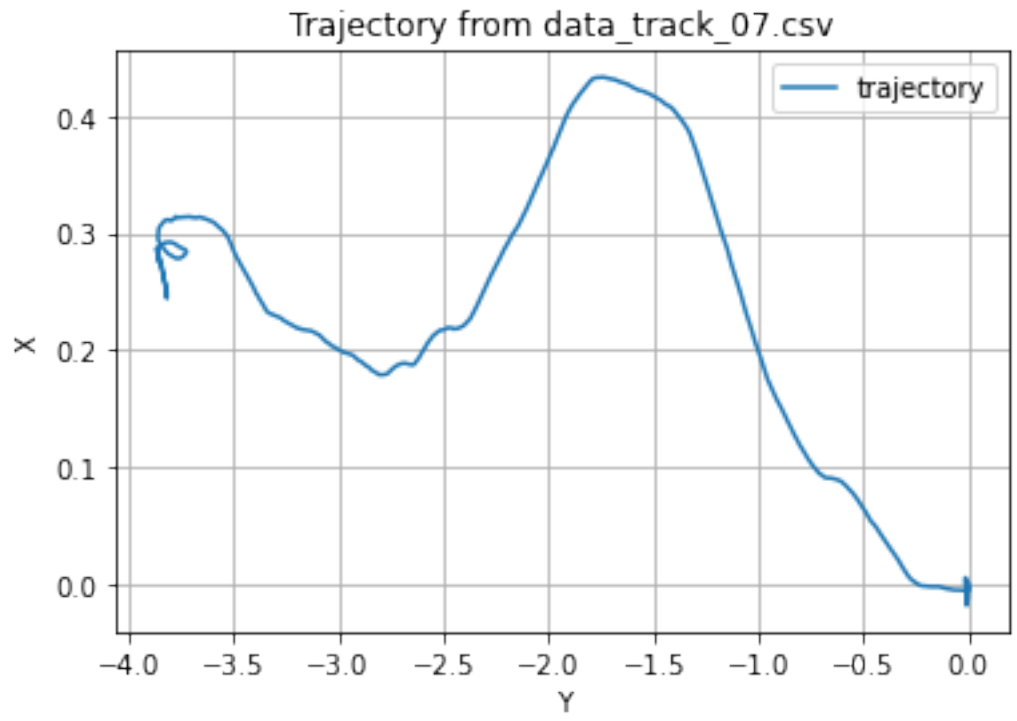

Trajectory from data_track_06.csv
trajectory
X
Y
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
0
1
2
3
4
5

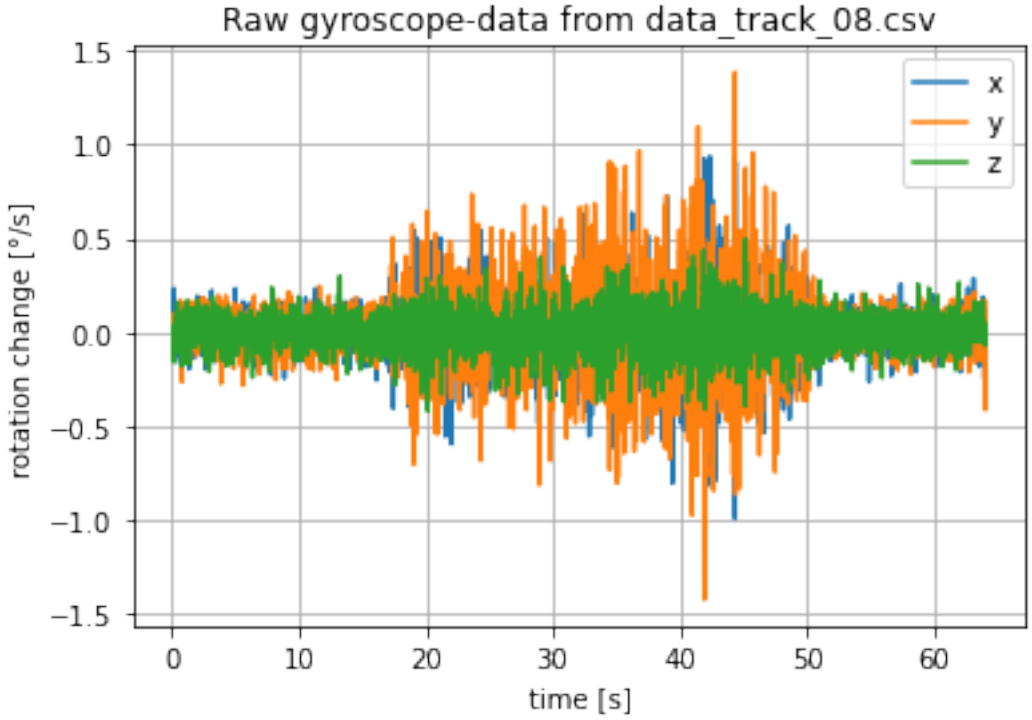

Raw gyroscope-data from data_track_07.csv
x
y
z
rotation change [°/s]
1
0
−1
−2
0
10
20
30
40
50
time [s]

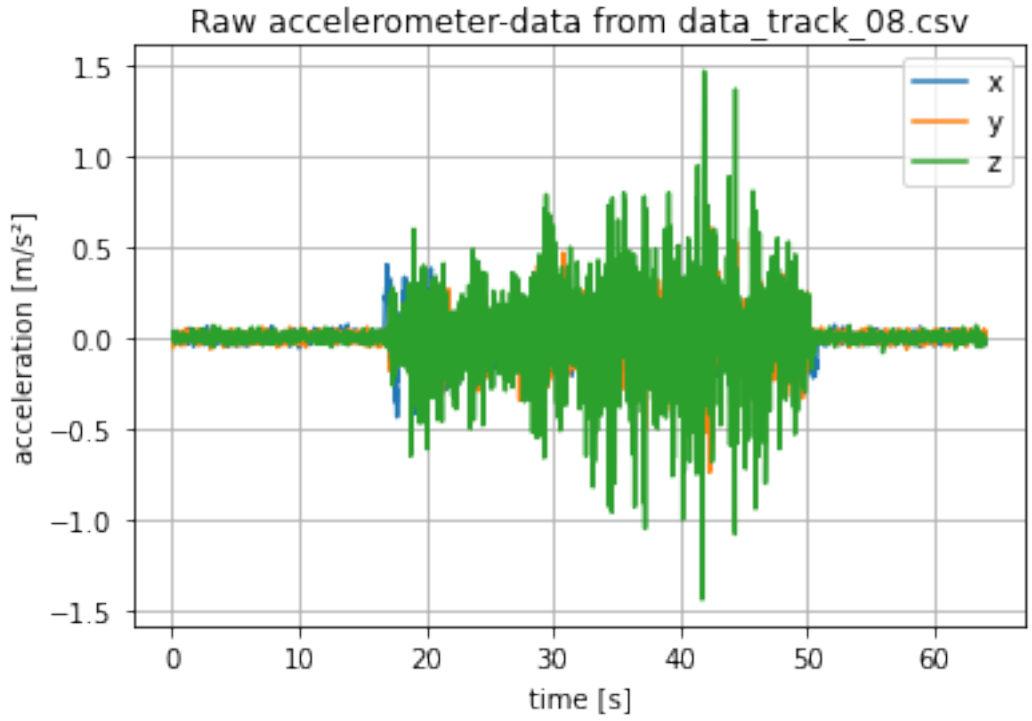

Raw accelerometer-data from data_track_07.csv
x
y
z
acceleration [m/s²]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
10
20
30
40
50
time [s]

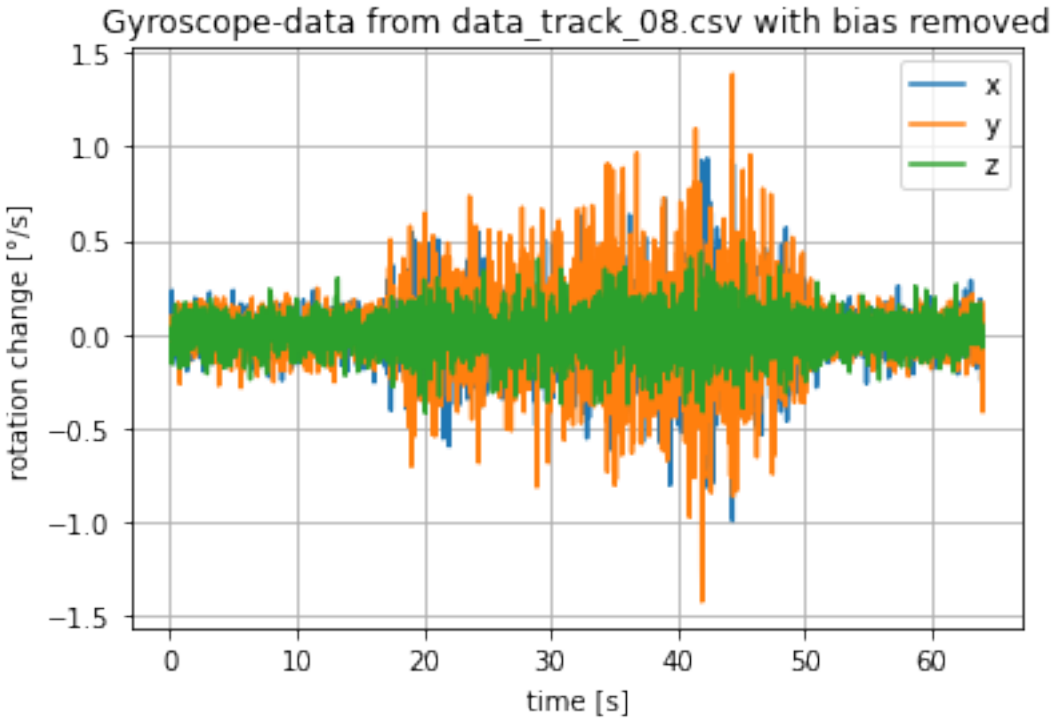

Gyroscope-data from data_track_07.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
1
0
−1
−2
0
10
20
30
40
50

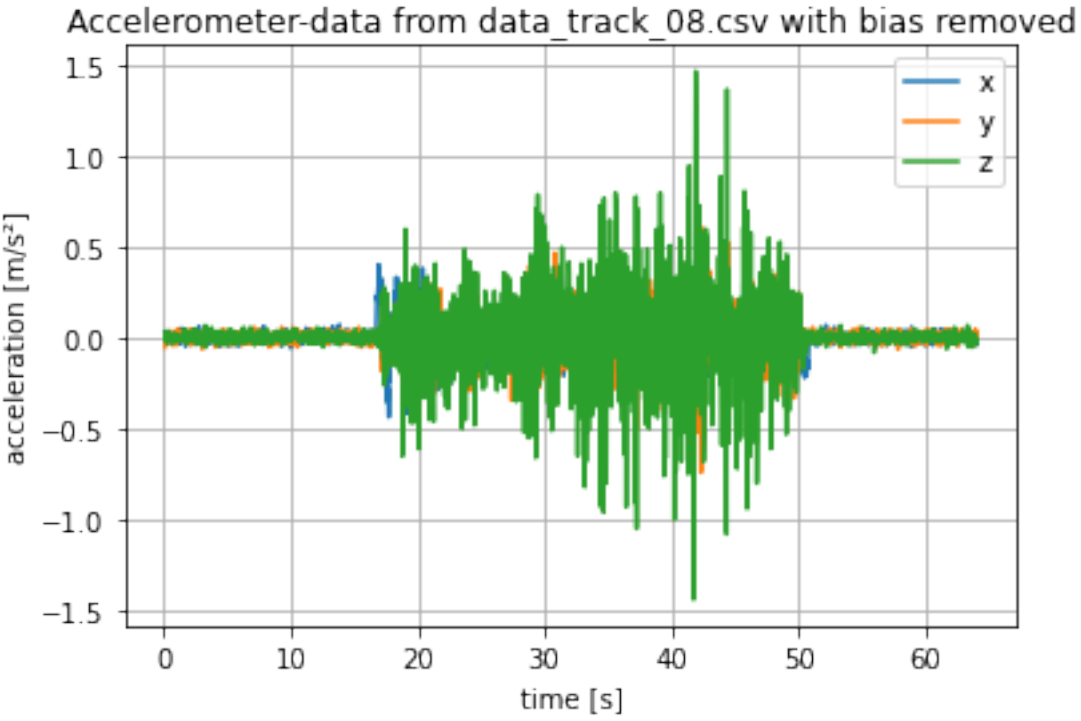

Accelerometer-data from data_track_07.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
10
20
30
40
50

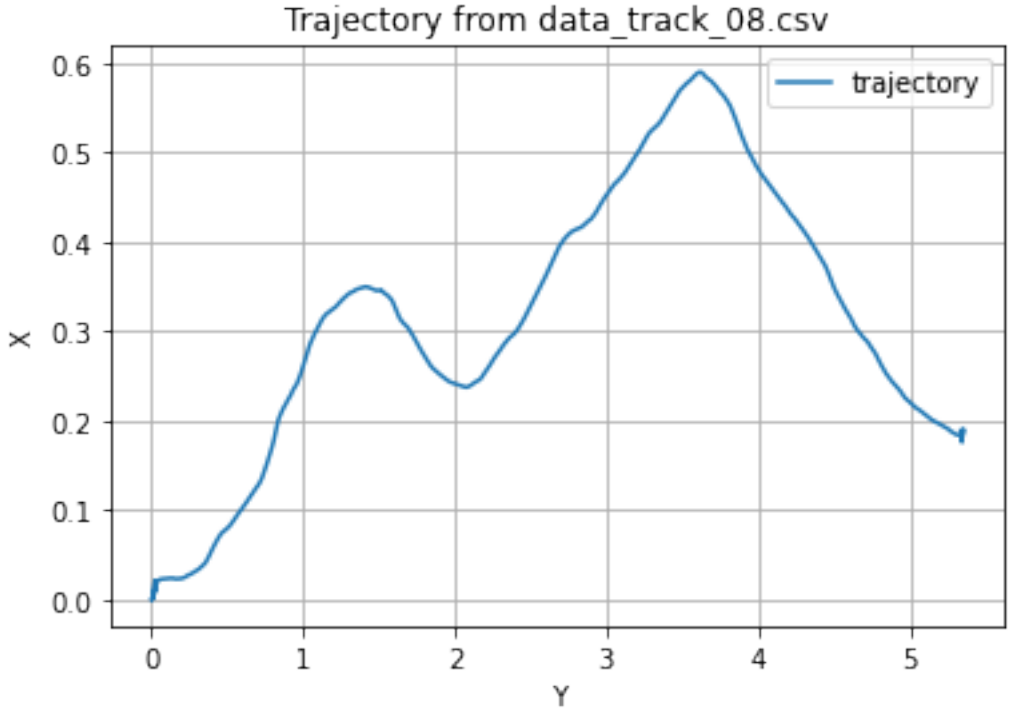

Trajectory from data_track_07.csv
trajectory
X
Y
0.4
0.3
0.2
0.1
0.0
−4.0
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0

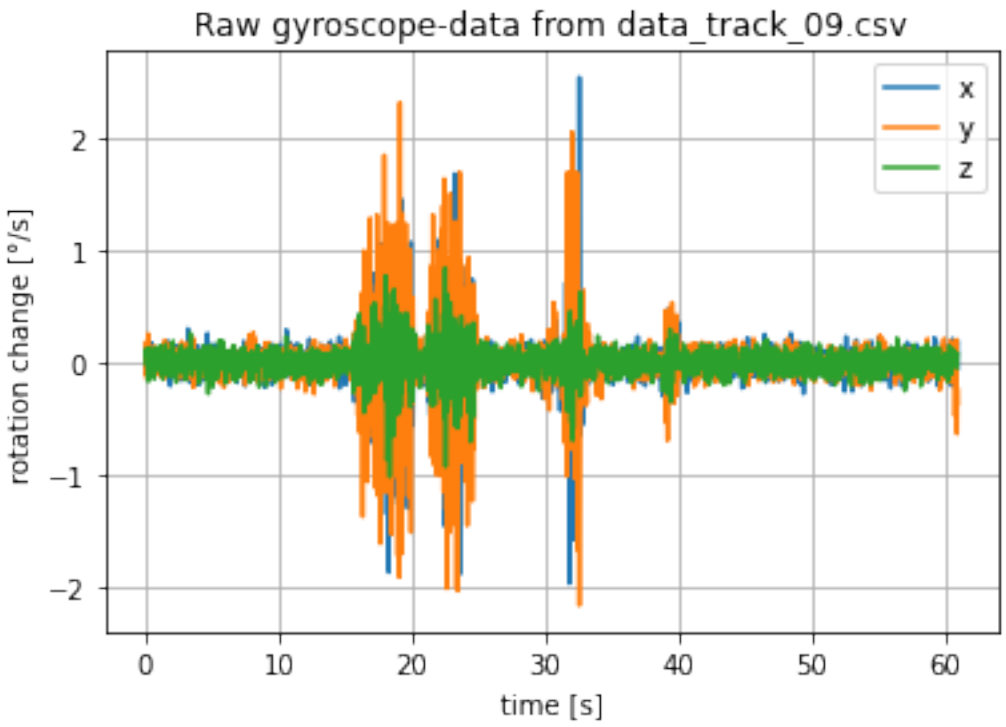

Raw gyroscope-data from data_track_08.csv
x
y
z
rotation change [°/s]
time [s]
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
10
20
30
40
50
60

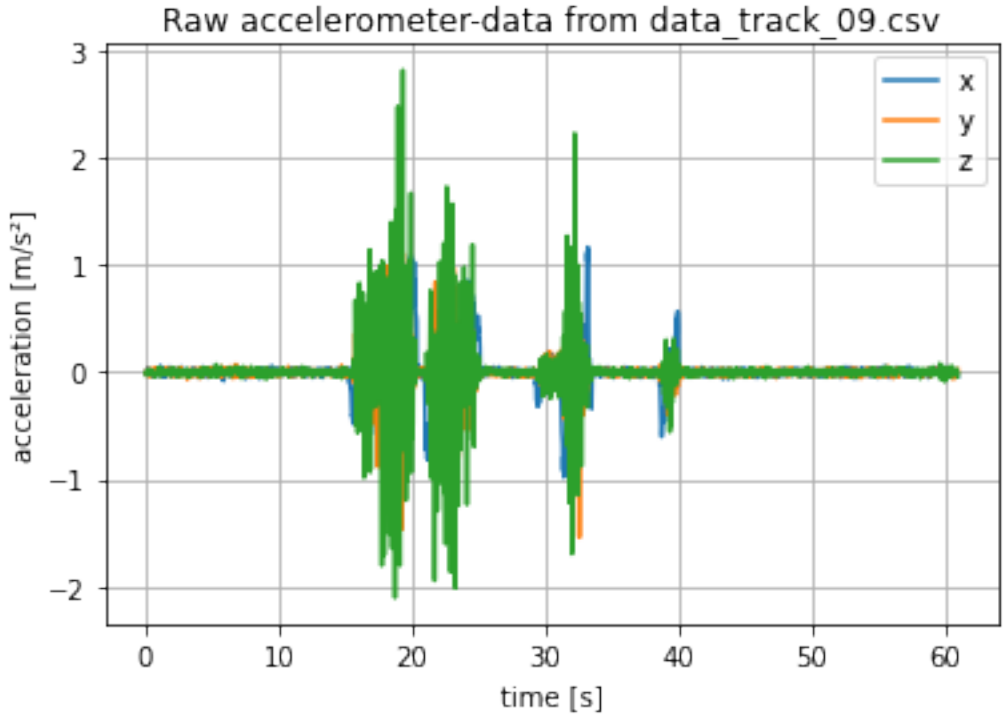

Raw accelerometer-data from data_track_08.csv
acceleration [m/s²]
time [s]
x
y
z
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
10
20
30
40
50
60

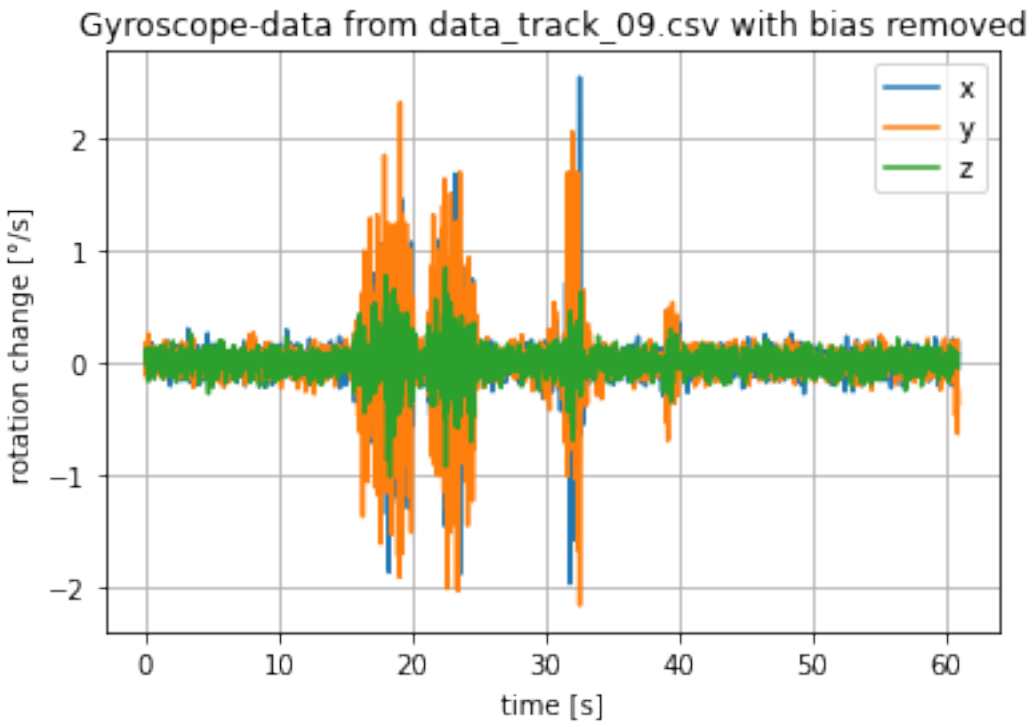

Gyroscope-data from data_track_08.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
10
20
30
40
50
60

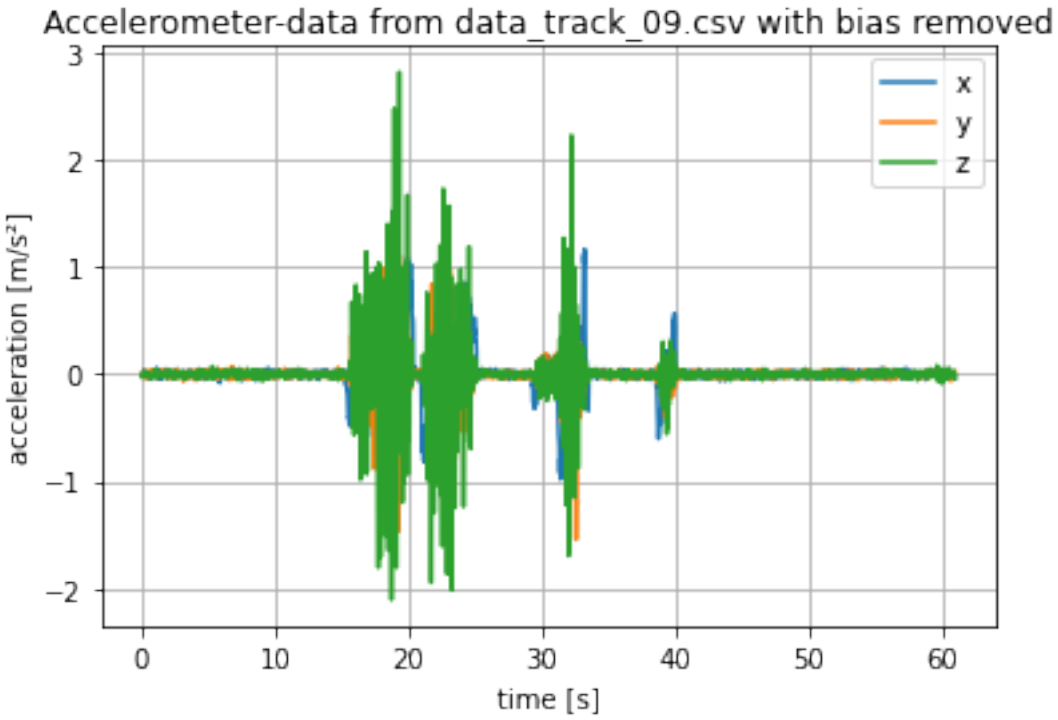

Accelerometer-data from data_track_08.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
10
20
30
40
50
60

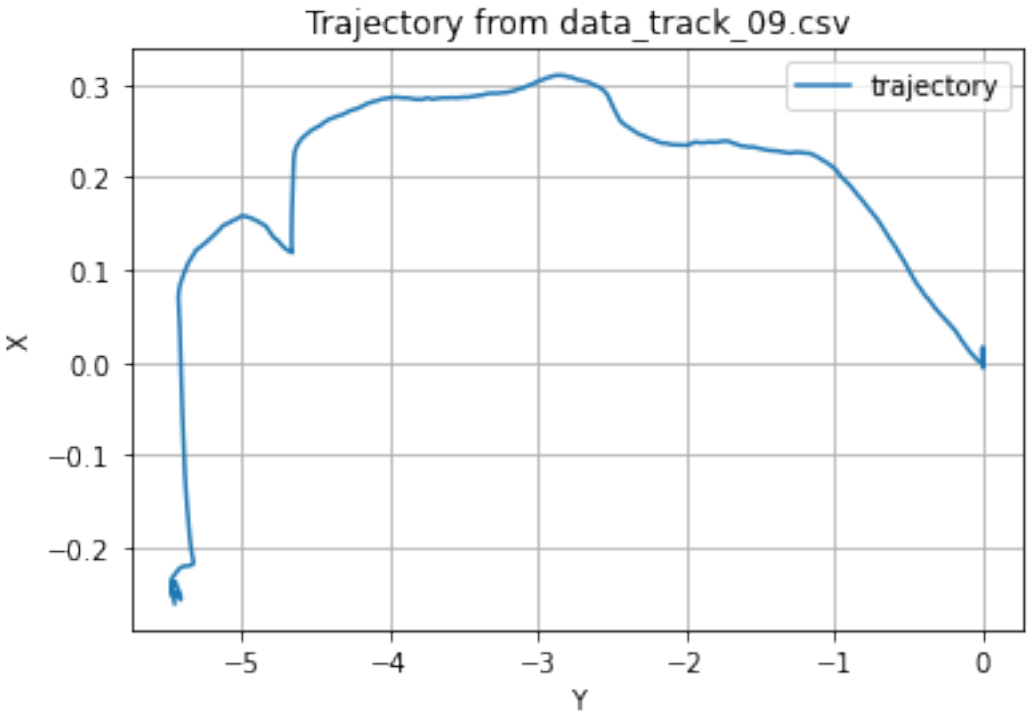

Trajectory from data_track_08.csv
trajectory
X
Y
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5

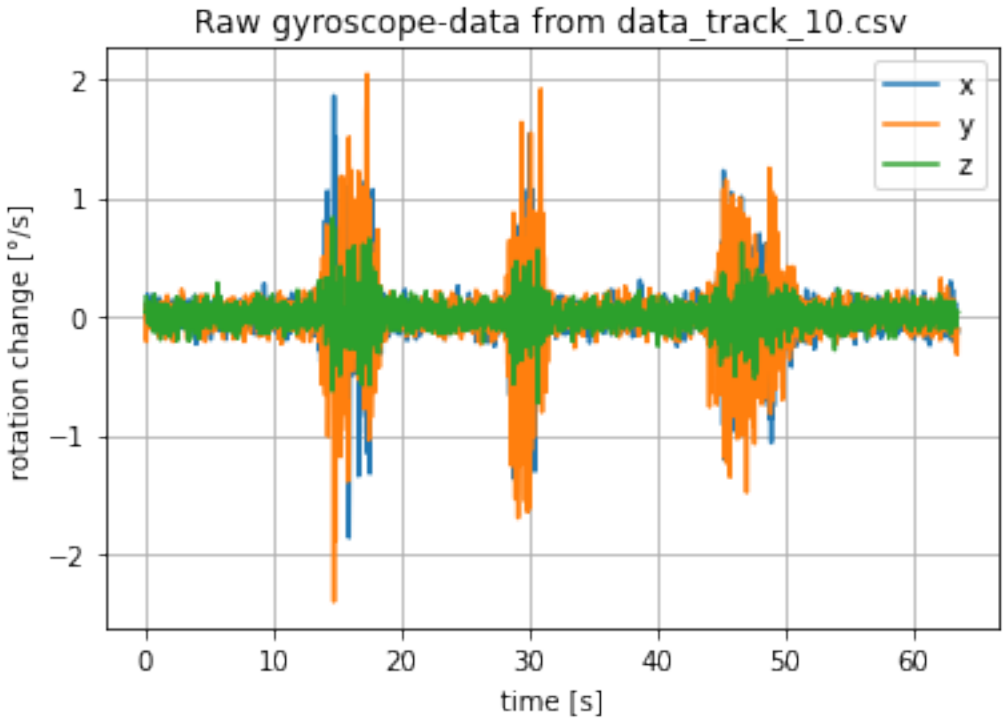

Raw gyroscope-data from data_track_09.csv
rotation change [°/s]
time [s]
x
y
z
2
1
0
−1
−2
0
10
20
30
40
50
60

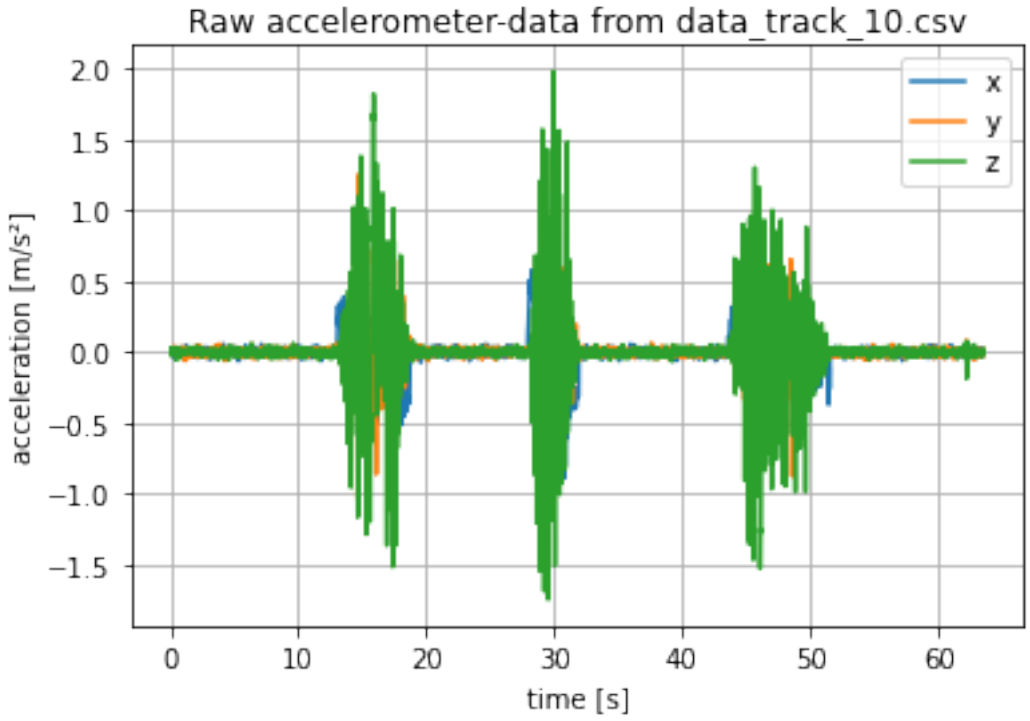

Raw accelerometer-data from data_track_09.csv
acceleration [m/s²]
time [s]
x
y
z
3
2
1
0
−1
−2
0
10
20
30
40
50
60

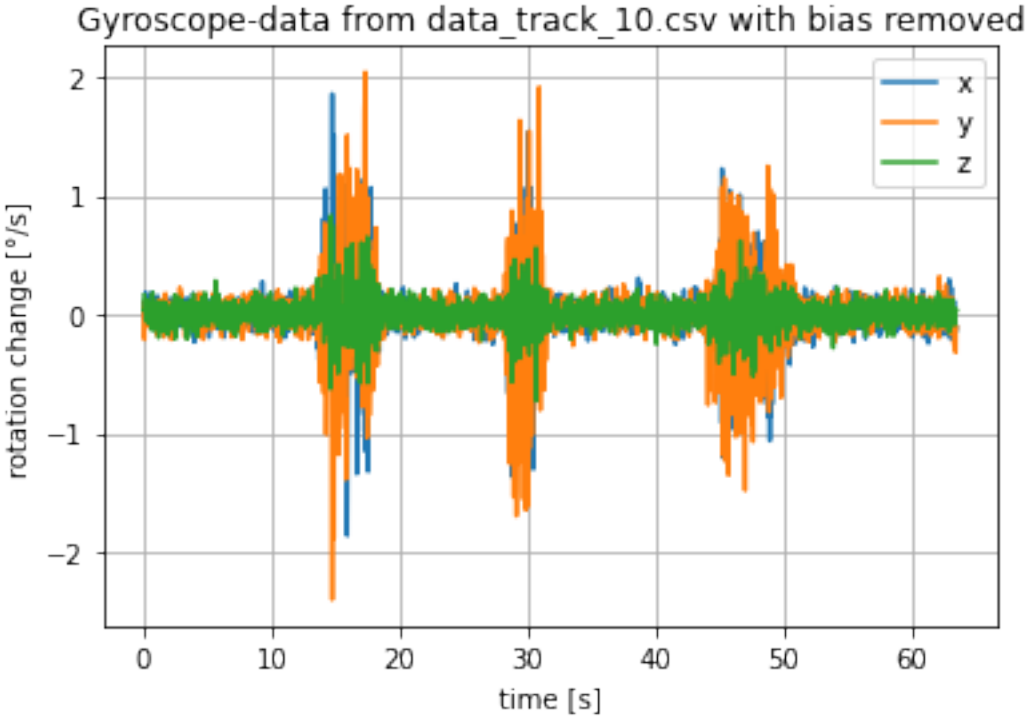

Gyroscope-data from data_track_09.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
2
1
0
−1
−2
0
10
20
30
40
50
60

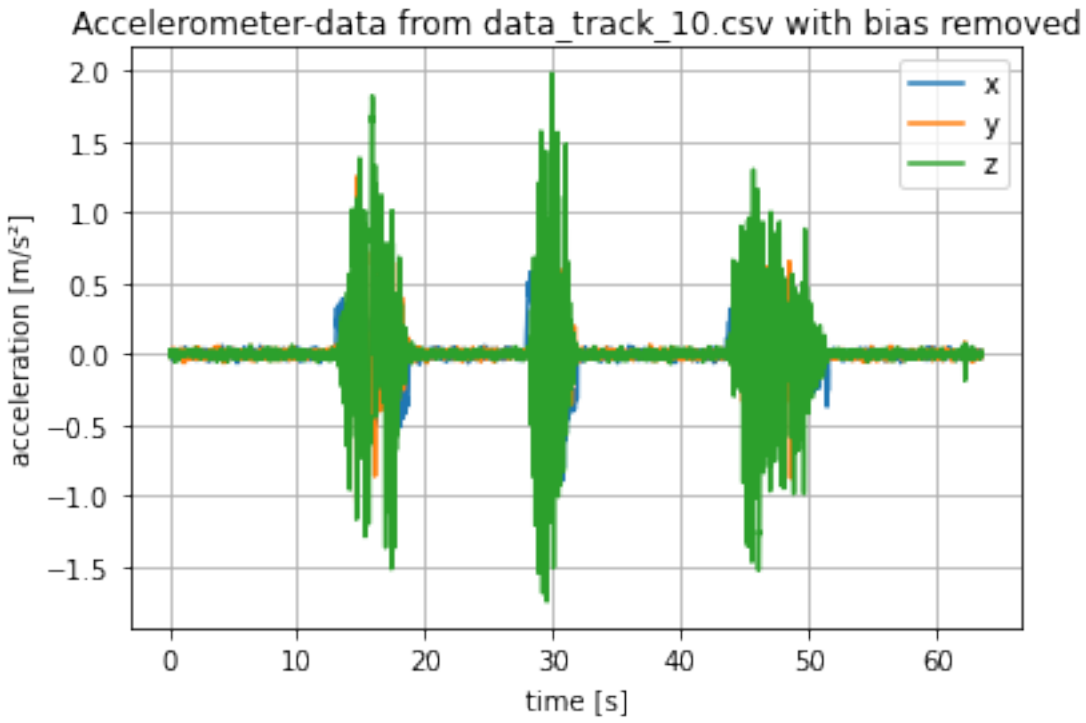

Accelerometer-data from data_track_09.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
3
2
1
0
−1
−2
0
10
20
30
40
50
60

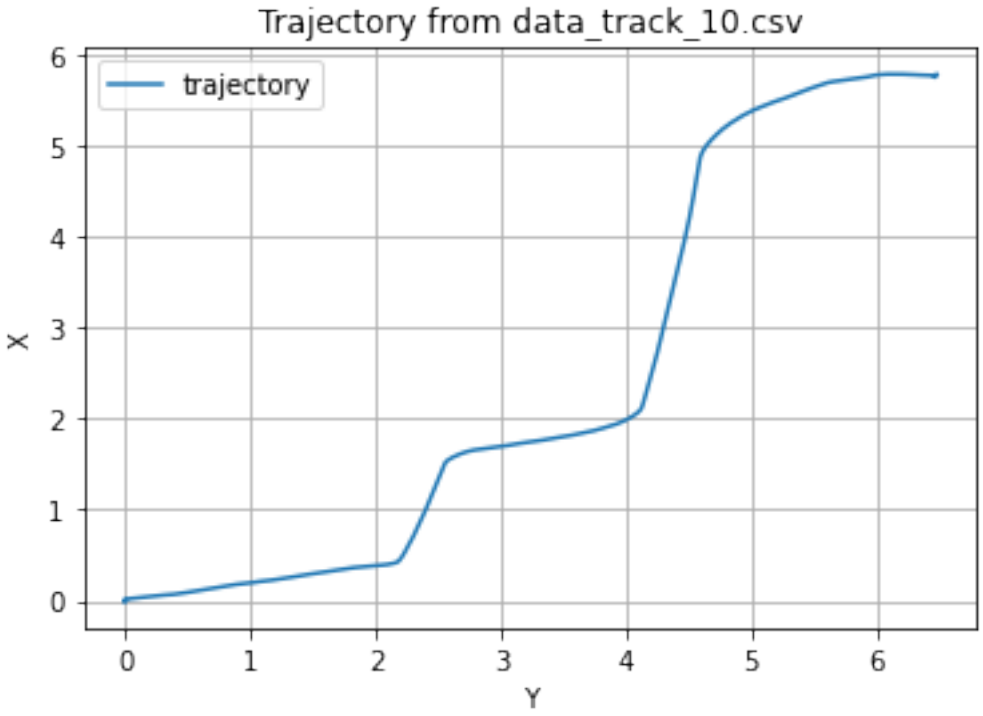

Trajectory from data_track_09.csv
trajectory
X
Y
0.3
0.2
0.1
0.0
−0.1
−0.2
−5
−4
−3
−2
−1
0

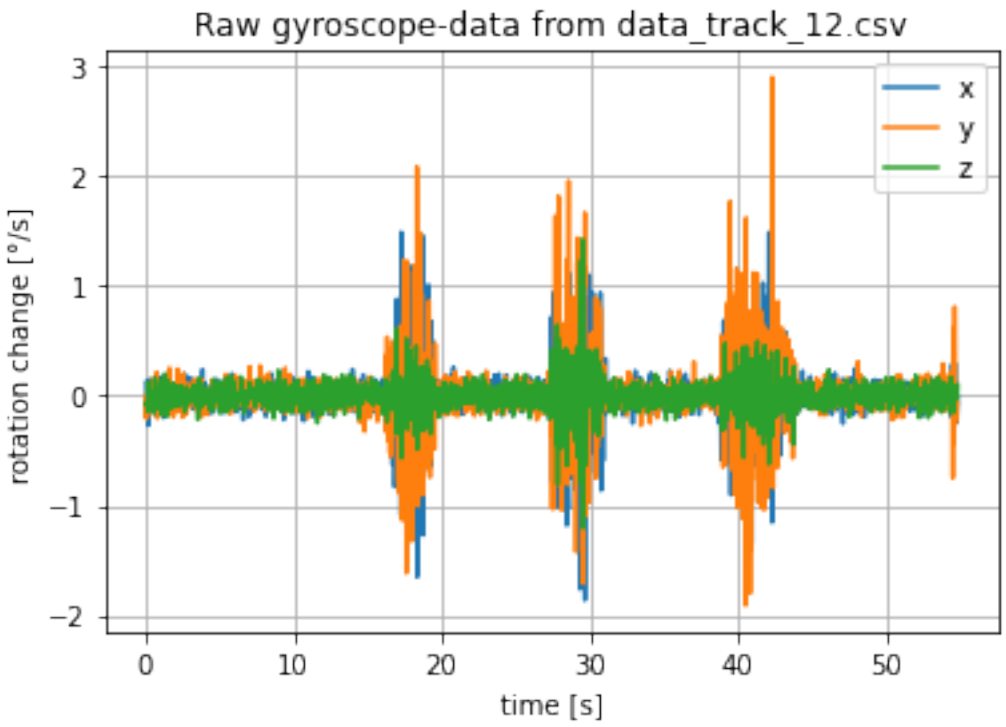

Raw gyroscope-data from data_track_10.csv
x
y
z
rotation change [°/s]
time [s]
2
1
0
−1
−2
0
10
20
30
40
50
60

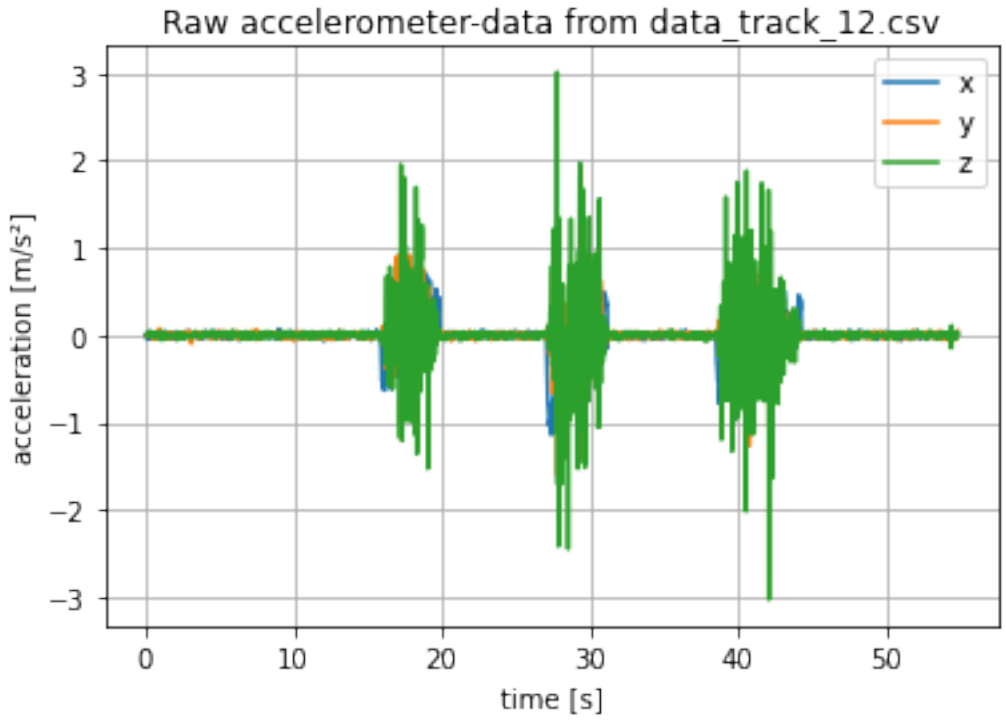

Raw accelerometer-data from data_track_10.csv
acceleration [m/s²]
time [s]
x
y
z
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
10
20
30
40
50
60

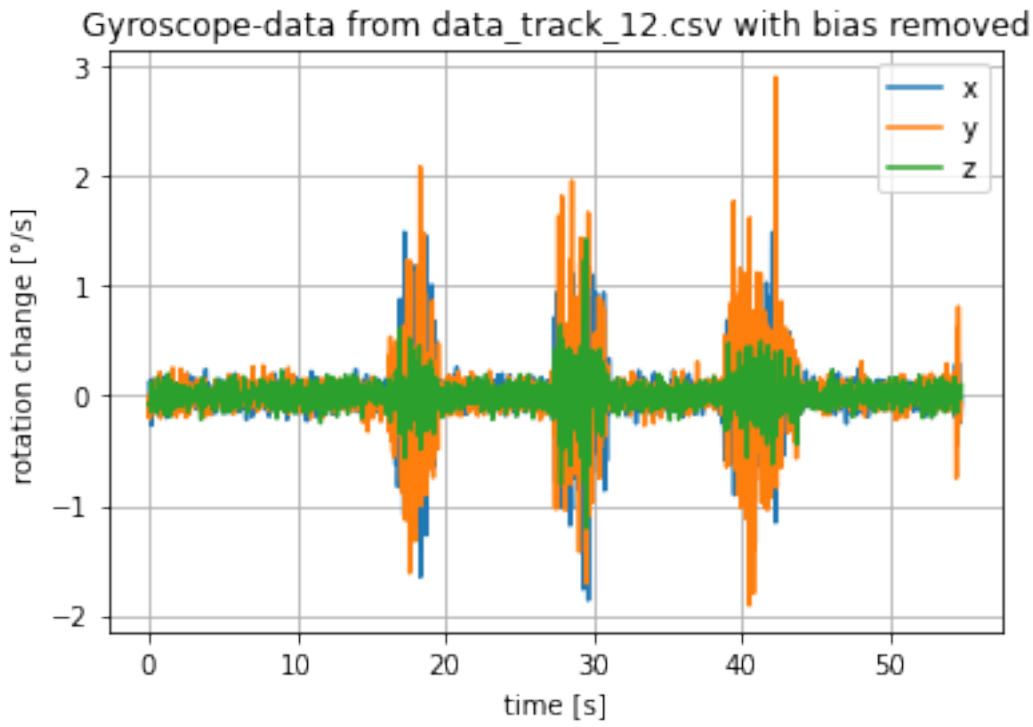

Gyroscope-data from data_track_10.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
2
1
0
−1
−2
0
10
20
30
40
50
60

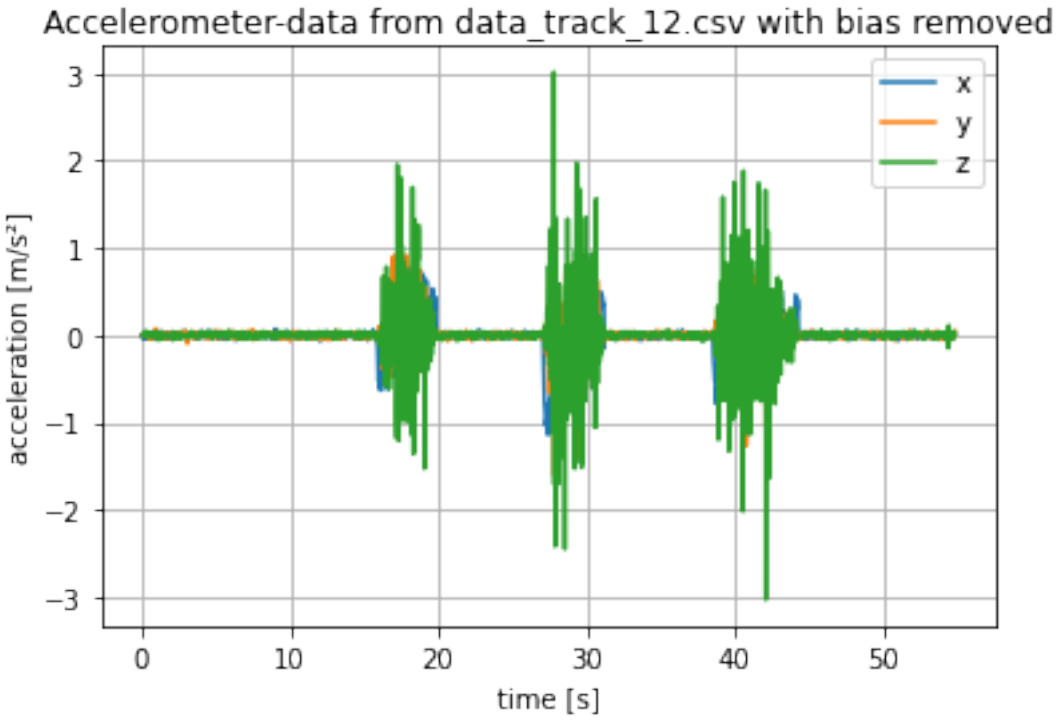

Accelerometer-data from data_track_10.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
10
20
30
40
50
60

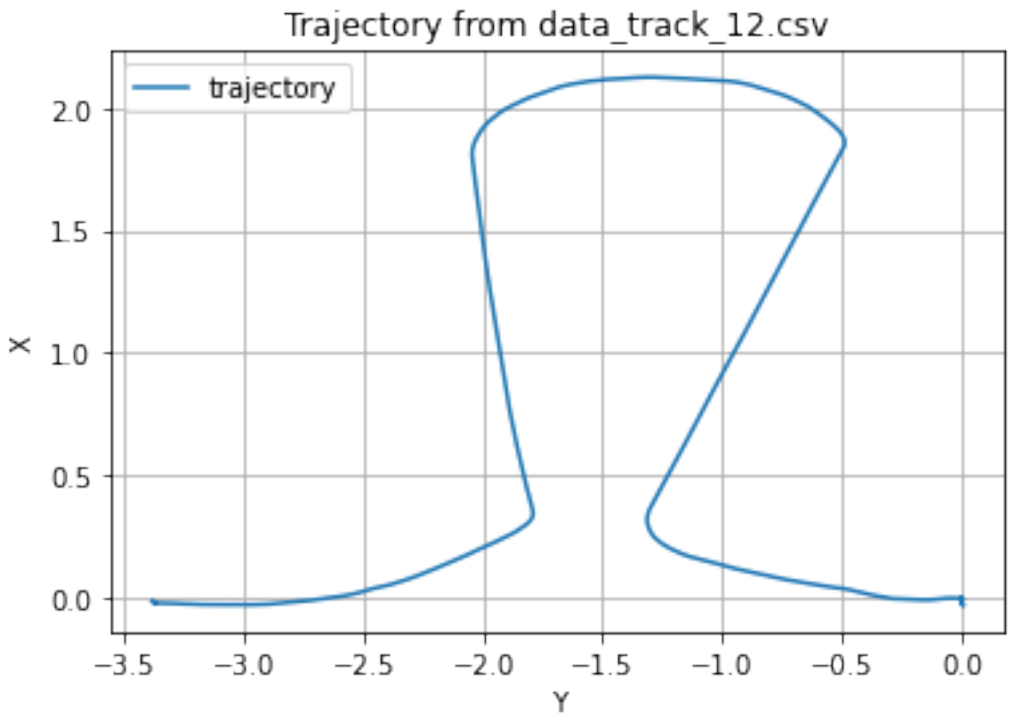

Trajectory from data_track_10.csv
trajectory
X
Y
6
5
4
3
2
1
0
0
1
2
3
4
5
6

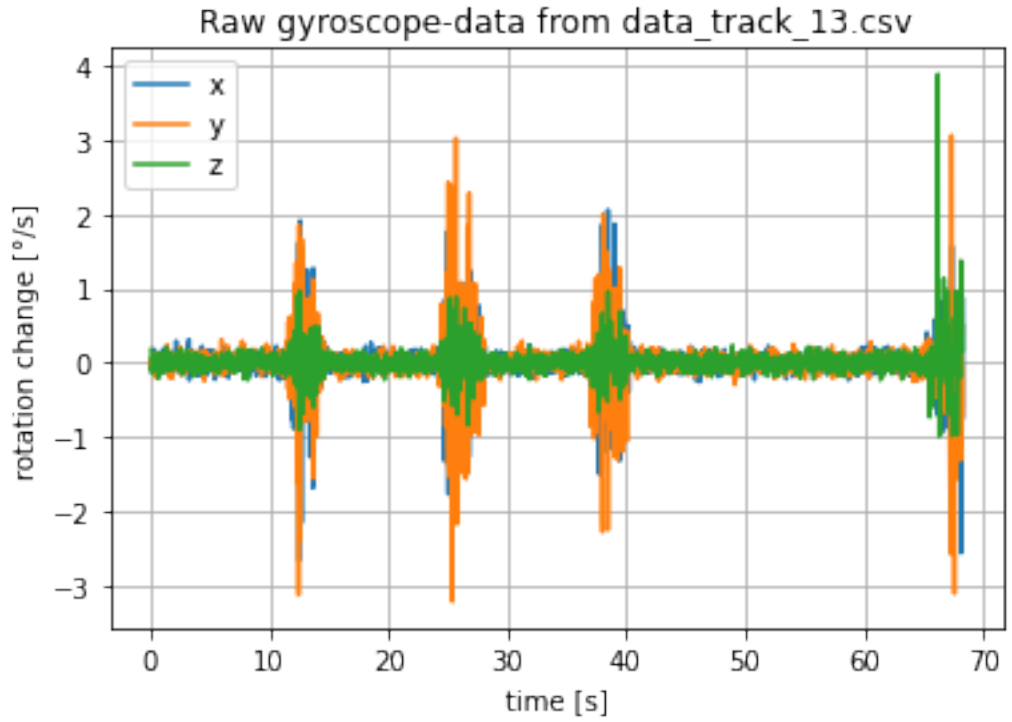

Raw gyroscope-data from data_track_12.csv
rotation change [°/s]
time [s]
x
y
z
3
2
1
0
−1
−2
0
10
20
30
40
50

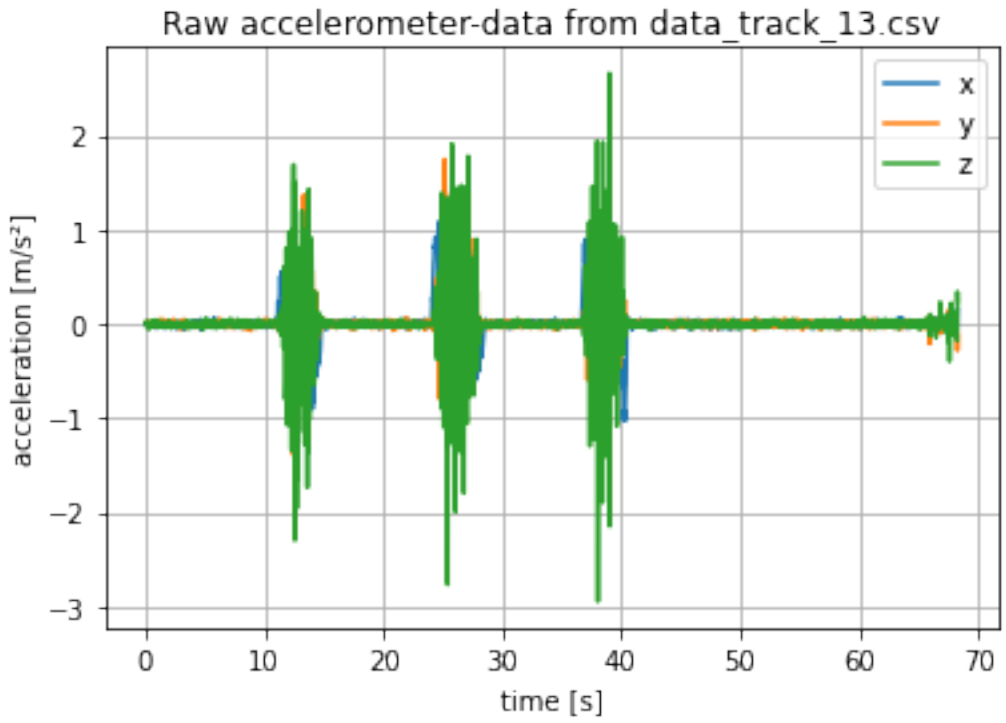

Raw accelerometer-data from data_track_12.csv
acceleration [m/s²]
time [s]
x
y
z
3
2
1
0
−1
−2
−3
0
10
20
30
40
50

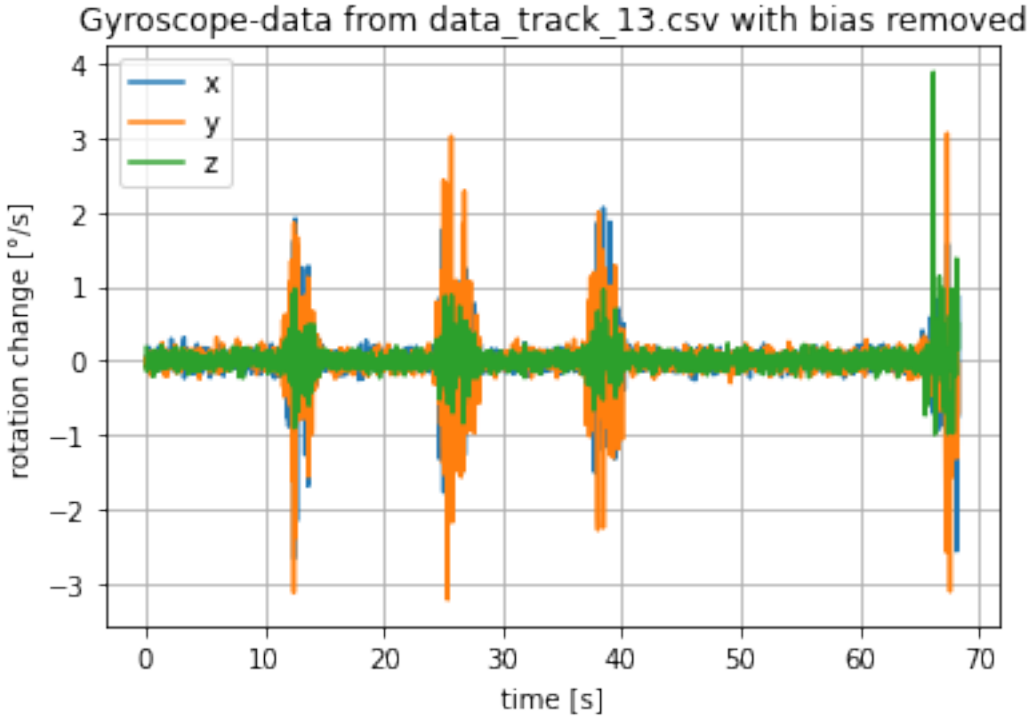

Gyroscope-data from data_track_12.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
3
2
1
0
−1
−2
0
10
20
30
40
50

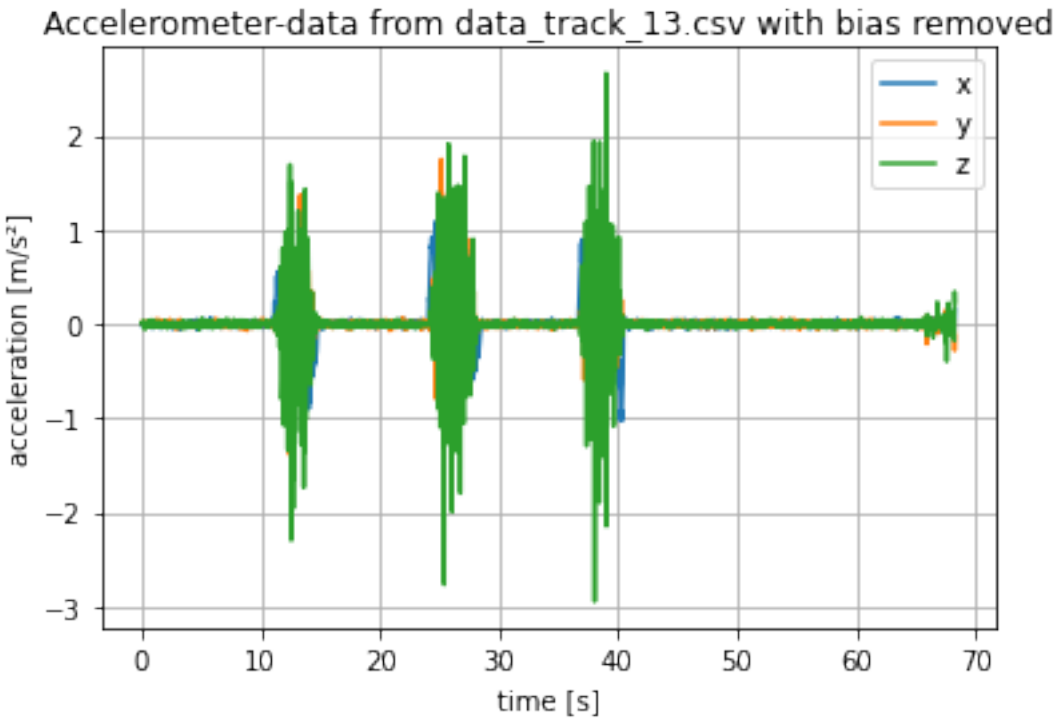

Accelerometer-data from data_track_12.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
3
2
1
0
−1
−2
−3
0
10
20
30
40
50

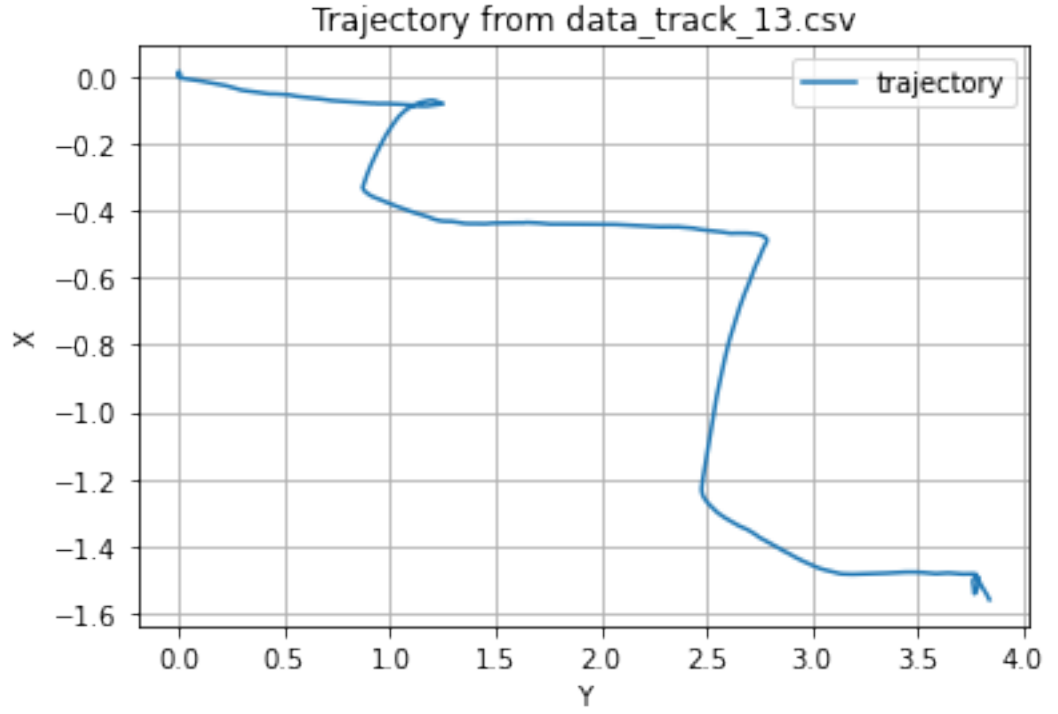

Trajectory from data_track_12.csv
trajectory
2.0
1.5
1.0
0.5
0.0
X
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
Y

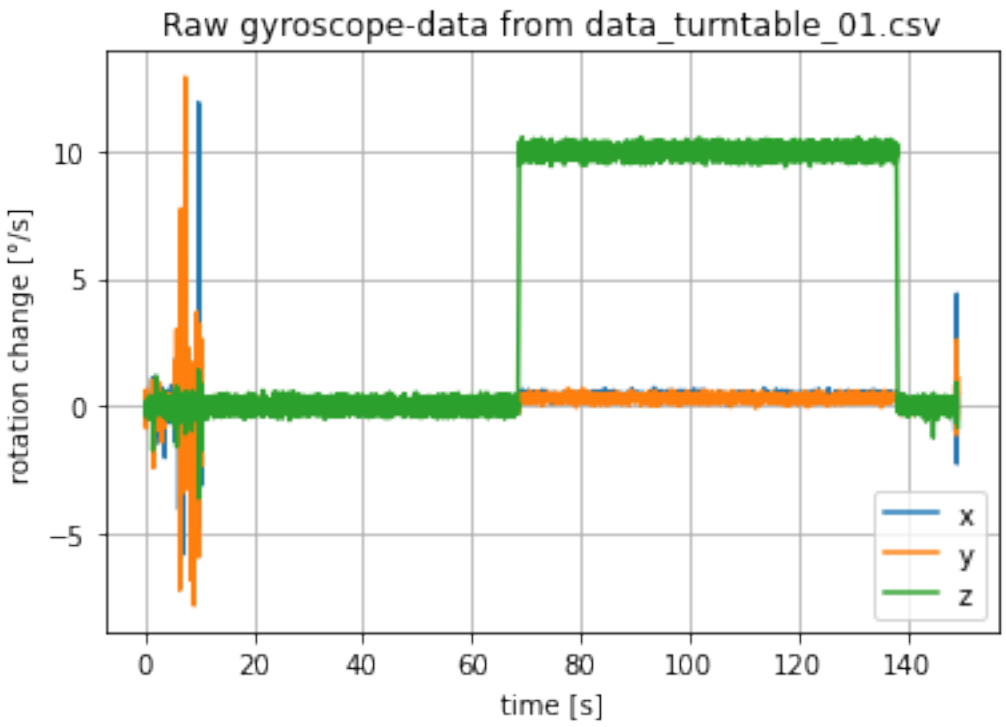

Raw gyroscope-data from data_track_13.csv
x
y
z
4
3
2
1
0
−1
−2
−3
rotation change [°/s]
0
10
20
30
40
50
60
70
time [s]

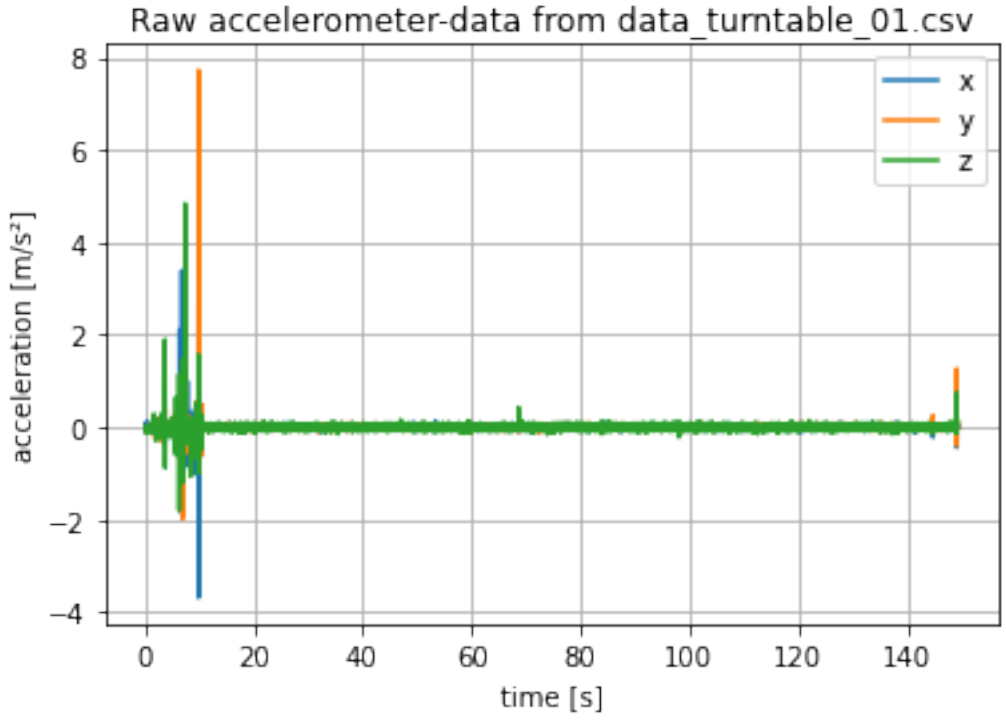

Raw accelerometer-data from data_track_13.csv
x
y
z
acceleration [m/s²]
time [s]

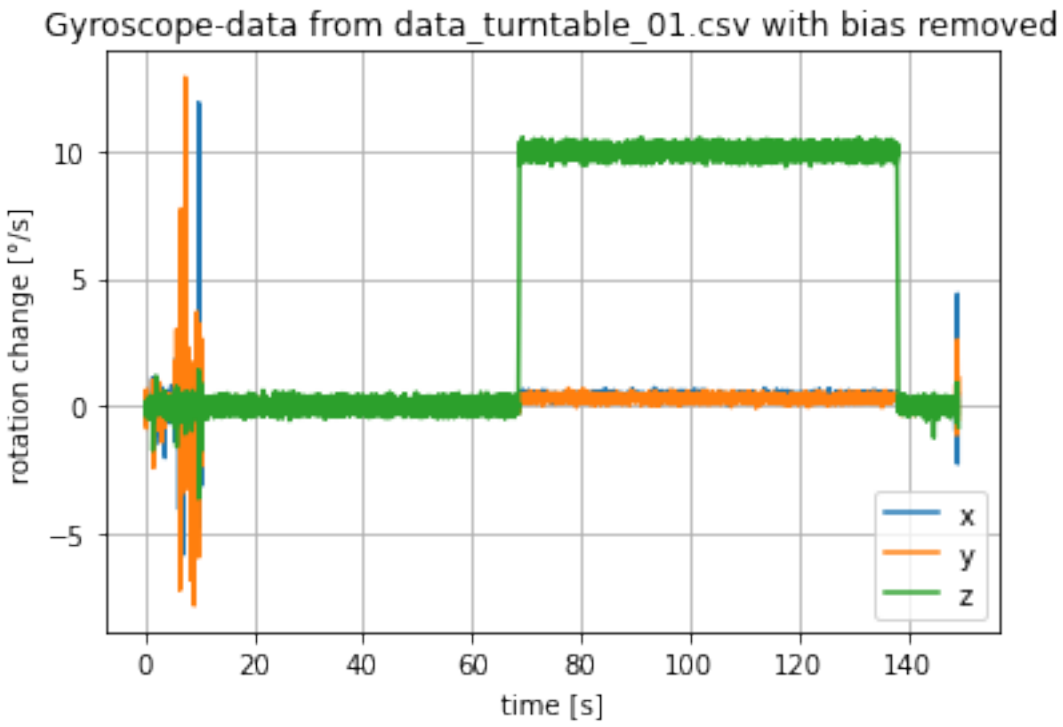

Gyroscope-data from data_track_13.csv with bias removed
x
y
z
rotation change [°/s]
time [s]

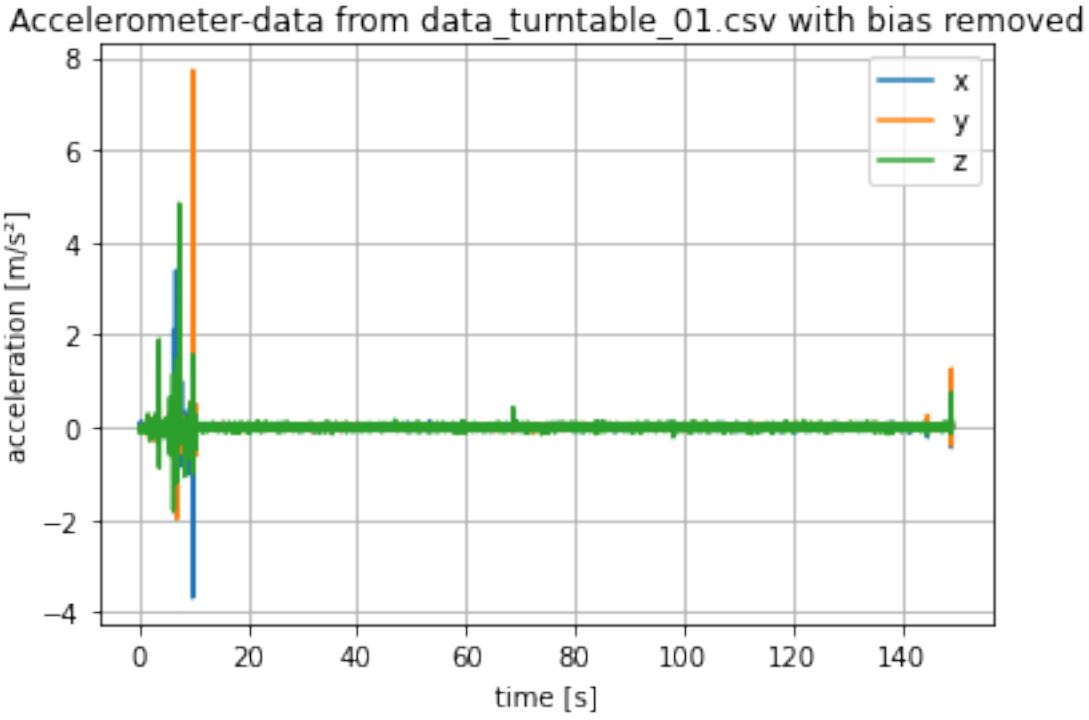

Accelerometer-data from data_track_13.csv with bias removed
x
y
z
acceleration [m/s²]
time [s]
2
1
0
−1
−2
−3
0
10
20
30
40
50
60
70

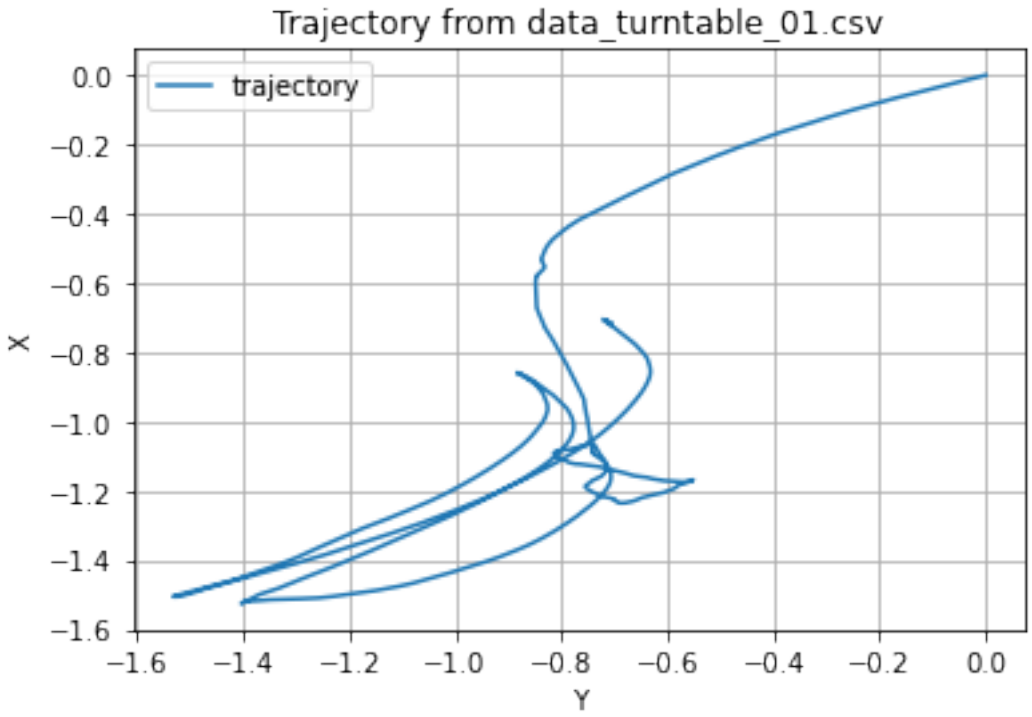

Trajectory from data_track_13.csv
trajectory
X
Y
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

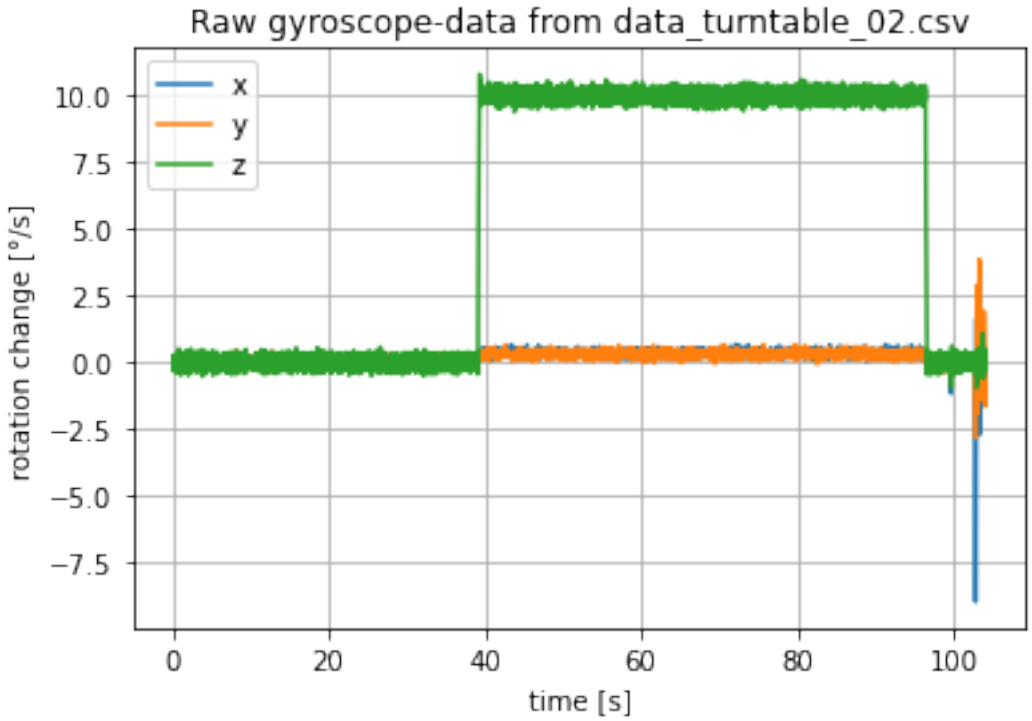

Raw gyroscope-data from data_turntable_01.csv
rotation change [°/s]
time [s]
x
y
z

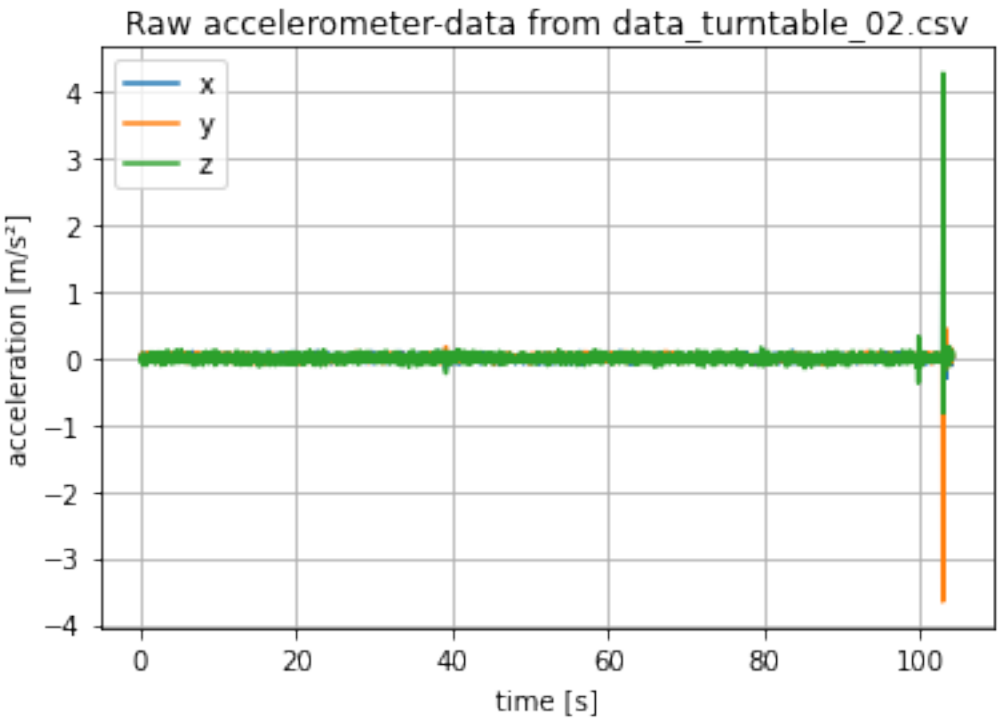

Raw accelerometer-data from data_turntable_01.csv
acceleration [m/s²]
time [s]
x
y
z

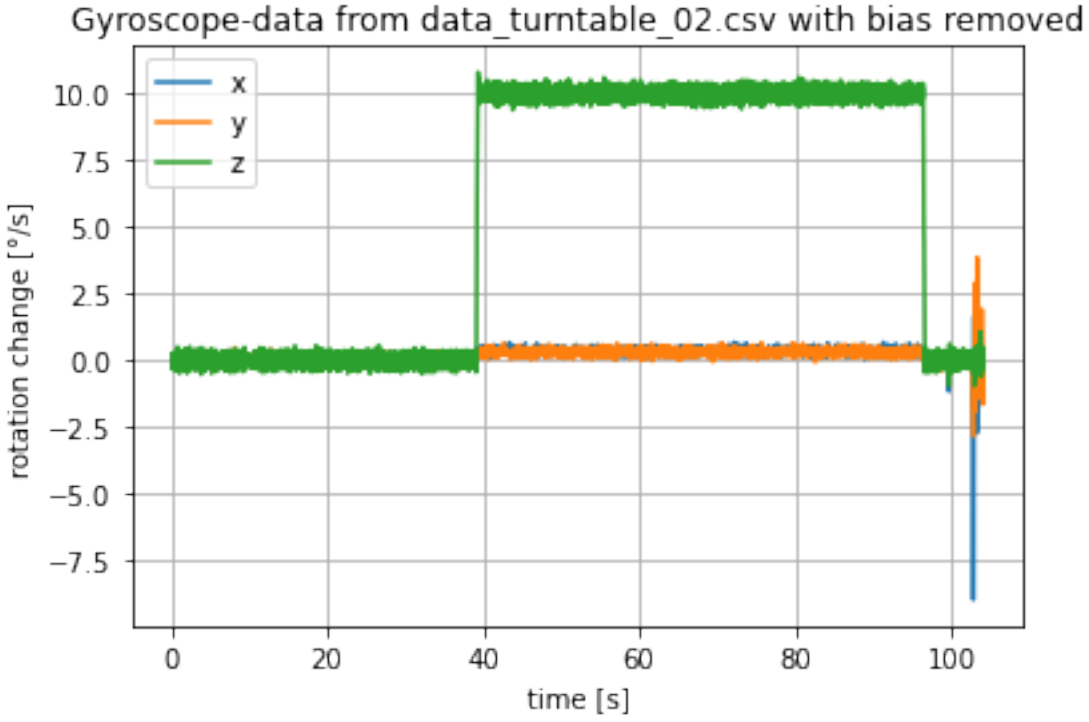

Gyroscope-data from data_turntable_01.csv with bias removed
rotation change [°/s]
time [s]
x
y
z

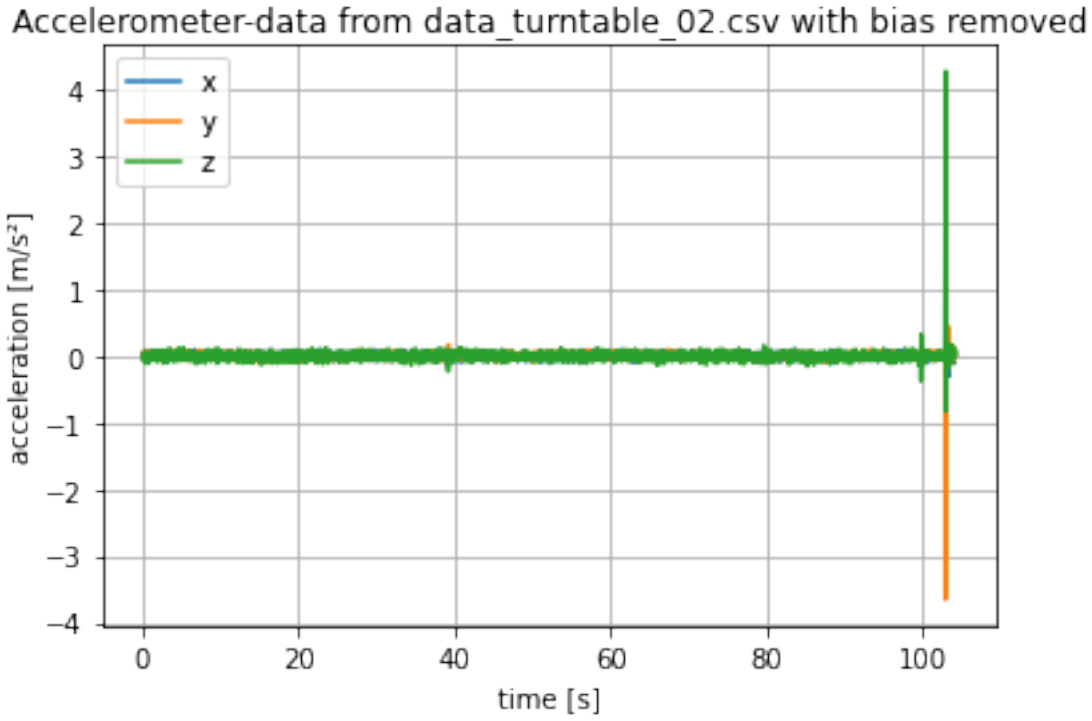

Accelerometer-data from data_turntable_01.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z

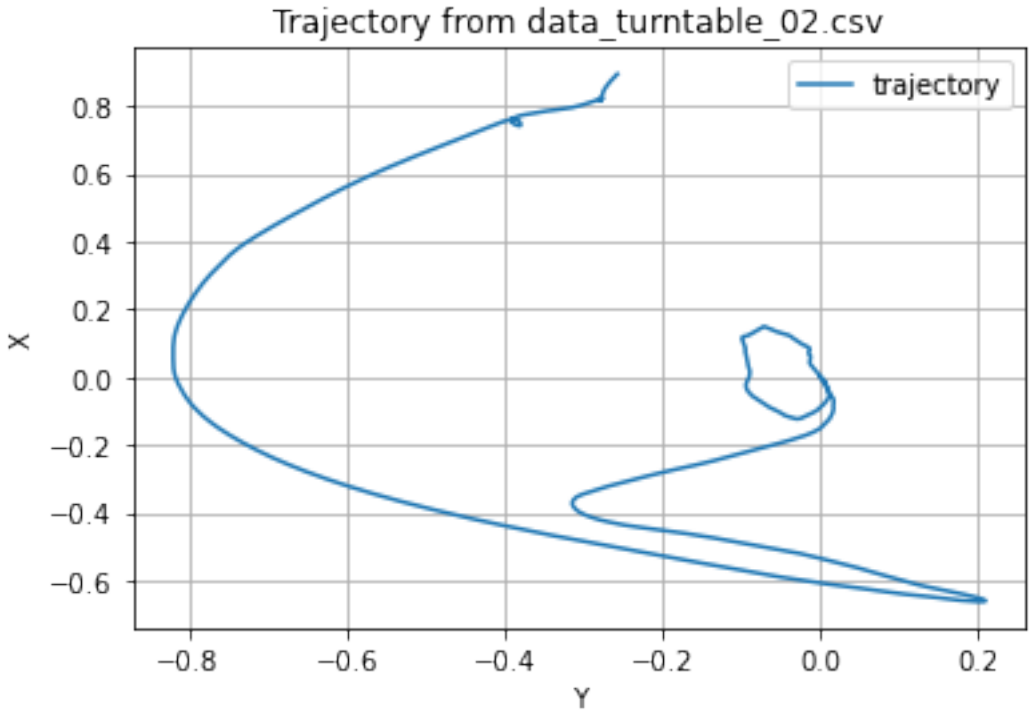

Trajectory from data_turntable_01.csv
trajectory
X
Y
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6

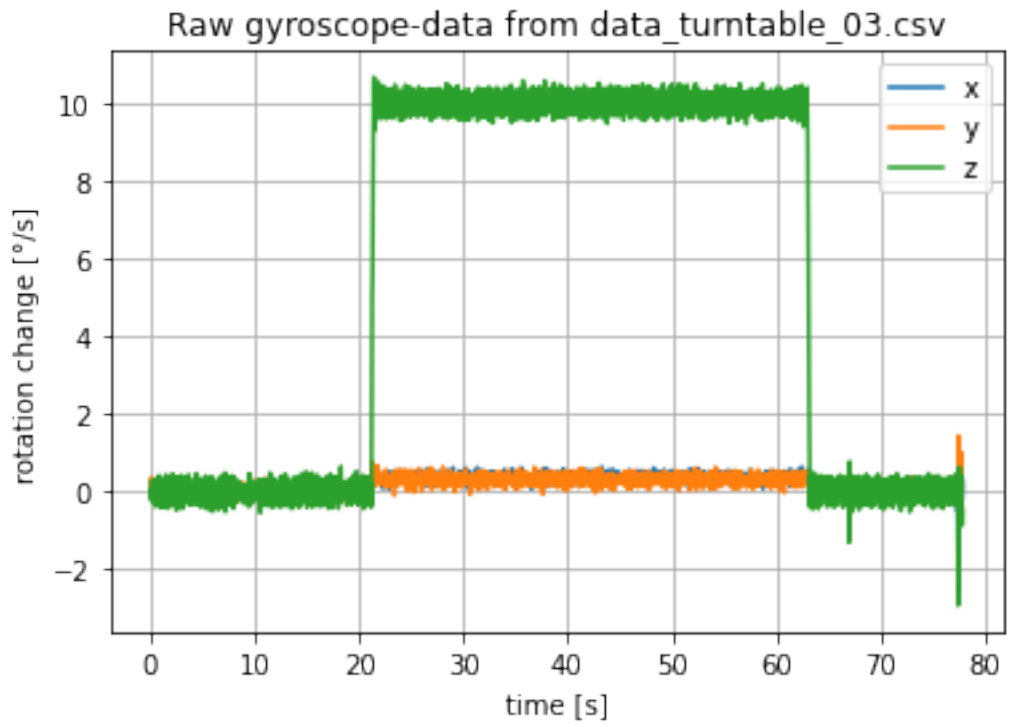

Raw gyroscope-data from data_turntable_02.csv
x
y
z
rotation change [°/s]
time [s]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
0
20
40
60
80
100

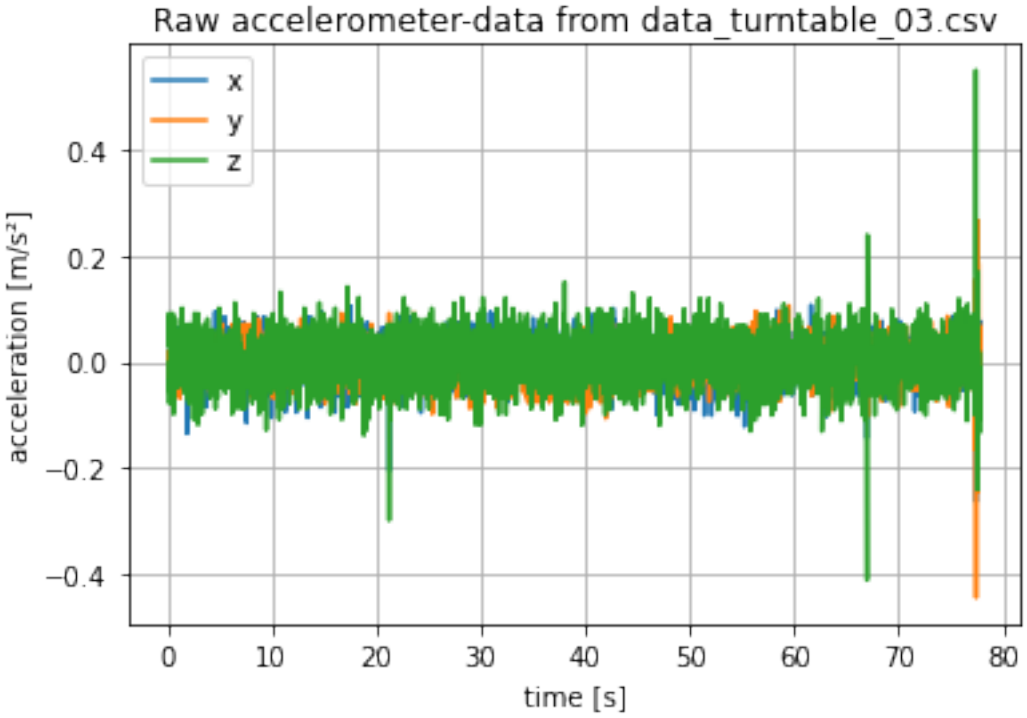

Raw accelerometer-data from data_turntable_02.csv
x
y
z
acceleration [m/s²]
time [s]

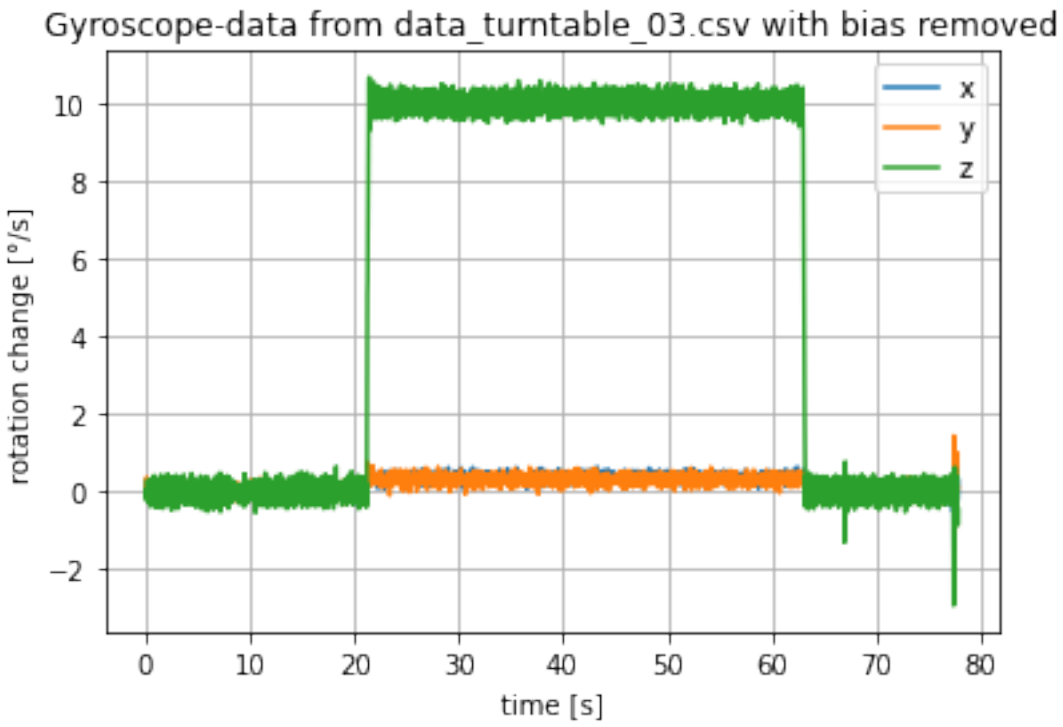

Gyroscope-data from data_turntable_02.csv with bias removed
x
y
z
rotation change [°/s]
time [s]

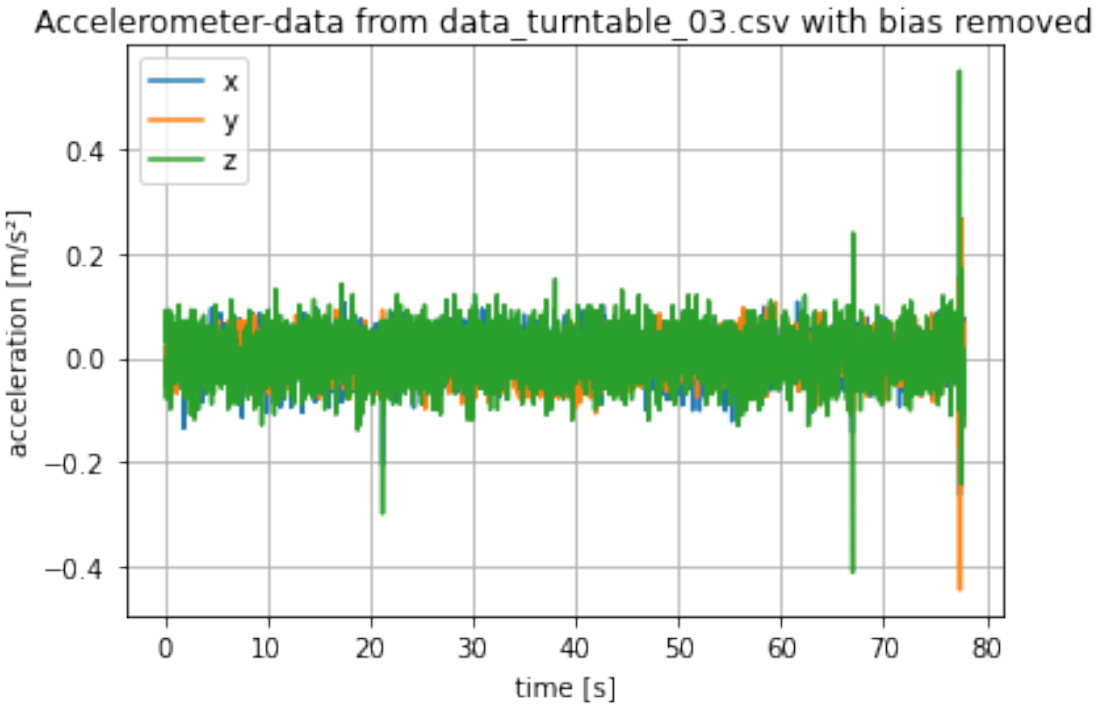

Accelerometer-data from data_turntable_02.csv with bias removed
x
y
z
acceleration [m/s²]
time [s]
4
3
2
1
0
−1
−2
−3
−4
0
20
40
60
80
100

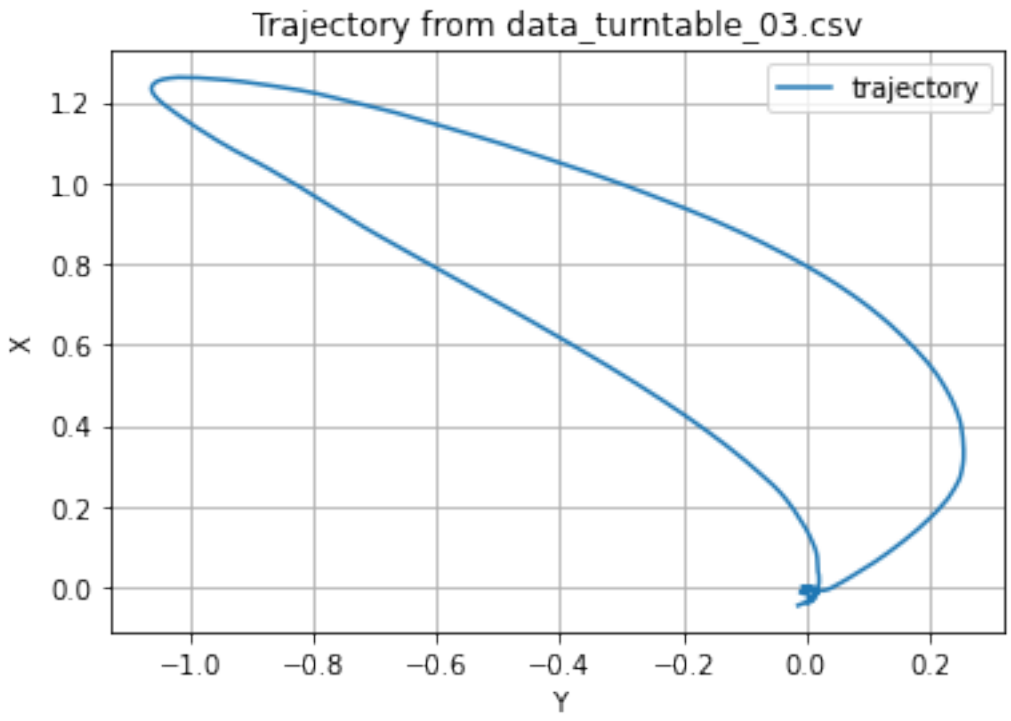

Trajectory from data_turntable_02.csv
trajectory
X
Y
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−0.6
−0.4
−0.2
0.0
0.2

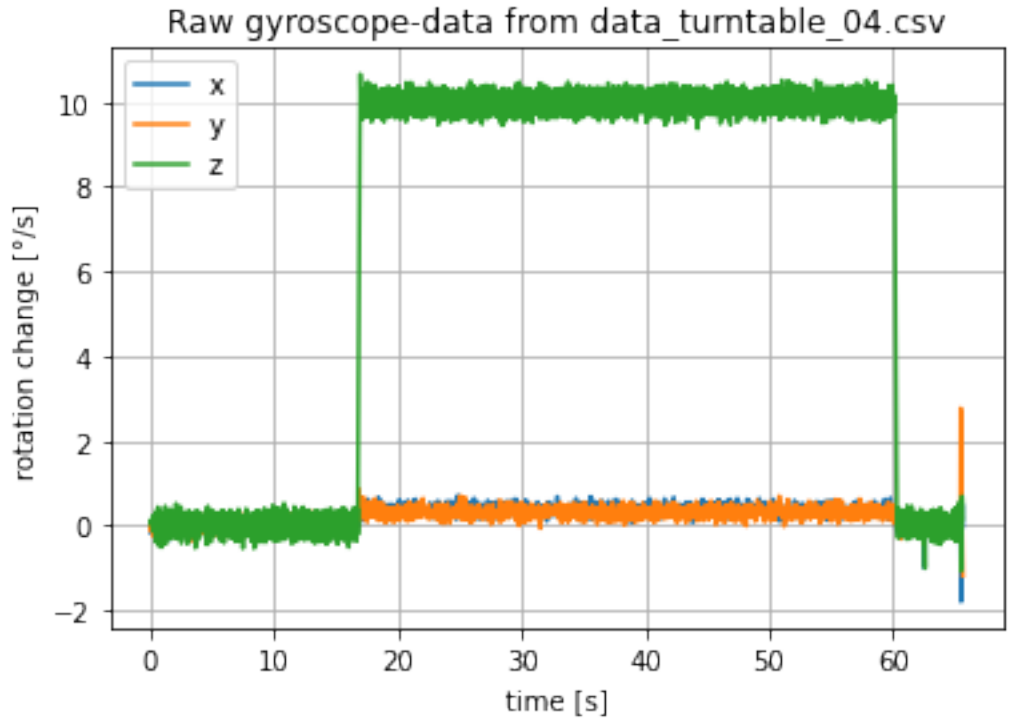

Raw gyroscope-data from data_turntable_03.csv
rotation change [°/s]
time [s]
x
y
z
10
8
6
4
2
0
−2
0
10
20
30
40
50
60
70
80

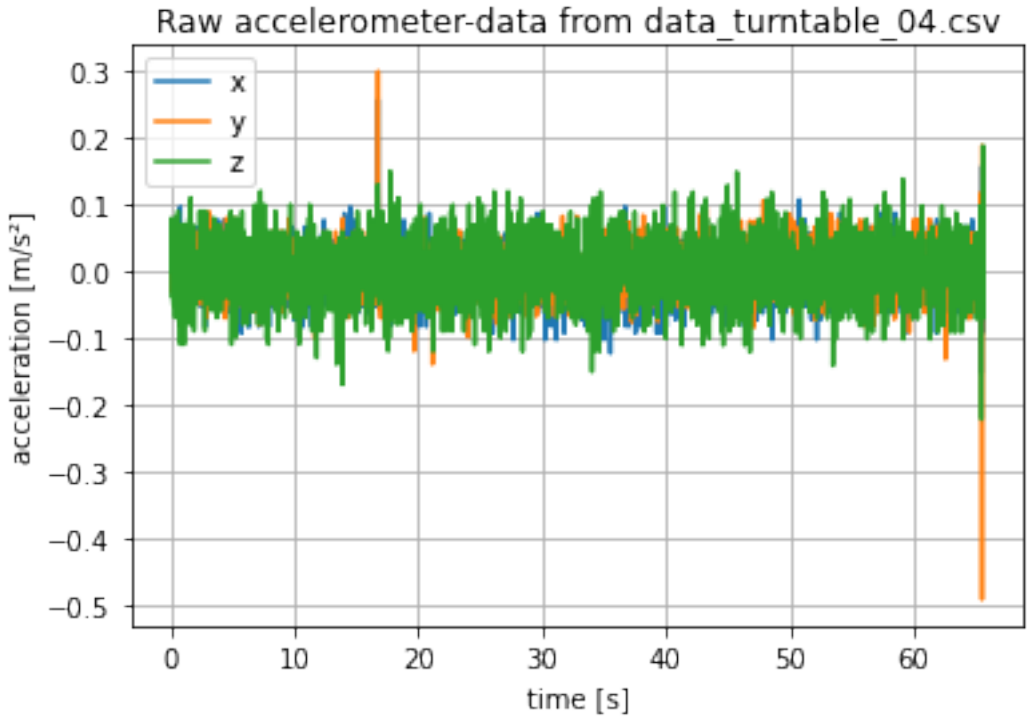

Raw accelerometer-data from data_turntable_03.csv
acceleration [m/s²]
time [s]
x
y
z
0.4
0.2
0.0
−0.2
−0.4
0
10
20
30
40
50
60
70
80

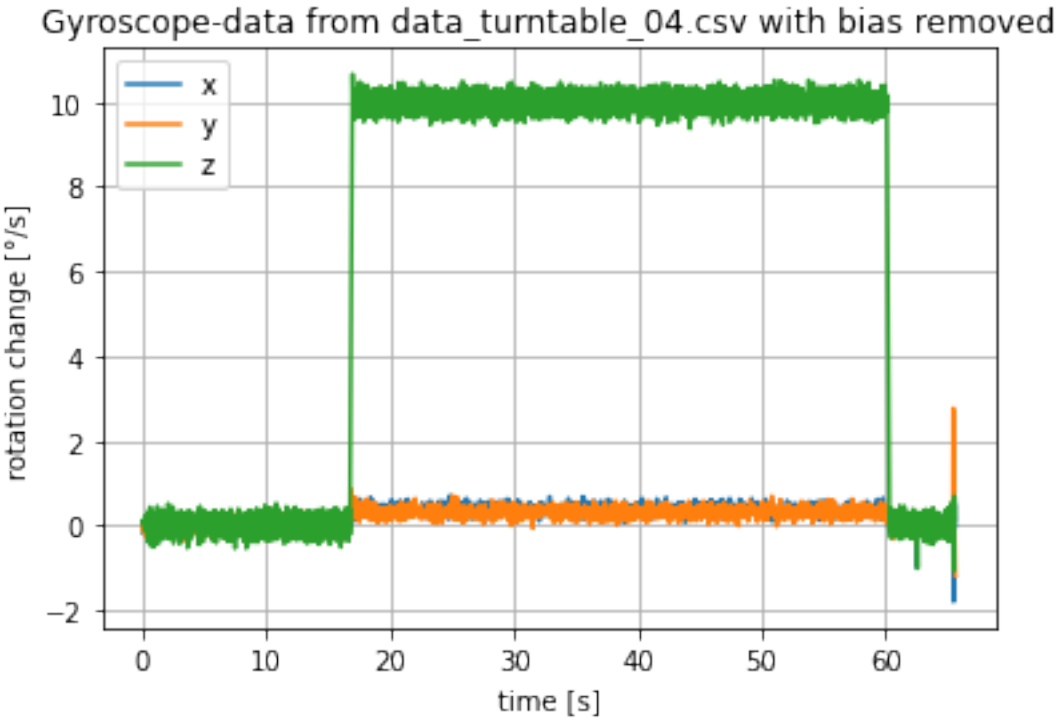

Gyroscope-data from data_turntable_03.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
10
8
6
4
2
0
−2
0
10
20
30
40
50
60
70
80

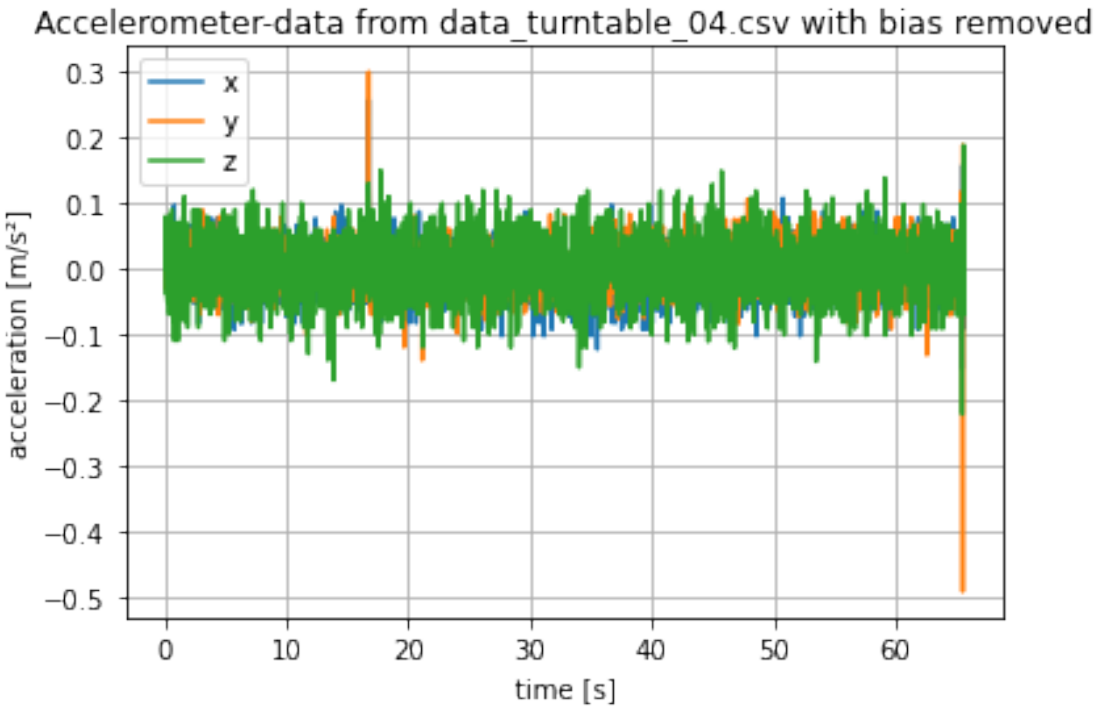

Accelerometer-data from data_turntable_03.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
0.4
0.2
0.0
−0.2
−0.4
0
10
20
30
40
50
60
70
80

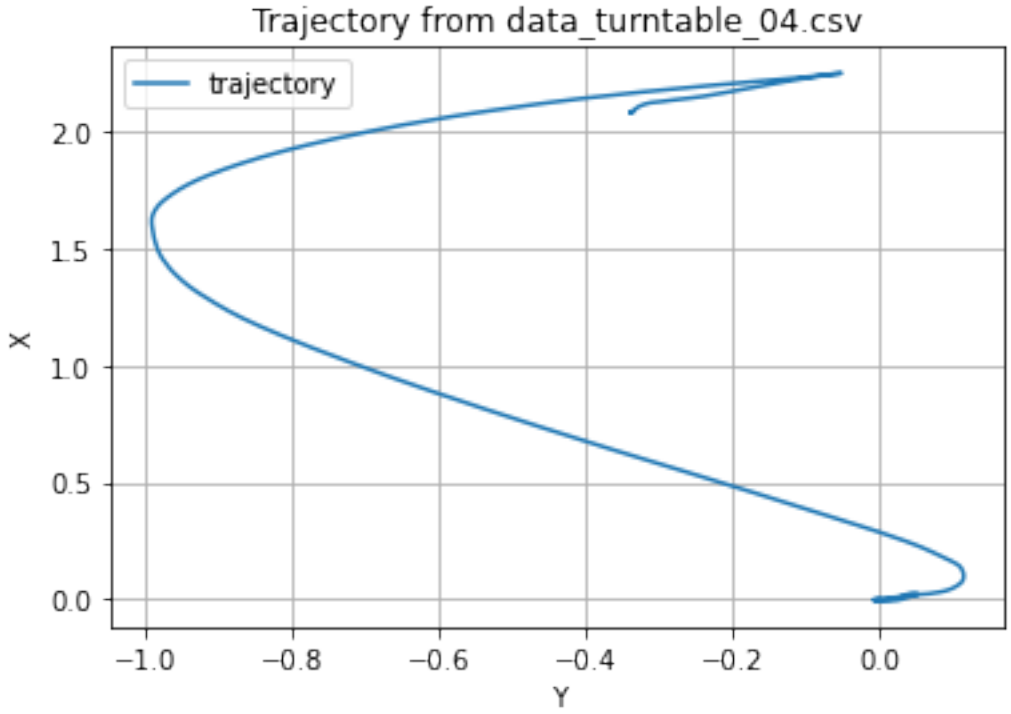

Trajectory from data_turntable_03.csv
trajectory
X
Y
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2

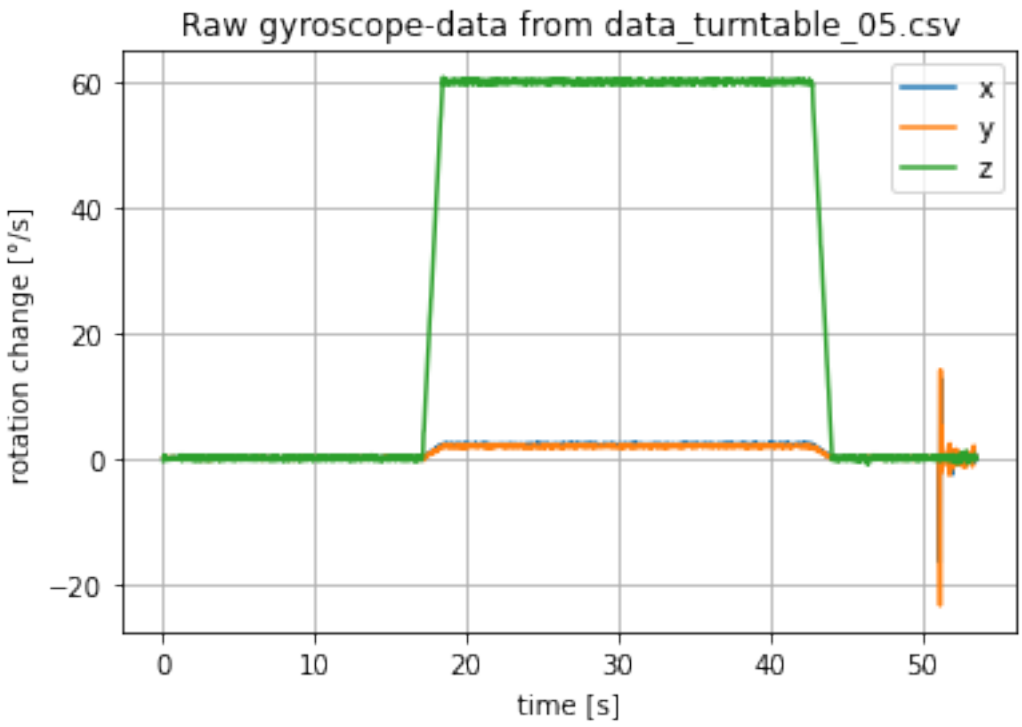

Raw gyroscope-data from data_turntable_04.csv
x
y
z
rotation change [°/s]
time [s]
10
8
6
4
2
0
−2
0
10
20
30
40
50
60

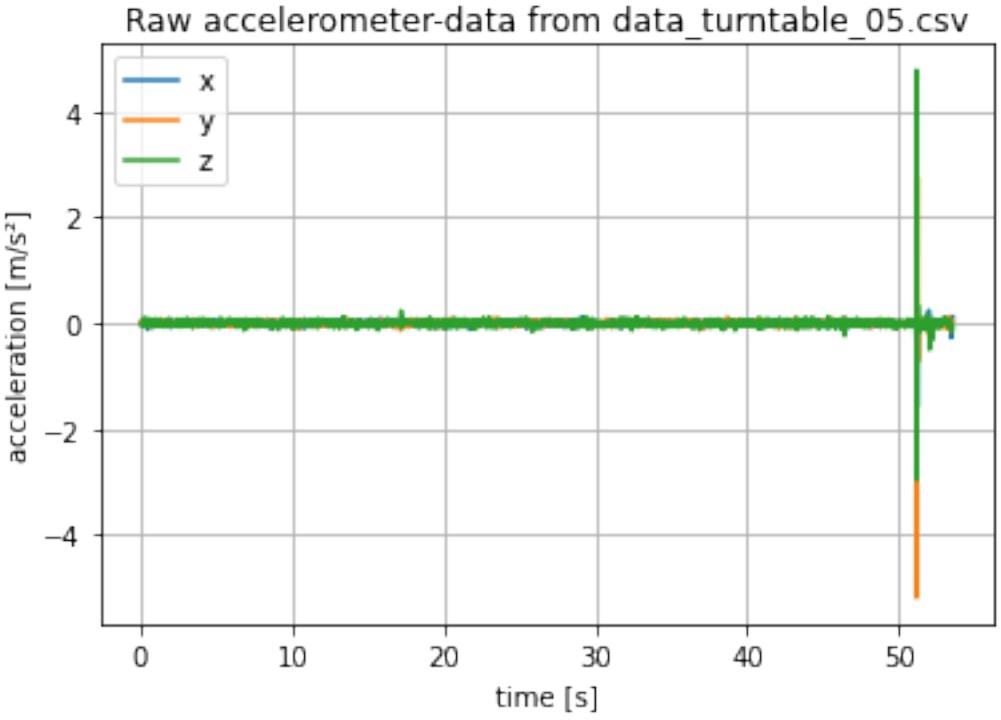

Raw accelerometer-data from data_turntable_04.csv
x
y
z
acceleration [m/s²]
time [s]

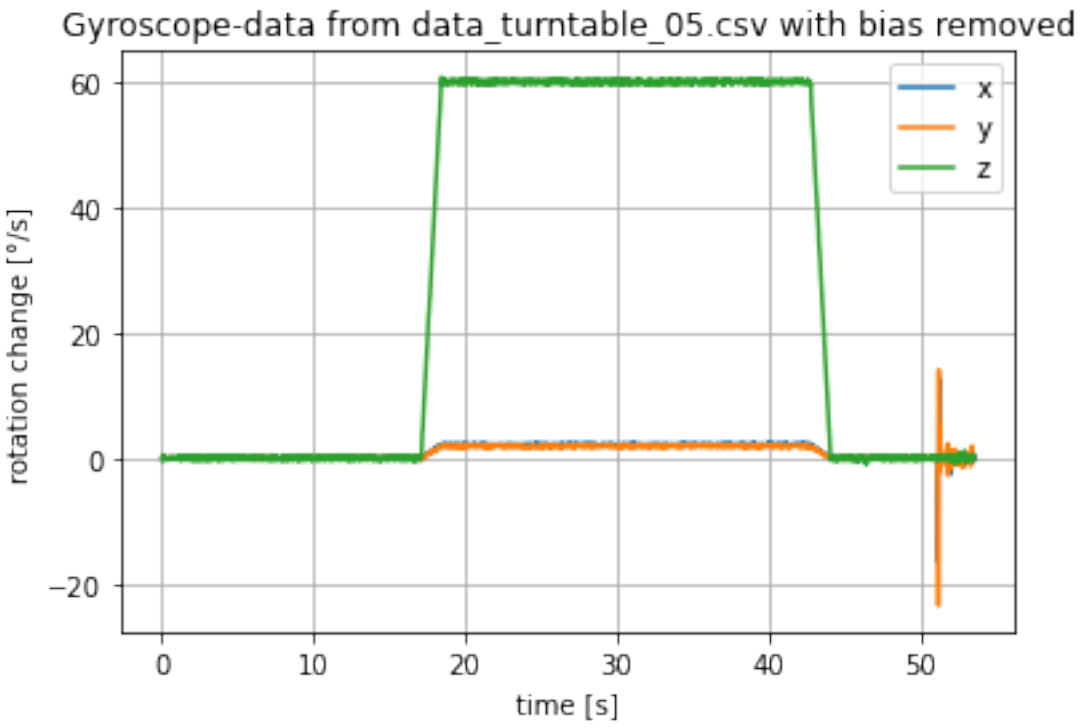

Gyroscope-data from data_turntable_04.csv with bias removed
x
y
z
rotation change [°/s]
time [s]

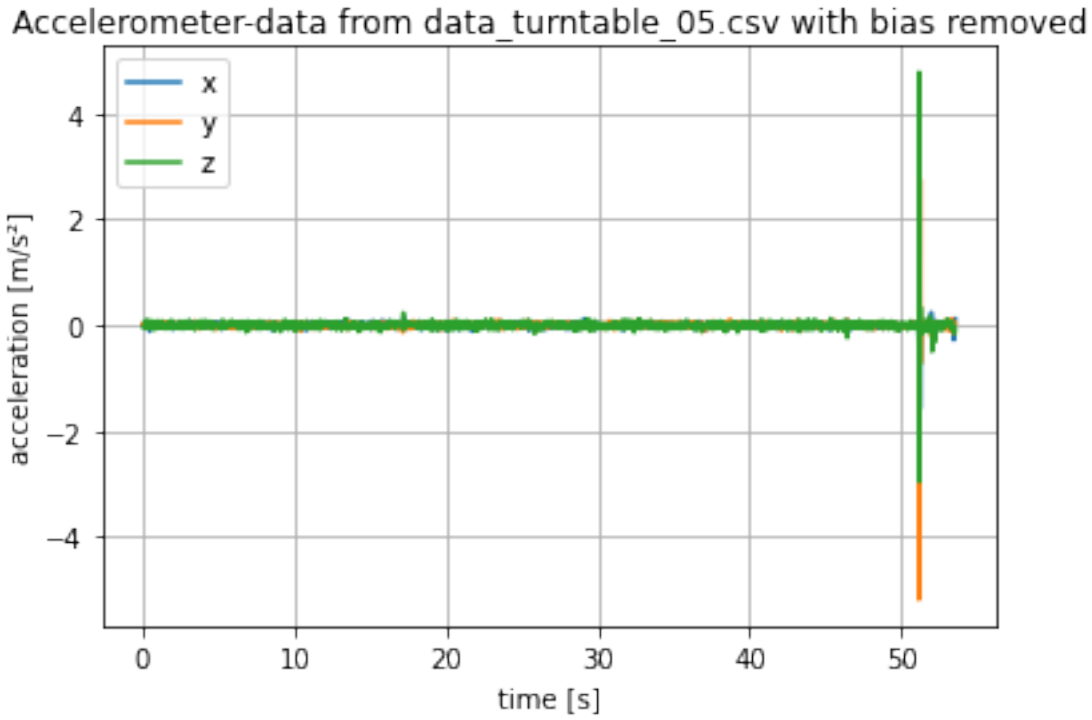

Accelerometer-data from data_turntable_04.csv with bias removed
x
y
z
acceleration [m/s²]
time [s]
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
0
10
20
30
40
50
60

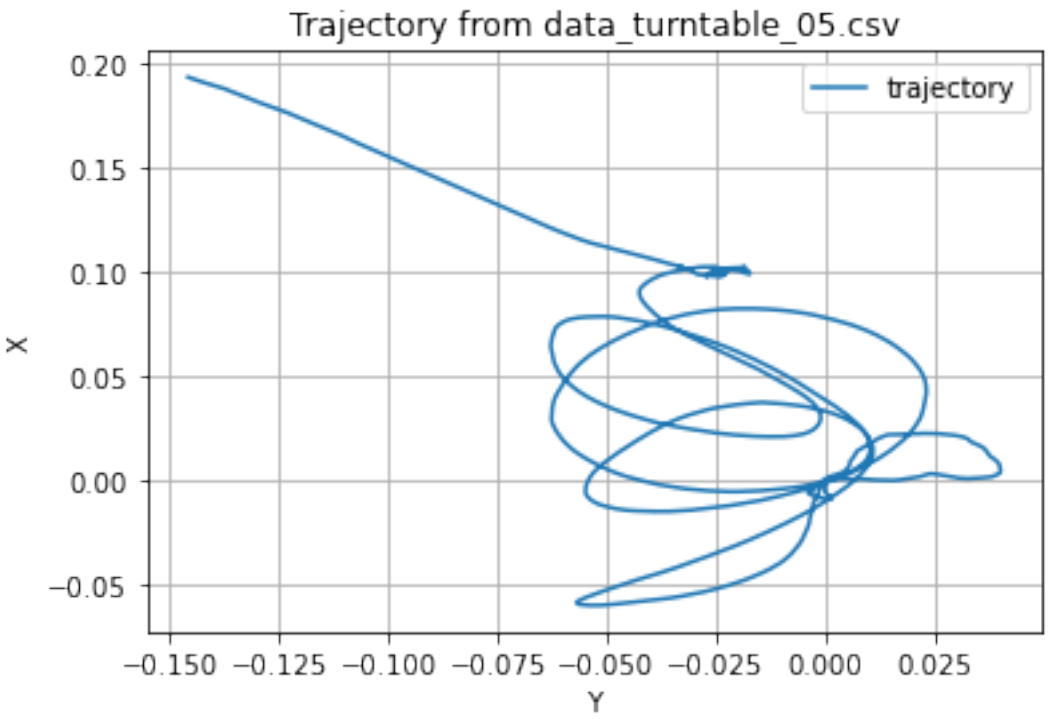

Trajectory from data_turntable_04.csv
trajectory
X
Y
2.0
1.5
1.0
0.5
0.0
−1.0
−0.8
−0.6
−0.4
−0.2
0.0

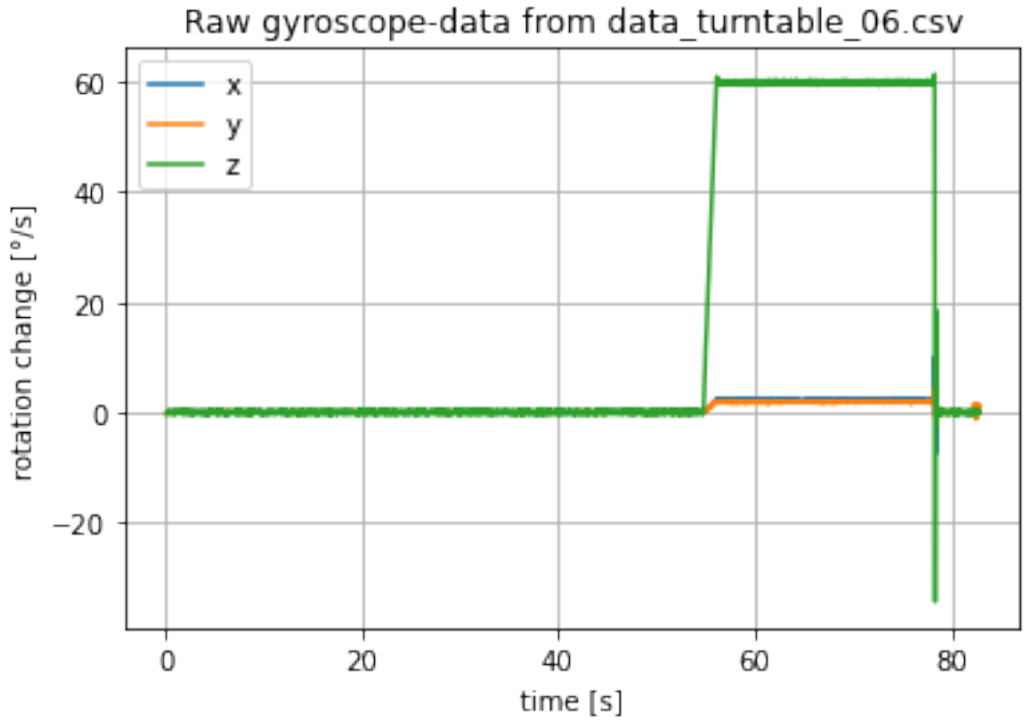

Raw gyroscope-data from data_turntable_05.csv
rotation change [°/s]
time [s]
x
y
z
60
40
20
0
−20
0
10
20
30
40
50

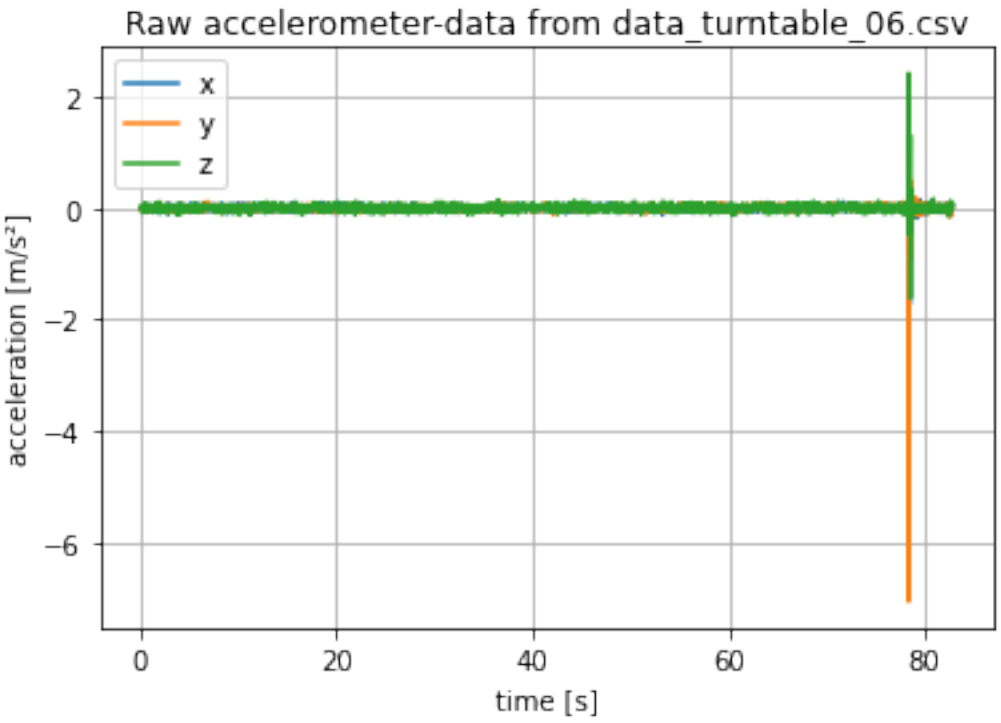

Raw accelerometer-data from data_turntable_05.csv
acceleration [m/s²]
time [s]
x
y
z
4
2
0
−2
−4
0
10
20
30
40
50

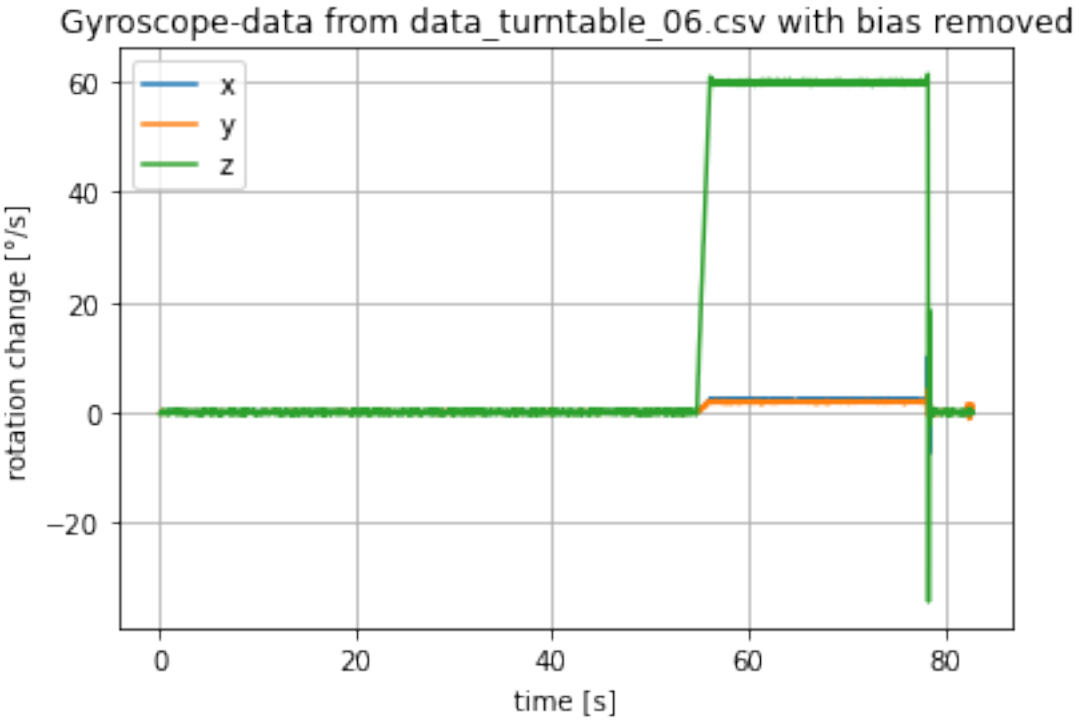

Gyroscope-data from data_turntable_05.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
60
40
20
0
−20
0
10
20
30
40
50

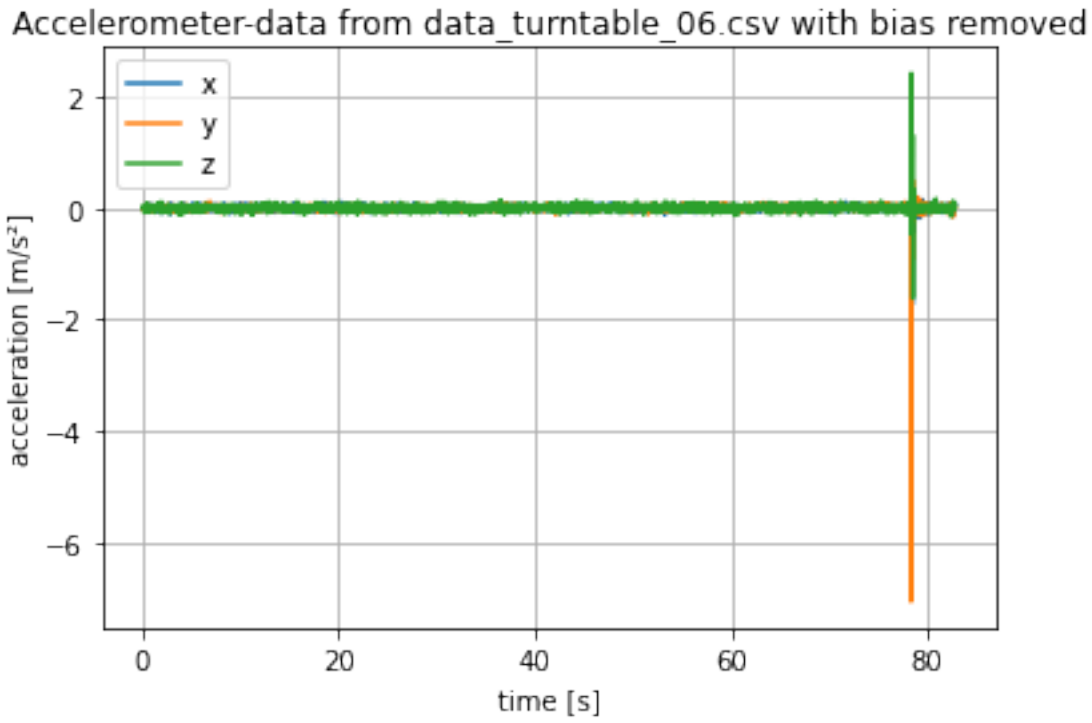

Accelerometer-data from data_turntable_05.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
4
2
0
−2
−4
0
10
20
30
40
50

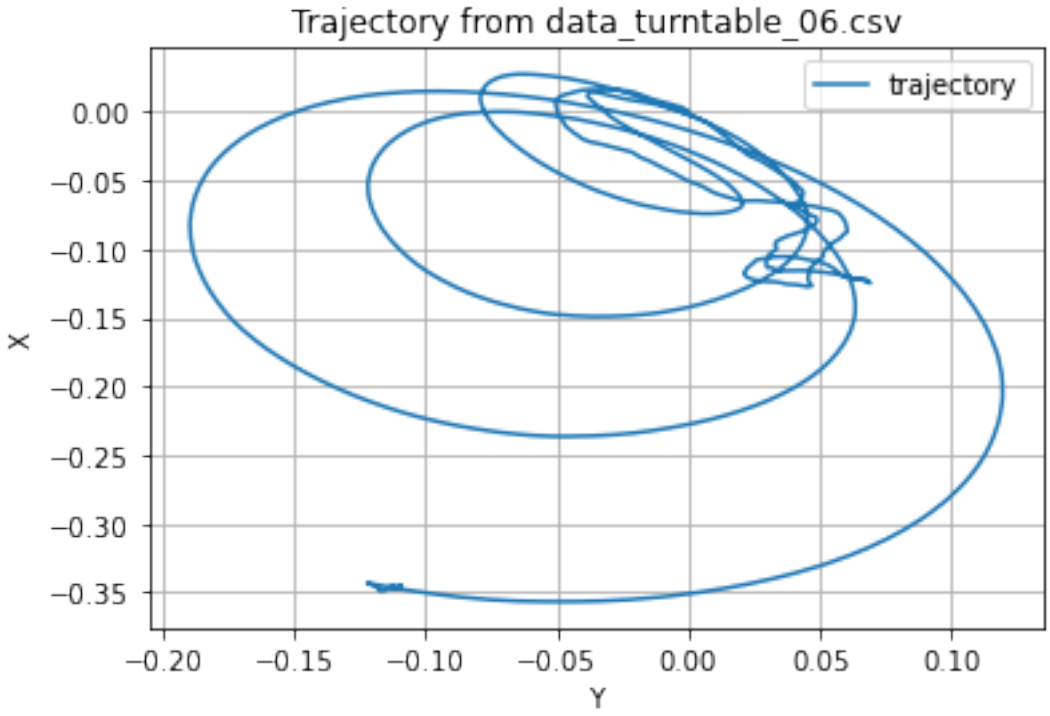

Trajectory from data_turntable_05.csv
trajectory
0.20
0.15
0.10
0.05
0.00
−0.05
X
−0.150
−0.125
−0.100
−0.075
−0.050
−0.025
0.000
0.025
Y

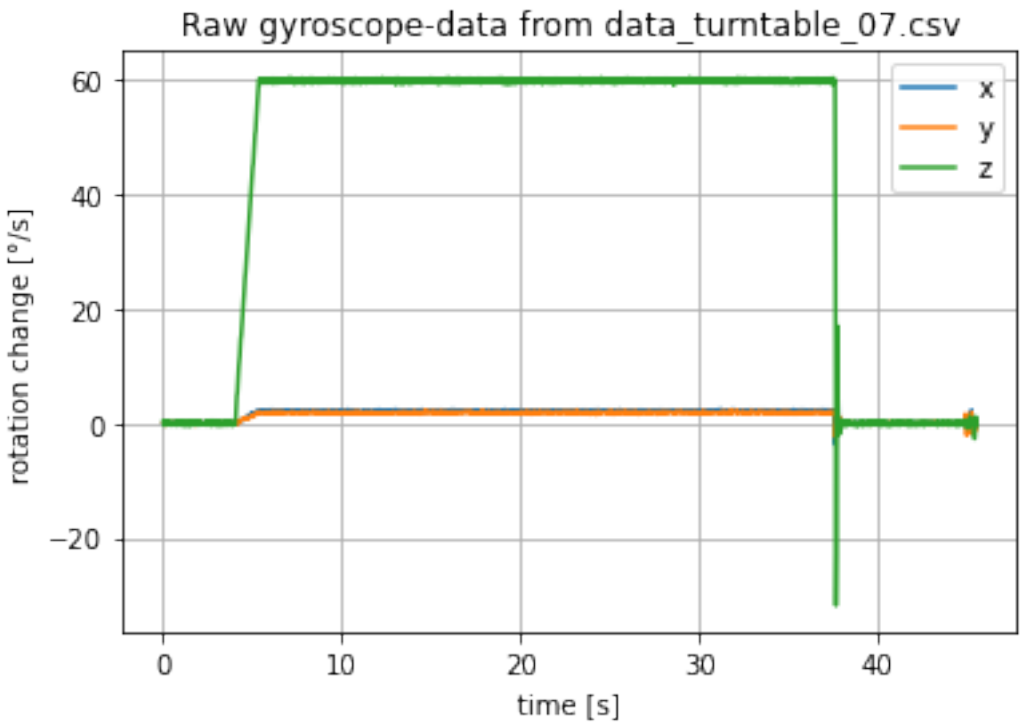

Raw gyroscope-data from data_turntable_06.csv
x
y
z
60
40
20
0
−20
rotation change [°/s]
0
20
40
60
80
time [s]

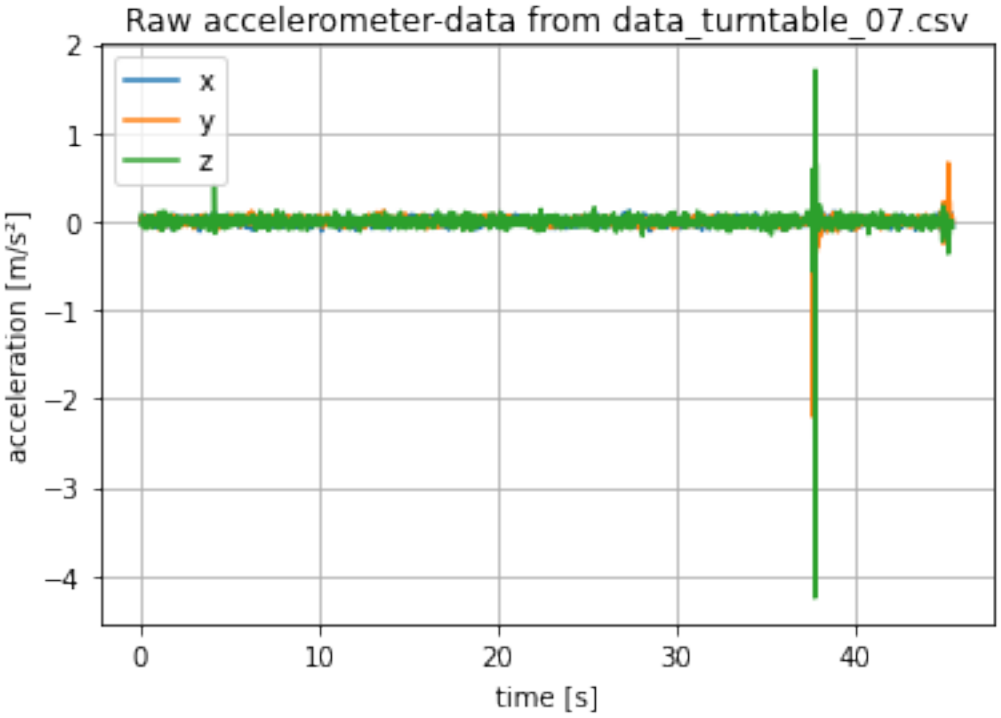

Raw accelerometer-data from data_turntable_06.csv
x
y
z
acceleration [m/s²]
2
0
−2
−4
−6
0
20
40
60
80
time [s]

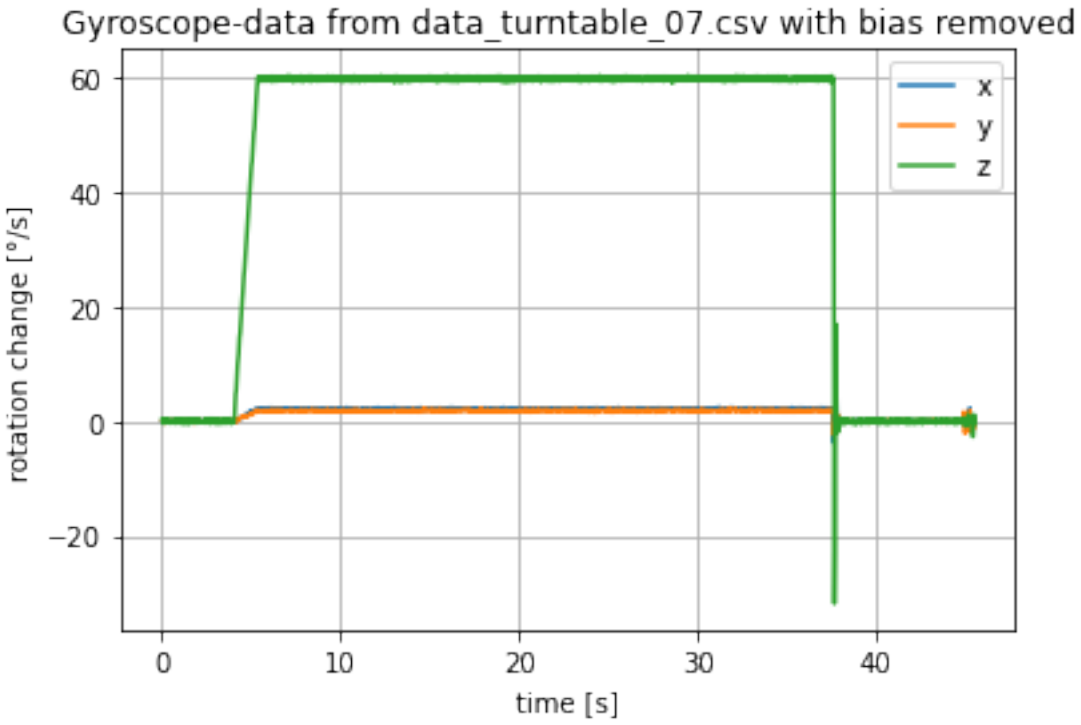

Gyroscope-data from data_turntable_06.csv with bias removed
x
y
z
rotation change [°/s]
60
40
20
0
−20
0
20
40
60
80
time [s]

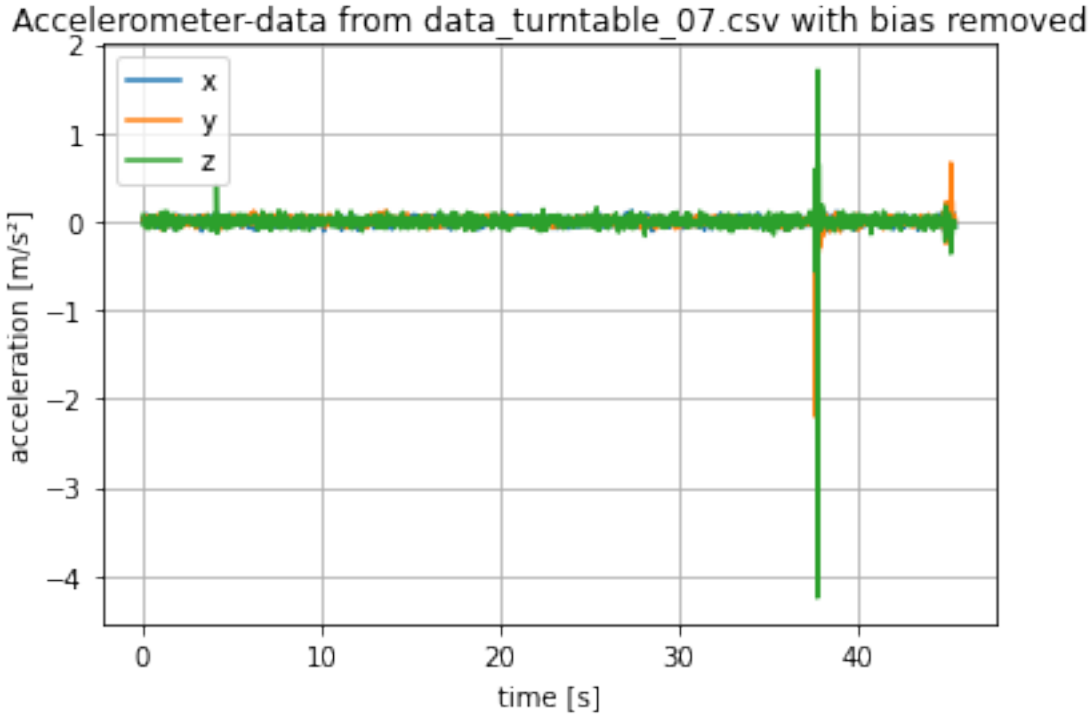

Accelerometer-data from data_turntable_06.csv with bias removed
x
y
z
acceleration [m/s²]
time [s]
2
0
−2
−4
−6
0
20
40
60
80

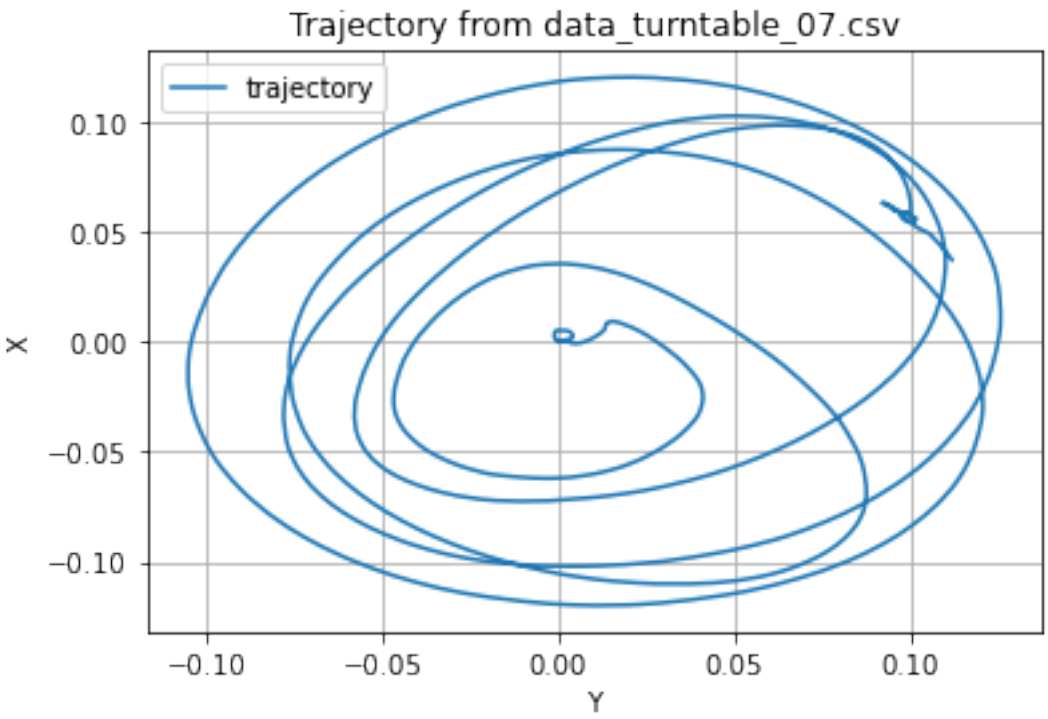

Trajectory from data_turntable_06.csv
trajectory
X
Y
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
−0.30
−0.35
−0.20
−0.15
−0.10
−0.05
0.00
0.05
0.10

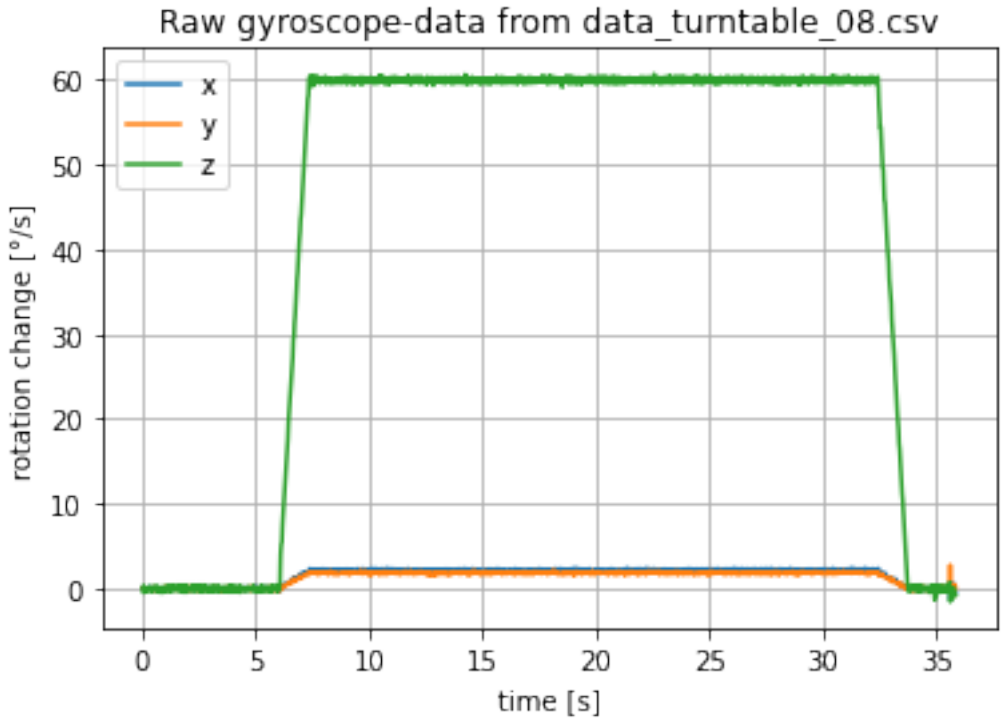

Raw gyroscope-data from data_turntable_07.csv
rotation change [°/s]
time [s]
x
y
z
60
40
20
0
−20
0
10
20
30
40

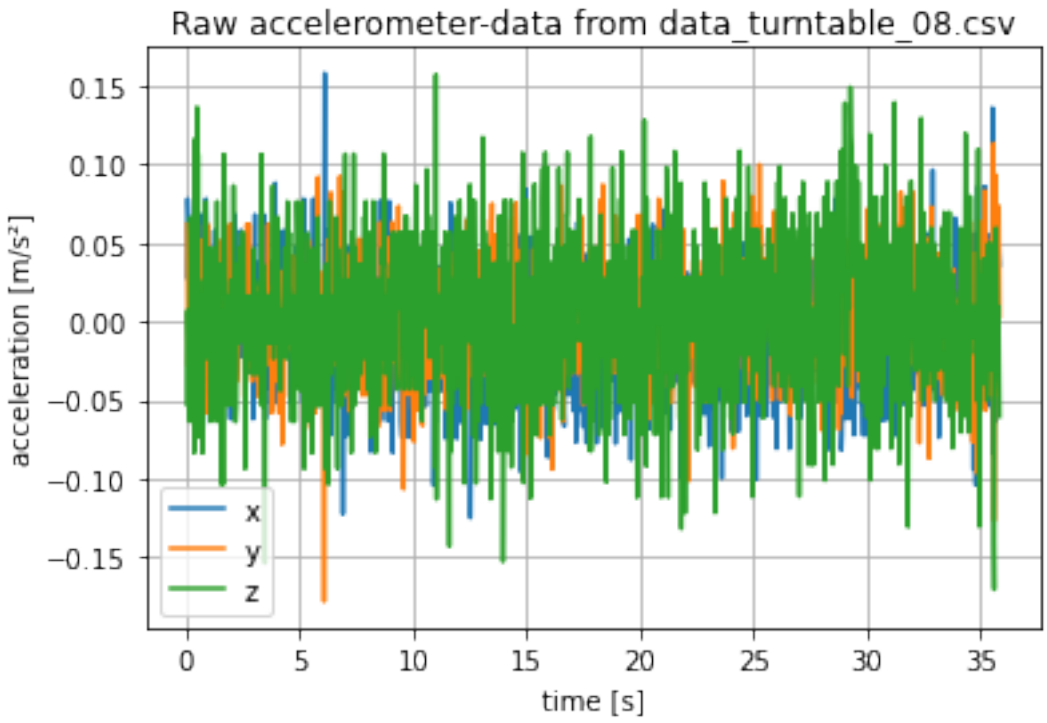

Raw accelerometer-data from data_turntable_07.csv
acceleration [m/s²]
time [s]
x
y
z
2
1
0
−1
−2
−3
−4
0
10
20
30
40

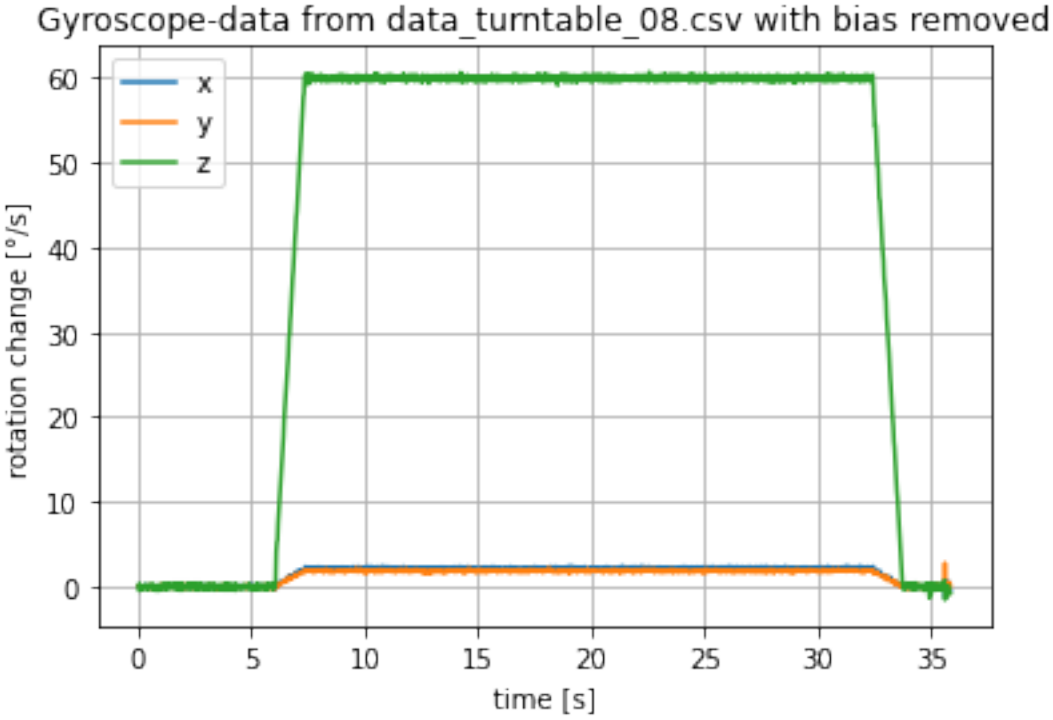

Gyroscope-data from data_turntable_07.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
60
40
20
0
−20
0
10
20
30
40

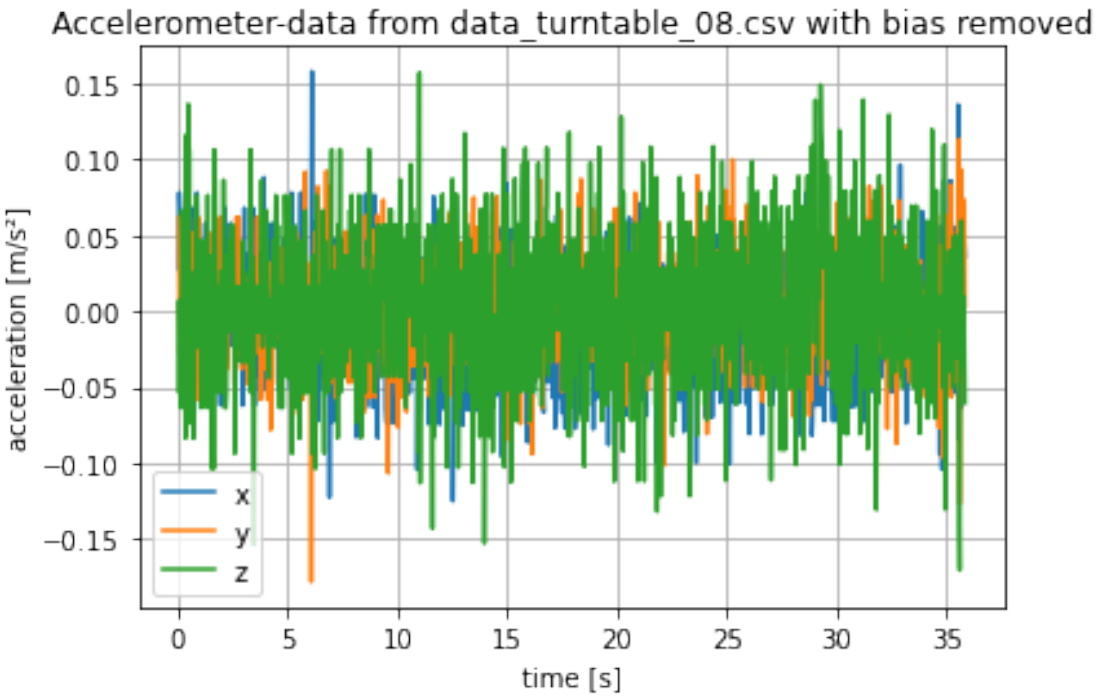

Accelerometer-data from data_turntable_07.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
2
1
0
−1
−2
−3
−4
0
10
20
30
40

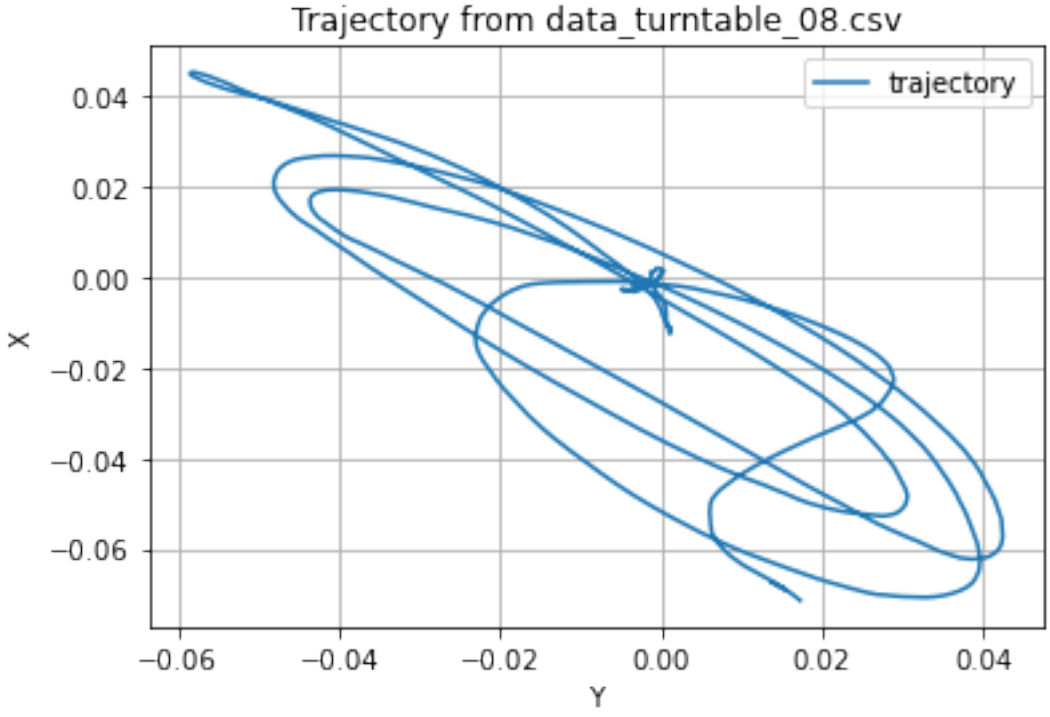

Trajectory from data_turntable_07.csv
trajectory
0.10
0.05
0.00
−0.05
−0.10
X
−0.10
−0.05
0.00
0.05
0.10
Y

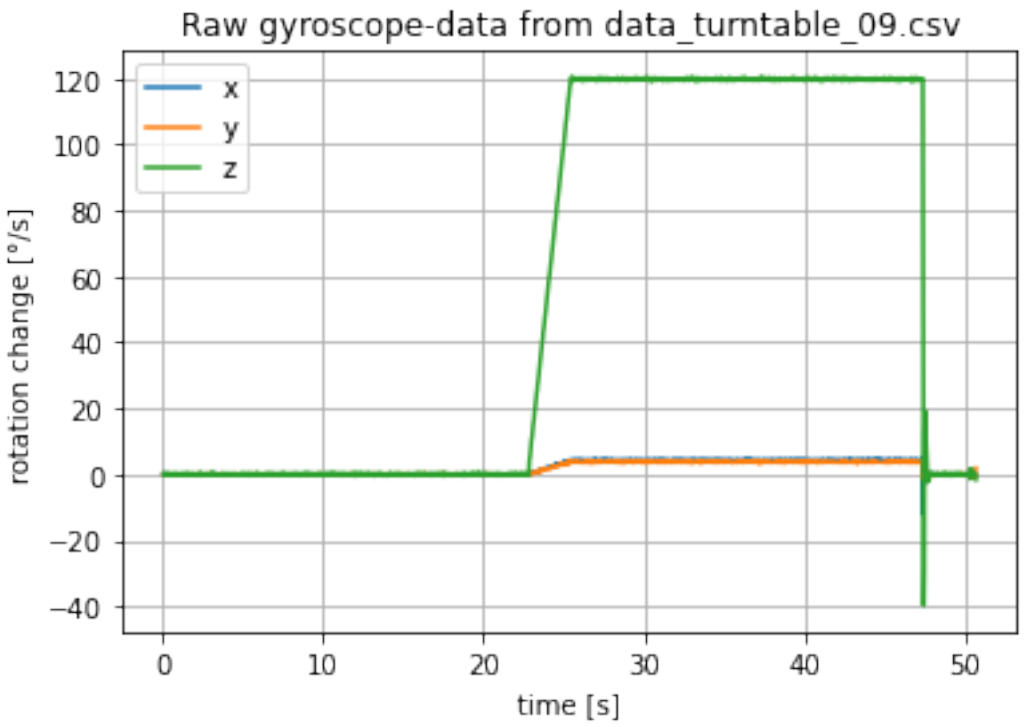

Raw gyroscope-data from data_turntable_08.csv
x
y
z
60
50
40
30
20
10
0
rotation change [°/s]
0
5
10
15
20
25
30
35
time [s]

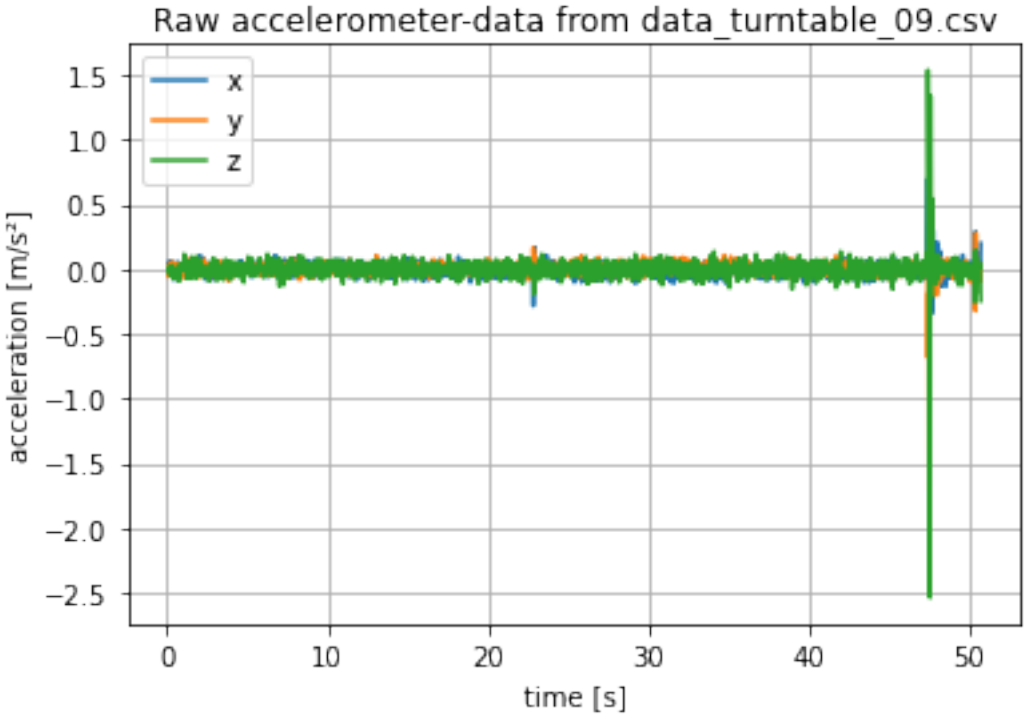

Raw accelerometer-data from data_turntable_08.csv
acceleration [m/s²]
time [s]
x
y
z

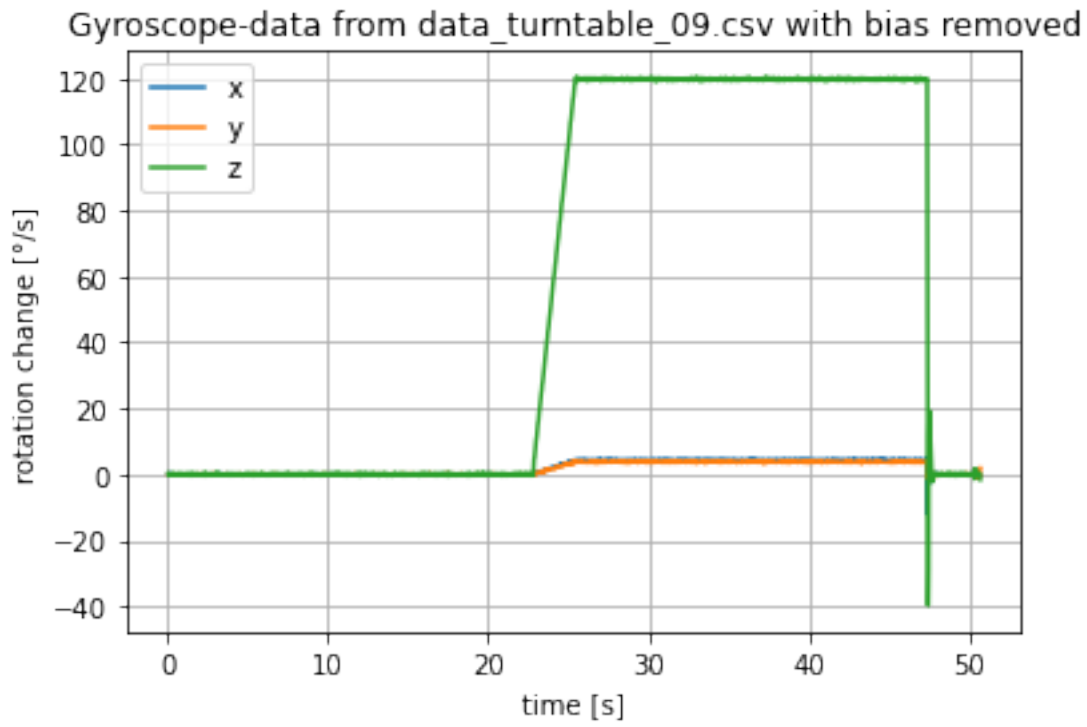

Gyroscope-data from data_turntable_08.csv with bias removed
rotation change [°/s]
time [s]
x
y
z

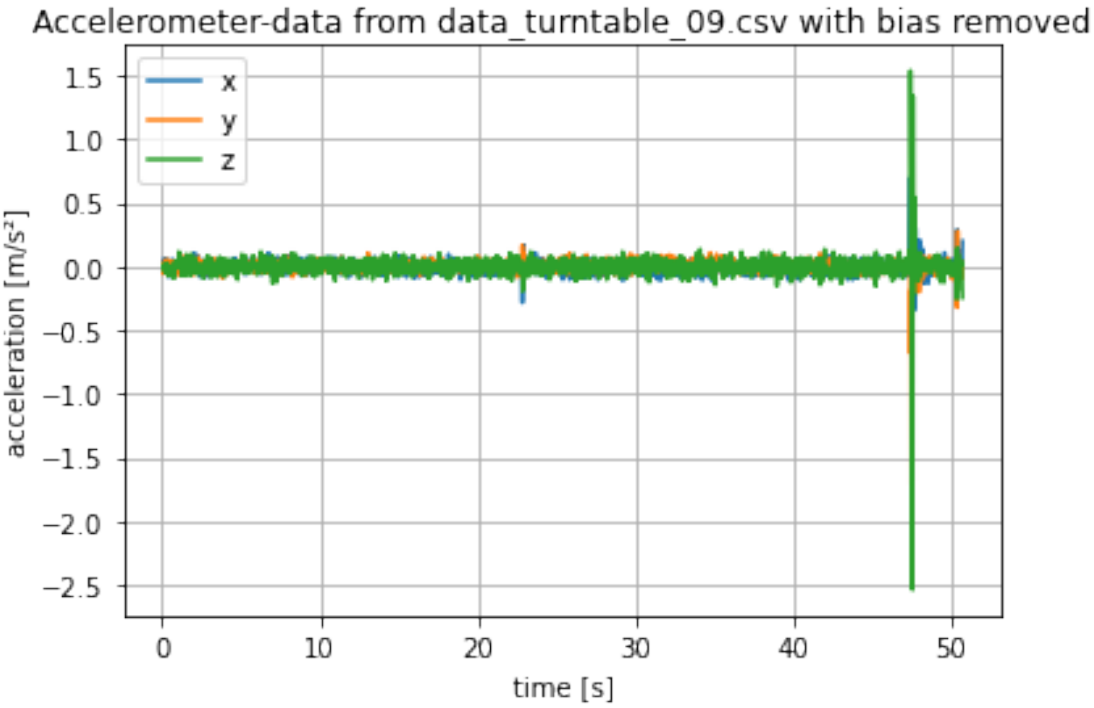

Accelerometer-data from data_turntable_08.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
0
5
10
15
20
25
30
35

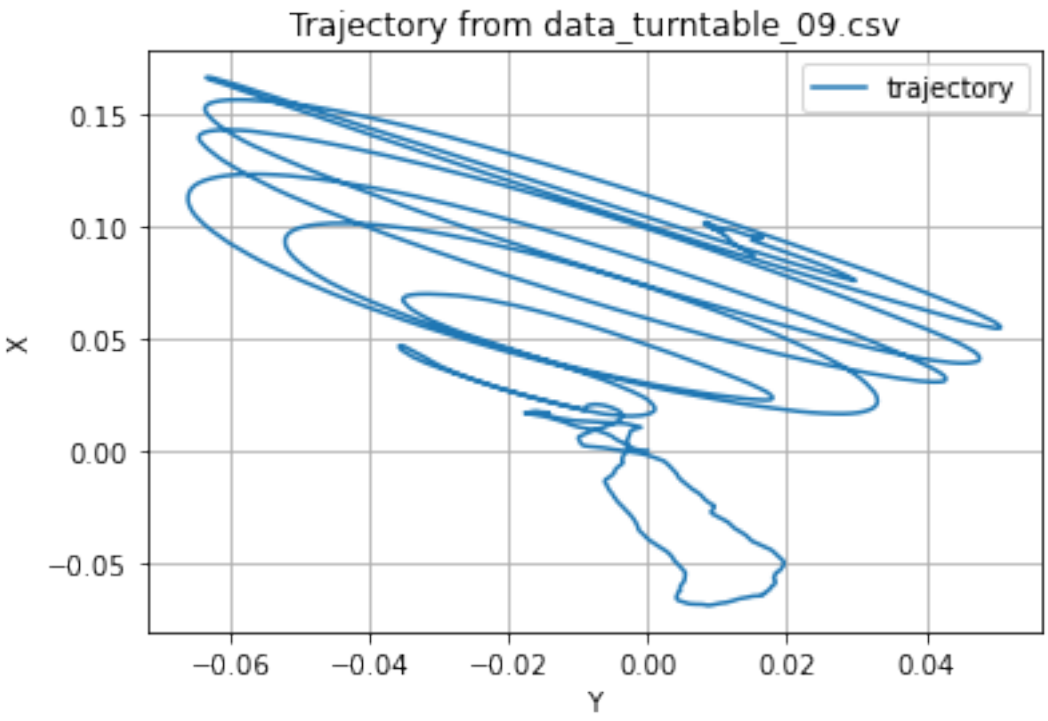

Trajectory from data_turntable_08.csv
trajectory
X
Y
0.04
0.02
0.00
−0.02
−0.04
−0.06
−0.06
−0.04
−0.02
0.00
0.02
0.04

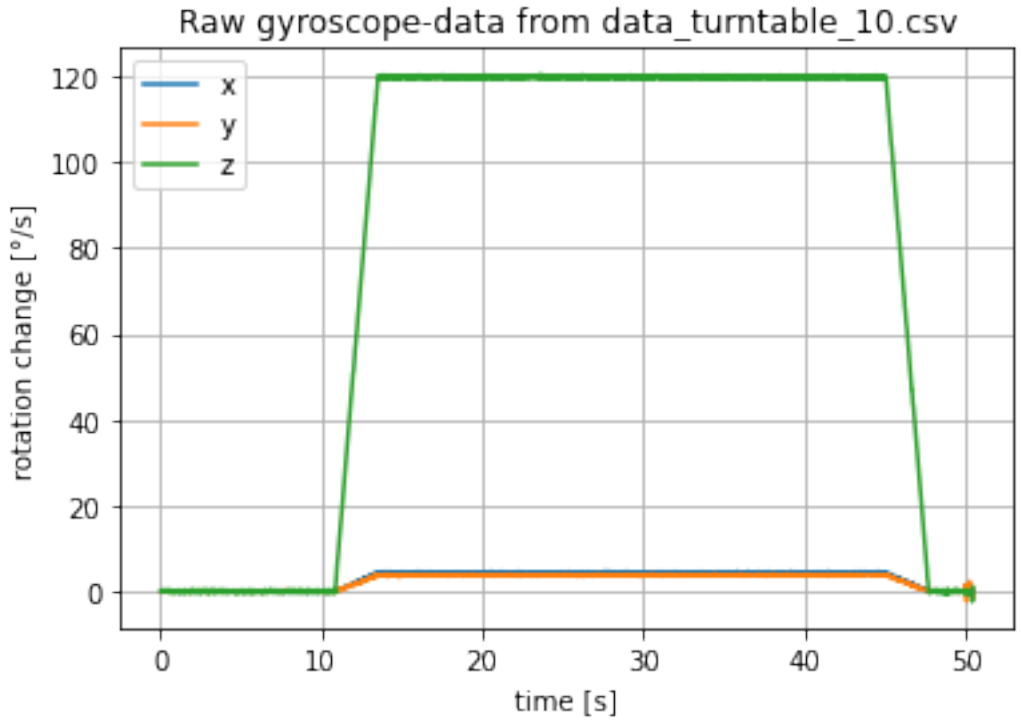

Raw gyroscope-data from data_turntable_09.csv
x
y
z
rotation change [°/s]
time [s]
120
100
80
60
40
20
0
−20
−40
0
10
20
30
40
50

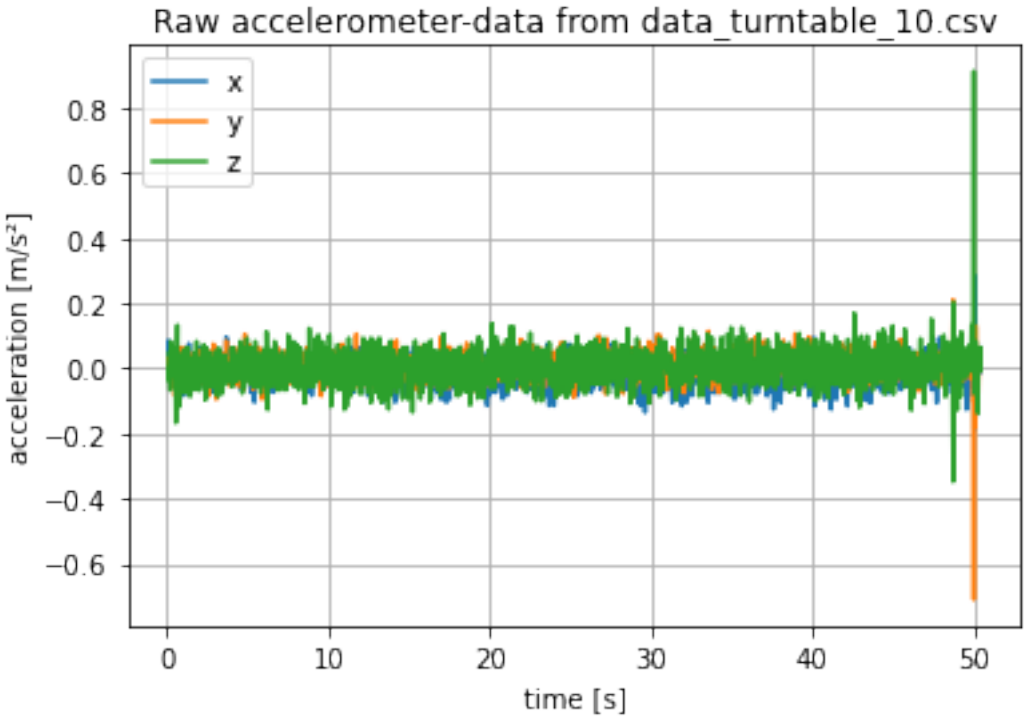

Raw accelerometer-data from data_turntable_09.csv
x
y
z
acceleration [m/s²]
time [s]
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
0
10
20
30
40
50

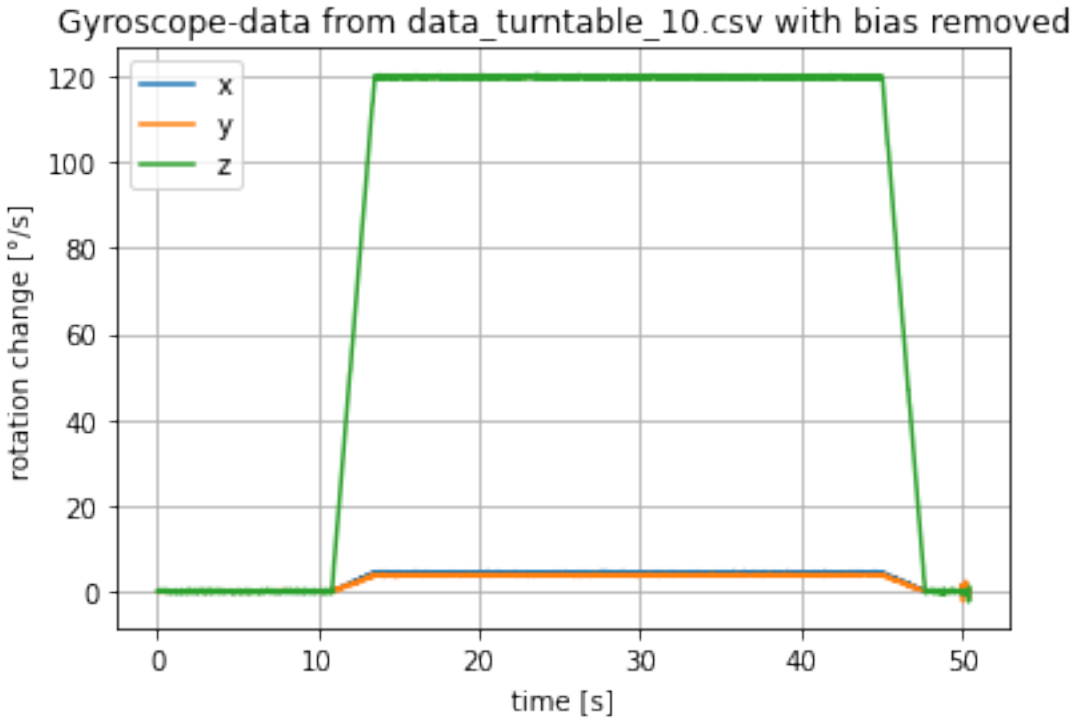

Gyroscope-data from data_turntable_09.csv with bias removed
x
y
z
rotation change [°/s]
120
100
80
60
40
20
0
−20
−40
0
10
20
30
40
50
time [s]

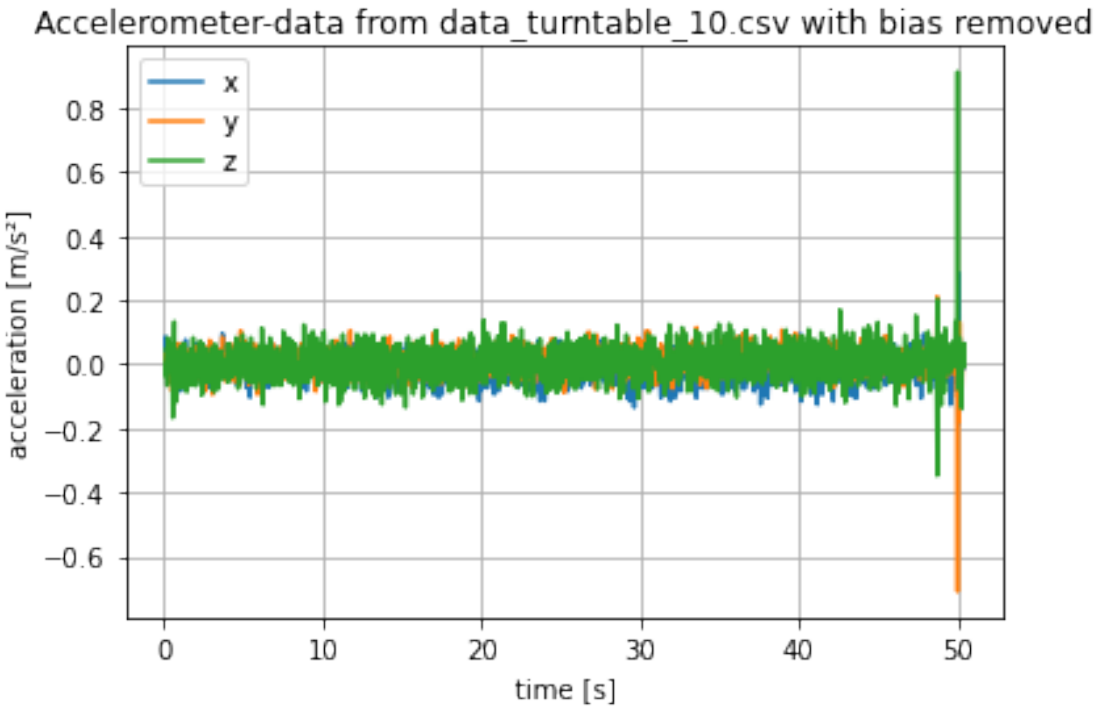

Accelerometer-data from data_turntable_09.csv with bias removed
x
y
z
acceleration [m/s²]
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
0
10
20
30
40
50
time [s]

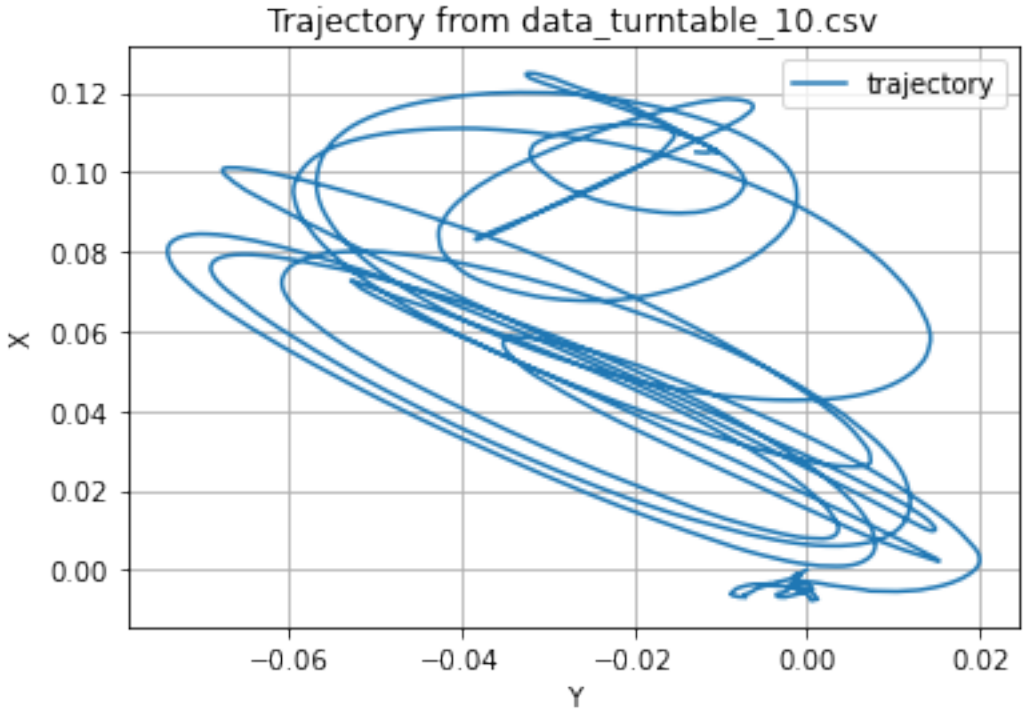

Trajectory from data_turntable_09.csv
trajectory
0.15
0.10
0.05
0.00
−0.05
X
−0.06
−0.04
−0.02
0.00
0.02
0.04
Y

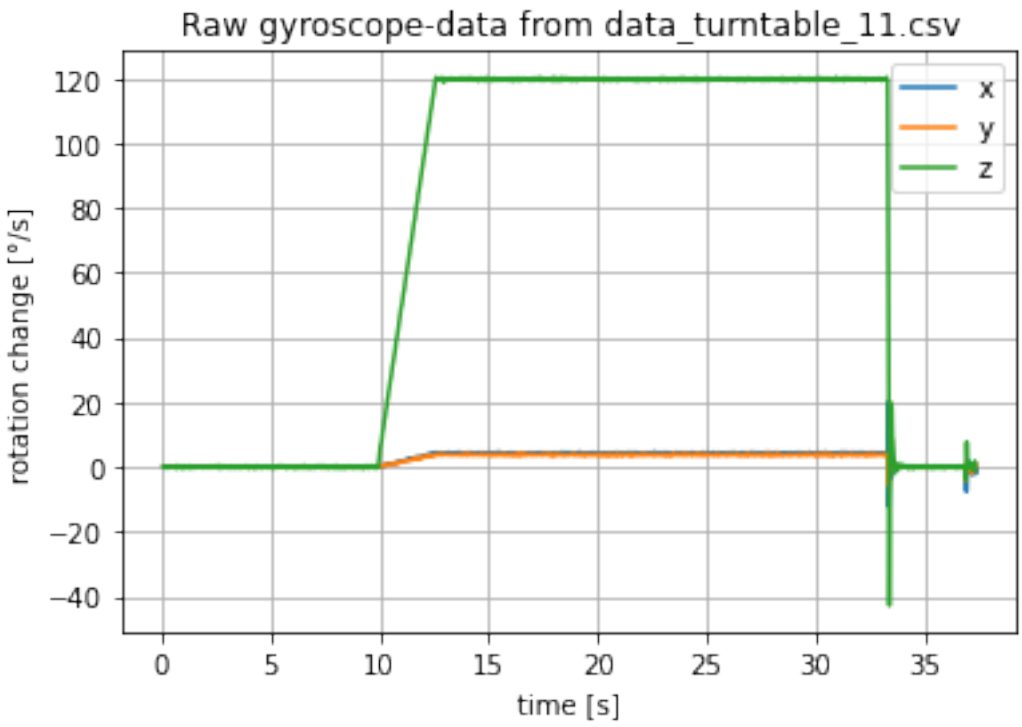

Raw gyroscope-data from data_turntable_10.csv
x
y
z
120
100
80
60
40
20
0
rotation change [°/s]
0
10
20
30
40
50
time [s]

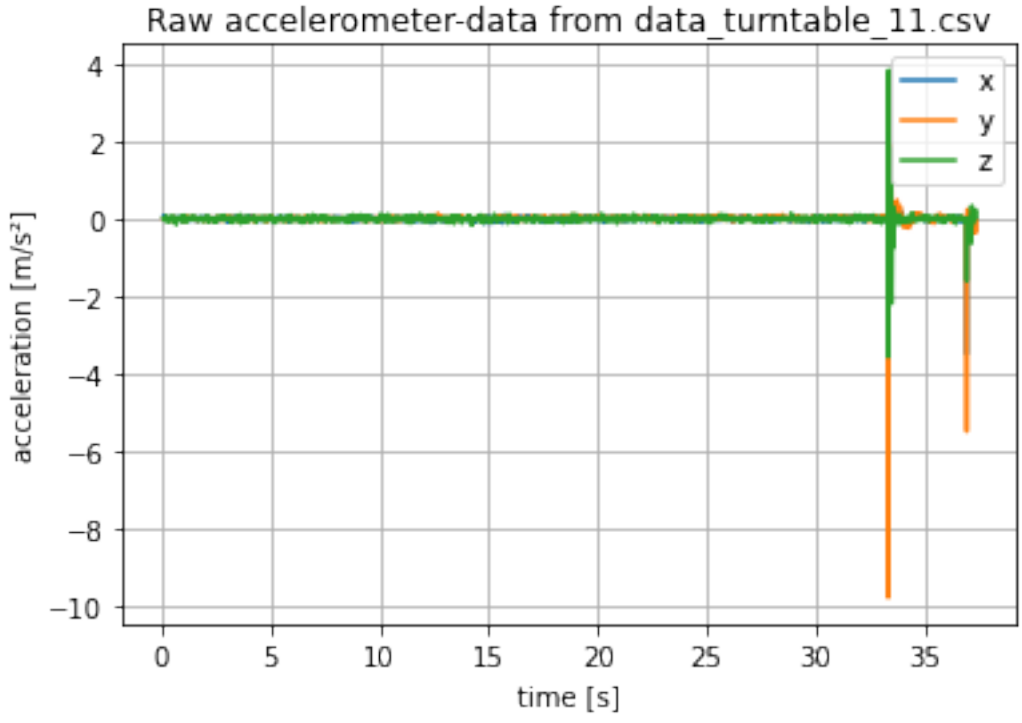

Raw accelerometer-data from data_turntable_10.csv
x
y
z
acceleration [m/s²]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0
10
20
30
40
50
time [s]

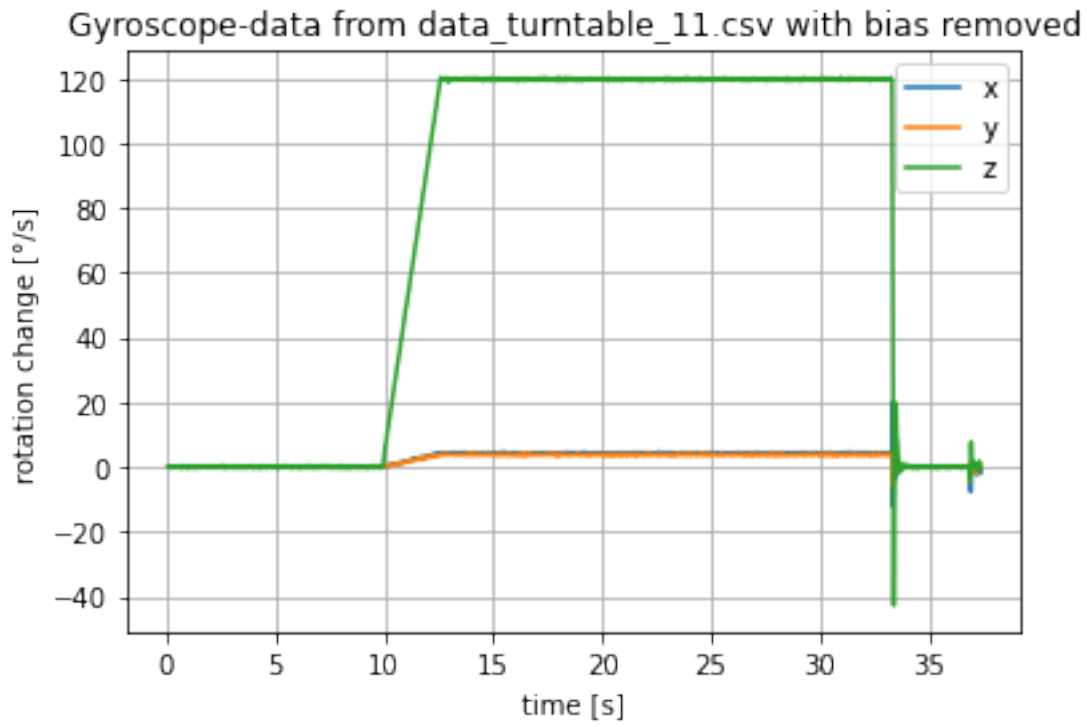

Gyroscope-data from data_turntable_10.csv with bias removed
x
y
z
rotation change [°/s]
120
100
80
60
40
20
0
0
10
20
30
40
50
time [s]

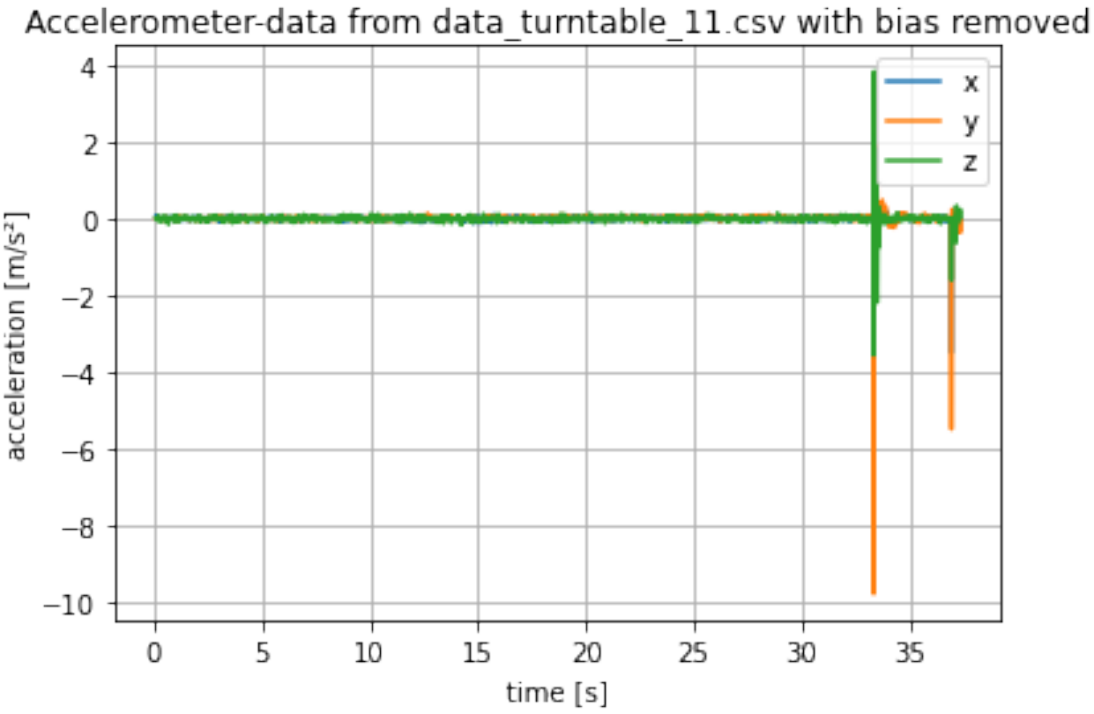

Accelerometer-data from data_turntable_10.csv with bias removed
x
y
z
acceleration [m/s²]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0
10
20
30
40
50
time [s]

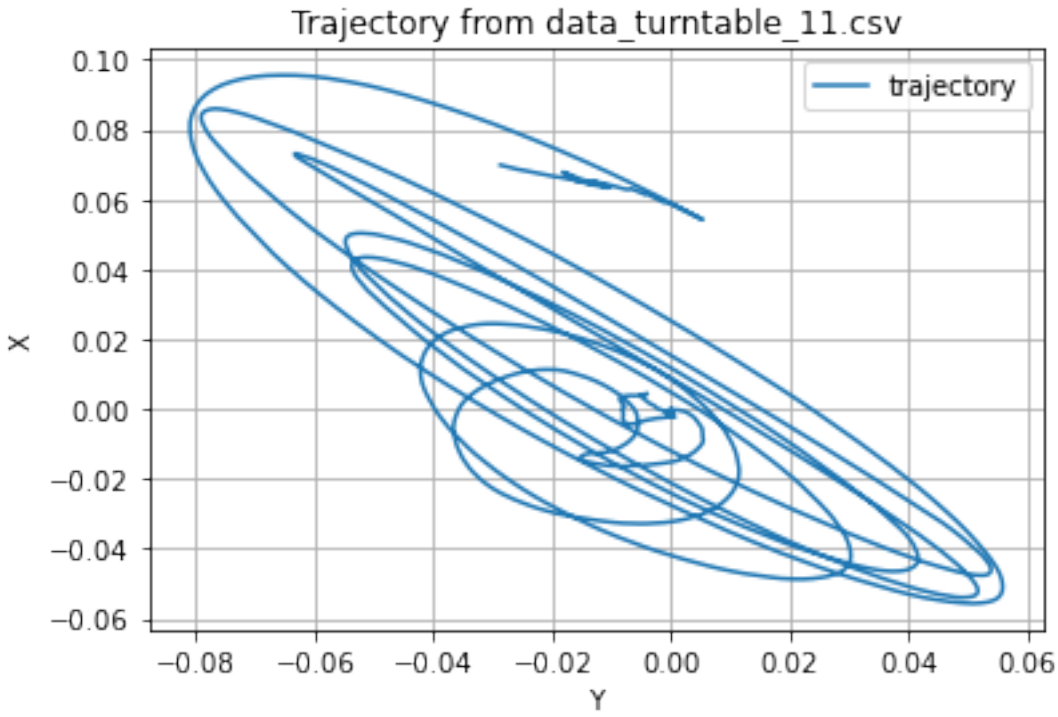

Trajectory from data_turntable_10.csv
trajectory
X
0.12
0.10
0.08
0.06
0.04
0.02
0.00
−0.06
−0.04
−0.02
0.00
0.02
Y

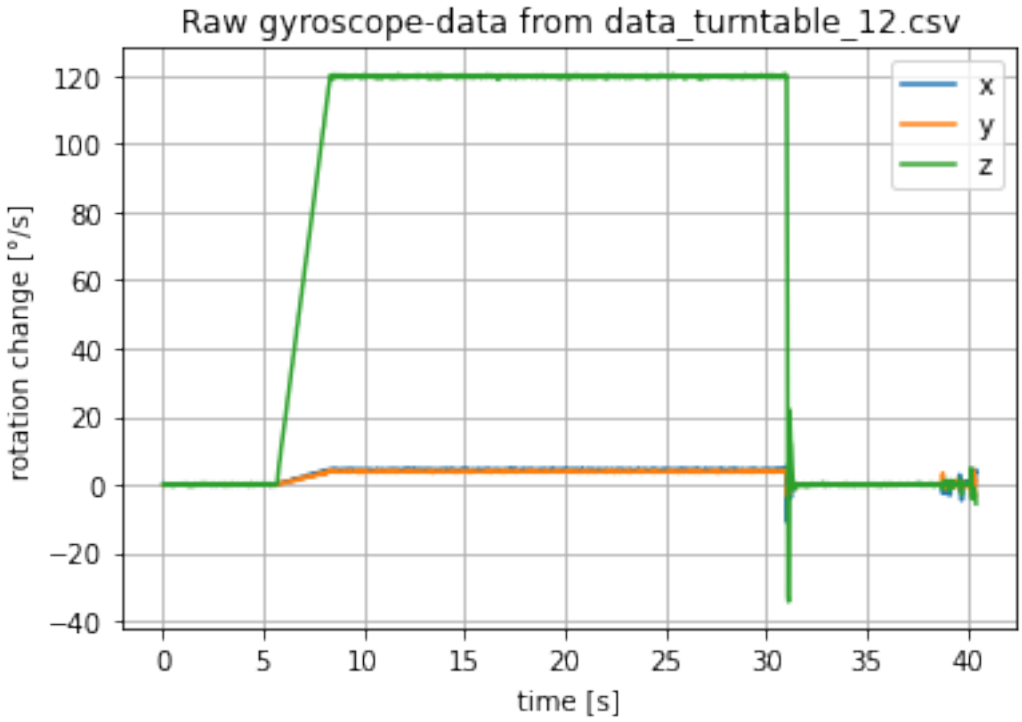

Raw gyroscope-data from data_turntable_11.csv
rotation change [°/s]
time [s]
x
y
z
120
100
80
60
40
20
0
−20
−40
0
5
10
15
20
25
30
35

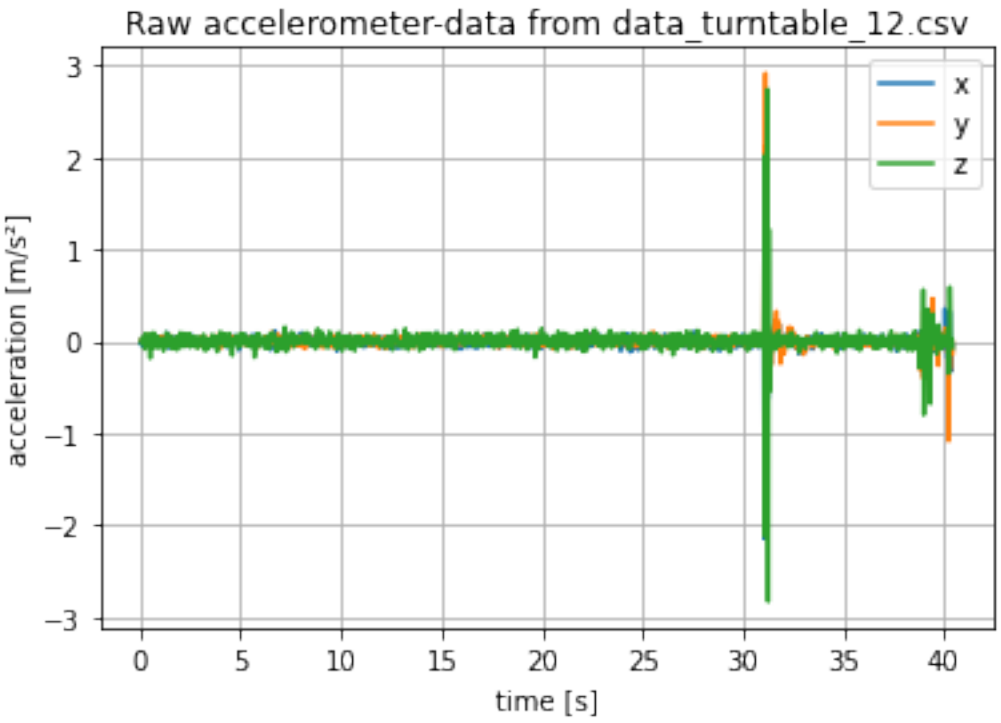

Raw accelerometer-data from data_turntable_11.csv
acceleration [m/s²]
time [s]
x
y
z
4
2
0
−2
−4
−6
−8
−10
0
5
10
15
20
25
30
35

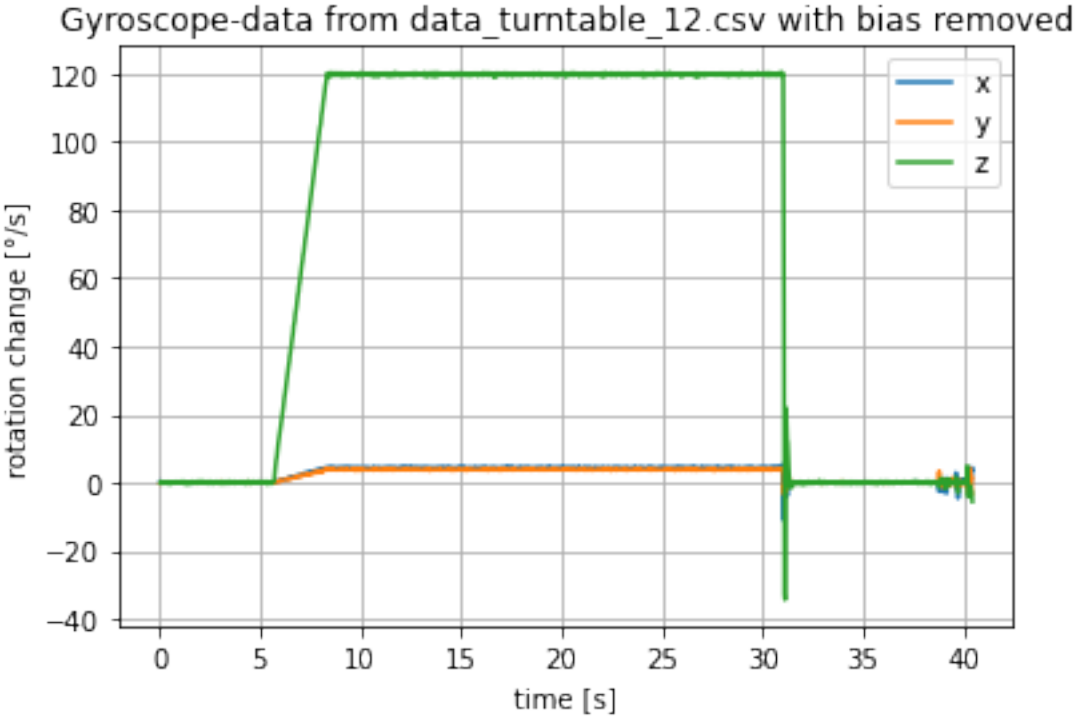

Gyroscope-data from data_turntable_11.csv with bias removed
rotation change [°/s]
time [s]
x
y
z
120
100
80
60
40
20
0
−20
−40
0
5
10
15
20
25
30
35

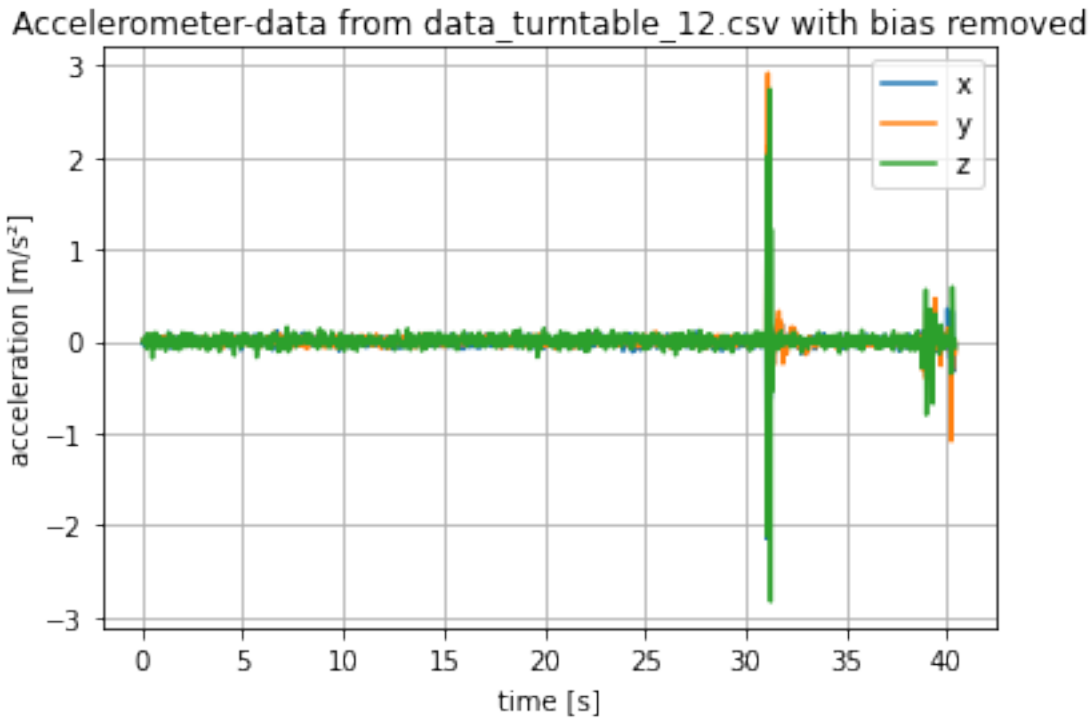

Accelerometer-data from data_turntable_11.csv with bias removed
acceleration [m/s²]
time [s]
x
y
z
4
2
0
−2
−4
−6
−8
−10
0
5
10
15
20
25
30
35

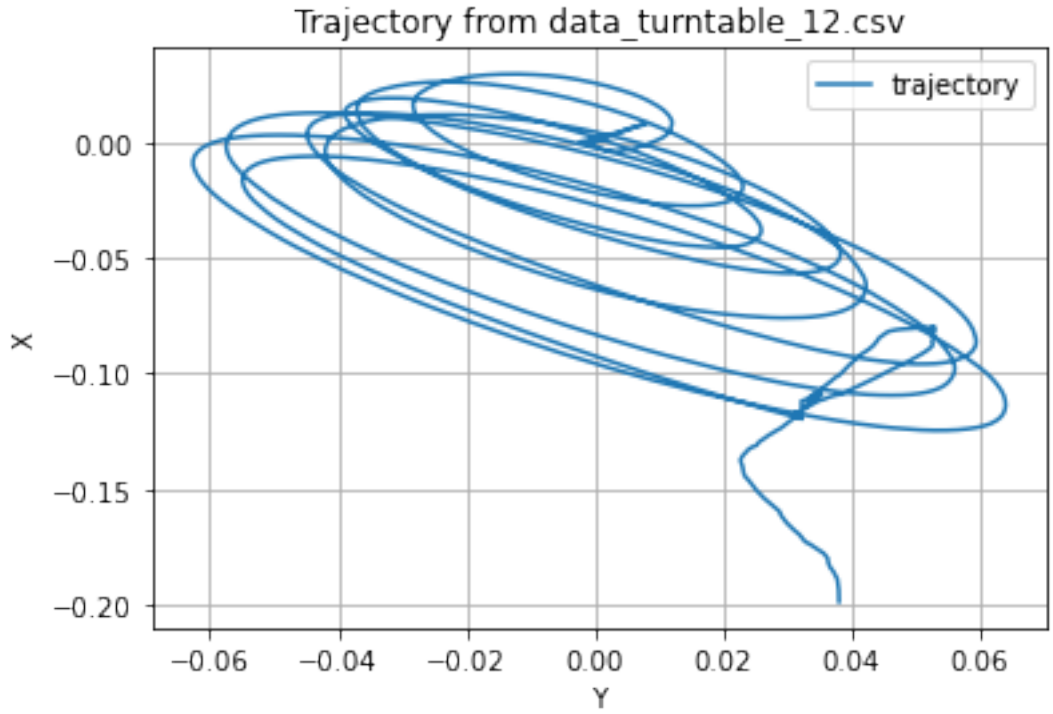

Trajectory from data_turntable_11.csv
trajectory
X
Y
0.10
0.08
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
−0.08
−0.06
−0.04
−0.02
0.00
0.02
0.04
0.06


Raw gyroscope-data from data_turntable_12.csv
x
y
z
rotation change [°/s]
time [s]
120
100
80
60
40
20
0
−20
−40
0
5
10
15
20
25
30
35
40


Raw accelerometer-data from data_turntable_12.csv
acceleration [m/s²]
time [s]
x
y
z


Gyroscope-data from data_turntable_12.csv with bias removed
rotation change [°/s]
time [s]
x
y
z


Accelerometer-data from data_turntable_12.csv with bias removed
x
y
z
acceleration [m/s²]
time [s]
3
2
1
0
−1
−2
−3
0
5
10
15
20
25
30
35
40


Trajectory from data_turntable_12.csv
trajectory
X
Y
0.00
−0.05
−0.10
−0.15
−0.20
−0.06
−0.04
−0.02
0.00
0.02
0.04
0.06

## 3.7 Table length determination

In the plot above regarding the position, hopefully you can see a straigt rising edge in one axis (x or y). This represents your moving direction along the table edge.

On basis of drifts, there is also a movement along the other axes possible and visible.

Now you can determin the table length with your measurement data. After that you can compare the result with the original length of your table. At least you can do an asumption regarding the quality of your result with respect to the limits of the used system.

### 3.7.1 Task 7

Programm the code for the determination of your table length.

> ***Tipp:*** Change the [...] to your own values.
>
> ***Tipp:*** Try again with the `numpy` library.

[ ]:
```
# table length with Pythagorean theorem
# table_length = np.sqrt(x_d[0,-1:]**2 + ... + ...)

# 'The length of my table is in real ... meter, but I have determined a length␣
 ↪with my measurement from {:2.3} meter!'.format(float(table_length))

distance_all = []

for measurement_id, e in enumerate(timestamps_all[0:12]):
    distance = mems.calc_distance(position_all[measurement_id],␣
 ↪stationary_parts[measurement_id]["before"],␣
 ↪stationary_parts[measurement_id]["after"])
    distance_all.append(distance)
    print(f'The distance for {files[measurement_id]} is {distance:.3f} m.')
```

```
The distance for data_track_01.csv is 5.188 m.
The distance for data_track_02.csv is 4.931 m.
The distance for data_track_03.csv is 5.041 m.
The distance for data_track_04.csv is 5.506 m.
The distance for data_track_05.csv is 5.506 m.
The distance for data_track_06.csv is 5.755 m.
The distance for data_track_07.csv is 4.304 m.
The distance for data_track_08.csv is 5.426 m.
The distance for data_track_09.csv is 5.524 m.
The distance for data_track_10.csv is 11.094 m.
The distance for data_track_12.csv is 5.914 m.
The distance for data_track_13.csv is 4.938 m.
```