Understanding IMU data acquired from May-30-2018 Oshawa Indoor Experiment

Jungwon Kang

Aug 3 2018
*Updated on Aug 20 2018

Objectives

- We acquired $\boldsymbol{a}^{\mathcal{G}} = (a_x^{\mathcal{G}}, a_y^{\mathcal{G}}, a_z^{\mathcal{G}})$ [acc wrt ground frame $\mathcal{G}$]

- Our localization algorithms need $\boldsymbol{a}^{\mathcal{B}} = (a_x^{\mathcal{B}}, a_y^{\mathcal{B}}, a_z^{\mathcal{B}})$ [acc wrt body frame $\mathcal{B}$]

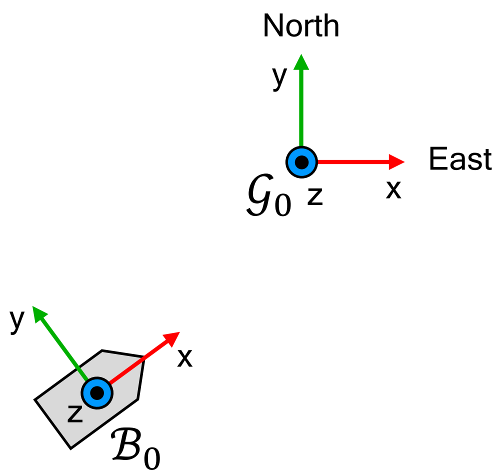
- Therefore, we need to convert the given $\boldsymbol{a}^{\mathcal{G}}$ into $\boldsymbol{a}^{\mathcal{B}}$.
  - The flight controller seems to provide us with absolute orientation $R_{\mathcal{G}}^{\mathcal{B}}$ of the drone, we expect we could get $\boldsymbol{a}^{\mathcal{B}}$ by $R_{\mathcal{G}}^{\mathcal{B}} \cdot \boldsymbol{a}^{\mathcal{G}}$.

Our Expected $\mathcal{G}$ and $\mathcal{B}$

$\mathcal{G}$: ground frame
$\mathcal{B}$: body frame

- Actually, we don't know exactly how $\mathcal{G}$ and $\mathcal{B}$ are set.

- We initially expect $\mathcal{G} = \mathcal{G}_0$, $\mathcal{B} = \mathcal{B}_0$,
  where $\mathcal{G}_0$ is ENU (East-North-Up), $\mathcal{B}_0$ is FLU (Front-Left-Up).



Our initially expected $\mathcal{G}_0$ and $\mathcal{B}_0$

(Top view)

$$\boldsymbol{a}^{\mathcal{G}_0} = (a_x^{\mathcal{G}_0}, a_y^{\mathcal{G}_0}, a_z^{\mathcal{G}_0})$$

$$\Big\downarrow R_{\mathcal{G}}^{\mathcal{B}} \text{ (from flight controller)}$$

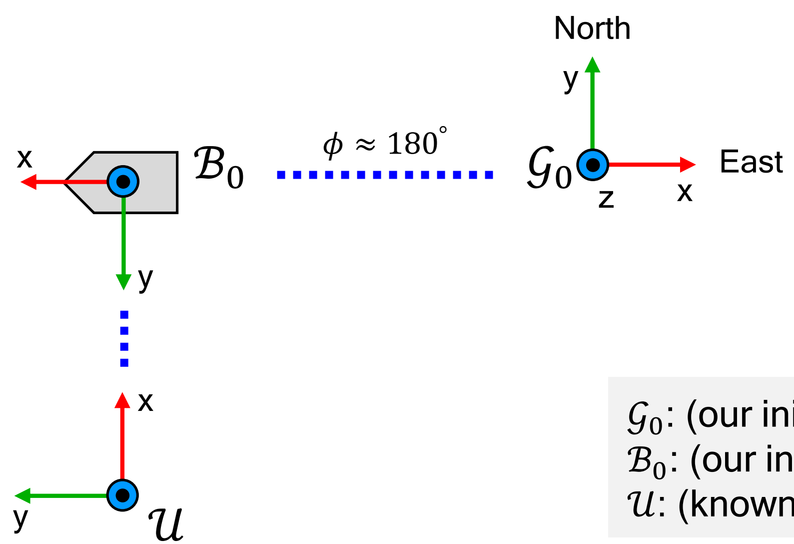
$$\boldsymbol{a}^{\mathcal{B}_0} = (a_x^{\mathcal{B}_0}, a_y^{\mathcal{B}_0}, a_z^{\mathcal{B}_0})$$

Our Expected $\mathcal{G}$ and $\mathcal{B}$

- In the experiment, we aligned the drone with the UWB frame $\mathcal{U}$
  $\rightarrow$ $\mathcal{U}$ and $\mathcal{B}_0$ are aligned. (although aligned axes are different)

- Furthermore, we saw $\phi \approx 180^\circ$, which means the drone is located in the opposite direction with the ground frame $\mathcal{G}_0$.
  $\rightarrow$ $\mathcal{B}_0$ and $\mathcal{G}_0$ are aligned.

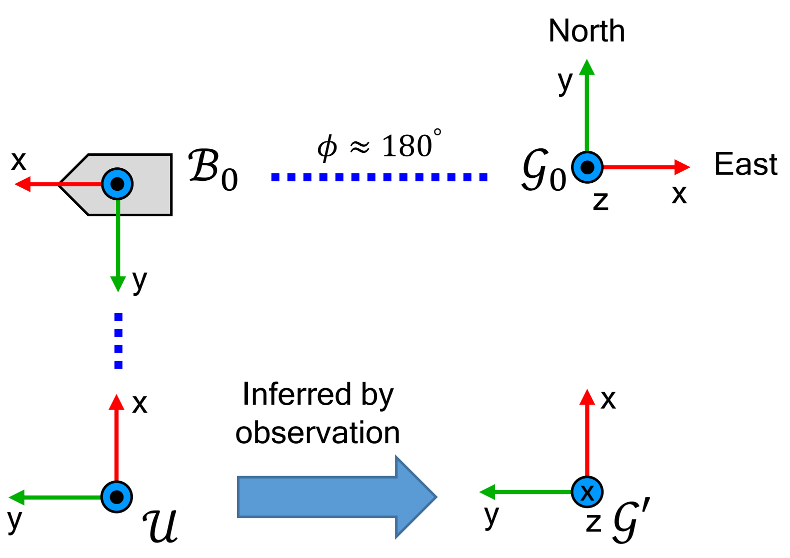
- In conclusion, $\mathcal{U}$ and $\mathcal{G}_0$ are aligned (although there is little misalignment in real).



$\mathcal{G}_0$: (our initially expected) ground frame
$\mathcal{B}_0$: (our initially expected) body frame
$\mathcal{U}$: (known) UWB frame

Inferring $\mathcal{G}$ from $\boldsymbol{a}_{gt}^{\mathcal{U}}$ and $\boldsymbol{a}^{\mathcal{G}}$

- We measured ground-truth position using the total station,
  $\rightarrow$ We could compute acc wrt the UWB frame $\mathcal{U}$: $\boldsymbol{a}_{gt}^{\mathcal{U}}$.
- Because $\mathcal{U}$ and $\mathcal{G}_0$ are thought to be aligned, we could expect the relationship between $\boldsymbol{a}^{\mathcal{G}}$ and $\boldsymbol{a}_{gt}^{\mathcal{U}}$, as in the table below.
  ("By our expectation based on $\mathcal{G}_0$")
- However, we discovered the relationship in ("By observation").
- Then, we could inversely guess the ground frame $\mathcal{G} = \mathcal{G}'$.



By our expectation based on $\mathcal{G}_0$	By observation
$a_{gt,x}^{\mathcal{U}} \approx a_y^{\mathcal{G}}$	$a_{gt,x}^{\mathcal{U}} \approx \lambda \cdot a_x^{\mathcal{G}}$
$a_{gt,y}^{\mathcal{U}} \approx -a_x^{\mathcal{G}}$	$a_{gt,y}^{\mathcal{U}} \approx \lambda \cdot a_y^{\mathcal{G}}$
$a_{gt,z}^{\mathcal{U}} \approx a_x^{\mathcal{G}}$	$a_{gt,z}^{\mathcal{U}} \approx -\lambda \cdot a_z^{\mathcal{G}}$

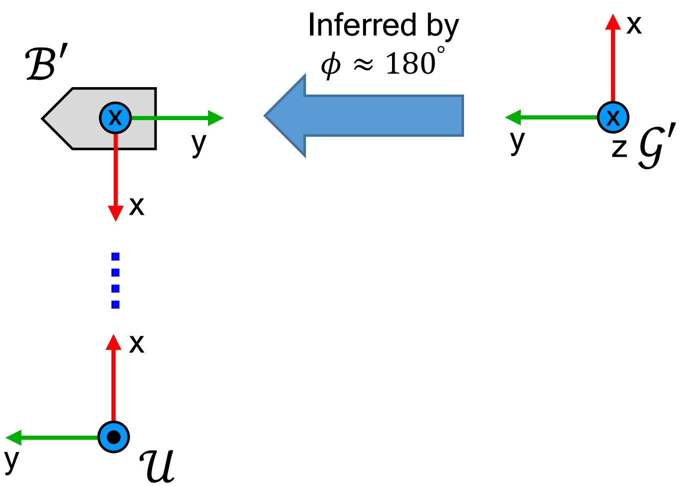
$\lambda = 0.1 \ (\approx \frac{1}{9.8})$

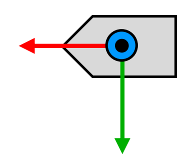
Note that $\boldsymbol{a}_{gt}^{\mathcal{U}}$ is computed from ground-truth position using total station, and $\boldsymbol{a}^{\mathcal{G}}$ is given from flight controller.

See appendix to see "By observation".

Inferring $\mathcal{B}$ from Newly Inferred $\mathcal{G}'$

- Based on $\phi \approx 180^{\circ}$, we could infer the updated $\mathcal{B}(=\mathcal{B}')$ from newly inferred $\mathcal{G}'$.
- However, the inferred $\mathcal{B}'$ does not follow the standard form, as $\mathcal{B}'$ is a left-handed frame and it is not FLU (Front-Left-Up).





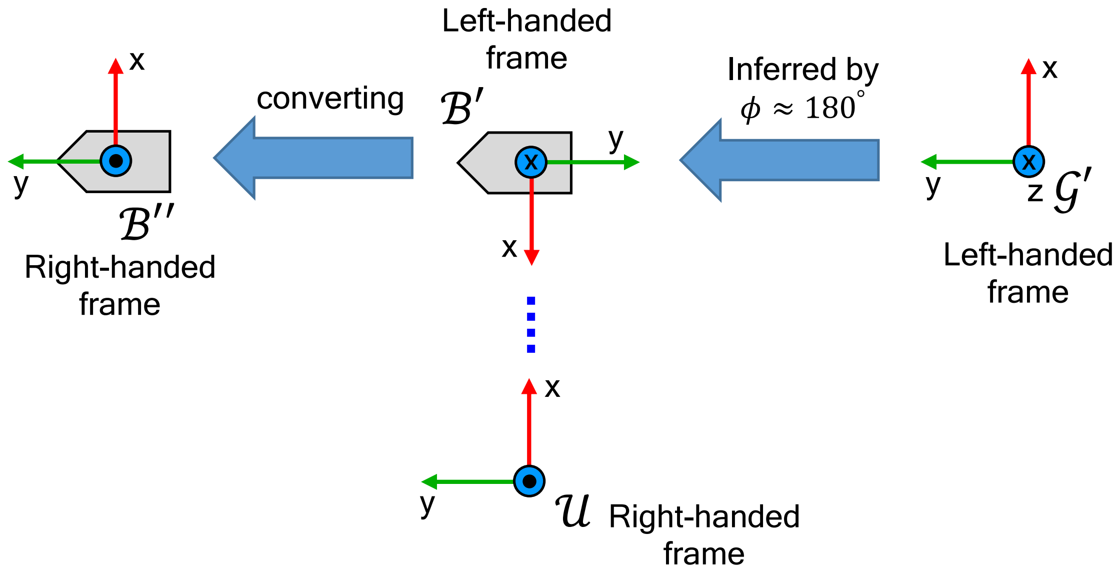
Body frame following FLU
(right-handed frame)

Setting New Body Frame $\mathcal{B}''$

- We hope to convert $\mathcal{B}'$ into new body frame $\mathcal{B}''$ so that

  (1) $\mathcal{B}''$ is a right-handed frame, and

  (2) $\mathcal{B}''$ is matched with the UWB frame $\mathcal{U}$, because we are doing a localization wrt $\mathcal{U}$ and it simplifies math expression.



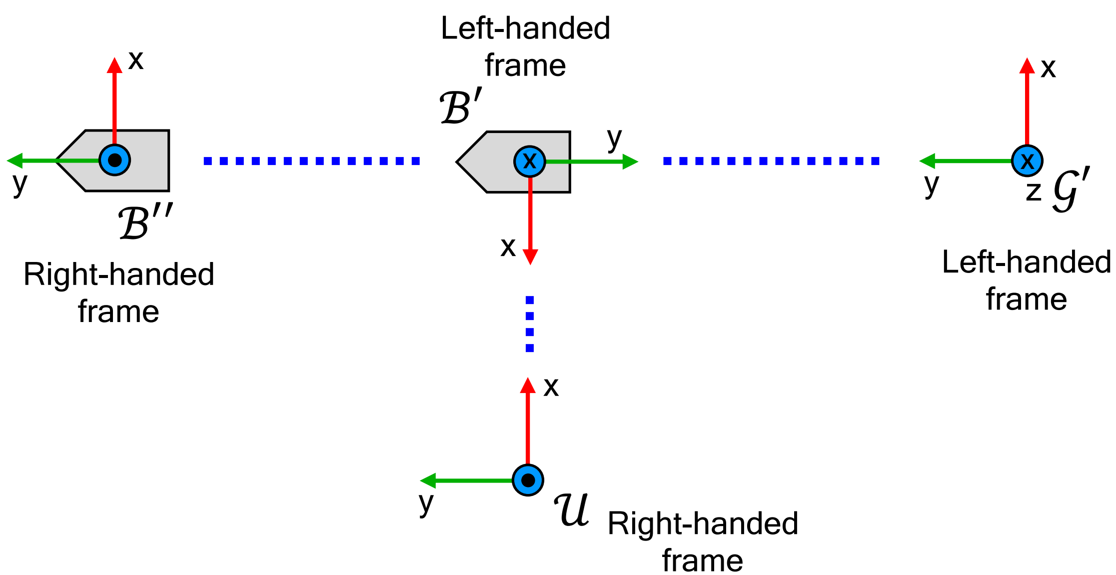
Conclusion

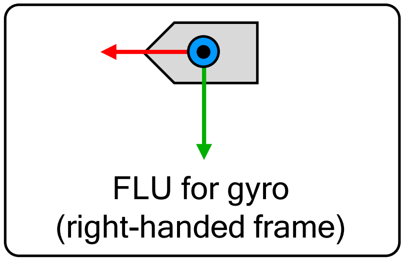
- We can convert $\boldsymbol{a}^{\mathcal{G}} = (a_x^{\mathcal{G}}, a_y^{\mathcal{G}}, a_z^{\mathcal{G}})$ into $\boldsymbol{a}^{\mathcal{B}=B''} = (a_x^{\mathcal{B}}, a_y^{\mathcal{B}}, a_z^{\mathcal{B}})$, by
  - $\begin{bmatrix} a_x^B \\ a_y^B \\ a_z^B \end{bmatrix} = R_{\mathcal{G}}^{\mathcal{B}}(\phi - 180°) \begin{bmatrix} \lambda \cdot a_x^{\mathcal{G}} \\ \lambda \cdot a_y^{\mathcal{G}} \\ -\lambda \cdot a_z^{\mathcal{G}} \end{bmatrix}$, where $\lambda = 0.1(\approx \frac{1}{9.8})$

$R_{\mathcal{G}}^{\mathcal{B}}(\phi - 180°)$ is expected to be almost an identity matrix.

  - Theoretically, $\begin{bmatrix} \Omega_x^B \\ \Omega_y^B \\ \Omega_z^B \end{bmatrix} = \begin{bmatrix} -\Omega_x \\ -\Omega_y \\ -\Omega_z \end{bmatrix}$. However, we found that $\begin{bmatrix} \Omega_x^B \\ \Omega_y^B \\ \Omega_z^B \end{bmatrix} = \begin{bmatrix} -\Omega_y \\ \Omega_x \\ \Omega_z \end{bmatrix}$ from the real data.

This is because axes for acc are different from axes for gyro.





Appendix. I

Velocity comparison

Velocity Comparison

Velocity from ground-truth position	Velocity from linear acceleration
$v_x(t_i') = \dfrac{x_{i+1} - x_i}{\Delta t}$	$v_x(t_{i+1}) = v_x(t_i) + \lambda \cdot a_{x,i} \cdot \Delta t$
$v_y(t_i') = \dfrac{y_{i+1} - y_i}{\Delta t}$	$v_y(t_{i+1}) = v_y(t_i) + \lambda \cdot a_{y,i} \cdot \Delta t$
$v_z(t_i') = \dfrac{z_{i+1} - z_i}{\Delta t}$	$v_z(t_{i+1}) = v_z(t_i) + -\lambda \cdot a_{z,i} \cdot \Delta t$

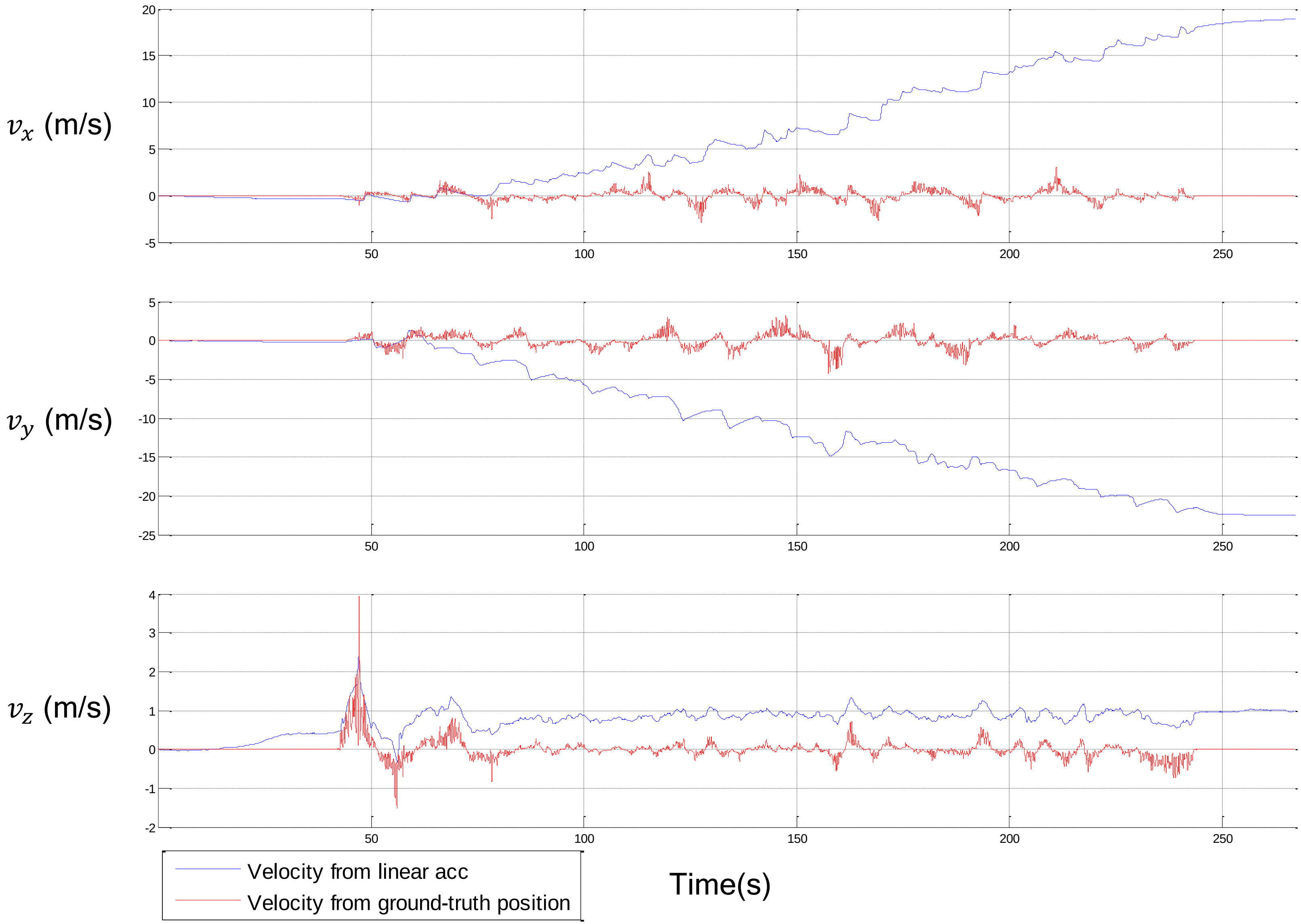
Blue letters indicate acquired data.

$\lambda = 0.1$

i: data index $\quad t_i' = \dfrac{t_{i+1} + t_i}{2} \quad \Delta t = t_{i+1} - t_i$

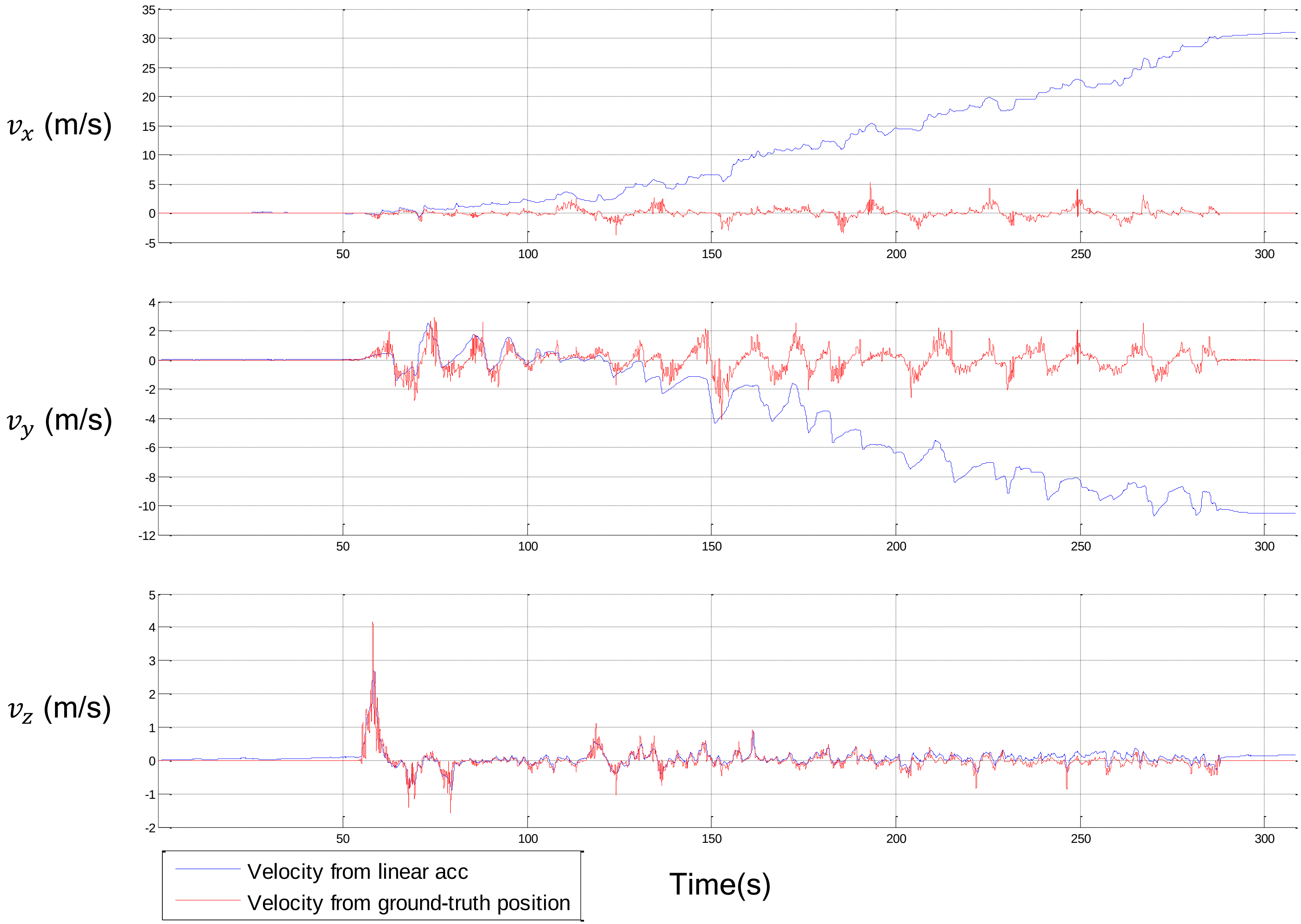
Set 1

# of data	26722
Time length (s)	267.196275



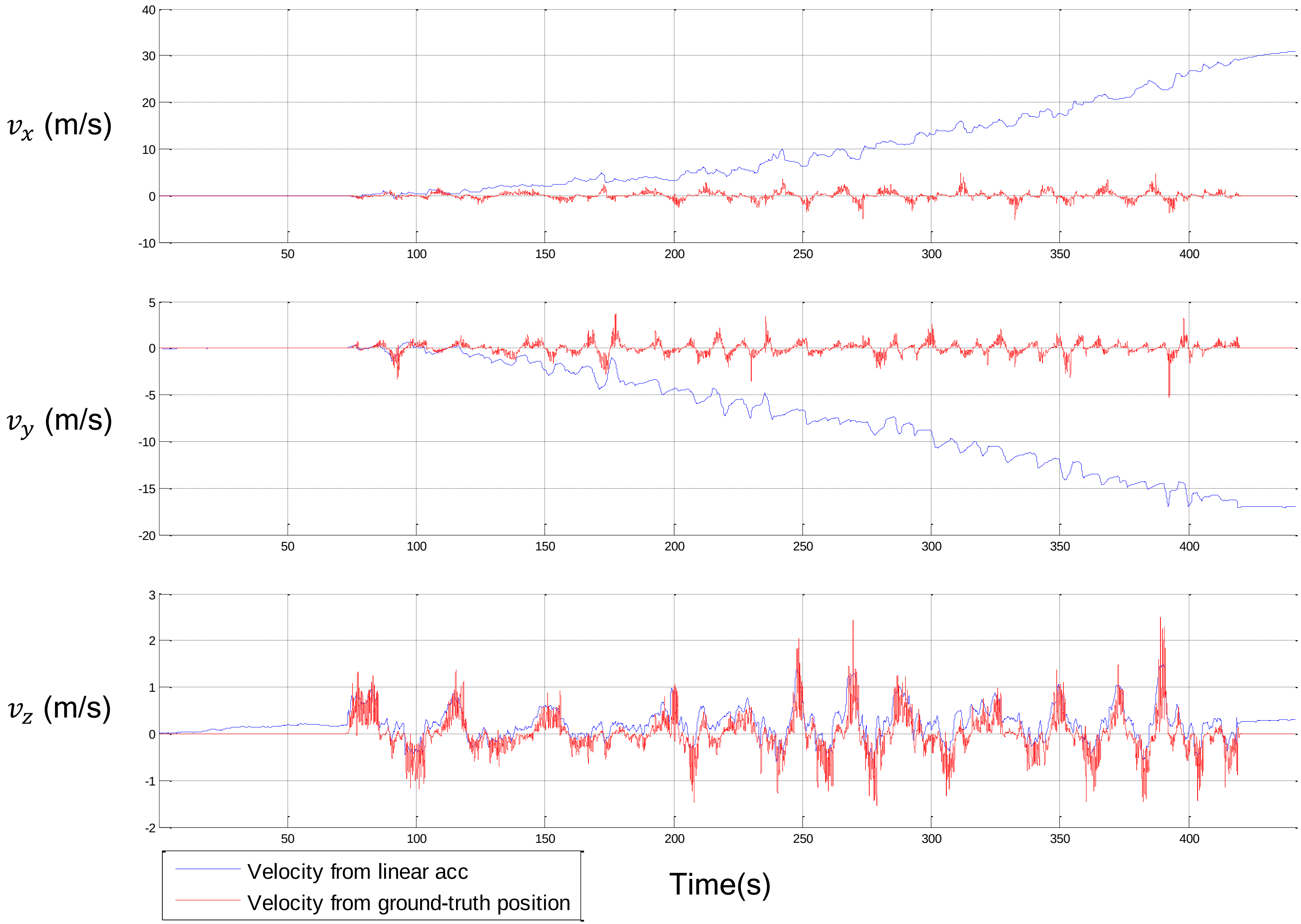
Set 2

# of data	30835
Time length (s)	308.336690



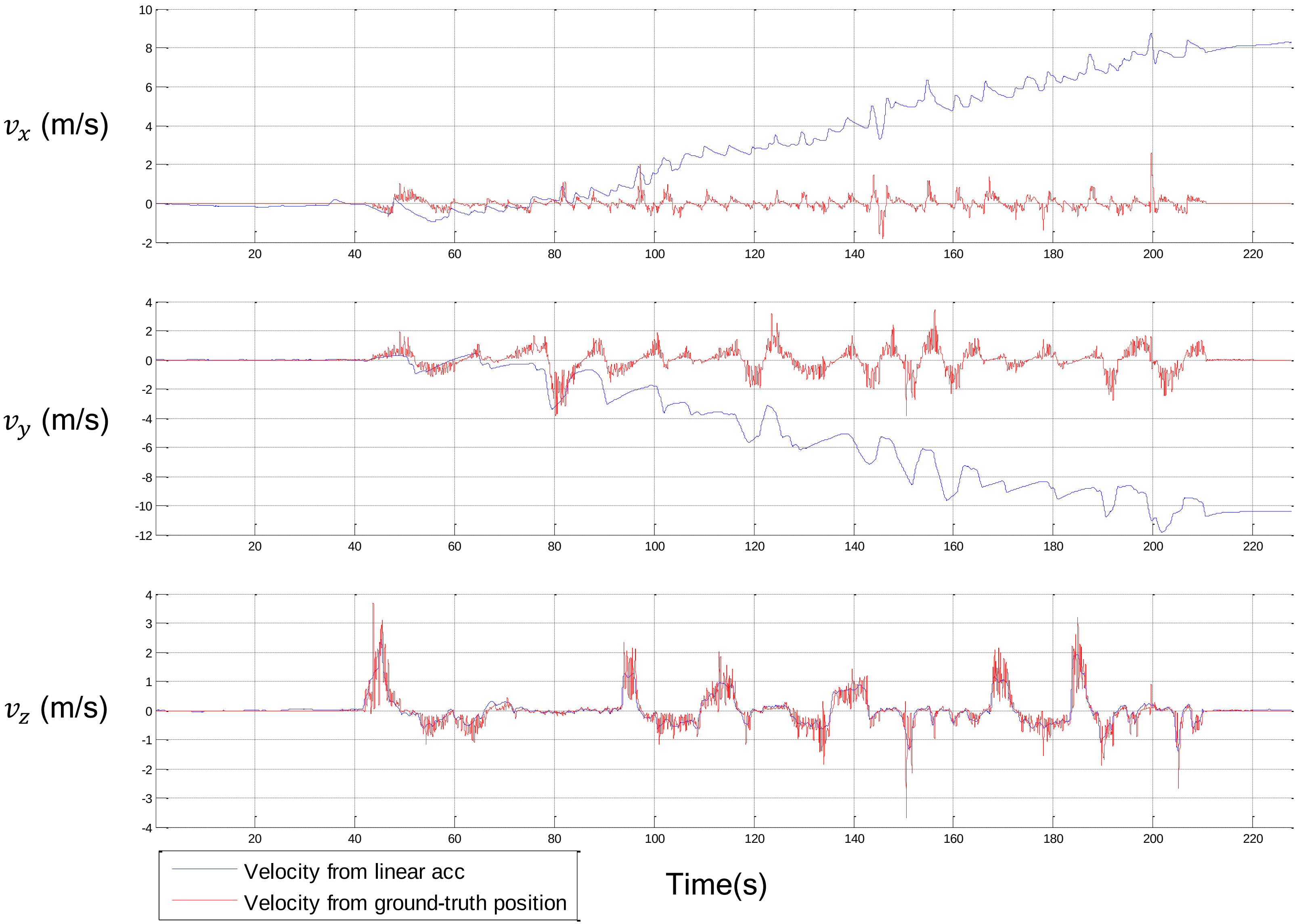
Set 3

# of data	44134
Time length (s)	441.309840



Set 4

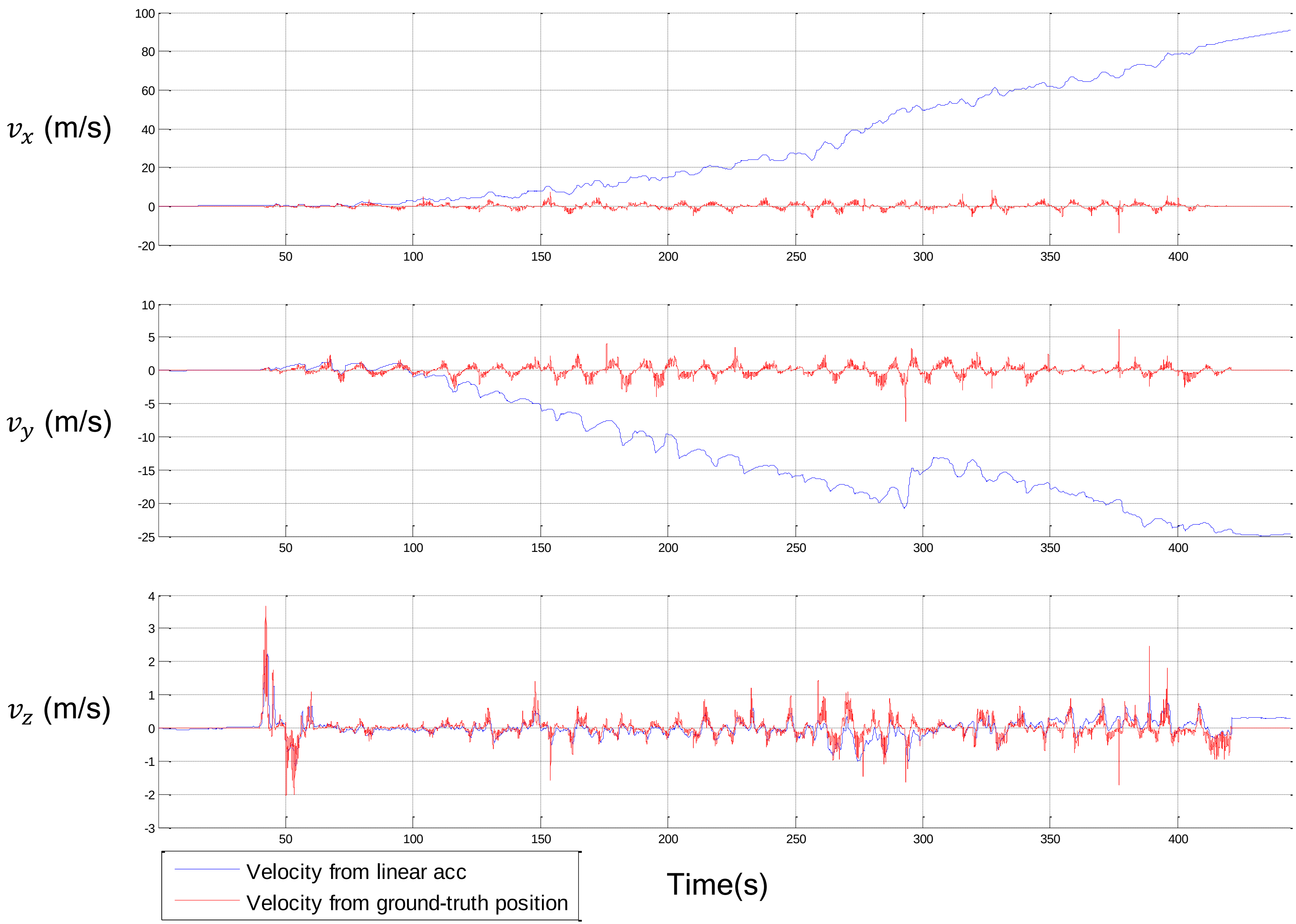
# of data	22773
Time length (s)	227.711090



Appendix. I

Set 5

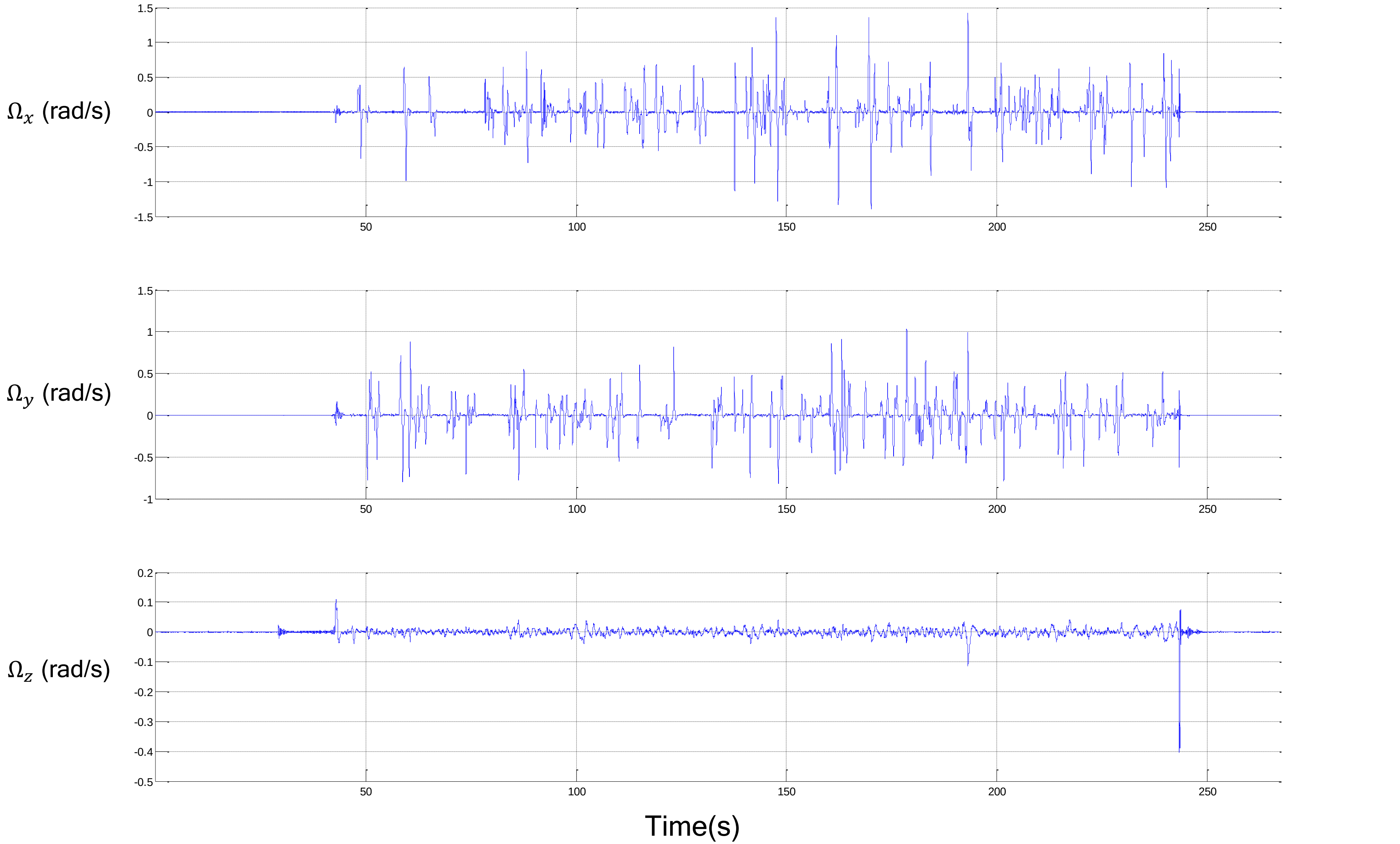
# of data	44414
Time length (s)	444.109007



Appendix. II

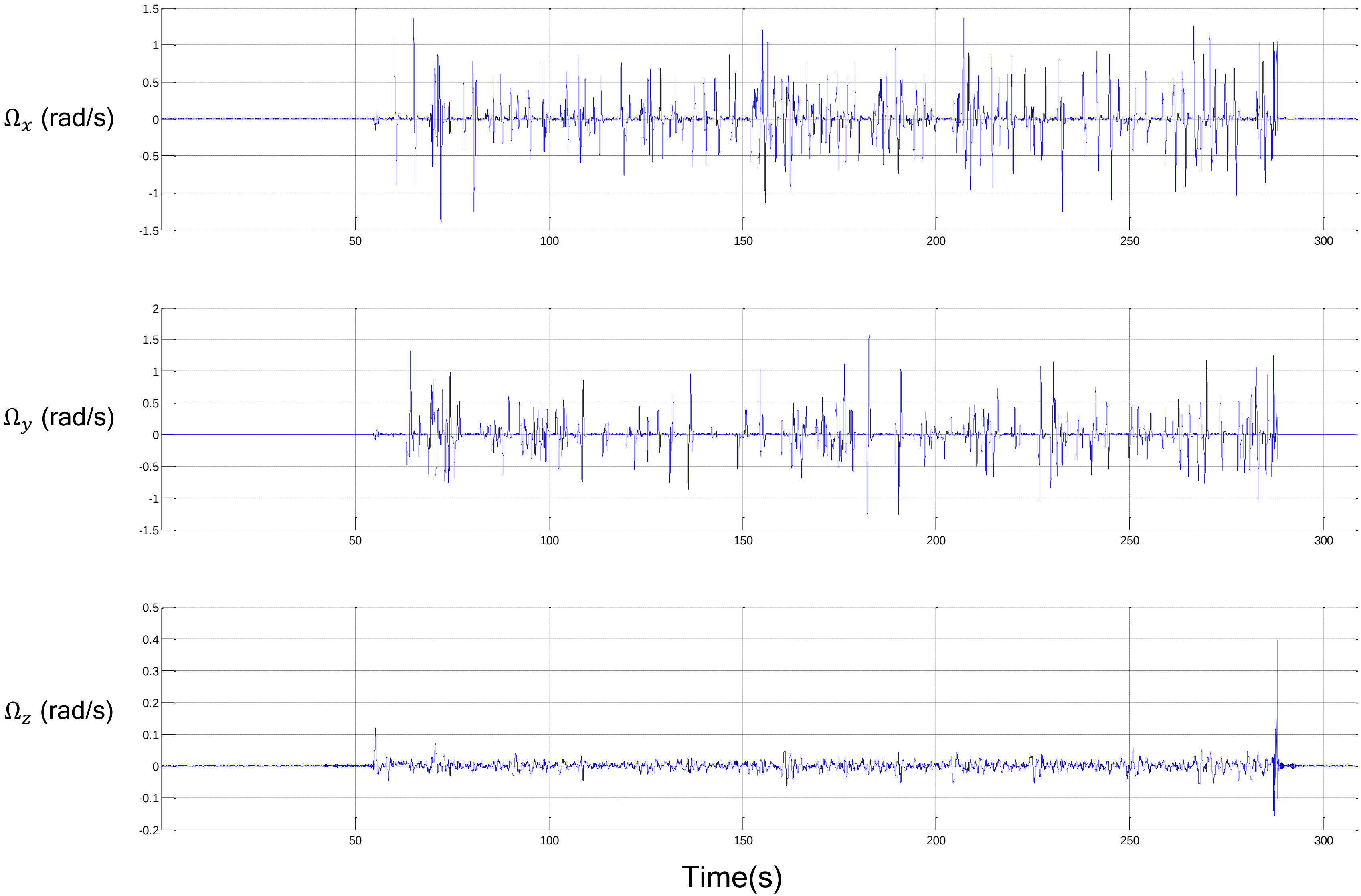
Angular velocity from flight controller

Set 1

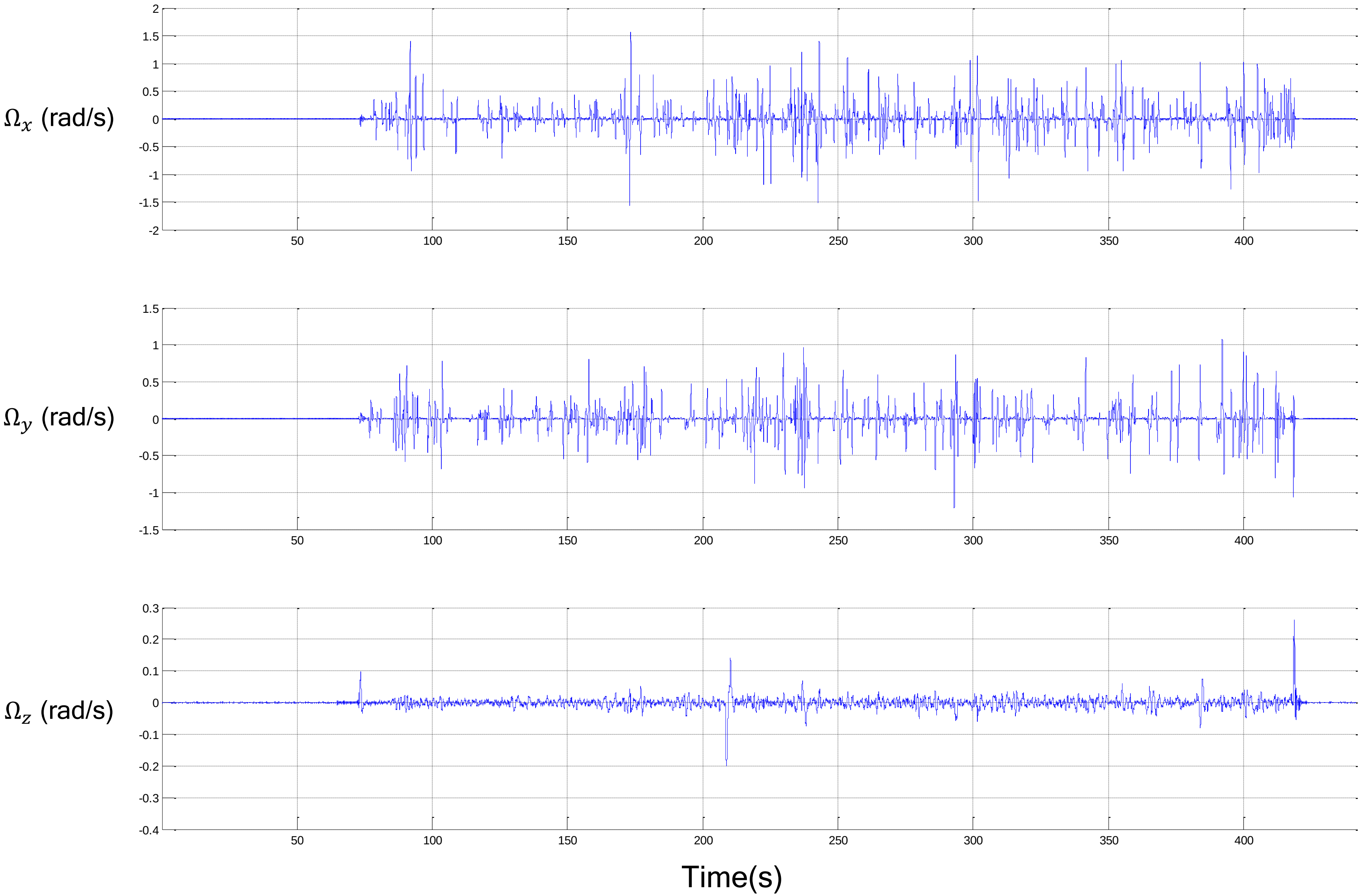


Ω_x (rad/s)
1.5
1
0.5
0
-0.5
-1
-1.5
50
100
150
200
250
Ω_y (rad/s)
1.5
1
0.5
0
-0.5
-1
50
100
150
200
250
Ω_z (rad/s)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
50
100
150
200
250
Time(s)

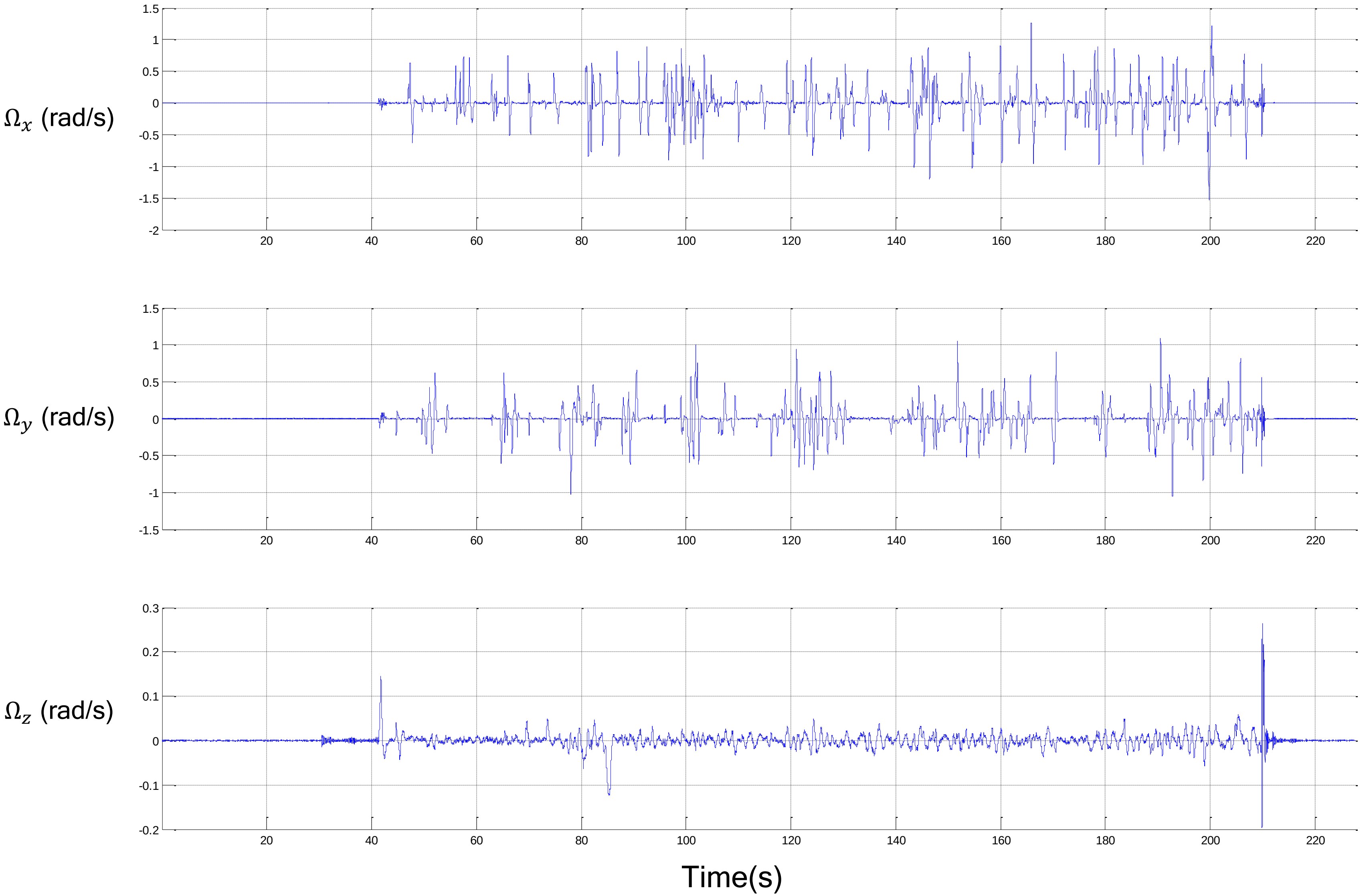
Set 2


Ω_x (rad/s)
1.5
1
0.5
0
-0.5
-1
-1.5
50
100
150
200
250
300
Ω_y (rad/s)
2
1.5
1
0.5
0
-0.5
-1
-1.5
50
100
150
200
250
300
Ω_z (rad/s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
50
100
150
200
250
300
Time(s)

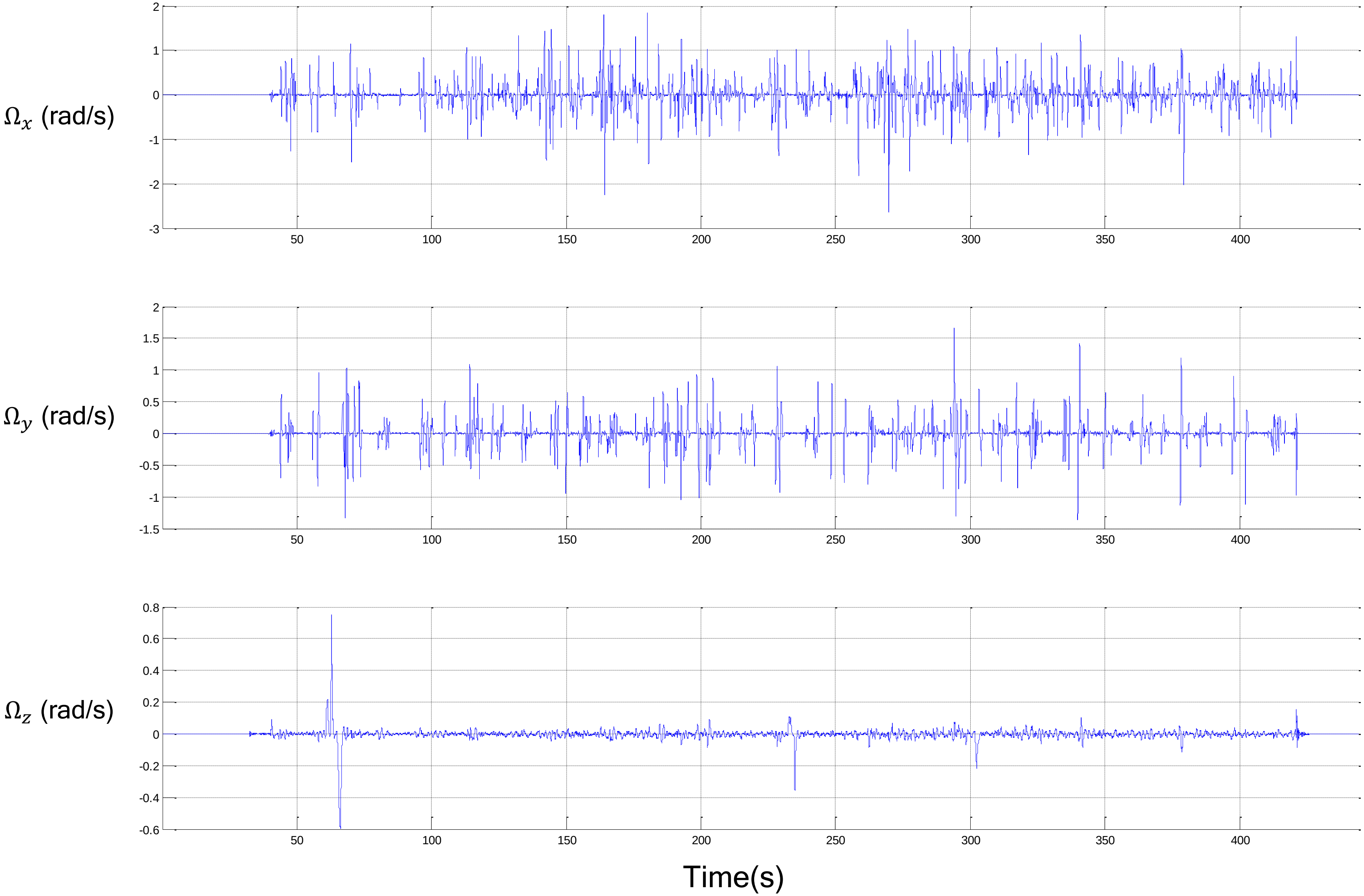
Set 3


Ω_x (rad/s)
Ω_y (rad/s)
Ω_z (rad/s)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0.3
0.2
0.1
-0.1
-0.2
-0.3
-0.4
50
100
150
200
250
300
350
400
Time(s)

Set 4


Ω_x (rad/s)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
20
40
60
80
100
120
140
160
180
200
220
Ω_y (rad/s)
1.5
1
0.5
0
-0.5
-1
-1.5
20
40
60
80
100
120
140
160
180
200
220
Ω_z (rad/s)
0.3
0.2
0.1
0
-0.1
-0.2
20
40
60
80
100
120
140
160
180
200
220
Time(s)

Set 5

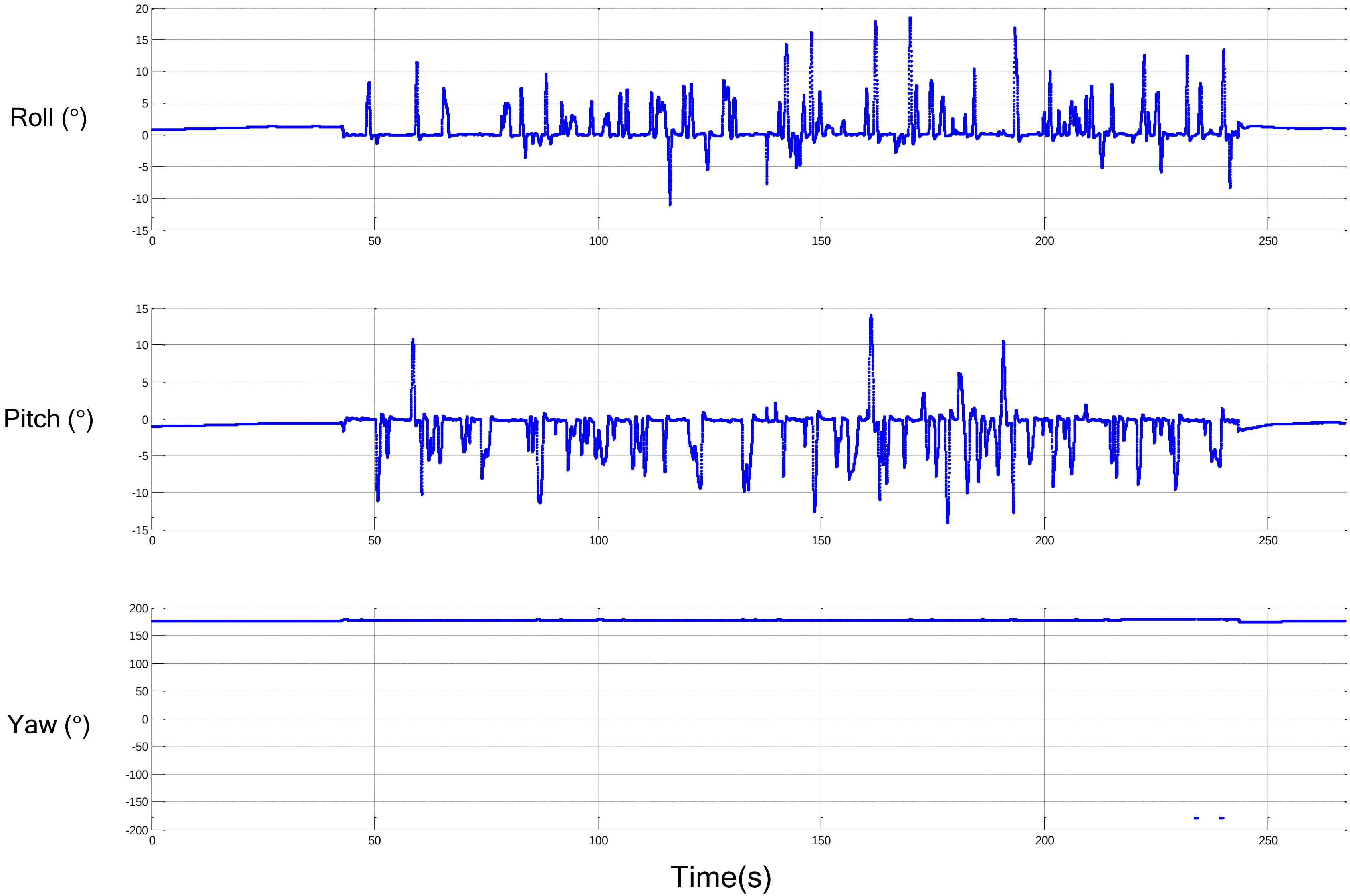


Ω_x (rad/s)
2
1
0
-1
-2
-3
50
100
150
200
250
300
350
400
Ω_y (rad/s)
2
1.5
1
0.5
0
-0.5
-1
-1.5
50
100
150
200
250
300
350
400
Ω_z (rad/s)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
50
100
150
200
250
300
350
400
Time(s)

Appendix. III

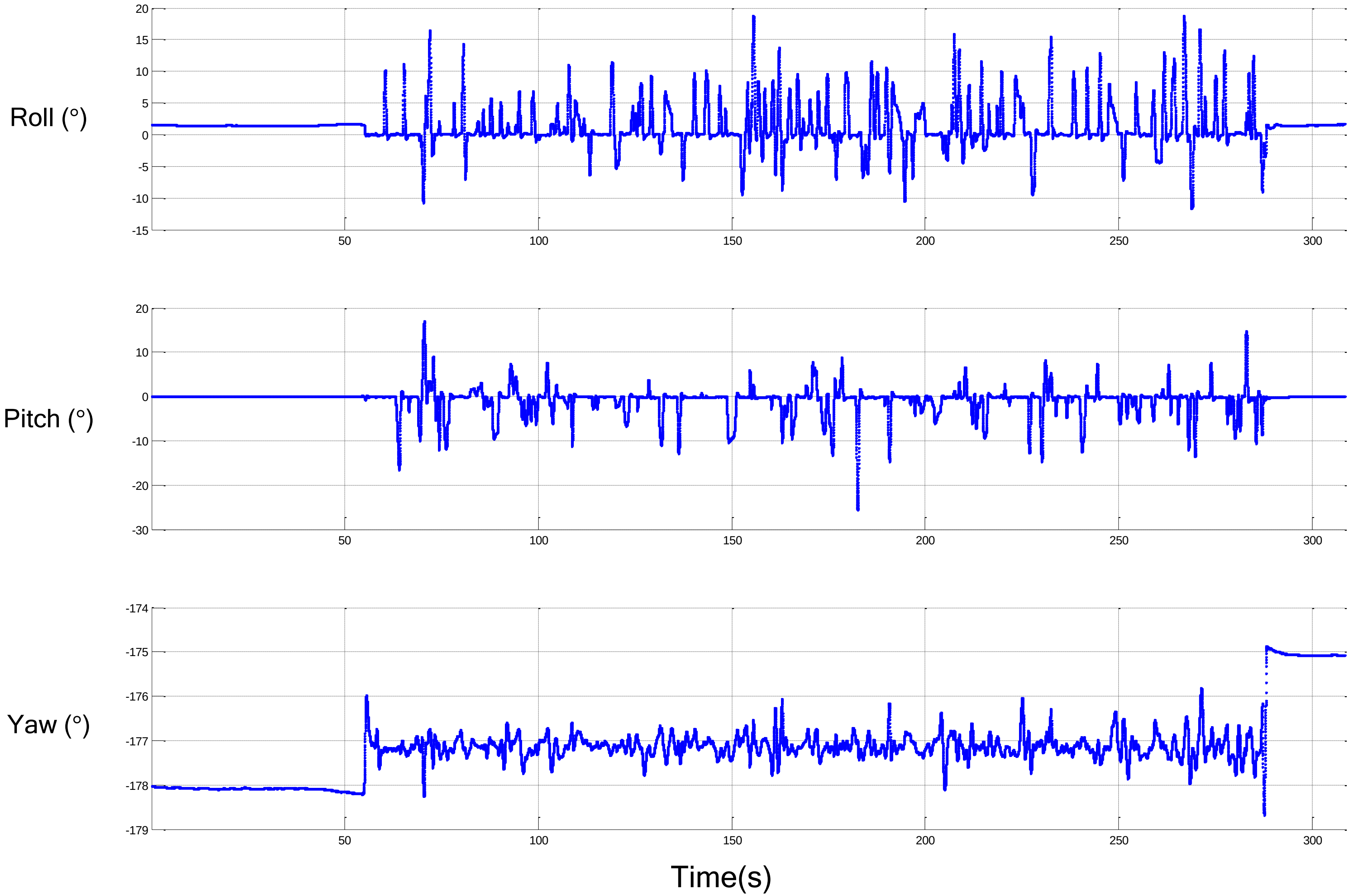
Orientation from flight controller

Set 1

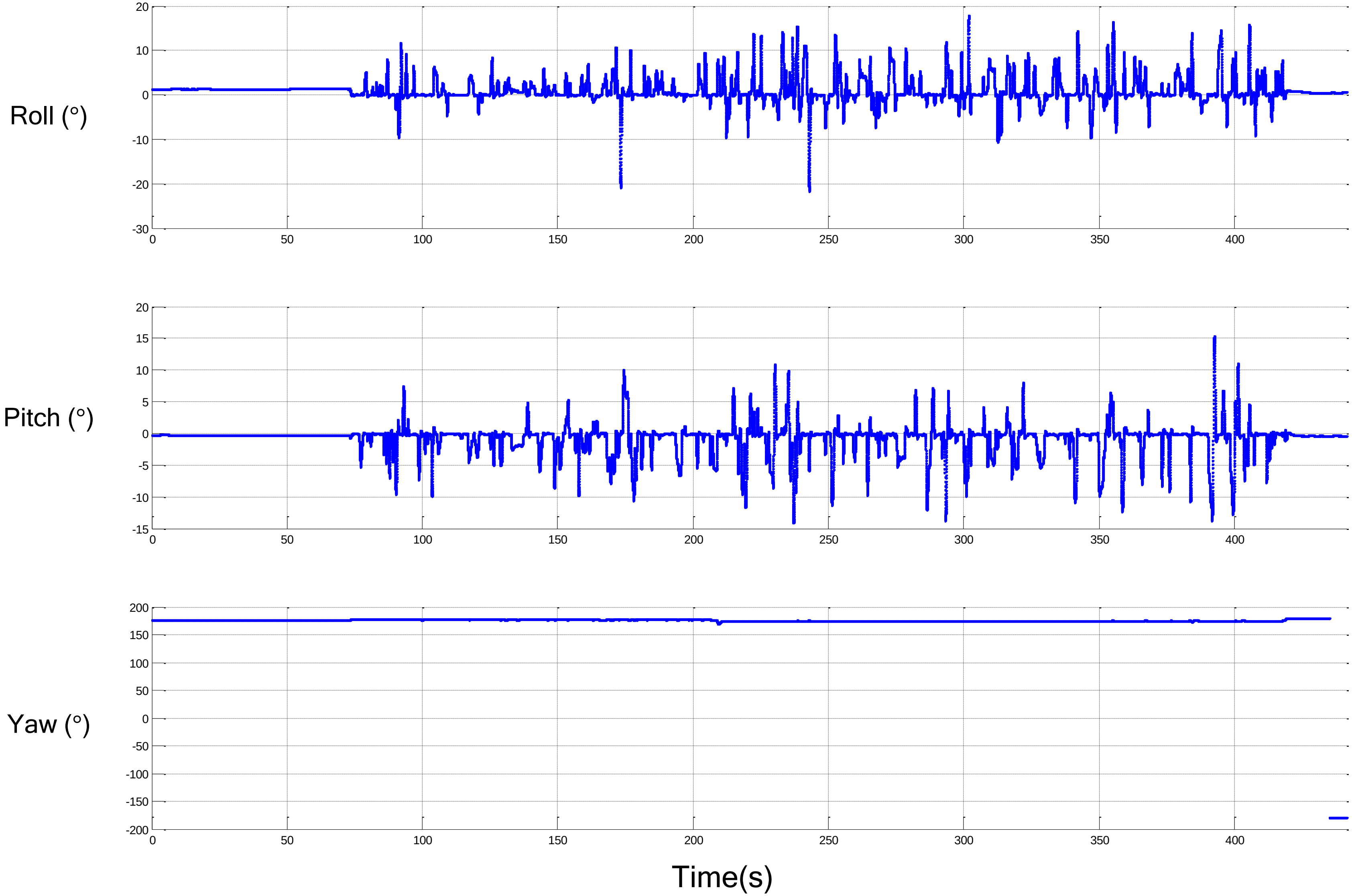


Roll (°)
20
15
10
5
0
-5
-10
-15
0
50
100
150
200
250
Pitch (°)
15
10
5
0
-5
-10
-15
Yaw (°)
200
150
100
50
0
-50
-100
-150
-200
Time(s)

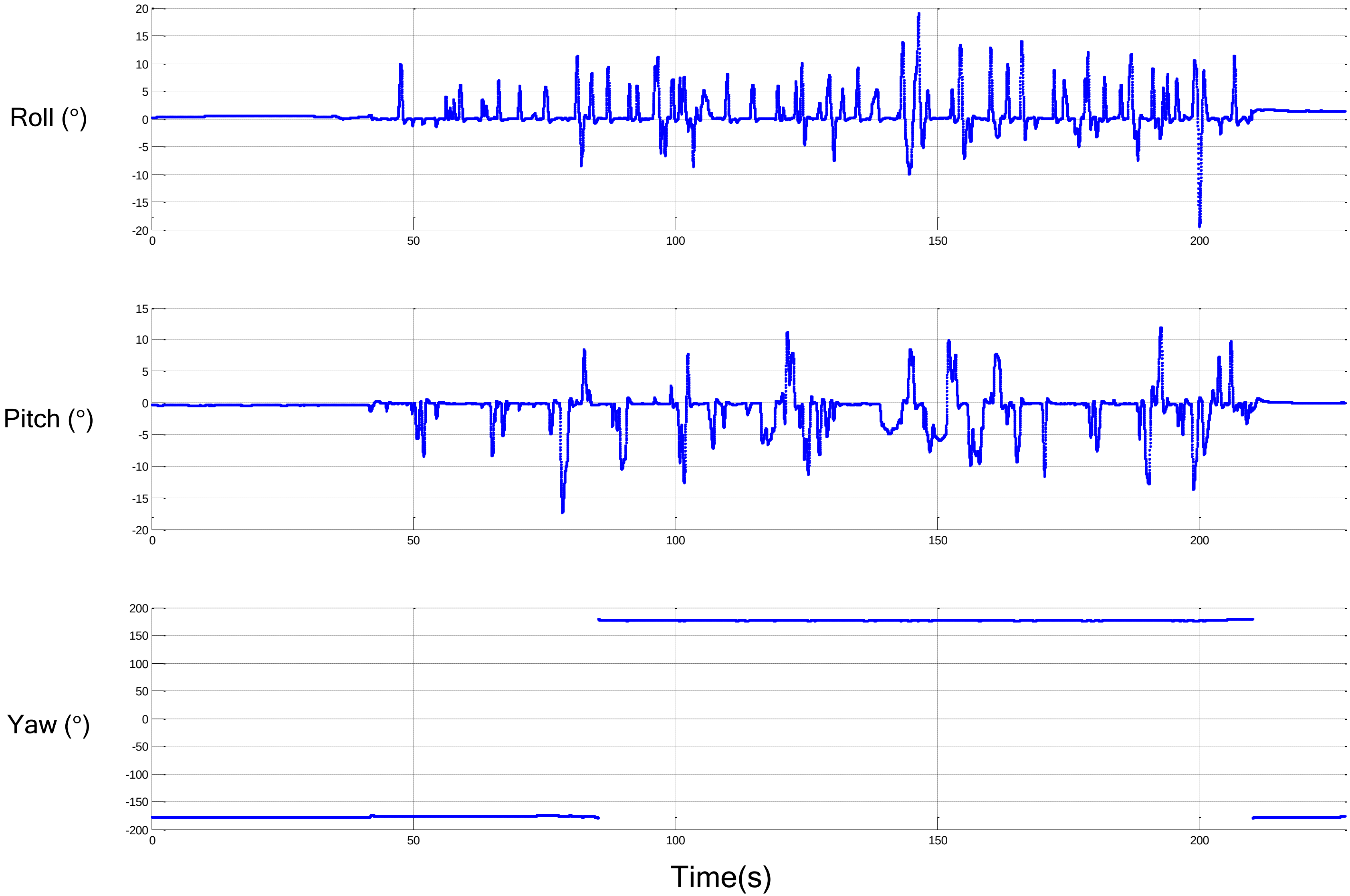
Set 2


Roll (°)
20
15
10
5
0
-5
-10
-15
50
100
150
200
250
300
Pitch (°)
20
10
0
-10
-20
-30
50
100
150
200
250
300
Yaw (°)
-174
-175
-176
-177
-178
-179
50
100
150
200
250
300
Time(s)

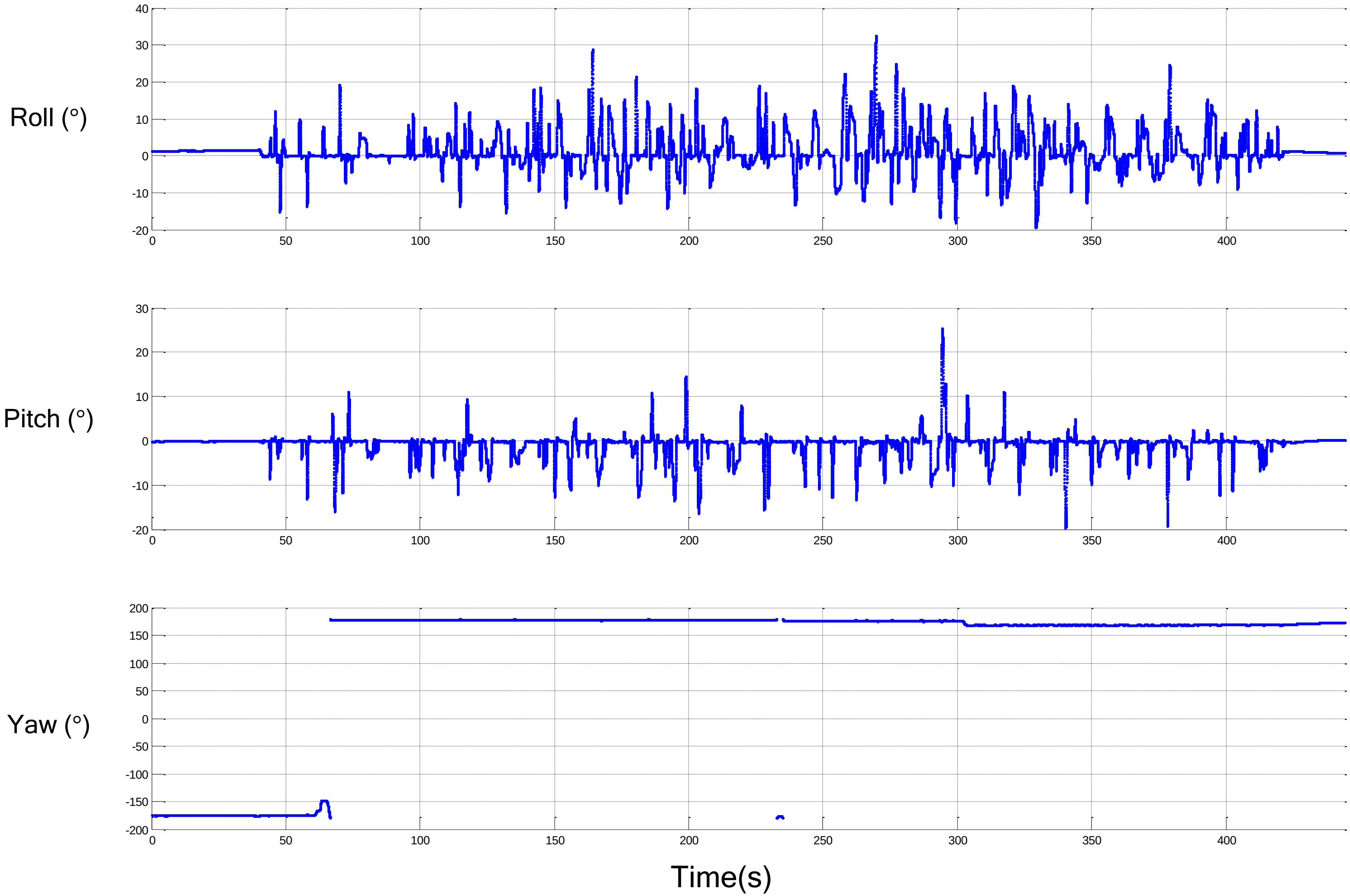
Set 3


Roll (°)
20
10
0
-10
-20
-30
Pitch (°)
20
15
10
5
0
-5
-10
-15
Yaw (°)
200
150
100
50
0
-50
-100
-150
-200
0
50
100
150
200
250
300
350
400
Time(s)

Set 4


Roll (°)
20
15
10
5
0
-5
-10
-15
-20
0
50
100
150
200
Pitch (°)
15
10
5
0
-5
-10
-15
-20
0
50
100
150
200
Yaw (°)
200
150
100
50
0
-50
-100
-150
-200
0
50
100
150
200
Time(s)

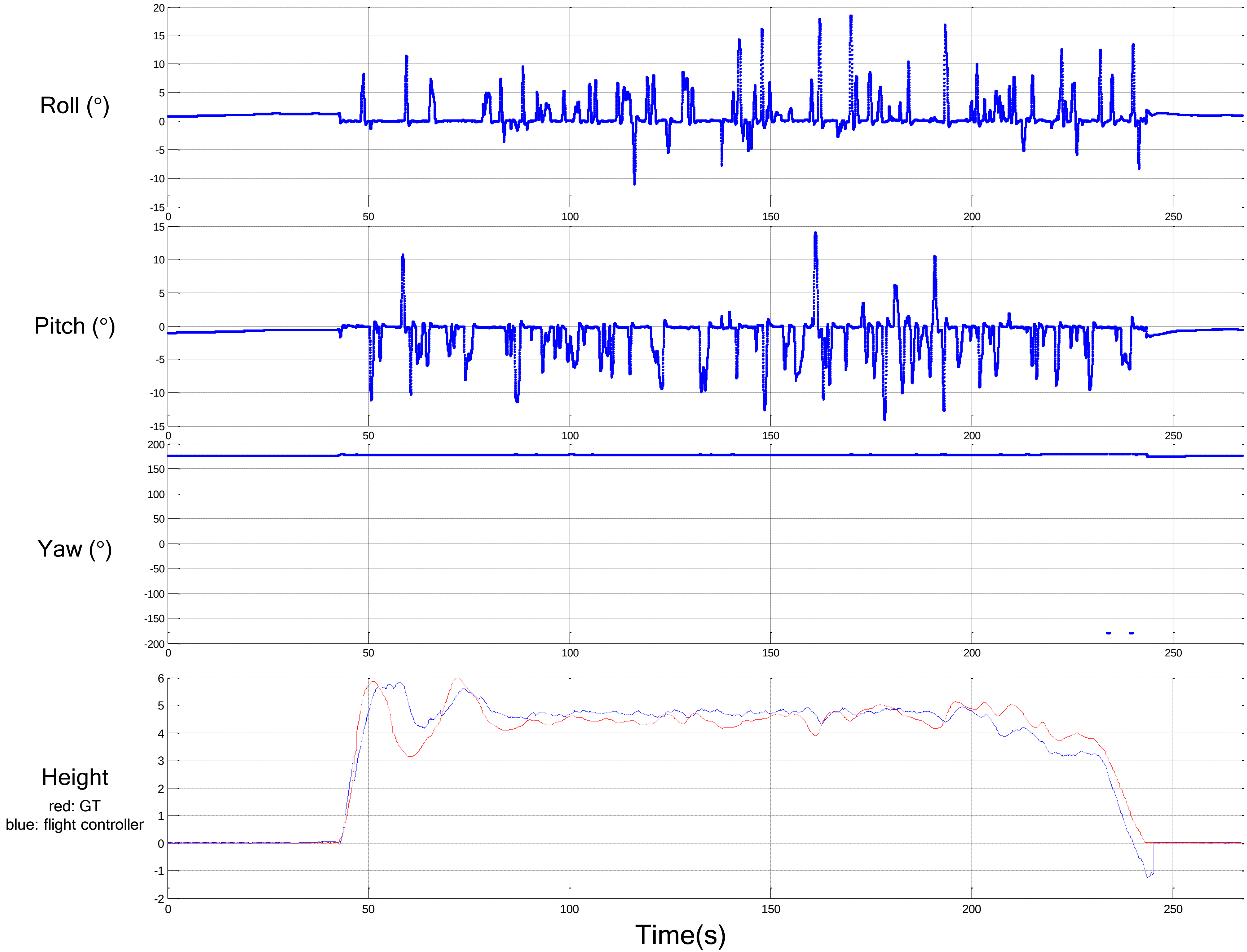
Set 5


Roll (°)
40
30
20
10
0
-10
-20
Pitch (°)
30
20
10
0
-10
-20
Yaw (°)
200
150
100
50
0
-50
-100
-150
-200
0
50
100
150
200
250
300
350
400
Time(s)

Appendix. IV

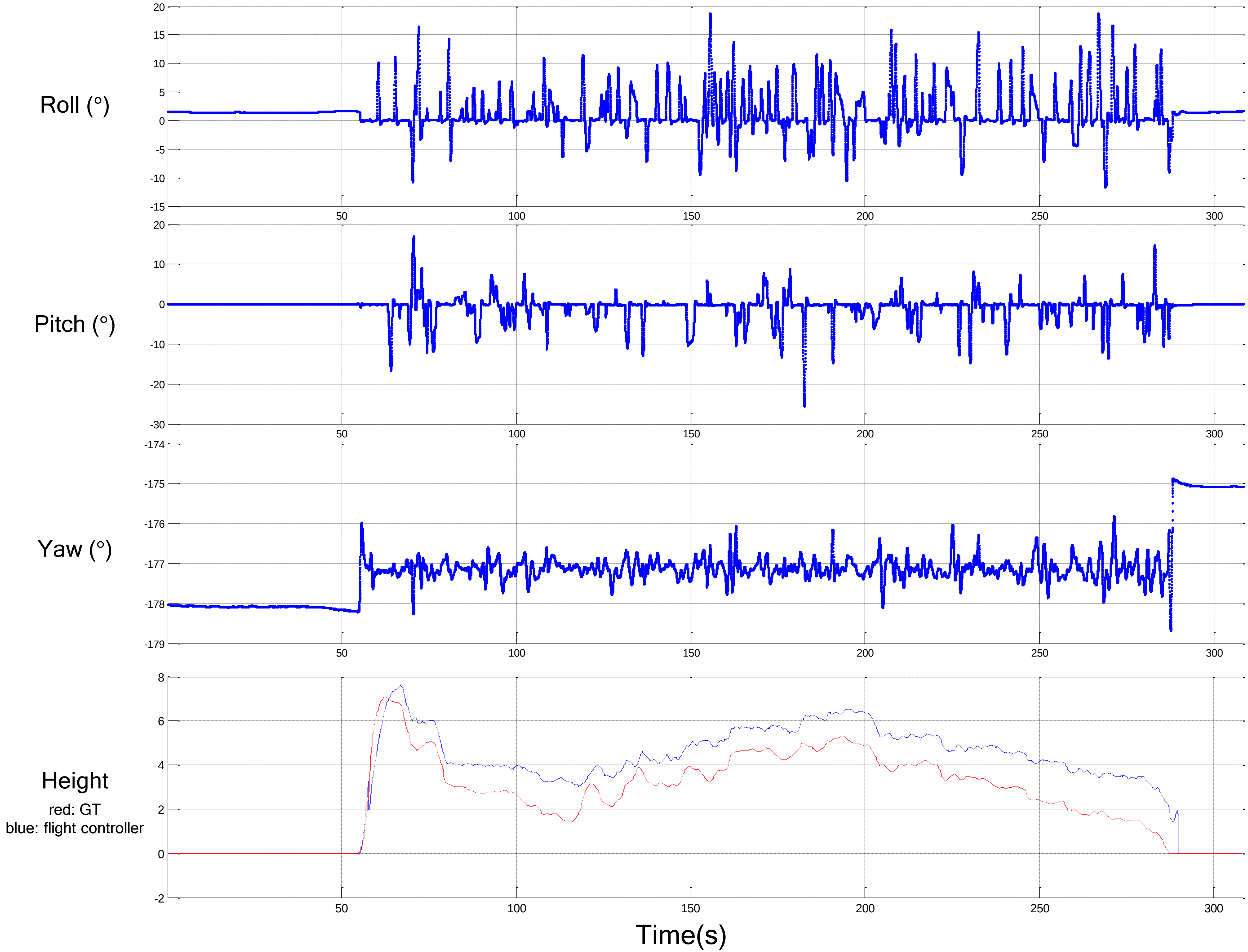
Orientation from flight controller
+ Height

Set 1


Roll (°)
Pitch (°)
Yaw (°)
Height
red: GT
blue: flight controller
Time(s)
20
15
10
5
0
-5
-10
-15
200
150
100
50
-50
-100
-150
-200
6
4
3
2
1
-1
-2
250

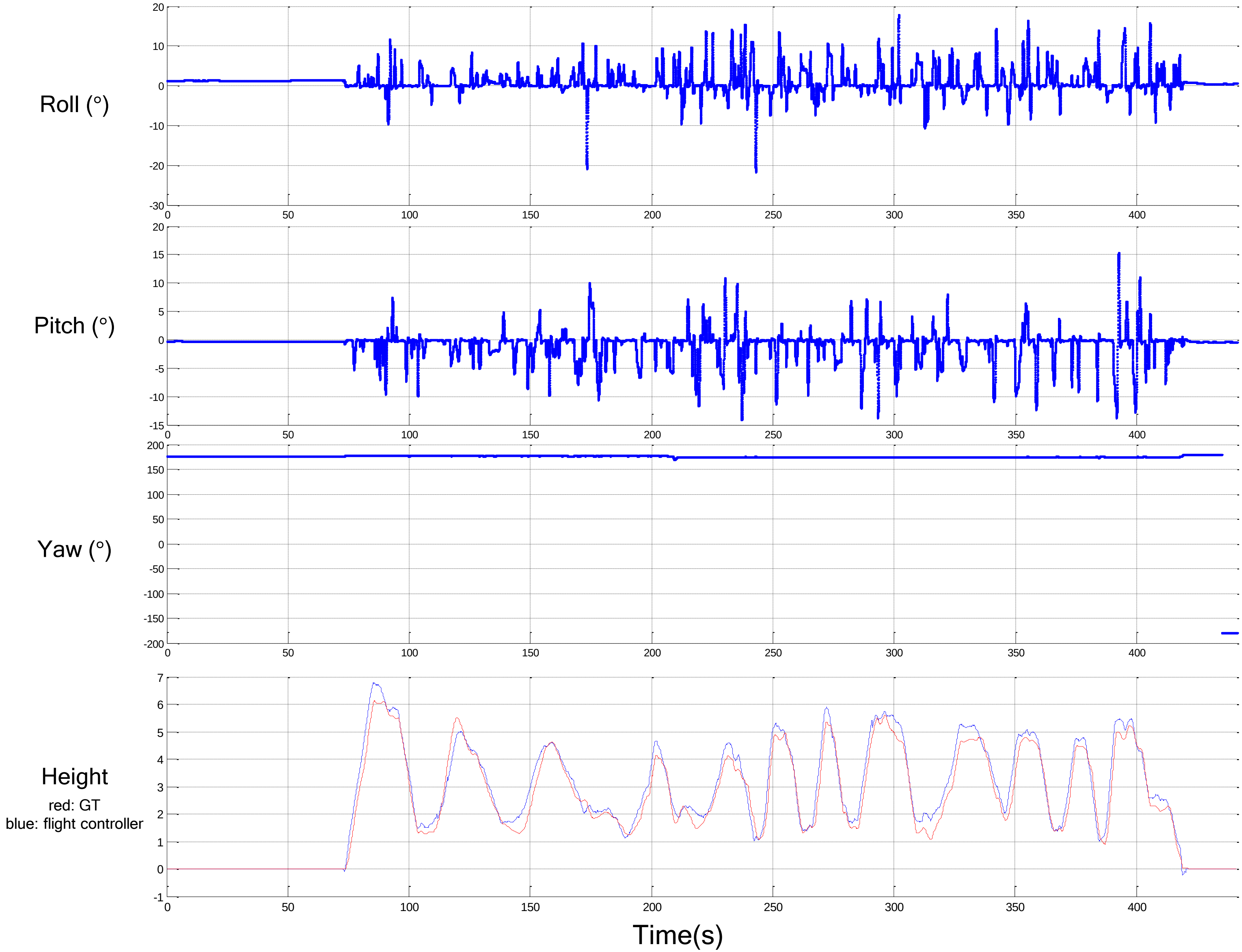
Appendix. IV

Set 2



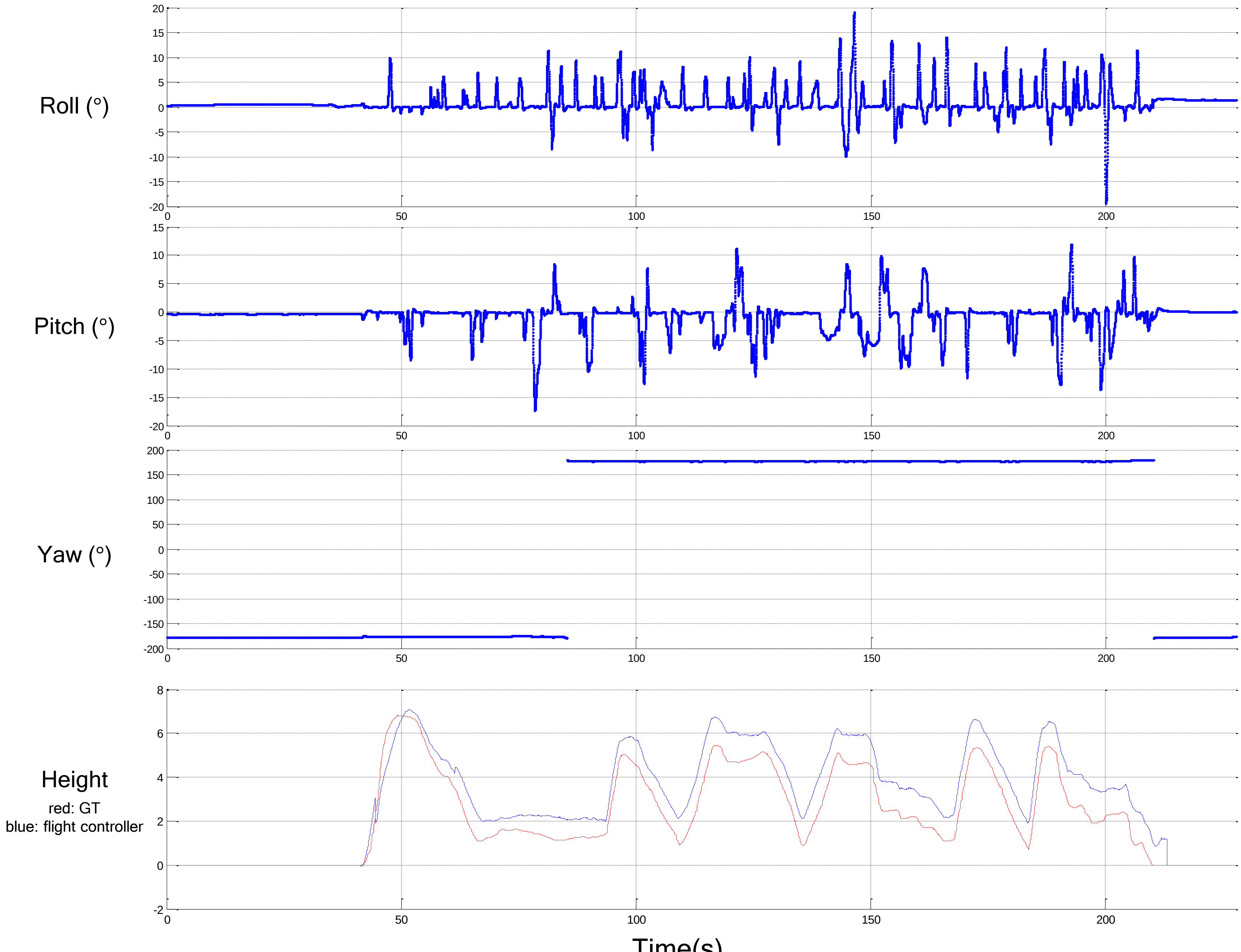
Appendix. IV

Set 3

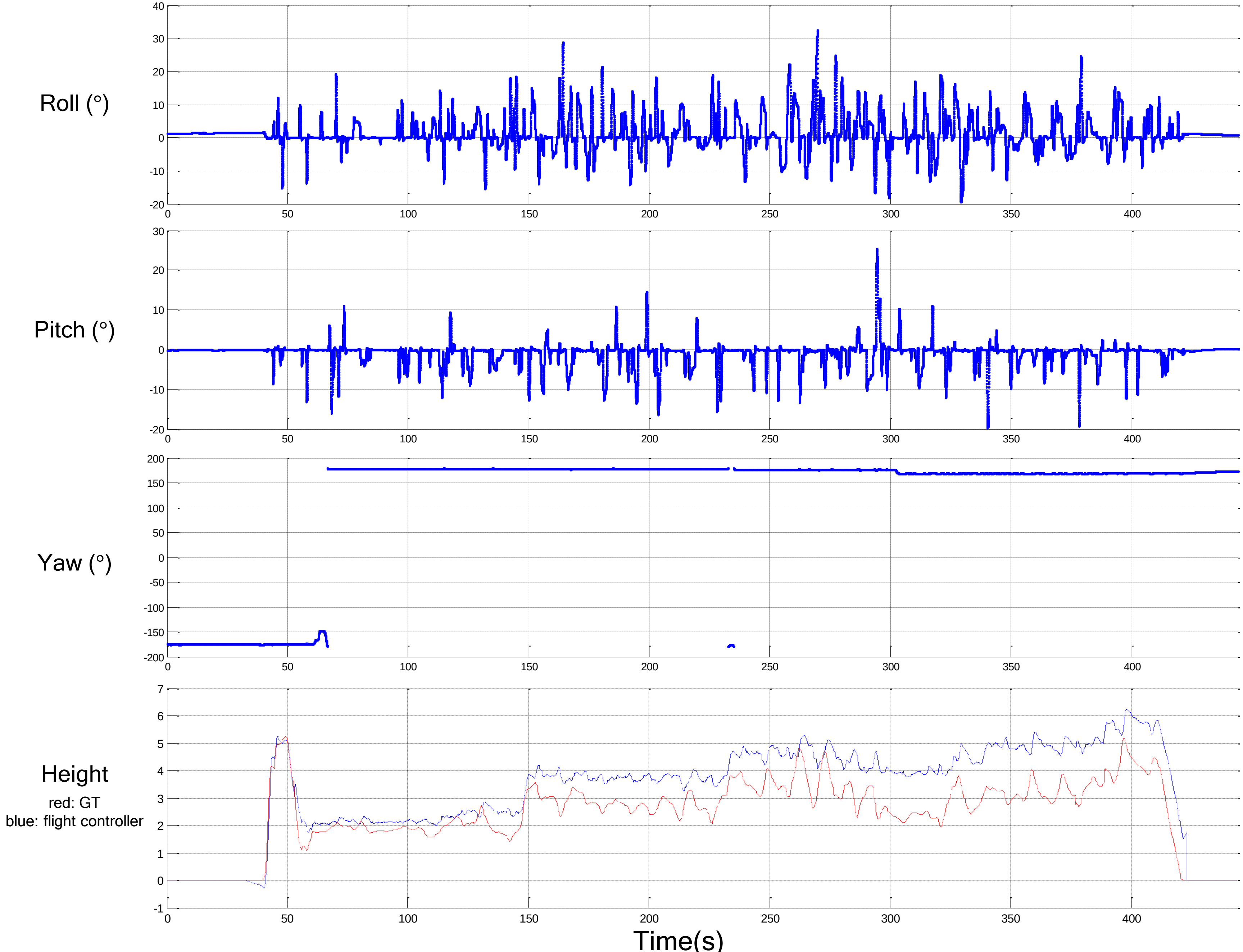


Appendix. IV

Set 4



Set 5



Understanding DJI M100 IMU Gyro Data

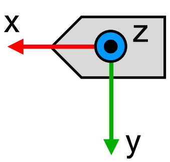
Jungwon Kang

2018/08/20

Description

Initially assumed frame

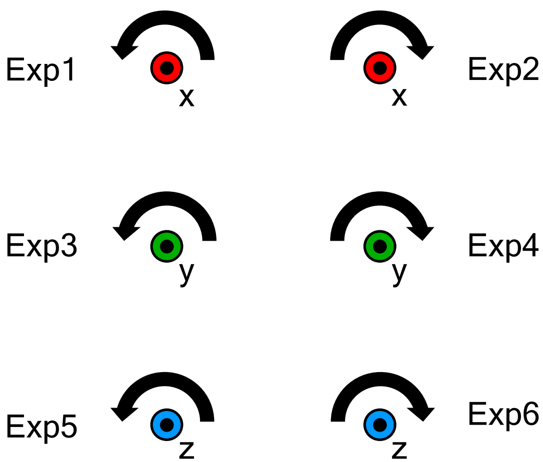
(→ In conclusion, it turned out that the initially assumed frame is the final frame.)



FLU: Front(x)-Left(y)-Up(z)
[right-handed frame]

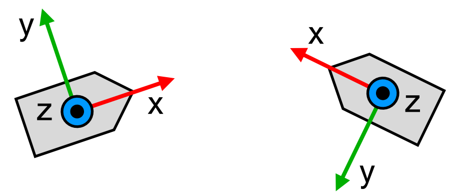
x: roll, y: pitch, z: yaw

Description of Experiment



In all ExpX, we changed 0° to 90°.

Pose (orientation)



yaw: 0°
(Rot 0)

yaw: 135°
(Rot 135)

We can get orientation (in the form of quaternion) from flight controller.
We strongly guess that the orientation is from IMU and Compass as well.
When x-axis is aligned with 401-East, it gives us zero yaw.

Question

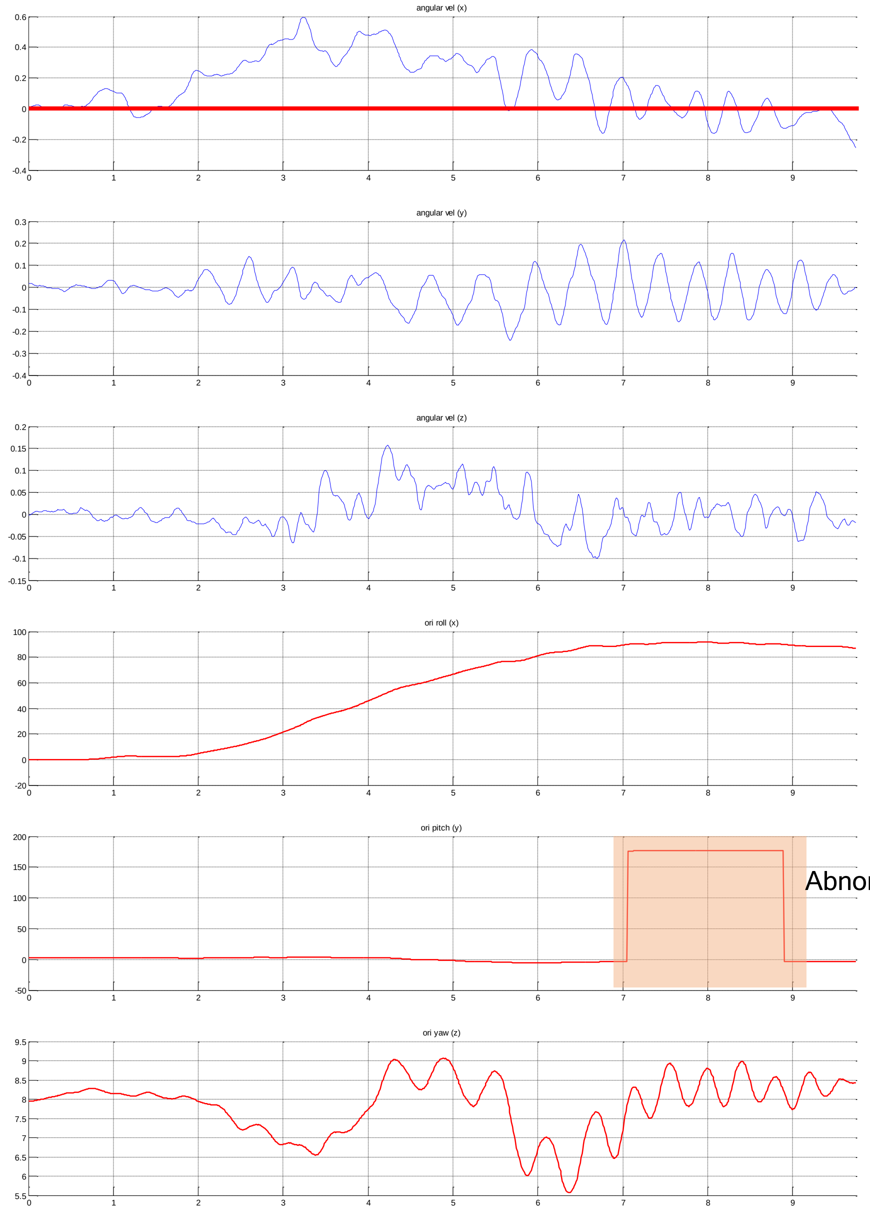
- 1. IMU gyro data (angular velocity) really follows FLU frame?
  - The answer is yes.

- 2. Orientation (from flight controller) also follows FLU frame?
  - The answer is yes.

Rot 0

Exp1 Rot 0, rotation wrt x (counter-clockwise)

- 2018-08-20-15-59-41_abs_rot0_exp1



It gives (+) angular velocity value.

average 0

average 0

It reached 90°

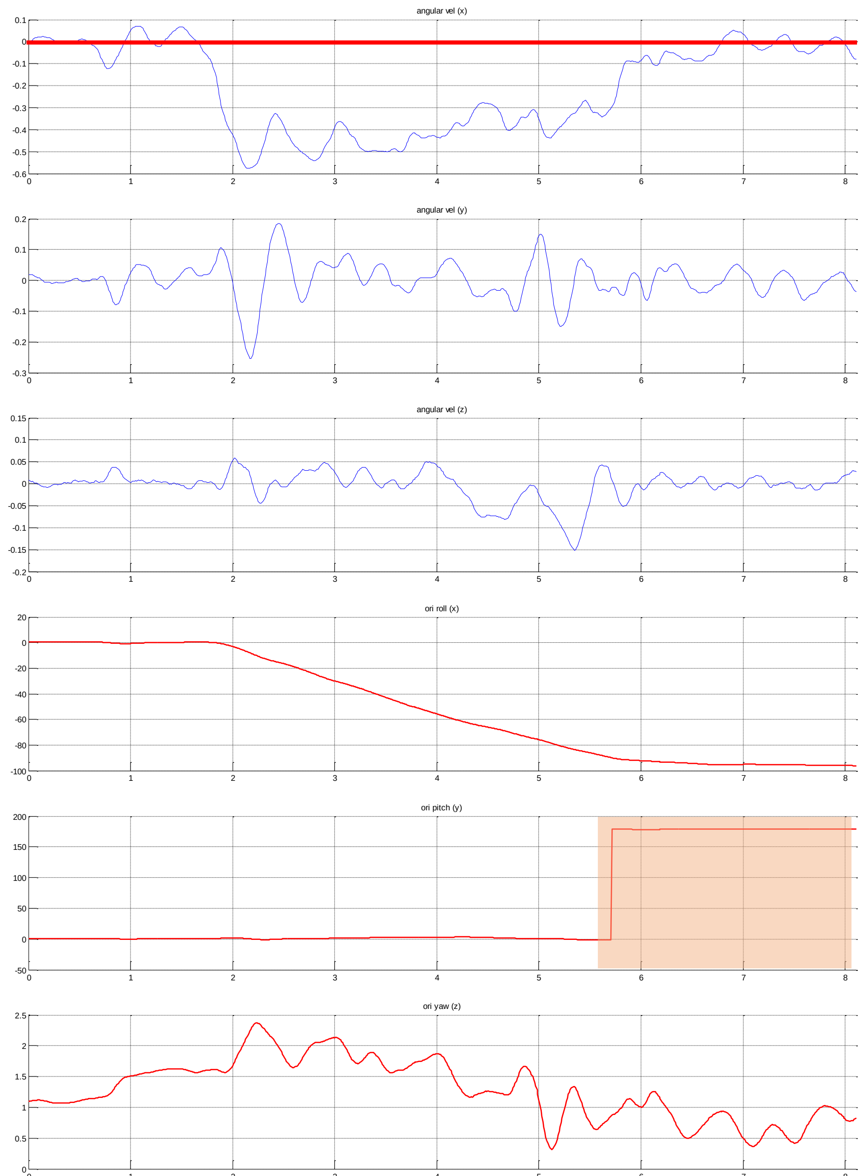
Abnormal section

negligible variation

Exp2

Rot 0, rotation wrt x (clockwise)

- 2018-08-20-16-00-37_abs_rot0_exp2



It gives (-) angular velocity value.

average 0

average 0

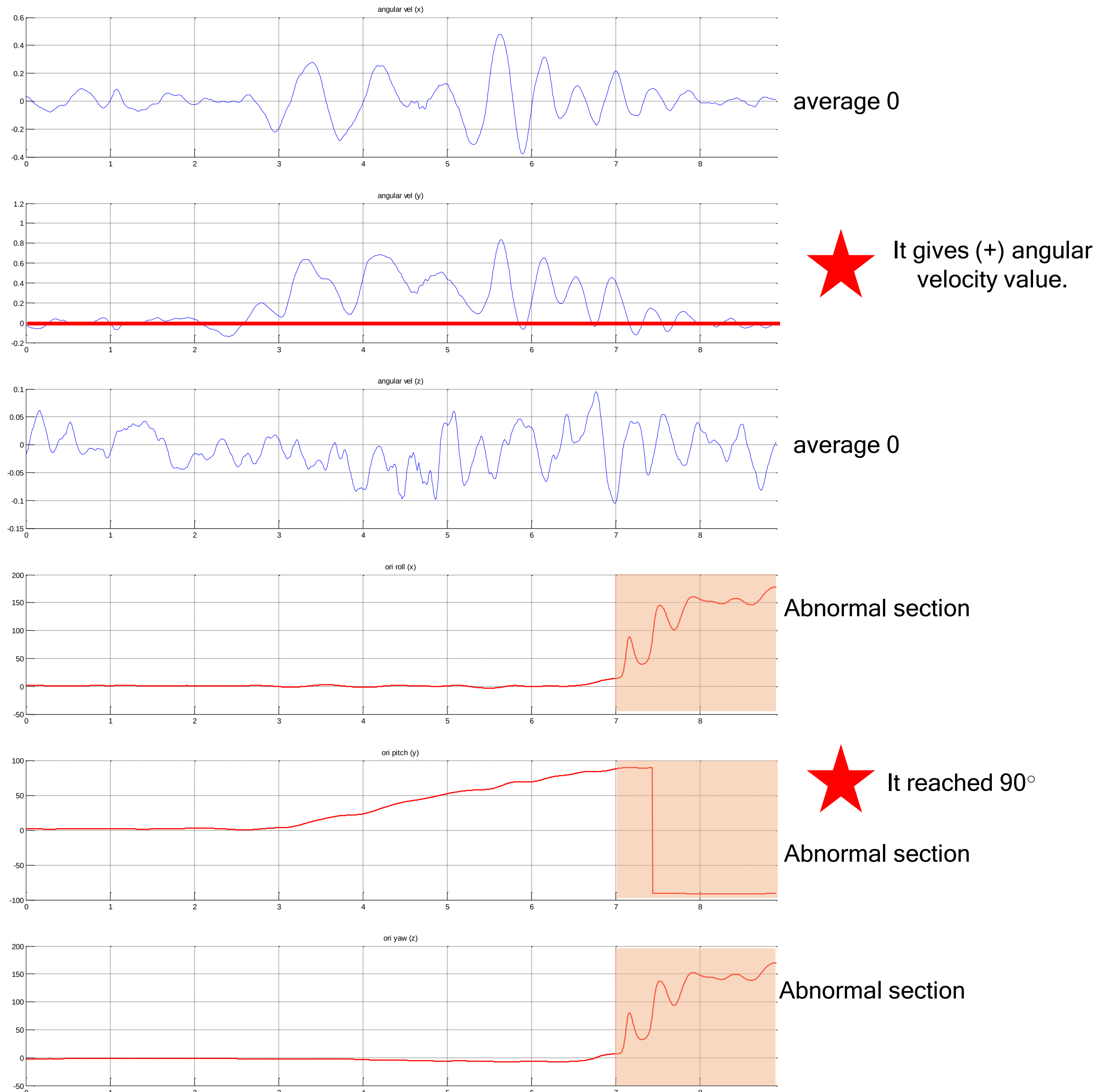
It reached -90°

Abnormal section

negligible variation

Exp3 Rot 0, rotation wrt y (counter-clockwise)

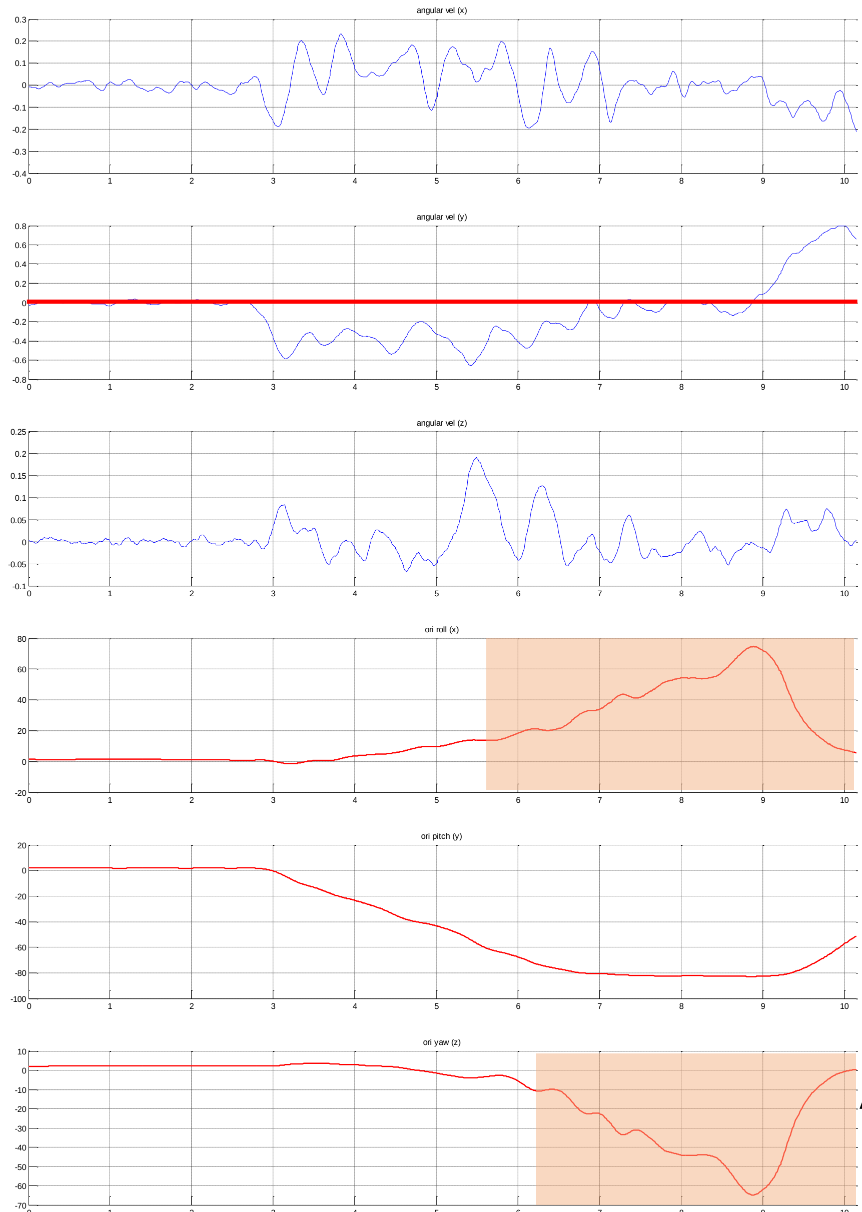
- 2018-08-20-16-01-10_abs_rot0_exp3



Exp4

Rot 0, rotation wrt y (clockwise)

- 2018-08-20-16-01-39_abs_rot0_exp4



average 0

★ It gives (-) angular velocity value.

average 0

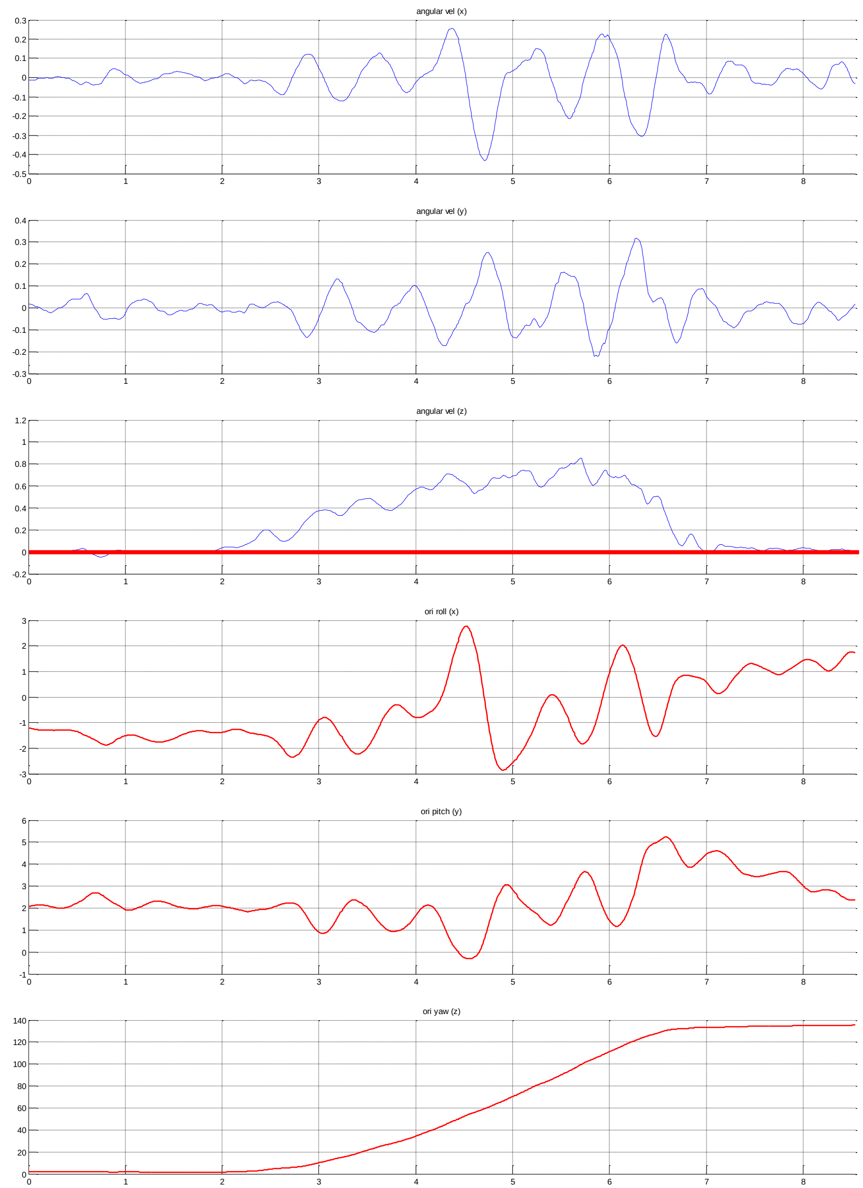
Abnormal section

★ It reached -90°

Abnormal section

Exp5 Rot 0, rotation wrt z (counter-clockwise)

- 2018-08-20-16-02-18_abs_rot0_exp5



average 0

average 0

It gives (+) angular velocity value.

negligible variation

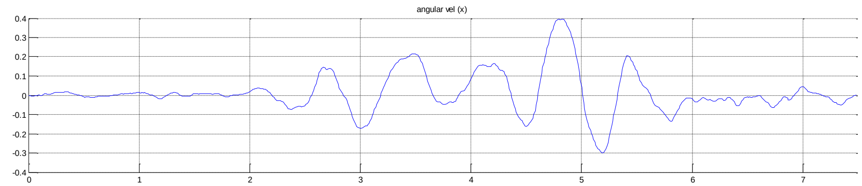
negligible variation

It reached 90°

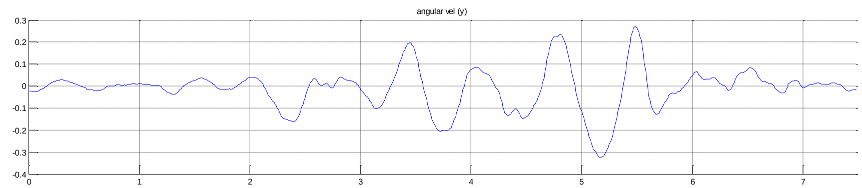
Exp6

Rot 0, rotation wrt z (clockwise)

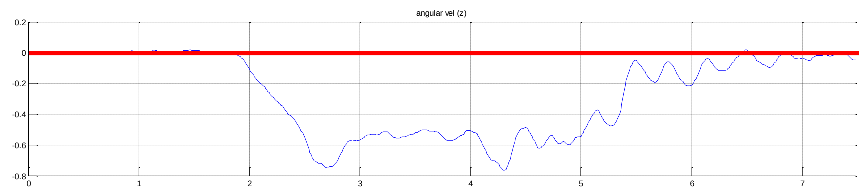
- 2018-08-20-16-02-47_abs_rot0_exp6



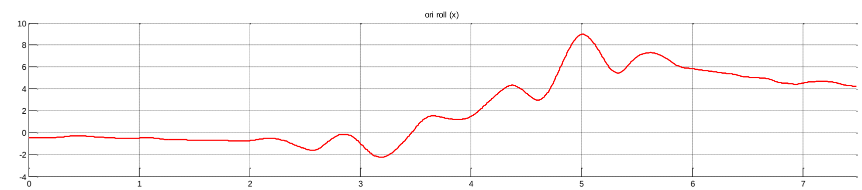
average 0



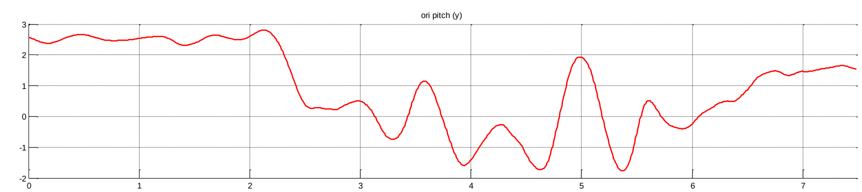
average 0



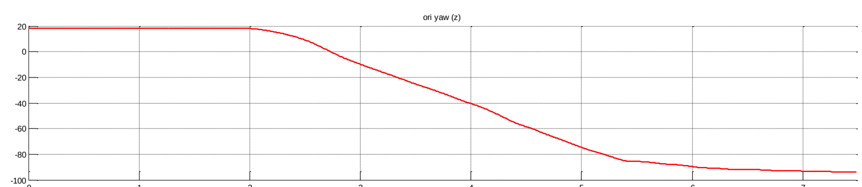
It gives (-) angular velocity value.



negligible variation



negligible variation

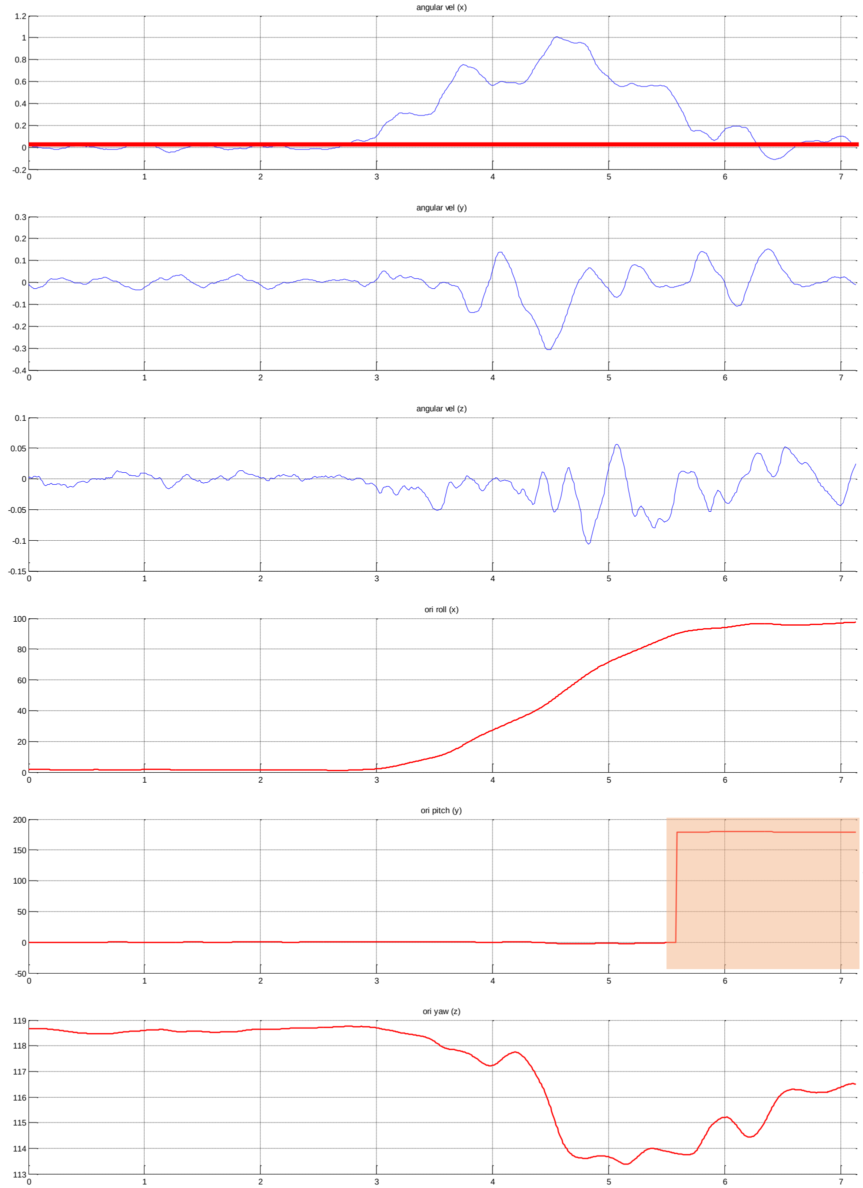


It reached -90◦

Rot 135

Exp1 Rot 135, rotation wrt x (counter-clockwise)

- 2018-08-20-16-04-22_abs_rot135_exp1



It gives (+) angular velocity value.

average 0

average 0

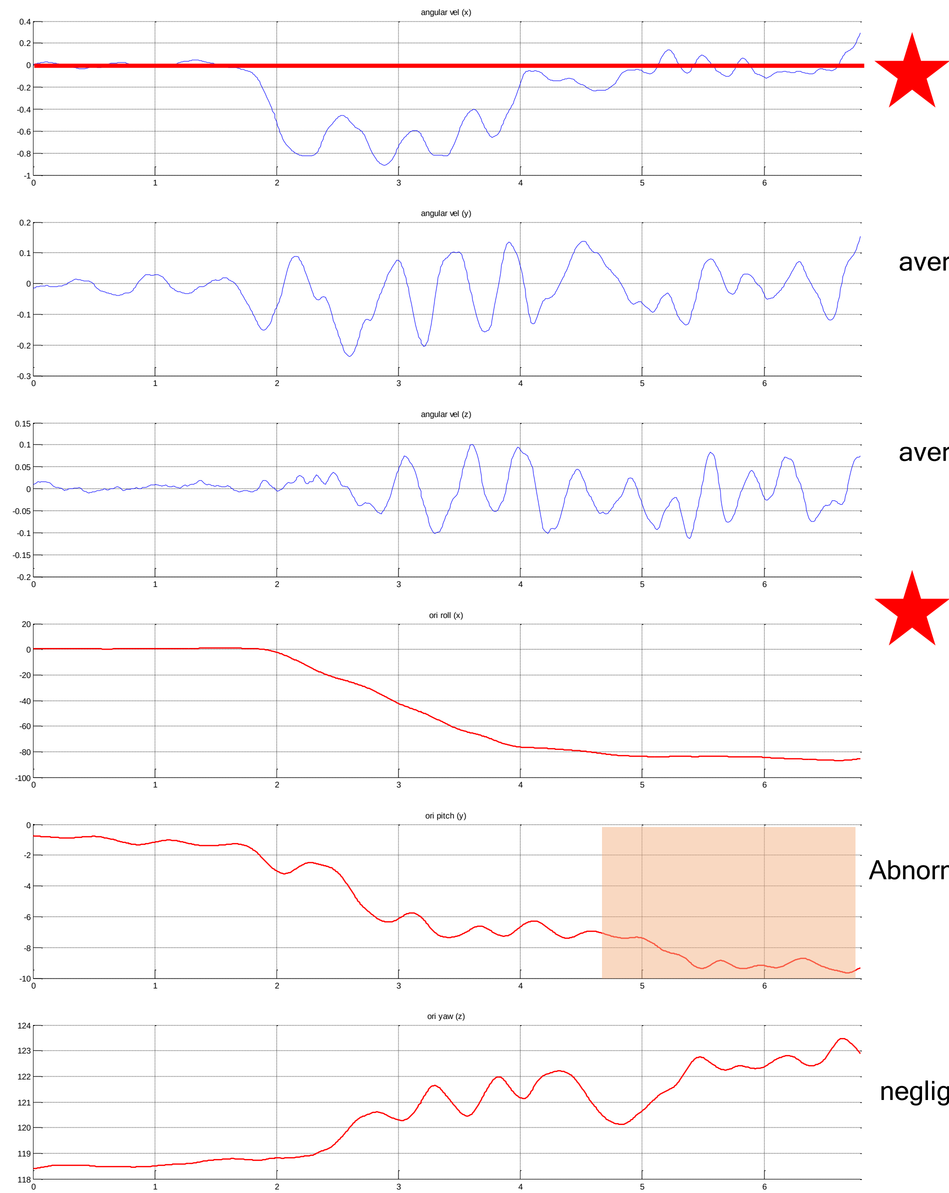
It reached 90°

Abnormal section

negligible variation

Rot 135, rotation wrt x (clockwise)

- 2018-08-20-16-04-22_abs_rot135_exp2



It gives (-) angular velocity value.

average 0

average 0

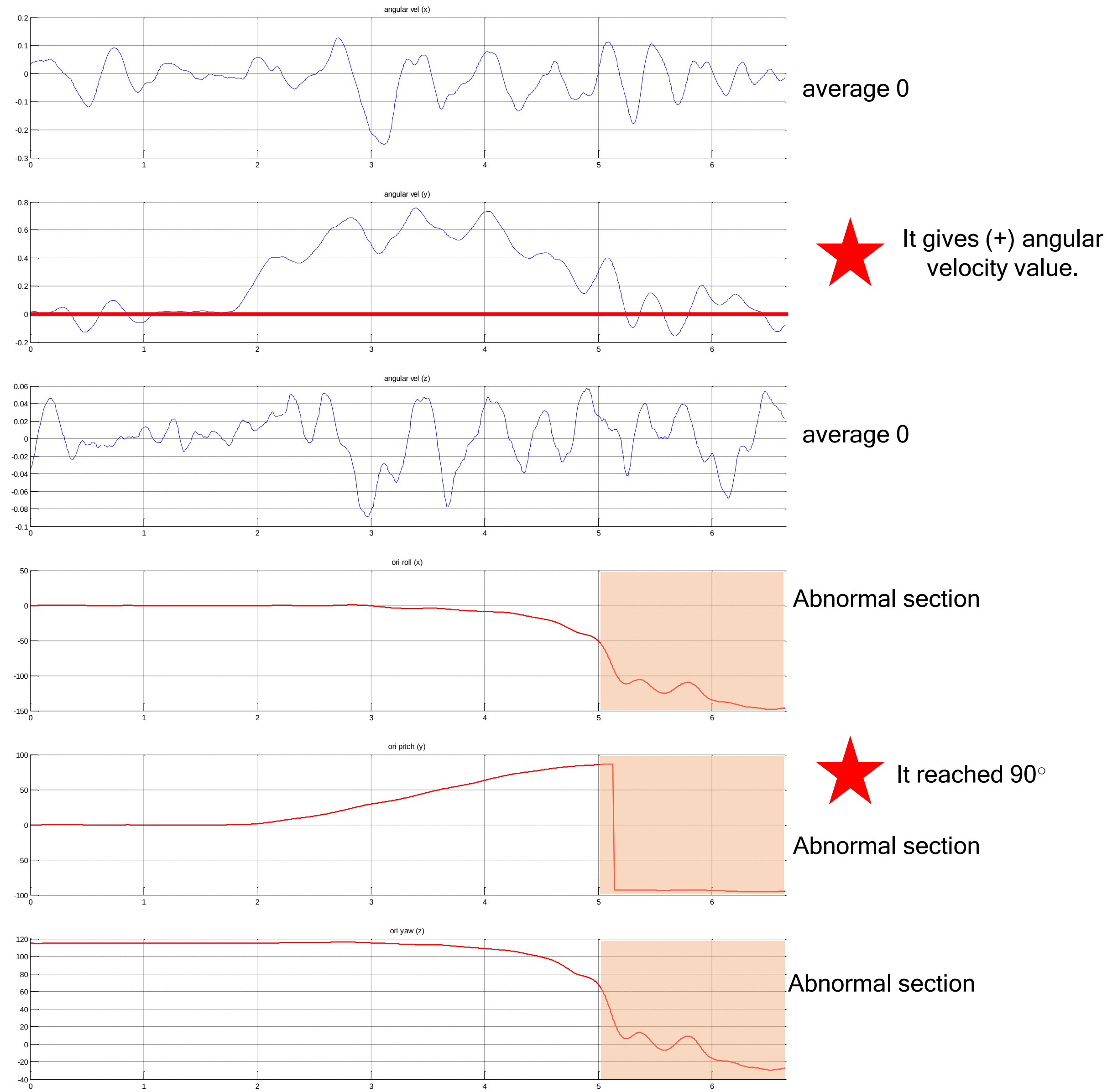
It reached -90°

Abnormal section

negligible variation

Rot 135, rotation wrt y (counter-clockwise)

- 2018-08-20-16-04-22_abs_rot135_exp3



Exp4

Rot 135, rotation wrt y (clockwise)

- 2018-08-20-16-06-08_abs_rot135_exp4

average 0

★ It gives (-) angular velocity value.

average 0

Abnormal section

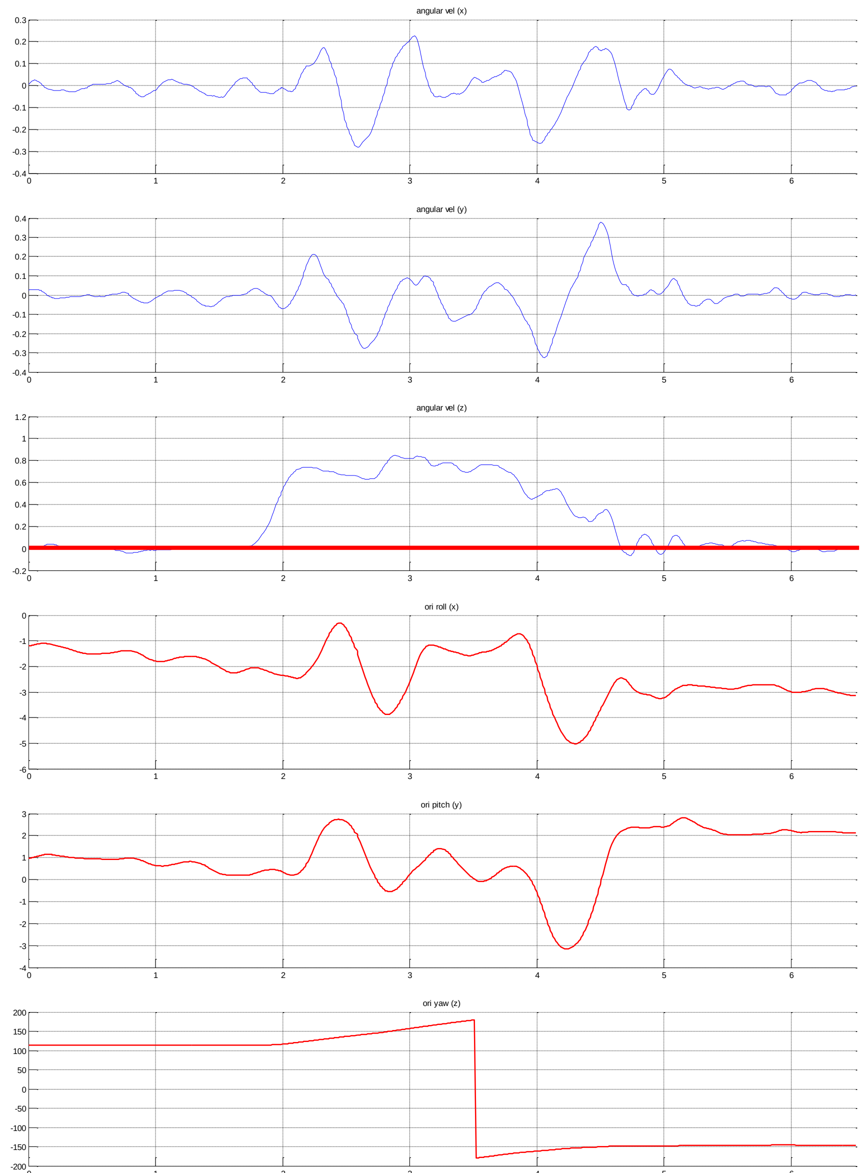
★ It reached -90°

Abnormal section

Exp5

Rot 135, rotation wrt z (counter-clockwise)

- 2018-08-20-16-06-41_abs_rot135_exp5



average 0

average 0

It gives (+) angular velocity value.

negligible variation

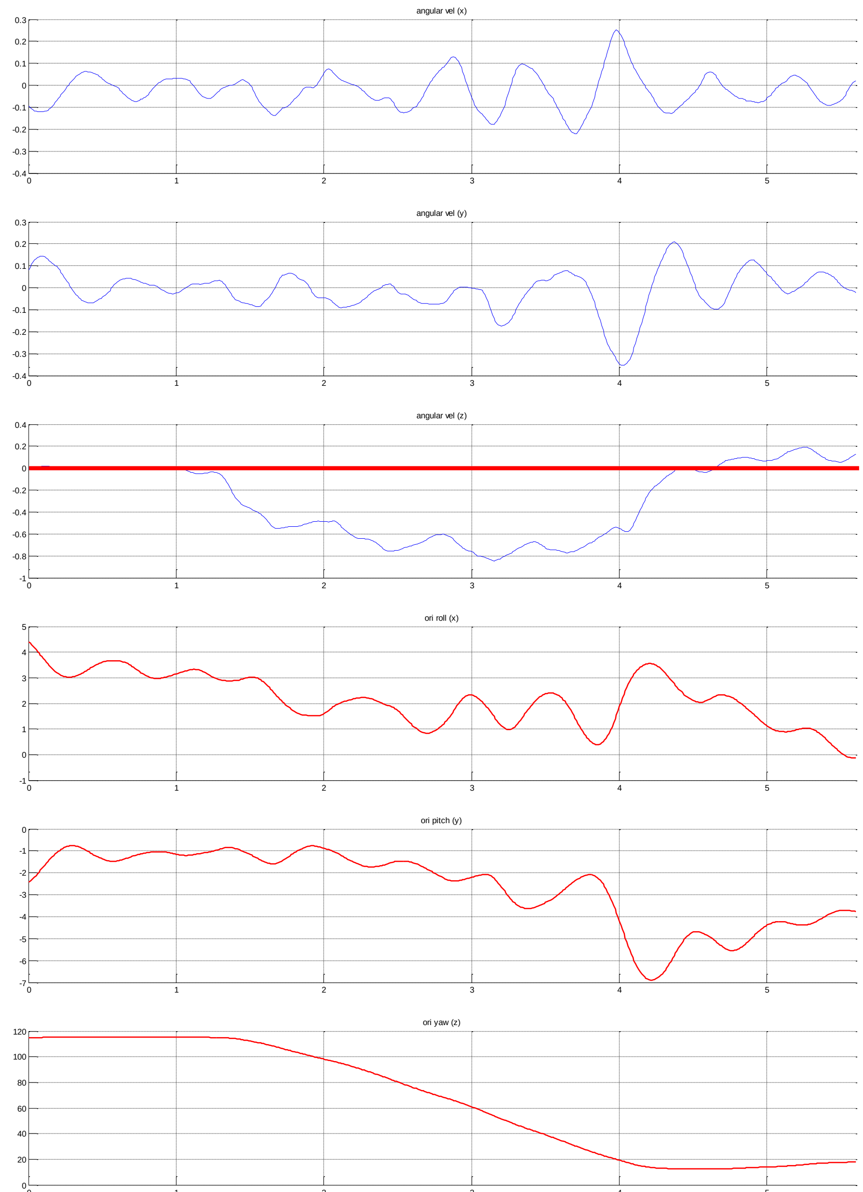
negligible variation

It reached around 135°

Exp6

Rot 135, rotation wrt z (clockwise)

- 2018-08-20-16-07-10_abs_rot135_exp6



average 0

average 0

It gives (-) angular velocity value.

negligible variation

negligible variation

It reached around 45°