Tether Conclusions

The following MATLAB Live Script details the conclusions of the tether experiments, including the resulting plots for a total of 30 experiments perfomed on the orange 4-limbed robot on the black mat. The data suggest that the influence of the tether is most pronounced with the original heavy tether, followed by the light sheath tether. Artefacts due to the movement / placement of the tether are present in the motion / twist plots which correlate with the videos. When the tether protocol is set to "not following", dependence on the tether movement are seen in twist plots as a dependence on the globale orientation of the robot. The comparative plots show that the tether influence is minimized when using the "no sheath" tether to the point that the tether protocol (following / not following) and placement do not have much impact on the resulting motion.

Future work includes analyzing the tether influence with lighter cables (AWG 32 vs the original AWG 26) and slip rings (to minimize torsion in the cable) as well as with newly synthesized gaits (as the current gaits are not optimized due to the influence of the tether on the data collection step of gait synthesis.

Extract and define parameters for GaitTest() objects.

From 20220707 Experiments:

Gait B-120 [heavy - not following (restting) - left/up]

Gait E-120 [heavy - not following - left/up]

Gait E-60 [heavy - not following - left/up]

Gait E-60* [heavy - not following - right/up] Caution! Not real E gait! Limb A not actuating

From 20220819 Experiments:

Gait B-120 [light sheath - not following (restting) - right/up]

From 20220829 Experiments:

Gait B Follow (Left)* [light sheath - following - left] Caution! Not real B gait! Limb A not actuating

Gait B Follow (Right)* [light sheath - following - right] Caution! Not real B gait! Limb A not actuating

Gait E Left (sheath on) [light sheath - not following - left]

Gait E Right (sheath on) [no sheath - not following - right]

Gait E Left (sheath off) [no sheath - not following - left]

Gait E Right (sheath off)* [no sheath - not following - right] Caution! Not real E gait! Limb B not actuating

From 20220901 Experiments:

Gait E Left (sheath off) [no sheath - not following - left (flipped)]

Gait B Follow (Left) Trial 1 [light sheath - following - left]

Gait B Follow (Left) Trial 2 [light sheath - following - left (flipped)]

Gait B Left (Sheath on) Trial 1 [light sheath - not following - left]

Gait B Left (Sheath on) Trial 2 [light sheath - not following - left (flipped)]

From 20220908 Experiments:

Gait B Right (sheath on) [sheath - not following - right] (not consistent / semi-following)

Gait B Right Follow (sheath off) Trial 1 [no sheath - following - right]

Gait B Right Follow (sheath off) Trial 2 [no sheath - following - right]

Gait B Left Follow (sheath off) Trial 1 [no sheath - following - left]

Gait B Left Follow (sheath off) Trial 2 [no sheath - following - left]

Gait B Right (sheath off) Trial 1 [no sheath - not following - right] (not consistent / semi-following)

Gait B Right (sheath off) Trial 2 [no sheath - not following - right] (not consistent / semi-following)

Gait B Left (sheath off) Trial 1 [no sheath - not following - left] (not consistent / semi-following)

Gait B Left (sheath off) Trial 2 [no sheath - not following - left] (not consistent / semi-following)

Gait B Right Follow (sheath on) [sheath - following - right]

Gait E Right (sheath off) Trial 1 [no sheath - not following - right] (not consistent / semi-following)

Gait E Right (sheath off) Trial 2 [no sheath - not following - right] (not consistent / semi-following)

Gait E Left (sheath off) Trial 1 [no sheath - not following - left] (not consistent / semi-following)

Gait E Left (sheath off) Trial 2 [no sheath - not following - left] (not consistent / semi-following)

From 20220928 Experiments:

Gait B Left AWG 32 Trial 1 [AWG 32 sheath - not following - left]

Gait B Left AWG 32 Trial 2 [AWG 32 sheath - not following - left]

Gait B Right AWG 32 Trial 1 [AWG 32 sheath - not following - right]

Gait B Right AWG 32 Trial 2 [AWG 32 sheath - not following - right]

Gait B Right AWG 32 Trial 1 [AWG 32 slip ring - not following - right]

Gait B Right AWG 32 Trial 2 [AWG 32 slip ring - not following - right]

Build Experiment Matrix

```
sorted_exps = 35×7 table
```

	Experiment	Gait	#Cycles	Tether	Protocol	Placement	Trial
1	31	'B'	'60'	'32'	'NF'	'L'	1
2	32	'B'	'60'	'32'	'NF'	'L'	2
3	33	'B'	'60'	'32'	'NF'	'R'	1
4	34	'B'	'60'	'32'	'NF'	'R'	2
5	35	'B'	'60'	'32SR'	'NF'	'R'	2
6	1	'B'	'120'	'H'	'NF'	'L'	
7	20	'B'	'60'	'NS'	'F'	'L'	
8	21	'B'	'60'	'NS'	'F'	'L'	2
9	18	'B'	'60'	'NS'	'F'	'R'	
10	19	'B'	'60'	'NS'	'F'	'R'	2
11	24	'B'	'60'	'NS'	'NF'	'L'	
12	25	'B'	'60'	'NS'	'NF'	'L'	2
13	22	'B'	'60'	'NS'	'NF'	'R'	
14	23	'B'	'60'	'NS'	'NF'	'R'	2
15	13	'B'	'60'	'S'	'F'	'L'	
16	14	'B'	'60'	'S'	'F'	'Lf'	
17	26	'B'	'60'	'S'	'F'	'R'	
18	15	'B'	'60'	'S'	'NF'	'L'	
19	16	'B'	'60'	'S'	'NF'	'Lf'	
20	5	'B'	'120'	'S'	'NF'	'R'	
21	17	'B'	'60'	'S'	'NF'	'R'	
22	6	'Bs'	'60'	'S'	'F'	'L'	
23	7	'Bs'	'60'	'S'	'F'	'R'	
24	2	'E'	'120'	'H'	'NF'	'L'	
25	3	'E'	'60'	'H'	'NF'	'L'	
26	10	'E'	'60'	'NS'	'NF'	'L'	
27	29	'E'	'60'	'NS'	'NF'	'L'	2
28	30	'E'	'60'	'NS'	'NF'	'L'	3
29	12	'E'	'60'	'NS'	'NF'	'Lf'	
30	27	'E'	'60'	'NS'	'NF'	'R'	
31	28	'E'	'60'	'NS'	'NF'	'R'	2
32	8	'E'	'60'	'S'	'NF'	'L'	
33	9	'E'	'60'	'S'	'NF'	'R'	

	Experiment	Gait	#Cycles	Tether	Protocol	Placement	Trial
34	4	'Es'	'60'	'H'	'NF'	'R'	
35	11	'Es'	'60'	'NS'	'NF'	'R'	

Analyze the experiment data:

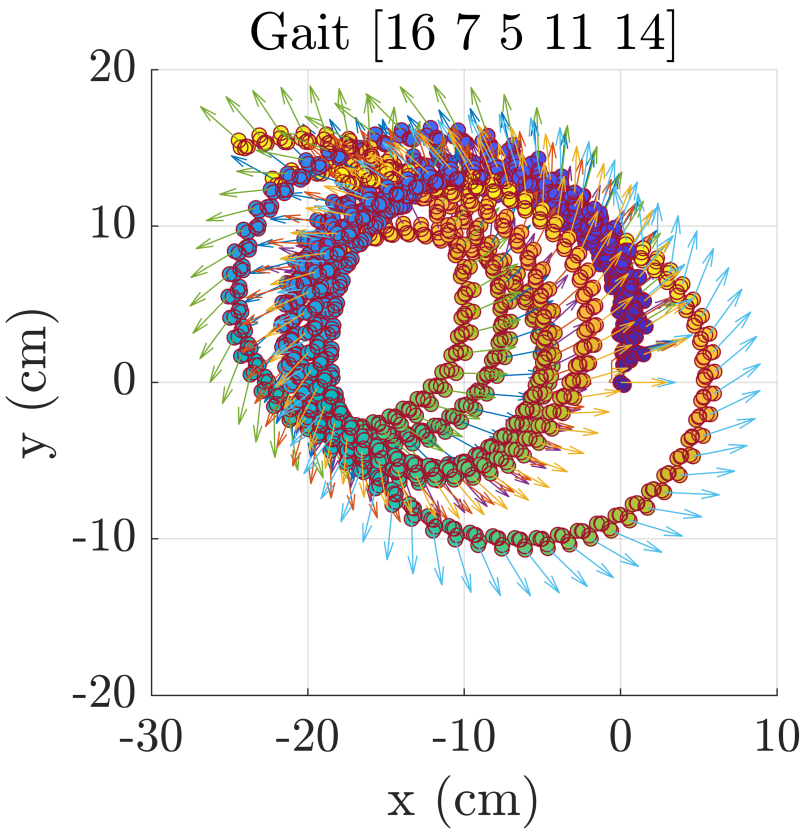
1. Rotate the data w.r.t. the initial global orientation.

2. Instantiate GaitTest() objects for each experimental trial.

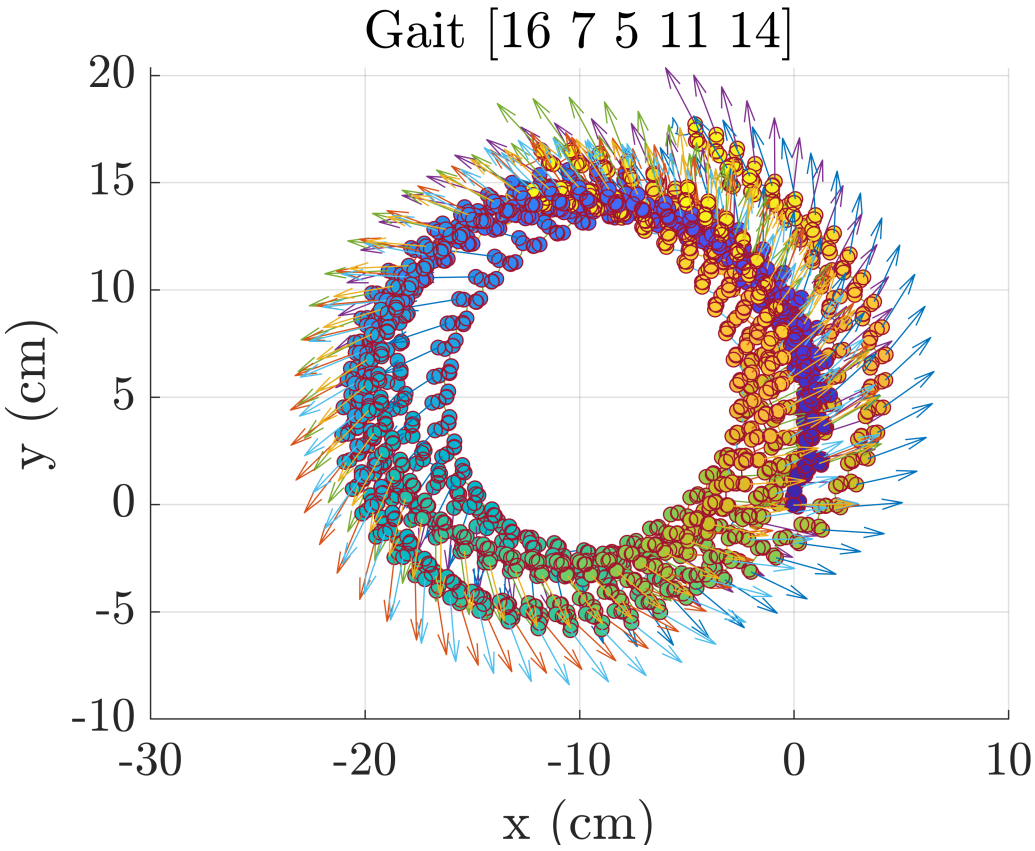
3. Calculate twists for each gait experiment.

Construct comparative motion plots.

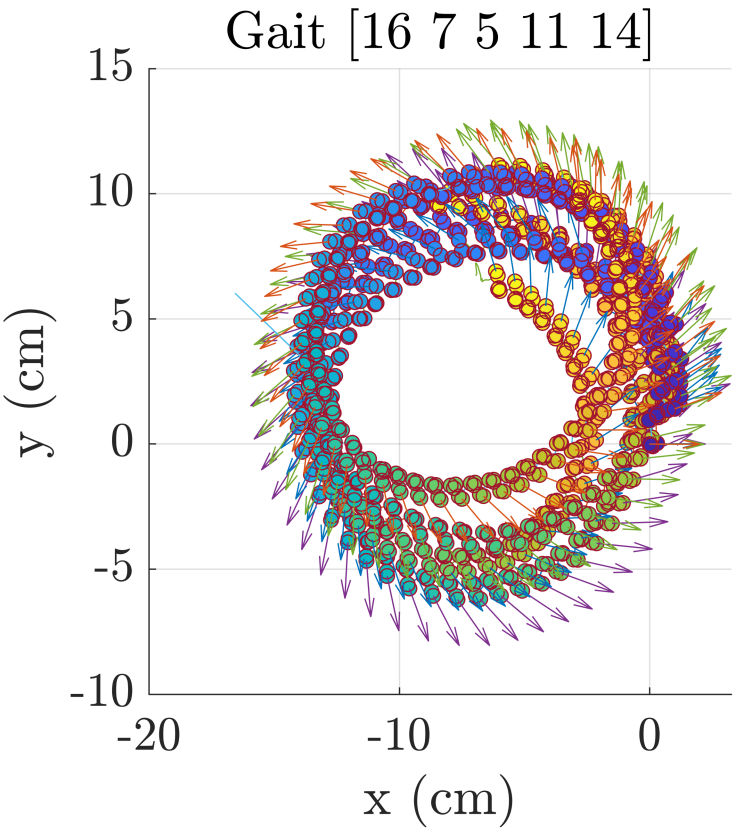
Comparison (overlay) of 6 trials of gait B (light sheath):



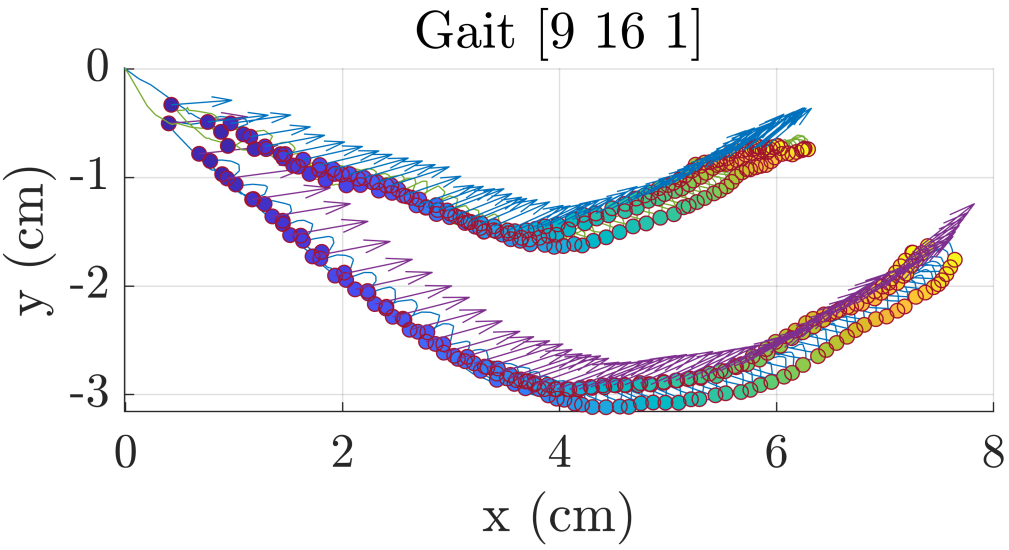
Comparison (overlay) of 6 trials of gait B (no sheath):



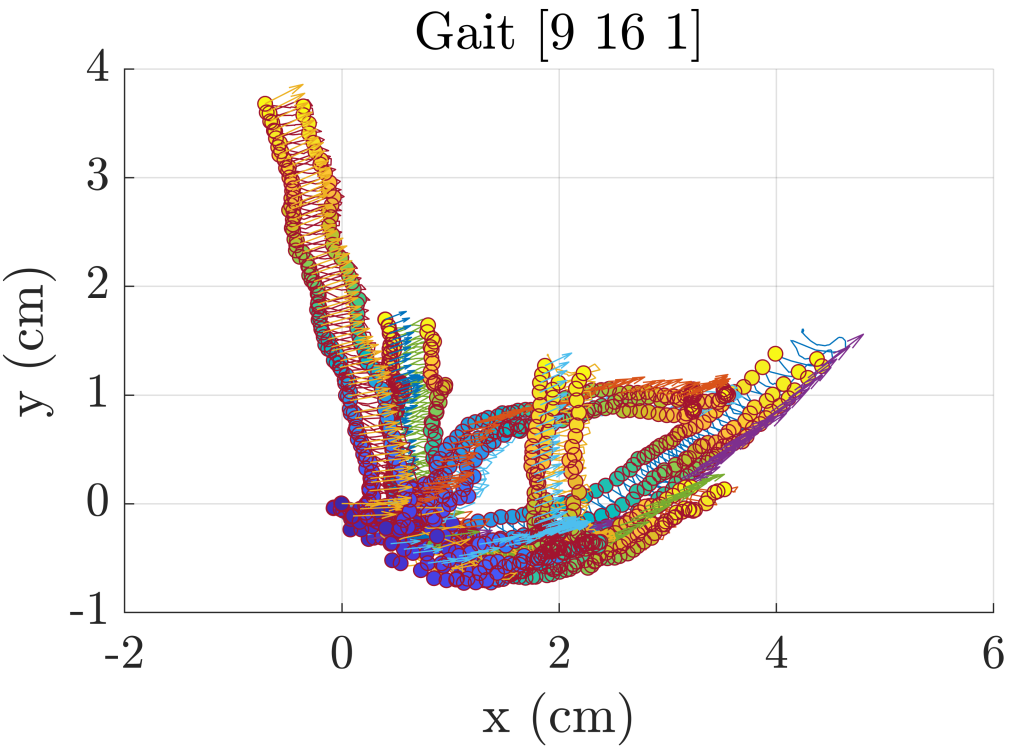
Comparison (overlay) of 5 trials of gait B (32 AWG sheath):



Comparison (overlay) of 2 trials of gait E (light sheath):

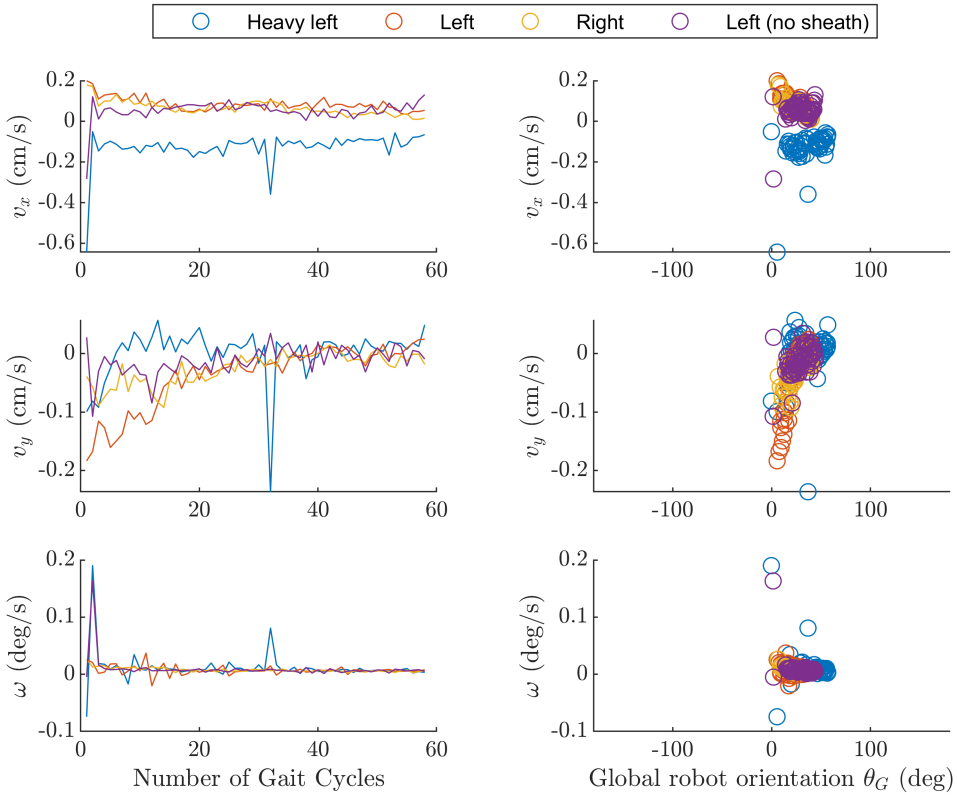


Comparison (overlay) of 6 trials of gait E (no sheath):

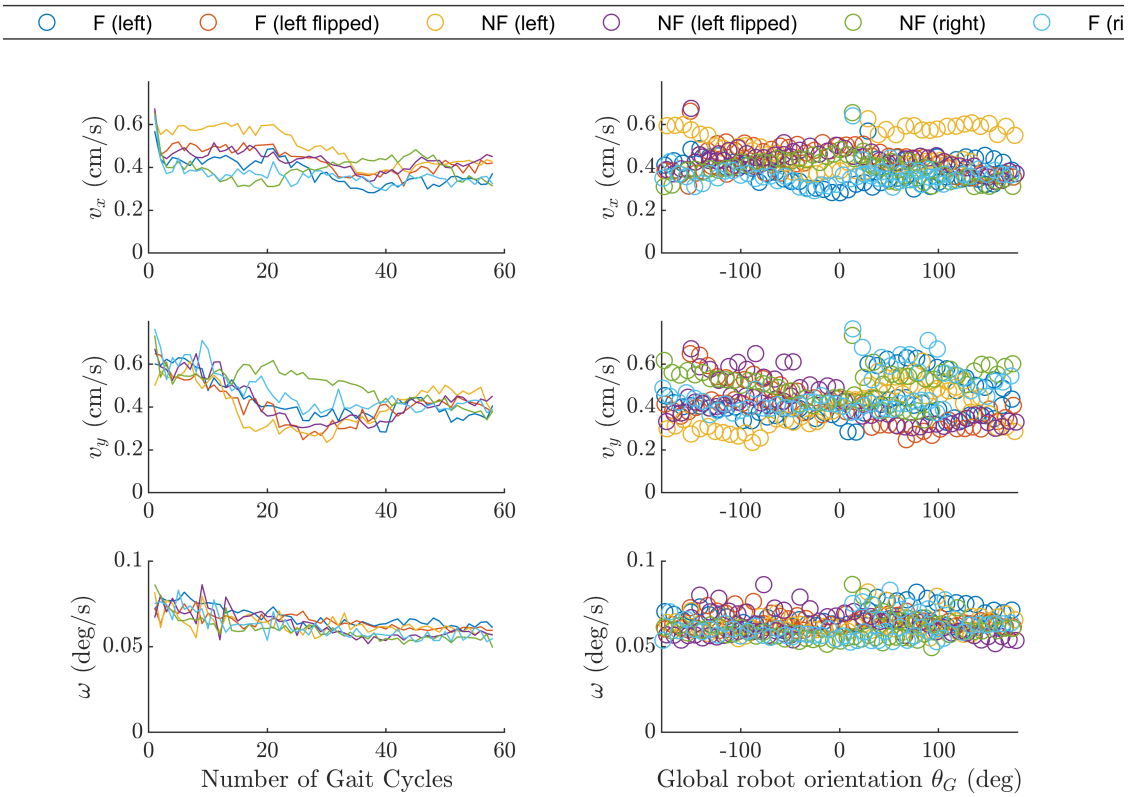


Construct comparative twist plots.

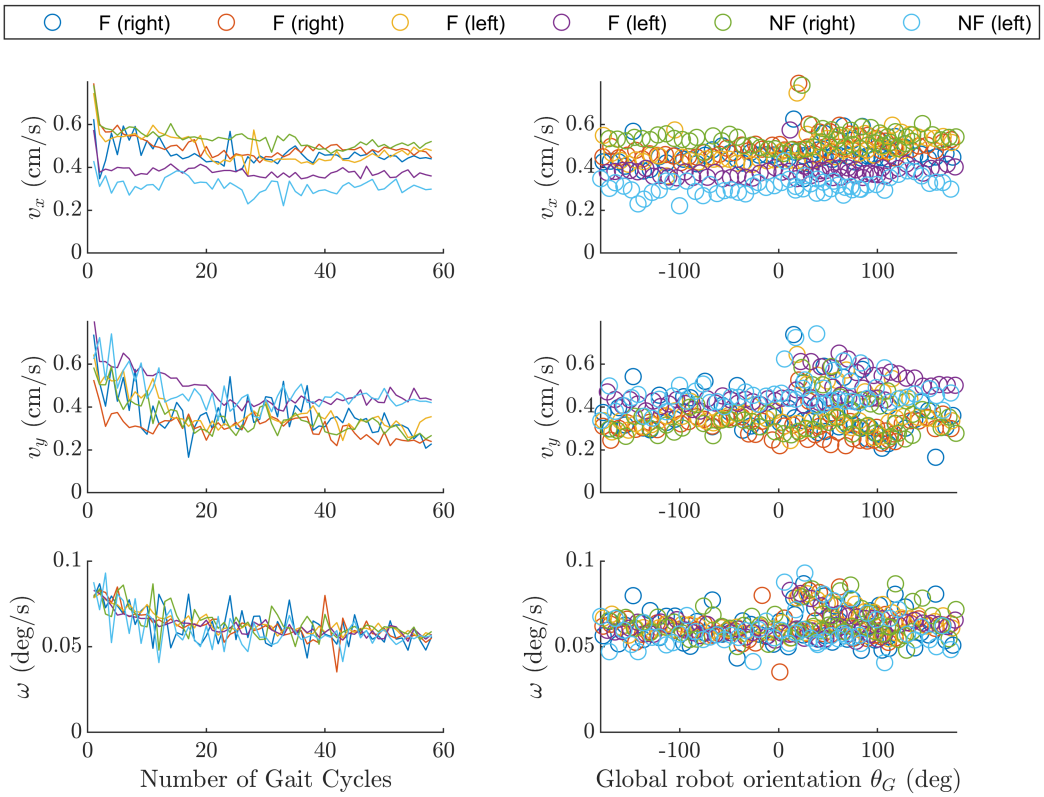
Twist comparison for 4 trials of gait E:



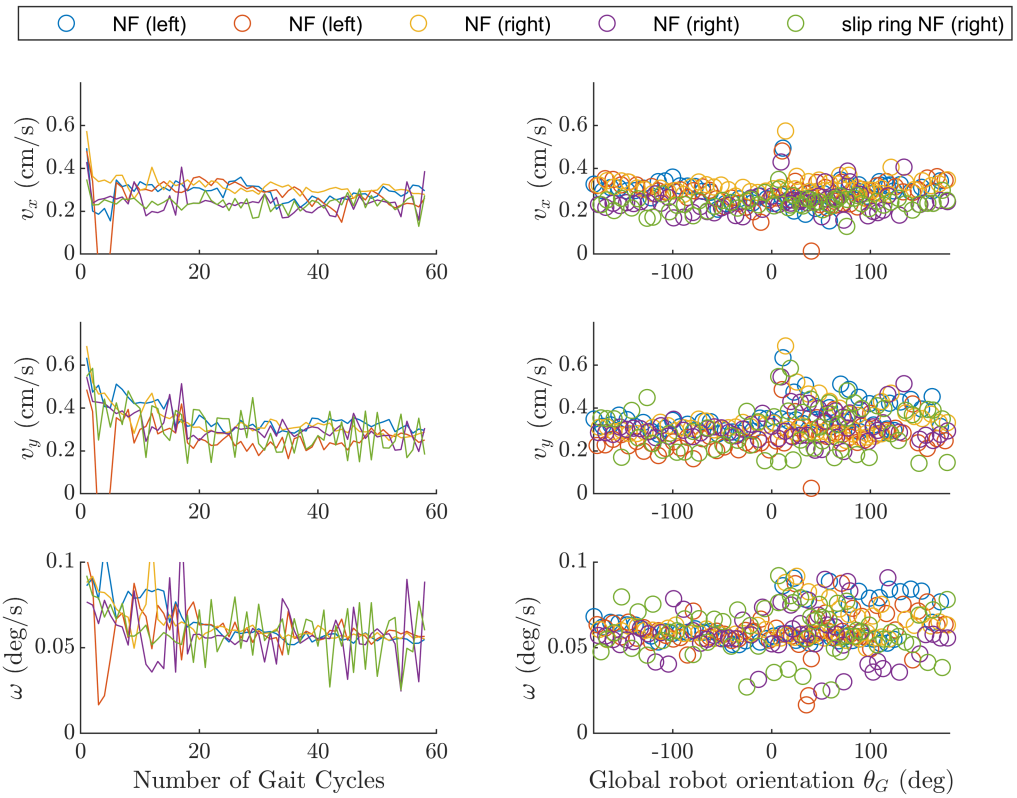
Twist comparison for 6 trials of gait B (light sheath):



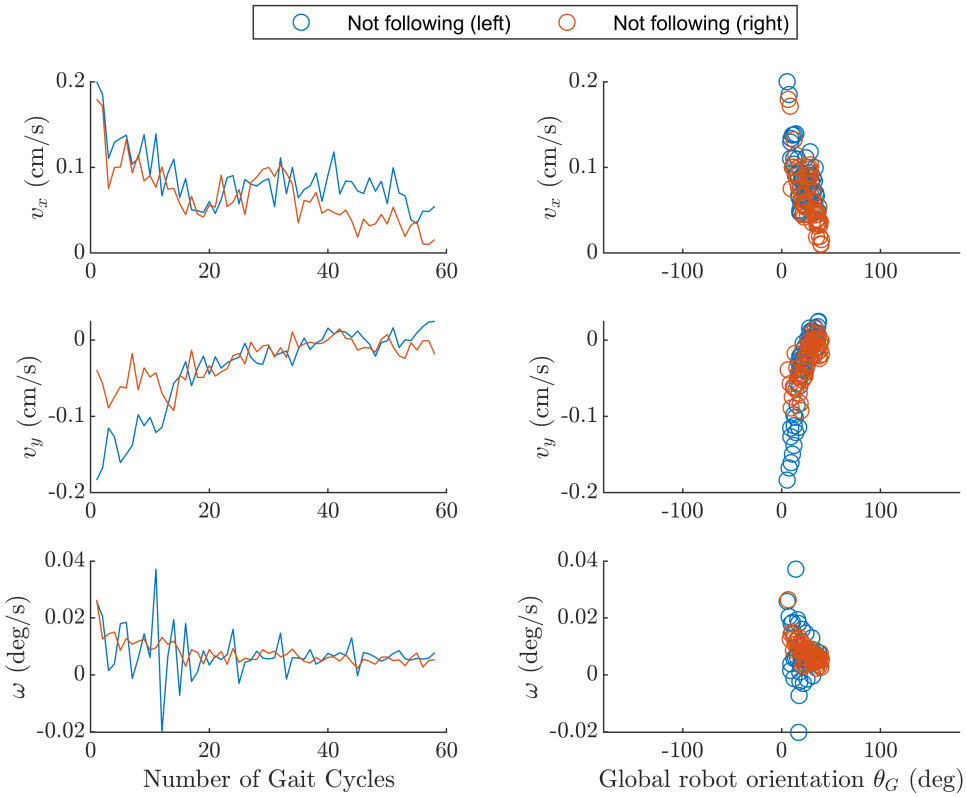
Twist comparison for 6 trials of gait B (no sheath):



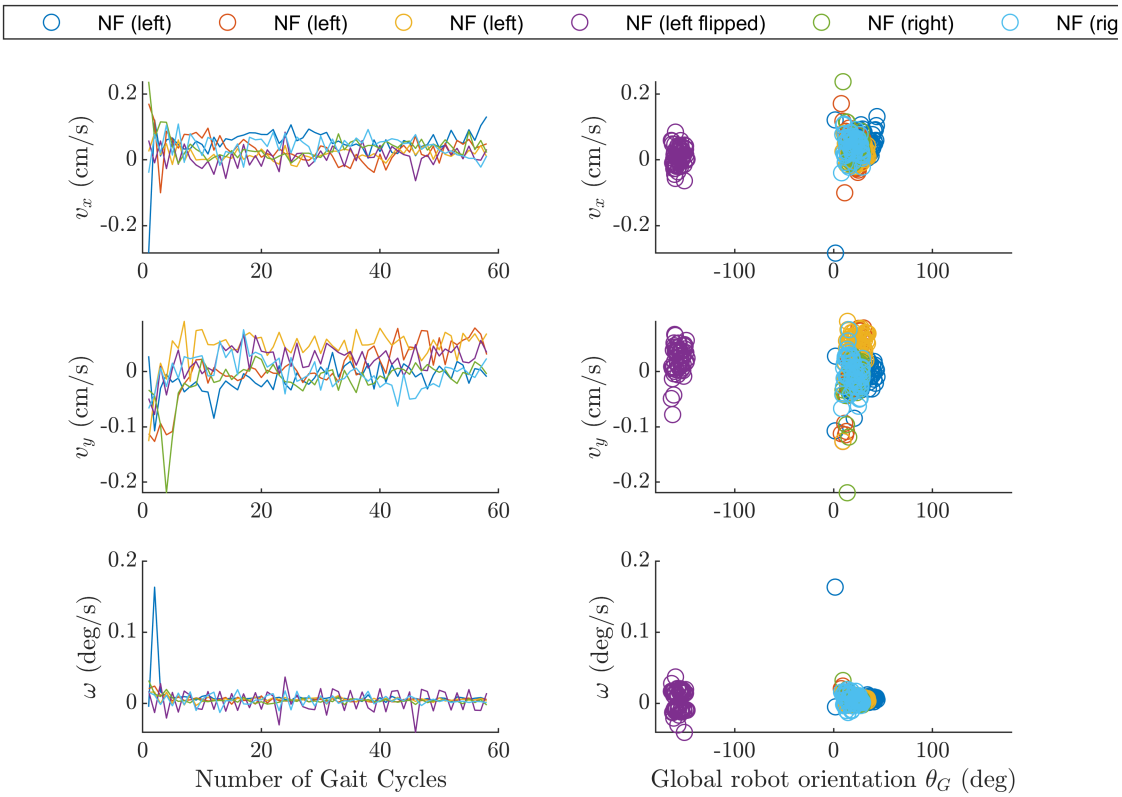
Twist comparison for 5 trials of gait B (32 AWG sheath):



Twist comparison for 2 trials of gait E (light sheath):

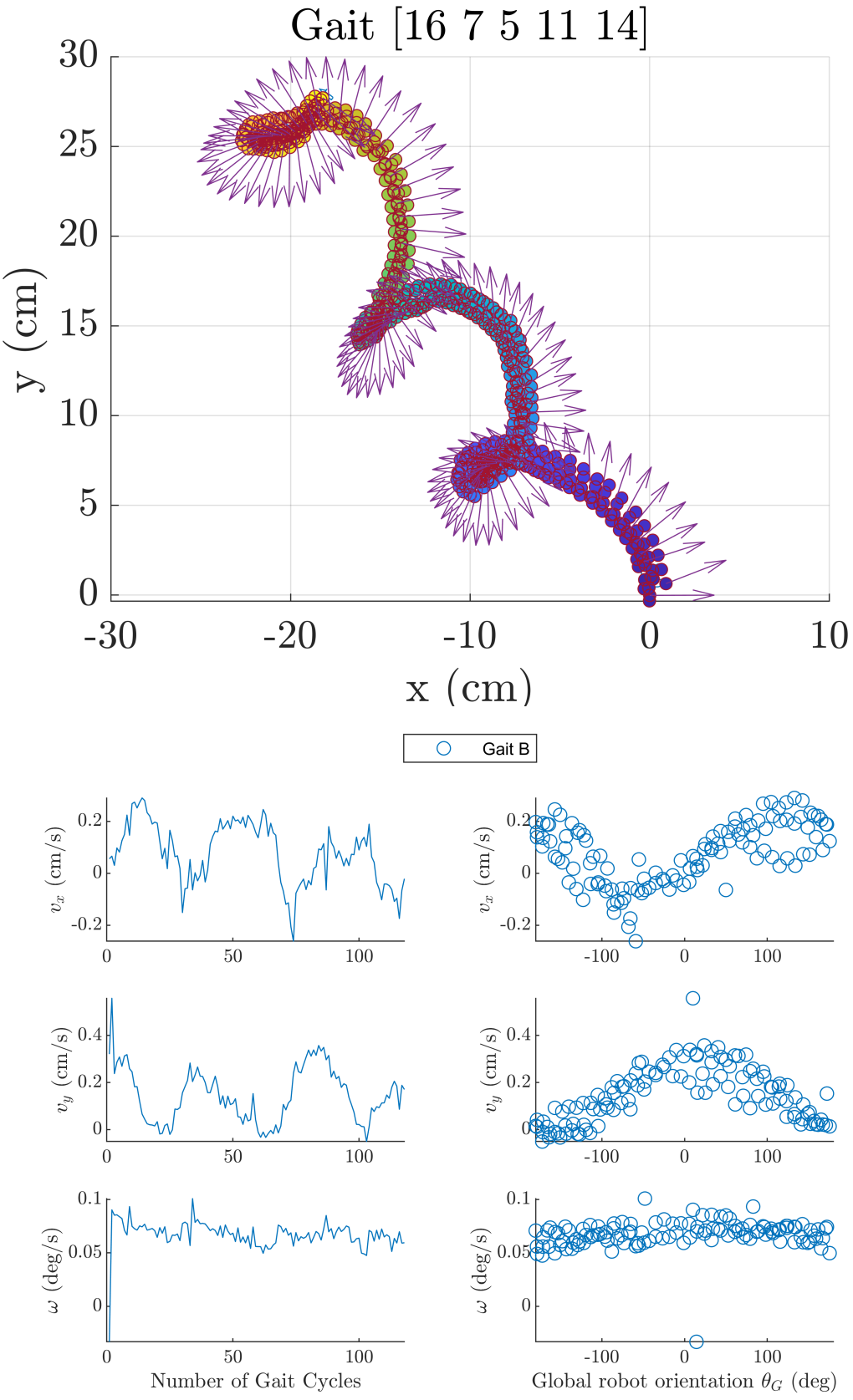


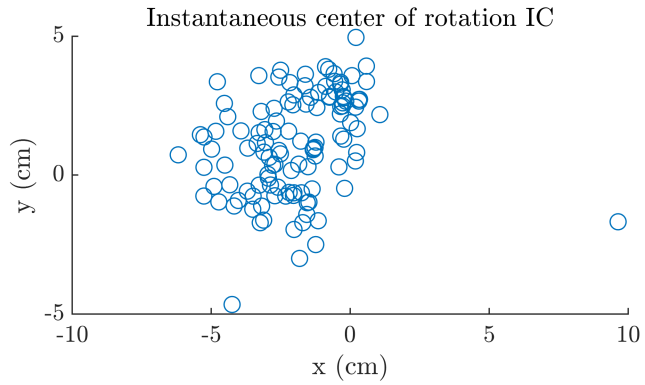
Twist comparison for 6 trials of gait E (no sheath):

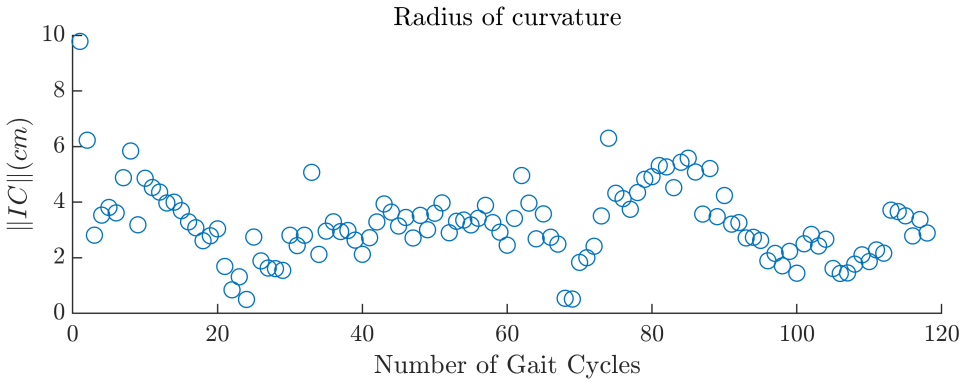


Make exhaustive plots for each experiment.

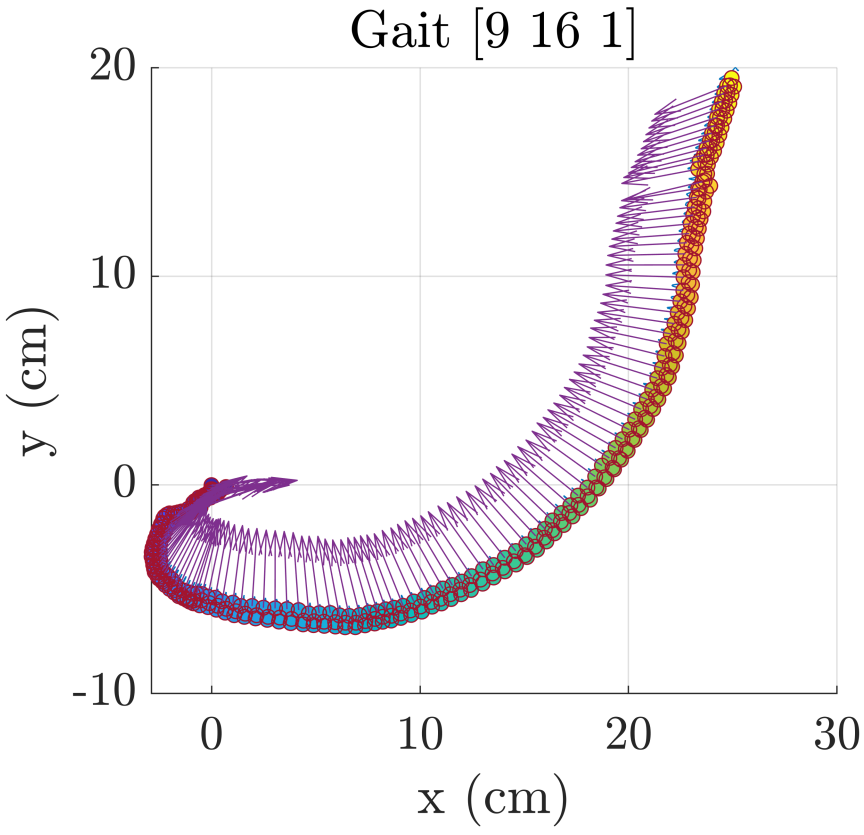
`Experiment 1 : 120 cycles of Gait B with heavy sheath tether ( left , not following ), trial 1`

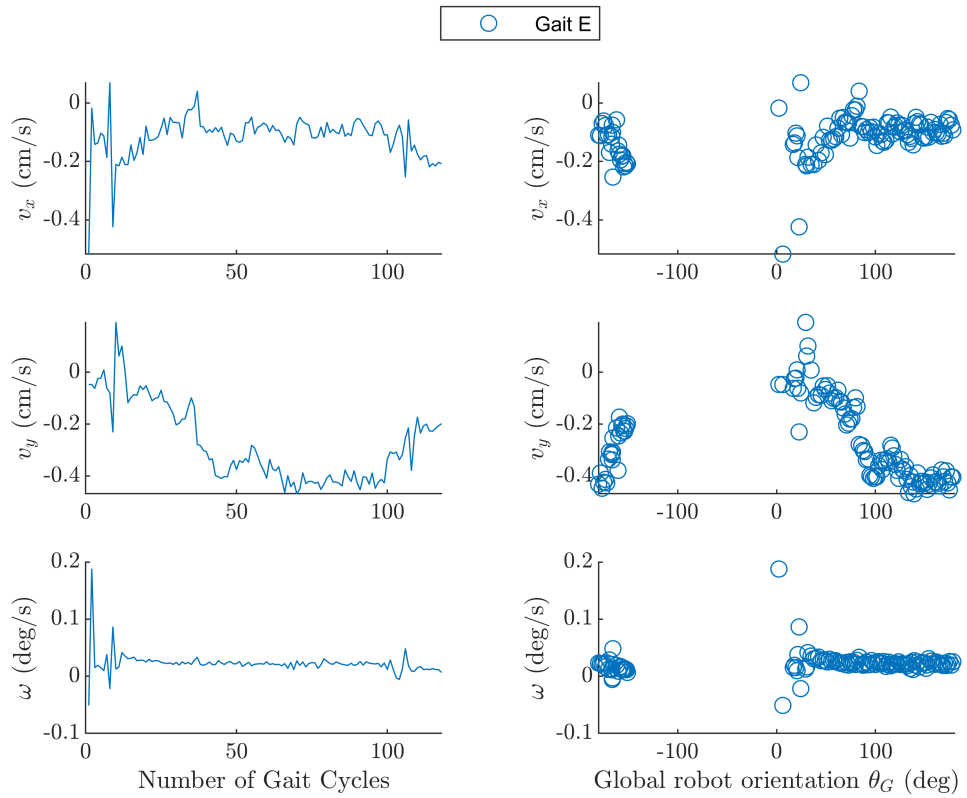

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

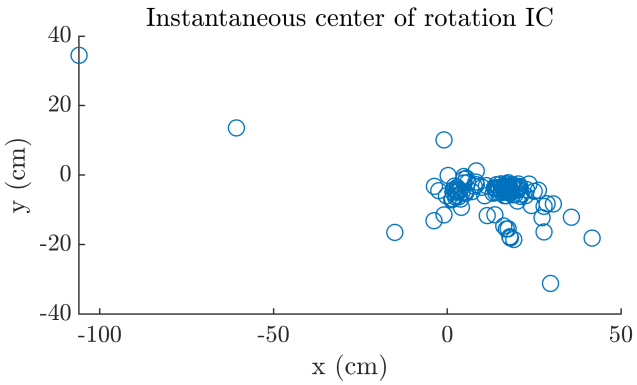


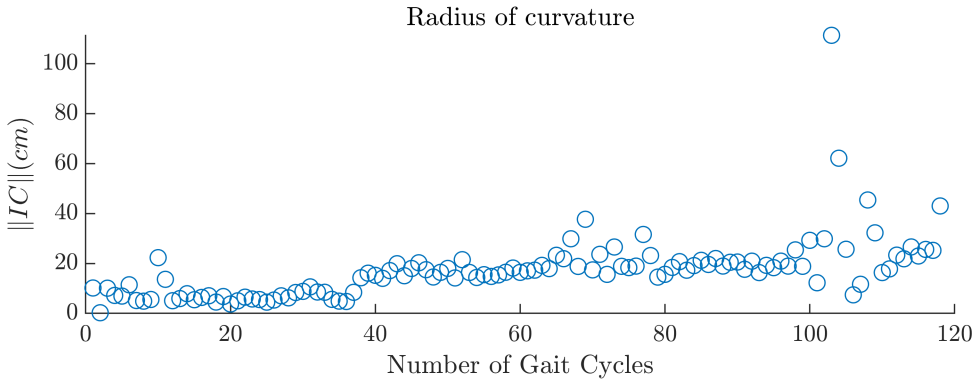


Experiment 2 : 120 cycles of Gait E with heavy sheath tether (left , not following), trial 1

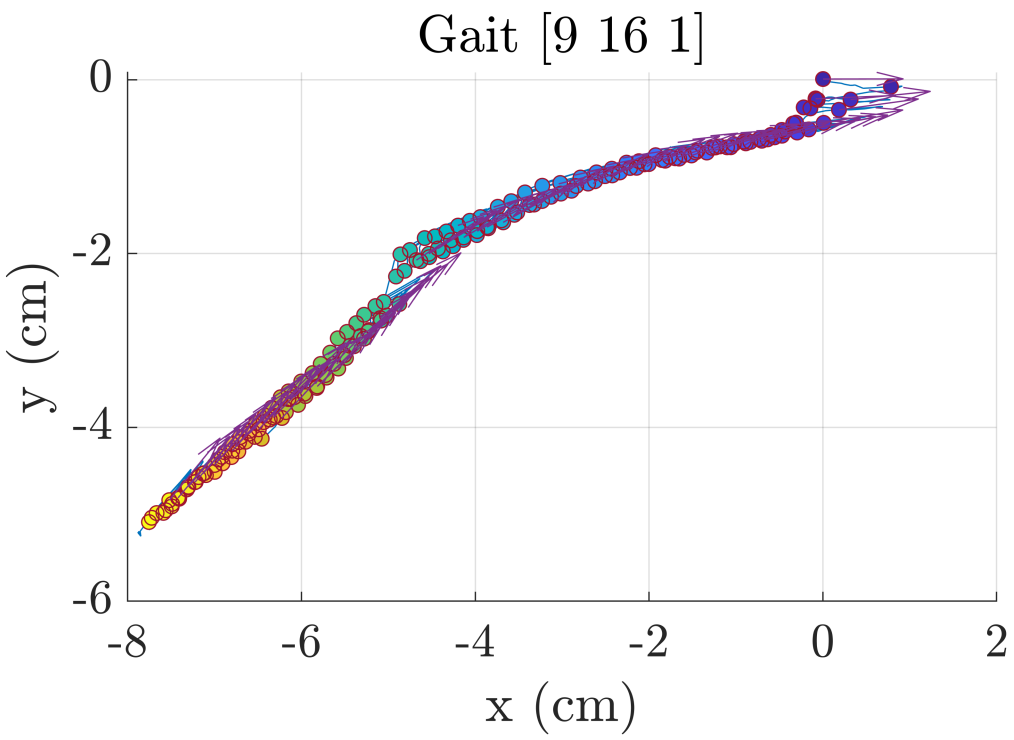


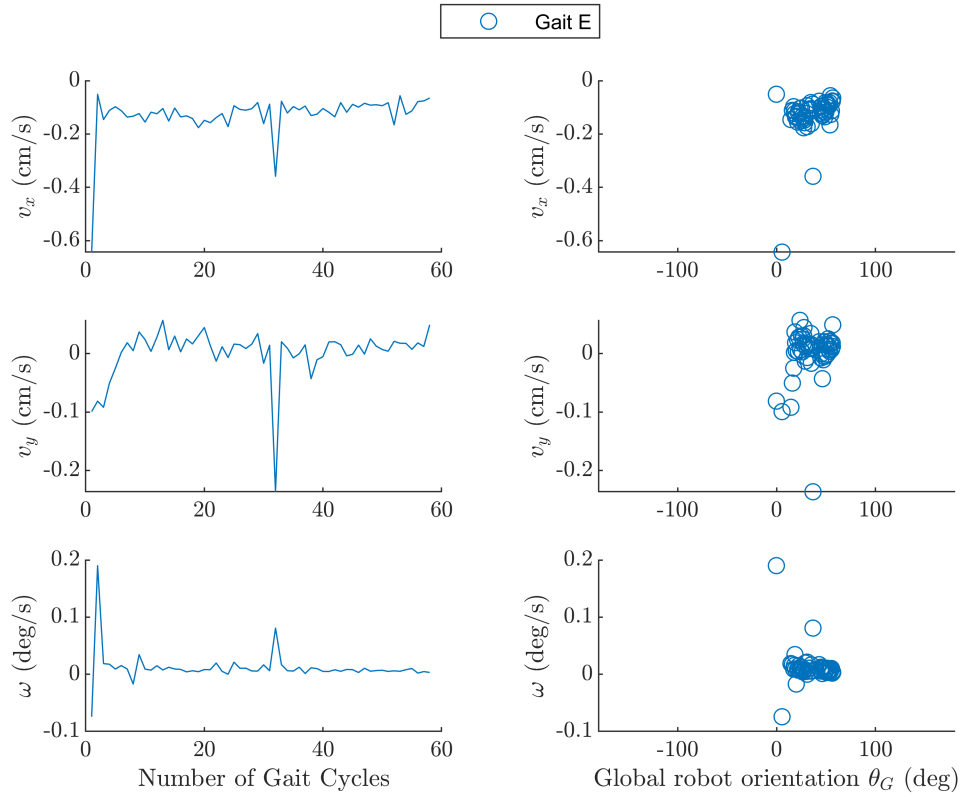


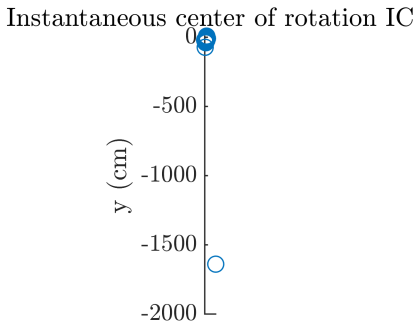


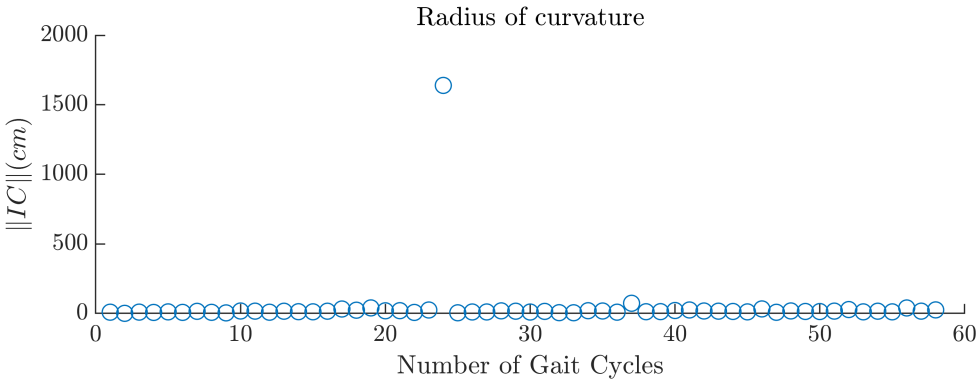


Experiment 3 : 60 cycles of Gait E with heavy sheath tether (left , not following), trial 1

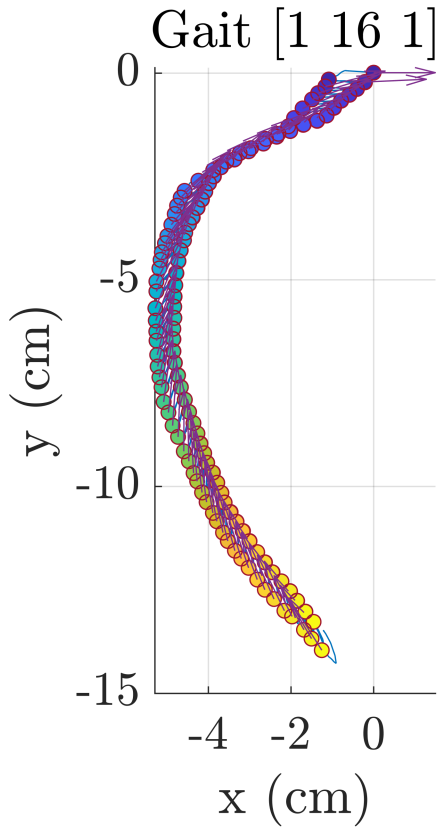

Gait [9 16 1]
y (cm)
x (cm)
0
-2
-4
-6
-8
-6
-4
-2
0
2

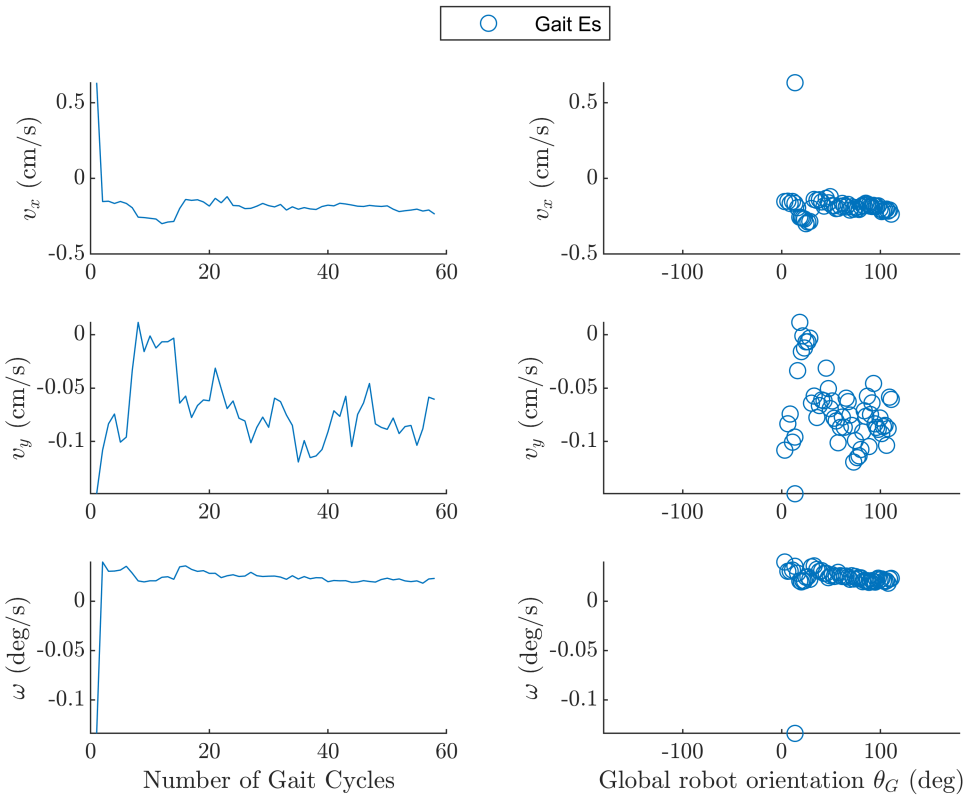

Gait E
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

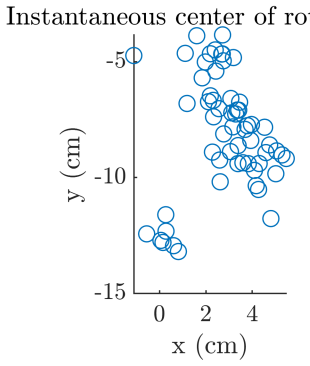


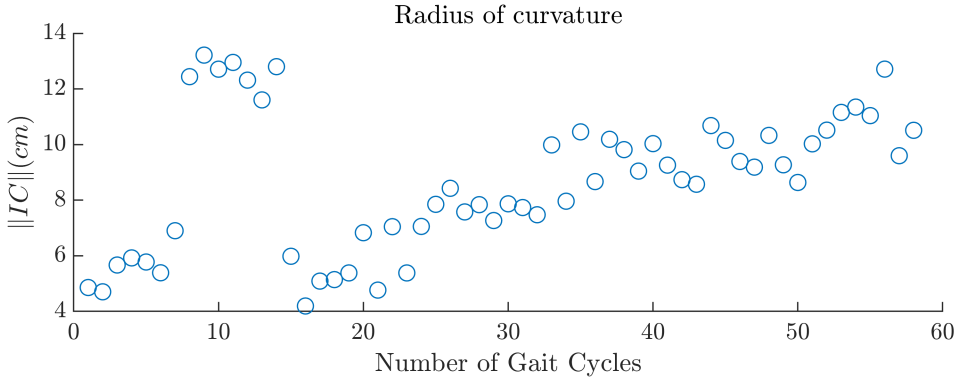


Experiment 4 : 60 cycles of Gait Es with heavy sheath tether (right , not following), trial 1

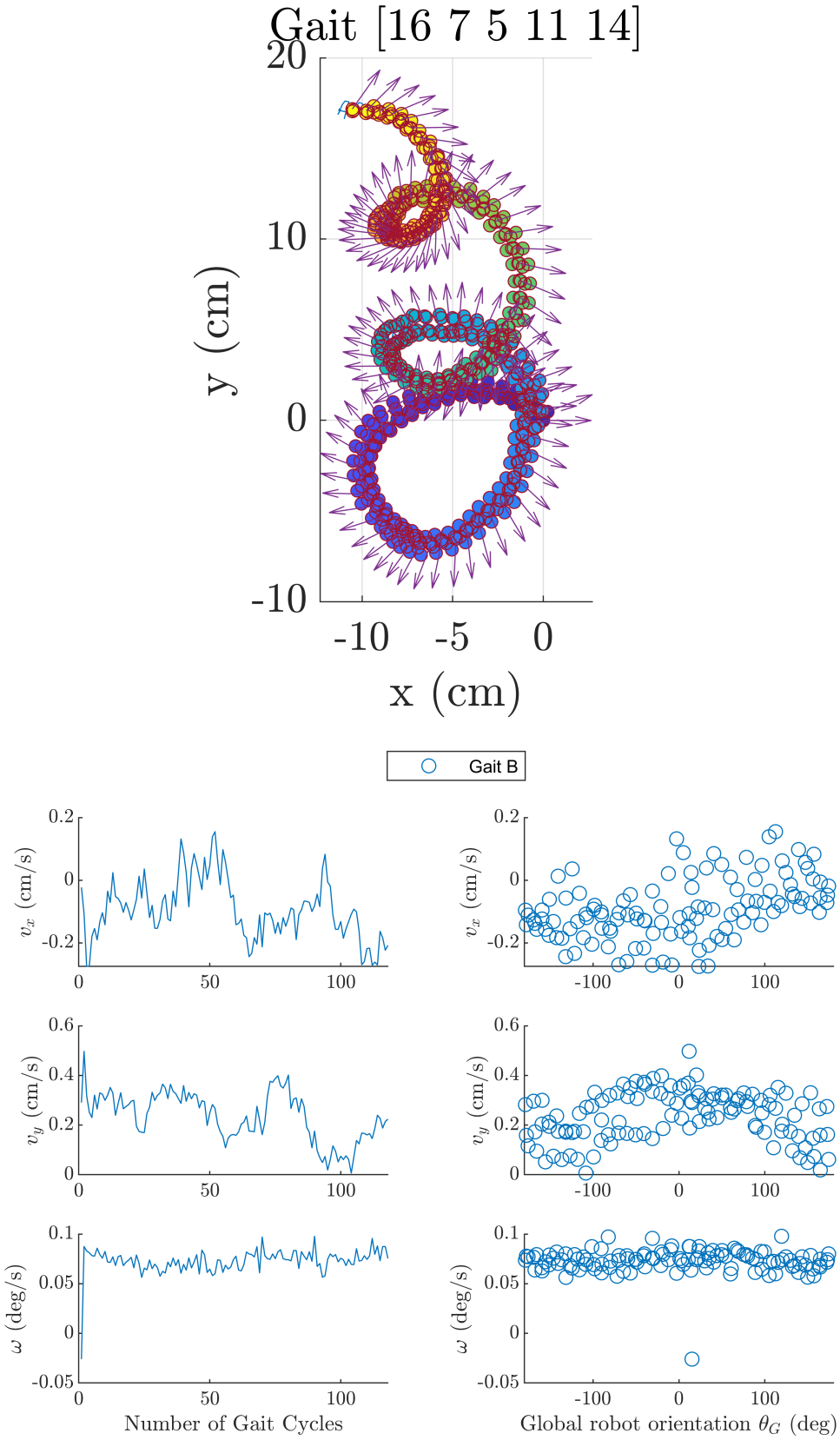


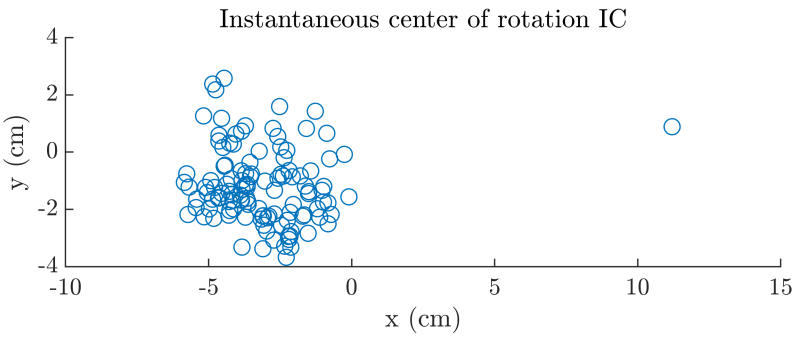


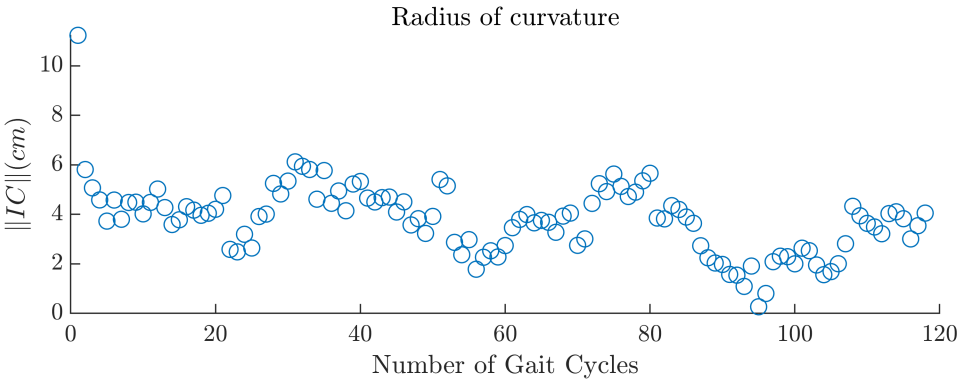




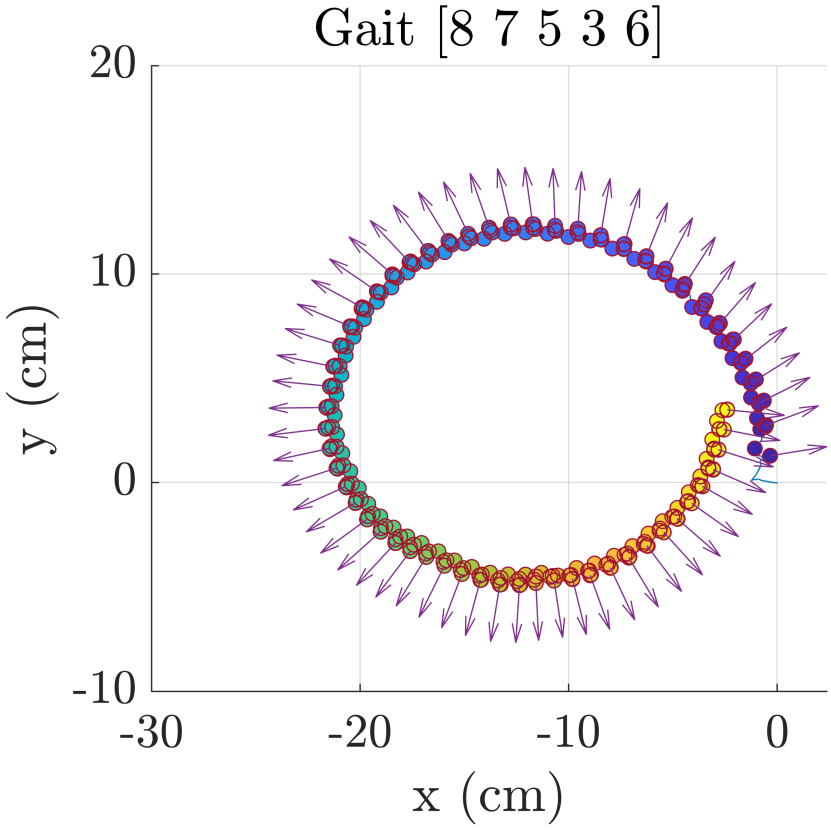
Experiment 5 : 120 cycles of Gait B with light sheath tether (right , not following), trial 1

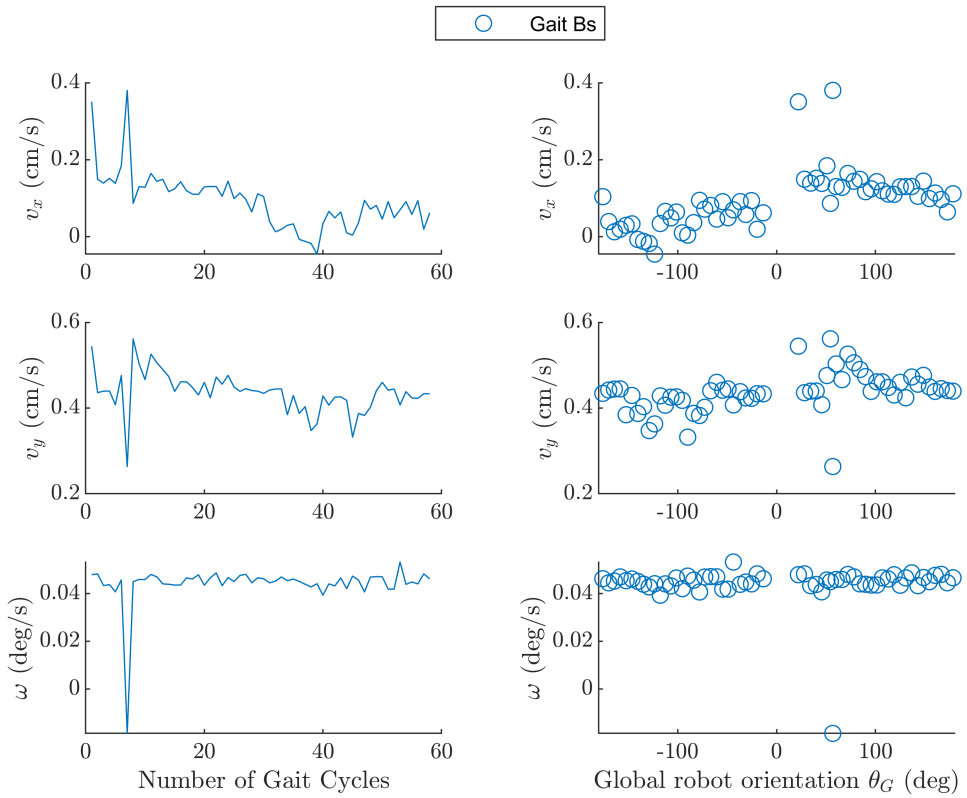

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

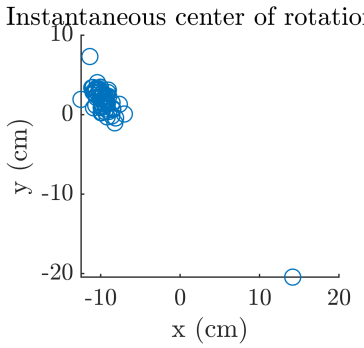


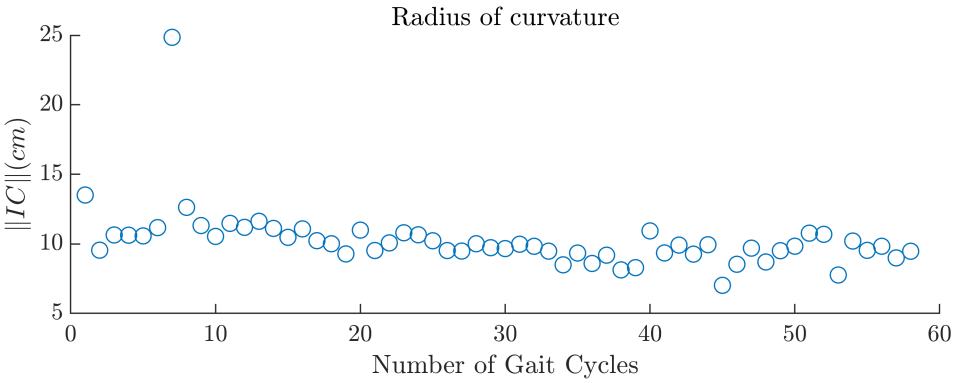


Experiment 6 : 60 cycles of Gait Bs with light sheath tether (left , following), trial 1

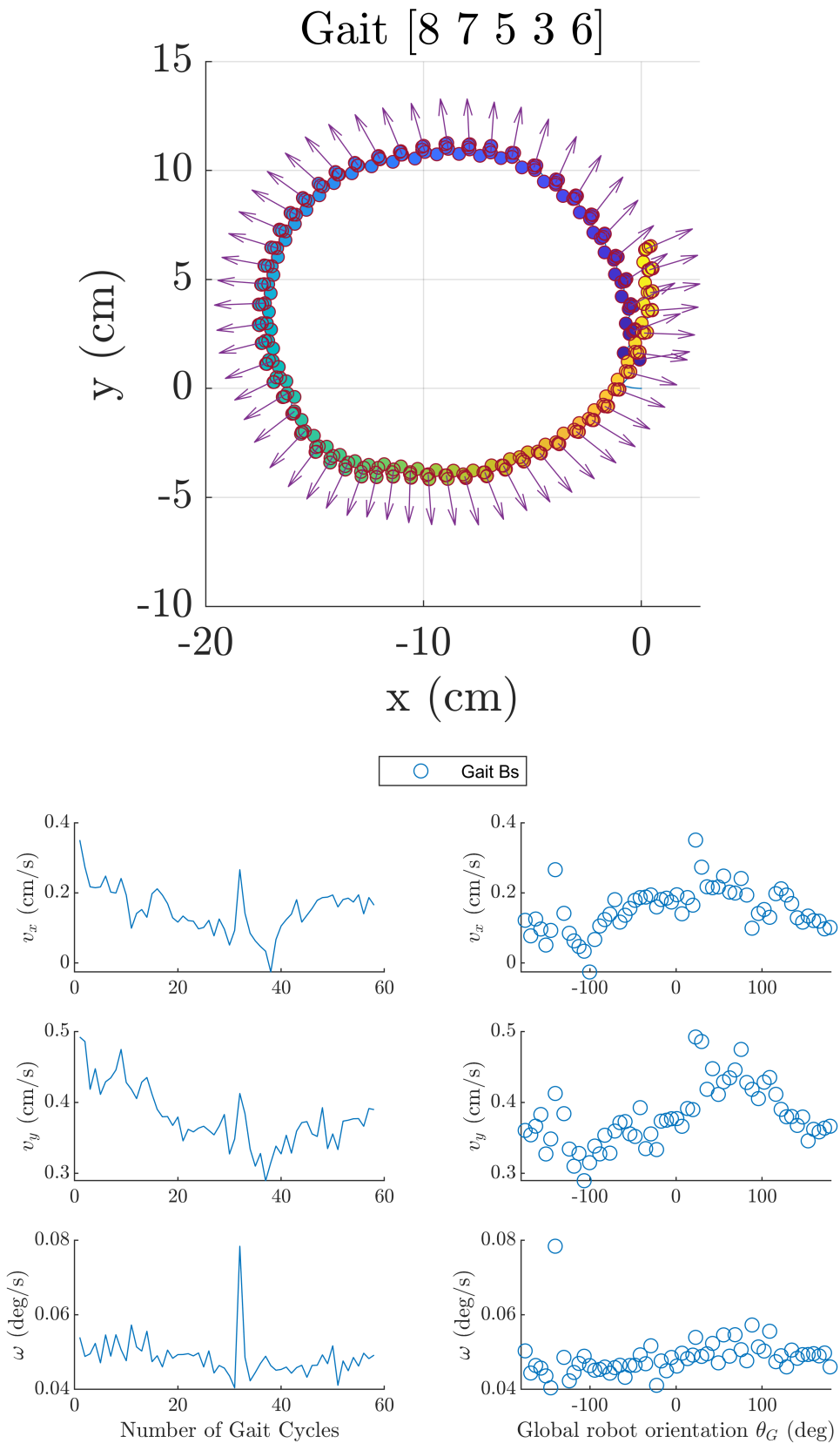


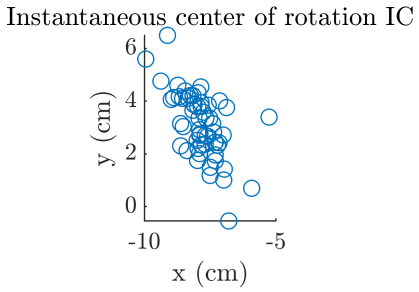


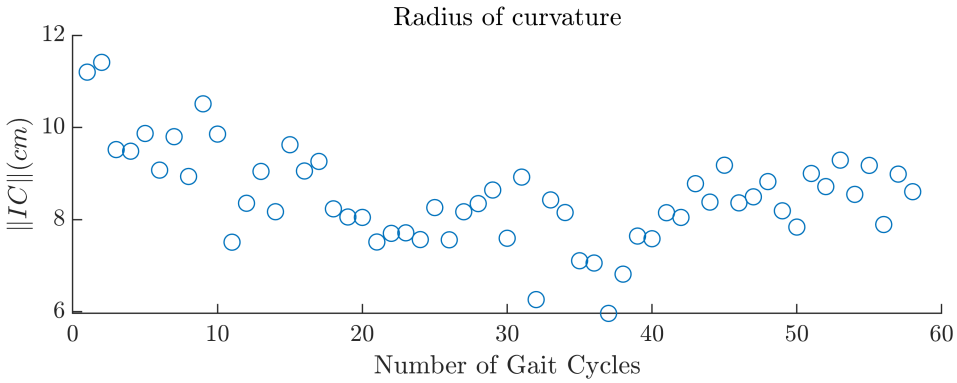




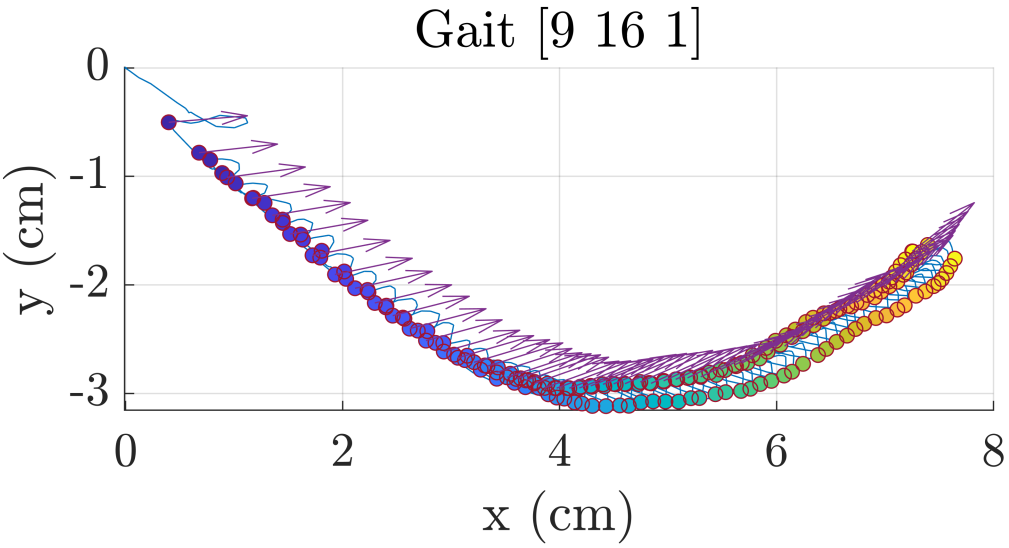
Experiment 7 : 60 cycles of Gait Bs with light sheath tether (right , following), trial 1

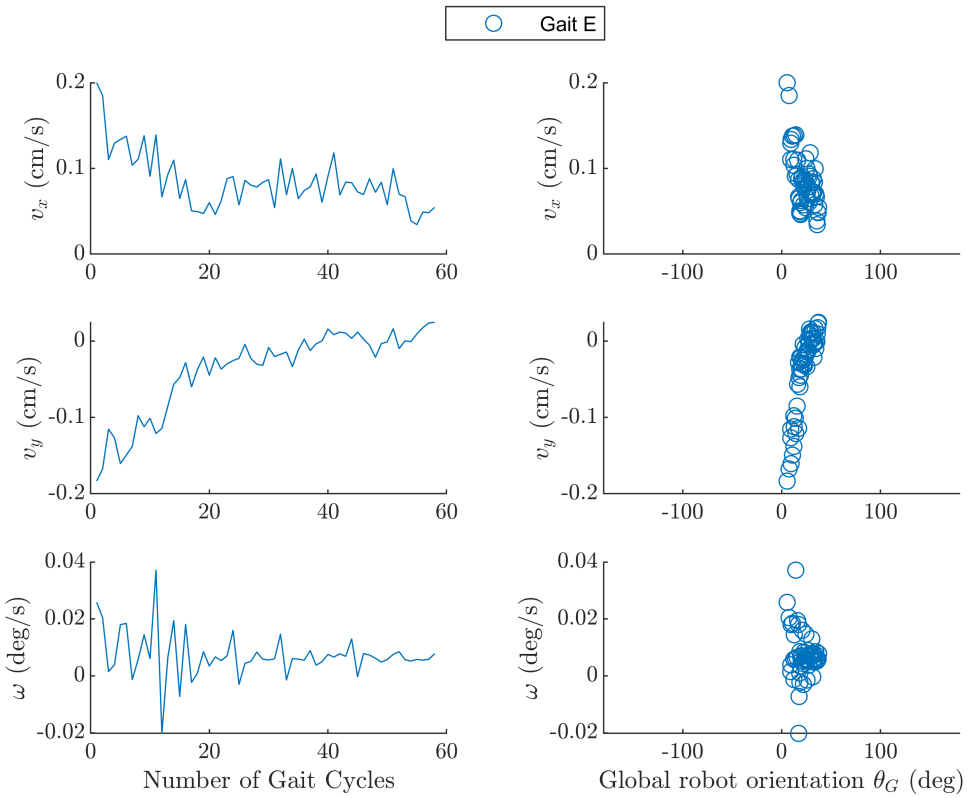

Gait [8 7 5 3 6]
y (cm)
x (cm)
Gait Bs
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

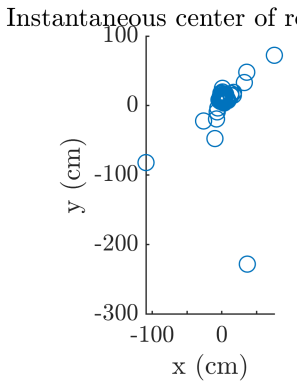


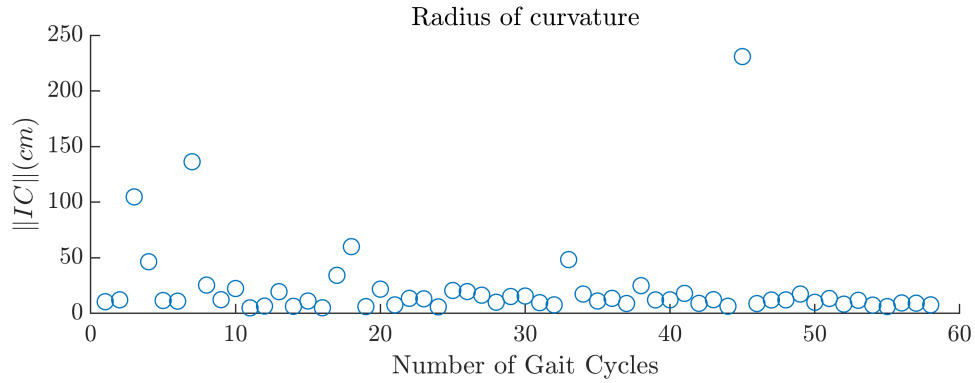


Experiment 8 : 60 cycles of Gait E with light sheath tether (left , not following), trial 1

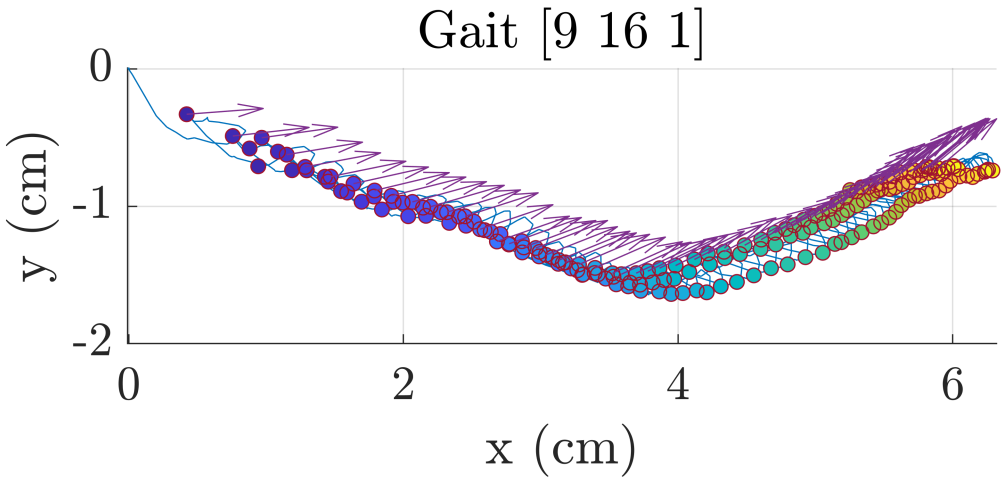


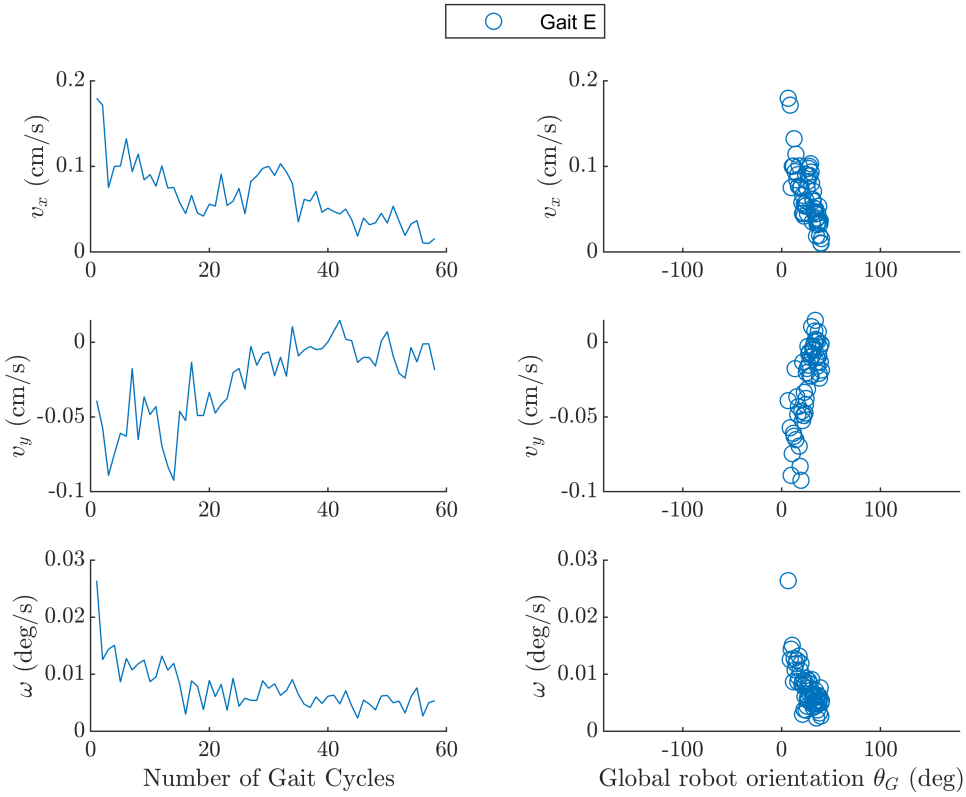


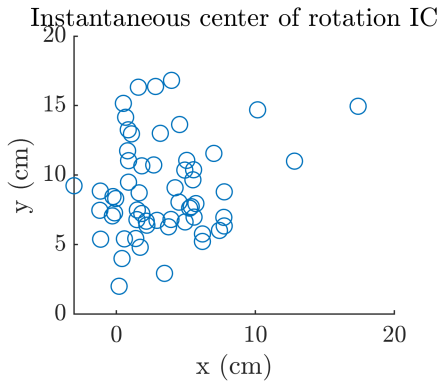


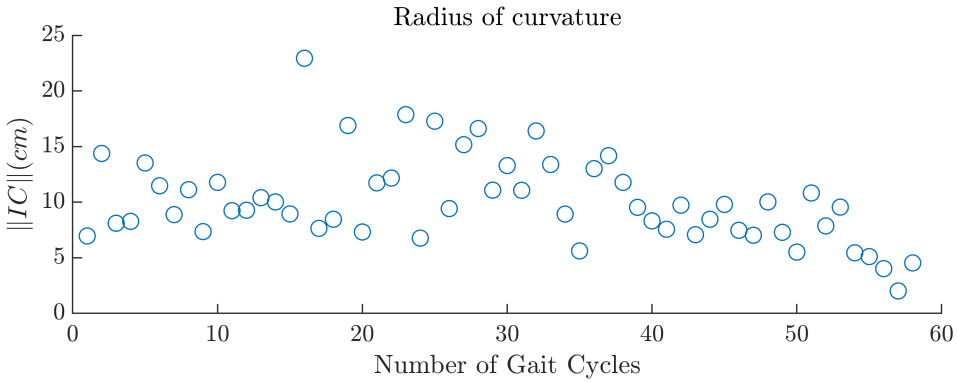


Experiment 9 : 60 cycles of Gait E with light sheath tether (right , not following), trial 1

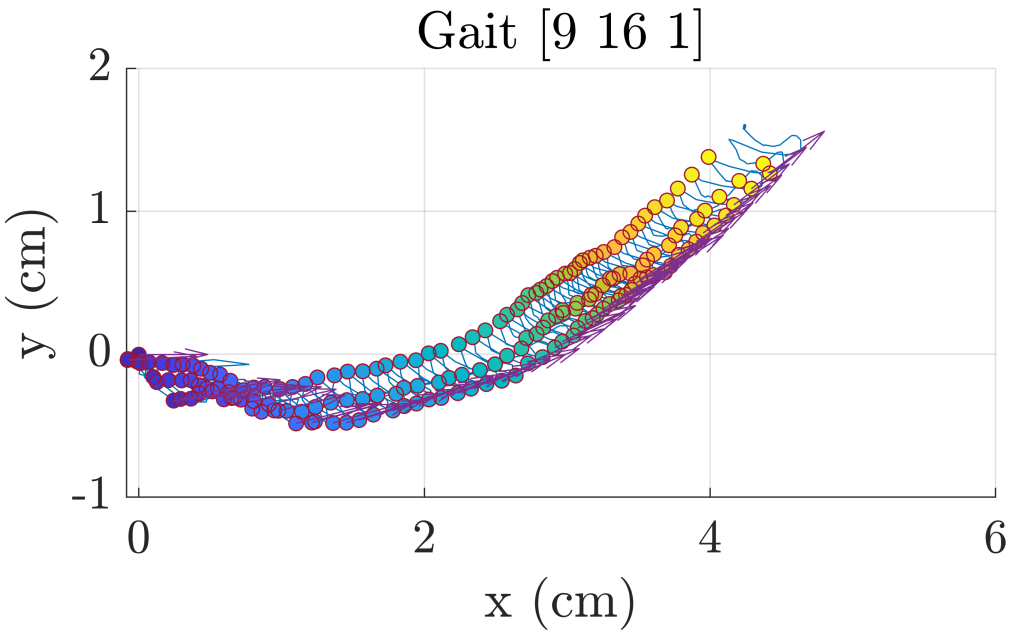

Gait [9 16 1]
y (cm)
x (cm)
0
-1
-2
0
2
4
6

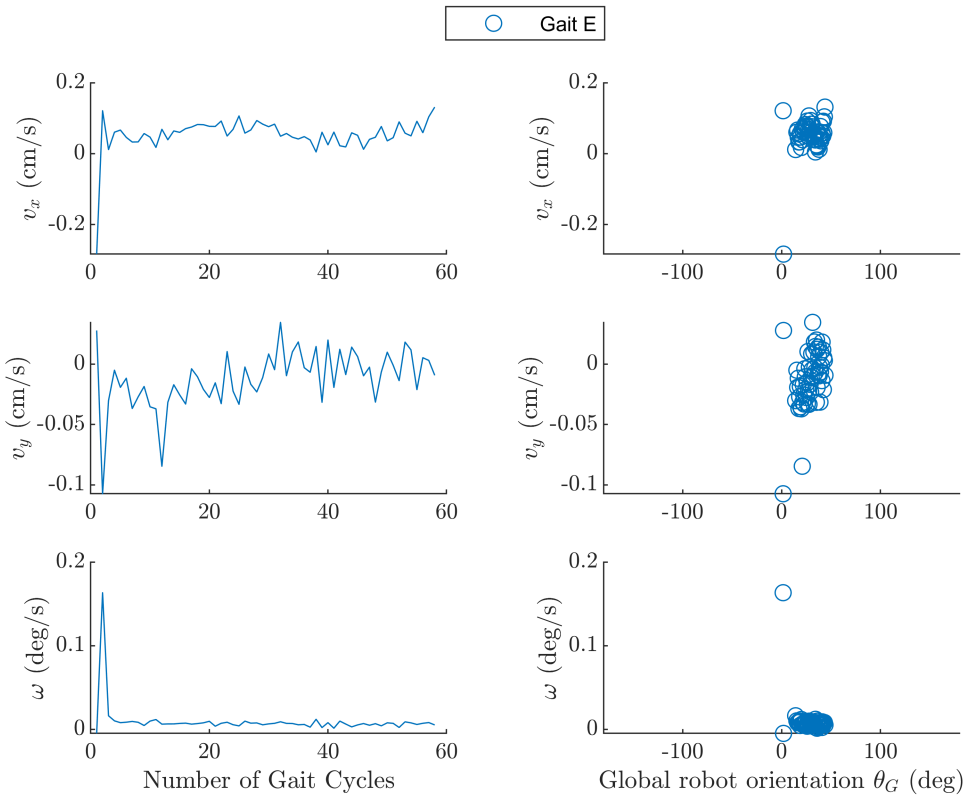

Gait E
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

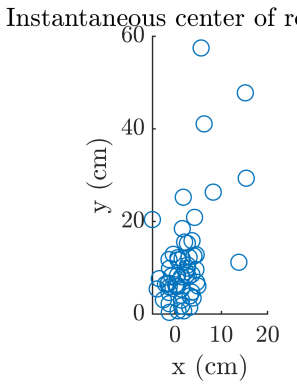


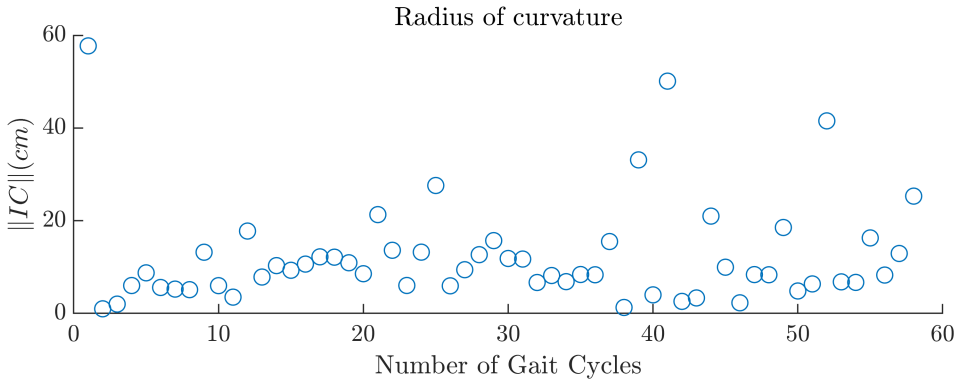


Experiment 10 : 60 cycles of Gait E with no sheath tether (left , not following), trial 1

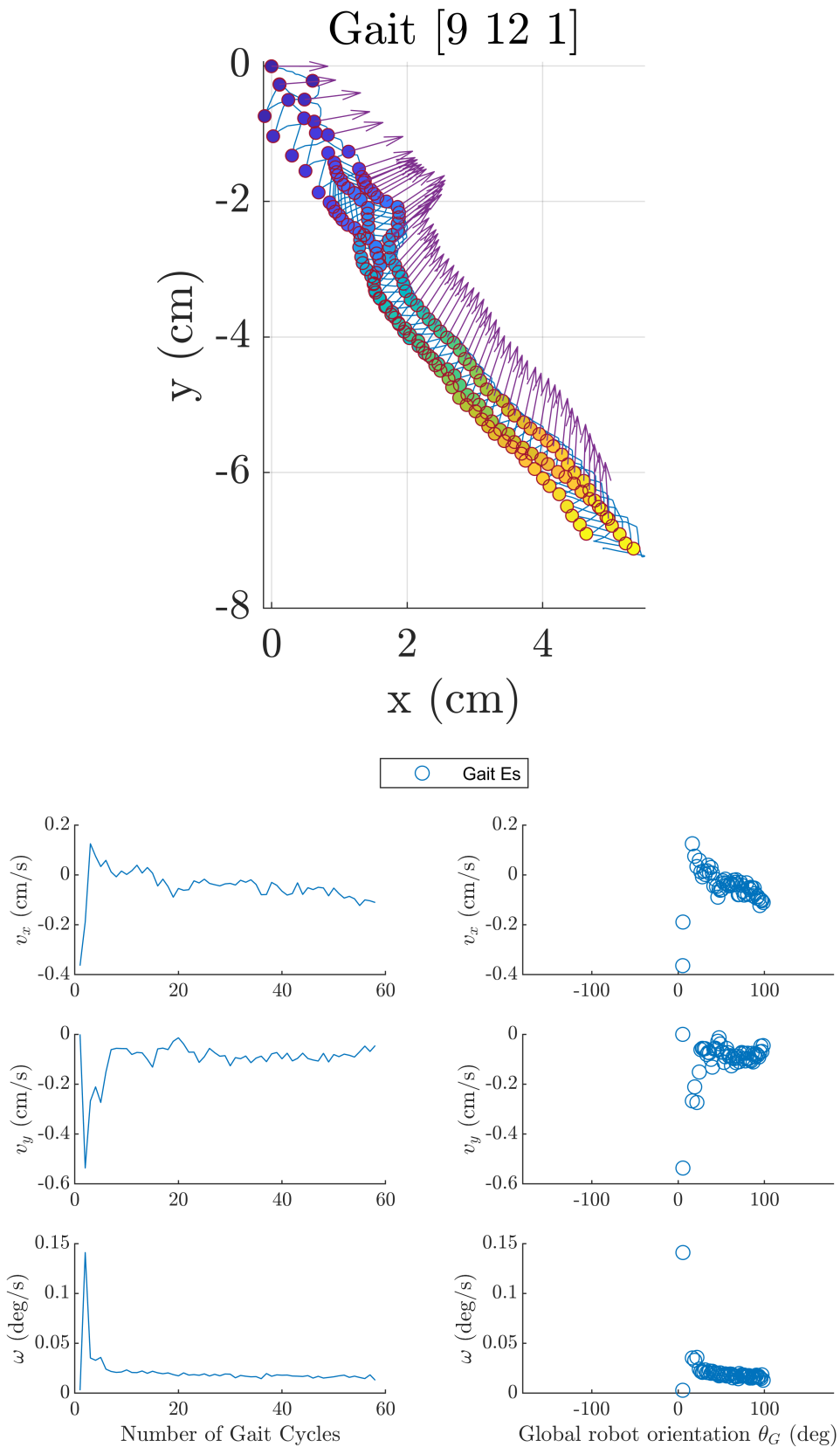


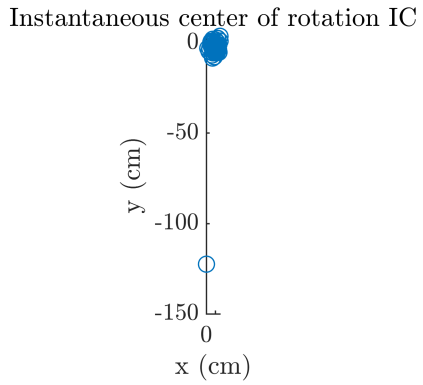


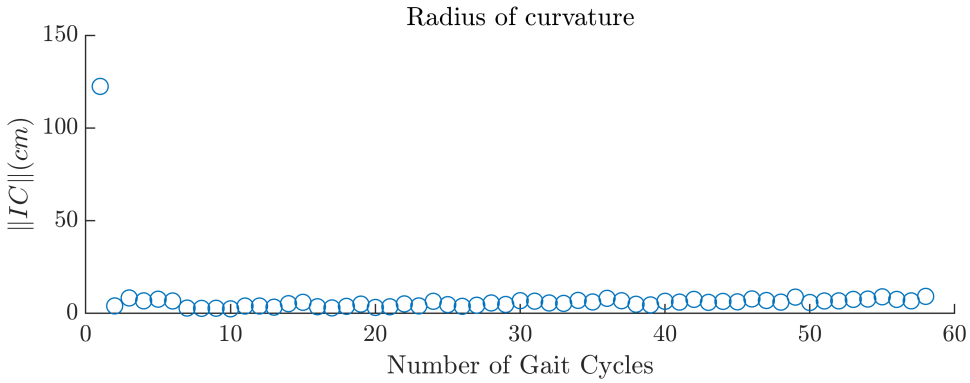




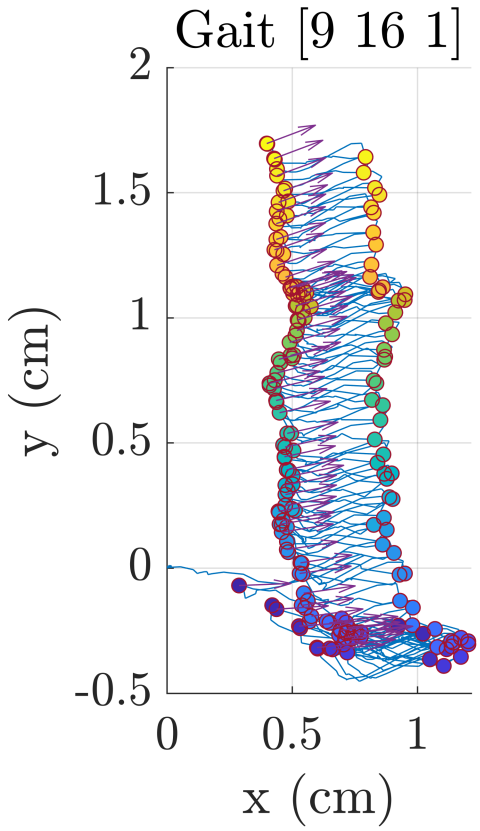
Experiment 11 : 60 cycles of Gait Es with no sheath tether (right , not following), trial 1

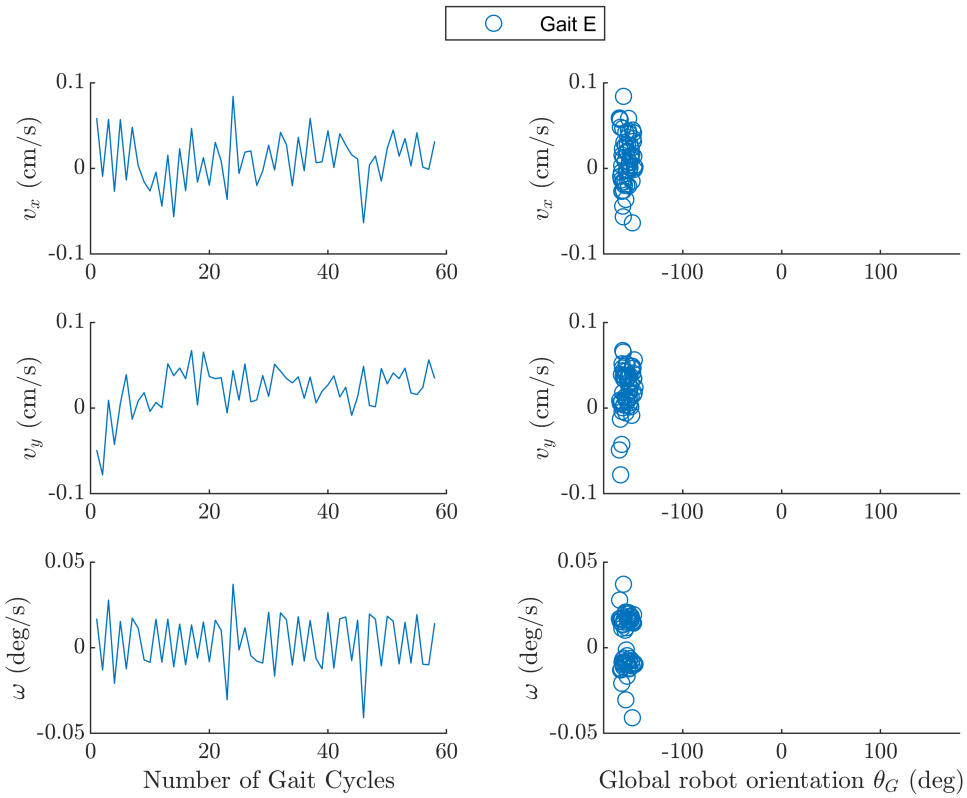

Gait [9 12 1]
y (cm)
x (cm)
Gait Es
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

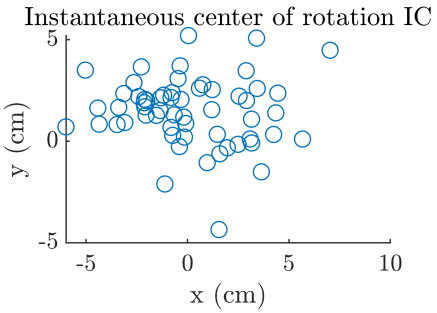


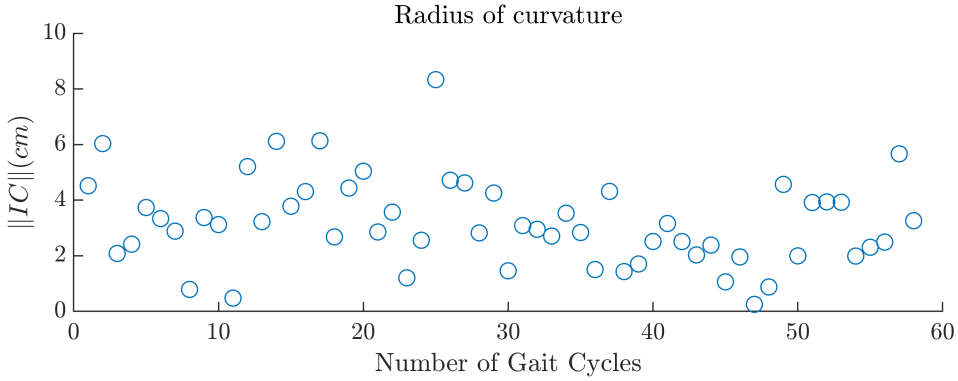


Experiment 12 : 60 cycles of Gait E with no sheath tether (Lf , not following), trial 1

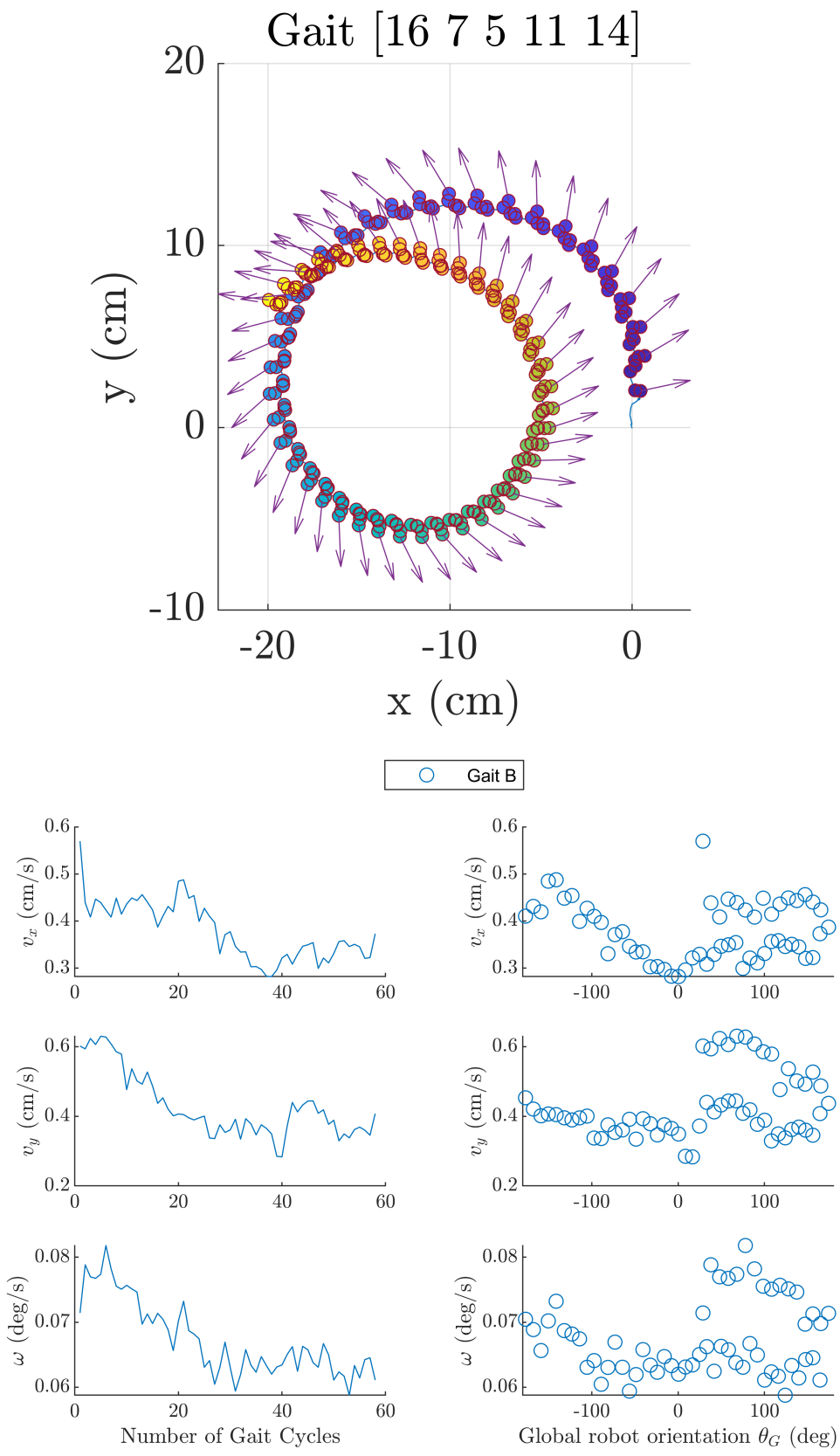


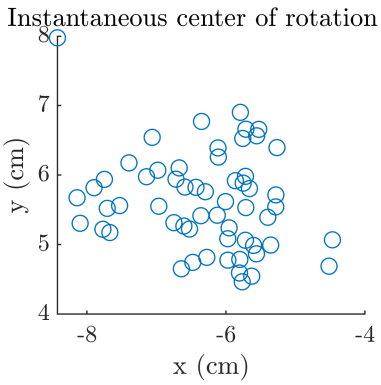


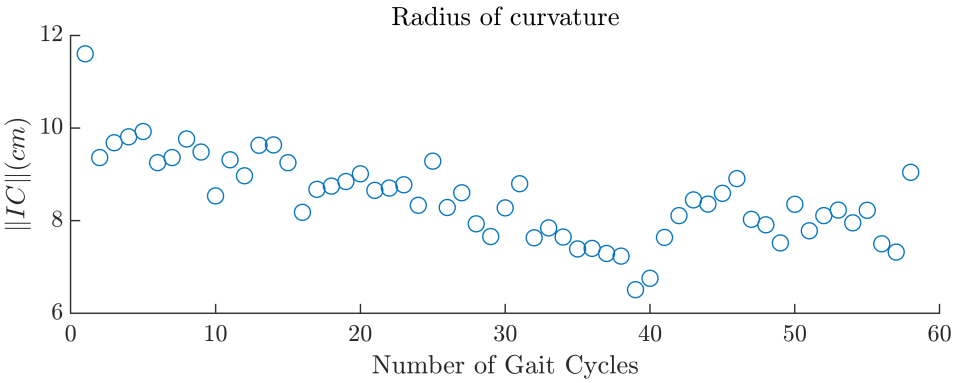




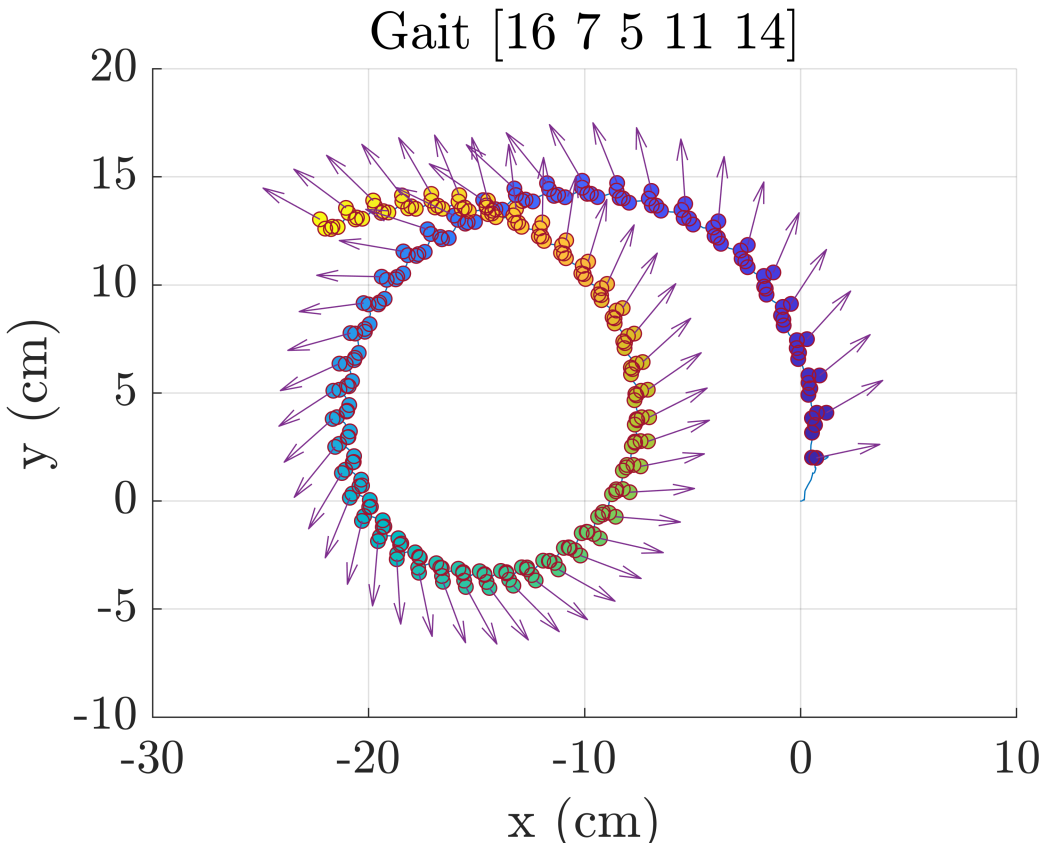
Experiment 13 : 60 cycles of Gait B with light sheath tether (left , following), trial 1

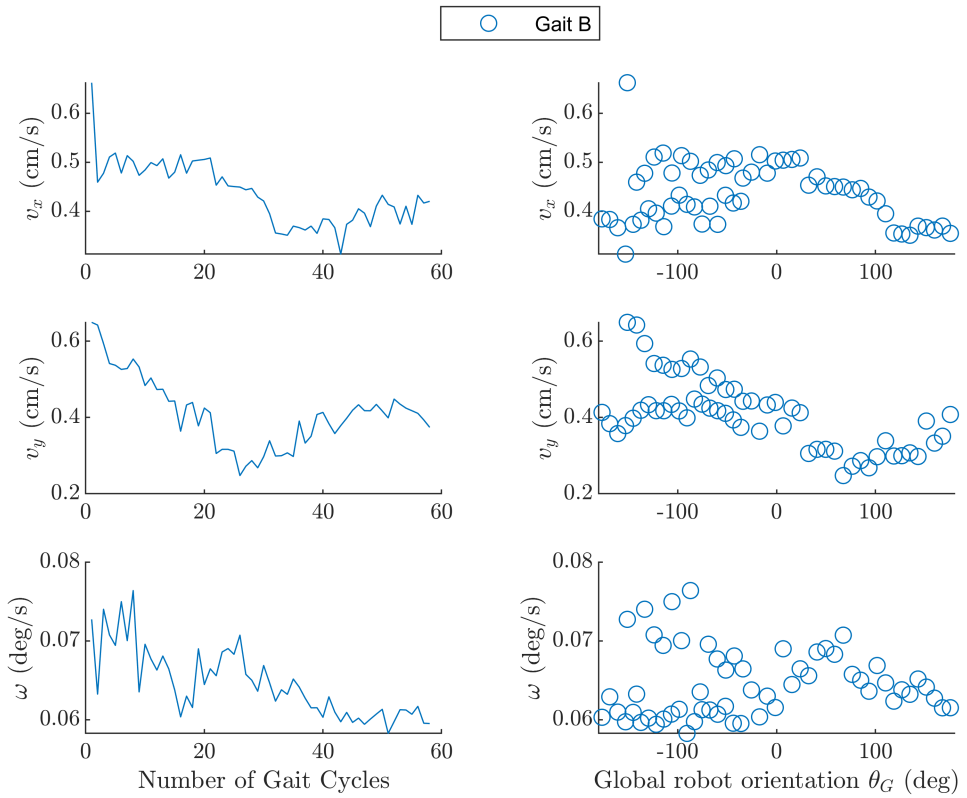

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

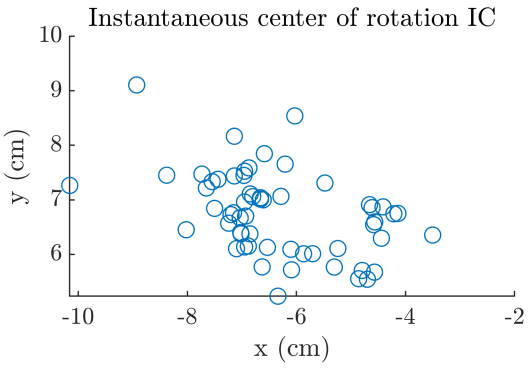


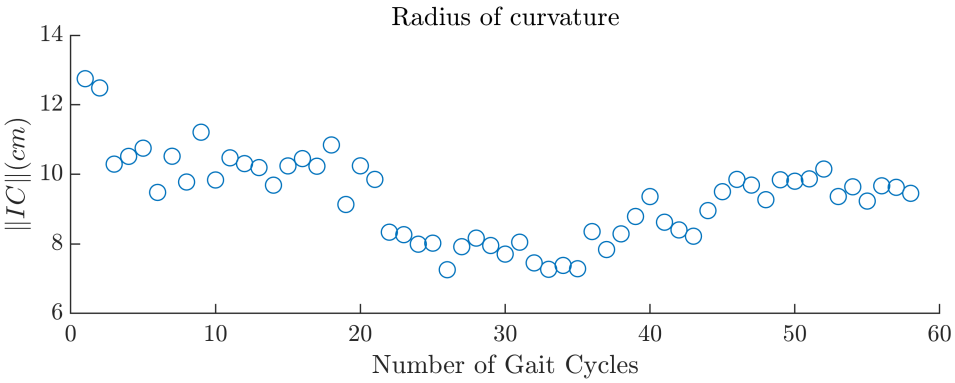


Experiment 14 : 60 cycles of Gait B with light sheath tether (Lf , following), trial 1

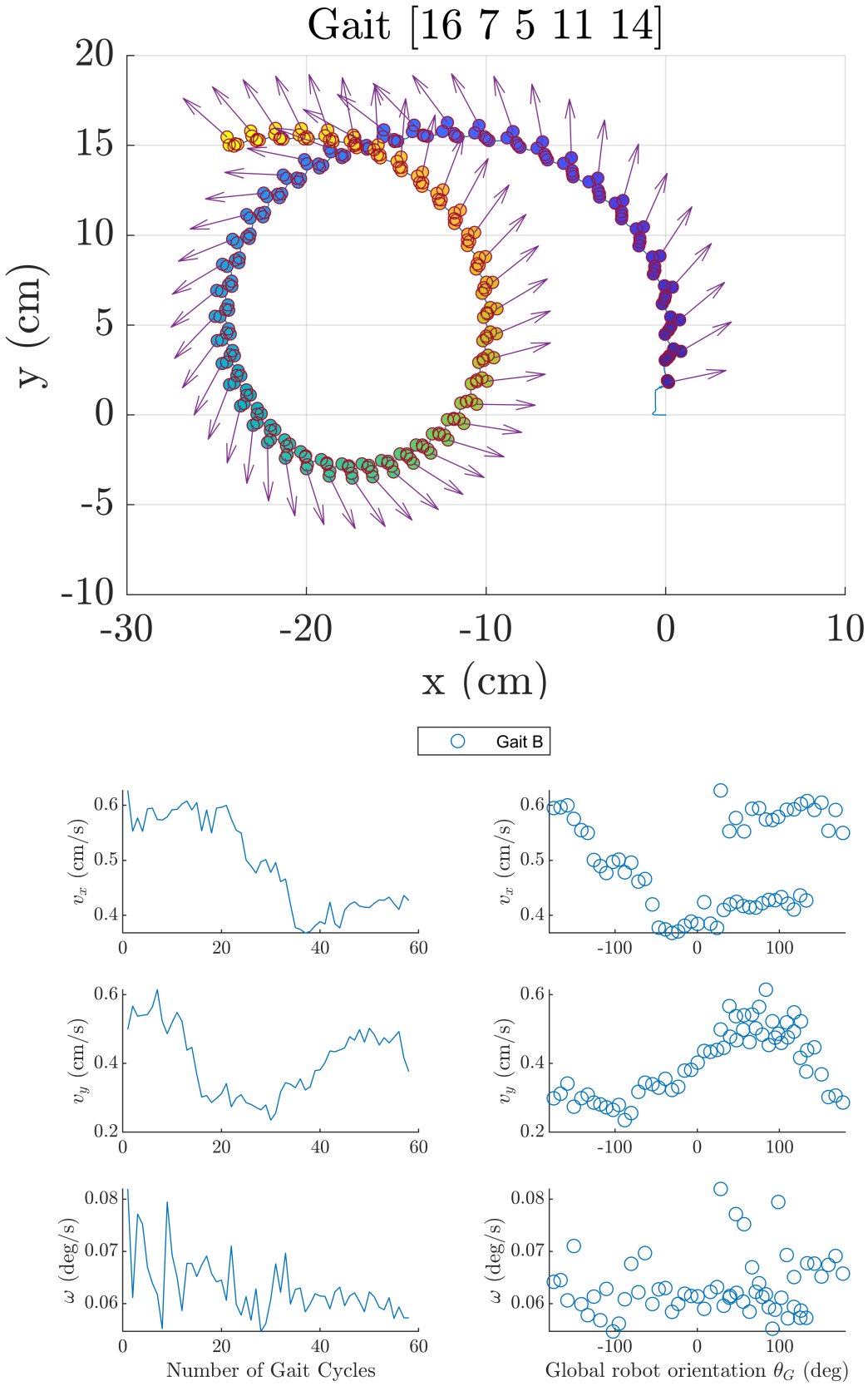


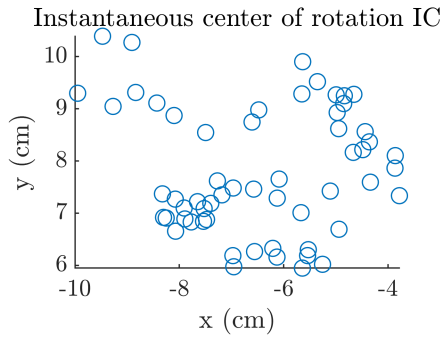


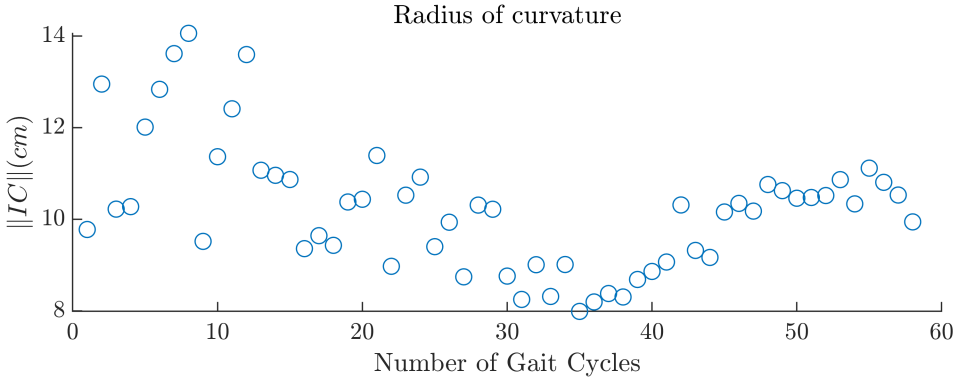




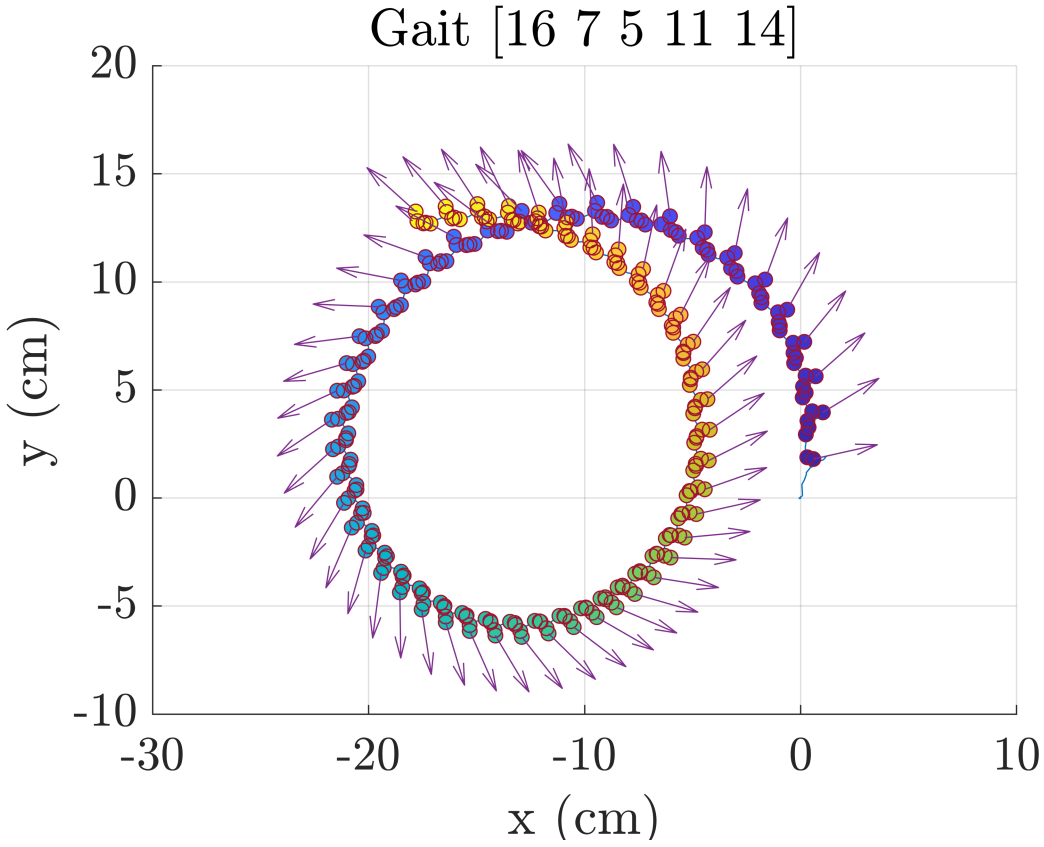
Experiment 15 : 60 cycles of Gait B with light sheath tether (left , not following), trial 1

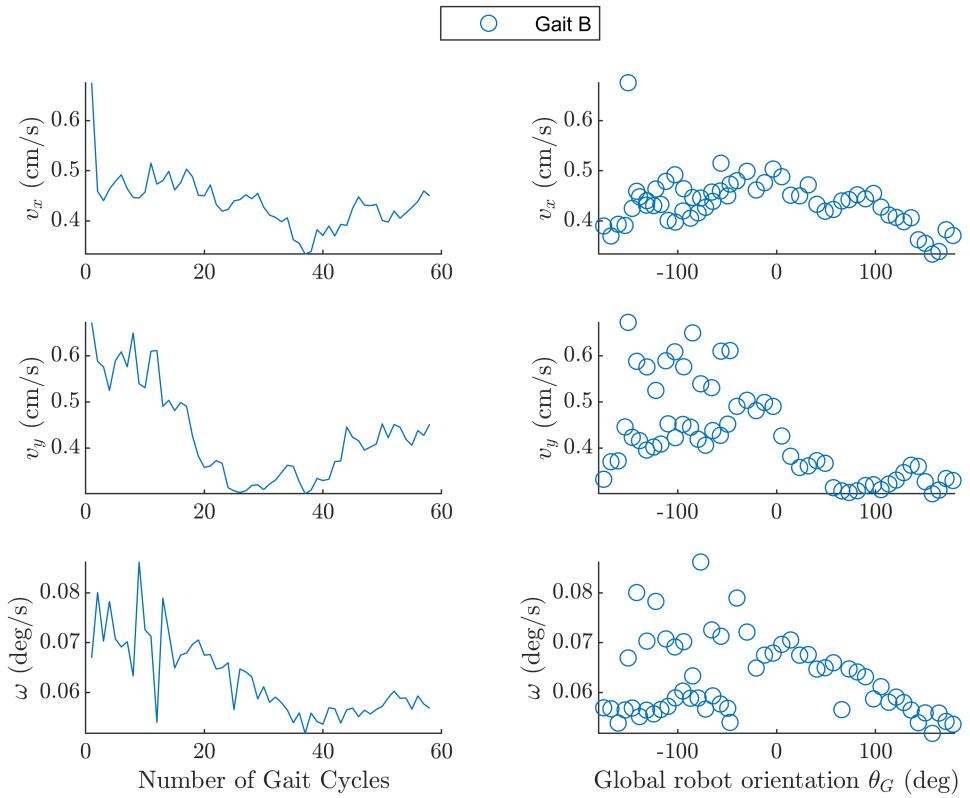

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

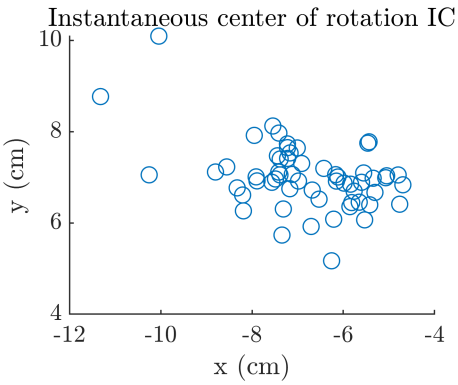


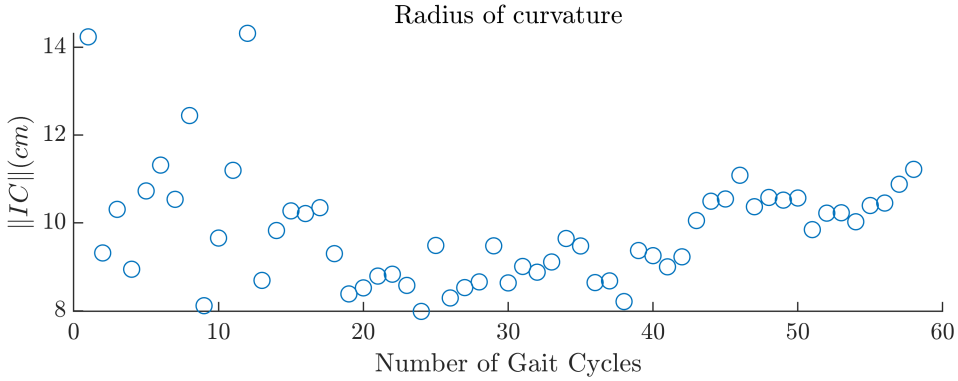


Experiment 16 : 60 cycles of Gait B with light sheath tether (Lf , not following), trial 1

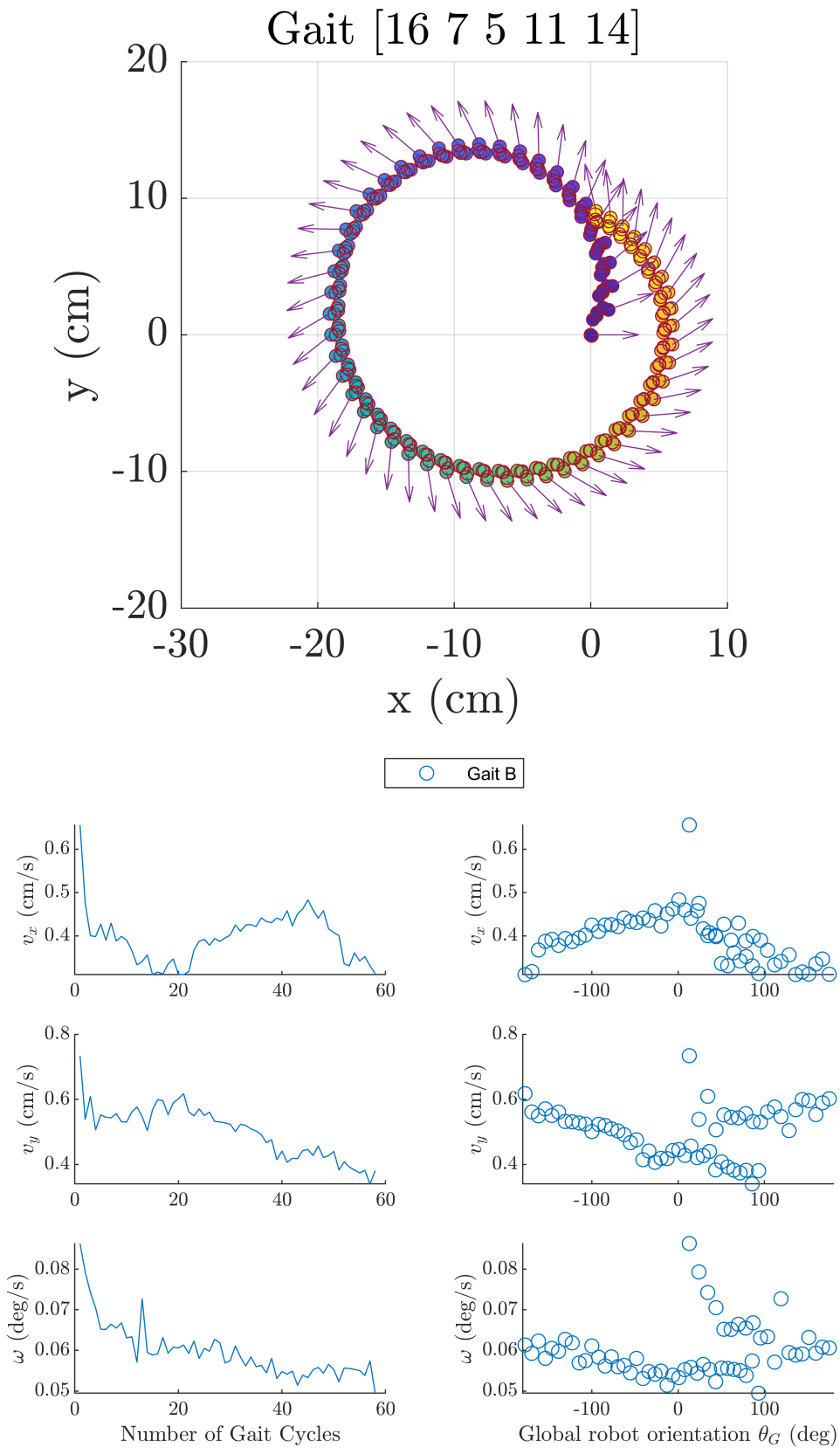


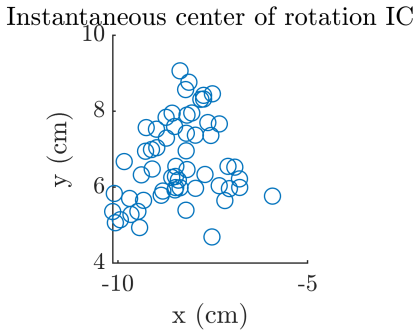


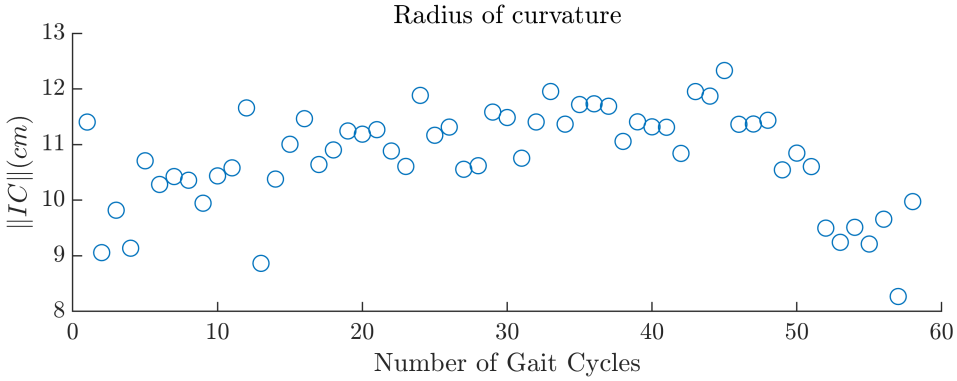




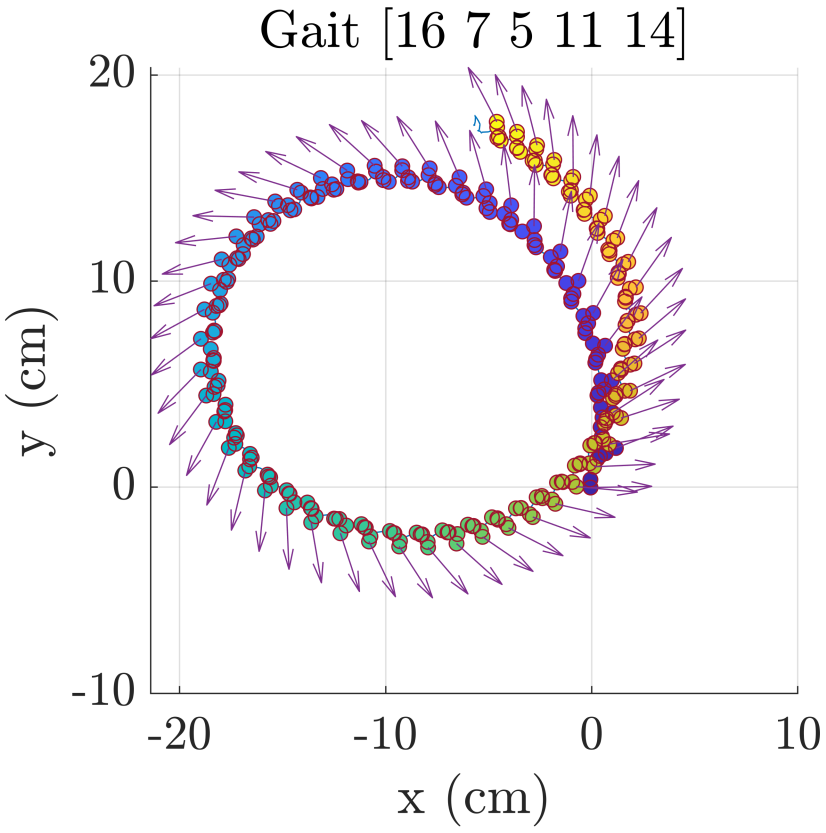
Experiment 17 : 60 cycles of Gait B with light sheath tether (right , not following), trial 1

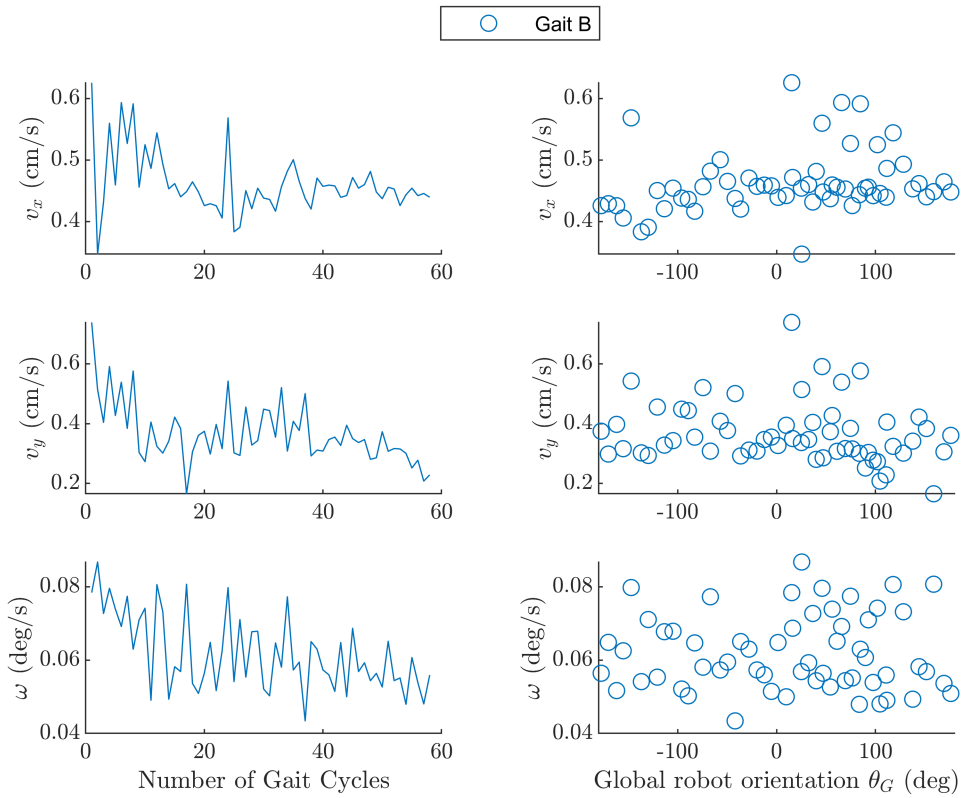

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

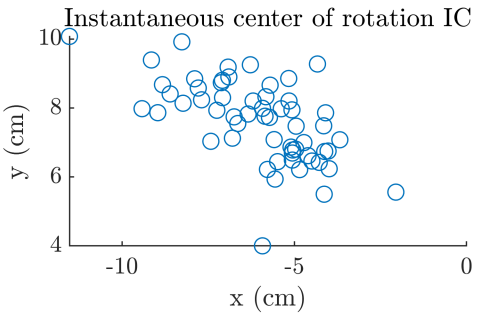


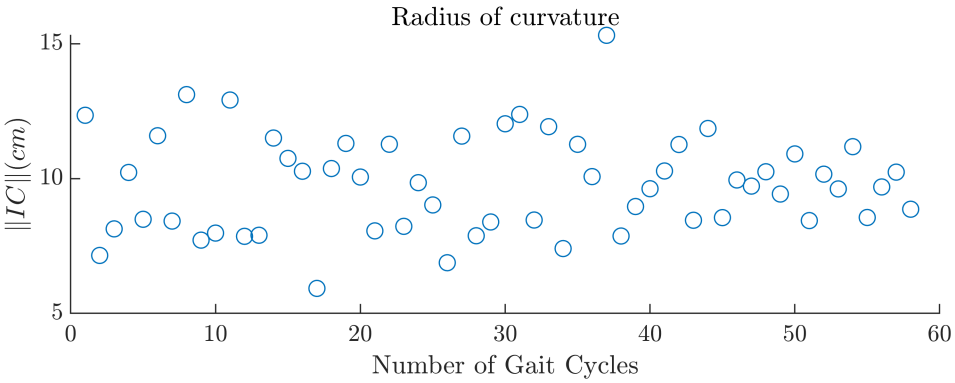



```
Experiment 18 : 60 cycles of Gait B with no sheath tether ( right , following ), trial 1
```

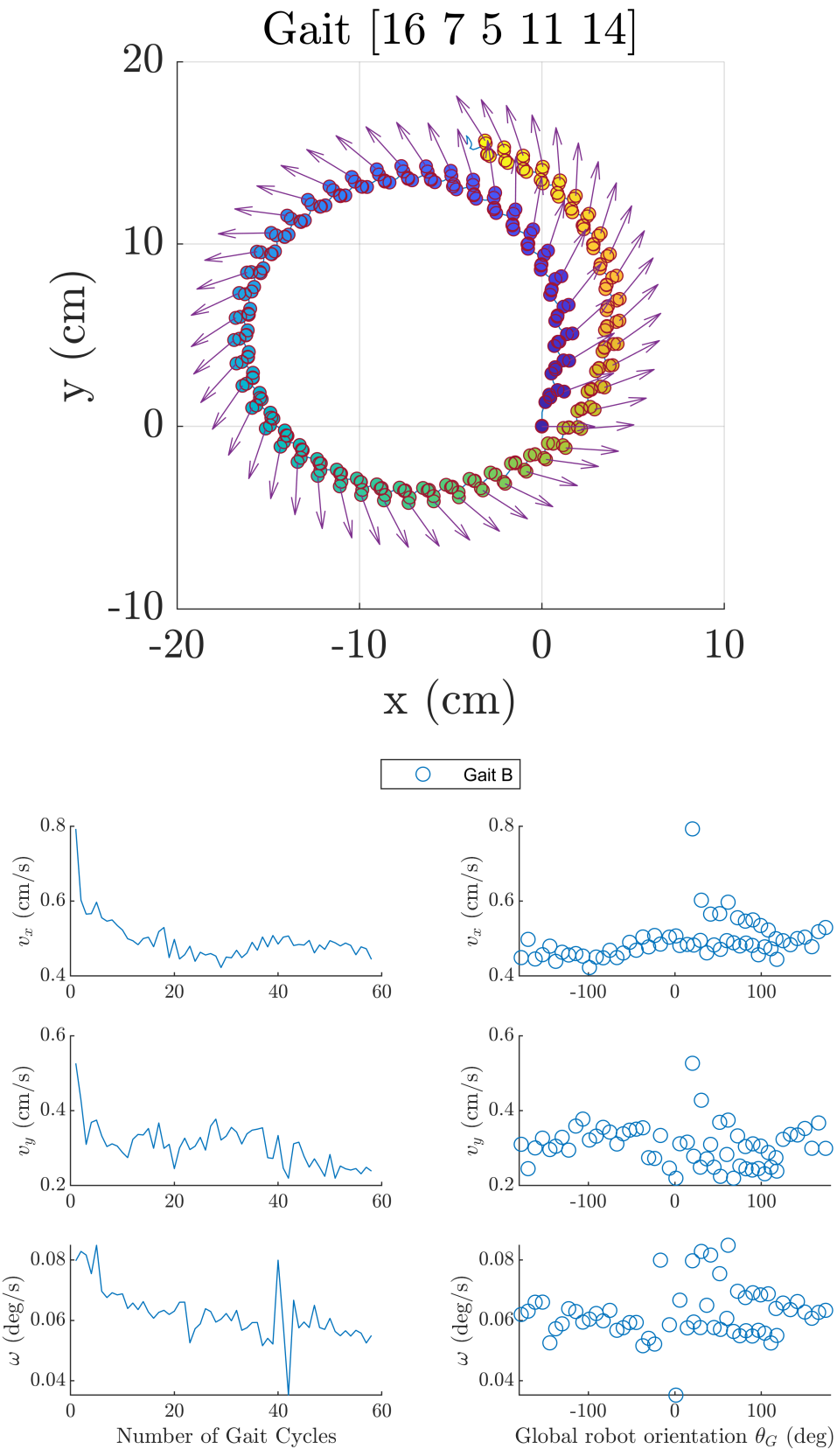


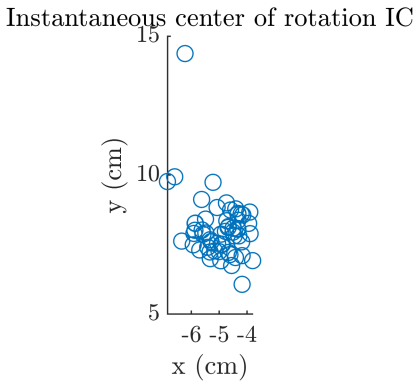


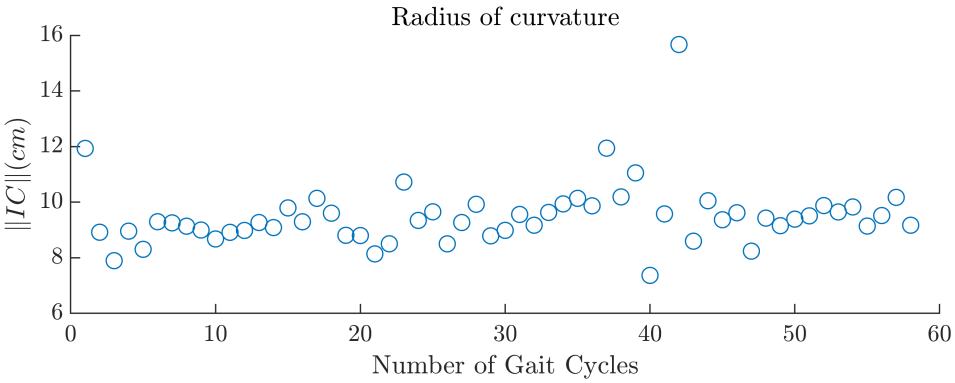




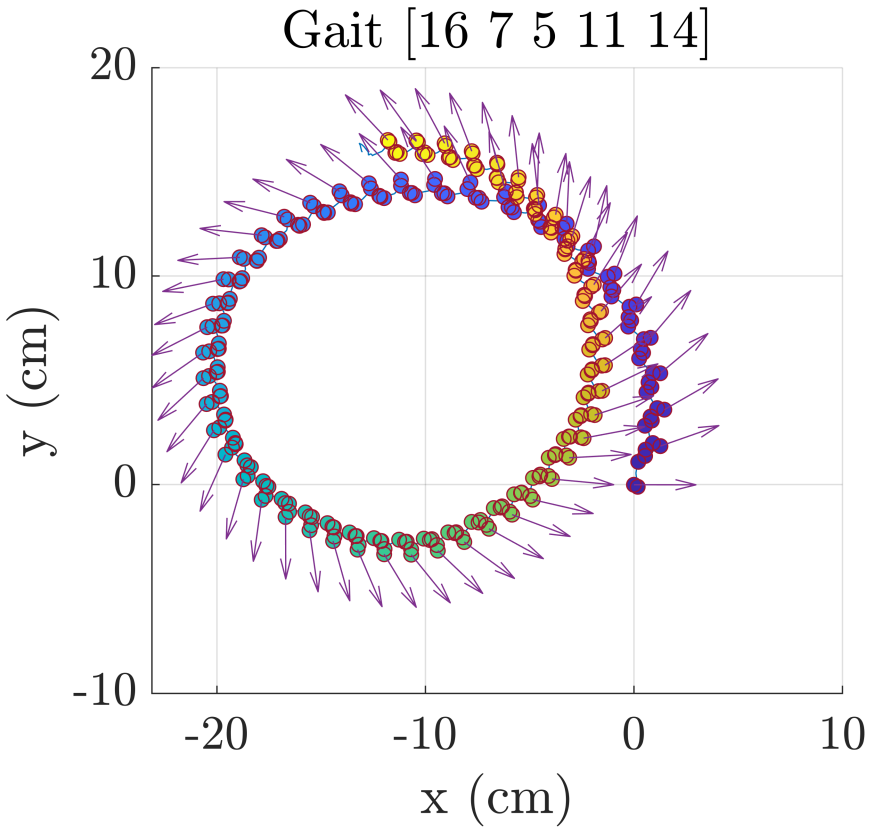
Experiment 19 : 60 cycles of Gait B with no sheath tether (right , following), trial 2

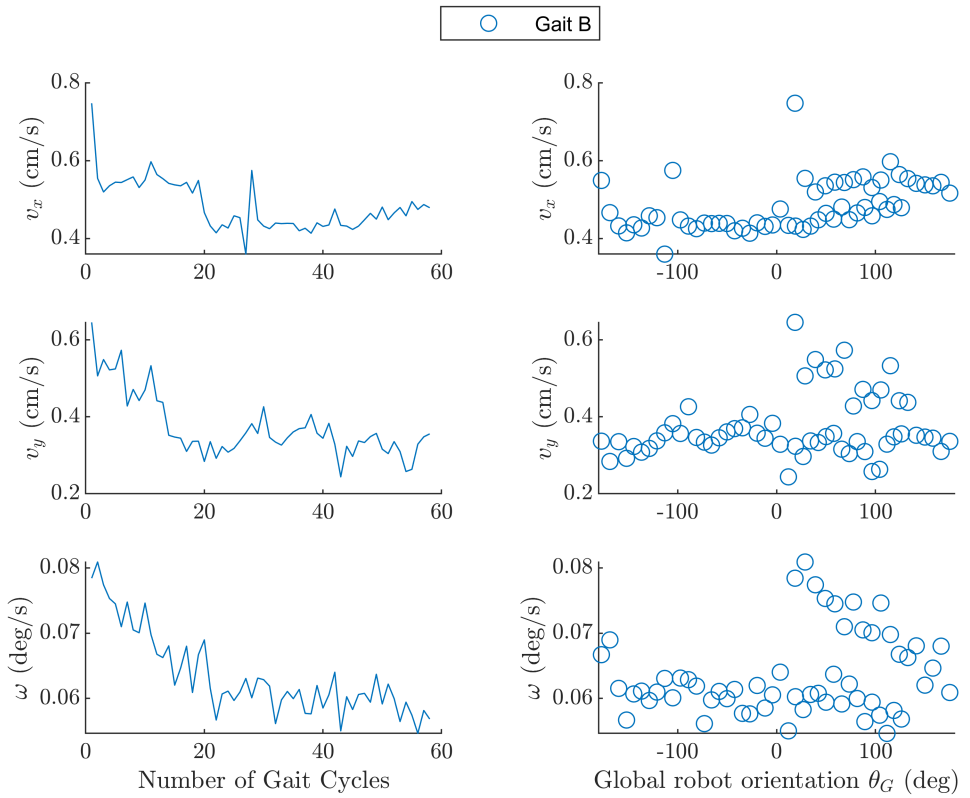

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)



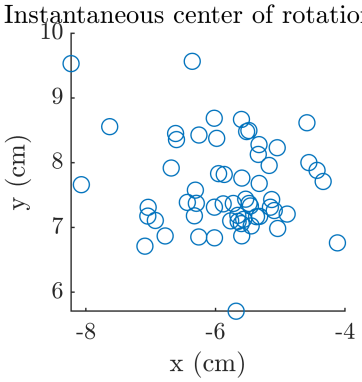


Experiment 20 : 60 cycles of Gait B with no sheath tether (left , following), trial 1

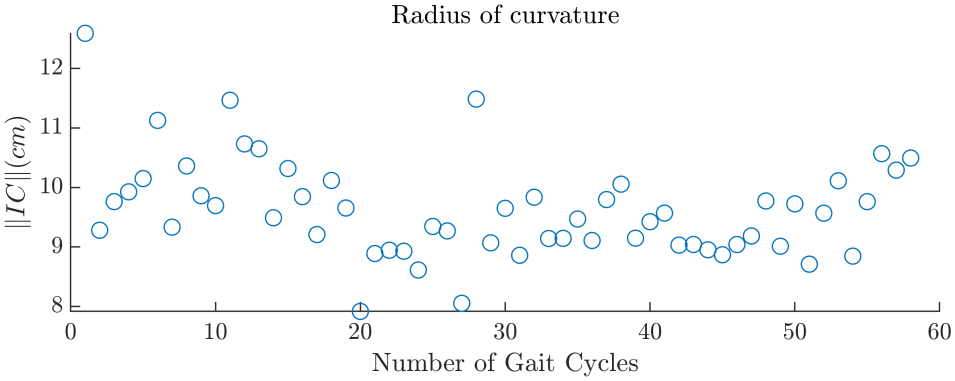




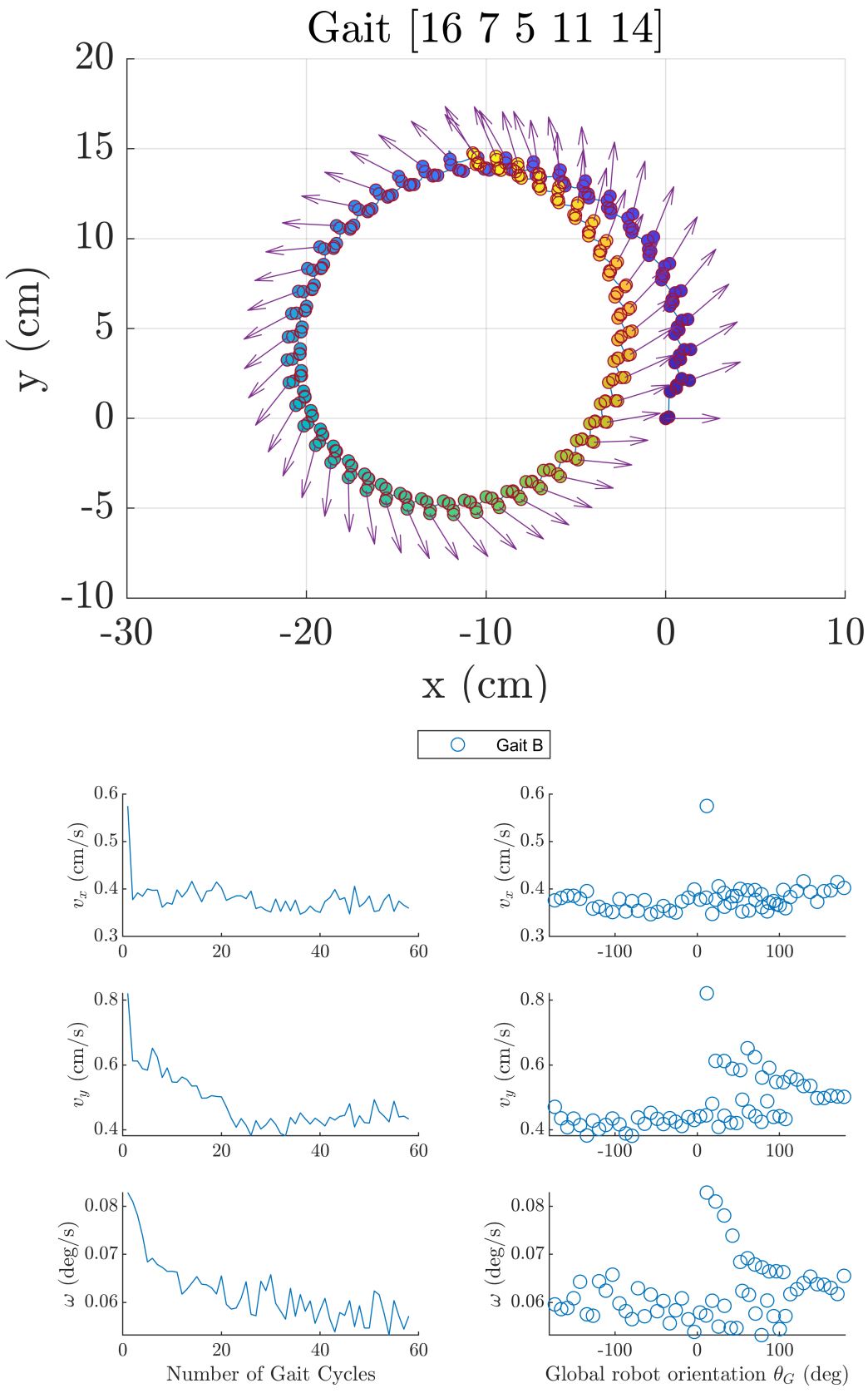
Instantaneous center of rotation IC

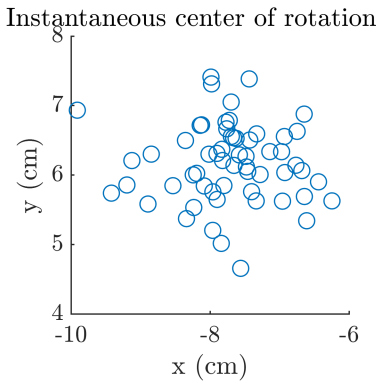


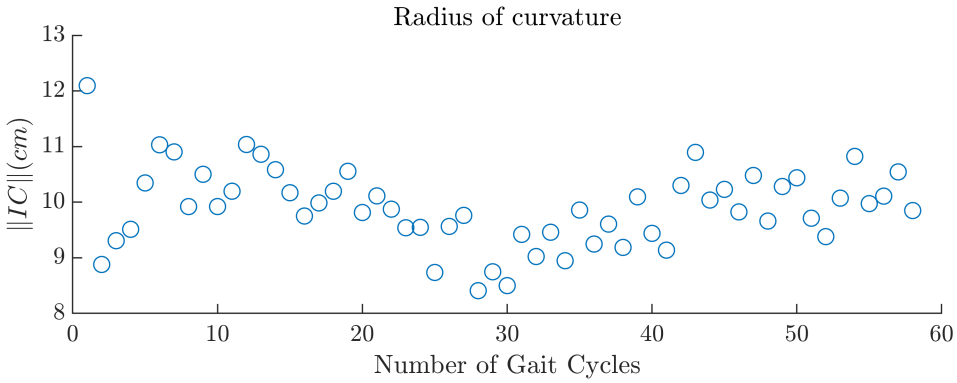
Radius of curvature



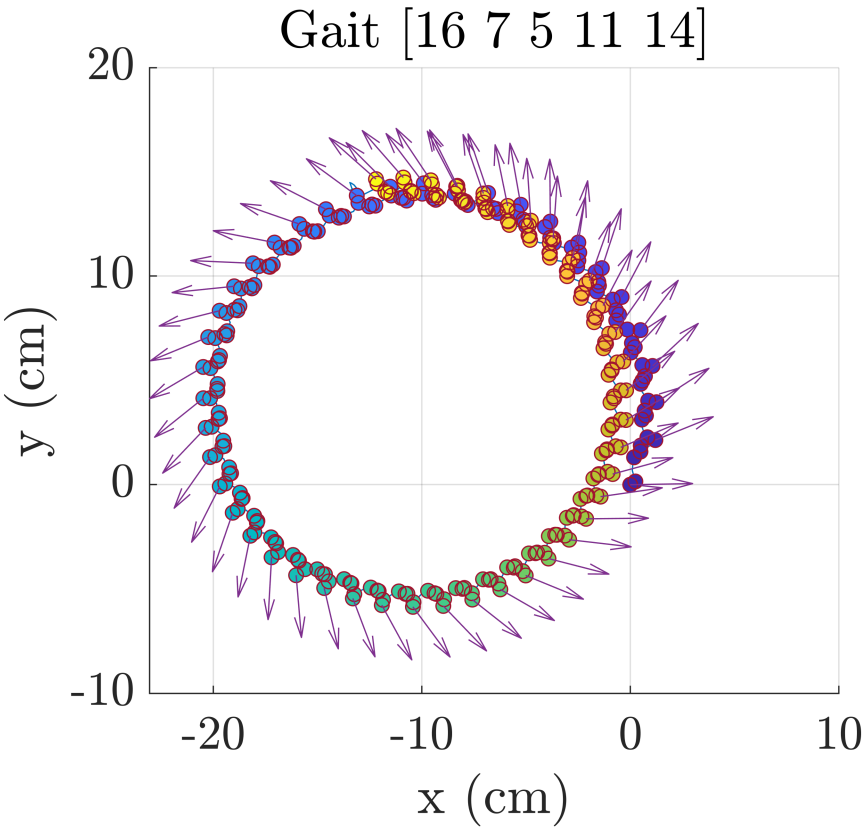
Experiment 21 : 60 cycles of Gait B with no sheath tether (left , following), trial 2

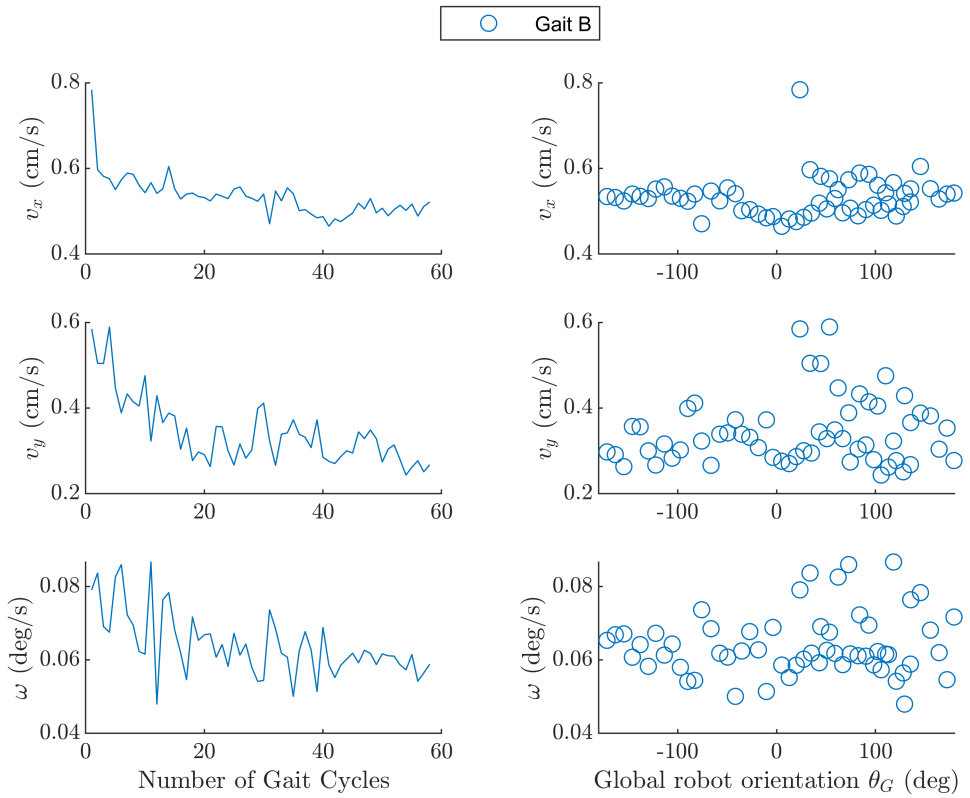

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

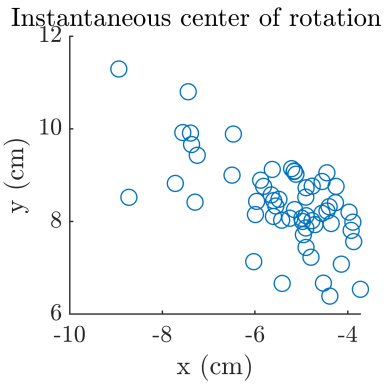


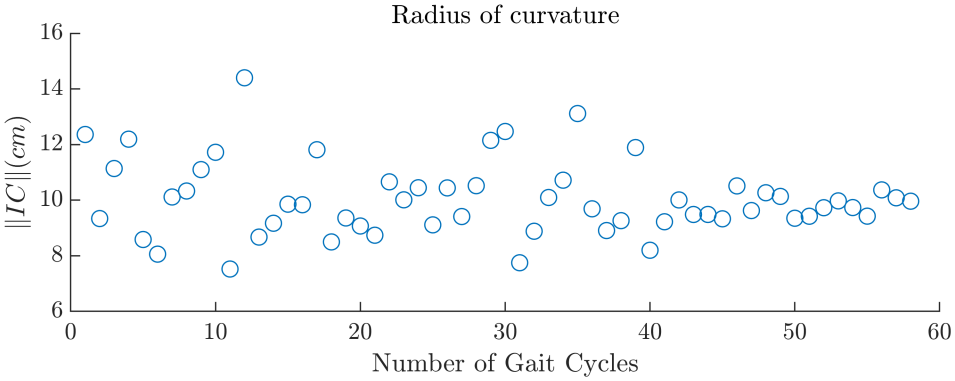


Experiment 22 : 60 cycles of Gait B with no sheath tether (right , not following), trial 1

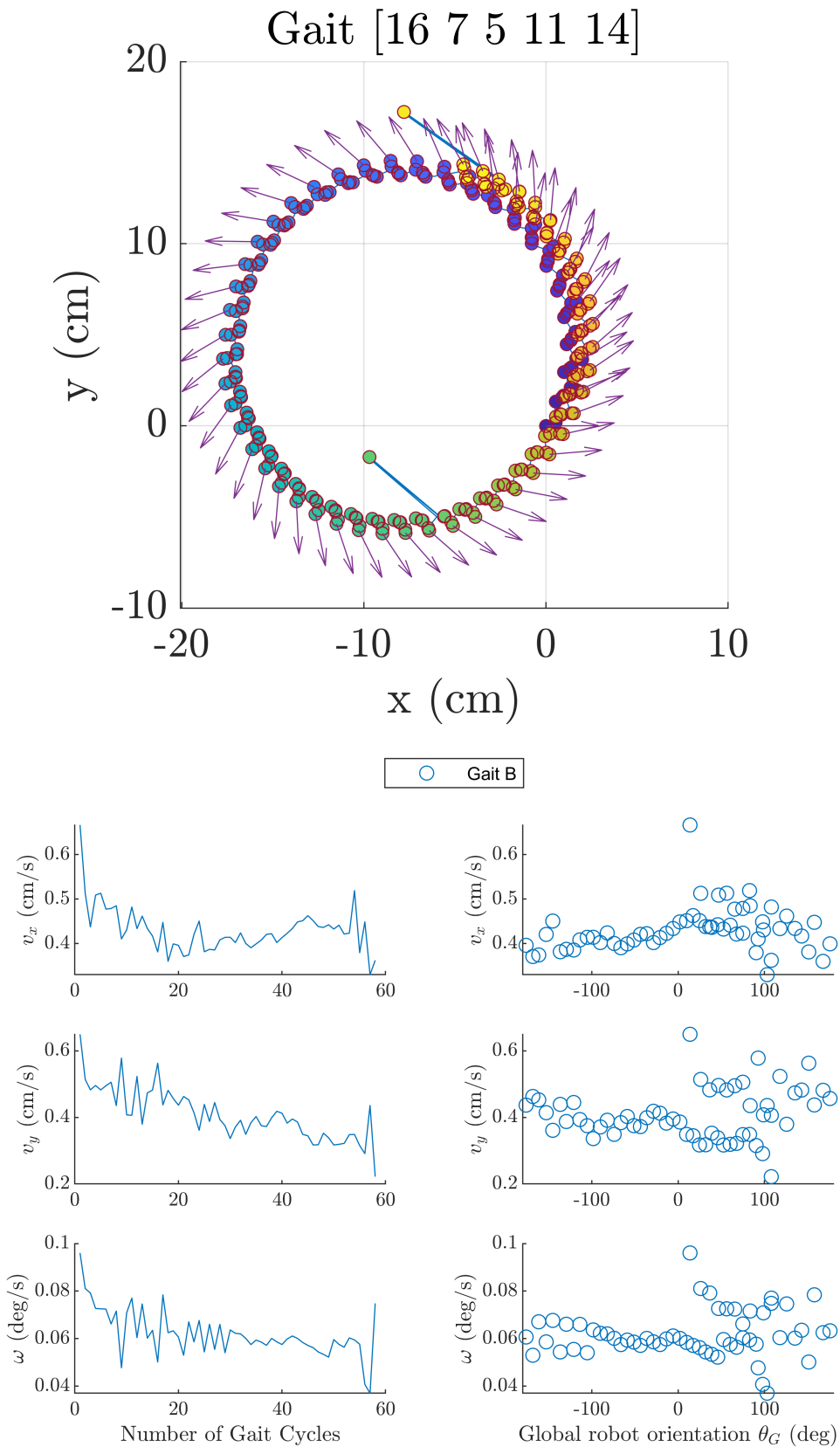


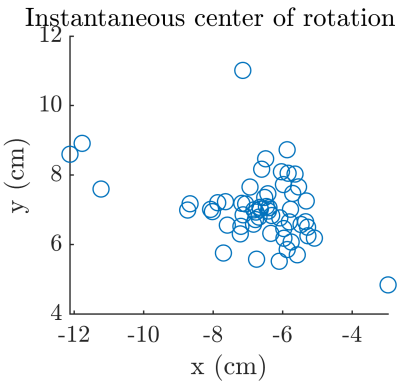


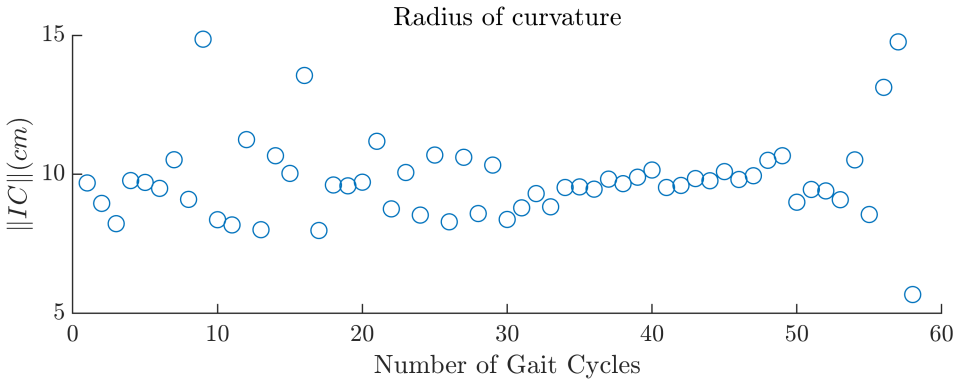




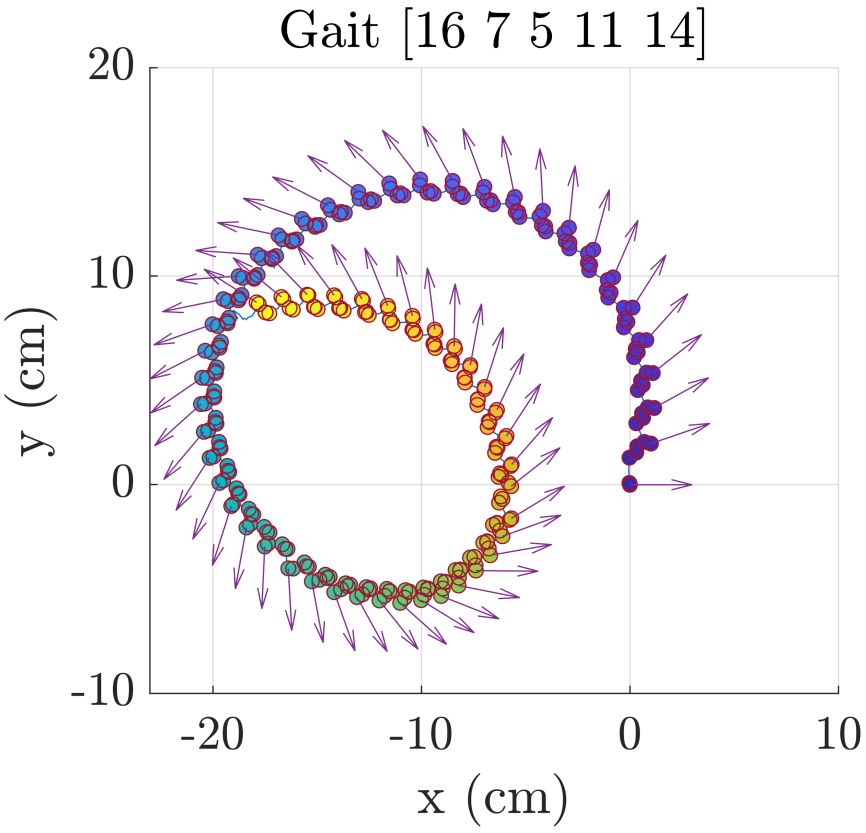
Experiment 23 : 60 cycles of Gait B with no sheath tether (right , not following), trial 2

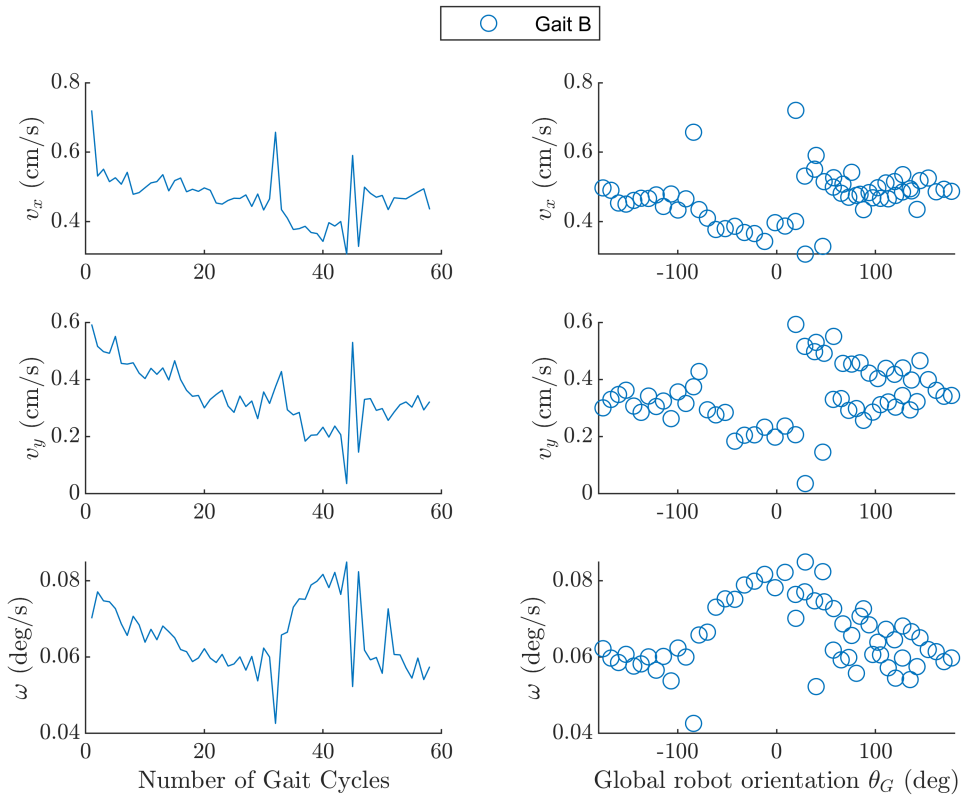

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

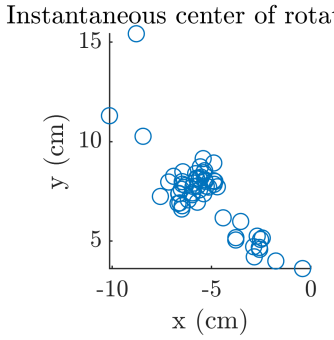


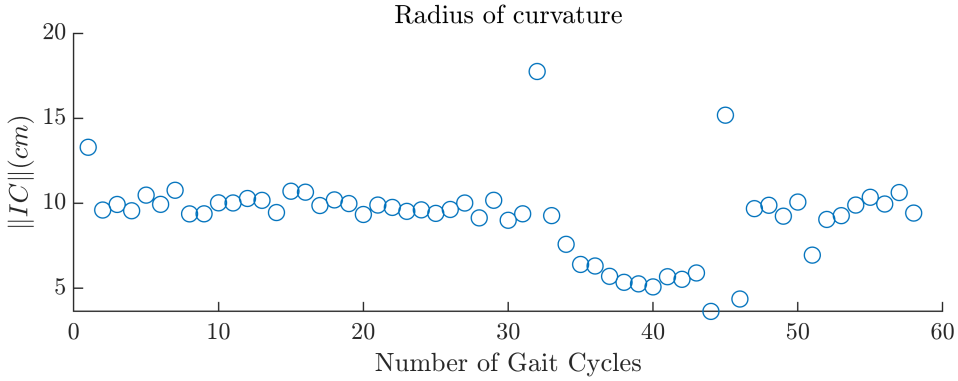


Experiment 24 : 60 cycles of Gait B with no sheath tether (left , not following), trial 1

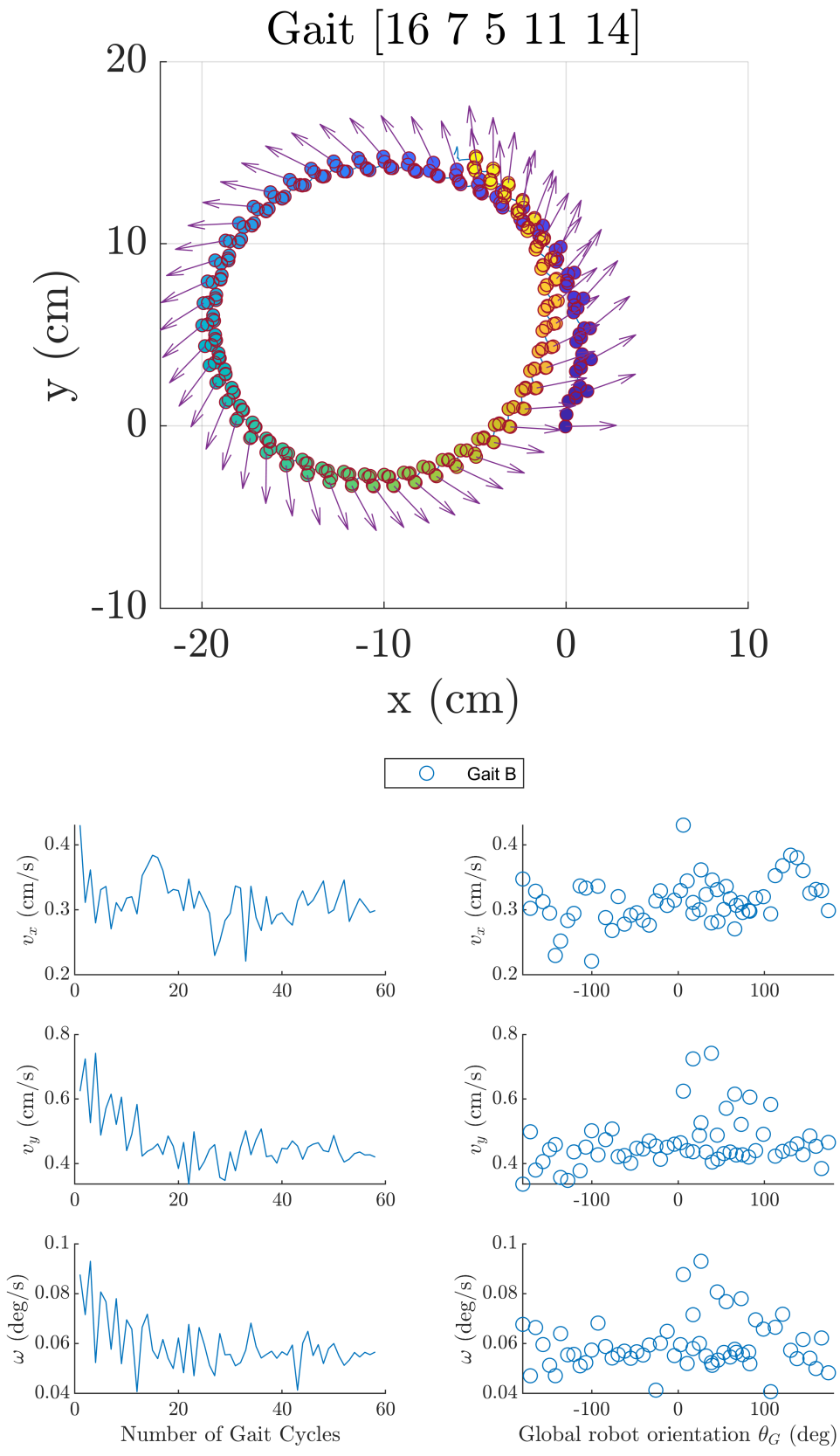


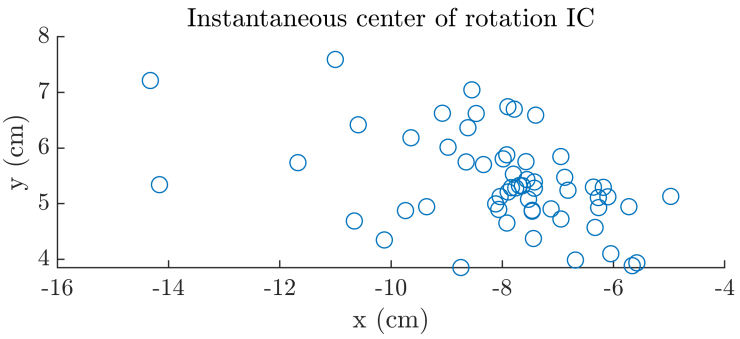


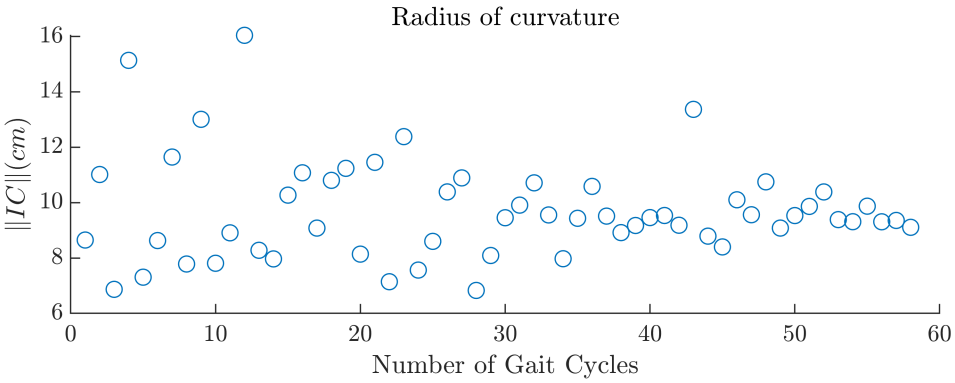




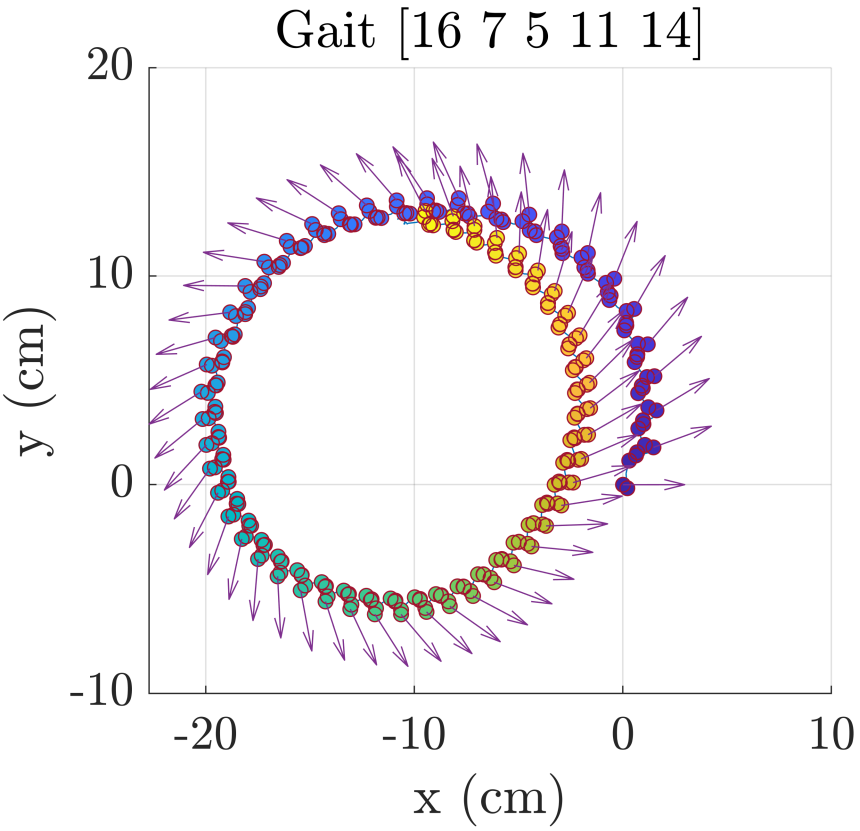
Experiment 25 : 60 cycles of Gait B with no sheath tether (left , not following), trial 2

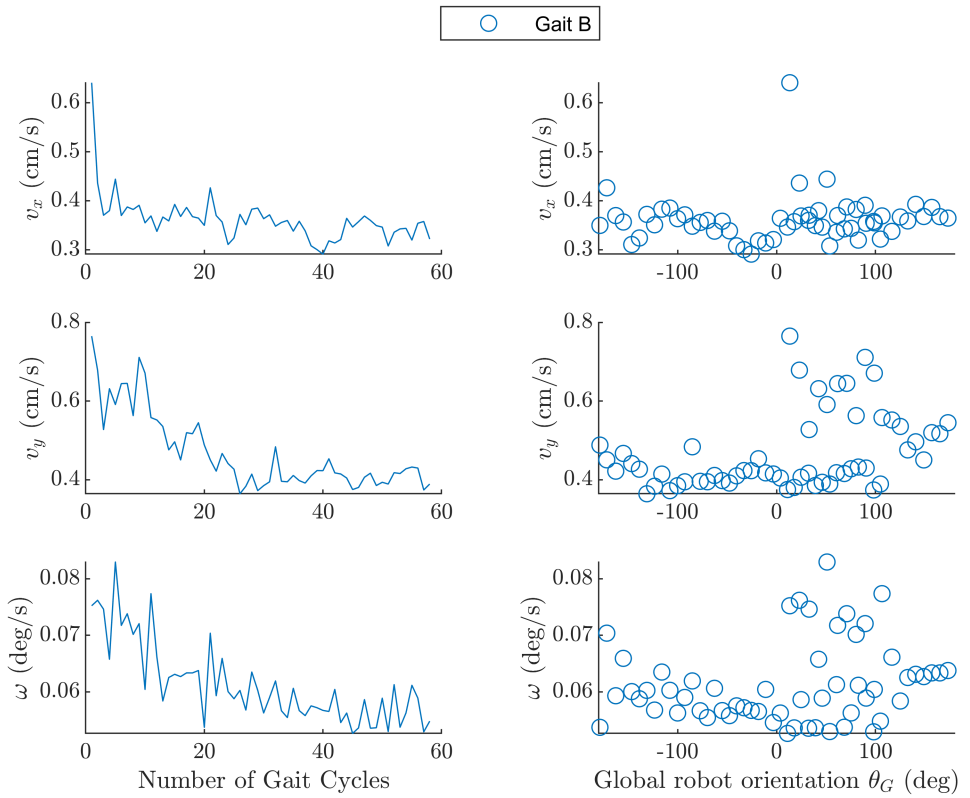

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

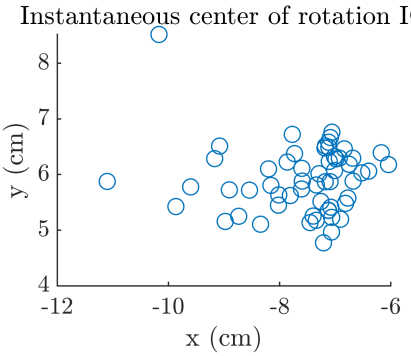


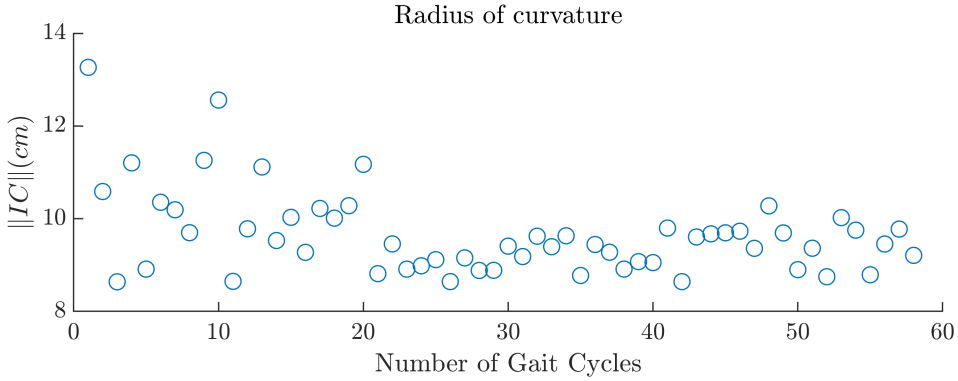


Experiment 26 : 60 cycles of Gait B with light sheath tether (right , following), trial 1

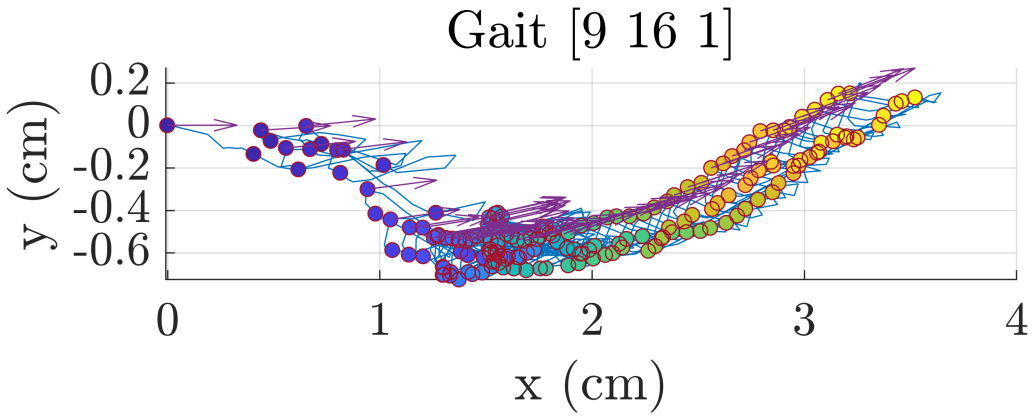


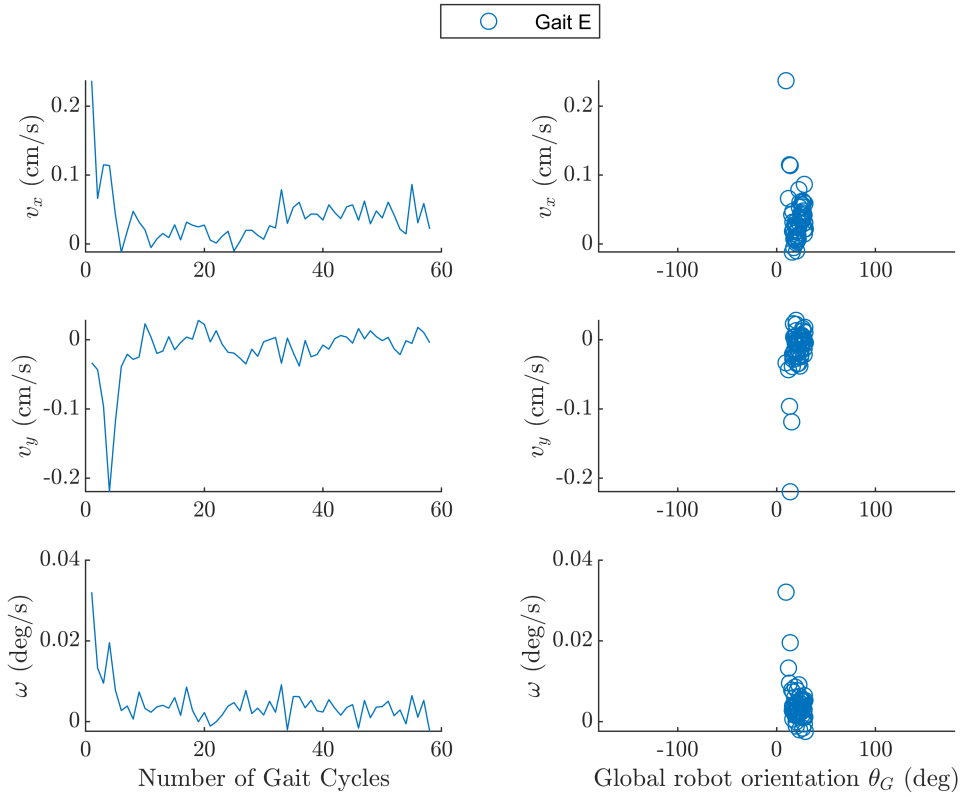


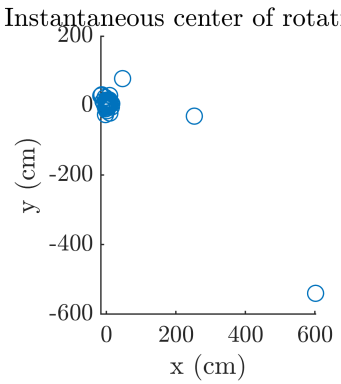


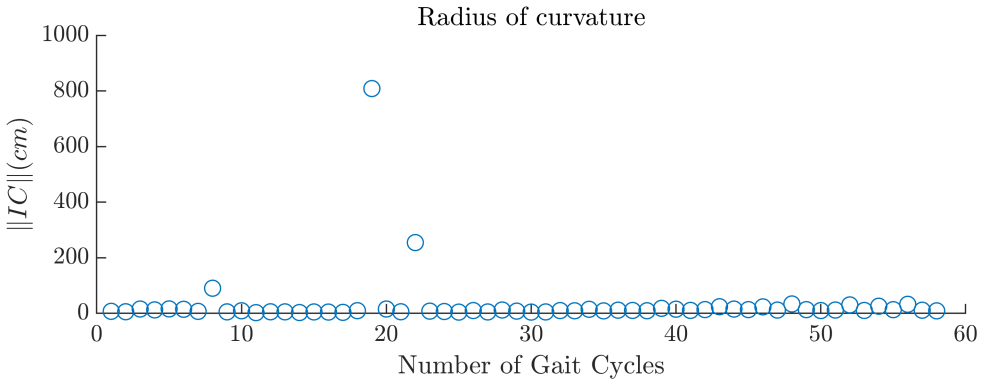


Experiment 27 : 60 cycles of Gait E with no sheath tether (right , not following), trial 1

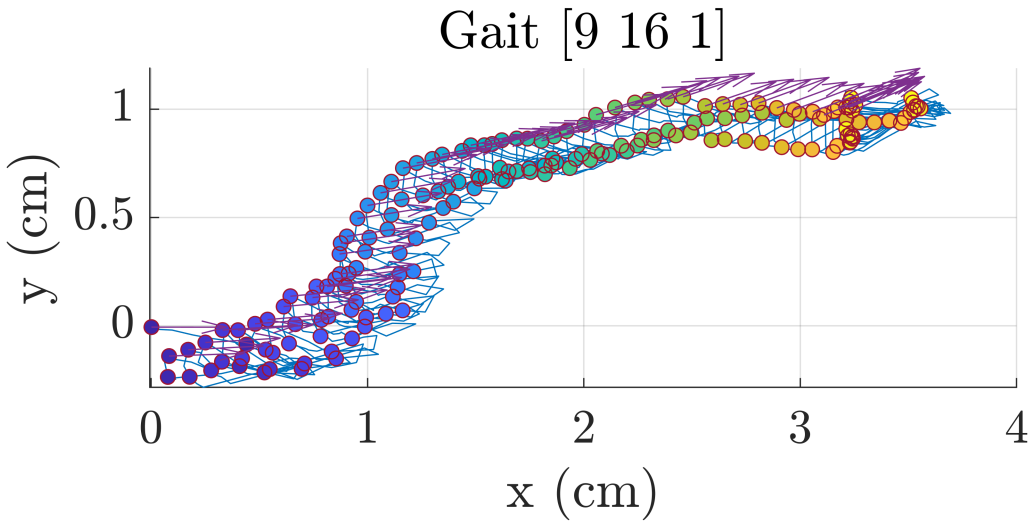

Gait [9 16 1]
y (cm)
x (cm)
0.2
0
-0.2
-0.4
-0.6
0
1
2
3
4

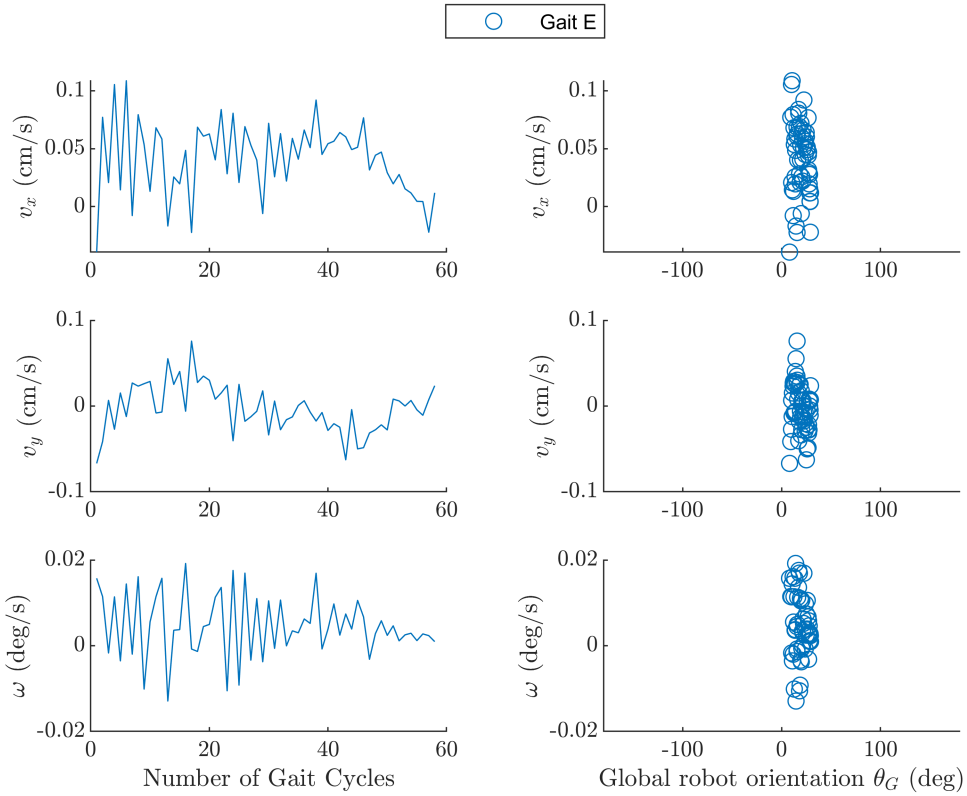

Gait E
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

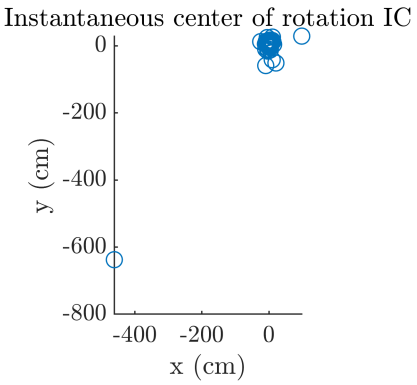


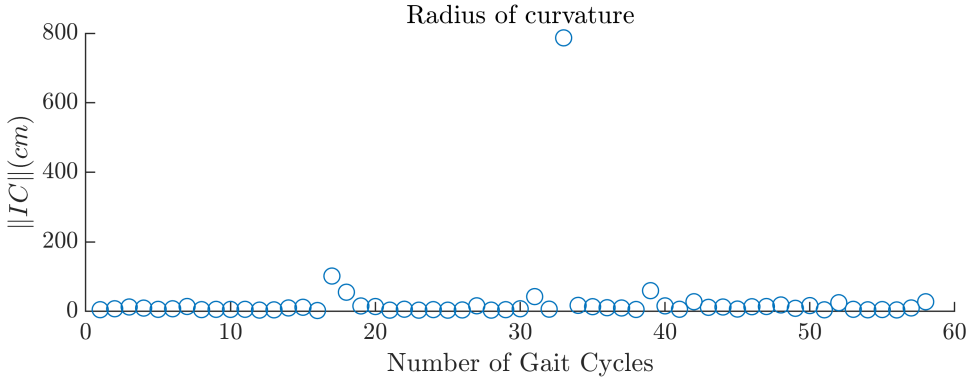


Experiment 28 : 60 cycles of Gait E with no sheath tether (right , not following), trial 2

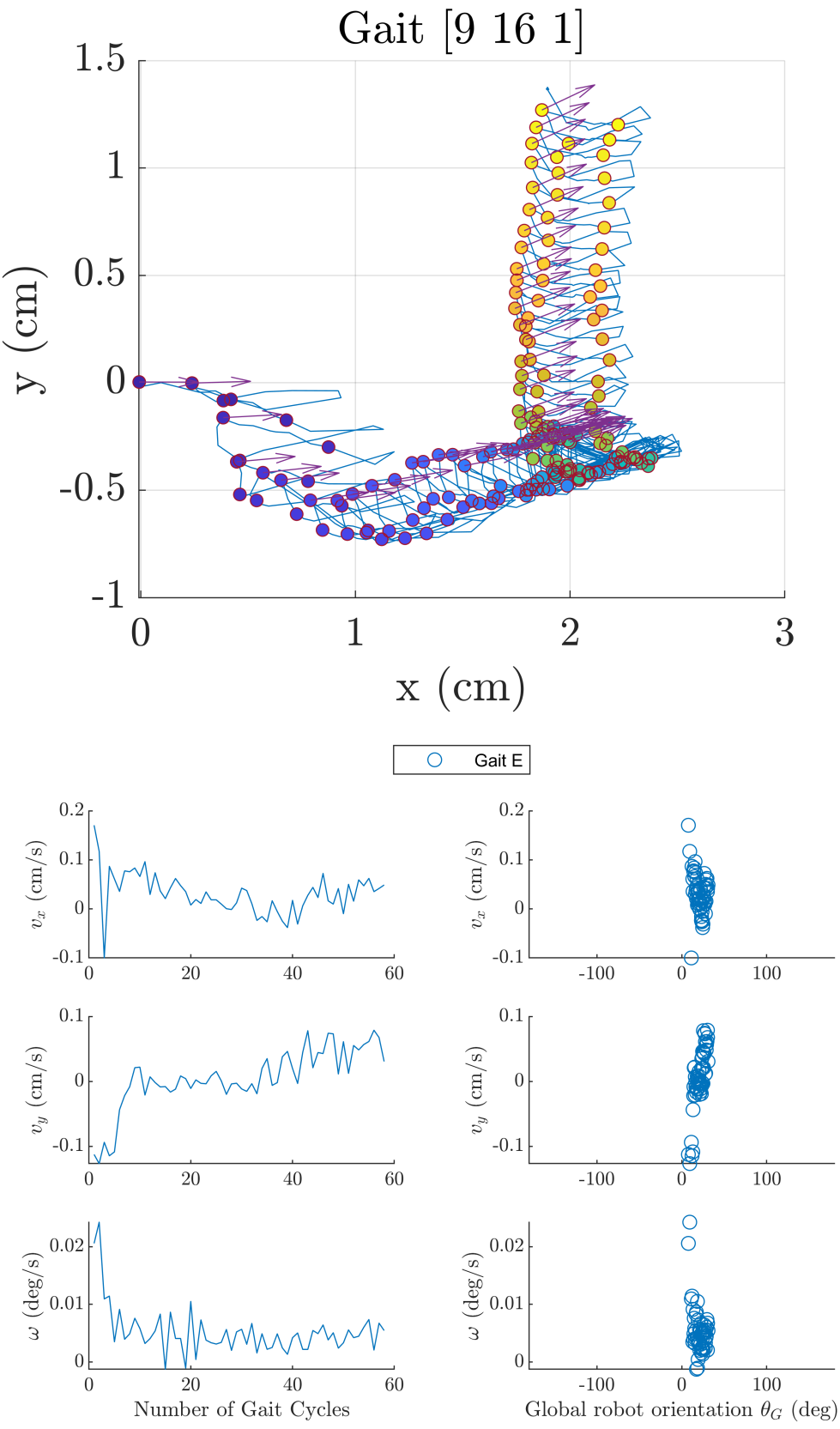


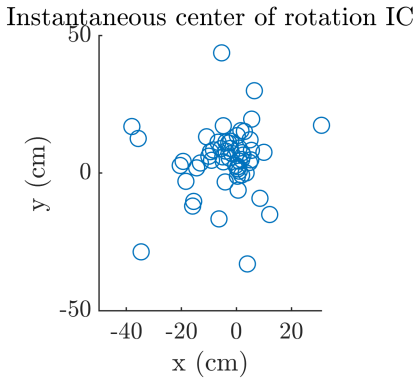


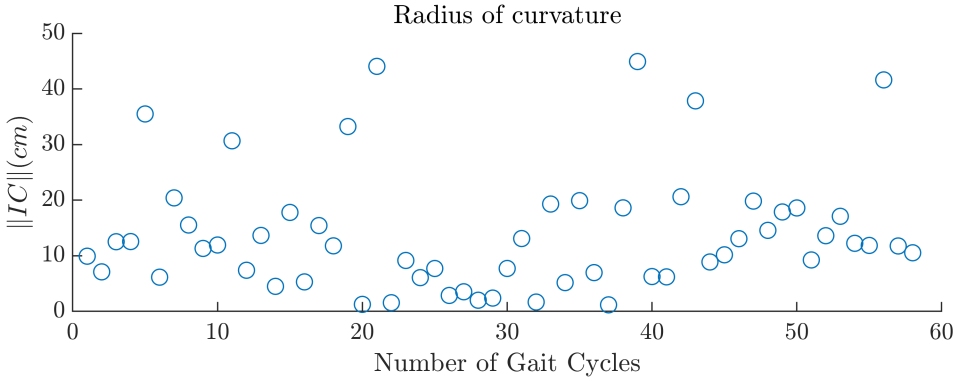




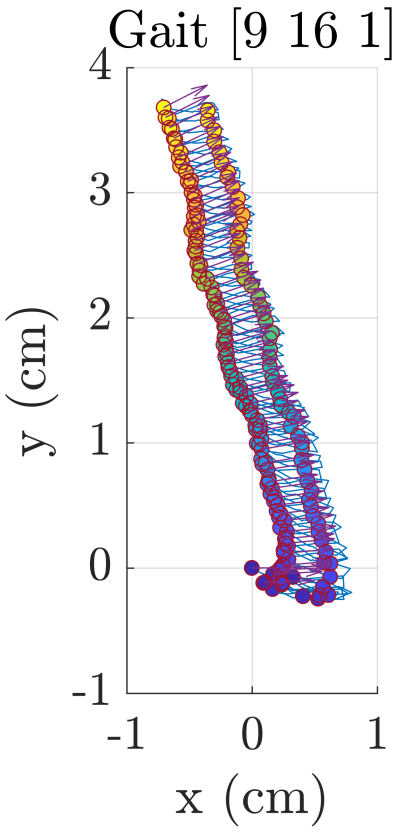
Experiment 29 : 60 cycles of Gait E with no sheath tether (left , not following), trial 2

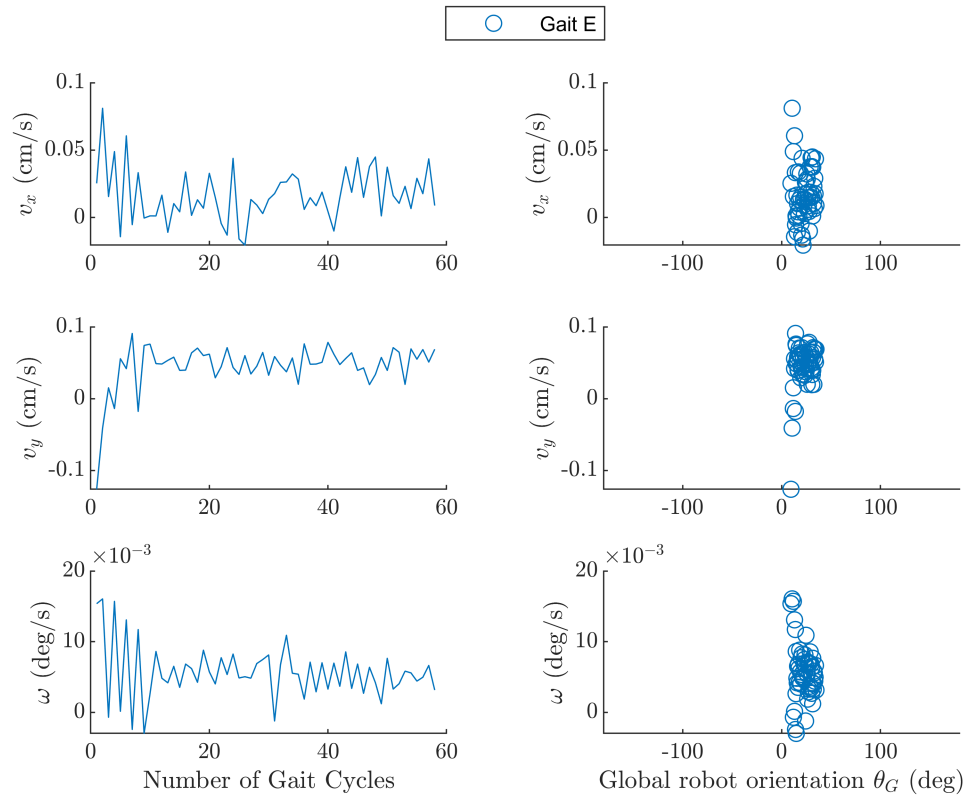

Gait [9 16 1]
y (cm)
x (cm)
Gait E
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

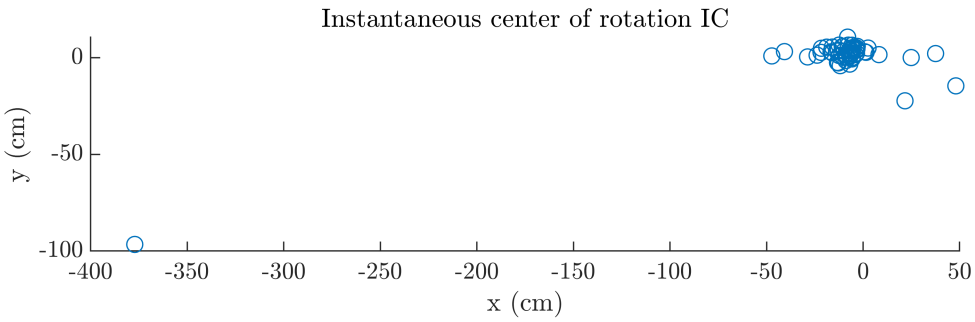


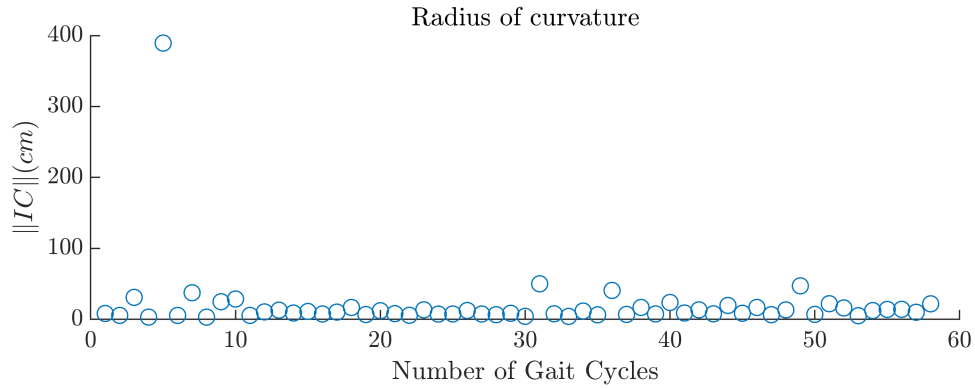


Experiment 30 : 60 cycles of Gait E with no sheath tether (left , not following), trial 3

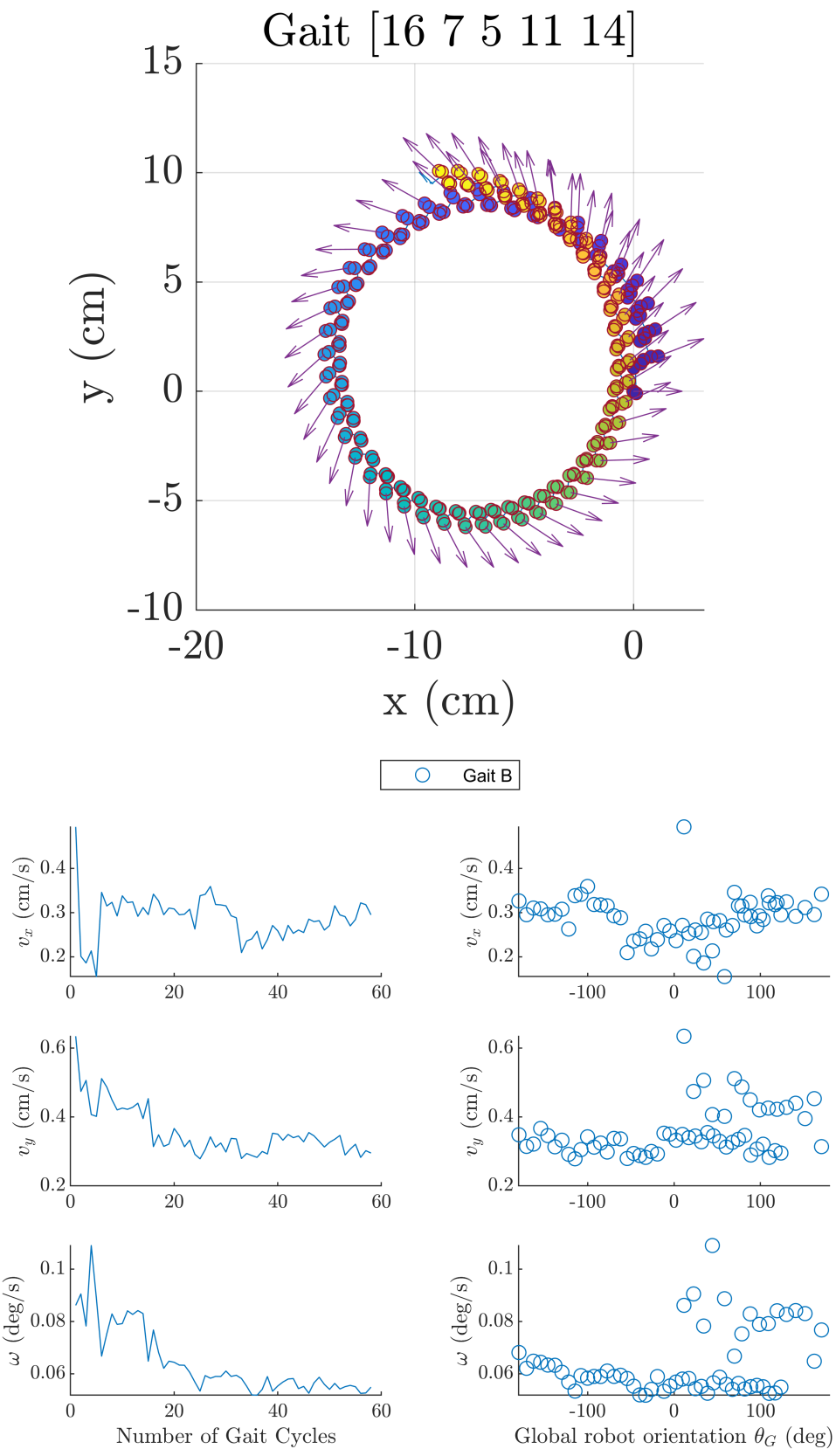


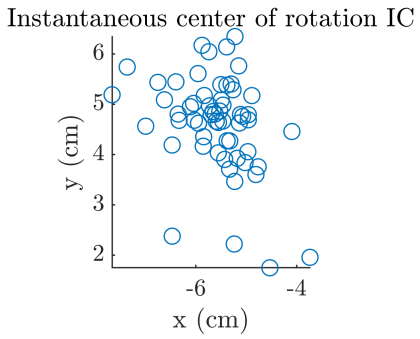


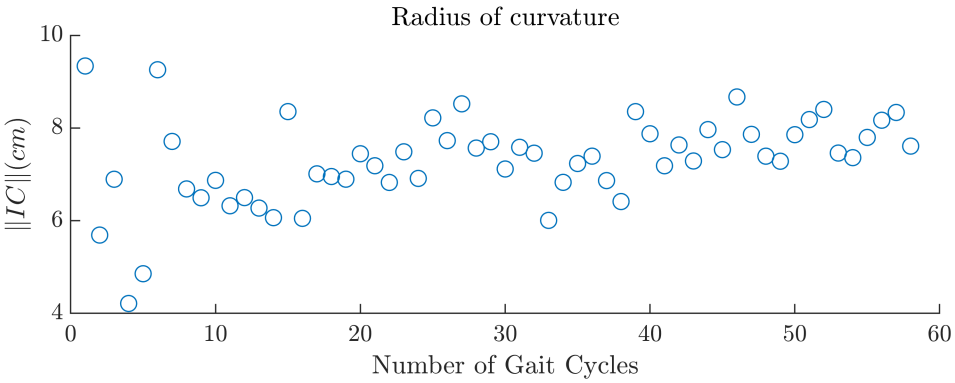




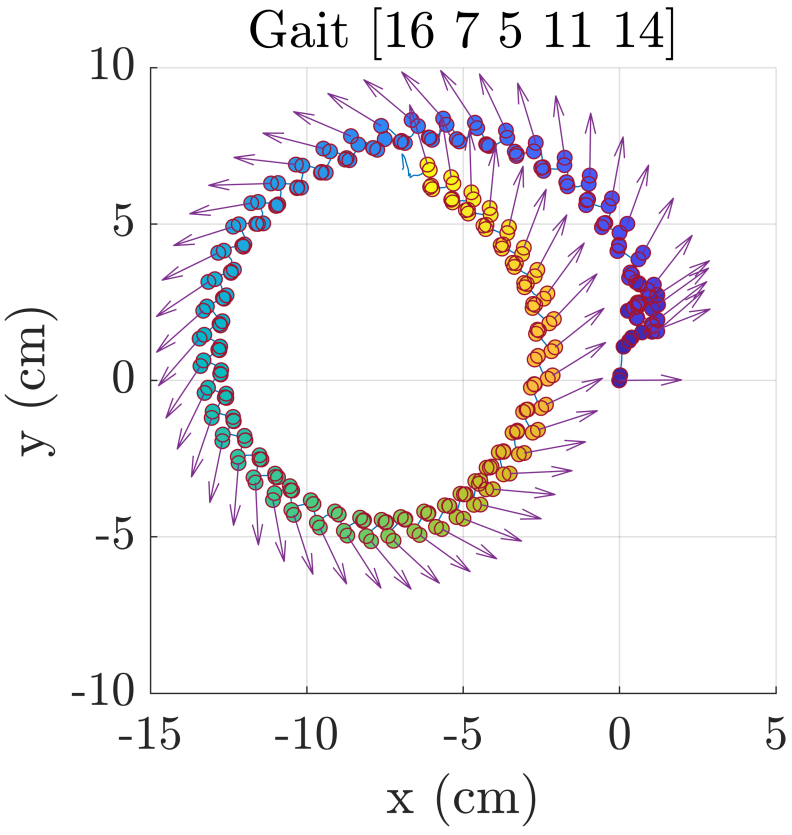
Experiment 31 : 60 cycles of Gait B with 32 tether (left , not following), trial 1

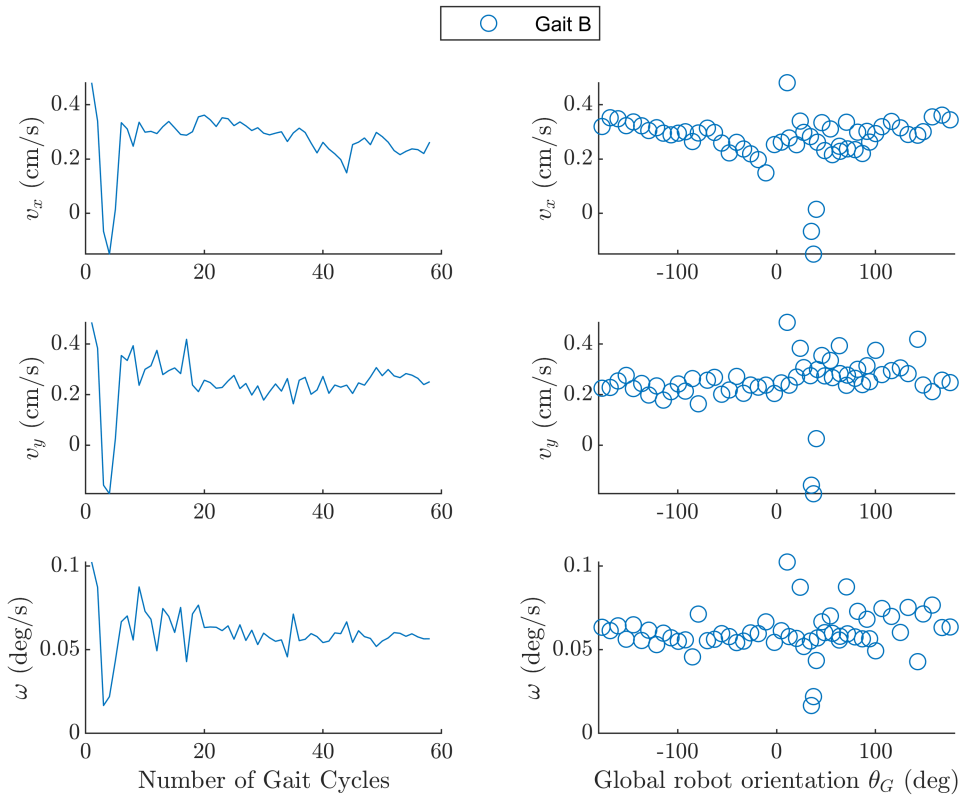

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

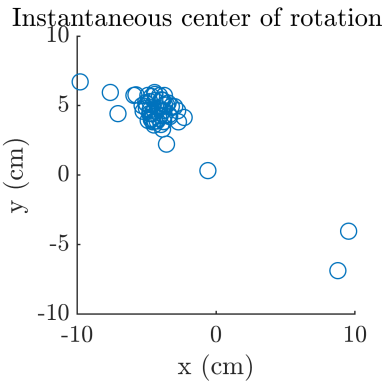


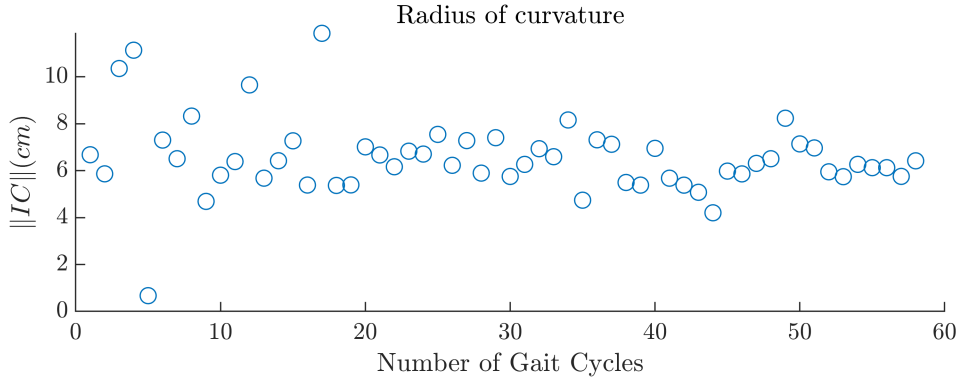


Experiment 32 : 60 cycles of Gait B with 32 tether (left , not following), trial 2

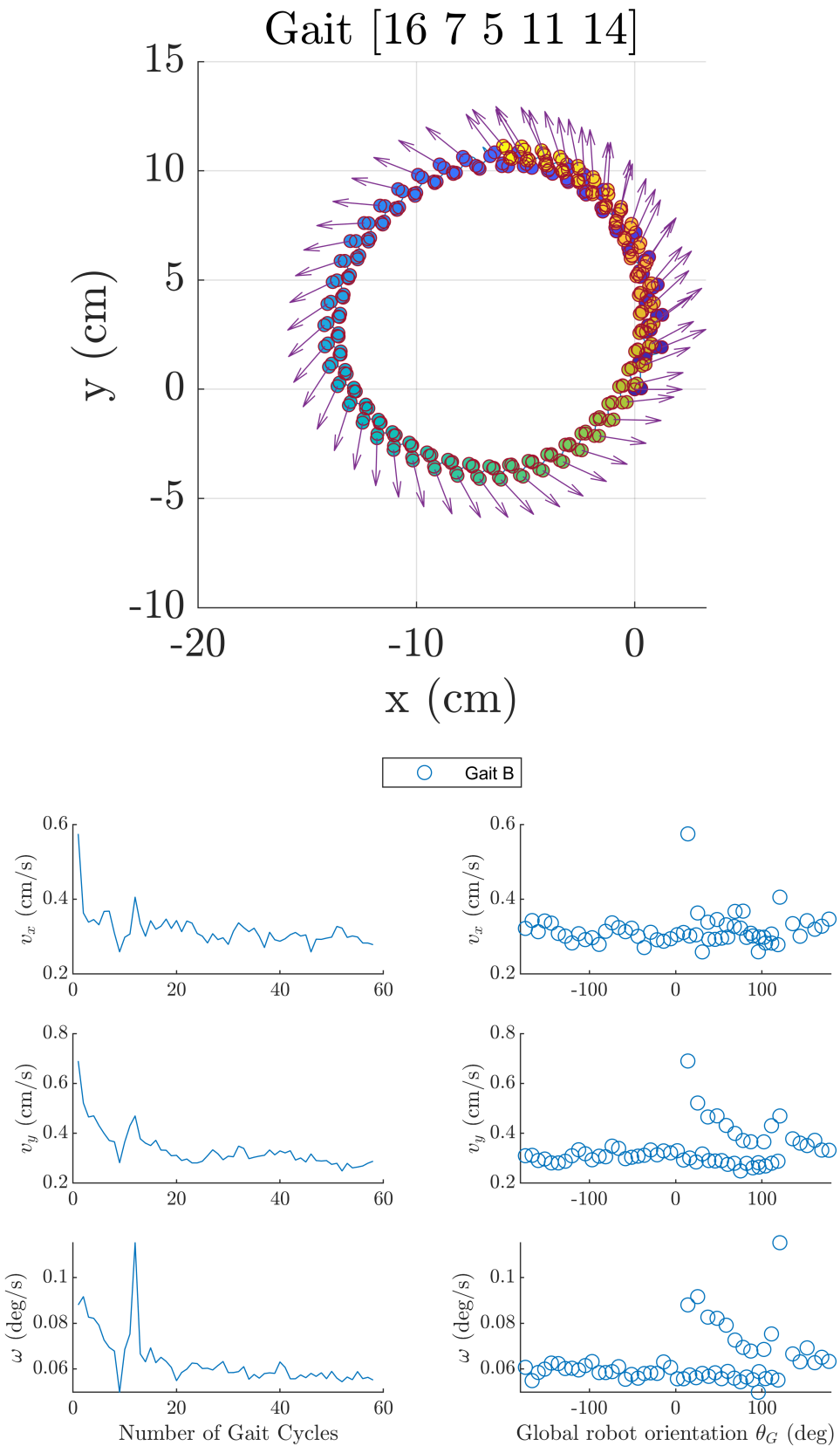


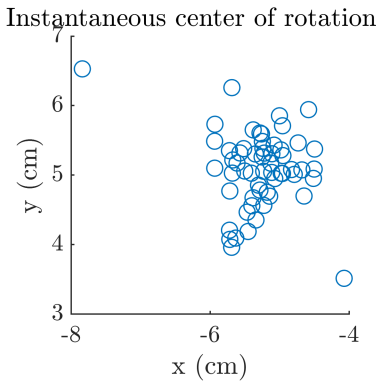


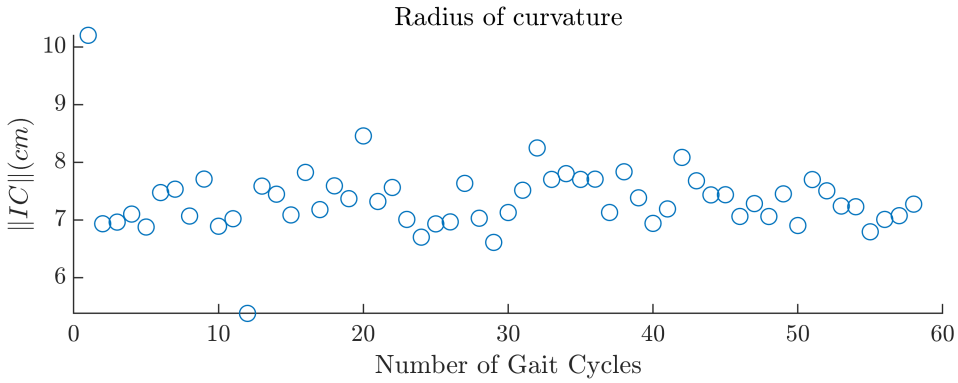




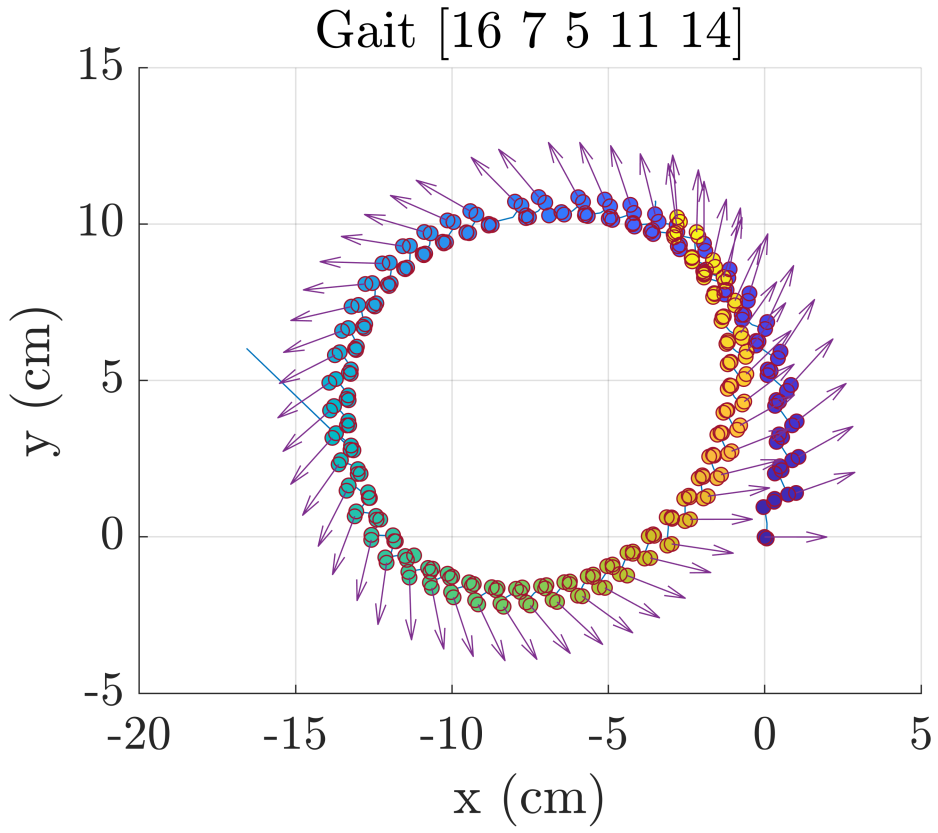
Experiment 33 : 60 cycles of Gait B with 32 tether (right , not following), trial 1

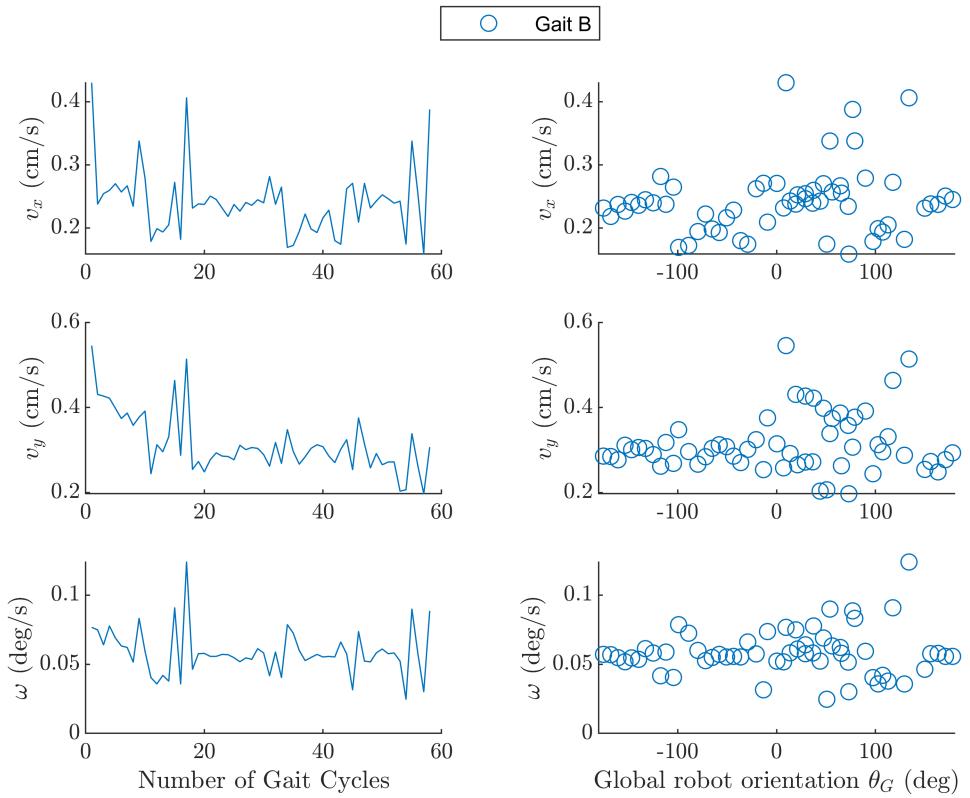

Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)

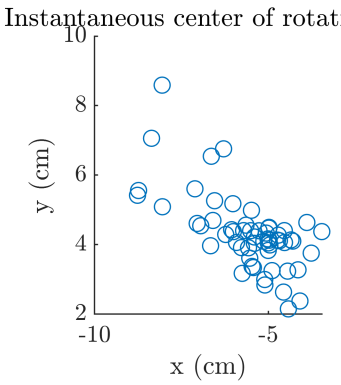


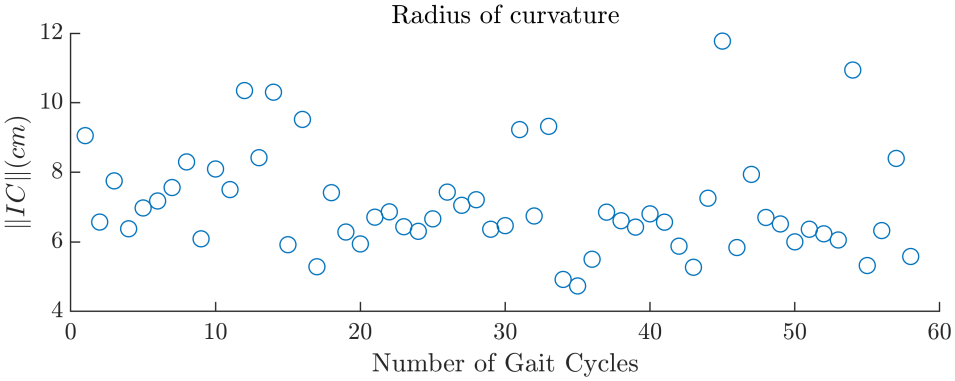


Experiment 34 : 60 cycles of Gait B with 32 tether (right , not following), trial 2

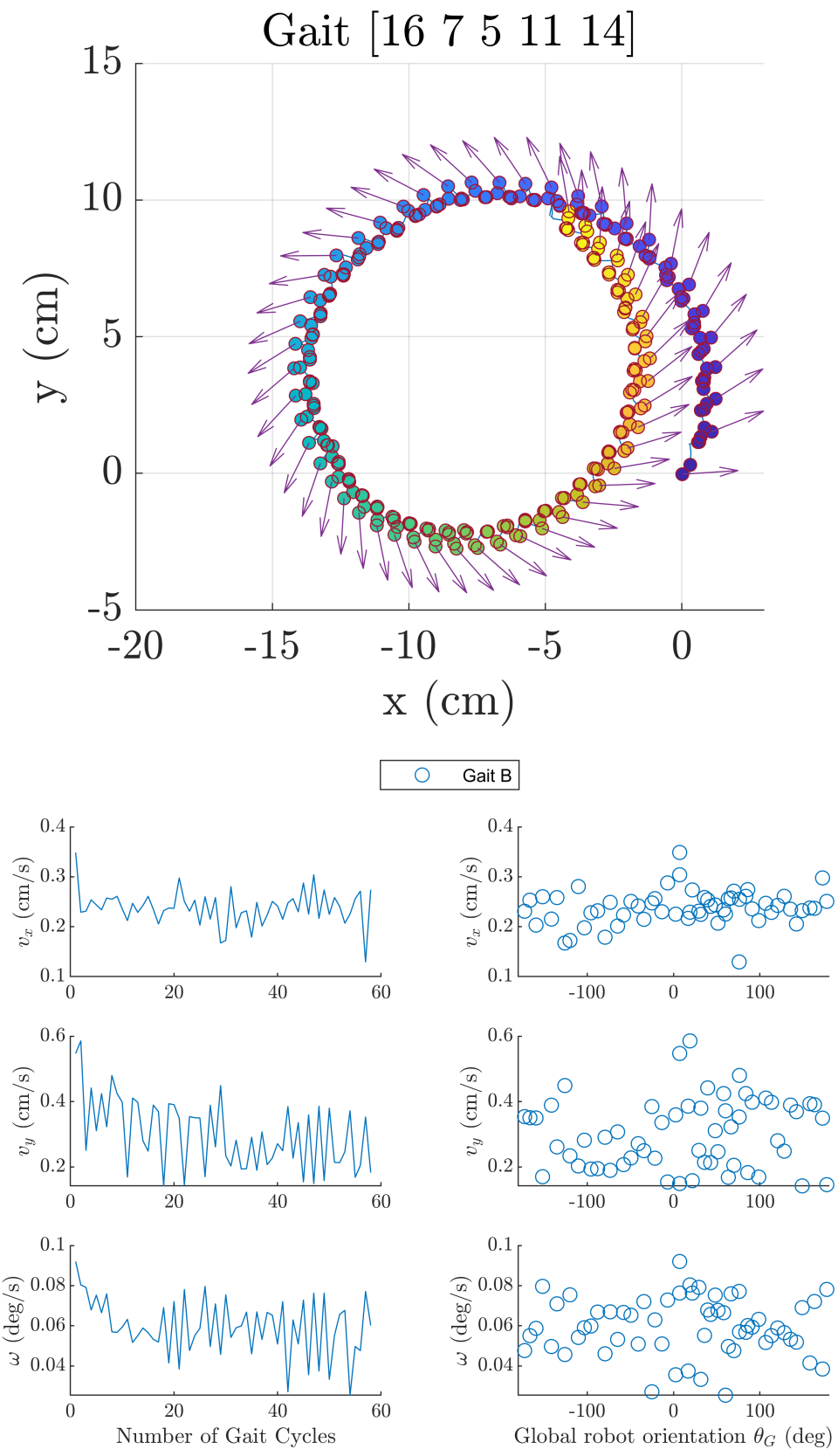


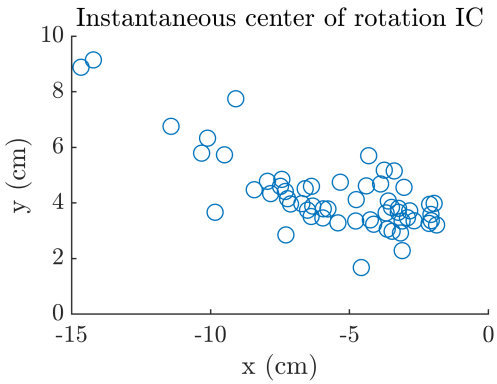


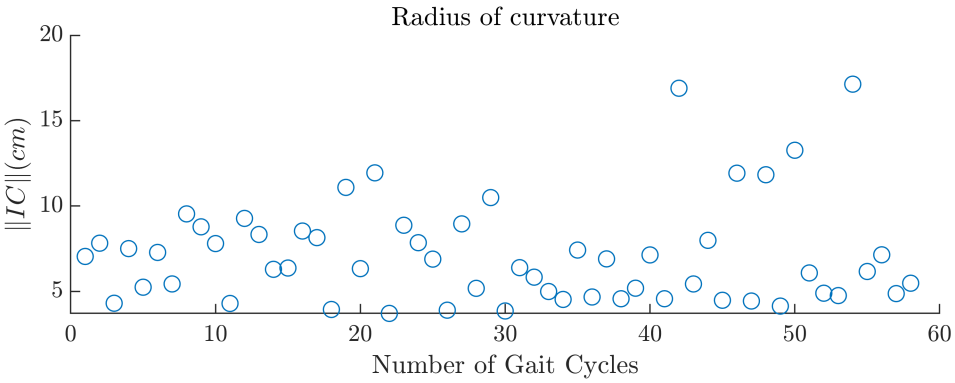




Experiment 35 : 60 cycles of Gait B with 32SR tether (right , not following), trial 2


Gait [16 7 5 11 14]
y (cm)
x (cm)
Gait B
v_x (cm/s)
v_y (cm/s)
ω (deg/s)
Number of Gait Cycles
Global robot orientation θ_G (deg)


Instantaneous center of rotation IC
y (cm)
x (cm)
10
8
6
4
2
0
-15
-10
-5
0


Radius of curvature
$\|IC\|(cm)$
Number of Gait Cycles
20
15
10
5
0
10
20
30
40
50
60