TÉCNICO LISBOA

Dynamics of Mechanical Systems

HW3 - G27

Excavator 1 - John Deere 60G

Task 1 – Excavate Area 1 (Rectangle Below the Ground Level)

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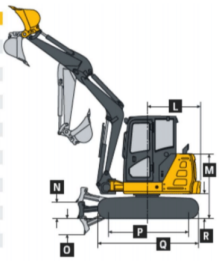
In this homework we had to perform the kinematic analysis of an excavator, more specifically the excavator *John Deer* (excavator 1), using the program *MUBOKAP*. The characteristics of this excavator are the following:

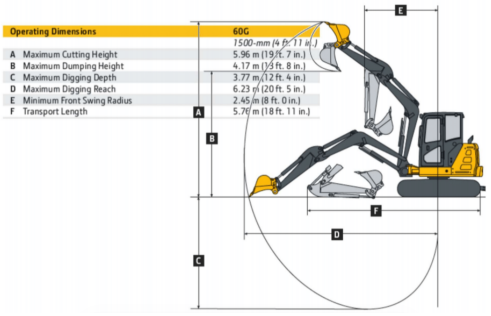
Excavator 1 John Deer 60G

(Bucket Capacity: 0.35 m²)

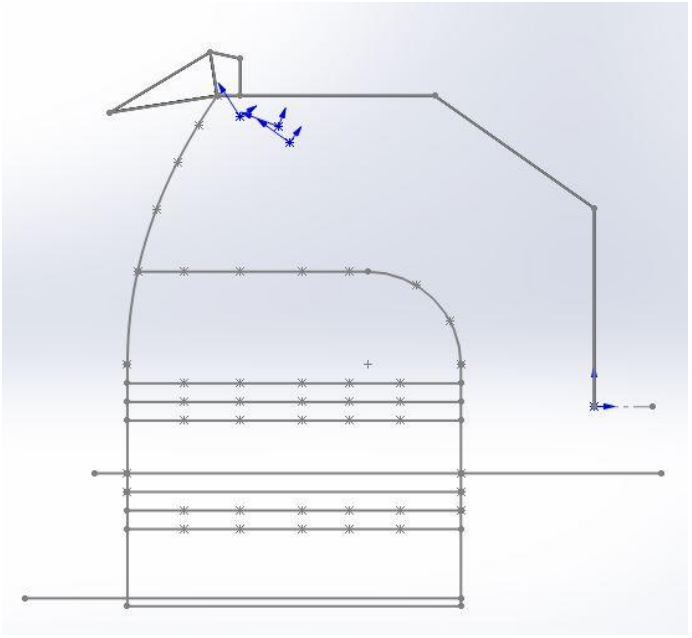
Machine Dimensions	
G Upperstructure Width	2.00 m (6 ft. 7 in.)
H Overall Height	2.54 m (8 ft. 4 in.)
I Track Width	400 mm (16 in.)
J Undercarriage Width	2.00 m (6 ft. 7 in.)
K Ground Clearance	340 mm (13 in.)
L Tail Swing Radius	
With Standard Arm	1.30 m (4 ft. 3 in.)
With Long Arm and Extra Counterweight	1.41 m (4 ft. 8 in.)
M Engine Cover Height	1.60 m (5 ft. 3 in.)
N Maximum Blade Lift Above Ground	460 mm (18 in.)
O Maximum Blade Drop Below Ground	370 mm (15 in.)
Blade	
Width	2.00 m (6 ft. 7 in.)
Height	420 mm (16 in.)
P Sprocket Center to Idler Center	1.99 m (6 ft. 6 in.)
Q Track Length	2.50 m (8 ft. 2 in.)
R Counterweight Clearance	620 mm (24 in.)



Operating Dimensions	60G
	1500-mm (4 ft. 11 in.)
A Maximum Cutting Height	5.96 m (19 ft. 7 in.)
B Maximum Dumping Height	4.17 m (13 ft. 8 in.)
C Maximum Digging Depth	3.77 m (12 ft. 4 in.)
D Maximum Digging Reach	6.23 m (20 ft. 5 in.)
E Minimum Front Swing Radius	2.45 m (8 ft. 0 in.)
F Transport Length	5.70 m (18 ft. 11 in.)



Using this pictures and measurements, a mock-up model of the excavator in *SOLIDWORKS* was created and can be seen below:



Now we move onto the questions asked:

(1.1) Build a path (or a sequence of paths) for the bucket to perform the excavation prescribed in your application. Note that for each pass of the bucket there is a limit of material that can be removed. If more than 3 passes are necessary, consider only the first 3 passes and identify the approximate shape of what is left to dig

First we present the 3 .txt files that serve as an input to *MUBOKAP* as the trajectory to follow. The first one is the *x* coordinate, the second one the *y* coordinate and the last one the *theta* angle. For each of these files there are 56 entries and 1 entry corresponds to one second.

Driver_001

Ficheiro Editar

```
0 -2826.95
1 -3000
2 -3250
3 -3500
4 -3750
5 -4000
6 -4000
7 -3666
8 -3333
9 -3000
10 -2666
11 -2333
12 -2000
13 -2000
14 -2100
15 -2400
16 -2700
17 -3000
18 -3300
19 -3550
20 -3800
21 -4000
22 -4000
23 -3666
24 -3333
25 -3000
26 -2666
27 -2333
28 -2000
29 -2000
30 -2100
31 -2400
32 -2700
33 -3000
34 -3300
35 -3550
36 -3800
37 -4000
38 -4000
39 -3666
40 -3333
41 -3000
42 -2666
43 -2333
44 -2000
45 -2000
46 -2100
47 -2400
48 -2700
49 -3000
50 -3300
51 -3200
52 -3100
53 -3000
54 -2900
55 -2850
56 -2826.95
```

Driver_002

Ficheiro Editar

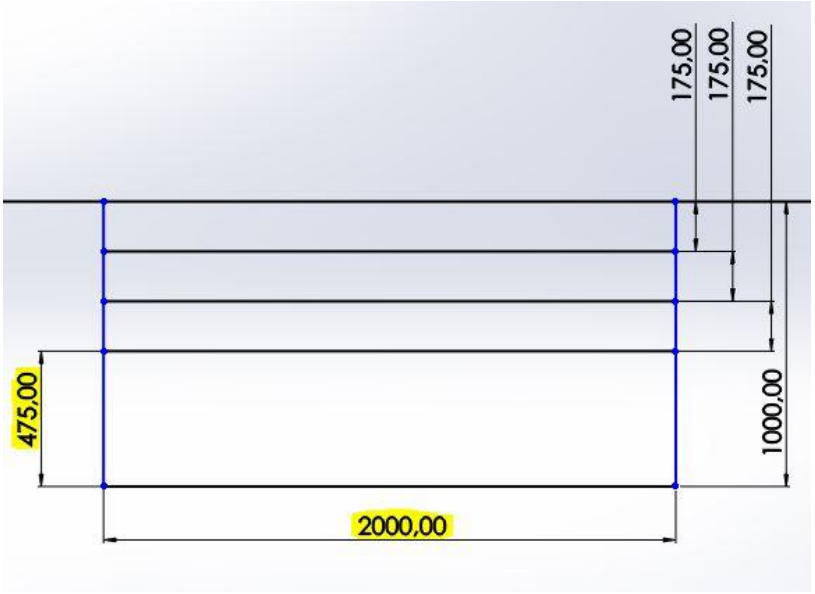
```
0 2339.01
1 2122.31
2 1839.04
3 1487.7
4 1016.44
5 316.38
6 176.38
7 176.38
8 176.38
9 176.38
10 176.38
11 176.38
12 176.38
13 316.38
14 646.72
15 912.12
16 1016.44
17 1016.44
18 1016.44
19 1016.44
20 1016.44
21 316.38
22 36.38
23 36.38
24 36.38
25 36.38
26 36.38
27 36.38
28 36.38
29 316.38
30 646.72
31 912.12
32 1016.44
33 1016.44
34 1016.44
35 1016.44
36 1016.44
37 316.38
38 -103.62
39 -103.62
40 -103.62
41 -103.62
42 -103.62
43 -103.62
44 -103.62
45 316.38
46 646.72
47 912.12
48 1016.44
49 1016.44
50 1016.44
51 1016.44
52 1016.44
53 1487.7
54 1839.04
55 2122.31
56 2339.01
```

Driver_003

Ficheiro Editar

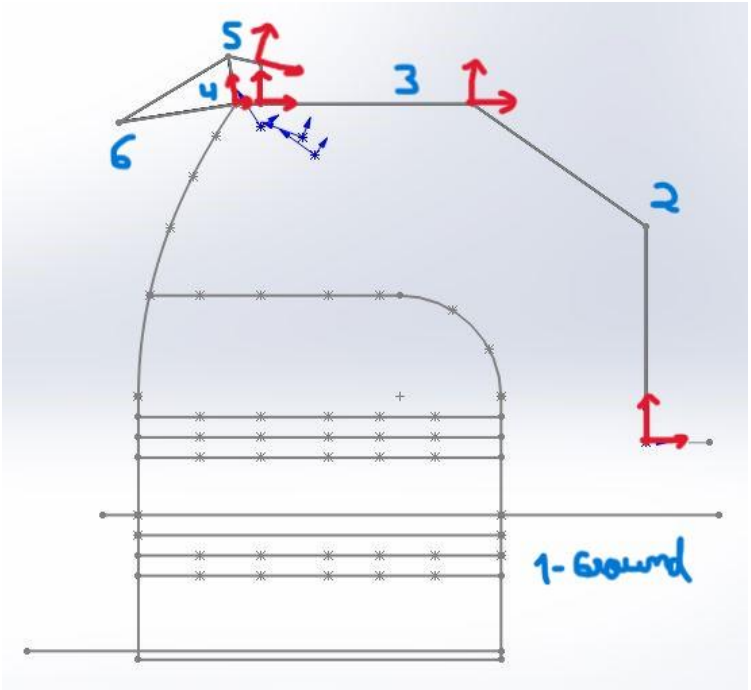
```
0 0.1557
1 0.43872
2 0.72174
3 1.00476
4 1.28778
5 1.5708
6 1.5708
7 1.5708
8 1.5708
9 1.5708
10 1.5708
11 1.5708
12 1.5708
13 1.5708
14 2.09412469282041
15 2.61681469282041
16 3.14181469282041
17 2.66381469282041
18 2.18581469282041
19 1.70781469282041
20 1.22911469282041
21 1.57079469282041
22 1.57079469282041
23 1.57079469282041
24 1.57079469282041
25 1.57079469282041
26 1.57079469282041
27 1.57079469282041
28 1.57079469282041
29 1.57079469282041
30 2.09412469282041
31 2.61681469282041
32 3.14181469282041
33 2.66381469282041
34 2.18581469282041
35 1.70781469282041
36 1.22911469282041
37 1.57079469282041
38 1.57079469282041
39 1.57079469282041
40 1.57079469282041
41 1.57079469282041
42 1.57079469282041
43 1.57079469282041
44 1.57079469282041
45 1.57079469282041
46 2.09412469282041
47 2.61681469282041
48 3.14181469282041
49 2.66381469282041
50 2.18581469282041
51 1.70781469282041
52 1.22911469282041
53 1.43404469282041
54 0.549114692820414
55 0.209114692820414
56 0.1557
```

Since our bucket had an area of 0.35m^2 and the area to dig is 2 square meters (2mx1m), more than 3 passes were necessary (3x 0.35 = 1.05m^2). As such, the area left to dig is equal to 0.95 m^2 (0.475x2). The image below shows all the measures mentioned.



(1.2) Guide the bucket position and orientation with the position drivers directly applied to the bucket body and,obtain the history of the positions of the points to which the hydraulic actuators are connected.

As for the model which was built, we decided to divide the excavator into 6 different bodies. In total there are 6 joints, all of them revolution joints. The bodies, their numbers and their local reference frames are depicted in the picture below



In addition to this, there are 3 conditions for the ground and 3 driver constraints as this model has 3 degrees of freedom. If we check:

*6*3 - 6*2 - 3*1 = 3 degrees of freedom*

The model information and its respective input file can be seen here:

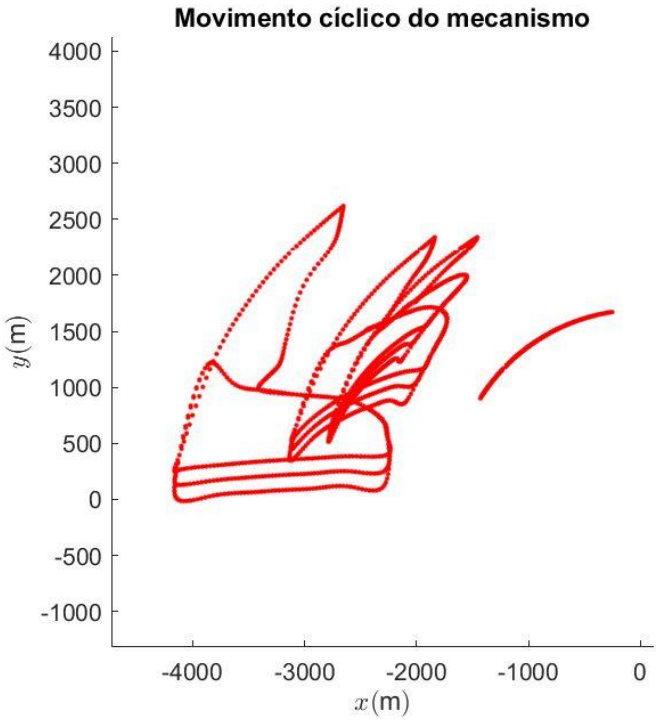
model_excavator

Ficheiro Editar Ver

```
6 6 0 0 0 0 0 3 3 4
0 0 0
0 0 0
-1195.69 2339.01 0
-2653.95 2339.01 0
-2653.95 2619.35 6.0683
-2826.95 2339.01 0.1557
1 2 0 0 0 0
2 3 -1195.69 2339.01 0 0
3 4 -1458.26 0 0 0
3 6 -1631.26 0 0 0
4 5 0 280.34 0 0
5 6 -230 0 0 333.4
1 1 0
1 2 0
1 3 0
3 6 1 0 0.000 0.000 0.000 0.000 4 1
3 6 2 0 0.000 0.000 0.000 0.000 4 2
3 6 3 0 0.000 0.000 0.000 0.000 4 3
3 0 0
4 0 0
5 0 0
6 -816.38 0
12 0.000001
0 0.1 56
```

Now we are ready to see the results. They are presented below as well:

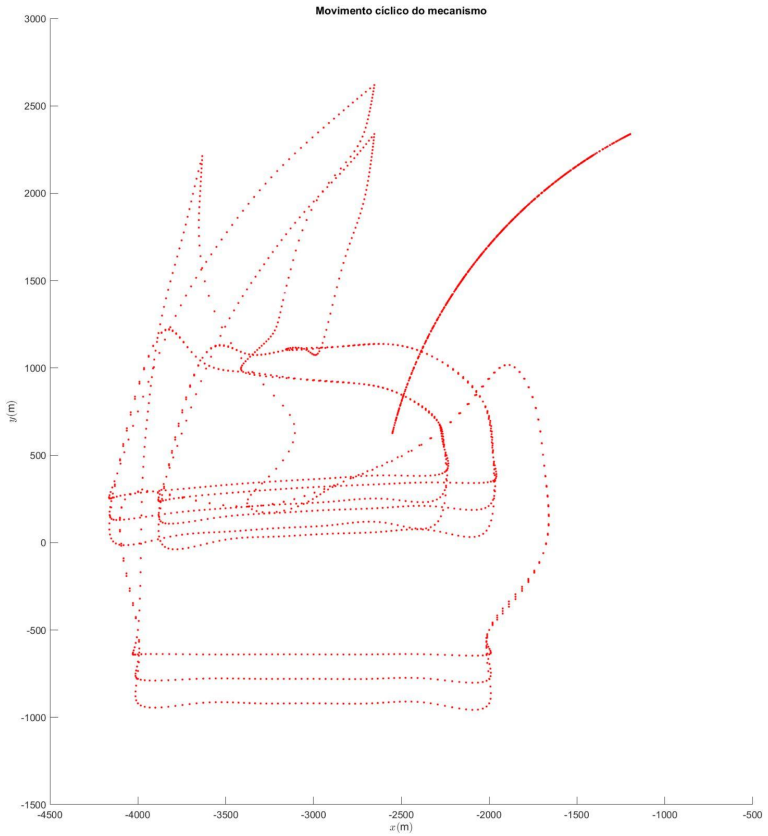
History of the positions of the points to which the hydraulic actuators are connected



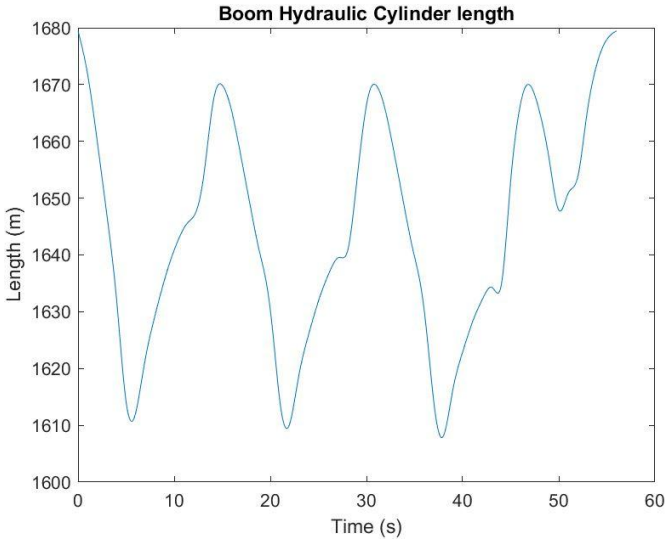
(1.3) Plot the trajectories of the bucket, obtained with the kinematic simulation, and the length of each one of the hydraulic actuators as functions of time

For the final question, some other plots were made:

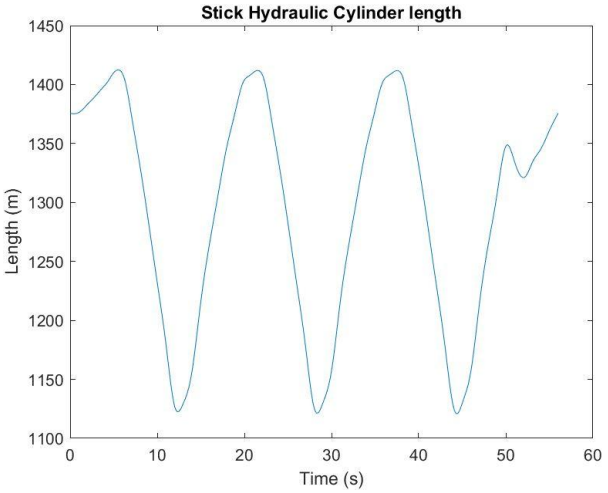
Trajectory of the bucket and other joint points



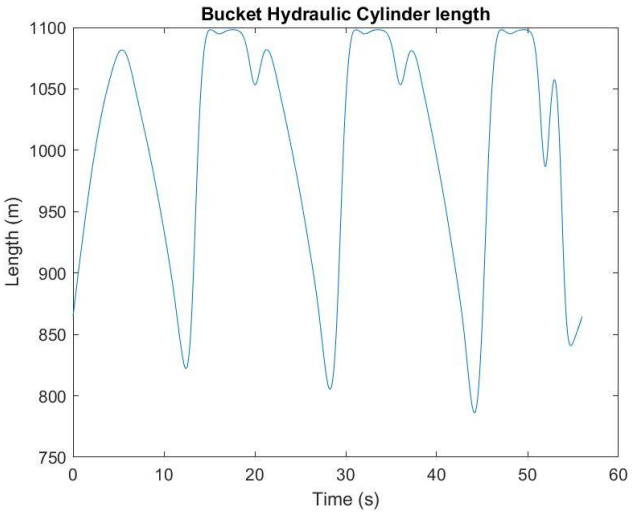
Length of hydraulic actuator number 1 as a function of time



Length of hydraulic actuator number 2 as a function of time



Length of hydraulic actuator number 3 as a function of time



This was the code used to obtain these lengths:

```
for i = 1:length(t)
    distance_hydraulic1(i) = sqrt((Pts.Int(1).q(1,i)-Pts.Int(2).q(1,i))^2 + ...
                             (Pts.Int(1).q(2,i)-Pts.Int(2).q(2,i))^2);
    distance_hydraulic2(i) = sqrt((Pts.Int(3).q(1,i)-Pts.Int(2).q(1,i))^2 + ...
                             (Pts.Int(3).q(2,i)-Pts.Int(2).q(2,i))^2);
    distance_hydraulic3(i) = sqrt((Pts.Int(5).q(1,i)-Pts.Int(4).q(1,i))^2 + ...
                             (Pts.Int(5).q(2,i)-Pts.Int(4).q(2,i))^2);

end
```

(2.1) Instead of driving the bucket of the excavator, drive the hydraulic actuators with point2point drivers so that the end kinematics of the bucket is that one prescribed in phase 1. Plot the bucket trajectory and orientation obtained with the new drivers together with the trajectory obtained in phase 1 (driving the bucket directly)

The driver files were made by extracting the previously calculated length of actuators as a function of time. This is the used input file and the various driver files:

model_excavator3.txt - Notepad

File Edit Format View Help

```
6 6 0 0 0 0 0 3 3 4
0 0 0
0 0 0
-1195.69 2339.01 0
-2653.95 2339.01 0
-2653.95 2619.35 6.0683
-2826.95 2339.01 0.1557
1 2 0 0 0 0
2 3 -1195.69 2339.01 0 0
3 4 -1458.26 0 0 0
3 6 -1631.26 0 0 0
4 5 0 280.34 0 0
5 6 -230 0 0 333.4
1 1 0
1 2 0
1 3 0
5 1 0 2 -100.000 0.000 -253.06 1672.45 4 4
5 2 0 3 -253.06 1672.45 -260.7 0.000 4 5
5 3 0 5 -640.43 0.000 0.000 0.000 4 6
2 -253.06 1672.45
3 -260.7 0
3 -640.43 0
5 0 0
12 0.000001
0 0.1 56
```

Driver_004.txt - Notepad

File Edit Format View Help

0	1679.43930110618
1	1671.76722047773
2	1659.98698923614
3	1647.06811756293
4	1632.30467027290
5	1614.12282959128
6	1612.19385650855
7	1621.70972877355
8	1629.30426647259
9	1635.65162154001
10	1640.84781477987
11	1644.68688294431
12	1646.71284843712
13	1653.07587520142
14	1666.39674576522
15	1669.88320958969
16	1665.20518286329
17	1656.84432165199
18	1647.86074402468
19	1639.65431029230
20	1630.29552038134
21	1614.12282959128
22	1610.17790962896
23	1619.06587103417
24	1626.09780768283
25	1631.85865594554
26	1636.39306608882
27	1639.44701622775
28	1640.49205904452
29	1653.07587520142
30	1666.39674576522
31	1669.88320958969
32	1665.20518286329
33	1656.84432165199
34	1647.86074402468
35	1639.65431029230
36	1630.29552038134
37	1614.12282959128
38	1608.10769785886
39	1616.40156245357
40	1622.89190371607
41	1628.09035484238
42	1631.99920505612
43	1634.33052635033
44	1634.51571537349
45	1653.07587520142
46	1666.39674576522
47	1669.88320958969
48	1665.20518286329
49	1656.84432165199
50	1647.86074402468
51	1650.94055226238
52	1653.93110298006
53	1665.68436652120
54	1673.82226805436
55	1677.93765062438
56	1679.43930110618

Driver_005.txt - Notepad

File Edit Format View Help

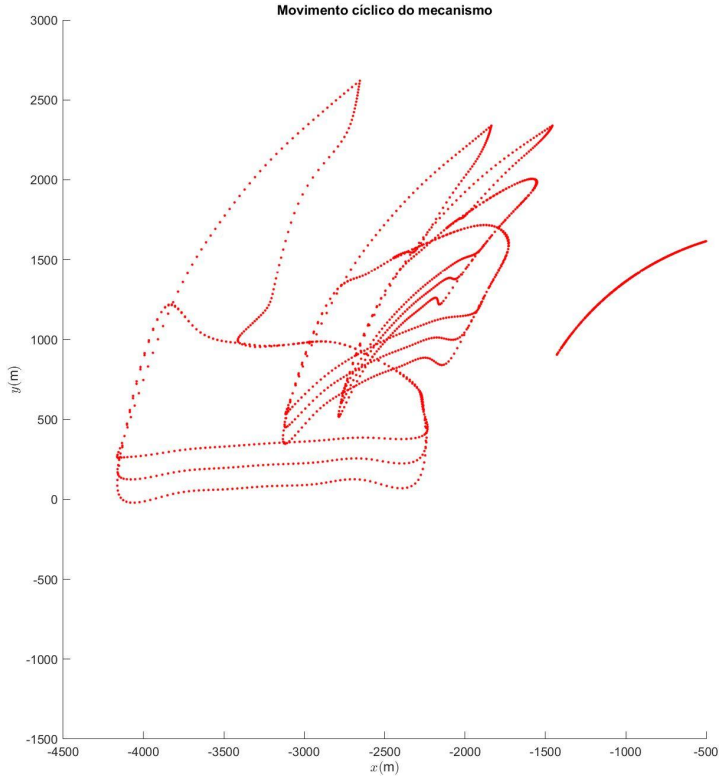
0	1375.61089065913
1	1376.29742415199
2	1383.33202257236
3	1391.03113874480
4	1399.44927440932
5	1410.04596822571
6	1409.45351934844
7	1375.74410944999
8	1331.78789435077
9	1283.24098890387
10	1232.11748489449
11	1179.88238880511
12	1127.04143203156
13	1129.77607486289
14	1157.27966238386
15	1215.80884425855
16	1265.01687948026
17	1307.34756308003
18	1347.71720151556
19	1378.44272004423
20	1403.88508556018
21	1410.04596822571
22	1409.19054372718
23	1375.25059020815
24	1331.15970398502
25	1282.49462939400
26	1231.24827307016
27	1178.87231071797
28	1125.85308916423
29	1129.77607486289
30	1157.27966238386
31	1215.80884425855
32	1265.01687948026
33	1307.34756308003
34	1347.71720151556
35	1378.44272004423
36	1403.88508556018
37	1410.04596822571
38	1409.27411308984
39	1375.40676714600
40	1331.35841144467
41	1282.73069650805
42	1231.52321046771
43	1179.19185476705
44	1126.22915047937
45	1129.77607486289
46	1157.27966238386
47	1215.80884425855
48	1265.01687948026
49	1307.34756308003
50	1347.71720151556
51	1334.57609921103
52	1321.09632653158
53	1333.32584085132
54	1345.13024949685
55	1361.04588660294
56	1375.61089065913

Driver_006.txt - Notepad

File Edit Format View He

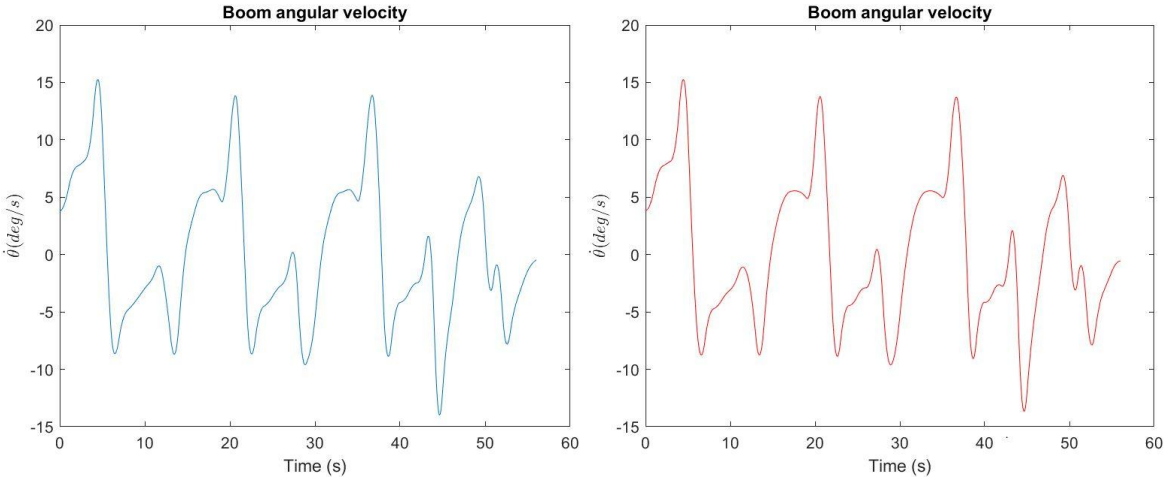
0	864.531705060689
1	924.736181389900
2	979.523300561191
3	1023.92154591698
4	1056.60980238723
5	1079.32548674141
6	1075.34095185830
7	1044.77583547230
8	1011.62682093648
9	975.359303667027
10	934.887936390792
11	888.786172462142
12	833.934554575618
13	858.508102568305
14	1040.99787738334
15	1097.97495531173
16	1094.86735538030
17	1097.61508512529
18	1097.82053774101
19	1086.84917769285
20	1053.26371702354
21	1079.32501773428
22	1071.39989669368
23	1038.30815455795
24	1002.72211910249
25	963.778432115932
26	920.152396951264
27	870.163941125090
28	810.309762791239
29	858.506491535307
30	1040.99787738334
31	1097.97495531173
32	1094.86735538030
33	1097.61508512529
34	1097.82053774101
35	1086.84917769285
36	1053.26371702354
37	1079.32501773428
38	1067.62231772664
39	1032.04640315424
40	994.085469815455
41	952.562359767402
42	905.944930486335
43	852.369122982359
44	788.130462673188
45	858.506491535307
46	1040.99787738334
47	1097.97495531173
48	1094.86735538030
49	1097.61508512529
50	1097.82053774101
51	1072.47130394799
52	986.949250003113
53	1057.41105775795
54	901.742738829434
55	843.612163457227
56	864.531705060689

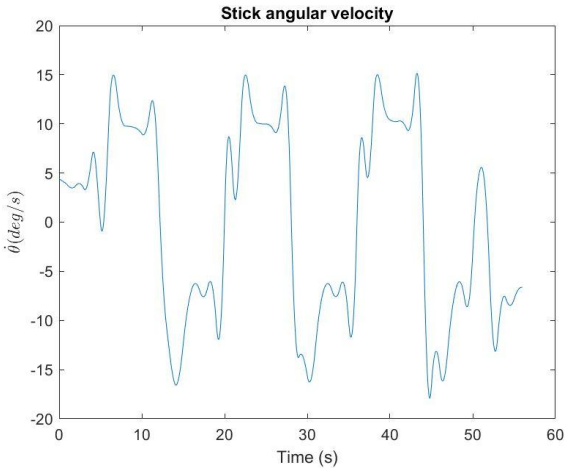
The obtained trajectory plot resembles the one done with type 3 drivers:

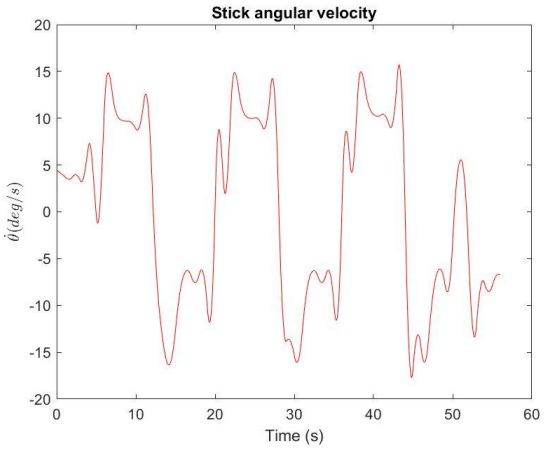


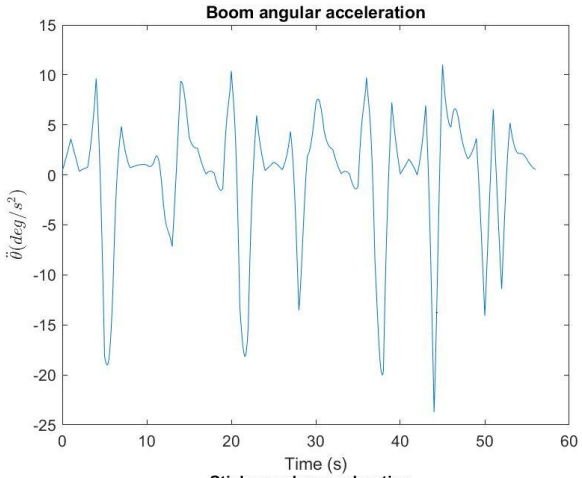
(2.2) Compare the angular velocities and accelerations of the arm and boom using the two types of drivers (the driven bucket in phase 1 and the point2point drivers in phase 2)

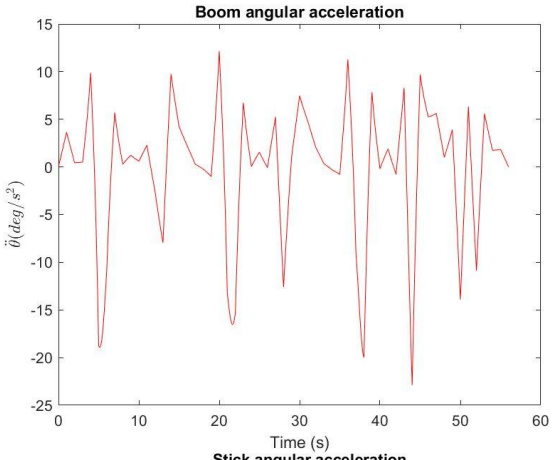
The angular velocities and accelerations obtained in phase 1 are in blue and the ones from phase 2 are in red. As we can see, and as expected, they are extremely similar:

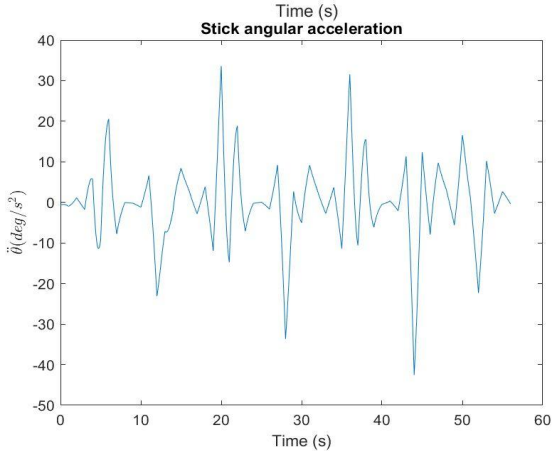


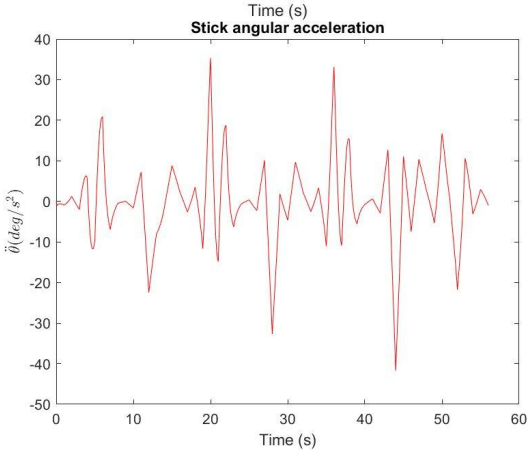

Stick angular velocity
$\dot{\theta}(deg/s)$
Time (s)


Stick angular velocity
$\dot{\theta}(deg/s)$
Time (s)


Boom angular acceleration
$\ddot{\theta}(deg/s^2)$
Time (s)


Boom angular acceleration
$\ddot{\theta}(deg/s^2)$
Time (s)


Stick angular acceleration
$\ddot{\theta}(deg/s^2)$
Time (s)


Stick angular acceleration
$\ddot{\theta}(deg/s^2)$
Time (s)