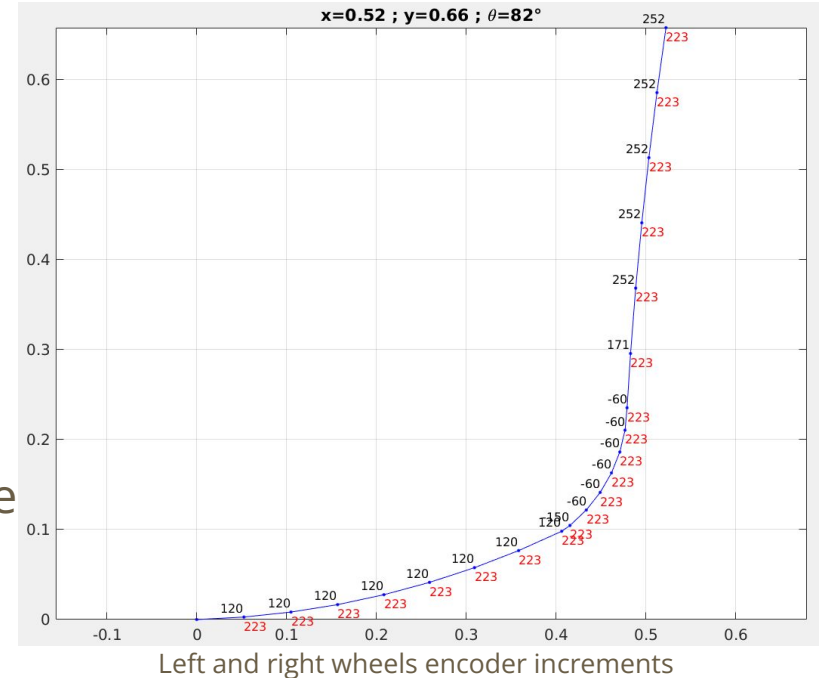

Robótica Móvel

— Robot Localization - Part 1 —

1- Odometry calculation for differential drive

- Consider a differential drive robot
 - Wheel diameter=20 cm
 - Wheel separation=60 cm
 - Pulses per full wheel turn = 2048
- What is the approximate final position and orientation of the robot if the encoders counters (**R**ight and **L**eft) showed the following values during the sampling times?
 - Consider the robot to start at (0,0,0)



R: 0, 223, 446, 669, 892, 1115, 1338, 1561, 1784, 2007, 2230, 2453, 2676, 2899, 3122, 3345, 3568, 3791, 4014, 4237, 4460, 4683
L: 0, 120, 240, 360, 480, 600, 720, 840, 960, 1080, 1200, 1320, 1440, 1560, 1680, 1800, 1920, 2040, 2160, 2280, 2400, 2520, 2640, 2760, 2880, 3000, 3120, 3240, 3360, 3480, 3600, 3720, 3840, 3960, 4080, 4200, 4320, 4440, 4560, 4680, 4800, 4920, 5040, 5160, 5280, 5400, 5520, 5640, 5760, 5880, 6000, 6120, 6240, 6360, 6480, 6600, 6720, 6840, 6960, 7080, 7200, 7320, 7440, 7560, 7680, 7800, 7920, 8040, 8160, 8280, 8400, 8520, 8640, 8760, 8880, 9000, 9120, 9240, 9360, 9480, 9600, 9720, 9840, 9960, 10080, 10200, 10320, 10440, 10560, 10680, 10800, 10920, 11040, 11160, 11280, 11400, 11520, 11640, 11760, 11880, 12000, 12120, 12240, 12360, 12480, 12600, 12720, 12840, 12960, 13080, 13200, 13320, 13440, 13560, 13680, 13800, 13920, 14040, 14160, 14280, 14400, 14520, 14640, 14760, 14880, 15000, 15120, 15240, 15360, 15480, 15600, 15720, 15840, 15960, 16080, 16200, 16320, 16440, 16560, 16680, 16800, 16920, 17040, 17160, 17280, 17400, 17520, 17640, 17760, 17880, 18000, 18120, 18240, 18360, 18480, 18600, 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35880, 36000, 36120, 36240, 36360, 36480, 36600, 36720, 36840, 36960, 37080, 37200, 37320, 37440, 37560, 37680, 37800, 37920, 38040, 38160, 38280, 38400, 38520, 38640, 38760, 38880, 39000, 39120, 39240, 39360, 39480, 39600, 39720, 39840, 39960, 40080, 40200, 40320, 40440, 40560, 40680, 40800, 40920, 41040, 41160, 41280, 41400, 41520, 41640, 41760, 41880, 42000, 42120, 42240, 42360, 42480, 42600, 42720, 42840, 42960, 43080, 43200, 43320, 43440, 43560, 43680, 43800, 43920, 44040, 44160, 44280, 44400, 44520, 44640, 44760, 44880, 45000, 45120, 45240, 45360, 45480, 45600, 45720, 45840, 45960, 46080, 46200, 46320, 46440, 46560, 46680, 46800, 46920, 47040, 47160, 47280, 47400, 47520, 47640, 47760, 47880, 48000, 48120, 48240, 48360, 48480, 48600, 48720, 48840, 48960, 49080, 49200, 49320, 49440, 49560, 49680, 49800, 49920, 50040, 50160, 50280, 50400, 50520, 50640, 50760, 50880, 51000, 51120, 51240, 51360, 51480, 51600, 51720, 51840, 51960, 52080, 52200, 52320, 52440, 52560, 52680, 52800, 52920, 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87360, 87480, 87600, 87720, 87840, 87960, 88080, 88200, 88320, 88440, 88560, 88680, 88800, 88920, 89040, 89160, 89280, 89400, 89520, 89640, 89760, 89880, 90000, 90120, 90240, 90360, 90480, 90600, 90720, 90840, 90960, 91080, 91200, 91320, 91440, 91560, 91680, 91800, 91920, 92040, 92160, 92280, 92400, 92520, 92640, 92760, 92880, 93000, 93120, 93240, 93360, 93480, 93600, 93720, 93840, 93960, 94080, 94200, 94320, 94440, 94560, 94680, 94800, 94920, 95040, 95160, 95280, 95400, 95520, 95640, 95760, 95880, 96000, 96120, 96240, 96360, 96480, 96600, 96720, 96840, 96960, 97080, 97200, 97320, 97440, 97560, 97680, 97800, 97920, 98040, 98160, 98280, 98400, 98520, 98640, 98760, 98880, 99000, 99120, 99240, 99360, 99480, 99600, 99720, 99840, 99960, 100000, 100120, 100240, 100360, 100480, 100600, 100720, 100840, 100960, 101080, 101200, 101320, 101440, 101560, 101680, 101800, 101920, 102040, 102160, 102280, 102400, 102520, 102640, 102760, 102880, 103000, 103120, 103240, 103360, 103480, 103600, 103720, 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148840, 148960, 149080, 149200, 149320, 149440, 149560, 149680, 149800, 149920, 150040, 150160, 150280, 150400, 150520, 150640, 150760, 150880, 151000, 151120, 151240, 151360, 151480, 151600, 151720, 151840, 151960, 152080, 152200, 152320, 152440, 152560, 152680, 152800, 152920, 153040, 153160, 153280, 153400, 153520, 153640, 153760, 153880, 154000, 154120, 154240, 154360, 154480, 154600, 154720, 154840, 154960, 155080, 155200, 155320, 155440, 155560, 155680, 155800, 155920, 156040, 156160, 156280, 156400, 156520, 156640, 156760, 156880, 157000, 157120, 157240, 157360, 157480, 157600, 157720, 157840, 157960, 158080, 158200, 158320, 158440, 158560, 158680, 158800, 158920, 159040, 159160, 159280, 159400, 159520, 159640, 159760, 159880, 160000, 160120, 160240, 160360, 160480, 160600, 160720, 160840, 160960, 161080, 161200, 161320, 161440, 161560, 161680, 161800, 161920, 162040, 162160, 162280, 162400, 162520, 162640, 162760, 162880, 163000, 163120, 163240, 163360, 163480, 163600, 163720, 163840, 163960, 164080, 164200, 164320, 164440, 164560, 164680, 164800, 164920, 165040, 165160, 165280, 165400, 165520, 165640, 165760, 165880, 166000, 166120, 166240, 166360, 166480, 166600, 166720, 166840, 166960, 167080, 167200, 167320, 167440, 167560, 167680, 167800, 167920, 168040, 168160, 168280, 168400, 168520, 168640, 168760, 168880, 169000, 169120, 169240, 169360, 169480, 169600, 169720, 169840, 169960, 170080, 170200, 170320, 170440, 170560, 170680, 170800, 170920, 171040, 171160, 171280, 171400, 171520, 171640, 171760, 171880, 172000, 172120, 172240, 172360, 172480, 172600, 172720, 172840, 172960, 173080, 173200, 173320, 173440, 173560, 173680, 173800, 173920, 174040, 174160, 174280, 174400, 174520, 174640, 174760, 174880, 175000, 175120, 175240, 175360, 175480, 175600, 175720, 175840, 175960, 176080, 176200, 176320, 176440, 176560, 176680, 176800, 176920, 177040, 177160, 177280, 177400, 177520, 177640, 177760, 177880, 178000, 178120, 178240, 178360, 178480, 178600, 178720, 178840, 178960, 179080, 179200, 179320, 179440, 179560, 179680, 179800, 179920, 180040, 180160, 180280, 180400, 180520, 180640, 180760, 180880, 181000, 181120, 181240, 181360, 181480, 181600, 181720, 181840, 181960, 182080, 182200, 182320, 182440, 182560, 182680, 182800, 182920, 183040, 183160, 183280, 183400, 183520, 183640, 183760, 183880, 184000, 184120, 184240, 184360, 184480, 184600, 184720, 184840, 184960, 185080, 185200, 185320, 185440, 185560, 185680, 185800, 185920, 186040, 186160, 186280, 186400, 186520, 186640, 186760, 186880, 187000, 187120, 187240, 187360, 187480, 187600, 187720, 187840, 187960, 188080, 188200, 188320, 188440, 188560, 188680, 188800, 188920, 189040, 189160, 189280, 189400, 189520, 189640, 189760, 189880, 190000, 190120, 190240, 190360, 190480, 190600, 190720, 190840, 190960, 19

Expressions to use for differential drive odometry

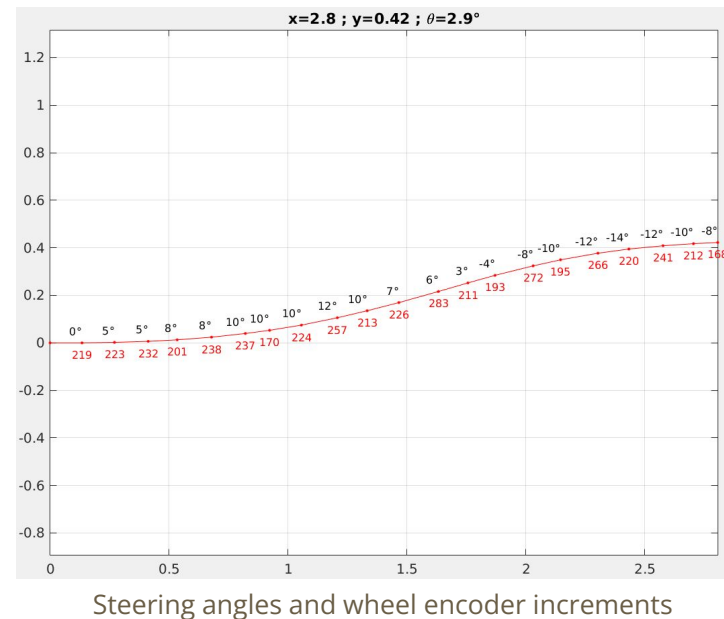
- $k = \frac{\pi d}{nC_e}$
 - d - wheel diameter
 - n - gear ratio (motor/wheel)
 - C_e - number of pulses per turn (encoder)
- $\Delta l_L = kN_L$
- $\Delta l_R = kN_R$
- $\Delta\theta_i = \frac{\Delta l_{R_i} - \Delta l_{L_i}}{D}$
- $\Delta l_i = \frac{\Delta l_{R_i} + \Delta l_{L_i}}{2}$
- $\theta_i = \theta_{i-1} + \Delta\theta_i$
- $x_i = x_{i-1} + \Delta l_i \cos \theta_i$
- $y_i = y_{i-1} + \Delta l_i \sin \theta_i$

2- Odometry calculation for a tricycle

- Consider a tricycle with steering and traction wheel in the front
 - Wheel diameter=20 cm
 - Distance to rear wheels =80 cm
 - Pulses per full wheel turn = 1024
 - Steering resolution = 1°
- What is the approximate final position and orientation of the robot if the encoder counter and the steering angle ($^\circ$) showed the following values during the sampling times?
 - Consider the robot to start at (0,0,0)

s: 0, 219, 442, 674, 875, 1113, 1350, 1520, 1744, 2001, 2214, 2440, 2723, 2934, 3127, 3399, 3594, 3860, 4080, 4321, 4533, 4701

α : 0, 0, 5, 5, 8, 8, 10, 10, 10, 12, 10, 7, 6, 3, -4, -8, -10, -12, -14, -12, -10, -8

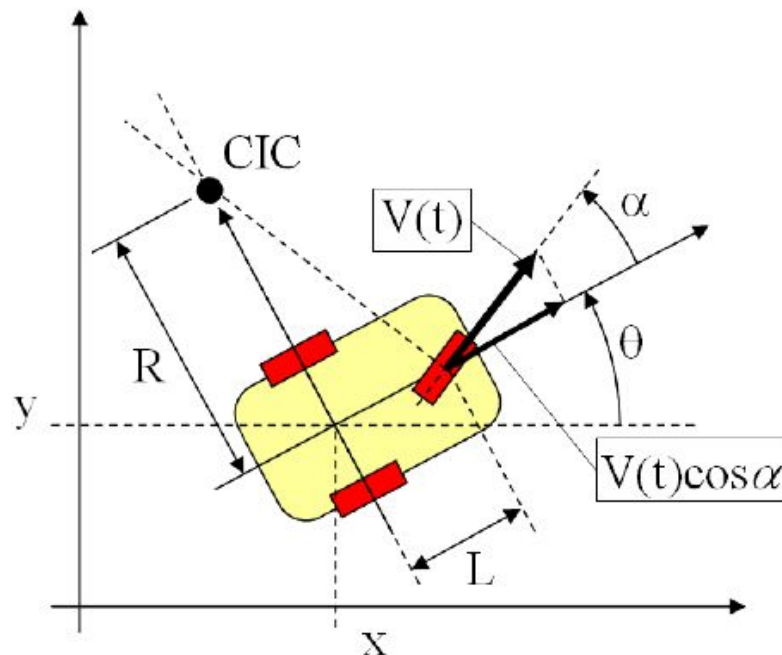


Expressions to use for tricycle odometry

- $$\begin{cases} \theta_i = \theta_{i-1} + \frac{V_i}{L} \sin \alpha_i \Delta t \\ x_i = x_{i-1} + V_i \cos \alpha_i \cos \theta_i \Delta t \\ y_i = y_{i-1} + V_i \cos \alpha_i \sin \theta_i \Delta t \end{cases}$$

$$V_i \Delta t = \Delta l_i$$

- Notice that the displacement of the steering wheel is measured with pulses from the encoder

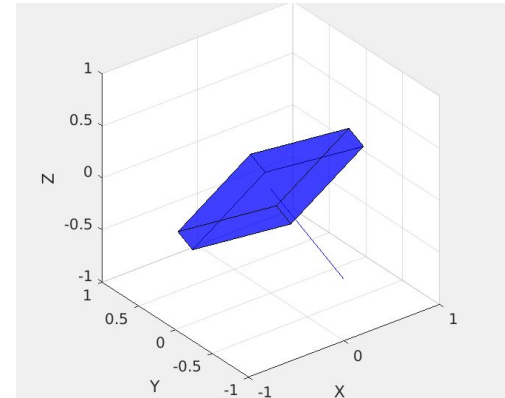
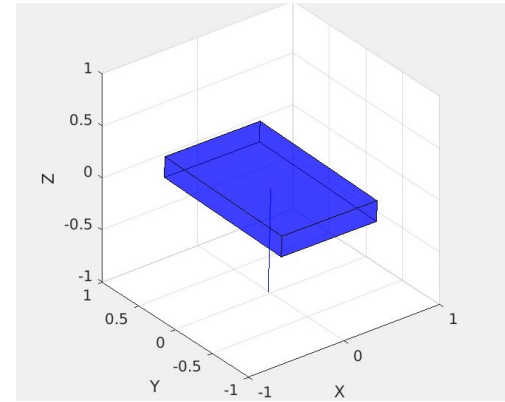


Inertial and positioning logging from smartphone

- Install Matlab Support Package for Android (or iOS) in your computer
- Install Matlab Mobile (Android or iOS) in your smartphone
- Run the application in smartphone and enter your mathworks account
- Select “sensors” in smartphone application
- Activate the sensors you want to monitor (acceleration, etc.)
- In the computer create a mobile device object
 - `m=mobiledev`
- Check the available data in the fields of **m**
 - Like `m.Acceleration`, `m.AngularVelocity`, etc.

3a - Represent continuously the 3D orientation of phone

- Obtain the gravity vector: $g = \text{accel} / \text{norm}(\text{accel})$
 - $g = [g_x \ g_y \ g_z]$
- Obtain the orientation angles
 - Pitch: around y $\rightarrow \text{atan2}(-g_x, \sqrt{g_y^2 + g_z^2})$;
 - Roll: around x $\rightarrow \text{atan2}(g_y, g_z)$
- Draw a parallelepiped emulating the smartphone and illustrate its orientation with data from the remote acquisition
 - System may be not very reactive depending on the network conditions
- See next page for drawing suggestions



3a (cont.) - Hints to draw in Matlab

Use a patch with vertices and faces like:

```
% Define the vertices of the smartphone
vertices = [0.5  0.5 -0.5 -0.5  0.5  0.5 -0.5 -0.5  %
X          0.8 -0.8 -0.8  0.8  0.8 -0.8 -0.8  0.8  %
Y          0.1  0.1  0.1  0.1 -0.1 -0.1 -0.1 -0.1]; %
Z
% Define the faces of the smartphone
faces = [1 2 6 5  % front
        4 3 7 8  % back
        1 4 8 5  % left
        2 3 7 6  % right
        1 2 3 4  % top
        5 6 7 8]; % bottom
% Plot the initial orientation of the model
h=patch('Vertices', vertices', 'Faces', faces,...
... 'FaceColor', 'b');
view(3)
```

Inside a while loop, calculate the new vertices and update:

```
% Compute rotated vertices
rotated_vertices= R_roll*R_pitch*
vertices;

% Update plot with rotated vertices
h.Vertices=rotated_vertices';
```

R_roll is a 3D rotation around x
R_pitch is a 3D rotation around y

3b-Integrate data from smartphone for localization

- Create a loop and get angular velocity and acceleration data from smartphone
 - You can obtain some initial data in rest to use as offset to reduce errors during motion
- Integrate angular velocities to try to obtain orientations
- Double integrate accelerations to obtain positioning
- Apply a moving average to signals to reduce noise
 - $v(n) = \text{mean}(v(n-1), v(n-2), v(n-3), \dots, v(n-N))$. Set N to several different values
- Perform simple trajectories with the smartphone to try to obtain a reasonable estimation of the localization with the inertial system.
- Results may not be as fine as expected!
 - What other tools do you expect to use to improve results?