Optimization of the TURTLE's acceleration

Bachelor End Project

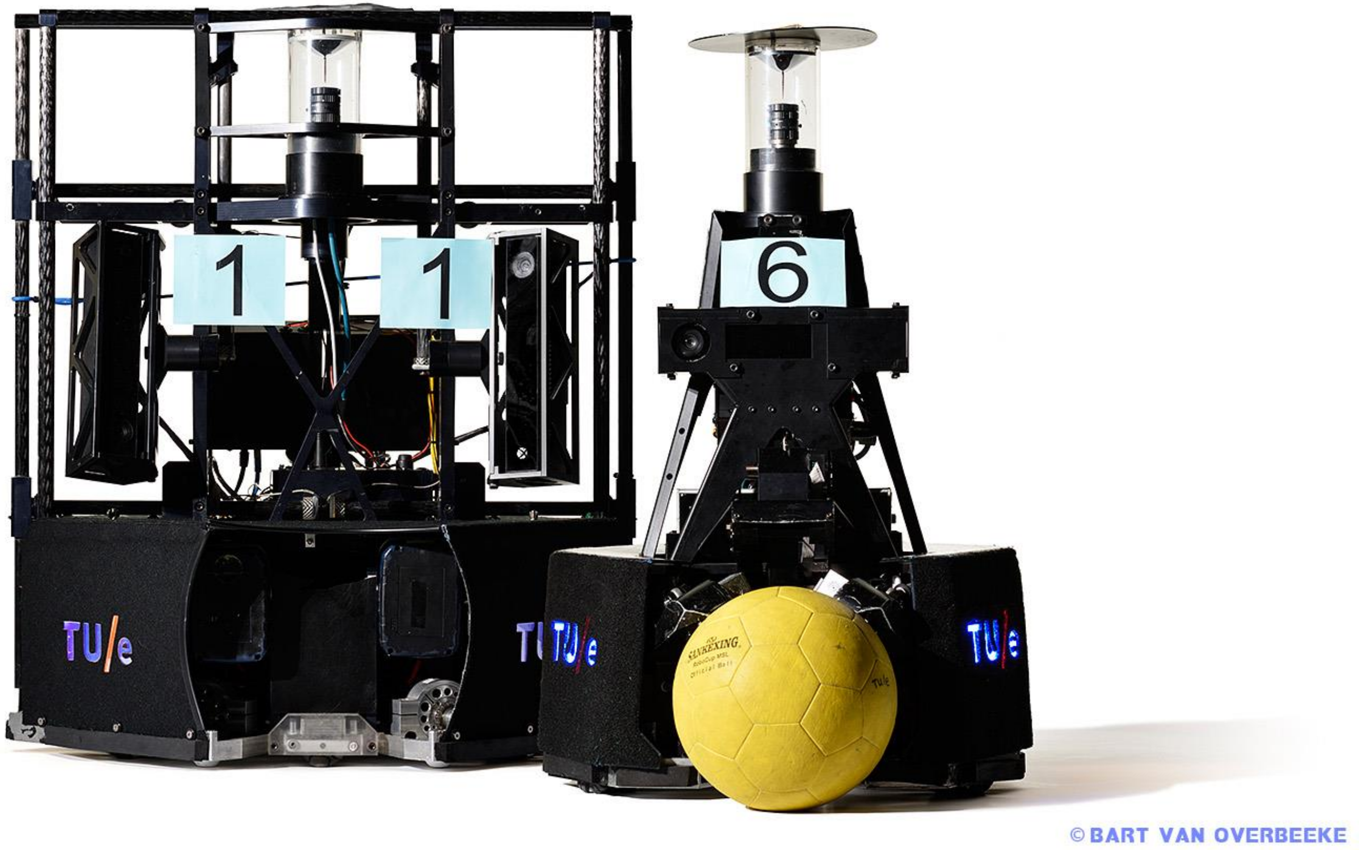
Luuk Poort

Tech United

Content

- Goal
- Theory
- Hardware
- Modelling
- Validation
- Conclusion
- Discussion

Questions



Goal

Problem

- The acceleration of the TURTLE is too limited by tipping and slipping

Research question

- *How can the acceleration of the TURTLEs be improved?*
    1. *What parameters influence the acceleration of the TURTLE and how?*
    2. *What are the current values of these influencing parameters?*
    3. *In what way can these parameters be changed to improve acceleration?*
    4. *Can the TURTLE's acceleration be made dependent on its current state?*

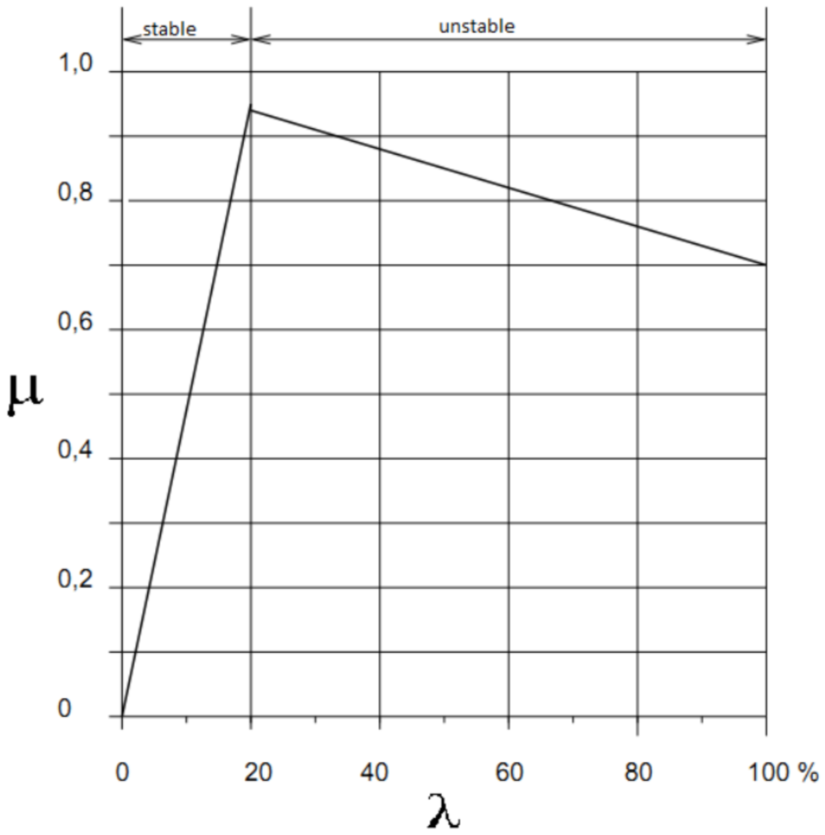
Theory: Slip

- Force and moment equilibrium on wheel
- Slip when exceed maximum value

- Always slip
- Slip can become unstable

$$\lambda = \frac{v_{wheel} - \omega_{wheel}\, r_{wheel}}{v_{wheel}}$$

$$F_a \geq \mu F_n$$



Theory: TURTLE dynamics

- Force and moment equilibrium

- $\vec{F}_A \qquad \vec{F}_B \qquad \vec{F}_C \qquad a \qquad \alpha$

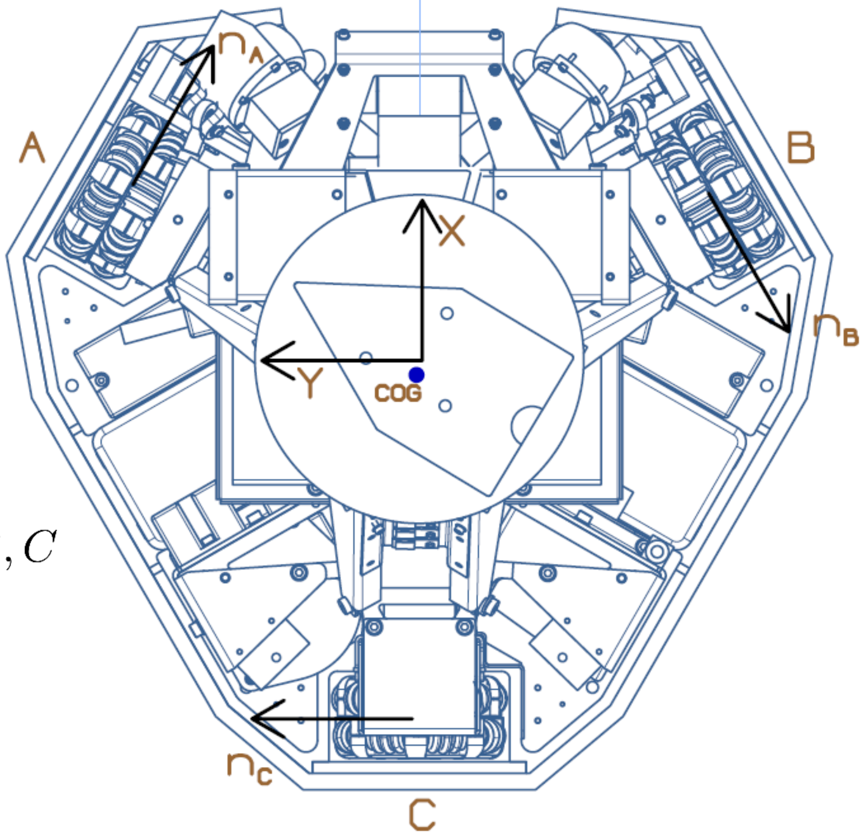
- 3 eq. $\rightarrow$ $\quad m\ a\ \vec{n}_a - m\ \vec{g} = \vec{F}_A + \vec{F}_B + \vec{F}_C$

3 eq. $\rightarrow$ $\quad I_{zz}\ \alpha\ \vec{n}_z = \vec{A}^G \times \vec{F}_A + \vec{B}^G \times \vec{F}_B + \vec{C}^G \times \vec{F}_C$

3 eq. $\rightarrow$ $\quad \begin{bmatrix} F_{i,x} \\ F_{i,y} \\ 0 \end{bmatrix} = \vec{n}_i \left\| \begin{matrix} F_{i,x} \\ F_{i,y} \\ 0 \end{matrix} \right\| = F_{a,i}\ \vec{n}_i$ $\qquad$ with $i = A, B, C$

1 eq. $\rightarrow$ $\quad \mu = \max_{i=A,B,C} \left(\left| \frac{F_{a,i}}{F_{n,i}} \right| \right)$

1 eq. $\rightarrow$ $\quad \alpha = f(a) = k\ a$



Hardware

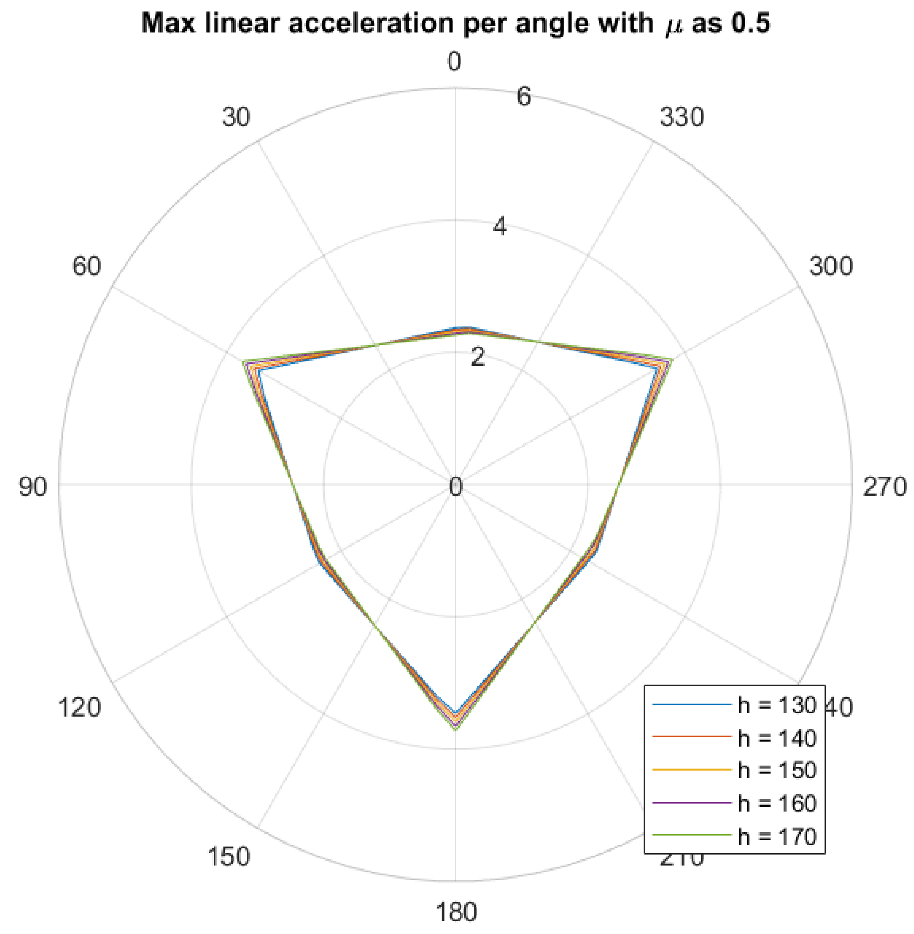
- Weighted all components
- Assigning densities to AutoDesk Inventor model

Component	Mass (kg)
PC	1.757
Beckhoff Module	1.238
RE25_20W_24V	0.357
Camera (incl. lens)	0.149
RE40_150W_24V	0.838
Housing	1.490
Kinect II	0.619
Kinect Printbox	0.2
Picture Housing	0.3

Properties	Value
$m\ [kg]$	36.0
$I_{zz}\ [kg\ m^2]$	0.799
$COG\ [mm]$	$[-3.46,\ 1.85,\ 165.59]^T$
$\vec{A}^0\ [mm]$	$[97.12,\ 168.23,\ 0]^T$
$\vec{B}^0\ [mm]$	$[96.63,\ -167.36,\ 0]^T$
$\vec{C}^0\ [mm]$	$[-206.25,\ 0,\ 0]^T$

Modelling: results and analysis

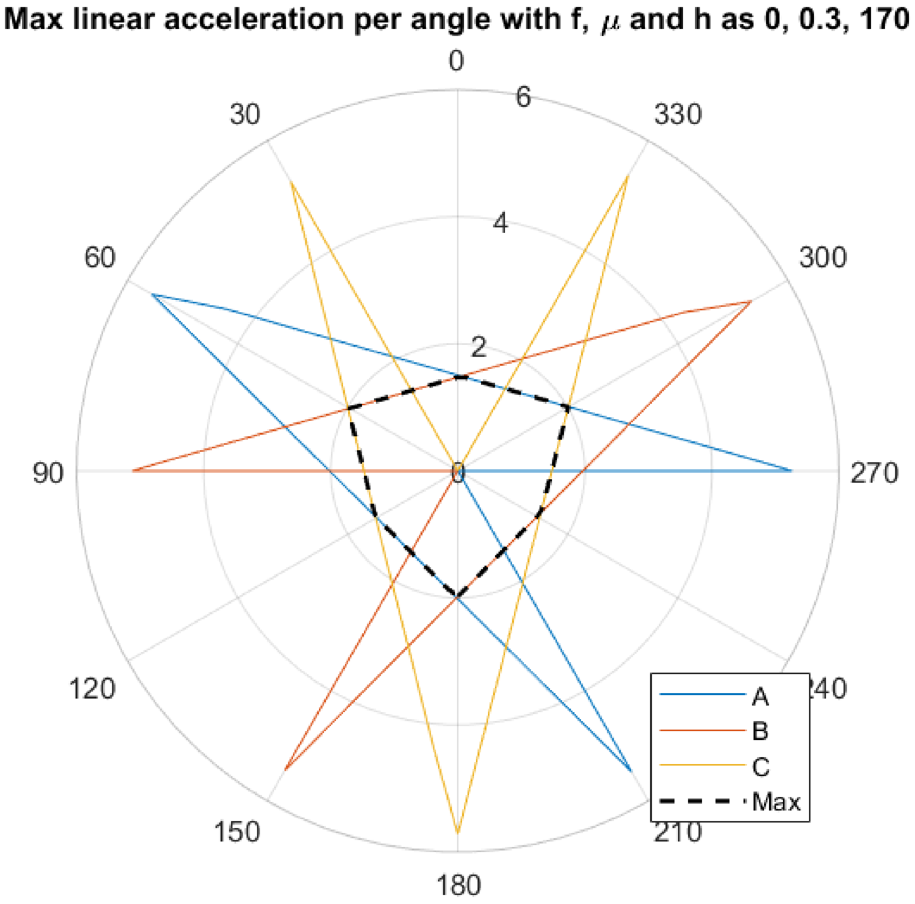
- Almost symmetrical
- Height of COG no significant influence



Modelling: results and analysis

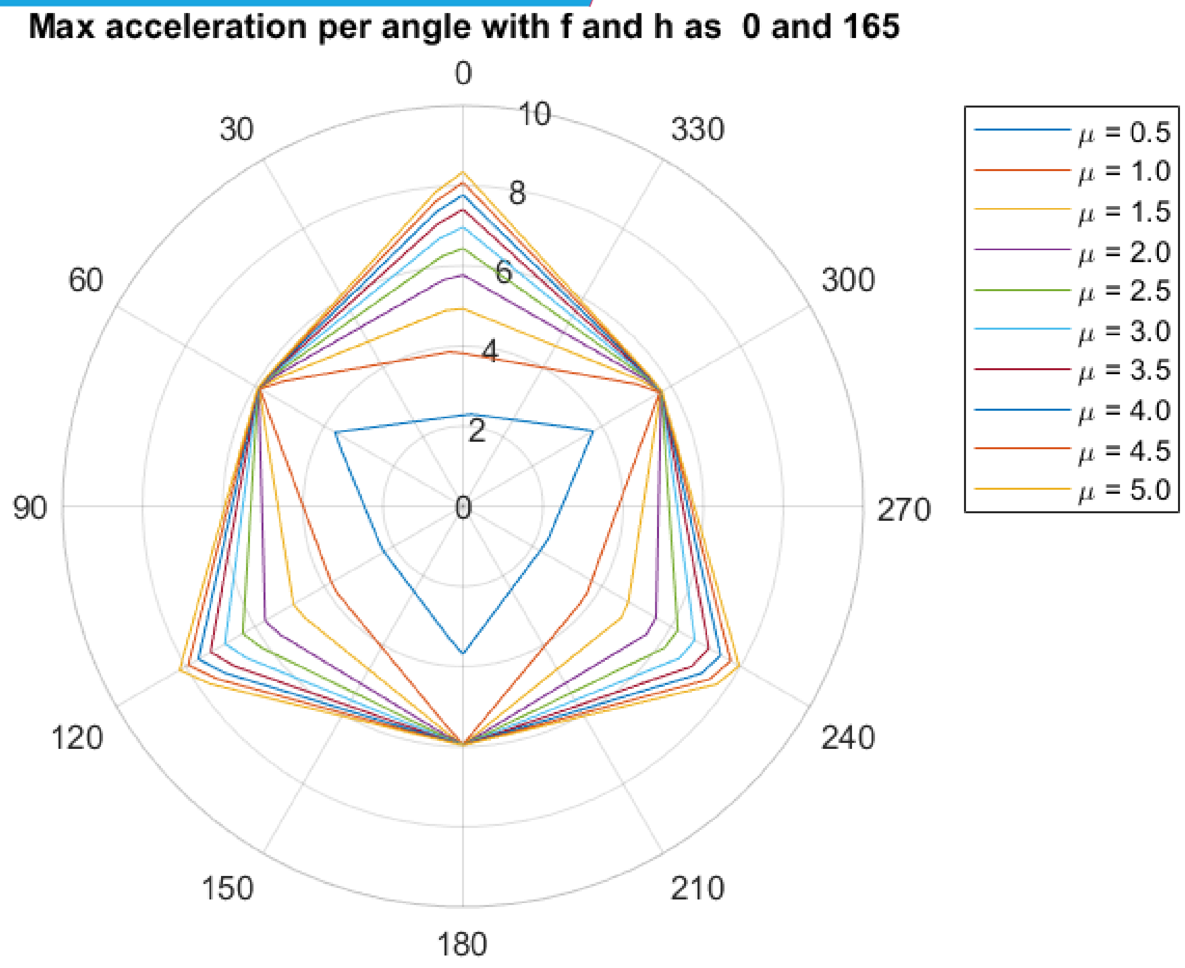
- Significant influence of angle of acceleration
- Linear relations

$$a = \frac{C_2}{\sin\psi - C_1 \cos\psi}$$



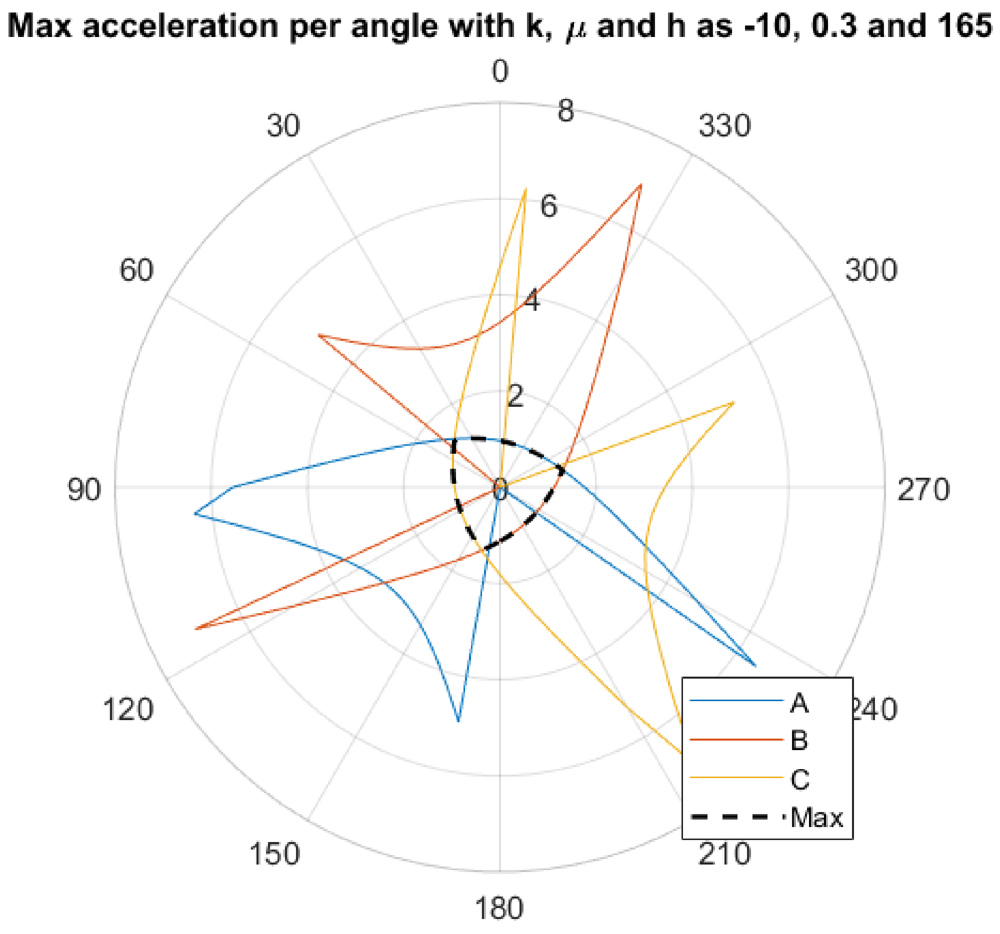
Modelling: results and analysis

- Friction factor has significant influence
- Tipping becomes limiting from $\mu = 1.0$



Modelling: results and analysis

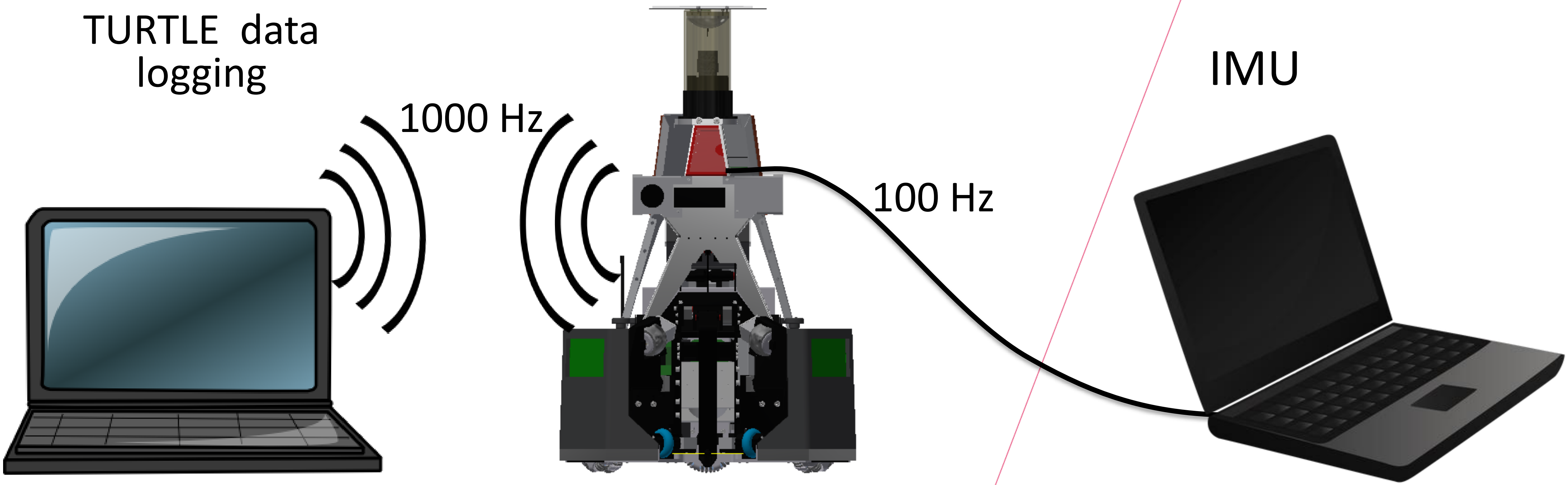
- Significant influence of angular acceleration
- Direction independent
- Shape changes with k in $\alpha = k\ a$



Validation: slip detection

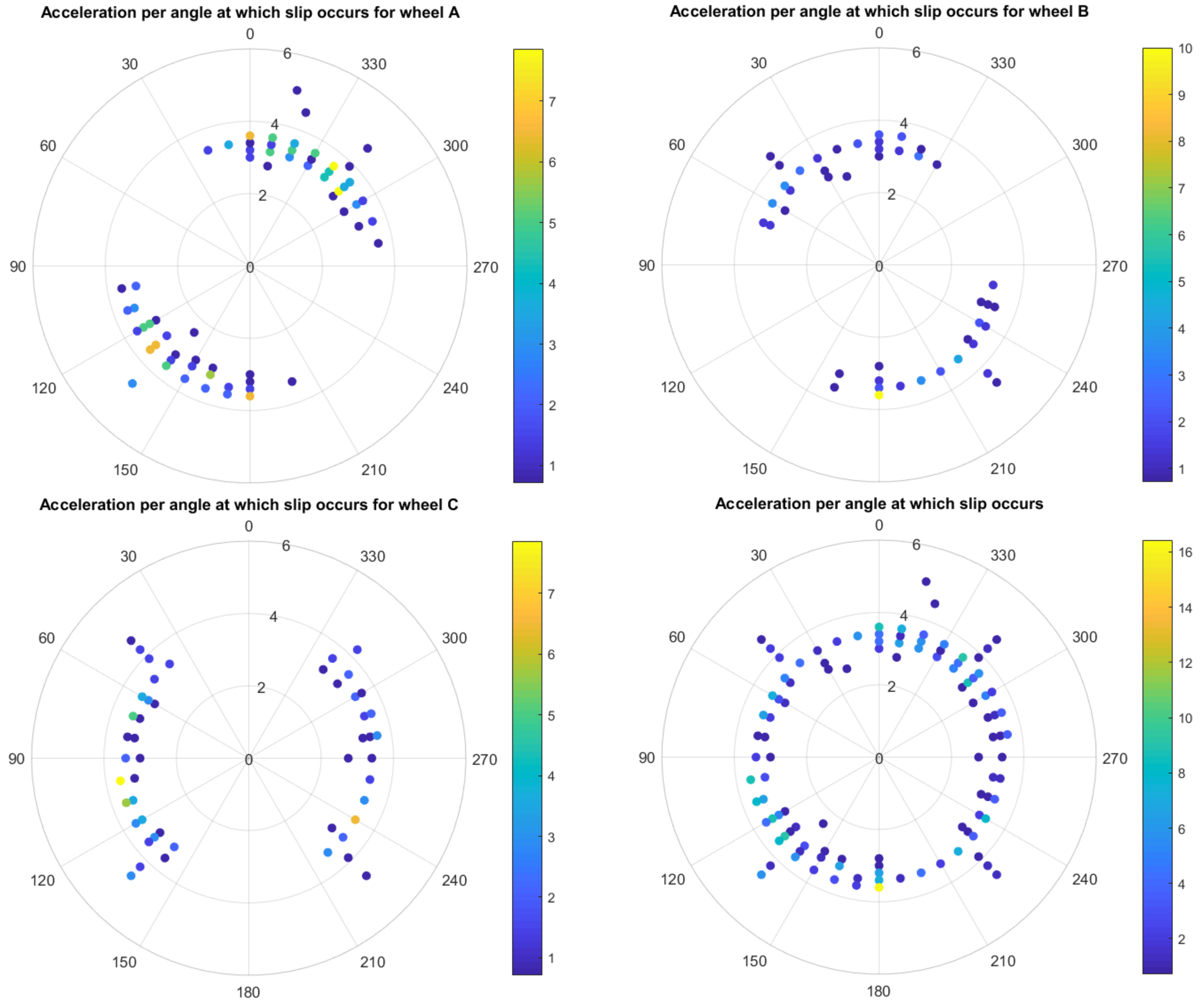
- Three methods
  - Motor effort → Inconsistent
  - Speed → unreliable over time
  - Acceleration → noisy → Filtering

Validation: data acquisition



Validation: data analysis

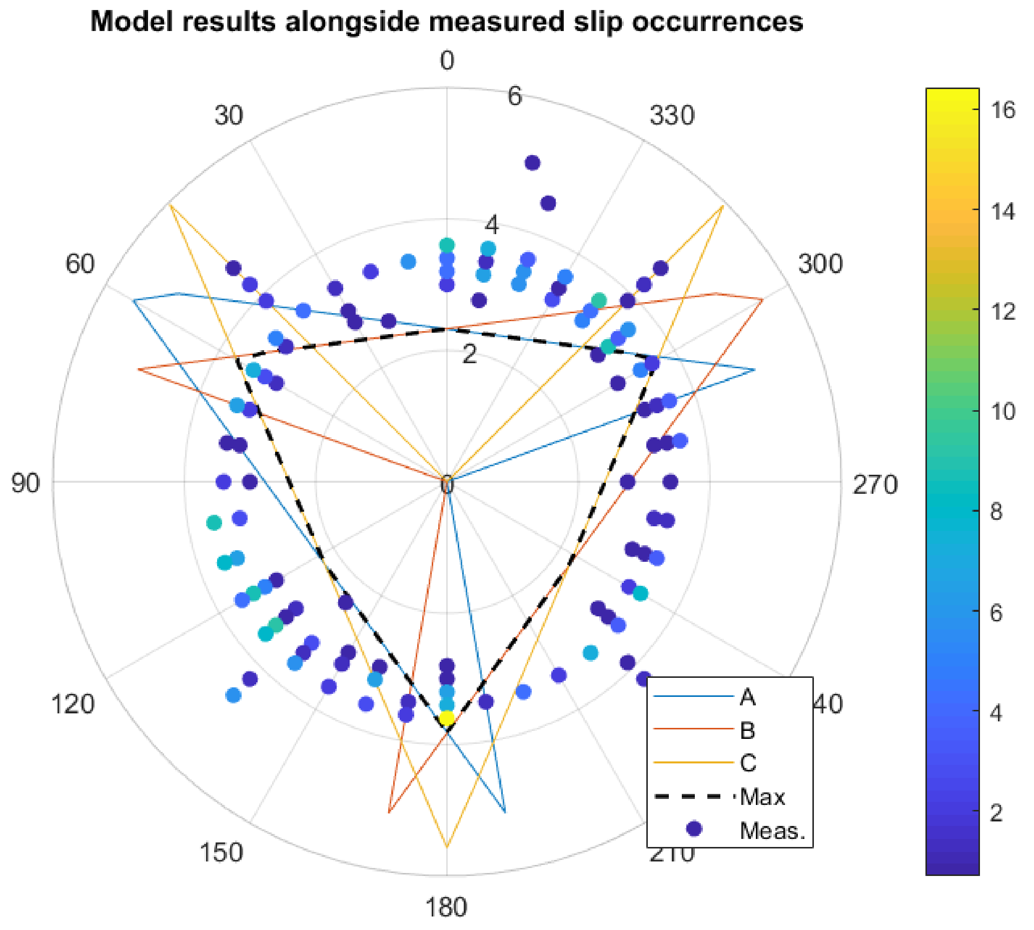
- Filtering with moving average filters
- Rotation of accelerometers
- Transformation to wheel accelerations
- Comparison encoders to IMU



Acceleration per angle at which slip occurs for wheel A
Acceleration per angle at which slip occurs for wheel B
Acceleration per angle at which slip occurs for wheel C
Acceleration per angle at which slip occurs
0
30
60
90
120
150
180
210
240
270
300
330
2
4
6

Validation: comparison

- No clear dependence on the angle
- No linear relations
- Slip per wheel in correct intervals
- Intervals not correct size



Conclusion

Parameter	Influence	Value
$m\ [kg]$	None	36.0
COG $[mm]$	Insignificant	$[-3.46,\ 1.85,\ 165.59]^T$
$I_{zz}\ [kg\ m^2]$	Insignificant	0.799
$\psi\ [rad]$	Significant $\pm$	$0 \geq \psi \geq 2\pi$
$\mu\ [-]$	Significant $+$	0.5
$k\ [rad/m]$	Significant $-$	$k \in \mathbb{R}$

Discussion

- Slip model
- Speed dependence
- Filtering
- Acceleration difference

Recommendations

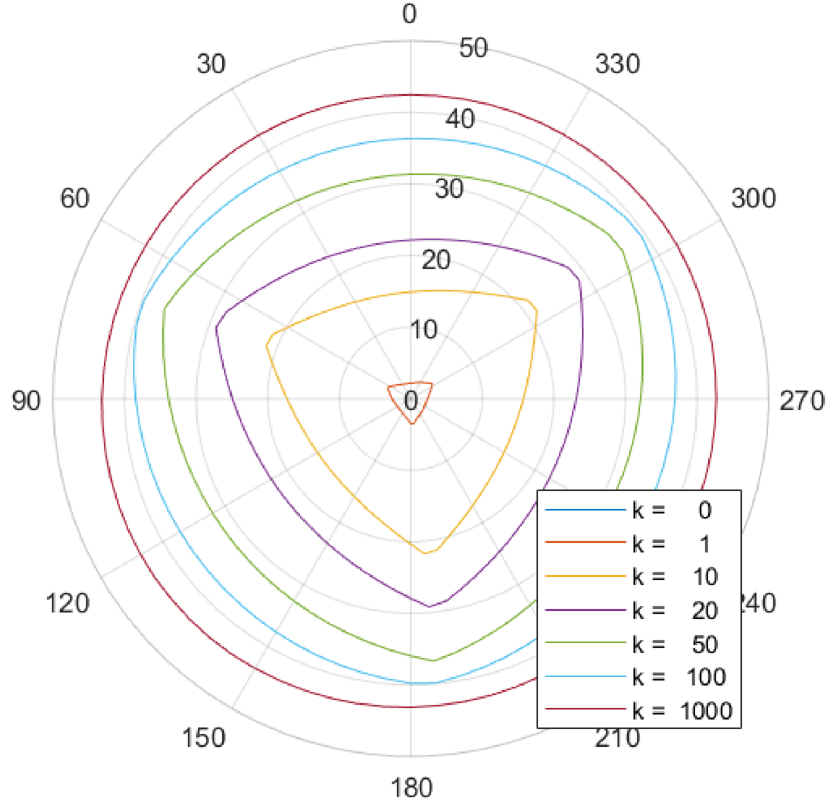
- Validation should be redone
- Model should be improved
- Friction factor might be improved

- Experimental maxima

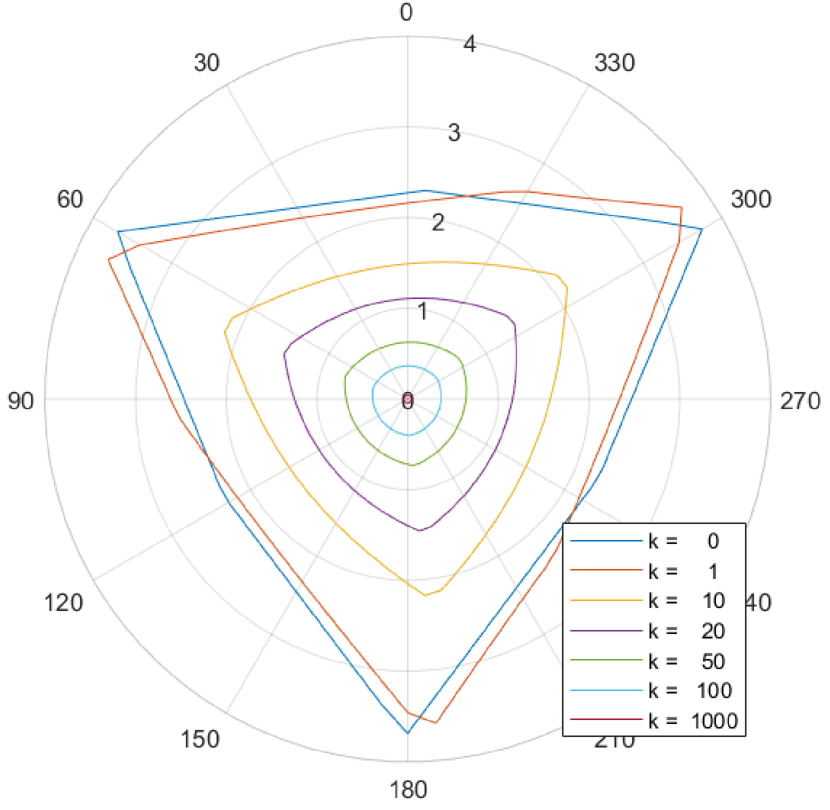
Questions?

Appendix

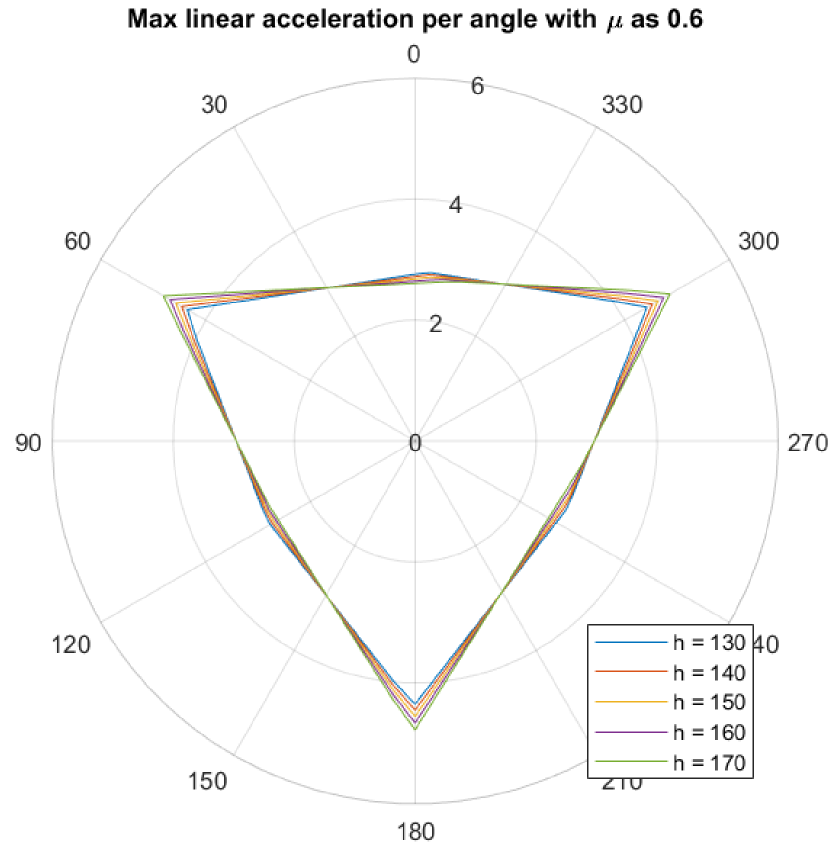
Max angular acceleration per angle with μ and h as 0.5 and 165



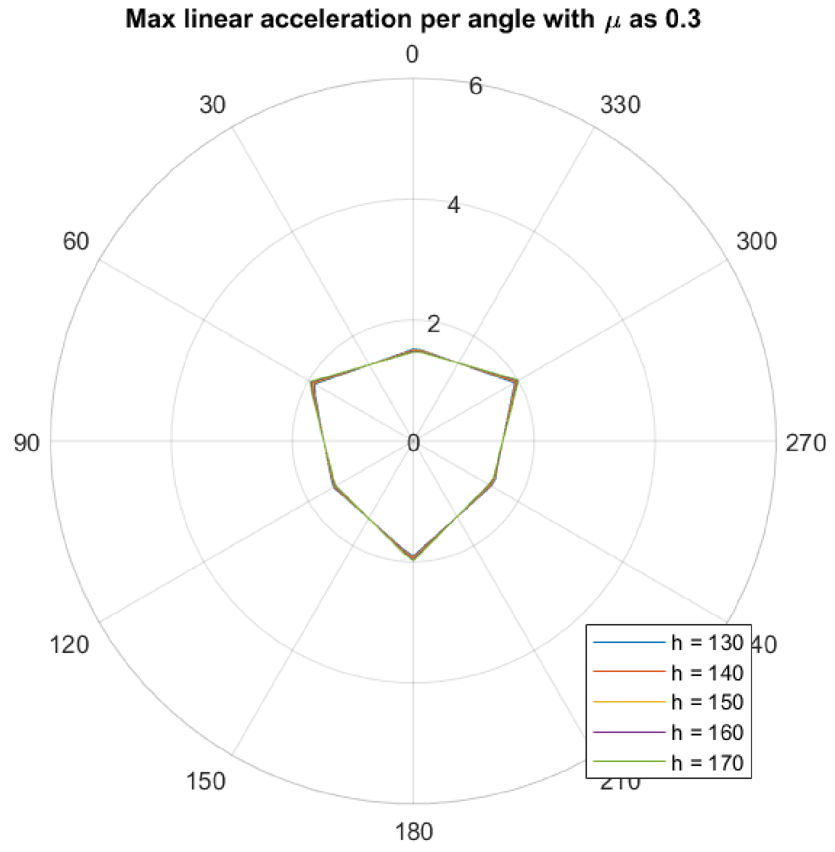
Max linear acceleration per angle with μ and h as 0.5 and 165



Appendix

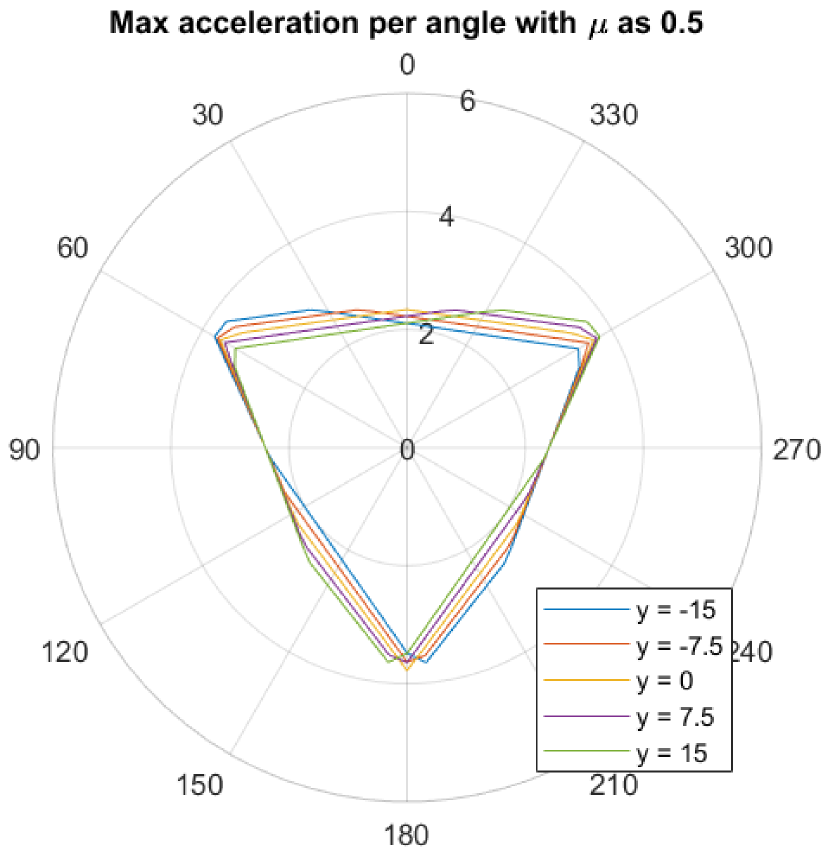


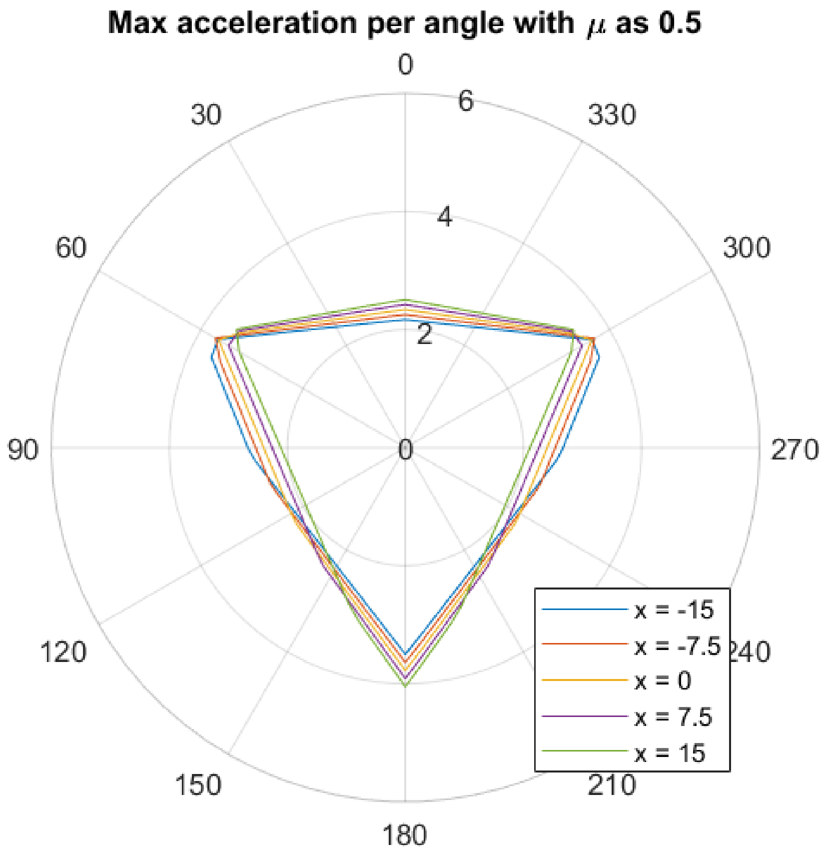
Max linear acceleration per angle with μ as 0.6
0
330
300
270
240
210
180
150
120
90
60
30
2
4
6
h = 130
h = 140
h = 150
h = 160
h = 170



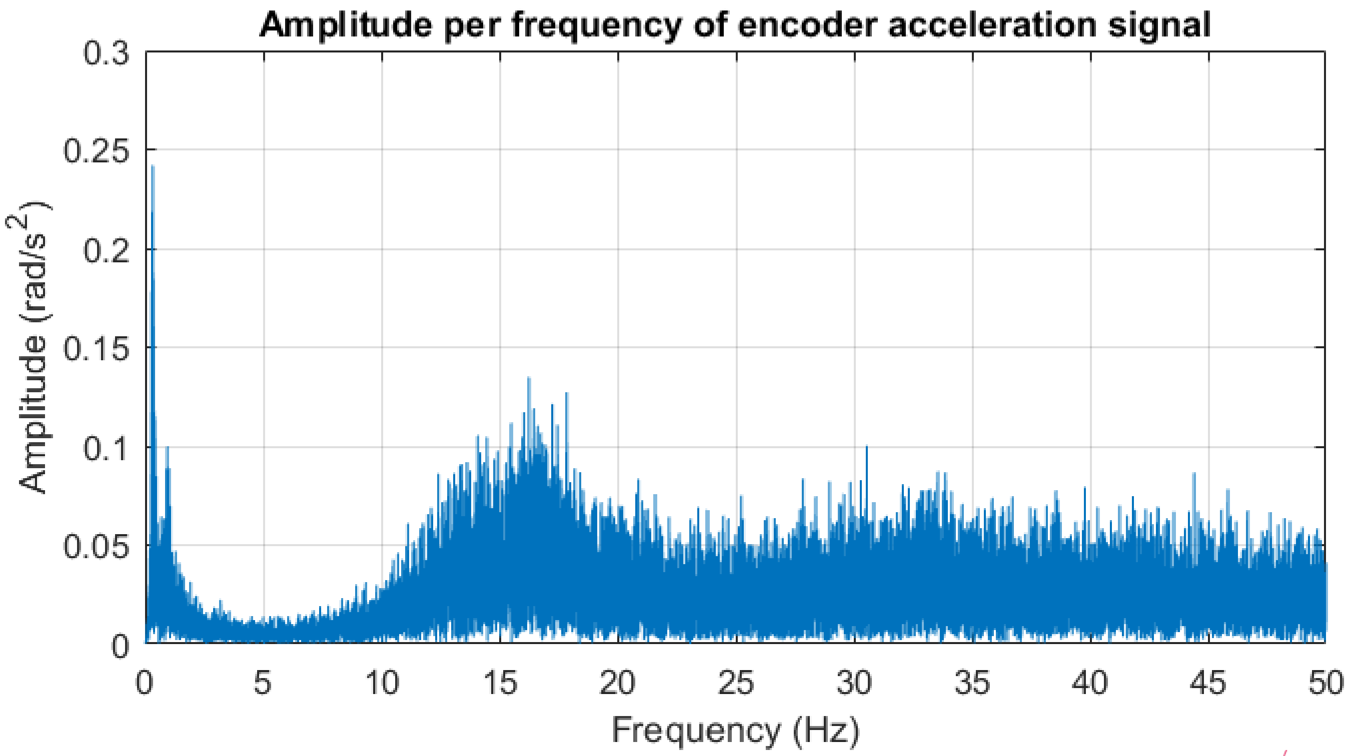
Max linear acceleration per angle with μ as 0.3
0
330
300
270
240
210
180
150
120
90
60
30
2
4
6
h = 130
h = 140
h = 150
h = 160
h = 170

Appendix


Max acceleration per angle with μ as 0.5
0
30
330
60
300
90
270
120
240
150
210
180
2
4
6
0
y = -15
y = -7.5
y = 0
y = 7.5
y = 15


Max acceleration per angle with μ as 0.5
0
30
330
60
300
90
270
120
240
150
210
180
2
4
6
0
x = -15
x = -7.5
x = 0
x = 7.5
x = 15

Appendix


Amplitude per frequency of encoder acceleration signal
0.3
0.25
0.2
0.15
0.1
0.05
0
Amplitude (rad/s²)
0
5
10
15
20
25
30
35
40
45
50
Frequency (Hz)

Appendix

- Almost symmetrical
- Height of COG no significant influence
- Dependent on the angle of acceleration

Angle range	Influence of height on acceleration
$-30 < \psi < 30$	negative
$30 < \psi < 90$	positive
$90 < \psi < 150$	negative
$150 < \psi < 210$	positive
$210 < \psi < 270$	negative
$270 < \psi < 330$	positive