DLS Lab Seminar

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Outline

1. Master thesis: "Dynamic control of 3D directional drilling systems using state estimation"
2. Research proposal: "Locomotion control of HyQ using max-plus algebra linear systems"
3. Further work

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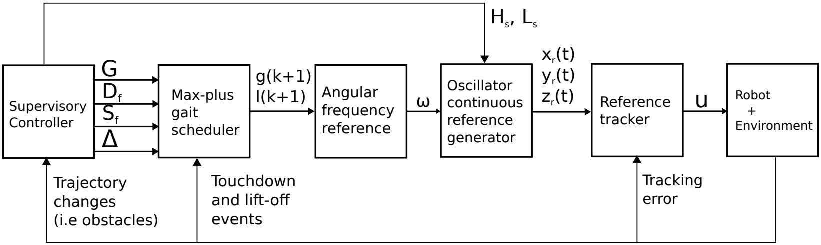
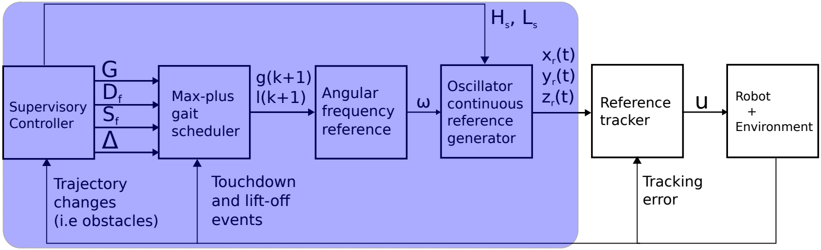
Motivation

- Provide versatility to the types of gaits that the robot can perform
- Have a unified and systematic way to generate motions of the legs according to the scenario
- Can be applied to other legged systems

General picture



General picture



Supervisory controller

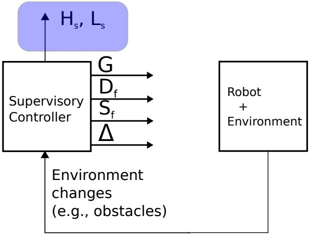
Main goal

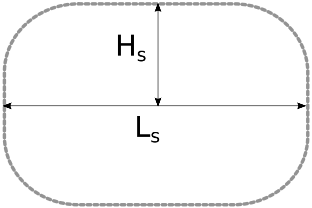
Provide **geometrical** and **time** gait parameters, based on sensory data, to overcome the scenario that the robot is facing.

Supervisory controller (continue)

Geometrical parameters:

- Step height H_s
- Step length L_s
- Oscillator "primitive" shape changes

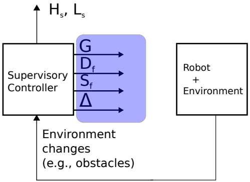




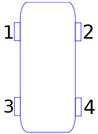
Supervisory controller (continue)

Time parameters:

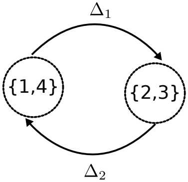
- Duty factor D_f



- Step frequency S_f



- Gait parameterization G (e.g., $G_{trot} = \{1, 4\} \prec \{2, 3\}$)



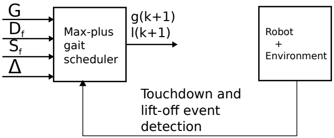
- Time difference vector Δ

Max-plus gait scheduler

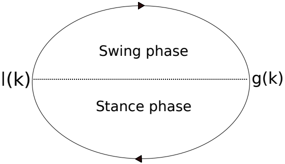
Main goal

Using the **time**-related gait parameters provided by the supervisory controller, generate the list of time-instants when each leg has to leave and touch the ground, so that a desired coordination is achieved.

Max-plus gait scheduler (continue)



$$G_{trot} = \{1,4\} \prec \{2,3\}$$
$$D_f = 0.58$$
$$S_f = 0.42$$
$$\Delta = [0.2, 0.2]$$



k	$g_1(k)$	$g_2(k)$	$g_3(k)$	$g_4(k)$	$l_1(k)$	$l_2(k)$	$l_3(k)$	$l_4(k)$
0	0	0	0	0	0	0	0	0
1	2.4	3.6	3.6	2.4,	1.4	2.6	2.6	1.4
2	4.8	6	6	4.8	3.8	5	5	3.8
3	7.2	8.4	8.4	7.2	6.2	7.4	7.4	6.2
4	9.6	10.8	10.8	9.6	8.6	9.8	9.8	8.6
5	12	13.2	13.2	12	11	12.2	12.2	11

Max-plus gait scheduler (continue)

- Systematic gait generation
- No coupling matrix $\mathbb{C}_{ij}$
- Total cycle time analysis (max-plus eigenvalues of A matrix in $x(k+1) = A \otimes x(k)$)
- Coupling time analysis ("settling time")
- Not computationally expensive
- Possibility to provide "optimal" gait switching

Angular frequency reference generator

Main goal

Making use of the **touchdown** and **lift-off** times of the max-plus gait scheduler, provide a function for the evolution of the angular frequency of the oscillator-based reference generator.

Angular frequency reference generator (continue)

Stance and swing period:

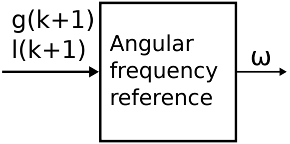
$$Ti_{st} = l_i(k+1) - g_i(k)$$
$$Ti_{sw} = g_i(k+1) - l_i(k+1),$$

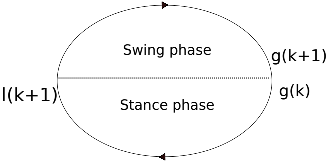
Average angular frequency:

$$\bar{\omega} = \begin{cases} \frac{\pi}{Ti_{st}} \ \textbf{for} \ t \in [g_i(k), l_i(k+1)] \\ \frac{\pi}{Ti_{sw}} \ \textbf{for} \ t \in (l_i(k+1), g_i(k+1)] \end{cases}$$

Condition for the angular frequency function:

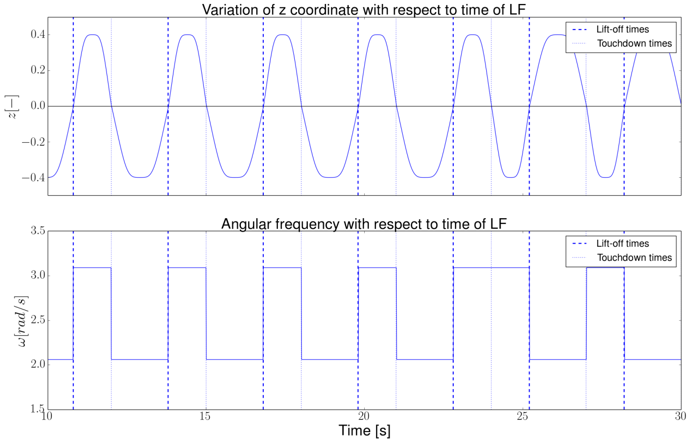
$$\frac{1}{Ti_p}\int^{Ti_p} \omega dt = \bar{\omega} \ \textbf{for} \ p = st, sw.$$





Angular frequency reference generator (continue)

$$\omega = \bar{\omega}$$



Oscillator continuous time reference generator

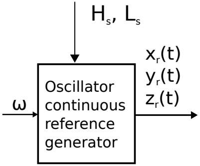
Main goal

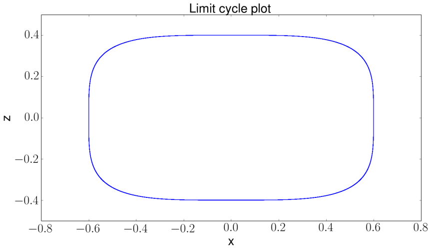
Generate reference trajectories for each of the legs of the robot in such a way that the desired gait is achieved, according to the angular frequency obtained from the angular frequency reference generator.

Oscillator continuous time reference generator (continue)

Oscillator equations:

$$x = \alpha(1 - \frac{16x^4}{L_s^4} - \frac{z^4}{H_s^4})x + \frac{1.18\omega L_s}{2H_s^3}z^3$$
$$z = \beta(1 - \frac{16x^4}{L_s^4} - \frac{z^4}{H_s^4})z - \frac{9.44\omega H_s}{L_s^3}x^3$$





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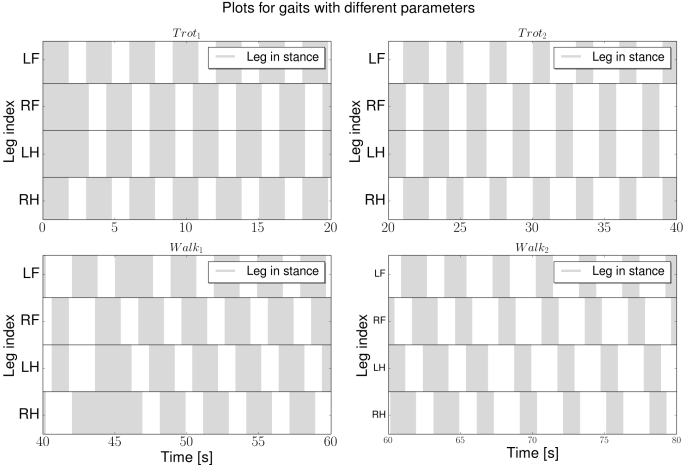
Parameters used

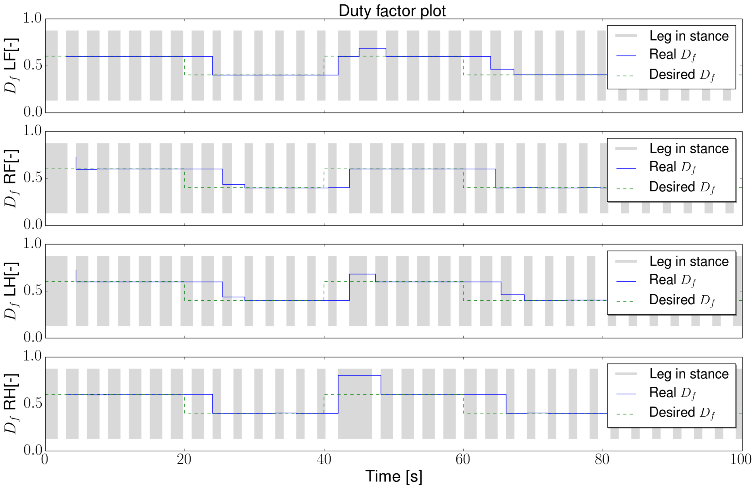
Switch between four different sets of gait parameters:

	G	D_f	$S_f[\frac{1}{s}]$	$\Delta[s]$
T_1	$\{1,4\} \prec \{2,3\}$	0.6	1/3	$[0.2, 0.4]$
T_2	$\{1,4\} \prec \{2,3\}$	0.4	1/3	$[-0.2, -0.4]$
W_1	$\{1\} \prec \{2\} \prec \{3\} \prec \{4\}$	0.6	1/3	$[-0.45, -0.45, -0.45, -0.45]$
W_2	$\{1\} \prec \{2\} \prec \{3\} \prec \{4\}$	0.4	1/3	$[-1.4, -0.7, -1.4, -0.7]$

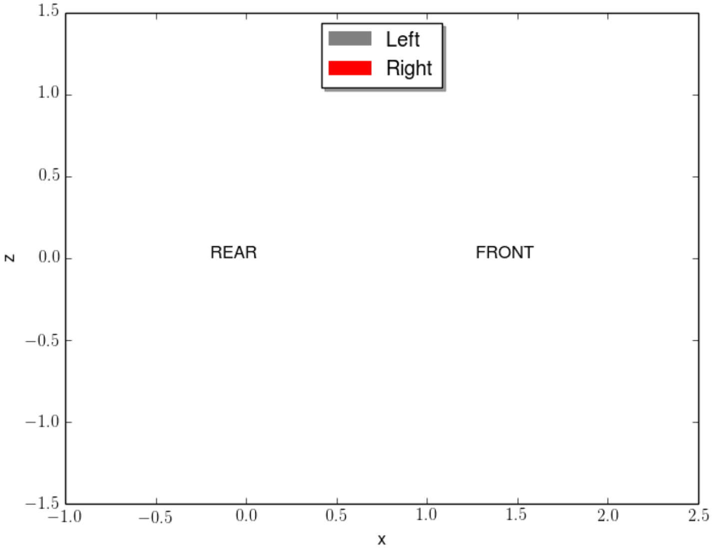
Generated motion references



Duty factor


Duty factor plot
D_f LF[-]
D_f RF[-]
D_f LH[-]
D_f RH[-]
1.0
0.5
0.0
0
20
40
60
80
100
Time [s]
Leg in stance
Real D_f
Desired D_f

Animation


Left
Right
REAR
FRONT
z
x
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5

Further work

- Use the proposed strategy in the current framework
- Design angular frequency generator
- Account for disturbances in the max-plus algebra gait scheduler
- Design of supervisory parameters according to sensory information
- Design transition between one set of parameters to another

Thank you. Questions or comments?