

# PhD Meeting: Planning and Control

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# Outline

- ① Control structure
- ② Numeric simulations
- ③ Further work

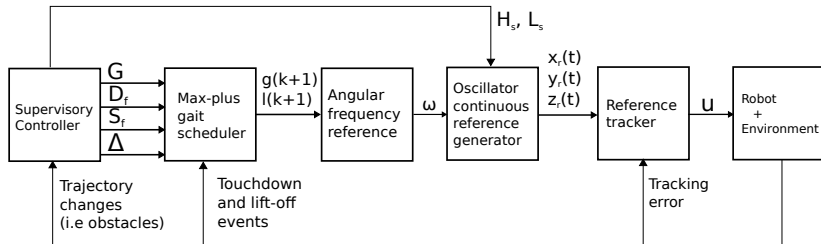
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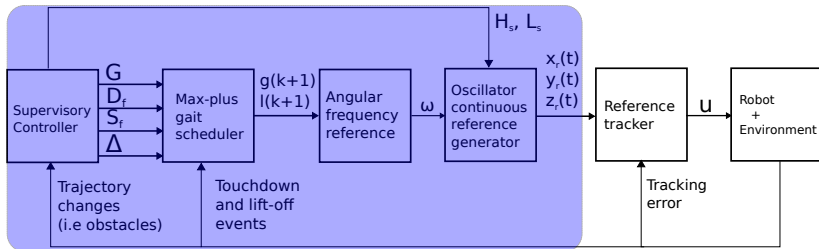
# Motivation

- 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

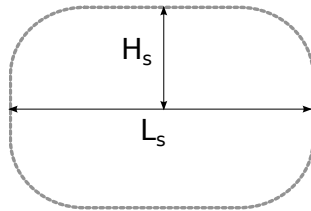
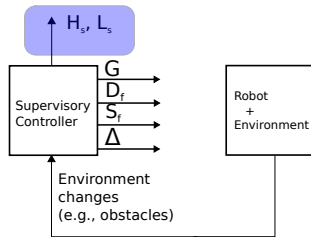
## Main goal

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

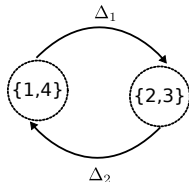
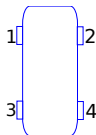
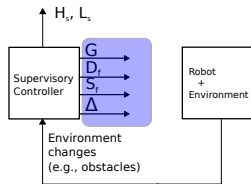




# Supervisory controller (continue)

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  $\Delta$

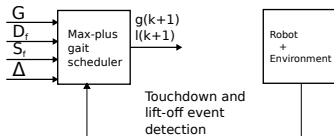


## Max-plus gait scheduler

### 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)

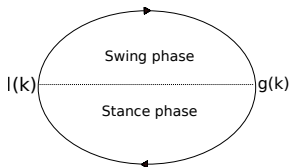


$$G_{trot} = \{1, 4\} \prec \{2, 3\}$$

$$D_f = 0.58$$

$$S_f = 0.42$$

$$\Delta = [0.2, 0.2]$$



$k$	$g_1(k)$	$g_2(k)$	$g_3(k)$	$g_4(k)$	$l_1(k)$	$l_2(k)$	$l_3(k)$	$l_4(k)$
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:

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

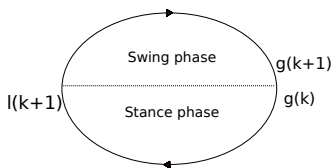
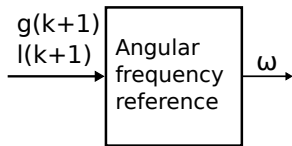
$$Ti_{sw} = g_i(k+1) - l_i(k+1),$$

Average angular frequency:

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

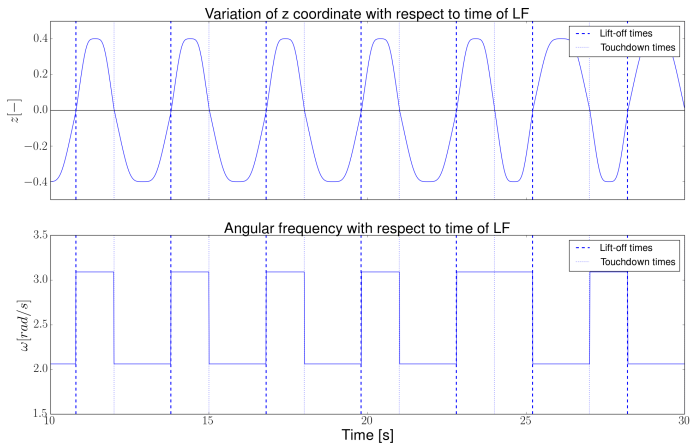
Condition for the angular frequency function:

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



# 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.

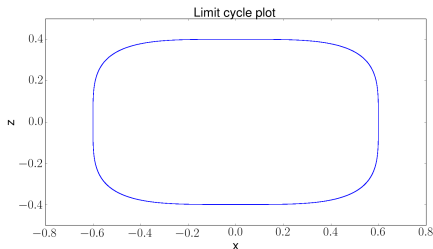
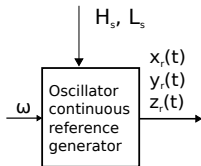


# Oscillator continuous time reference generator (continue)

Oscillator equations:

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

$$\dot{z} = \beta \left( 1 - \frac{16x^4}{L_s^4} - \frac{z^4}{H_s^4} \right) z - \frac{9.44\omega H_s}{L_s^3} x^3$$



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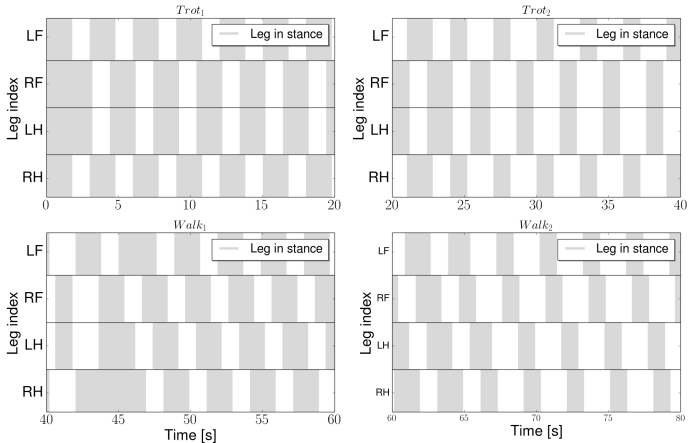
## Parameters used

Switch between four different sets of gait parameters:

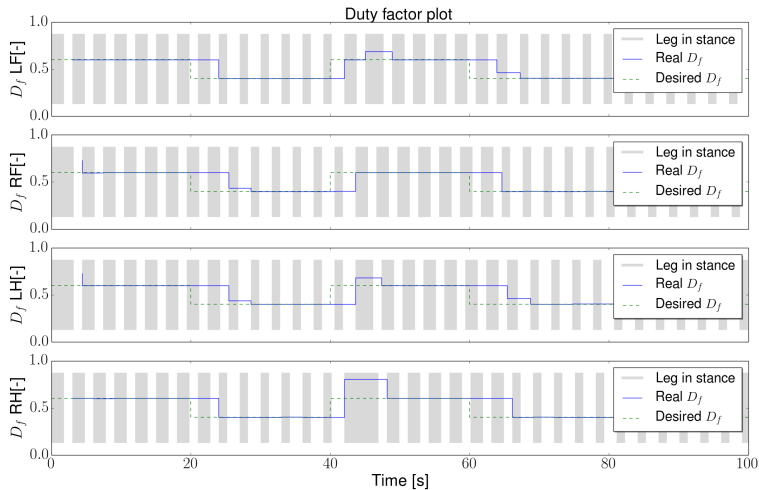
	$G$	$D_f$	$S_f[\frac{1}{s}]$	$\Delta[s]$
$T_1$	$\{1, 4\} \prec \{2, 3\}$	0.6	1/3	$[0.2, 0.4]$
$T_2$	$\{1, 4\} \prec \{2, 3\}$	0.4	1/3	$[-0.2, -0.4]$
$W_1$	$\{1\} \prec \{2\} \prec \{3\} \prec \{4\}$	0.6	1/3	$[-0.45, -0.45, -0.45, -0.45]$
$W_2$	$\{1\} \prec \{2\} \prec \{3\} \prec \{4\}$	0.4	1/3	$[-1.4,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

# Generated motion references

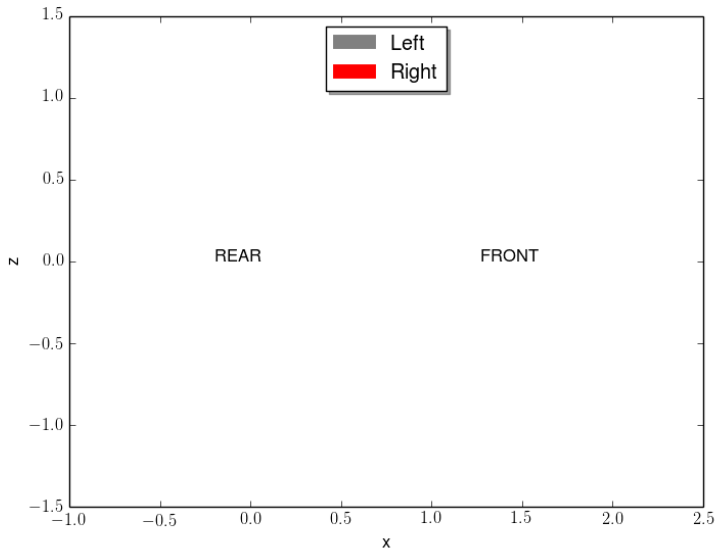
Plots for gaits with different parameters



# Duty factor



# Animation



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## 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?