### **DLS Lab Seminar**

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#### Outline

Control structure

Numeric simulations

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Numeric simulations

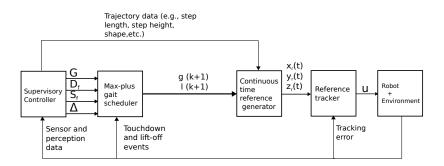
#### Motivation

 Provide versatility to the types of gaits that the robot can perform

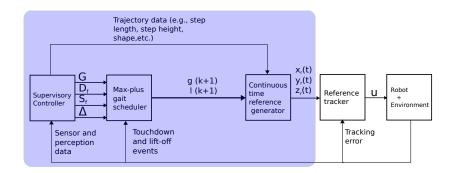
 Have a unified and systematic way to generate motions of the legs according to the scenario

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.

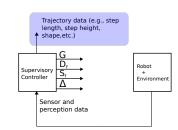
## Supervisory controller (continue)

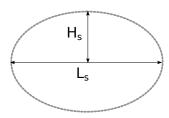
#### Geometrical parameters:

• Step height H<sub>s</sub>

• Step length Ls

Oscillator "primitive" shape changes





# Supervisory controller (continue)

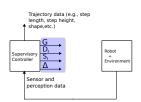
#### Time parameters:

Duty factor D<sub>f</sub>

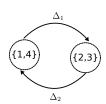
• Step frequency  $S_f$ 

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

• Time difference vector  $\Delta$ 





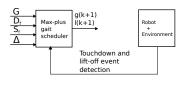


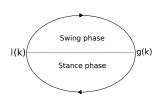
## Max-plus gait scheduler

#### 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 <sub>3</sub> (k)	$g_4(k)$	$l_1(k)$	$l_2(k)$	13(k)	14(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:

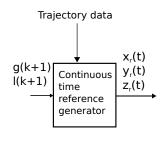
$$Ti_{st} = l_i(k+1) - g_i(k)$$
  
 $Ti_{sw} = g_i(k+1) - l_i(k+1),$ 

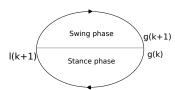
Average angular frequency:

$$ar{\omega} = egin{cases} rac{\pi}{T_{i_{st}}} & ext{for } t \in [g_i(k), l_i(k+1)] \ rac{\pi}{T_{i_{sw}}} & ext{for } t \in (l_i(k+1), g_i(k+1)] \end{cases}$$

Condition for the angular frequency function:

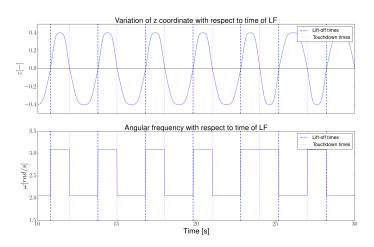
$$\frac{1}{Ti_p}\int^{Ti_p}\omega dt=\bar{\omega}$$
 for  $p=st,sw$ .





## Angular frequency reference generator (continue)

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



## Oscillator continuous time reference generator

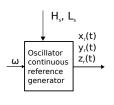
#### Main goal

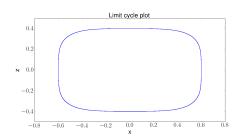
Generate reference trajectories for each of the legs of the robot in such a way that the desired gait is achieved, according to the angular frequency obtained from the angular frequency reference generator.

# Oscillator continuous time reference generator (continue)

Oscillator equations:

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





#### Outline

Control structure

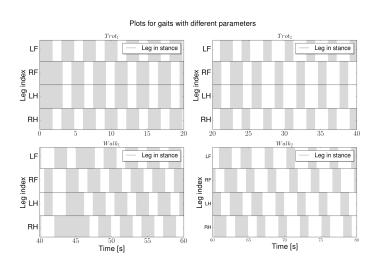
Numeric simulations

#### Parameters used

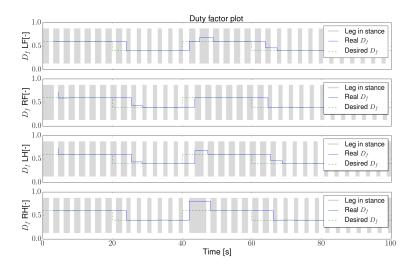
Switch between four different sets of gait parameters:

	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]

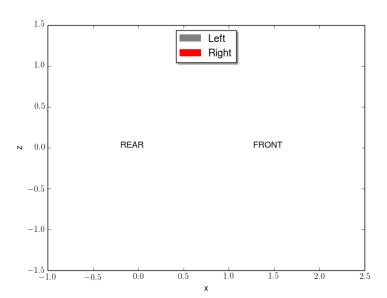
#### Generated motion references



## **Duty factor**



## Animation



#### Outline

Control structure

Numeric simulations

- 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?