

# DLS Lab annual seminar

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Istituto Italiano di Tecnologia

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

# Introduction

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# About me

Octavio Antonio Villarreal Magaña

- MSc. Mechanical Engineering, track Control Engineering (TUDelft, The Netherlands)
- BSc. Mechatronic Engineering (UNAM, Mexico)
- Research interests:
  - Control Methods for Robotics
  - Robust Control



**Master thesis: "Dynamic control  
of 3D directional drilling systems  
using state estimation"**

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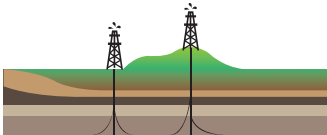
# Dynamic control of 3D directional drilling systems

- Challenging dynamic system
- Interesting robustness problem (not addressed here)
- Collaboration between researchers of TU Delft, TU Eindhoven and the University of Minnesota

# Applications of directional drilling



- Extract oil, mineral and thermal energy resources

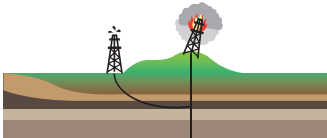


- Reach targets that need complex geometries such as:

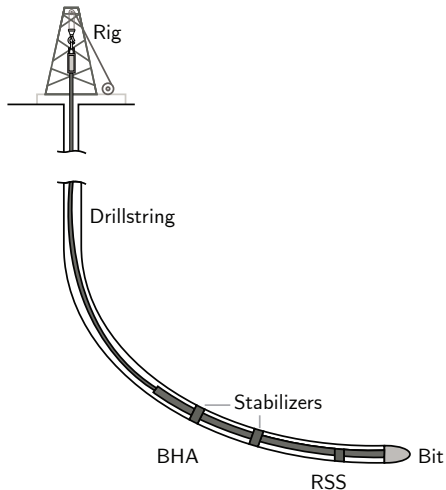
- Under a city or an ecosystem

- Far from the drill rig

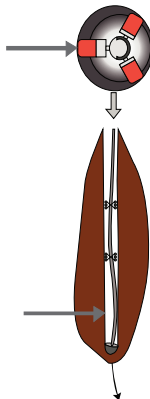
- Relief for hazardous situations



# General description of the system

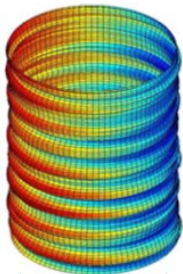


## Rotary Steerable System (RSS)



BHA: Bottom hole assembly





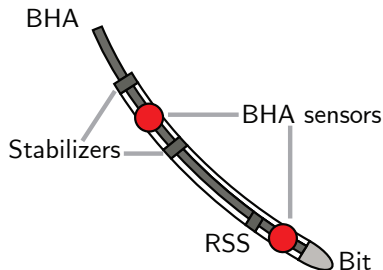
[Sugiura 2009]

- State-of-practice: constant RSS force (open loop)
- Negative effects: kinking, rippling and spiraling
- Consequences of negative effects: reduced penetration rate and accuracy

Develop a control strategy for a 3D directional drilling system, that allows to drill boreholes with complex geometries, while avoiding undesired behaviors.

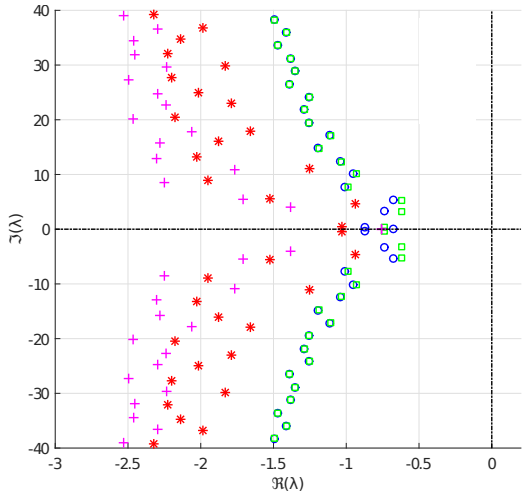
# Scenario and challenges

- Function of length (not time)
- Model: nonlinearly coupled delay differential equations
- Control orientation of the bit
- No access to measurements
- Infinite number of poles (no pole-placement)

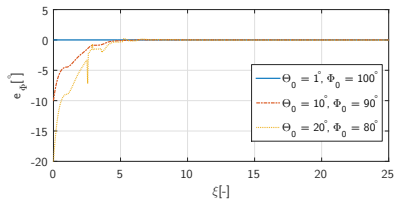
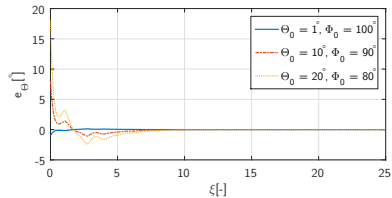
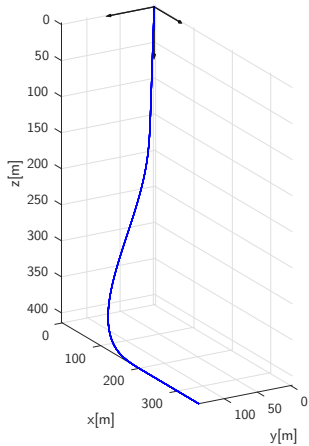


# Approach and solution

- No measurements: state estimation using **observers**
- Infinite poles: **spectral** approach [Michiels and Niculescu 2007]
- Performance: **optimize** location of right-most dominant pole of the system



# Simulation results

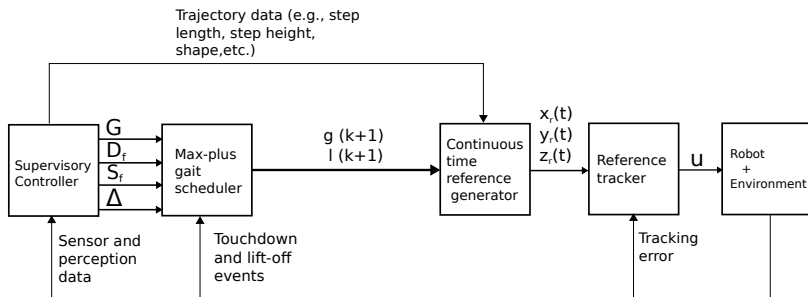


**Research proposal: "Locomotion control of HyQ using max-plus algebra linear systems"**

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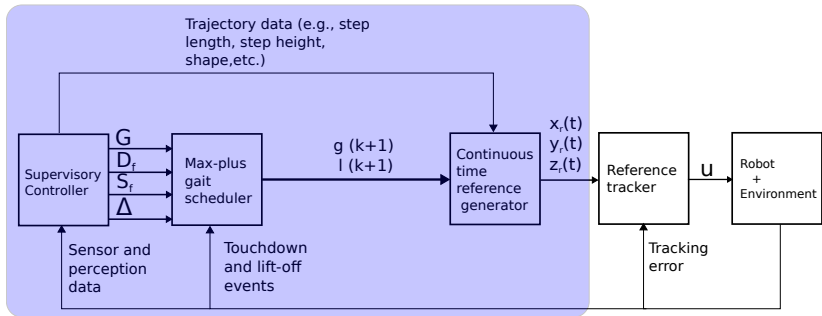
- Provide versatility to the types of gaits that the robot can perform
- Have a unified and systematic way to generate motions of the legs according to the scenario
- Can be applied to other legged systems

# General picture





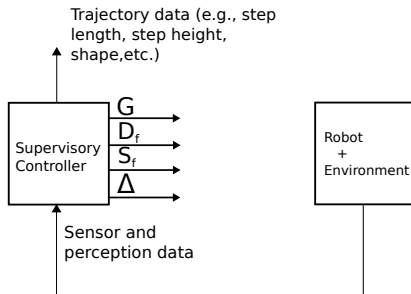
# General picture



# Supervisory controller

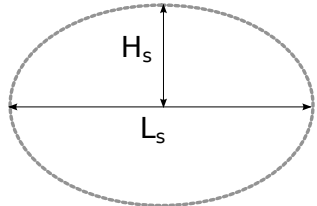
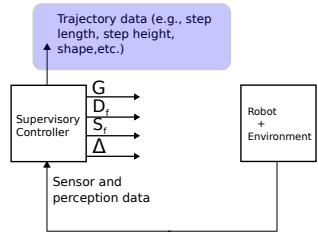
## Main goal

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



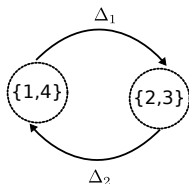
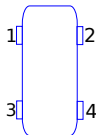
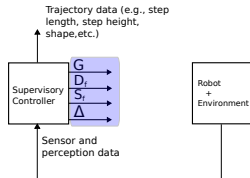
# Geometrical parameters

- Not necessarily the same for all four legs
- Examples of trajectory parameters:
  - Oscillator shape parameters [Barasuol et.al. 2013]
  - Control points of a Bézier (spline) curve [Hyun et.al. 2014]



# Time parameters

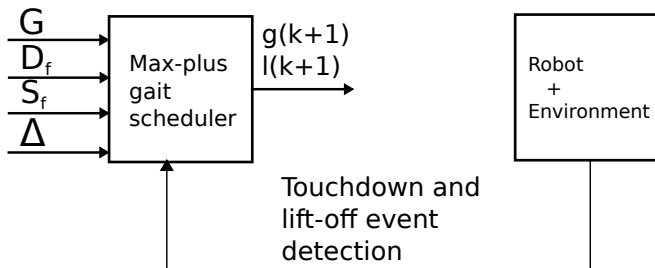
- Duty factor  $D_f$
- Step frequency  $S_f$
- Gait parameterization  $G$  (e.g.,  
 $G_{trot} = \{1, 4\} \prec \{2, 3\}$ )
- Time difference vector  $\Delta$



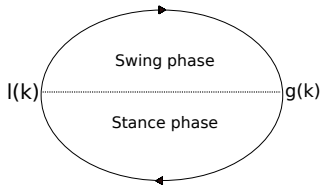
# Max-plus gait scheduler

## Main goal

Using the **time**-related gait parameters provided by the supervisory controller, generate the times that each leg has to touch or leave the ground.



# 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

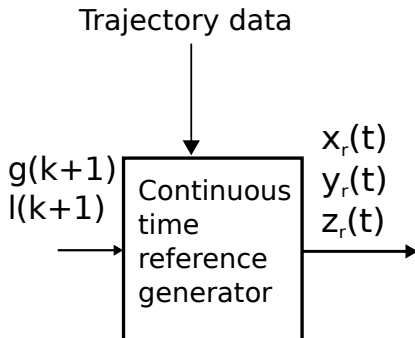
## Max-plus gait scheduler (continue)

- Systematic coordinated gait generation
- Total cycle time analysis (max-plus linear systems theory)
- Coupling time analysis ("settling time")
- Not computationally expensive

# Continuous reference generator

## Main goal

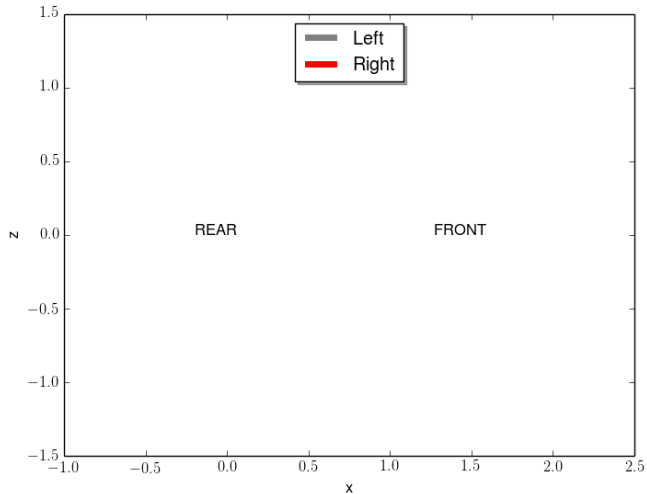
Making use of the **touchdown** and **lift-off** times of the max-plus gait scheduler, provide a reference trajectory for each of the legs.



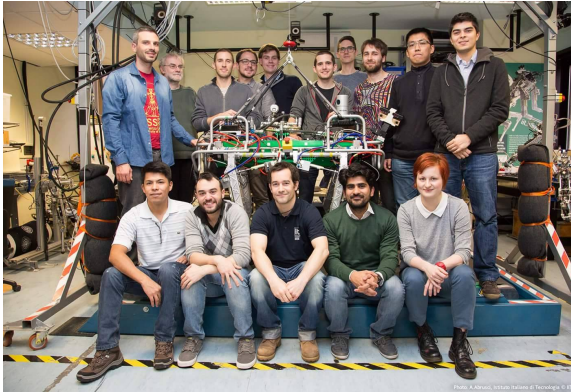


# Animation

Change of parameters at 10 seconds



# Thank you. Questions or comments?



## Group members:

- Claudio Semini
- Alex Oleg Posatskiy
- Yannick Berdou
- Yifu Gao
- Michele Focchi
- Victor Barasuol
- Romeo Orsolino
- Andreea Radulescu
- Carlos Mastalli
- Marco Camurri
- Marco Frigerio
- Roy Featherstone
- Josephus Driessen
- Antonios Gkikakis
- Roodra Singh