DLS Lab annual seminar

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Introduction

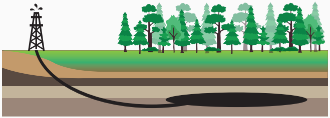
About me

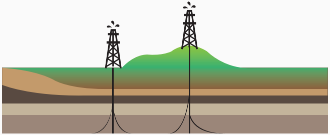
Master thesis: ”Dynamic control of 3D directional drilling systems using state estimation”

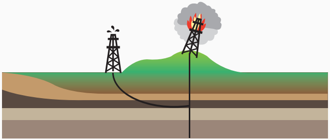
Dynamic control of 3D directional drilling systems

- Challenging dynamic system
- Collaboration between researchers of TU Delft, TU Eindhoven and the University of Minnesota
- Little research on this field

Applications of directional drilling

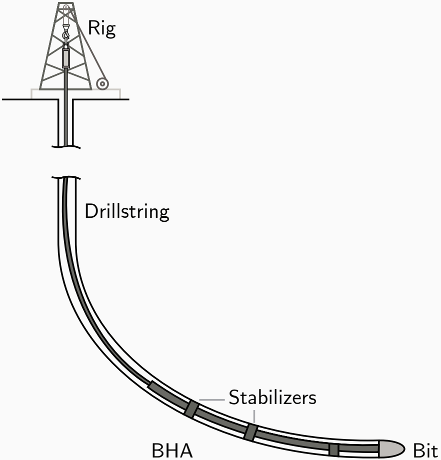






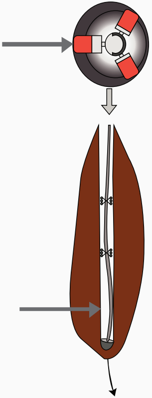
- Extract oil, mineral and thermal energy resources
- Reach targets that need complex geometries such as:
  - Under a city or an ecosystem
  - Far from the drill rig
  - Relief for hazardous situations

General description of the system

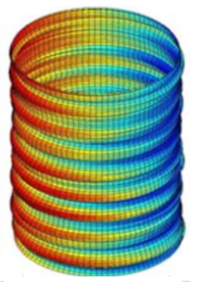


BHA: Bottom hole assembly

Rotary Steerable System (RSS)



Context and challenges



[Sugiura 2009]

- State-of-practice: Constant RSS force
- Negative effects: kinking, rippling and spiraling
- Consequences of negative effects: reduced penetration rate and accuracy

Research goals

Main goal

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

Previous works

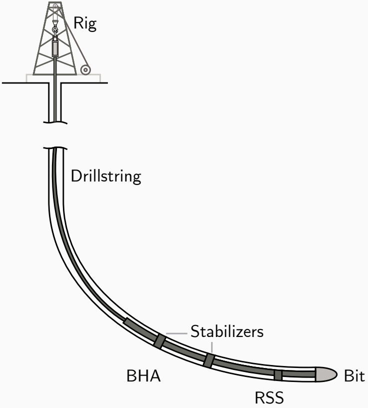
- Model of 3D directional drilling systems [Perneder 2013]
- Model-based decoupled control of a 3D directional drilling system [Monsieurs 2015]
    - State-feedback controller
    - Relies on availability of measurements of the states (not possible in practice)

Subgoals

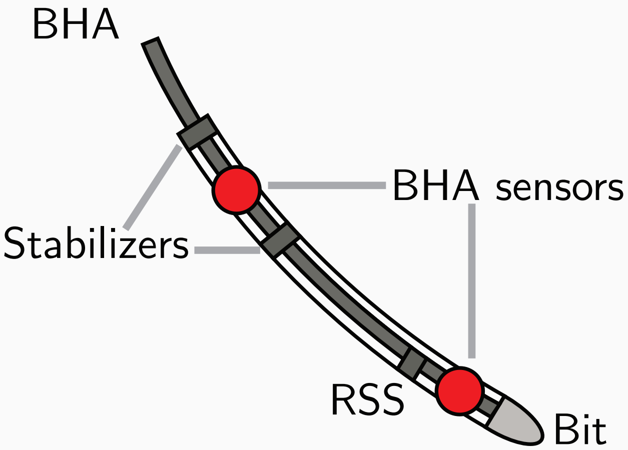
- Control strategy that relies only on local measurements
- Robustness against parametric uncertainty

Model charateristics

- Function of (dimensionless) borehole length ξ
- Model form: nonlinear coupled delay differential equations (delays: BHA should fit in already drilled borehole)
- States: borehole inclination (Θ) and azimuth (Φ) at the bit
- No access to measurements of the states (output equations of sensors)



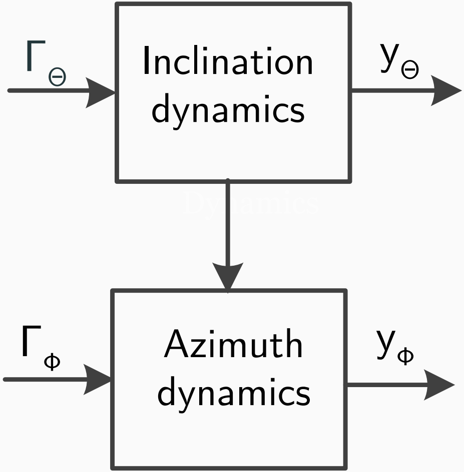
Available measurements



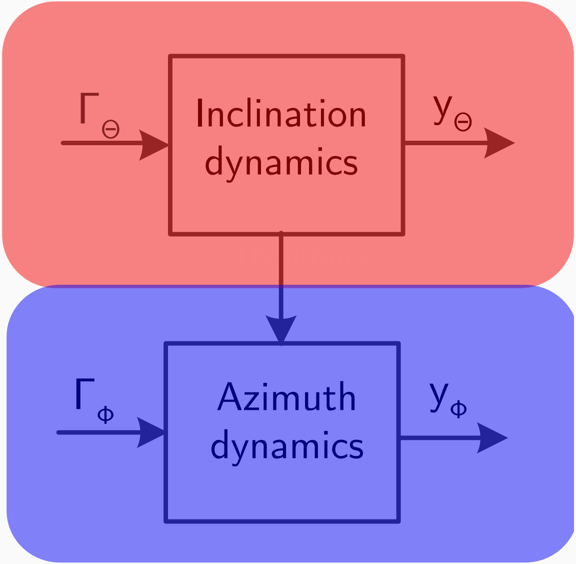
Control objectives

- Track a desired reference trajectory corresponding to a complex borehole geometry
- The response of the system should have favorable transient behavior (avoid kinking, rippling and spiraling)

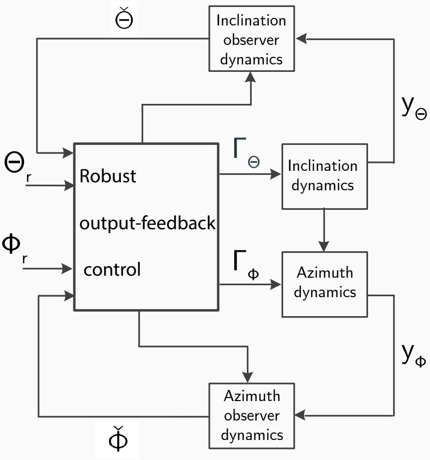
Plant definition



Plant definition



Output-feedback strategy

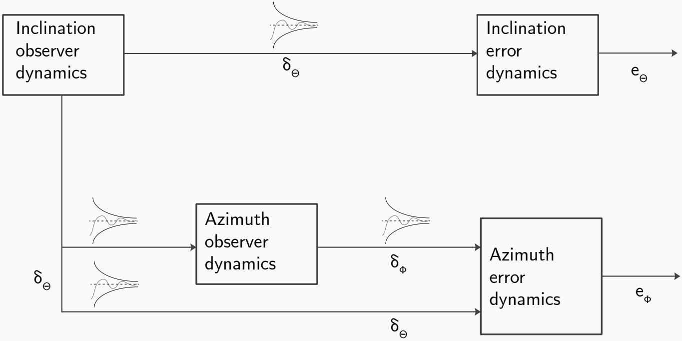


- Focus of the research: Include observer in the control structure
- Challenges
  - Nonlinear coupling between states while $\Theta \neq \check{\Theta}$
  - Controller and observer gain design

$e_i := i_r - i \qquad \delta_i := i - \check{i}_i \quad \text{for } i = \Theta, \Phi$

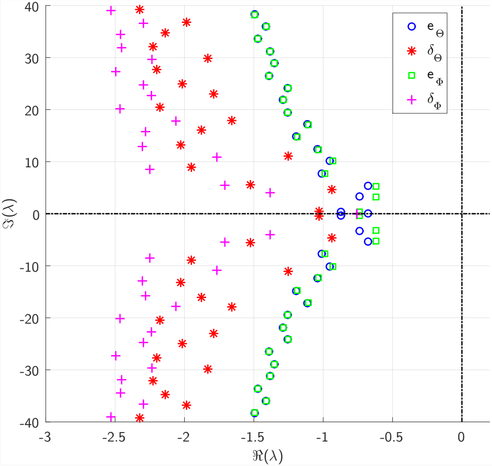
Controller synthesis

- Define isolated systems e_Θ, δ_Θ, e_Φ and δ_Φ
- Synthesize K_Θ, L_Θ, K_Φ and L_Φ for each isolated system separately
- Favorable transient performance

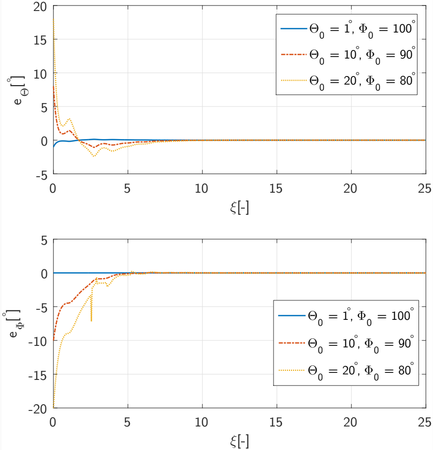


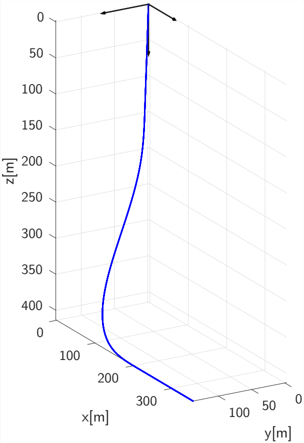
Controller synthesis

- Infinite number of poles in delay systems (no pole-placement)
- Spectral approach [Michiels and Niculescu 2007]
- Optimize location of right-most pole over K_i (state-feedback gain) and L_i (observer-feedback gain)



Simulation results



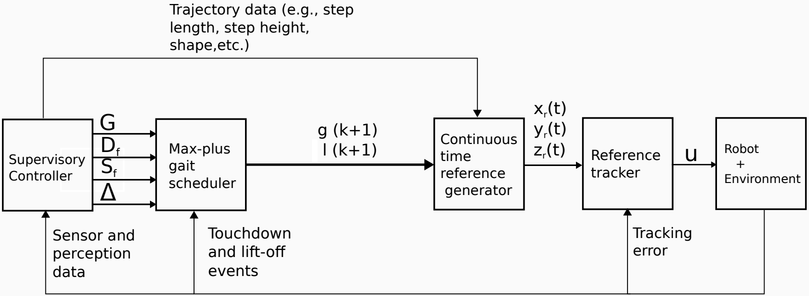


Research proposal: ”Locomotion control of HyQ using max-plus algebra linear systems”

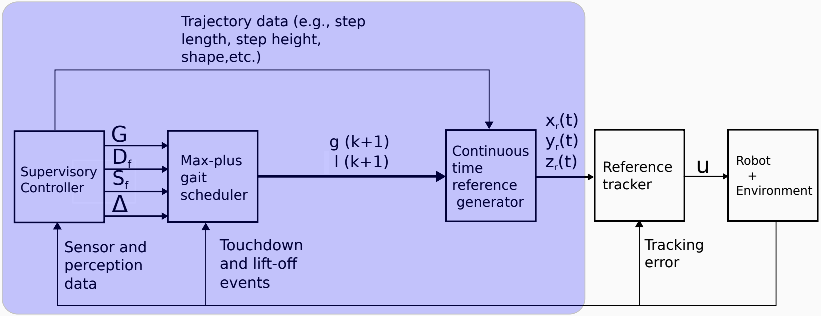
Motivation

- 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



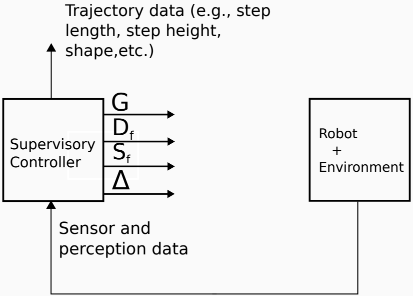
General picture



Supervisory controller

Main goal

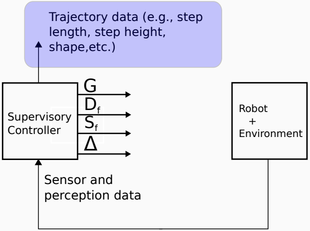
Decide **geometrical** and **time** gait parameters, based on sensory data, to overcome the scenario that the robot is facing.

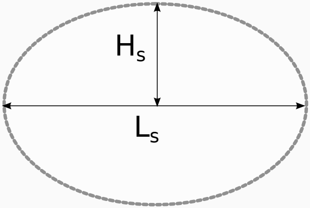


Geometrical parameters

- Not necessarily the same for all four legs

- Examples of trajectory parameters:
  - Oscillator shape parameters [Barasuol et.al. 2013]
  - Control points of a Bzier curve [Hyun et.al. 2014]

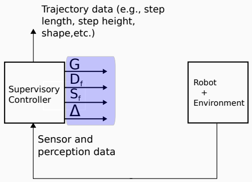


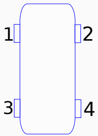


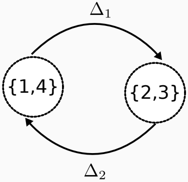
Supervisory controller (continue)

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



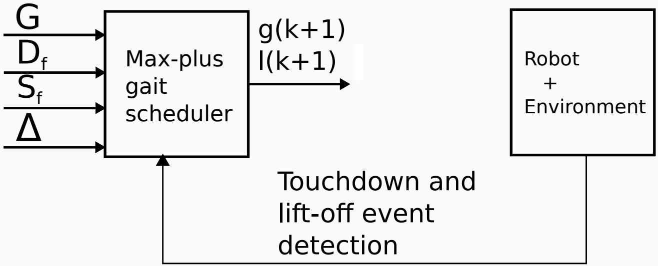




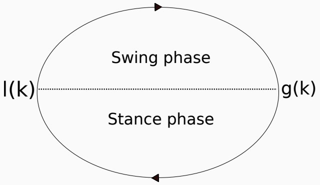
Max-plus gait scheduler

Main goal

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



Max-plus gait scheduler (continue)



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

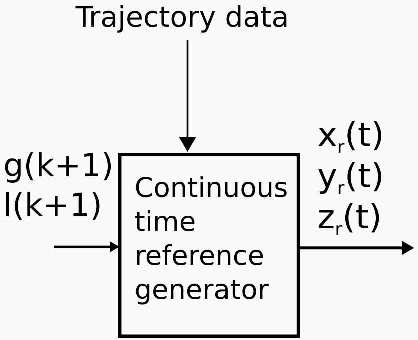
k	$g_1(k)$	$g_2(k)$	$g_3(k)$	$g_4(k)$	$l_1(k)$	$l_2(k)$	$l_3(k)$	$l_4(k)$
0	0	0	0	0	0	0	0	0
1	2.4	3.6	3.6	2.4,	1.4	2.6	2.6	1.4
2	4.8	6	6	4.8	3.8	5	5	3.8
3	7.2	8.4	8.4	7.2	6.2	7.4	7.4	6.2
4	9.6	10.8	10.8	9.6	8.6	9.8	9.8	8.6
5	12	13.2	13.2	12	11	12.2	12.2	11

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

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.



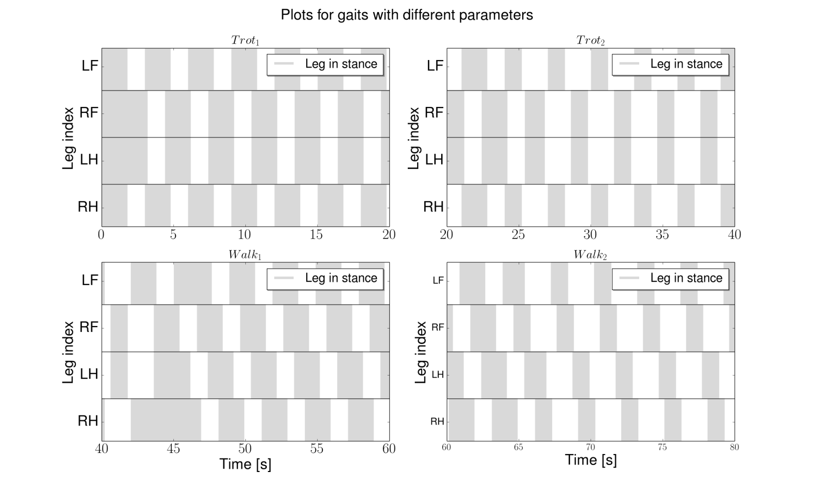
Continuous reference generator

Possible alternatives:

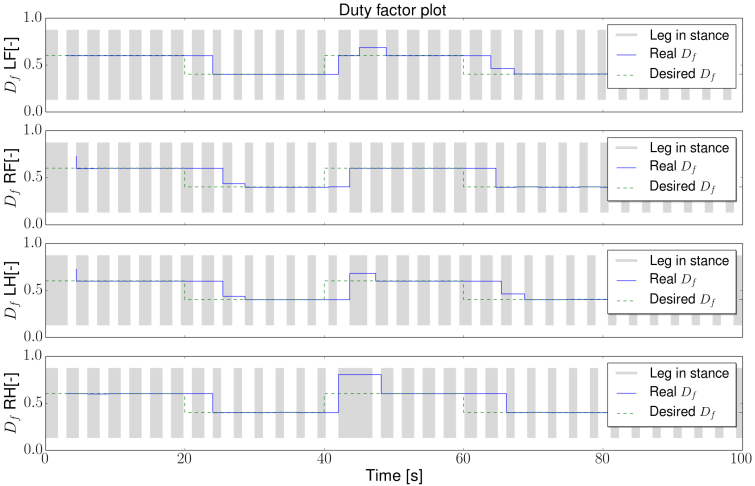
- Oscillator with angular frequency modulation according to max-plus scheduler
- Parameterized velocity profile using lift-off $l(k+1)$ and touchdown $g(k+1)$ as initial and final times respectively

Simulations

Change gait parameters every 20 seconds

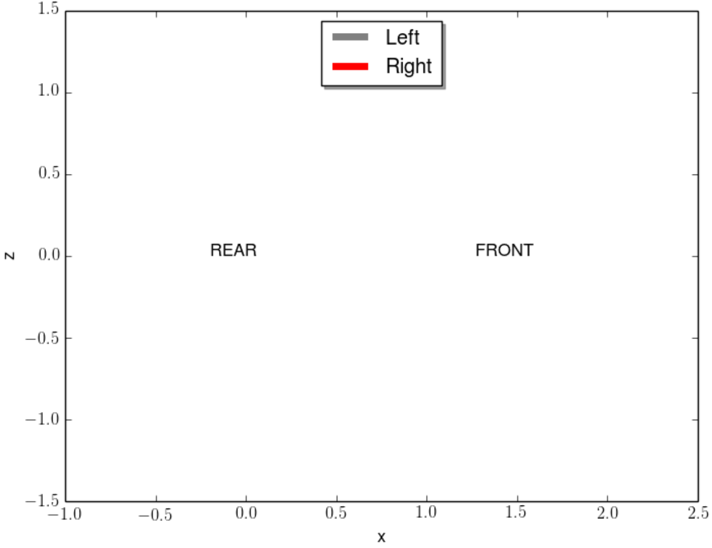


Duty factor



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

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

Thank you. Questions or comments?