

# Cubli: Dynamic Control of a Reaction Wheel Inverted Pendulum

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# Agenda

Cubli: Dynamic Control  
of a Reaction Wheel  
Inverted Pendulum

Classical Controller  
Design

## Classical Controller Design

# Classical Controller Design

## SISO Block Diagram

Cubli: Dynamic Control  
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Classical Controller  
Design

2

SISO Block Diagram

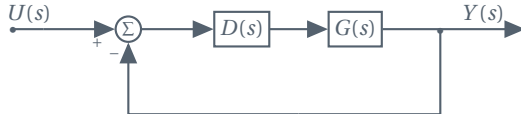
Stability Analysis

Root Locus Design

Discretization

Simulation of the Controller

Implementation



- ▶  $U(s)$  refers to the desired angular position of the frame
- ▶  $Y(s)$  is the actual angular position of the frame

# Classical Controller Design

## Stability Analysis

Cubli: Dynamic Control  
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### ► Nyquist plot

Classical Controller  
Design

SISO Block Diagram

Stability Analysis

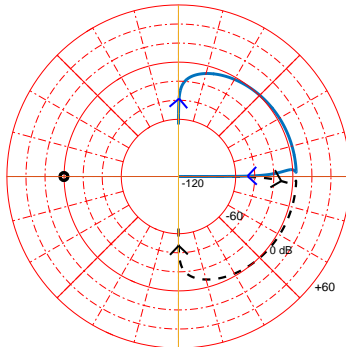
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3



$$Z_{RHP} = N + P_{RHP}$$

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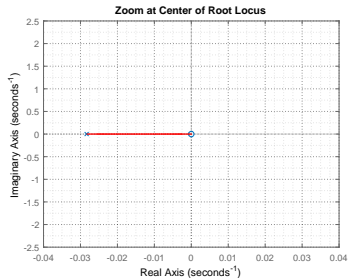
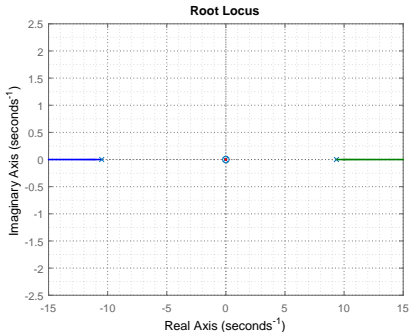
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4

### ► Root Locus



# Classical Controller Design

## Root Locus Design

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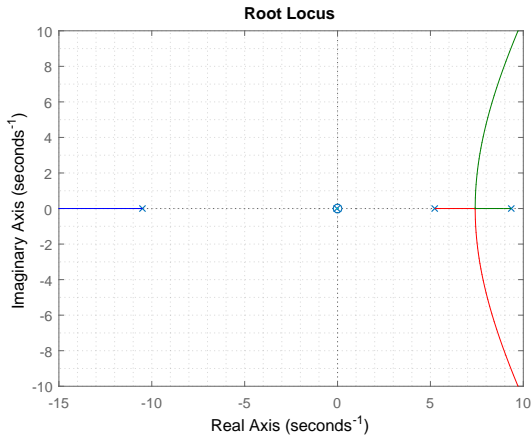
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5



# Classical Controller Design

## Root Locus Design

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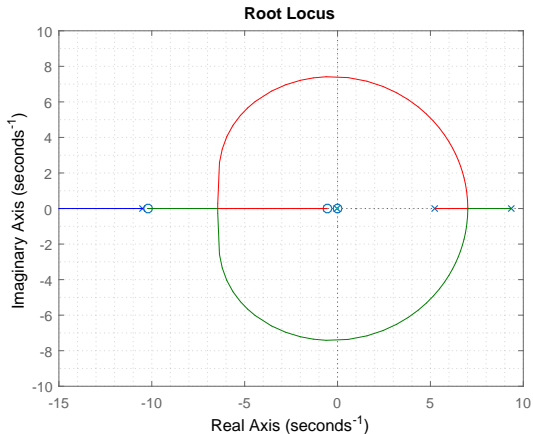
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6



# Root Locus Designed Controller

## Root Locus Design

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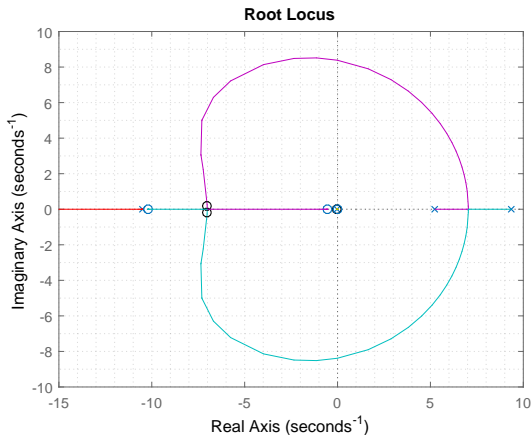
Root Locus Design

Discretization

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7





# Root Locus Designed Controller

## Root Locus Design

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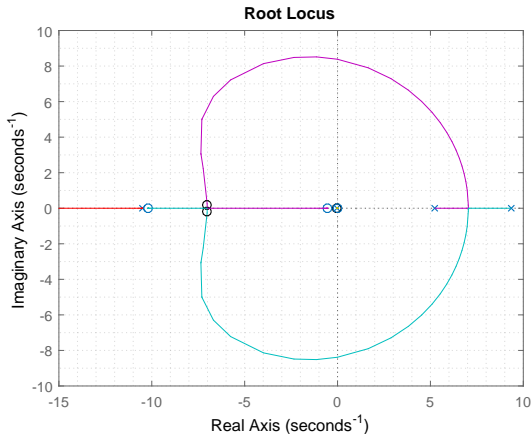
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7



$$D(s) = -4059,8 \cdot \frac{(s + 10,2) \cdot (s + 0,546)}{(s - 5,23) \cdot (s + 100) \cdot (s + 200)}$$

# Root Locus Designed Controller

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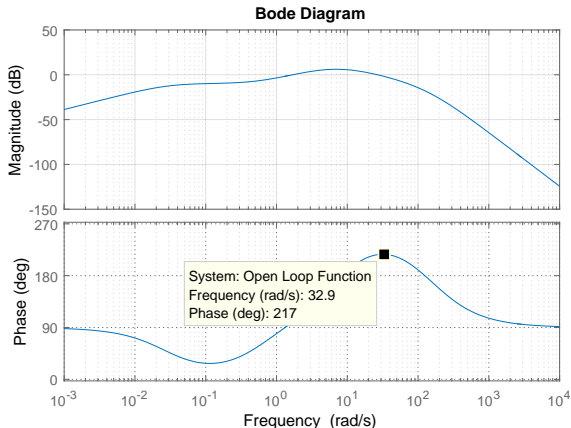
Root Locus Design

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8



# Root Locus Designed Controller

## Discretization

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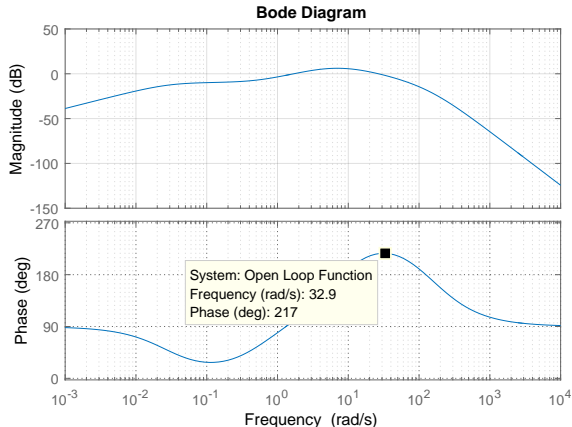
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8



$$D(z) = \frac{\tau_{m,w}(z)}{e_{\theta}(z)} = \frac{-7,338 + 6,58 \cdot z^{-1} + 7,335 \cdot z^{-2} - 6,584 \cdot z^{-3}}{1 - 1,3879 \cdot z^{-1} + 0,3409 \cdot z^{-2} + 0,001576 \cdot z^{-3}}$$

# Root Locus Designed Controller

## Simulation of the Controller

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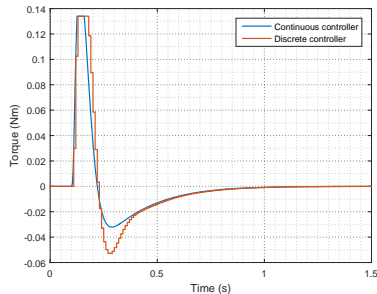
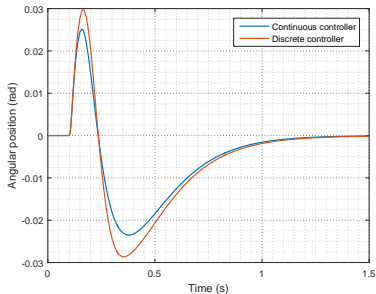
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9

- Behavior of the continuous and the discrete controllers in simulation



# Root Locus Designed Controller Implementation

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10

## ► Difference equation

$$\begin{aligned}\tau_m[n] = & -8.314 \cdot e_\theta[n] + 7.422 \cdot e_\theta[n-1] + 8.3023 \cdot e_\theta[n-2] \\ & -7.434 \cdot e_\theta[n-3] + 1.382 \cdot \tau_m[n-1] - 0.3415 \cdot \tau_m[n-2] \\ & -0.001638 \cdot \tau_m[n-3]\end{aligned}$$

11

# Root Locus Designed Controller Implementation

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11

- Angular position of the frame and angular velocity of the wheel in the real Cubli

