Simscape Model - Nano Active Stabilization System

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From last sections:

- Uniaxial: No stiff nano-hexapod (should also demonstrate that here)
- Rotating: No soft nano-hexapod, Decentralized IFF can be used robustly by adding parallel stiffness

In this section:

- Take the model of the nano-hexapod with stiffness 1um/N
- Apply decentralized IFF
- Apply HAC-LAC
- Check robustness to payload change
- Simulation of experiments

1 Control Kinematics

- Explained during the last section: HAC-IFF Decentralized IFF Centralized HAC, control in the frame of the struts
- To compute the positioning errors in the frame of the struts
  - Compute the wanted pose of the sample with respect to the granite using the micro-station kinematics (Section 1.1)
  - Measure the sample pose with respect to the granite using the external metrology and internal metrology for Rz (Section 1.2)
  - Compute the sample pose error and map these errors in the frame of the struts (Section 1.3)
- The complete control architecture is shown in Section 1.4

  positioning_error: Explain how the NASS control is made (computation of the wanted position, measurement of the sample position, computation of the errors)

  Schematic with micro-station + nass + metrology + control system =¿ explain what is inside the control system

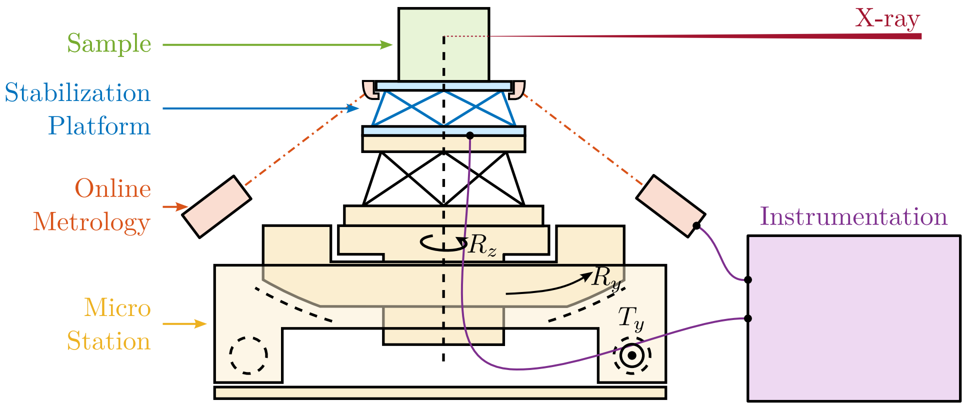


Figure 1.1: Figure caption

1.1 Micro Station Kinematics

- from **??**, computation of the wanted sample pose from the setpoint of each stage.

wanted pose = Tdy * Try * Trz * Tu

1.2 Computation of the sample's pose error

From metrology (here supposed to be perfect 6-DoF), compute the sample's pose error. Has to invert the homogeneous transformation.

In reality, 5DoF metrology =¿ have to estimate the Rz using spindle encoder + nano-hexapod internal metrology (micro-hexapod does not perform Rz rotation).

1.3 Position error in the frame of the struts

Explain how to compute the errors in the frame of the struts (rotating):

- Errors in the granite frame
- Errors in the frame of the nano-hexapod
- Errors in the frame of the struts =¿ used for control

1.4 Control Architecture

- Say that there are many control strategies. It will be the topic of chapter 2.3. Here, we start with something simple: control in the frame of the struts

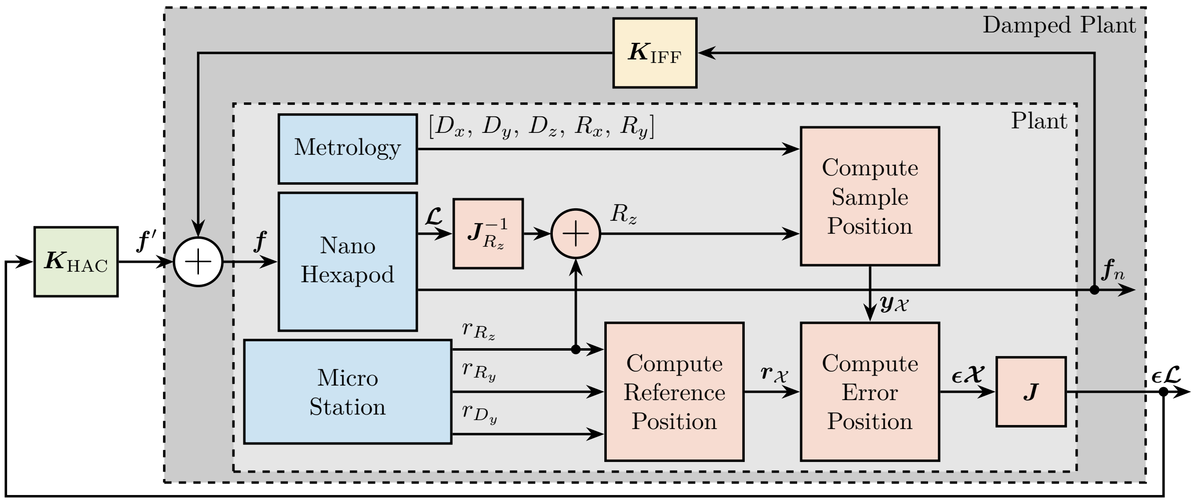


Figure 1.2: The physical systems are shown in blue, the control kinematics in red, the decentralized Integral Force Feedback in yellow and the centralized High Authority Controller in green.

2 Decentralized Active Damping

- How to apply/optimize IFF on an hexapod?
- Robustness to payload mass
- Root Locus
- Damping optimization
- **Parallel stiffness?**

Explain which samples are tested:

- 1kg, 25kg, 50kg
- cylindrical, 200mm height?

  control_active_damping

  active damping for stewart platforms

  Vibration Control and Active Damping

2.1 IFF Plant

Show how it changes with the payload mass (1, 25, 50)

Effect of rotation (no rotation - 60rpm)

Added parallel stiffness

Coupling

Effect of rotation

Effect of payload mass

2.2 Controller Design

Low pass filter needs to be added (because now: DC gain)

$$\boldsymbol{K}_{\text{IFF}}(s) = g \cdot \begin{bmatrix} K_{\text{IFF}}(s) & & 0 \\ & \ddots & \\ 0 & & K_{\text{IFF}}(s) \end{bmatrix}, \quad K_{\text{IFF}}(s) = \frac{1}{s} \tag{2.1}$$

Loop Gain: Root Locus =¿ Stability

- Use Integral controller (with parallel stiffness)
- Show Root Locus (show that without parallel stiffness =¿ unstable?)
- Choose optimal gain. Here in MIMO, cannot have optimal damping for all modes. (there is a paper that tries to optimize that)

  Show robustness to change of payload (loci?) / Change of rotating velocity ?
- Reference to paper showing stability in MIMO for decentralized IFF

2.3 Sensitivity to disturbances

Disturbances:

- floor motion
- Spindle X and Z
- Direct forces?
- Compute sensitivity to disturbances with and without IFF (and compare without the NASS)
- Maybe noise budgeting, but may be complex in MIMO... ?

3 Centralized Active Vibration Control

uncertainty_experiment: Effect of experimental conditions on the plant (payload mass, Ry position, Rz position, Rz velocity, etc...)

- Effect of micro-station compliance
- Effect of IFF
- Effect of payload mass
- Decoupled plant
- Controller design

From control kinematics:

- Talk about issue of not estimating Rz from external metrology? (maybe could be nice to discuss that during the experiments!)
- Show what happens is Rz is not estimated (for instance supposed equaled to zero =¿ increased coupling)

3.1 HAC Plant

Compute transfer function from $\boldsymbol{f}$ to $\boldsymbol{\epsilon\mathcal{L}}$ (with IFF applied) for all masses

Show effect of rotation

Show effect of payload mass

Compare with undamped plants

Effect of rotation:

Effect of IFF:

Effect of payload mass

Advantage of using IFF:

3.2 Controller design

Show design HAC with formulas and parameters

Show robustness with Loci for all masses

$$K_{\text{HAC}}(s) = g_0 \cdot \underbrace{\frac{\omega_c}{s}}_{\text{int}} \cdot \underbrace{\frac{1}{\sqrt{\alpha}}\frac{1 + \frac{s}{\omega_c/\sqrt{\alpha}}}{1 + \frac{s}{\omega_c\sqrt{\alpha}}}}_{\text{lead}} \cdot \underbrace{\frac{1}{1 + \frac{s}{\omega_0}}}_{\text{LPF}}, \quad (\omega_c = 2\pi 5\,\text{rad/s},\ \alpha = 2,\ \omega_0 = 2\pi 30\,\text{rad/s}) \tag{3.1}$$

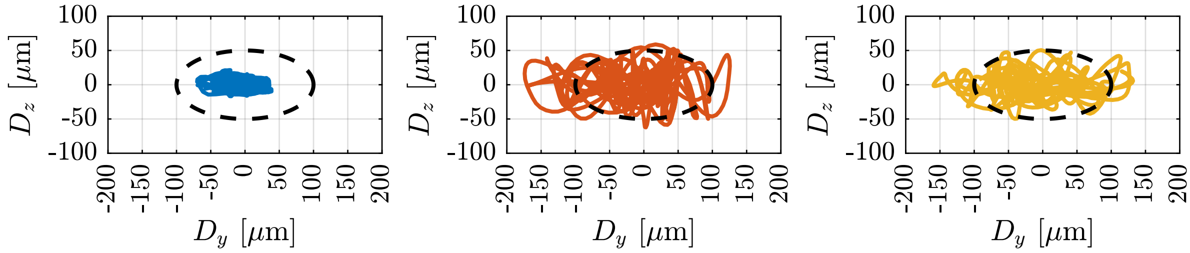
"Decentralized" Loop Gain: Characteristic Loci for three masses:

3.3 Sensitivity to disturbances

- Compute transfer functions from spindle vertical error to sample vertical error with HAC-IFF Compare without the NASS, and with just IFF
- Same for horizontal

3.4 Tomography experiment

- With HAC-IFF, perform tomography experiment, and compare with open-loop
- Take into account disturbances, metrology sensor noise. Maybe say here that we don't take in account other noise sources as they will be optimized latter (detail design phase)
- Tomography + lateral scans (same as what was done in open loop here)
- Validation of concept



(a) $m = 1\,kg$ (b) $m = 25\,kg$ (c) $m = 50\,kg$

Figure 3.1: Simulation of tomography experiments

4 Conclusion