Simscape Model - Nano Hexapod

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Contents

Introduction:

- Choice of architecture to do 5DoF control (Section 1)
- Stewart platform (Section 2) Show what is an hexapod, how we can define its geometry, stiffness, etc... Some kinematics: stiffness matrix, mass matrix, etc...
- Need to model the active vibration platform: multi-body model (Section 3) Explain what we want to capture with this model Key elements (plates, joints, struts): for now simplistic model (rigid body elements, perfect joints, ...), but in next section, FEM will be used
- Control (Section 4)

1 Active Vibration Platforms

Goals:

- Explain why Stewart platform architecture is chosen
- Explain what is a Stewart platform (quickly as it will be shown in details in the next section)
- Quick review of active vibration platforms (5 or 6DoF)

Active vibration platform with 5DoF or 6DoF? Synchrotron applications?

- Literature review? (**maybe more suited for chapter 2**)
  - `file:///home/thomas/Cloud/work-projects/ID31-NASS/matlab/stewart-simscape/org/bibliography.org`
  - Talk about flexible joint? Maybe not so much as it should be topic of second chapter. Just say that we must of flexible joints that can be defined as 3 to 6DoF joints, and it will be optimize in chapter 2.
- [1]
- For some systems, just XYZ control (stack stages), example: holler
- For other systems, Stewart platform (ID16a), piezo based
- Examples of Stewart platforms for general vibration control, some with Piezo, other with Voice coil. IFF, ... Show different geometry configuration
- DCM: tripod?

1.1 Active vibration control of sample stages

Review of stages with online metrology for Synchrotrons

Talk about external metrology?

Talk about control architecture?

Comparison with the micro-station / NASS

1.2 Serial and Parallel Manipulators

Goal:

- Explain why a parallel manipulator is here preferred
- Compact, 6DoF, higher control bandwidth, linear, simpler
- Show some example of serial and parallel manipulators
- A review of Stewart platform will be given in Chapter related to the detailed design of the Nano-Hexapod

2 The Stewart platform

- Some history about Stewart platforms
- What is so special and why it is so used in different fields: give examples Explain advantages compared to serial architecture
- Little review (very quick: two extreme sizes, piezo + voice coil) Complete review of Stewart platforms will be made in Chapter 2
- Presentation of tools used to analyze the properties of the Stewart platform =¿ useful for design and control

2.1 Mechanical Architecture

file:///home/thomas/Cloud/work-projects/ID31-NASS/matlab/stewart-simscape/org/stewart-architecture.org

Presentation of the typical architecture

- Explain the different frames, etc...
- explain key elements:
  - two plates
  - joints
  - actuators

Make well defined notations.

- {F}, {M}
- si, li, ai, bi, etc.

  Make figure with defined frames, joints, etc... Maybe can use this figure as an example:

  [scale=1]/home/thomas/Cloud/work-projects/ID31-NASS/phd-thesis-chapters/A0-nass-introduction/figs/introdu

2.2 Kinematic Analysis

Inverse Kinematics

Forward Kinematics

Jacobian Matrix

- Velocity Loop Closure
- Static Forces

Singularities

- Briefly mention singularities, and say that for small stroke, it is not an issue, the Jacobian matrix may be considered constant

2.3 Static Analysis

How stiffness varies with orientation of struts. Same with stroke? Or maybe in the detailed chapter?

2.4 Dynamic Analysis

Very complex =¿ multi-body model For instance, compute the plant for massless struts and perfect joints (will be compared with Simscape model). But say that if we want to model more complex cases, it becomes impractical (cite papers).

Conclusion

All depends on the geometry. Reasonable choice of geometry is made in chapter 1. Optimization of the geometry will be made in chapter 2.

3 Multi-Body Model

Goal:

- Study the dynamics of Stewart platform
- Instead of working with complex analytical models: a multi-body model is used. Complex because has to model the inertia of the struts. Cite papers that tries to model the stewart platform analytically Advantage: it will be easily included in the model of the NASS
- Mention the Toolbox (maybe make a DOI for that)

  Have a table somewhere that summarizes the main characteristics of the nano-hexapod model

  - location of joints
  - size / mass of platforms, etc...

3.1 Model Definition

Make a schematic of the definition process (for instance knowing the ai, bi points + {A} and {B} allows to compute Jacobian, etc...)

- What is important for the model:
  - Inertia of plates and struts
  - Positions of joints / Orientation of struts
  - Definition of frames (for Jacobian, stiffness analysis, etc...)

Then, several things can be computed:

- Kinematics, stiffness, platform mobility, dynamics, etc...
- Joints: can be 2dof to 6dof
- Actuators: can be modelled as wanted

3.2 Nano Hexapod

Start simple:

- Perfect joints, massless actuators

Joints: perfect 2dof/3dof (+ mass-less) Actuators: APA + Encoder (mass-less)

- k = 1N/um
- Force sensor

Definition of each part + Plant with defined inputs/outputs (force sensor, relative displacement sensor, etc...)

3.3 Model Dynamics

- If all is perfect (mass-less struts, perfect joints, etc...), maybe compare analytical model with simscape model?
- Say something about the model order Model order is 12, and that we can compute modes from matrices M and K, compare with the Simscape model
- Compare with analytical formulas (see number of states)

Conclusion

- Validation of multi-body model in a simple case
- Possible to increase the model complexity when required
  - If considered 6dof joint stiffness, model order increases
  - Can have an effect on IFF performances: [2]
  - Conclusion: during the conceptual design, we consider a perfect, but will be taken into account later
  - Optimization of the Flexible joint will be performed in Chapter 2.2
- MIMO system: how to control? =¿ next section

4 Control of Stewart Platforms

MIMO control: much more complex than SISO control because of interaction. Possible to ignore interaction when good decoupling is achieved. Important to have tools to study interaction Different ways to try to decouple a MIMO plant.

Reference book: [3]

4.1 Centralized and Decentralized Control

- Explain what is centralized and decentralized:
  - linked to the sensor position relative to the actuators
  - linked to the fact that sensors and actuators pairs are "independent" or each other (related to the control architecture, not because there is no coupling)
- When can decentralized control be used and when centralized control is necessary? Study of interaction: RGA

4.2 Choice of the control space

file:///home/thomas/Cloud/research/matlab/decoupling-strategies/svd-control.org

- Jacobian matrices, CoK, CoM, control in the frame of the struts, SVD, Modal, ...
- Combined CoM and CoK =¿ Discussion of cubic architecture ? (quick, as it is going to be in detailed in chapter 2)
- Explain also the link with the setpoint: it is interesting to have the controller in the frame of the performance variables Also speak about disturbances? (and how disturbances can be mixed to different outputs due to control and interaction)
- Table that summarizes the trade-off for each strategy
- Say that in this study, we will do the control in the frame of the struts for simplicity (even though control in the cartesian frame was also tested)

4.3 Active Damping with Decentralized IFF

Guaranteed stability: [4]

> I think there is another paper about that

For decentralized control: "MIMO root locus" can be used to estimate the damping / optimal gain Poles and converging towards *transmission zeros*

How to optimize the added damping to all modes?

> Add some papers citations

Compute:

> Plant dynamics

> Root Locus

4.4 MIMO High-Authority Control - Low-Authority Control

Compute:

> compare open-loop and damped plant (outputs are the encoders)

> Implement decentralized control?

> Check stability:
>
> - Characteristic Loci: Eigenvalues of $G(j\omega)$ plotted in the complex plane
> - Generalized Nyquist Criterion: If $G(s)$ has p_0 unstable poles, then the closed-loop system with return ratio $kG(s)$ is stable if and only if the characteristic loci of $kG(s)$, taken together, encircle the point -1, p_0 times anti-clockwise, assuming there are no hidden modes

> Show some performance metric? For instance compliance?

Conclusion

Conclusion

- Configurable Stewart platform model
- Will be included in the multi-body model of the micro-station =¿ nass multi body model
- Control: complex problem, try to use simplest architecture

Bibliography

[1] H. Taghirad, *Parallel robots : mechanics and control*. Boca Raton, FL: CRC Press, 2013 (cit. on p. 4).

[2] A. Preumont, M. Horodinca, I. Romanescu, *et al.*, "A six-axis single-stage active vibration isolator based on stewart platform," *Journal of Sound and Vibration*, vol. 300, no. 3-5, pp. 644–661, 2007 (cit. on p. 9).

[3] S. Skogestad and I. Postlethwaite, *Multivariable Feedback Control: Analysis and Design - Second Edition*. John Wiley, 2007 (cit. on p. 10).

[4] A. Preumont, B. De Marneffe, and S. Krenk, "Transmission zeros in structural control with collocated multi-input/multi-output pairs," *Journal of guidance, control, and dynamics*, vol. 31, no. 2, pp. 428–432, 2008 (cit. on p. 11).