Journal Club

Vision-Assisted Control for Manipulation Using Virtual Fixtures

Alessandro Bettini, Panadda Marayong, Samuel Lang, Allison M. Okamura, and Gregory D. Hager

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Department of Computer Science, The Johns Hopkins University, USA.
Department of Mechanical Engineering, The Johns Hopkins University, USA.

Presenter: Ehsan Azimi
Overview

• Design and implementation of a vision-based system for cooperative manipulation at millimeter to micrometer scales.
• System uses computer vision as a sensor for providing a reference trajectory
• Description of both hard (unyielding) and soft (yielding) virtual fixtures
• Define the trajectory in physical space by
  ➢ Visualization of risk structures (blood vessels, ventricles)
  ➢ Tool placement and orientation
Paper Selection and Relevance

• Relevance to the aims of our project:
  Implementation of virtual fixtures
• Application in the steady hand paradigm
• Similarities in the IO interface

Cooperative manipulation with the JHU Steady-Hand Robot
Methods

• Two modes:

- Reference Target
- Reference Curve

• Virtual Fixture Implementation
  - Using fixtures as a control law in steady hand paradigm
  - Constraining virtual contact between tool and boundaries
  - Modeling the relationship between velocity and force by a linear viscous friction law
  - Defining a direction of motion for the tooltip along a Cartesian curve in space
Methods

• Isotropic Admittance
  • Equal stiffness in every direction

• Anisotropic Admittance
  • Biased toward preferred direction of motion

Tool positioning for surgical navigation system
Methods

Derivation of the control law

- Projection Matrix
  \[ D_\delta \equiv \delta (\delta' \delta)^{-1} \delta'. \]

- Force components
  \[ f_\delta \equiv D_\delta f \]
  \[ f_\tau \equiv f - f_\delta. \]
  \[ v = c(f_\delta + f_\tau). \]

- Attenuation
  \[ c_\tau \in [0, 1] \]
  \[ v = c(f_\delta + c_\tau f_\tau) \]
  \[ = c(D_\delta + c_\tau (I - D_\delta))f = G(c, c_\tau, \delta)f. \]

- Input Velocity

- Transfer function
  \[ \frac{V_i(s)}{F_i(s)} = \frac{s + (k_p + k_v s)c}{m_i s^2 + (b_i + k_v) s + k_p} \]
Experiments

Three classes of Experiments:

1. Robot operating autonomously
2. Path following task and acquiring the performance data
3. Broader set of tests to evaluate the correctness and performance of the complete class of fixtures

Results:

Summary:

- Hard virtual fixtures provided the best performance.
- 78% improvement in accuracy
- 32% enhancement in execution time

Experimental setup of the SHR using virtual fixtures to assist in path-following and positioning tasks.

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CIS Lab
Conclusion

- Basic implementation of the controller was validated by robot and human-machine cooperation experiments performed for path following and positioning tasks.
- The fine positioning method of switching from soft to hard virtual fixturing showed the best performance for approaching a target.
- Improving performance beyond the results obtained in this work presents significant challenges in robot design and control.

Future Work

- Development and evaluation of the proposed framework, both in a general context and for the specific application of microsurgery.
- Performing a comprehensive user study to quantify average performance enhancement and the learning effects involved in the approach.
- Human intent sensing by considering the larger problem of developing HMCS
Analysis and Review

Room for enhancement:

• Implementation of virtual fixtures without robot kinematics
• Needs another processing block to handle Cartesian velocities
• Combination and more general approach can be done in one processing block
• Hard to implement for sophisticated systems
• Number of subjects (8) may not be enough for drawing conclusions

Advantages:

• Clear and coherent text that is easy to follow
• Easy for implementation for cases with decoupled robot configuration
• Small study as evidence of the functionality of the method
References


Thank You!