3/15/2011
Advanced Topics in Robotics and Mechanism Synthesis Term Projects

<u>Due date</u>: 4/23/09

On 4/19/11 and 4/21/11 you will present a 10-15 minute presentation about your work. During this presentation you will focus on explaining the problem and how you mathematically modeled it and verified the theory using simulations. The focus of the presentation will be on the breadth of literature review that your present, the thoroughness of your results, and the success you achieve in conveying your lessons learned from your project to your class members.

On 4/25/11 you will be required to submit a written report including all programs that you wrote and your PowerPoint presentation.

Suggested topics

1. <u>Applications of elimination methods for direct kinematics of parallel robots.</u> Based on papers [1], [2], and chapter 2 of [3]. The aim of this work will be to verify and adapt the solution in [2] to use an eigenvalues solution as in [1] and [3]. The specific robots to be solved is the 3-PPSR parallel robot presented in [2] and also a planar 5-bar mechanism.

   The presentation should explain 1) the theoretical background on the transition from polynomial systems to eigenvalues problem. 2) the resultants method and the method you plan to use 3) explain the transition from a resultant formulation to a generalized eigenvalue problem 4) explain the generalized eigenvalue problem and how it is solved.

   The written report should also include Matlab/Mathematica/Maple simulations that show the effectiveness of the solution and all the material you included in your presentation. The simulation should also draw the robot in all real configurations of the direct kinematics solution. You should also explain how you determined the upper bounds for the number of solutions.

2. <u>Stability of grasps with soft fingers having point contact with friction.</u> Based on extending the material presented in class and also based on the works of [4-7]. The problem will be to analyze the stability of a 3-fingered hand holding a ball with three fingers. During the presentation you should: explain 1) the mathematical modeling of the problem 2) the conditions for stability assuming linearized finger model 3) the difference between linearized and non-linearized finger models 4) a kinematic model of a ball held by 3 fingers and perturbed by two angles δx and δy (I suggest using quaternions). This kinematic model should relate the movement of the contact points on the ball with the movement along the finger "spring". 5) The concept of grasp regions as defined by friction cones. 6) explain the relationship with line geometry as explained by [8].

   For the written report also include in addition to the problem formulation the following additional material: 1) write a simulation and determine the stability bounds on the preload of the "springs" modeling the fingers. 2) Calculate the determinant of the Hessian of the grasp 3) calculate the grasp forces using the grip matrix.

3. Stability of wire-actuated parallel robot with 8 wires. Evaluate the effectiveness of actuation redundancy in enlarging the workspace of the robot and in providing stiffness modulation. This work will be based on [9-11] and other works provided by the instructor. Evaluate the improvement in dexterity and global kinematic conditioning. The simulation will be based on an 8-wire actuated parallel robot to be specified by the instructor.

   In the presentation you should focus on: 1) Explain the conditions for stability of wire actuated robots. 2) explain the relationship between the number of wires and the mobility of the moving platform has 3) explain the mathematical algorithm for solving the statics and the kinematics of a general 6 DoF wire actuated robot with n wires (where n>6). 4) explain the concept of dexterity of wire actuated robots 5) explain the problem of stiffness modulation as defined in [9-11]. 6) propose and explain the algorithm for computing the reachable workspace of wire actuated robots.

   In the written report you should include all material included in the presentation and also include Matlab simulations that show 1) plot the workspace of the wire actuated robots in 3D for both the configurations with 7 and 8 wires. 2) Calculate the % increase in the work volume as the number of actuation wires is increased from 7 to 8 wires while maintaining the same maximal allowable axial strain in the wires. 3) generate condition number plots through an x-y cross section of the workspace 4) Calculate the improvement in the global conditioning index over the reachable workspace while assuming the moving platform remains parallel to the base.

4. Application of computational line geometry for singularity detection. Based on the works of [12-13], [14], [15]. The work should mainly be based on [12] and you should scan the workspace of a Stewart 6-6 robot searching for singularity and then at a given singular configuration you should perform the singular complex approximation to obtain the pitch and axis of the twist associated with the self motion of the robot and then you should explain the expected behavior of the robot. Specifically, you are required to explain the Fichter and Hunt singularities described in [16-17] by using the singular complex approximation. You will be required to write a Matlab simulation that shows the robot at a singular configuration and also presents the results obtained from the singular complex approximation.

   In the presentation you should explain the mathematical modeling of singular complex approximations including the singular value decomposition and the generalized eigenvalues problems (proof that the problem amounts to a generalized eigenvalues problem). Explain some of the results presented in the literature.

   In the written report you should summarize and include all the proofs related to the singular values approximation algorithm presented in [12-15]. You should also include the Matlab simulation and the results related to explaining the Fichter and Hunt singularities described in [16-17] by using the singular complex approximation.

5. Application of decomposition of screws to derive the inverse Jacobian and the redundancy resolution solutions for redundant robots. The method relies on constructing a basis of screws that span the null space of the robot Jacobian by using reciprocal products among twists of serial robots. Write a report based on the work of [18], and references therein. Summarize the algorithm, explain the method used for

   a. maximizing joint range availability,

   b. minimizing torque inputs,

   c. suggest your own solution on how to extend the method for obstacle avoidance while considering a fixed obstacle.

For solving a, b, c you may assume that your robot is one of the 7 DoF robots in the paper (discuss with the instructor before you start your simulation).

Submit your report with simulations and compare this method with some other methods you will learn in class.

6. Applications of Homotopy continuation methods for direct kinematics of parallel robots. Based on papers [19-23] and book chapters provided by the instructor. The aim of this work will be to test the solution of homotopy continuation starting from [24] and [22]. The specific robots to be solved is the 3-PPSR parallel robot presented in [2] and also a planar 5-bar mechanism.

The presentation should explain

a. the theoretical background on homotopy continuation
b. The predictor-corrector method
c. The effects of homogenizing the polynomial systems on the number of paths for the continuation,
d. The different types of start systems that you may choose.

The written report should also include Matlab/Mathematica/Maple simulations that show the effectiveness of the solution and all the material you included in your presentation. The simulation should also draw the robot in all real configurations of the direct kinematics solution. You should also explain how you determined the upper bounds for the number of solutions.

7. Application of kinematics methods for hand-eye calibration. Assume you have a 6 DoF Fanuc Arc-Mate robot with given kinematic model. Assume that you create an artificial model for an ideal camera that tells you the relative position of a fixed object in space with respect to a coordinate frame of the camera. Assume that the camera is fixed on the robot. Your aim is to calculate the position and orientation of the camera with respect to the robot end effector. In your solution you will create multiple "vision" points using the direct kinematics and then use the algorithm of [25]. Your presentation and report should include:

a. A detailed summary of at least 2 different methods widely used in the literature

b. Details of your simulation

c. Plots of calibration convergence

d. Assume now that all your "camera" points have a random noise of a maximal norm of 1 mm in position and 1 degree in orientation. Run your code again and see what your calibration results be as a function of the number of points used for calibration.

8. Application of global optimization methods for redundancy resolution. Based on [26-27], summarize the algorithm. Explain the relationship between the algorithm and variational calculus. Simulate the same robot as in [26] for optimizing obstacle avoidance and joint rates. In your presentation explain the difference between this method and the methods learned in class. Explain the theoretical background behind the method, and present your simulations.

9. Static balancing of parallel mechanisms. Based on [28-30], summarize the methods available for static balancing of parallel robots. Simulate a robot with at least 3DoF with static balancing. In your presentation

you should also evaluate the robustness of static balancing to uncertainty in mass properties. Simulate the required joint torques with and without static balancing. Simulate the statics ellipsoids with and without static balancing at chosen 24 poses inside the workspace.

10. Variable geometry mechanism synthesis. Review at least 3 papers on synthesis methods of variable geometry four-bar mechanisms for motion and path generation. Simulate a design optimization of a robot that uses a variable geometry mechanism as part of its kinematic chains and present a synthesis strategy. Plot the structural error introduced by the variable geometry mechanism.

11. Mechanism synthesis using dual quaternions. Based on [31-34] review synthesis methods of serial kinematic chains for spatial motion generation. Simulate a case study with at least 4 DoF. Simulate the design optimization of the kinematic chain and the structural error along a desired motion path.

13. Algorithms for quaternion and dual-quaternion resolved rates path planning and control for serial robots. Review works on quaternions and dual quaternions for resolved rates motion control of serial robots. Simulate the Puma 560 using the resolved rates algorithm that relies on quaternion formulation.

[1] M. Ghazvini, "Reducing the Inverse Kinematics of Manipulators to the Solution of a Generalized Eigenproblem," in *Computational Kinematics*, J. Angeles, Ed., 1993, pp. 15-26.

[2] R. Ben-Horin, "Kinematics, Dynamics and construction of a planarly actuated parallel robot," in *Mechanical Engineering*. vol. Ph.D. Haifa: Technion, 1999.

[3] N. Simaan, "Task-Based Design and Synthesis of Variable Geometry Parallel Robots," in *Mechanical Engineering*. vol. Ph.D. Haifa: Technion - Israel Institute of Technology, 2002.

[4] V. Brodsky and M. Shoham, "On the Modeling of Grasps with a Multi-Fingered Hand," in *Computational Kinematics*, 1995, pp. 271-280.

[5] M. Mason and K. Salisbury, *Robot Hands and the Mechanics of Manipulation (Artificial Intelligence)* The MIT Press, 1985.

[6] J. Kerr and B. Roth, "Analysis of Multifingered Hands," *International Journal of Robotics Research*, vol. 4, pp. 3-17, 1986.

[7] ______________, "____________," *Transactions of the ASME. Journal of Mechanisms, Transmissions, and Automation in Design*, vol. 105, pp. 37-41 1983.

[8] J. Ponce, S. Sullivan, A. Sudsang, J.-D. Boissonnat, and J.-P. Merlet, "Computing four-finger equilibrium and force-closure grasps of polyhedral objects," *International Journal of Robotics Research*, vol. 16, pp. 11-35, 1997.

[9] N. Simaan and M. Shoham, "Geometric Interpretation of the Derivatives of parallel Robot's Jacobian Matrix with Application to Stiffness Control," *ASME J. of Mechanical Design*, vol. 125, pp. 33-41, 2003.

[10] N. Simaan and M. Shoham, "Stiffness Synthesis of a Variable Geometry Six Degrees-of-Freedom Double Planar Parallel Robot " *International Journal of Robotics Research*, vol. 22, pp. 757 - 775, 2003.

[11] N. Simaan and M. Shoham, "Stiffness Synthesis of a Variable Geometry Planar Robot " in *Advances in Robot Kinematics: Theory and Applications*, 2002, pp. 463-472.

[12] **H. Pottmann and M. Peternell, "Aproximation in Line Space- Applications in Robot KInematics and Surface Reconstruction," in *Recent Advances in Robot Kinematics (ARK)*, 1998.**
[13] **N. Simaan and M. Shoham, "Singularity Analysis of a Class of Composite Serial In-Parallel Robots," *IEEE Transactions on Robotics and Automation,* vol. 17, pp. 301-311, 2001.**
[14] **A. Wolf, "Investigation of Singularities and Self-Motions of the 3-UPU Robot," in *Advances in Robot Kinematics*, J. Lenarcic and F. Thomas, Eds.: Kluwer Academic Publishers, 2002, pp. 165-174.**
[15] **H. Pottmann, M. Peternell, and B. Ravani, "An Introduction to Line Geometry With Applications," *Computer-Aided Design,* vol. 31, pp. 13-16, 1999.**
[16] **E. F. Fichter, "STEWART PLATFORM-BASED MANIPULATOR: GENERAL THEORY AND PRACTICAL CONSTRUCTION," *International Journal of Robotics Research,* vol. 5, p. 157, 1986.**
[17] **K. H. Hunt, "STRUCTURAL KINEMATICS OF IN-PARALLEL-ACTUATED ROBOT-ARMS," *Journal of Mechanisms, Transmissions, and Automation in Design,* vol. 105, p. 705, 1983.**
[18] **R. P. Pohdhorodeski, A. A. Goldenberg, and R. G. Fenton, "A Null-Space Solution of the Inverse Kinematics of Redundant Manipulators Based on a Decomposition of Screws," *Journal of Mechanical Design,* vol. 115, pp. 530-539, 1993.**
[19] **P. Cummings, "Continuation Methods for Qualitative Analysis of Aircraft Dynamics," NASA2004.**
[20] **F. Freudenstein and B. Roth, "Numerical solution of systems of nonlinear equations," *Association for Computing Machinery -- Journal,* vol. 10, pp. 550-556, 1963.**
[21] **M. Raghavan and B. Roth, "Solving polynomial systems for the kinematic analysis and synthesis of mechanisms and robot manipulators," *Journal of Mechanical Design, Transactions of the ASME,* vol. 117B, pp. 71-79, 1995.**
[22] **L.-W. Tsai, "Appendix A: Continuation Method," in *Robot Analysis - The Mechanics of serial and parallel manipulators*, pp. 457-471.**
[23] **C. W. Wampler, A. P. Morgan, and A. J. Sommese, "Numerical Continuation Methods for Solving Polynomial Systems Arising in Kinematics," *Journal of Mechanical Design, Transactions of the ASME,* vol. 112, pp. 59-68, 1990.**
[24] **E. L. Allgower and K. Georg, *Numerical Continuation Methods An Introduction*: Springer-Verlag, 1980.**
[25] **J. Angeles, G. Soucy, and F. P. Ferrie, "The online Solution of the Hand-Eye Problem," *IEEE Transactions on Robotics and Automation,* vol. 16, pp. 720-731, 2000.**
[26] **Y. Nakamura and H. Hanafusa, "OPTIMAL REDUNDANCY CONTROL OF ROBOT MANIPULATORS," *International Journal of Robotics Research,* vol. 6, p. 32, 1987.**
[27] **Y. Nakamura, *Advanced Robotics Redundancy and Optimization*: Addison Esley Publishing Company, 1991.**
[28] **C. M. Gosselin, "Static balancing of spherical 3-DoF parallel mechanisms and manipulators," *International Journal of Robotics Research,* vol. 18, pp. 819-29, 1999.**
[29] **T. Laliberte, C. M. Gosselin, and M. Jean, "Static balancing of 3-DOF planar parallel mechanisms," *IEEE/ASME Transactions on Mechatronics,* vol. 4, pp. 363-77, 1999.**
[30] **A. Russo, R. Sinatra, and F. Xi, "Static balancing of parallel robots," *Mechanism and Machine Theory,* vol. 40, pp. 191-202, 2005.**
[31] **A. Perez and J. M. McCarthy, "Dimensional synthesis of Bennett linkages," *Journal of Mechanical Design, Transactions of the ASME,* vol. 125, pp. 98-104, 2003.**

[32] A. Perez and J. M. McCarthy, "Dual quaternion synthesis of constrained robotic systems," *Journal of Mechanical Design, Transactions of the ASME*, vol. 126, pp. 425-435, 2004.

[33] A. Perez and J. M. McCarthy, "Clifford algebra exponentials and planar linkage synthesis equations," *Journal of Mechanical Design, Transactions of the ASME*, vol. 127, pp. 931-940, 2005.

[34] A. Perez-Gracia and J. M. McCarthy, "Kinematic synthesis of spatial serial chains using Clifford algebra exponentials," *Proceedings of the Institution of Mechanical Engineers, Part C (Journal of Mechanical Engineering Science)*, vol. 220, pp. 953-68, 2006.