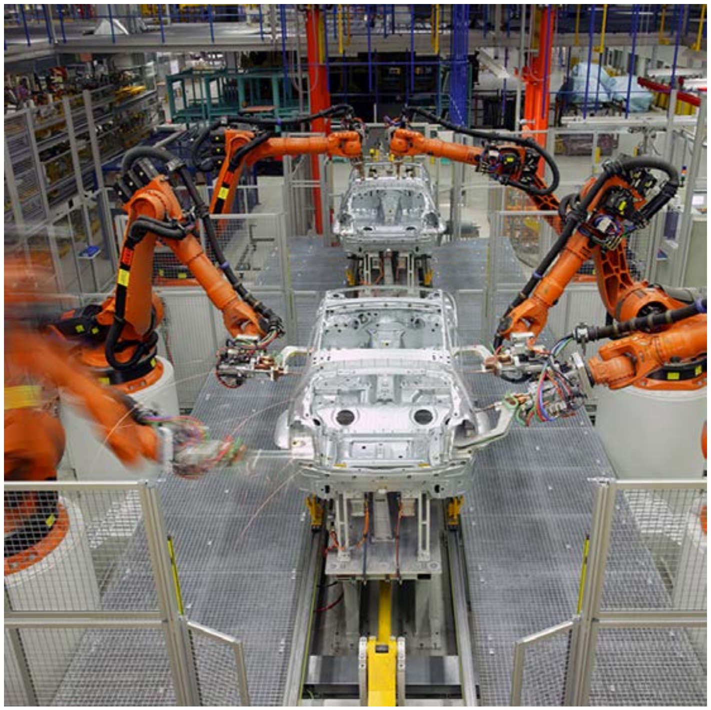
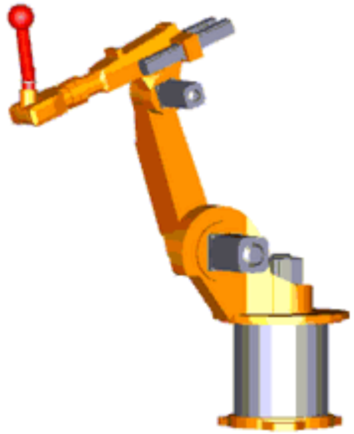
MSE 429 – Advanced Kinematics for Robotic Systems

Individual Course Project:

Design and analyze a 6-DOF serial robot manipulator that will be used to complete a particular task.



(Kuka Systems, Wikipedia 2016)



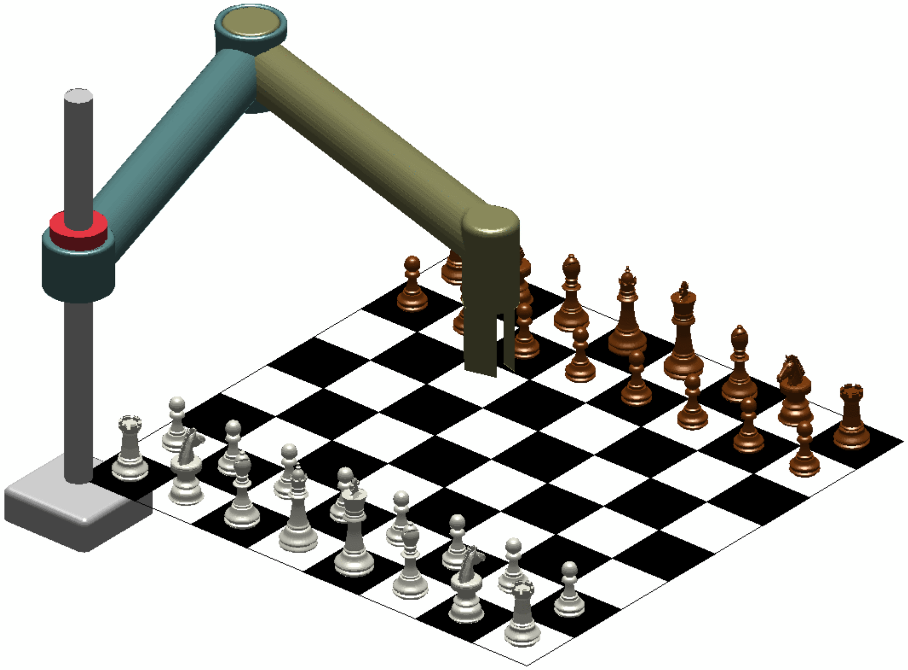
(Claytex, 2016)

MSE 429 – Advanced Kinematics for Robotic Systems

Individual Course Project

Students will analyze the kinematics and generate the trajectory of the designed 6-DOF manipulator to complete a chosen task.

Students will transfer CAD designs of each part into Matlab and manipulate the position/orientation of each link throughout the trajectory. Please use codes provided.



MSE 429 – Advanced Kinematics for Robotic Systems

Individual Project Submissions:

There are four submissions for this project

October 5 – Introduction, Design Specifications and Forward Kinematics

October 19 – Inverse Kinematics, Workspace Analysis and Kinematic Reconstruction.

November 2 – Path Generation, Trajectory Generation and Animation

December 7 – Jacobians, Velocity & Static Force Analysis, Dynamics and Simulation.

During week 2 of the course, students will receive the kinematic layout that will be used for this project.

MSE 429 – Advanced Kinematics for Robotic Systems

Project Definition and Design:

Define a particular application, potential projects may be:

- Industrial applications: painting, welding, metal cutting, assembling, material handling, etc.
- Other applications: Medical, household (e.g., clothes folding), entertainment (e.g. robot that drives a movie character), etc.
- Creative applications

Design in SolidWorks a 6-DOF model following the kinematic layout provided. Make sure to generate each link as an individual part in CAD.

MSE 429 – Advanced Kinematics for Robotic Systems

Report I Guideline:

Abstract or Executive Summary

Introduction

Describe the application (e.g. neurosurgery) and the use or potential use of a robotic manipulator. Report any commercial/research manipulators used for the chosen (or similar) application. (2-3 pages)

Design a 6-DOF Spatial Manipulator

Design a simple CAD model of the 6-DOF manipulator using the kinematic layout provided. You may change the length of the links (greater than zero). Also, design the end-effector to be used in the application.

MSE 429 – Advanced Kinematics for Robotic Systems

Report I Guideline (cont'ed):

Design Specifications

Specify joint limits. For example, a revolute joint rotates between 180 and 300 degrees, or a prismatic joint moves from d_{min} to d_{max}.

Specify the dimensions of the links. Do not eliminate links from the provided layout.

Specify the materials and masses of the links.

Select commercial actuators that can be used in your manipulator.

MSE 429 – Advanced Kinematics for Robotic Systems

Report I Guideline (cont'ed):

Forward Kinematics

Illustrate the link attachment on the manipulator, this includes frames {0}, {1}, …, {6}, {e.e.}

Determine the Denavit and Hartenberg Parameters

Solve the Forward Kinematics, make sure to determine ${}^{0}_{3}\mathbf{T}$ and ${}^{3}_{6}\mathbf{T}$ before finding ${}^{0}_{ee}\mathbf{T}$.

Conclusions

References

MSE 429 – Advanced Kinematics for Robotic Systems

Report II Guideline:

Abstract or Executive Summary

Inverse Kinematics

Solve the Inverse Kinematics of the manipulator, both symbolically (based on a symbolic homogeneous transform ${}^{0}_{ee}\mathbf{T}_s$) and numerically (based on a desired numerical homogeneous transform ${}^{0}_{ee}\mathbf{T}_n$ that you choose).

Workspace Analysis

Determine the reachable workspace of the wrist, i.e. use only ${}^{0}_{w}\mathbf{T}$, which includes the first three joints. Use the proposed joint limits. Use the file provided.

MSE 429 – Advanced Kinematics for Robotic Systems

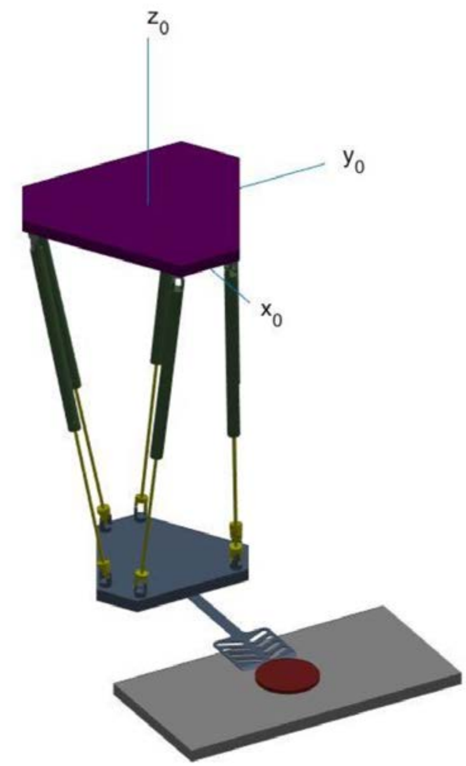
Report II Guideline (cont'ed):

Kinematic Reconstruction

Export the SolidWork links into Matlab

In Matlab, input the desired numerical homogeneous transform ${}_{ee}^{0}\mathbf{T}_{n}$ and solve for the joint displacements

Reconstruct the posture of the manipulator.



Courtesy of Bowen Liu, Brent Gatlabayan, and Terry Zhu (2018)

Conclusions

References

Include all required Matlab Files as a compressed zip/rar file in the electronic submission

MSE 429 – Advanced Kinematics for Robotic Systems

Report III Guideline:

Abstract or Executive Summary

Path Generation

Establish at least 15-20 postures of the end-effector that will define the desired path of the task, i.e., the position (x, y, z) and the Euler / Fixed Angles (α, β, γ).

Trajectory Generation

Generate the trajectory using the provided scheme: match velocities/accelerations.

Plot the Joint Displacements, Joint Velocities and Joint Accelerations throughout the Trajectory.

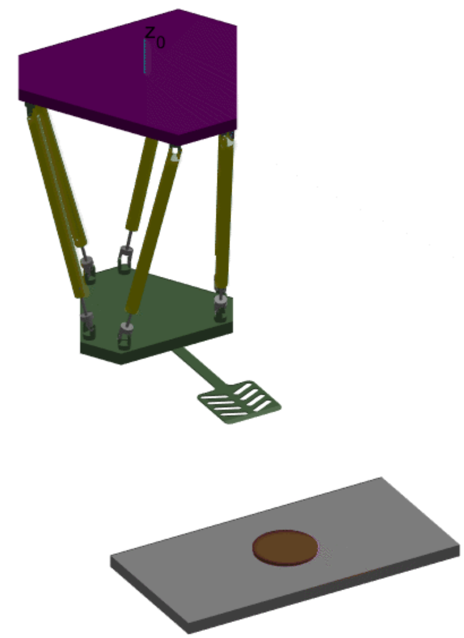
MSE 429 – Advanced Kinematics for Robotic Systems

Report III Guideline (cont'ed):

Trajectory Generation (cont'ed)

Plot the end-effector's motion in 3D, use function `comet3(Xee,Yee,Zee)`

Emulate the manipulator motion throughout the trajectory in 3D (Employ the template given on Canvas as the base for your code).



Courtesy of Bowen Liu, Brent Gatlabayan, and Terry Zhu (2018)

Conclusions

References

Include all required Matlab Files as a compressed zip/rar file in the electronic submission

SFU

MSE 429 – Advanced Kinematics for Robotic Systems

Report IV Guideline:

Abstract or Executive Summary

Jacobian

Determine the Jacobian of the Manipulator $({}^{ref}\mathbf{J}_w)$

Determine the Singular Configurations

Solve for $\mathbf{T}_V$ and the Forward/Inverse velocity problem

Solve for $\mathbf{T}_F$ and the Inverse Static Force problem

Link Modelling

Model Links, i.e., determine the Inertia Tensors of the links with respect to their centre of mass.

MSE 429 – Advanced Kinematics for Robotic Systems

Report IV Guideline (cont'ed):

Dynamics

~~Solve symbolically the dynamic equation of the *main arm* (from base to wrist that is only actuated by the first three joints) using both~~

- ~~Newton-Euler Recursive Formulation~~
- ~~Lagrangian Formulations~~

~~*Do not do it by hand, use Matlab's symbolic computation*~~.

Code the Newton-Euler Recursive Formulation for numerical computation of the 6-DOF manipulator.

MSE 429 – Advanced Kinematics for Robotic Systems

Report IV Guideline (cont'ed):

Simulation

Plot the Torque/Forces required by each joint during the Trajectory (Report III) using the Newton-Euler Recursive Formulation.

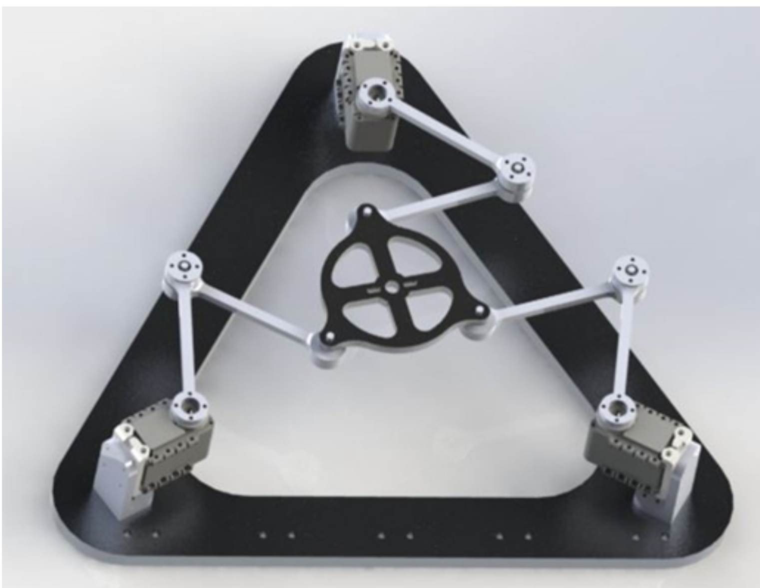
Conclusions

Include all required Matlab Files as a compressed zip/rar file in the electronic submission

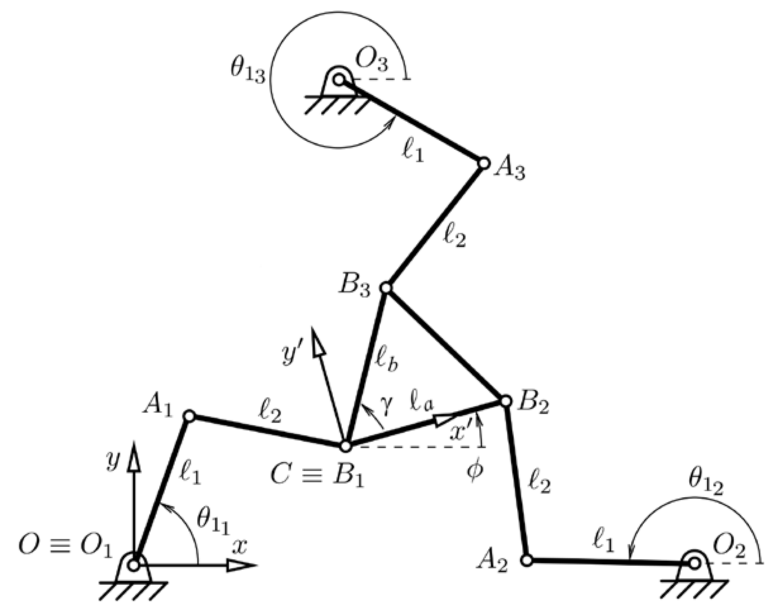
MSE 429 – Advanced Kinematics for Robotic Systems

Team Course Project:

Design and analyze a 3-RRR planar parallel manipulator that will be used to complete a particular task (your choice).



3-RRR Parallel Manipulator, Taarlab Example Don Bosco University (video)



Courtesy of Bonev (2001)

MSE 429 – Advanced Kinematics for Robotic Systems

Report Guideline (due November 16):

Abstract or Executive Summary

Introduction

Describe a potential application for the 3-R̲RR Planar Parallel Manipulator. (1 page)

Design a 3-DOF PPM

Design a simple CAD model that represent the links of the manipulator. Define the length of the links and the geometry of the fixed and mobile platforms.

Design a simple representation of the 3-RRR planar parallel manipulator in Matlab (no need to export CAD parts, use lines for simplicity)

MSE 429 – Advanced Kinematics for Robotic Systems

Report Guideline (cont'ed):

Kinematics

Solve the Inverse Kinematics Problem. For a particular position and orientation of the mobile platform $(x, y, \phi)^*$, determine and plot all the assembly modes.

Solve the Forward Kinematics Problem. For a particular set of joint displacements $(\theta_{1_1}, \theta_{1_2}, \theta_{1_3})^*$, determine and plot all the postures of the mechanism (select a set of joint displacement that yield at least four solutions).

Create a simple trajectory, plot joint displacements.

* The selection of either (x, y, ϕ) or $(\theta_{1_1}, \theta_{1_2}, \theta_{1_3})$ is up to you. Try different values.

MSE 429 – Advanced Kinematics for Robotic Systems

Report Guideline (cont'ed):

Jacobians

Determine the Jacobians of the manipulator ($\boldsymbol{J}_x$ and $\boldsymbol{J}_q$)

Evaluate the inverse of the condition number ($1/\kappa$) to 'estimate' the proximity to a singular configuration.

Solve the Forward Velocity Problem (velocity of centre of mobile platform as a function of the joint rates)

Solve the Forward Static Problem (determine the required torques based on an external force (f_x, f_y) and moment (m_z) acting at the end-effector.

Conclusions & References

Include all required Matlab Files in a compressed file

MSE 894 – Advanced Kinematics for Robotic Systems

For Graduate Students (MASc and PhD):

Research Project:

- Graduate students will work on the kinematics of a parallel manipulator (e.g., Delta, Gough-Stewart, etc.) or a non-spherical wristed 6-DOF serial manipulator
- Each student will also include a research component in the report, e.g., Forward Kinematics, Dynamics, Control, multiple manipulators, etc.

Syllabus:

Additional Lectures (potential dates)

- Week 3: Kinematics of Non-Spherical Wrists
- Week 5: Kinematics of Gough-Stewart Platform
- Week 12: Screw Theory