Computer-Aided Design of Shapes and Motions
MEC 572, Spring 2020

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Lecture:	FREY HALL 309, Monday 1-3:50 PM
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Course Description

This class would focus on presenting a unifying treatment for the design of geometric shapes, such as curves and surfaces as well as motions of entities, such as lines, planes, and rigid bodies. It will be shown that in the language of projective geometry, one can design curves, surface, and motions utilizing same algorithms and similar data structures. In the process, the students will learn the theory of NURBS (Non-Uniform Rational B-splines), which is the standard representation in existing CAD/CAM system and extend it to the space of rigid body displacements for the design of motions. By the end of the class, students will be able to devise new methods for motion design problem and implement shape and motion design algorithms in graphical computer programs.

Course Purpose

MEC572 is a graduate level class in the Mechanical Engineering department accessible to both MS and PhD students. In addition, undergraduate seniors in the Five-year BS/MS program are also allowed to enroll in the class.

MEC572 is one of the classes offered as part of the *Design and Manufacturing* specialty, MS focus area, and PhD minor requirements. Students interested in pursuing thesis or dissertation research with a faculty in this or related area are strongly advised to take this class.

Although, MEC572 has no formal pre-requisites, the students taking this class are expected to know Linear Algebra, Differential Calculus, and Computer Programming. In this class, students learn the theory of NURBS (Non-Uniform Rational B-splines) geometry, which is the standard representation in existing CAD/CAM system, algorithms for designing curves and surfaces, and extend them to the space of rigid body displacements for the design of motions. By the end of the class, the students will have acquired skills in developing algorithms for shape and motion design problems and will be writing computer programs using 3D graphics API, such as OpenGL with low-cost and simple user interfaces. This will help them develop engineering software systems, while research-oriented students will use the knowledge acquired in this class to further their dissertation research in CAD/CAM, theoretical and Computational Kinematics, and in general, Machine design areas.

Course Learning Outcomes (CLO)

Upon completion of this course, students will be able to:

1. Explain difference between vectors and points from a representation perspective
2. Explain why Affine and Projective spaces provide a better setting for doing geometric modeling
3. Model geometric transformations using Linear, Affine, and Projective Maps and implement them in Computer Programs
4. Calculate points and normal on Bezier, B-spline, NURBS, and subdivision Curves and Surfaces using design algorithms
5. Implement Bezier, B-spline, and Rational Curves and Surface design algorithms in graphical computer programs
6. Apply rigid body kinematics to the NURBS and subdivision geometry synthesis algorithm to design rational motions
7. Implement motion algorithms in graphical computer programs with a light-weight user interface
8. Implement algorithms for computing distance between spatial displacements in Computer Programs
9. Devise new motion generation, refinement, manipulation, and control algorithms by bringing together Geometric Modeling of shapes with rigid body kinematics and implementing it into Computer Programs
10. Determine a unified Representation of Kinematic Constraints for Linkages and apply Exact and Approximate Synthesis of Planar Four-Bar Linkages with Revolute and Prismatic Joints

Course Learning Outcomes Assessment

The CLOs will be assessed by HW, Term paper, in-class feedback, and final project. Information about HWs, and requirements for term paper and project will be posted later on the class web site.

Course Topics

The following is a tentative list of topics that I plan to cover. Some topics and their order may be changed at the instructor's discretion on account of time constraints or interest shown by the class.

1: Geometry of Fundamental Constructs

- 1.1 Points and Vectors
- 1.2 Affine coordinates and combinations
- 1.3 Affine and Linear Transformation
- 1.4 Homogeneous Coordinates: Points, Lines, and Planes
- 1.5 Projective Duality
- 1.6 Multivector Algebra

2: Bezier and B-spline Representation and Modeling

- 2.1 Implicit and Parametric Forms

2.2 Bezier representation
2.3 B-spline representation
2.4 Rational Bezier and B-spline representation
2.5 Beyond NURBS representation

3: Geometry of Rigid Body Displacements

3.1 Displacement Representation and Kinematic Mapping: Quaternions, Dual Quaternions, and Bi-quaternions
3.2 Image Space of Planar, Spherical, and Spatial Kinematics

4: Geometry of Free-form Motions

4.1 One- and Two-Parameter Rational Motions
4.2 Control Position Modification
4.3 Dual Weights
4.4 Constraint-Based Motion Modification

5: Geometric-Kinematic Algorithms for Motion Generation of Linkages

5.1 Distance metric for displacements
5.2 Introduction to Mechanism Synthesis; Unified Representation of Kinematic Constraints for Linkages
5.3 Exact and Approximate Synthesis of Planar Four-Bar Linkages with Revolute and Prismatic Joints

References:

1. Curves and Surfaces for CAGD: A Practical Guide (Fifth Ed.) by Gerald Farin, Academic Press
2. Curves and Surfaces in Geometric Modeling: Theory and Algorithms by Jean Gallier, Morgan Kaufmann, 2000
3. The NURBS Book (Monographs in Visual Communication) by Piegl and Tiller, Springer, 1996

Grading: Homework 50%, Project and Term Paper 50%

Homework: Homework will be either assigned in the class or posted at blackboard. You can access Blackboard at: http://blackboard.sunysb.edu. If you have never used Stony Brook's Blackboard system, your initial password is your SOLAR ID# and your username is the same as your Stony Brook (sparky) username, which is generally your first initial and the first 7 letters of your last name. For help or more information see: https://it.stonybrook.edu/services/tlt-student-help-desk For problems logging in, go to the helpdesk in the Main Library SINC Site or the Union SINC Site, you can also call: 631-632-9602 or e-mail: helpme@ic.sunysb.edu

Classroom Expectations and Information

1. **Communication**
   Outside the class, I use email and blackboard exclusively to communicate with you, therefore please make sure that your email id is a current one on the blackboard system. http://blackboard.stonybrook.edu

2. **Pre-requisites**
   This class requires that you must have taken a course in Linear Algebra and Differential Calculus and have programming experience. For programming assignments, I will provide skeleton code in hybrid C and C++. Although I prefer code in C or C++, you are free to use any language (C#, Java, C++, C, Fortran, php) for writing your programs. If you are not familiar with a programming language, you will find it difficult to complete programming based HWs. In some assignments, you will also use OpenGL 3D graphics library for drawing shapes. I do not expect you to write very sophisticated or high-performance code but it should be readable and easy to understand.

3. **Development Environment**
   Please follow the instructions posted on Bb in the set-up document to download Visual Studio and other tools needed to compile programs that I will provide to you.

4. **Laptops, smartphones, tablets**
   Electronic devices should only be used during class for class purposes (e.g. taking notes, research, Blackboard, eTextbook, etc). Facebook, email, texting, or accessing other forms of media that are not part of the seminar should wait until after class.

5. **Instructor email and appointments**
   I am accessible via email and will try to respond to your emails as soon as I can. However, I may not check email continuously throughout the day so please do not wait until the last minute to email concerns or questions – typically any question that requires a more complicated response or thoughtful conversation should be asked in person (e.g. grading concerns; further explanation of readings, etc). When sending emails, please include the class/section in the subject line and your full name somewhere in the body of the email. Students are encouraged to make an appointment with me or see me during my office hours on Wednesdays from 2-5 pm.

6. **Student Accessibility Support Center Statement**
   If you have a physical, psychological, medical or learning disability that may impact your course work, please contact Student Accessibility Support Center, ECC (Educational Communications Center) Building, Room 128, (631)632-6748. They will determine with you what accommodations, if any, are necessary and appropriate. All information and documentation is confidential.
   Students who require assistance during emergency evacuation are encouraged to discuss their needs with their professors and Student Accessibility Support Center. For procedures and information go to the following website: http://www.stonybrook.edu/ehs/fire/disabilities.

7. **Academic Integrity**
   Each student must pursue his or her academic goals honestly and be personally

accountable for all submitted work. Representing another person's work as your own is always wrong. Faculty is required to report any suspected instances of academic dishonesty to the Academic Judiciary. Faculty in the Health Sciences Center (School of Health Technology & Management, Nursing, Social Welfare, Dental Medicine) and School of Medicine are required to follow their school-specific procedures. For more comprehensive information on academic integrity, including categories of academic dishonesty please refer to the academic judiciary website at http://www.stonybrook.edu/commcms/academic_integrity/index.html

8. **Critical Incident Management**
   Stony Brook University expects students to respect the rights, privileges, and property of other people. Faculty are required to report to the Office of University Community Standards any disruptive behavior that interrupts their ability to teach, compromises the safety of the learning environment, or inhibits students' ability to learn. Faculty in the HSC Schools and the School of Medicine are required to follow their school-specific procedures. Further information about most academic matters can be found in the Undergraduate Bulletin, the Undergraduate Class Schedule, and the Faculty-Employee Handbook.