ME 57400 – Additive Manufacturing (3 credits)
Department of Mechanical and Energy Engineering
Indiana University-Purdue University Indianapolis

Prerequisites

Graduate standing or instructor's consent. For IUPUI students this is:

ME 26200: Engineering Design, Ethics and Entrepreneurship
ME 34400: Introduction to Engineering Materials, or equivalent

Instructors

Dr. Andres Tovar, Associate Professor (Design, 9 weeks)
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Dr. Hazim El-Mounayri, Associate Professor (Manufacturing, 3 weeks)
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Dr. Jing Zhang, Assistant Professor (Materials, 3 weeks)
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Teaching Assistant

Homero Valladares Guerra, Ph.D. student
Department of Mechanical and Energy Engineering, IUPUI
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References

Textbook

Gibson, I. and Rosen, D. and Stucker, B., "Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing." Springer New York, 2014, ISBN: 9781493921126.

Other references

Andreas Gebhardt, “Understanding Additive Manufacturing. Rapid Prototyping – Rapid Tooling – Rapid Manufacturing.” Carl Hanser Verlag, Munich 2012
ISBN: 978-3-446-42552-1

Hod Lipson, Melba Kurman, “Fabricated: The New World of 3D Printing” Wiley, 2013
ISBN: 978-1-118-35063-8

Joan Horvath,“Mastering 3D Printing” Technology in Action, 2014
ISBN-13: 978-1484200261

Justification of Course Need

Additive Manufacturing (AM) is an important asset for fabricating complex components directly from a CAD file, avoiding tooling and increasing efficiency. AM is also becoming increasingly popular in educational and home use, democratizing product development. The unique capabilities of AM-enabled design have several characteristics:

1. Shape complexity: Any shape can be made.
2. Hierarchical complexity: Multi-scale structures can be made.
3. Material complexity: A different material can be made at every point, line, or layer.
4. Functional complexity: Fully functional assemblies and mechanisms can be made.

AM is used to manufacture prototypes, tools, patterns, and final products. This technology has penetrated every major industry -- automotive, aerospace, defense, medical, dental, and consumer products. Learning about AM is necessary for every Mechanical Engineer.

Justification that course will be taught at a graduate level

Justifications for the course to be taught at a graduate level include the following: The course topics are current. While AM started in the 1980s, theoretical aspects were not researched until recently. Very few textbooks in AM are currently available; thus, the field provides vast opportunities for these graduate students. The reference book used contains related papers on AM modeling that are appropriate for a graduate course. Finally, the course is available as a technical elective to undergraduate students who are expected to rise to the level of graduate work and are motivated to be assessed in the same manner as graduate students..

Description

During this course, students evaluate the engineering aspects and physical principles of available AM technologies (binder and material jetting, sheet lamination, vat photopolymerization, directed energy deposition, powder bed fusion, and material extrusion technologies) as well as these technologies’ most relevant applications and criteria in order to successfully select the AM technology that is best suited for the embodiment of a particular design (material compatibility, interface issues, strength requirements).

The topics of this course are grouped into three modules: (1) AM Technologies (2) Design for AM (3) AM Process Planning. During the first module (50% of the course), the historical development of AM is examined and then the underlying physical principles of current AM technologies are evaluated. The second module (25% of the course) focuses on investigating the mathematical principles and technical aspects of design optimization methods for AM (including topology optimization). The third module (25% of the course) incorporates product evaluation (mechanical properties and dimensional accuracy), process optimization, and applications.

Students taking this course will create original products using CAD/CAE systems and topology optimization tools. Students will hone skills on image post-processing, segmentation, vectorization, and generation of STL files. Students also will execute tasks using several 3D printers and manipulate different AM technologies including material extrusion, vat photopolymerization, and powder-bed fusion. They will also have the opportunity to visit local industries and interact with AM practitioners. This course is collaboratively taught by specialists in the areas of manufacturing, design, and materials.

Learning Outcomes and Evaluation

After completion of this course, the students should be able to:

1. Apply knowledge of manufacturing, design, and material science and engineering in 3D printing and understand why it has become one of the most important manufacturing technology for product development and innovation. Evaluation: Homework, Exam, In-class exercises.
2. Demonstrate comprehensive knowledge of the underlying thermo-mechanical and other physical principles in current AM technologies. Evaluation: Homework, Exam, In-class exercises.
3. Assemble and operate selected 3D printers and then evaluate and improve their performance. Evaluation: course project.
4. Design and fabricate 3D printed free-form components that are digitally generated understanding the constraints of current AM technologies. Evaluation: homework and midterm project.
5. Evaluate the capabilities and limitations of AM technologies and their application to engineering product design. Evaluation: homework and midterm project.

Grading

Items	***Percentage***
Quizzes and in-class assignments	20%
Homework	25%

Exam 1	15%
Exam 2	15%
Final project	25%
Total	**100%**

Grade	A+	A	A-	B+	B	B-	C+	C	C-	F
Minimum%	97	93	90	87	83	80	77	73	70	0

Course policies

1. Neatness and clarity count in homework problems. Do not hand in pages ripped out of spiral notebooks. Make sure computer printouts are no larger than letter sized paper.
2. All homework must represent your own work. Consultation with other members of the class is allowed, but all work must represent an individual effort.
3. If you should arrive late, please be courteous to your fellow students by entering the room quietly, and quickly taking a seat.
4. It is highly recommended that you attend all classes. In either case, you are responsible for turning in assignments on time and making up any work that you missed.

Course schedule

The schedule shows the topics to be covered in each class meeting. You are expected to come to class prepared by studying the assigned material before the lecture. This allows for a more effective use of the class time. Note that the assigned material helps you establish some useful/relevant background on the subject but this doesn't necessarily mean that the exact same material will be covered during the lecture.

Assignments: homework, quizzes and in-class assignments

Homework and other assignments will be submitted via Canvas. If you are unable to attend a class, you may attach a note to your homework and submit it in advance. Late homework and other assignments will not be accepted under normal circumstances. Test problems will be of a difficulty level similar to that of homework problems. You are strongly advised to study the example solutions in the textbook/handouts and problems solved in class as well as work out additional problems from the textbook /handouts. All homework must represent your own work. Consultation with other members of the class is allowed, but all work must represent an individual effort. Academic dishonesty is subject to punishment according to the relevant regulations. Cheating is cause for severe punishment.

Problem solution format

Homework and test answers must be on engineering paper or letter size white paper and in proper format. Homework solutions carried out using computer software may be submitted as a computer print-out. Neatness and a proper format are considered while grading.

Canvas usage

Canvas shall be used, but not as a comprehensive tool. Basic usage includes communicating with students, making course material (such as assignments, solutions, lecture notes, and handouts)

Cheating and plagiarism

Academic misconduct is subject to university punishment. Academic misconduct includes, but is not limited to, the following: 1) Cheating; 2) Fabrication; 3) Plagiarism; 4) Interference; 5) Violation of course rules; and 6) Facilitating Academic Dishonesty. Students needed to check IUPUI Student Misconduct policy section of the IUPUI Student Code of Conduct (http://life.iupui.edu/dos/code.htm), if they are not already familiar with it.

Additional policies

If you should arrive late, please be courteous to your fellow students by entering the room quietly, and quickly taking a seat. It is highly recommended that you attend all classes. In either case, you are responsible for turning in assignments on time and making up any work that you missed.

Additional help

During the semester, if you find that life stressors are interfering with your academic or personal success, consider contacting Counseling and Psychological Services (CAPS). All IUPUI students are eligible for counseling services at minimal fees. CAPS also performs evaluations for learning disorders and ADHD; fees are charged for testing. CAPS is located in UN418 and can be contacted by phone (317-274-2548). For more information, see the CAPS web-site at: http://life.iupui.edu/caps/

Course outline

The course is divided in three modules: AM technology, Design for AM, and AM process evaluation and future directions.

- AM technologies
- Design for AM
- AM process planning and applications

Lectures Weekly Schedule
(Subject to changes)

Week	Content	Instructor
1	Introduction and Basic Principles (Ch. 1) Development of AM Technology (Ch. 2)	Tovar
2	Generalized AM Process Chain (Ch. 3)	Tovar
3	Vat Photopolymerization Process (Ch. 4)	Tovar
4	Powder Bed Fusion Processes (Ch. 5)	Zhang
5	Extrusion-Based Systems (Ch. 6)	Zhang
6	Sheet Lamination Process (Ch. 9)	Zhang
7	Material Jetting (Ch. 5) Exam 1	Tovar
8	Binder Jetting (Ch. 6) Directed Energy Deposition (Ch. 10)	Tovar
9	Direct Write Technologies (Ch. 11)	Tovar
10	The Impact of Low-Cost AM Systems (Ch. 12) Guidelines for Process Selectin (Ch. 13)	El-Mounayri
11	Post-processing (Ch. 14)	El-Mounayri
12	Software Issues for AM (Ch. 15) Direct Digital Manufacturing (Ch. 16)	El-Mounayri
13	Design for AM (part 1) (Ch. 17) Exam 2	Tovar
14	Design for AM (part 2) (Ch. 17)	Tovar
15	Rapid Tooling (Ch. 18) Applications for AM (Ch. 19)	Tovar

Project and reports

Week	Content	Instructor
1	Students will be informed to make groups of 2 ± 1. The TA of the course will present the Affinibot assembly experience and 3D printed parts in the second session.	TA
2	Inform if about the group member and the printer kit (their own or borrowed from IUPUI)	TA
6	All groups should have their kit purchased	TA
10	All printers should be assembled. From week 8, assignments may require 3D printed parts, e.g., topology optimization (DfAM). Use Slic3r vs. Cura vs. Simplify3d.	TA
12	DOE for calibration. Optimal parameters for two materials: PLA and other.	TA
14	Mechanical properties of the 3D printed part. Anisotropic properties.	TA