TELE 7374 – Building Digital Twins

COURSE INFORMATION

Course Title**:** Building Digital Twins
Course Number: TELE 7374
Term and Year: Spring 2024
Credit Hour: 4
Course Format: In-person (Boston) w/Livestreaming if / when appropriate and permitted as per University policy

INSTRUCTOR INFORMATION

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COURSE PREREQUISITES

See the Northeastern course catalog for details

- URL: https://catalog.northeastern.edu/search/?P=TELE%207374

COURSE DESCRIPTION

The Building Digital Twins course is all about making the Digital Twins 'work', and as such, involves substantial software development using Python, C# and / or C++, a 3D physics / gaming engine (either Unity 3D or other – ***subject to change***), Git source code management, and some Linux (via WSL 2) or macOS shell scripting (depending on your OS).

Building Digital Twins assignments are different than what you might normally see in a course. Each assignment serves as the basis for the next one, so it's **VERY IMPORTANT** that you start working on each as soon as possible, as they get progressively more difficult and can take many days to implement.

Although specialized device hardware (e.g., an SBC with attached sensors and actuators) is NOT required for the course, you will need a reasonably powerful and modern development workstation or laptop with a modern GPU (ideally dedicated) and monitor / keyboard / mouse, as we'll be building 3D visualizations within a 3D physics / gaming engine (again, Unity 3D or other – ***subject to change***) to process and interpret simulated data sets. If your current system can easily run Unity 2022 or higher and Visual Studio (or Visual Studio Code) simultaneously without issue, I expect your system will work fine for the requisite lab modules. The required lab modules can technically run on a single system running Windows 10 / 11 (with some components running in WSL 2) or macOS; I'll mostly be teaching and demonstrating code using Windows 11 / WSL 2.

We'll use Teams and / or Zoom to collaborate. It's very important that you join the Teams site to stay up-to-date and connect into our meetings. For more information and the link to join, please see the course Canvas site.

COURSE LEARNING OUTCOMES

Upon successful completion of this course, students are expected to understand, and build some of the software necessary to support, the following core Digital Twins concepts and technologies:

- Digital Twins architectures (edge to cloud)
- Core Digital Twins concepts (telemetry, state, models)
- Basic implementation concepts: telemetry generation, state synchronization, data modeling
- Digital Twin use cases (system management, basic predictive maintenance, user training & simulation)
- Tools and standards (3D environments, DTDL, etc.)

REQUIRED TEXTBOOK

Programming the Internet of Things, by Andy King
ISBN-13: 978-1-492-08141-8

- URL: Northeastern Scholar OneSearch - Programming the Internet of Things
- Direct URL (O'Reilly): Programming the Internet of Things (oreilly.com)

COURSE WEBSITE

- URL: https://labbenchstudios.com/programming-digital-twins/building-digital-twins/

TENTATIVE SCHEDULE (subject to change / adjustment)

WEEK	*PART*	*TOPIC*	*TYPE*
1	*01*	*Foundational Concepts and DevOps: Digital Twin Basics*	*Lecture/Lab*
2		*Architecture and Core Digital Twin Components – Part 01 of 02*	*Lecture/Lab*
3		*Architecture and Core Digital Twin Components – Part 02 of 02*	*Lecture/Lab*
4		*Quiz No. 1 (Part 01)*	*Lecture/Quiz*
5	*02*	*Telemetry Generation*	*Lecture/Lab*
6		*State Synchronization*	*Lecture/Quiz*
7		*System Modeling*	*Lecture/Lab*
8		*Quiz No. 2 (Part 02)*	*Lecture/Quiz*
9	*03*	*System Integration & Management*	*Lecture/Lab*
10		*Basic Predictive Maintenance*	*Lecture/Lab*
11		*User Training & Simulation*	*Lecture/Lab*
12		*Quiz No. 3 (Part 03)*	*Lecture/Quiz*
13	*04*	*Final Project Use Case Selection; Other Topics – Part 01 of 02*	*Lecture/Lab*
14		*Final Project Use Case Selection; Other Topics – Part 02 of 02*	*Lecture/Lab*
15		*Final Project Completion and Presentation*	*Project Presentations*

INSTRUCTION METHODOLOGY

This course is comprised of lectures and discussions, where we'll explore principles, concepts and the 'why' of a Digital Twin ecosystem, along with numerous hands-on labs where we'll dig into the 'what' and 'how'.
Some course lab content is covered throughout Programming the Internet of Things and the book's associated GitHub Kanban Board.

This course has its own Kanban Board specific to Digital Twins-related lab module exercises, so while it's useful to read through Programming the Internet of Things in tandem with the Building Digital Twins coursework, the exercises will be different. Please keep in mind that Digital Twins and the IoT in general comprise very broad and deep technology spaces, so we won't cover every aspect.

- Book URL: Northeastern Scholar OneSearch - Programming the Internet of Things
- Lab Module Kanban Board URL: Programming Digital Twins (github.com)

A BRIEF FAQ

What hardware do I need?

As mentioned earlier, you'll need development workstation / laptop that can run either Windows 10 / 11 (with WSL 2) or macOS. Your system should be capable of running a modern 3D-intensive video game, as you'll be using a 3D graphics rendering / physics simulation environment to run many of your lab module solutions. The data you'll use for your digital twin can be exclusively simulated, although we'll discuss methods of processing live telemetry sourced from actual sensors as well.

Please NOTE: At this time, the client application that renders your digital twin solution is only expected to run properly in Windows 10 / 11 and macOS.

What about software?

As I mentioned, programming experience with Python (3.9 or higher), likely C# and .NET (possibly some C++) is required, as well as knowledge of Git. We'll use GitHub for all source code management and may also incorporate features of GitHub Classroom. In general, GitHub will be used to manage all assignments and submissions.

You'll essentially build two separate applications: An 'Edge Device App' written in Python, and a Digital Twin App' that runs within a 3D game engine environment (as of now, I expect this will involve C# development specifically for the Unity 3D game engine, although this is subject to change). There will be other libraries you'll need to incorporate that will be provided either in full or with some requisite modifications depending on the lab module. Each application will start with very basic functionality and build up its capabilities with each class and associated Lab Module.

As referenced earlier, lab module specifics are referenced within the Programming Digital Twins Kanban Board.

Please NOTE: There will be several 3rd party tools and library dependencies which I'll cover during the first class.

GRADING POLICY

Coursework will be weighted as follows:

Assignments / Lab Modules	25%
Final Project	20%
Final Project Presentation	5%
Quizzes	50%

MAKEUP POLICY

All assignments and labs are due at the specified time / date indicated in Canvas. While extensions may be permitted on a case-by-case basis with permission of the Instructor, a late penalty will be applied as per the grading rubric for the assignment unless the delay is excused via University policy. **All coursework must be completed before the last meeting day of class for this course (Class 15)**, otherwise a '0' will be the grade.

EXAMINATION POLICY

There will be three (3) or four (4) quizzes throughout the semester, each based largely on the section for which it's associated (e.g., Quiz No. 1 is related to Part 01, etc.) Some quizzes will inevitably incorporate questions pertaining to material in a previous section, although each will largely be centered on the content from the related part (e.g., Quiz No. 3 will focus on Part 03 material, but may also reference material from Part 01 and Part 02). I'll host a brief review of the relevant part just prior to each quiz. For information on the date / time for each quiz, please see the course Canvas site.

GRADING SYSTEM

Please NOTE: In order to receive an 'A' in this course, your numerical grade must be 96 or higher. See the numerical definition chart below for details.

Grade	Weight	Numerical Definition	Definition
A	4.000	96 – 100	Outstanding achievement
A-	3.667	90 – 95	
B+	3.333	87 – 89	Good achievement
B	3.000	83 – 86	
B-	2.667	80 – 82	
C+	2.333	77 – 79	Satisfactory achievement
C	2.000	73 – 76	
C-	1.667	70 – 72	
D+	1.333	67 – 69	Poor achievement
D	1.000	63 – 66	
D-	0.667	60 – 62	
F	0.000	0 – 59	Failure

- URL: https://registrar.northeastern.edu/article/university-grading-system/

ATTENDANCE POLICY
Attendance is a crucial element for success in class. Unless you cannot make it due to illness or other urgent or emergent reasons, it is required. Contact me via e-mail before class for allowed absence unless you cannot. As per the student handbook: Students will not be penalized for excused absences, with the understanding that students may need to make up for the academic commitment from which they were excused. Reasons for an excused absence include religious, medical issues, jury duty, bereavement, and military service. See the course catalog and other applicable policies for attendance and excusal guidelines.

ACADEMIC INTEGRITY
A commitment to the principles of academic integrity is essential to the mission of Northeastern University. Promoting independent and original scholarship ensures that students derive the most from their educational experience and pursuit of knowledge. Academic dishonesty violates the most fundamental values of an intellectual community and undermines the achievements of the entire University.

As academic community members, students must become familiar with their rights and responsibilities. In each course, they are responsible for knowing the requirements and restrictions regarding research and writing, examinations of whatever kind, collaborative work, using study aids, the appropriateness of assistance, and other issues. Students are responsible for learning documentation conventions and acknowledging sources in their fields. Northeastern University expects students to complete all examinations, tests, papers, creative projects, and assignments according to the highest ethical standards, as set forth either explicitly or implicitly in this Code or by the direction of instructors. Go to http://www.northeastern.edu/osccr/academic-integritypolicy/ to access the full academic integrity policy.

UNIVERSITY HEALTH AND COUNSELING
As a student enrolled in this course, you are fully responsible for assignments, work, and course materials outlined in this syllabus and the classroom. Over the semester, if you experience any health issues, please contact UHCS. For more information, visit https://www.northeastern.edu/uhcs.

STUDENT ACCOMMODATIONS
Northeastern University and the Disability Resource Center (DRC) are committed to providing disability services that enable students who qualify under Section 504 of the Rehabilitation Act and the Americans with Disabilities Act Amendments Act (ADAAA) to participate fully in the university's activities. To receive accommodations through the DRC, students must provide appropriate documentation demonstrating a substantially limiting disability. For more information, visit http://www.northeastern.edu/drc/getting-started-with-the-drc/.

LIBRARY SERVICES
The Northeastern University Library is the hub of campus intellectual life. Resources include over 900,000 print volumes, 206,500 e-books, and 70,225 electronic journals. For more information and for education-specific resources, visit https://library.northeastern.edu.

24/7 CANVAS TECHNICAL HELP
For immediate technical support for Canvas, call 617-373-4357 or e-mail help@northeastern.edu
Canvas Faculty Resources: https://canvas.northeastern.edu/faculty-resources/
Canvas Student Resources: https://canvas.northeastern.edu/student-resources/
For assistance with my Northeastern e-mail and essential technical support:
Visit ITS at https://its.northeastern.edu
E-mail: help@northeastern.edu
ITS Customer Service Desk: 617-373-4357

DIVERSITY AND INCLUSION

Northeastern University is committed to equal opportunity, affirmative action, diversity, and social justice while building a climate of inclusion on and beyond campus. In the classroom, members of the University community work to cultivate an inclusive environment that denounces discrimination through innovation, collaboration, and an awareness of global perspectives on social justice. I intend that students from all backgrounds and perspectives will be well served by this course and that the diversity students bring to this class will be viewed as an asset. I welcome individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, socioeconomic backgrounds, family education levels, ability – and other visible and non-visible differences. All class members are expected to contribute to a respectful, welcoming, and inclusive environment for every other class member. Your suggestions are encouraged and appreciated. Please visit http://www.northeastern.edu/oidi/ for complete information on Diversity and Inclusion.

TITLE IX

Title IX of the Education Amendments of 1972 protects individuals from sex or gender-based discrimination, including discrimination based on gender identity, in educational programs and activities that receive federal financial assistance. Northeastern's Title IX Policy prohibits Prohibited Offenses, defined as sexual harassment, sexual assault, relationship or domestic violence, and stalking. The Title IX Policy applies to the entire community, including male, female, transgender students, faculty, and staff. In case of an emergency, please call 911. Please visit https://www.northeastern.edu/ouec for a complete list of reporting options and resources on and off campus.

This course syllabus may be subject to change.