# ECE 659 Intelligent Sensors and Sensor Networks

*Held in conjunction with*

## ECE 493-T20 IOT Signal Processing

SPRING 2024

**INSTRUCTOR: Dr. Haitham Amar —hamar@uwaterloo.ca**

**TA INFORMATION:**

- TBA
- TBA

**Lectures and Tutorials**

- Regular Lectures: 08:30AM-09:50AM. Mondays and Fridays
  ROOM E7 4043
- Substitute Lectures: 4:00 PM - 5:20 PM: Thursday May 9th; May 30th; June 20th; Thirsday July 11th
- Tutorials: 7:00 PM - 7:50 PM. Thursdays and Thursdays

## 1 COURSE DESCRIPTION

Wireless networks provides the backbone for ubiquitous information access and resource sharing, which dramatically changes the way people and devices compute and communicate. The unprecedented recent advancements in wireless networks and embedded computing have spawned the emergence of Internet of Things (IoT) as an important field that

is poised to change our lives, personally and professionally. It is estimated that by 2025, there will be more than 31 billion connected IOT devices communicating through the Internet. Connected coffee makers, vehicles, sensors attached to cattle, or connected machines in a production plant, are examples of IoT realizations.

Sensor technology is a key part, as well as a tangible realization, of IoT. It is a technology domain that is experiencing a rapid growth and is believed to be a multi-billion dollar industry. Wireless sensor networks are distributed systems, in which autonomous devices or Motes, observe what could be complex environments to collect data such as temperature, humidity, motion, and sound) or, even medical data (such as heart rate, blood oxygen level and pulse rate). The data is collected through a network, fused/aggregated, routed and transported to control/analytics/ and decision making applications Sensor networks are an enabler for a broad range of applications in different sectors such as agriculture, healthcare, manufacturing, mining, smart cities, etc.

This course is intended to introduce the student to fundamental topics and issues that are typical in IOT systems design, deployment and management. It highlights the importance of IoT developments in our society, and studies important components of typical IoT devices and networks, and discusses current and future IOT trends. The course emphasizes the role of AI in addressing IOT network complexities, self-awareness, and Big Data processing problems. As well, it introduces topics that are central to IOT networks, including data fusion, synchronization, cloud computing, localization, embedded/tiny AI, and Graph Signal Processing, compressed sensing, clustering and IOT analytics, Blockchain and its application in IoT. Sensor networks will be utilized as an emerging application domain in IOT.

In this course, the students will learn WSN theory and technology such as routing and security as well as will gain hands-on skills and practical knowledge in WSN. The course introduces diverse fundamental concepts encountered in designing and analyzing intelligent sensors and sensor networks (mobile and stationary), with emphases on mission critical applications. The course will cover theoretical models, and design principles; and explores the latest development and open research issues in wireless sensor network algorithms, protocols, architectures, and applications. Topics covered in this course include: Introduction to sensing and sensor networks, attributes of sensor networks, communication model and network stack, information routing, localization and synchronization, compressive sensing, sensor fusion and aggregation, graph signal processing, security, middleware and bigdata environments. .

## 2 LEARNING OBJECTIVES

The objective of this course is to make the students

- Understand the basic WSN technology and supporting protocols,
- Understand the different sensor network stack in terms of layers and their role, op-

erations and challenges,

- Understand and appreciate sensor fusion and data aggregation techniques as means for achieving accurate sensing and efficient data capture and transport,
- Learn the different layers of the sensor network stack in terms of their role, operations and challenges,
- Learn how Graph Signal Processing is emerging as a new domain of signal processing for analyzing the dynamics and topology of large scale sensor networks.
- Learn key routing protocols for sensor networks
- Understand the importance of sensor localization and synchronization and learn techniques for achieving location-aware synchronous sensor networks
- Appreciate how sensors are typically capable of wireless communication, but at the same time are significantly constrained in terms of the amount of available resources such as energy, storage and computation.
- The students will learn how such constraints make the design and operation of sensor networks considerably different from contemporary wireless networks. They will learn the importance of resource conscious protocols and management techniques.
- Learn advanced emerging sensor network security paradigms such as lightweight cryptography, and Blockchain.
- The student will learn various IoT applications of signal processing and how design considerations, constraints, and interfacing between the physical world and the devices are dealt with.
- The student will learn how design trade-offs between hardware and software requirements are managed.
- The student will also learn advanced topics relating to network signal processing, data routing data fusion and aggregation, security, authentication, device management, resource constrained signal processing, and localization.
- The students will learn how to translate IOT system requirements into a comprehensive IOT design and implementation that integrate a wide range of the theoretical topics covered in the course.
- The student will learn the role of AI in realizing IOT devices and networks that can sense, perceive and act with autonomy.

- Both simulation and/or physical realizations will be used to reinforce course material. Two simulation environments will be introduced: one to emphasize the topic of sensor networks as an IoT application, the other will emphasize IoT implementation concepts. Furthermore, in conjunction with the simulation tools, a number of devices, platforms and software tools will be introduced during the course from various vendors.

- Students are expected to work in groups of two or three on projects that involve the design, development and testing of a realistic IoT system for a specific domain, with a demonstration target.

The course will emphasize the role of AI techniques in developing solutions to a wide range of problems in intelligent sensor networks. Tiny machine learning (tinyML) is the intersection of machine learning and embedded internet of things (IoT) devices. The field is an emerging engineering discipline that has the potential to revolutionize many industries.

## 3 DETAILED COURSE TOPICS:

| | |
|---|---|
| Introduction/Applications | Application domains of sensor networks.<br>Enabling technologies: hardware/software platforms.<br>Performance metrics. |
| Technology Stack | Wireless sensor architecture and protocol stack. Stack layers: roles and challenges. Network capacity, |
| Routing | Data centric-protocols<br>Hierarchical protocols<br>Location-based (Geographical) protocols and energy-aware routing<br>Multipath-routing |
| Localization and Synchronization | Global location (GPS-based) and relative location (Beacon-based).<br>Localization methods: anchor-free, anchor-based, range-free, range-based.<br>Timing/synchronization<br>Coverage and connectivity: properties and quality aspects. |
| Sensor Fusion and Aggregation | Sensor fusion paradigms, Probabilistic, Dempster-Shafer based, centralized and distributed Kalman filter, Q-digest |
| Compressive Sensing | Sampling theory, Sparse representations. Compressible signals, Sensing matrix design, Signal recovery, Lx-Norm Optimization |
| IOT Signal Processing<br>Graph Signal Processing | Distrbuted SP, and Wavelet SP,<br>Introduction to graph concepts, Spectral graph theory – Orthogonal transforms review Frequency interpretation – Nodal Theorem, Graph filtering – Vertex and Spectral interpretations |
| Advanced Topics | Bigdata, Security, Blockchain in WSN. |

## 4 Learning Resources

- The course material will be published on the course website on LEARN.
- Supplementary material such as scientific articles and technical reports will be posted on the course website on LEARN in synchrony with topics covered.
- The OMNET++ simulation environment and MATLAB S/W will be used to help the students practice the course topics.
- Recommended Reading Material:

- Signal Processing for 5G: Algorithms and Implementations
- Cooperative and Graph Signal Processing, 1st Edition. Principles and Applications
- Security and Privacy in Internet of Things (IoTs): Models, Algorithms, and ...By Fei Hu
- Pattern Analysis, Intelligent Security and the Internet of Things, edited by Ajith Abraham, Azah Kamilah Muda, Yun-Huoy Choo
- EMBEDDED SOFTWARE FOR THE IOT, By Klus Eik
- DSP Software Development Techniques for Embedded and Real-Time Systems, By Robert Oshana
- Learning in Embedded Systems, by Leslie Kaelbling, MIT Press

## 5 RESEARCH ARTICLES:

Research articles that report recent developments related to the course topics will be published on the LEARN course website regularly.

## 6 ASSESSMENTS:

The final course grade will be calculated using the following categories:

| Assessment | Percentage of Final Grade |
|---|---|
| Assignments | 30% |
| Project Problem Statement | 5% |
| Project Presentation | 15% |
| Final Exam | 50% |

## 7 COURSE POLICIES

- Late-work policy: If you submit work after the deadline your mark will be reduced by 10
- Integrity: ( Please refer to the University of Waterloo Policy 71) “Academic integrity is a commitment to five basic values: honesty, trust, fairness, respect and responsibility. It applies to all academic endeavours – teaching, learning and scholarship, and applies to a range of academic activities, from conduct in research to the writing of co-op work term reports.

- Students are expected to know what constitutes academic integrity, to avoid committing offences, and to take responsibility for their actions.
- Students are responsible for demonstrating behaviour that is honest and ethical in their academic work. Such behaviour includes:

  - Abiding by University policies and provincial and federal legislation.

  - Following the expectations articulated by instructors for referencing sources of information and for group work.

  - Submitting original work, citing sources fully, and respecting the authorship of others.

  - Preventing their work from being used by others, e.g. not lending assignments to others, protecting access to computer files.

  - Asking for clarification of expectations as necessary. Students who are in any doubt as to whether an action on their part may be viewed as a violation of the standards of academic integrity should ask their instructors, lab assistants and/or advisors.

  - Adhering to the principles of academic integrity when conducting and reporting research." Accommodations for students with disabilities: "If you have a disability and require accommodations, please refer to https://uwaterloo.ca/english-teaching-portal/managing-your-section-or-tutorial/accommodating-students-disabilities

  If you have an accommodations letter from the Disability Services Office, I encourage you to discuss your accommodations and needs with me as early in the semester as possible.

  I will work with you to ensure that accommodations are provided as appropriate.