PURDUE UNIVERSITY | College of Engineering

CE 597: Vehicular Cyber-Physical Systems (Spring 2023)

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[Description] Cyber-physical systems (CPS) are a new frontier for computational systems that transform the way people interact with engineered systems, which benefit applications in fields like transportation, aerospace, manufacturing, and health care. This course introduces students to the theoretical and practical foundations of CPS, with an emphasis on their usages in connected and automated vehicles (CAV). Upon finishing the course, students are expected to obtain the basic knowledge of CPS and CAV, and know how to develop a model-based autonomous system to be applied to the transportation system.

[Prerequisites] This course is intended for **graduate students only**. Basic understanding of software engineering, autonomous systems, and internet of things is preferred.

[Topics] This course is planned to cover the following topics:

- **Cyber-physical systems (CPS)**
  - sensors and actuators for physical processes
  - system modeling, model-based design, and digital twins
  - CPS applications in various fields
- **Connected and automated vehicle (CAV) systems**
  - CAV modules: communication, localization, perception, planning, and control
  - mechanism of popular CAV functions: object detection (perception), behavior prediction (planning), and car following (control)
  - CAV applications: personalized/cooperative adaptive cruise control, cooperative lane change, and cooperative driving at intersections
  - edge computing and cloud computing for CAV
- **Advanced simulation technologies for CPS and CAV**
  - X-in-the-loop simulation
  - virtual reality and augmented reality for virtual prototyping
  - agent-based modeling and simulation with game engines
- **State-of-the-art in CPS and CAV industries**
  - Invited talks from guest speakers in industry (software and automotive companies)

[Grading] There will be no written homework or exam throughout the semester, and the overall grade of this course will be based on in-class quizzes and a course project. The details of the course project can be found in the [Project] section of this syllabus.

[References] Following textbook and position/survey papers are useful references of this course:

1. [**CPS**] E. A. Lee and S. A. Seshia, "Introduction to Embedded Systems: A Cyber-Physical Systems Approach", 2017, available: https://ziranw.github.io/CE597/Lee_CPS_Book.pdf.
2. [**DT**] C. Schwarz and Z. Wang, "The Role of Digital Twins in Connected and Automated Vehicles", IEEE Intelligent Transportation Systems (ITS) Magazine, 2022.

3. [**DT**] Z. Wang et al., "Mobility Digital Twin: Concept, Architecture, Case Study, and Future Challenges", IEEE Internet of Things Journal., vol. 9, no. 18, 2022.
4. [**DT**] Z. Hu et al., "Review and Perspectives on Driver Digital Twin and Its Enabling Technologies for Intelligent Vehicles", IEEE Transactions on Intelligent Vehicles (IV), 2022.
5. [**Computing**] S. Liu et al., "Edge Computing for Autonomous Driving: Opportunities and Challenges," Proceedings of the IEEE, vol. 107, no. 8, 2019.
6. [**AV**] C. Badue et al., "Self-Driving Cars: A Survey", Expert Systems with Applications, vol. 165, 2021.
7. [**CAV**] A. Eskandarian et al., "Research Advances and Challenges of Autonomous and Connected Ground Vehicles", IEEE Transactions on ITS, vol. 22, no. 2, 2021.
8. [**Localization**] G. Bresson et al., "Simultaneous Localization and Mapping: A Survey of Current Trends in Autonomous Driving", IEEE Transactions on IV, vol. 2, no. 3, 2017.
9. [**Perception**] E. Marti et al., "A Review of Sensor Technologies for Perception in Automated Driving", IEEE ITS Magazine, vol. 11, no. 4, 2019.
10. [**Planning**] W. Schwarting et al., "Planning and Decision-Making for Autonomous Vehicles", Annual Review of Control, Robotics, and Autonomous Systems, vol. 1:187-210, 2019, available: https://ziranw.github.io/CE597/schwarting2018.pdf.
11. [**Planning**] B. Paden et al., "A Survey of Motion Planning and Control Techniques for Self-Driving Urban Vehicles", IEEE Transactions on IV, vol. 1, no. 1, 2016.
12. [**Control**] J. Guanetti et al., "Control of Connected and Automated Vehicles: State of the Art and Future Challenges", Annual Reviews in Control, vol. 45, 2018.
13. [**Control**] Z. Wang et al., "A Survey on Cooperative Longitudinal Motion Control of Multiple Connected and Automated Vehicles", IEEE ITS Magazine, vol. 12, no. 1, 2022

[Project] The course project aims to introduce the students to CPS and CAV technologies, and to encourage the students to conduct in-depth research into a particular topic. There are essentially three options for the project type, and each student is asked to choose one of them:

- **Options:**
  1. **Comprehensive Survey of State-of-the-Art**
     a. Goal: Students are expected to become proficient in one research domain by conducting a comprehensive literature review of all relevant papers.
     b. Group Size: 1 student, or 2 students in a group
     c. Evaluation Matrix:
        i. No less than 30 references (60 references for group project)
        ii. In-depth insights with summary of pros and cons of each paper
        iii. Discussions regarding open challenges in this research domain in general

  2. **Reimplementation of Existing Papers**
     a. Goal: Students are expected to get hands-on experience in particular research domains by reimplementing methods and reproducing results of SOTA paper(s).
     b. Group Size: 1 student, or 2 students in a group
     c. Evaluation Matrix:
        i. Implementation details and source codes of 1 paper (2 papers for group project)
        ii. In-depth insights of pros and cons of the implemented methods compared to other SOTA methods
        iii. Discussions of potential solutions to further improve the paper(s)

  3. **Development of a Brand-New Idea**
     a. Goal: Students are expected to propose a brand-new research idea by developing methods in theory and evaluating results in experiment.
     b. Group Size: 1 student, or 2 students in a group
     c. Evaluation Matrix:
        i. Novelty of the proposed idea
        ii. Technical contributions of the proposed idea
        iii. Soundness of the experiment results

- **Grading:**
  1. **Project proposal elevator pitch: 10%**
     a. This will be conducted in class during week 7
     b. The presentation should be delivered within 3 minutes on a single slide (same for single and group project)
     c. Concisely state the introduction (what), motivation (why), technical contribution (how), and expected outcome of the proposed project
  2. **Mid-term project report: 10%**
     a. This will be submitted online during week 10
     b. This report should reflect the status of the ongoing project by showing the introduction, motivation, proposed method, planned next steps, and expected outcome (no less than 1.5 pages excluding references)
     c. IEEE double-column conference template is required: https://www.ieee.org/conferences/publishing/templates.html

   d. Submission should be in PDF format
3. **Final project presentation: 40%**
   a. This will be conducted in class during week 14 & 15
   b. The presentation should be delivered within 15 minutes (30 minutes for group project)
   c. Present the whole pipeline of the project with details
4. **Final project paper: 40%**
   a. This will be submitted online during the final week
   b. IEEE double-column conference template is required: https://www.ieee.org/conferences/publishing/templates.html
   c. Submission should be in PDF format, with 6-8 pages in length (including references at the end)

- **Notes:**

1. Both single projects and group projects are encouraged. The workload of group project is expected to be doubled compared to the single project for a fair grading of all students.
2. For project option 1, all reviewed papers should be relevant to the survey topic. References #4, #6-9, #11-13 of this syllabus can be referred to properly write a survey paper.
3. For project options 2, SOTA papers should at least satisfy one of the following:
   a. Highly cited: no less than 100 citations based on Google Scholar
   b. Published on top journals (impact factor no less than 5)
   c. Published on top conferences: AI/ML (NeurIPS, ICML, ICLR, AAAI, IJCAI, CVPR, ICCV, ECCV), Robotics (ICRA, IROS), Vehicles (IV, ITSC, VTC)

   If none of above is satisfied for the selected papers, please reach out to Prof. Wang for the permission of an exception.
4. If the student wants to change the option/subject of the project after the proposal, please reach out to Prof. Wang for the permission of an modification.
5. For all designated grading deadlines, if the submission is overdue, no communication needs to be made with Prof. Wang. The totally available grade G of that submission will be automatically decreased based on the number of overdue days n: $G = 100\% - n \times 10\%$. For example, if the final project paper is overdue by 2 days, the student can only receive a maximum of 80% of the designated grade for this item.