CS7351 传感系统原理与设计
Principles and Design of Sensing Systems
第一讲：绪论
Principles and Design of Sensing Systems

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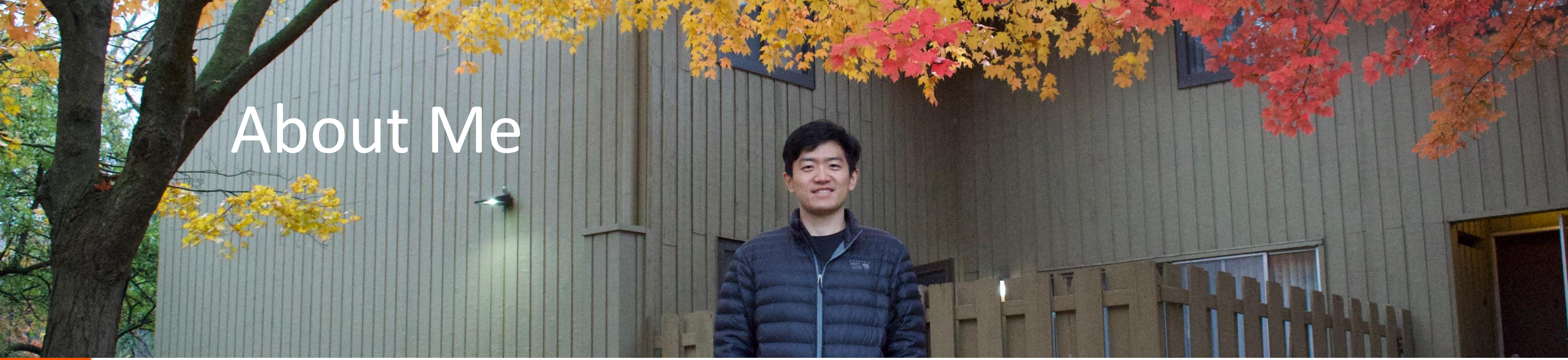
2025年秋季

Some of the material adapted from Fadel Adib (https://6808.github.io/index.html) and Pat Pannuto (https://patpannuto.com/)

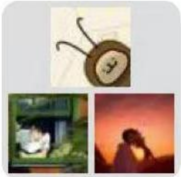


About Me

- 2013年从电院（自动化系）毕业
- 2015年密西根大学安娜堡分校硕士，电子科学（EE）
- 2020年密西根大学安娜堡分校博士，计算机科学与工程（Computer Science and Engineering, CSE）
- 个人主页及实验室研究介绍
  - https://chendy.tech/

How to Reach Out

- Emails are most effective：chendy@sjtu.edu
- Homework and tasks will be announced in ca
- WeChat group is for urgent notification
- My office: Software Building, 1108-1



群聊: CS7351-2025秋季-课程群

该二维码7天内(9月25日前)有效，重新进入将更新

About You

- Please sign up the following sheet

姓名	感兴趣研究方向	导师

CS7351-信息收集

Scan the QR code to open it or share it with your contacts.

- Tencent Docs -

Online real-time editing by multiple users with controlled permissions and security.

Introducing Our TA

- 申王伟

sw18237277811@sjtu.edu.cn

Grades

- 论文阅读: 30%
  - 每个章节开始的时候会提供一个论文列表（reading list）。在这堂课上课之前，每位学生需要提交一个关于所读论文的介绍(英文)，每一篇论文的介绍不少于 300 个单词，包括摘要、创新点、局限性和自己的思考。打分由指导教师和助教完成，评分标准由下面四项组成：
    - 这篇论文解决的问题是什么，这一问题的重要性如何?
    - 本论文的核心 idea 是什么?
    - 这篇工作与前期相关工作的区分点在哪里?
    - 这篇文章存在怎样的问题?你会如何解决这些难题?
  - Presenting the paper to the class
  - Extra credits if you can **reproduce** this work!
- 课堂参与:20%

Grades

- 课程项目（50%）
  - 我们在课上讲解传感系统经典工作(例如通过智能手机实现驾驶环境感知，等等)。
  - 我们计划有5-7个project
  - 建议时间安排
    - 学期1-2周内分组
    - 在7-8周内确定选题，并邮件联系我
      - 邮件题目“CS7351课程项目”，我会和你们约时间讨论
  - 本学期最后一天会有课堂的原理presentation和demo展示

Course Outline

- Course introduction
- Chapter1: sensing modalities
  - 惯性传感器 (inertial measurement units)
  - 摄像头 (camera-based system)
  - 磁场传感器(1) (magnetometers)
  - 磁场传感器(1) (magnetometers)
  - 射频及其他 (RF signal and beyond)
- Chapter 2: Energy-efficient Design
  - 设计原则 (design principles)
  - 无电池设计 (Energy harvesting design)
  - 其他低功耗设计思路 (Other low-energy design schemes)
- Chapter 3: Privacy and Security
  - 系统漏洞分析 (Security analysis)
  - 旁路攻击（side-channel attack）
  - Mobile OS security
  - Privacy
- Frontiers on Sensing Technologies (前沿研究探讨)

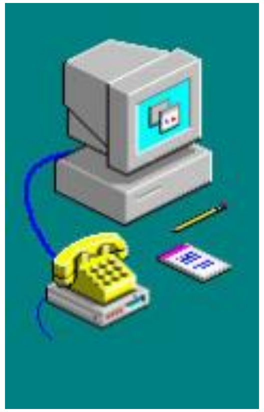
What is IoT (internet of things)?

By definition: IoT technology wirelessly connect sensing devices with the Internet, thus achieving novel applications

Connect the digital and physical world

The Timeline of Sensing Technologies

1980s



Personalized computer

- Computing power
- E.g., e-mail

- Miniatured computer
- Advances in wireless communication

2010s

“Little” computers

- E.g., smartphones

- Advances in algorithm and computing power

>2017

Intelligent Assistant

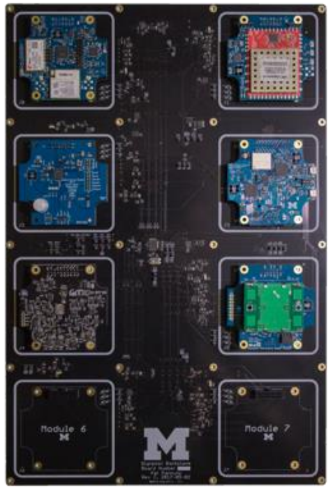
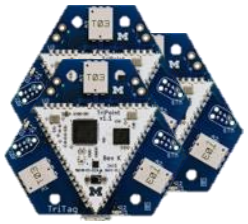
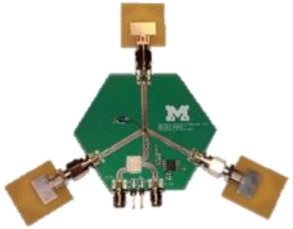
- E.g., smart speakers (小爱同学)

What is Sensing System?

- Why sensing technologies are essential?

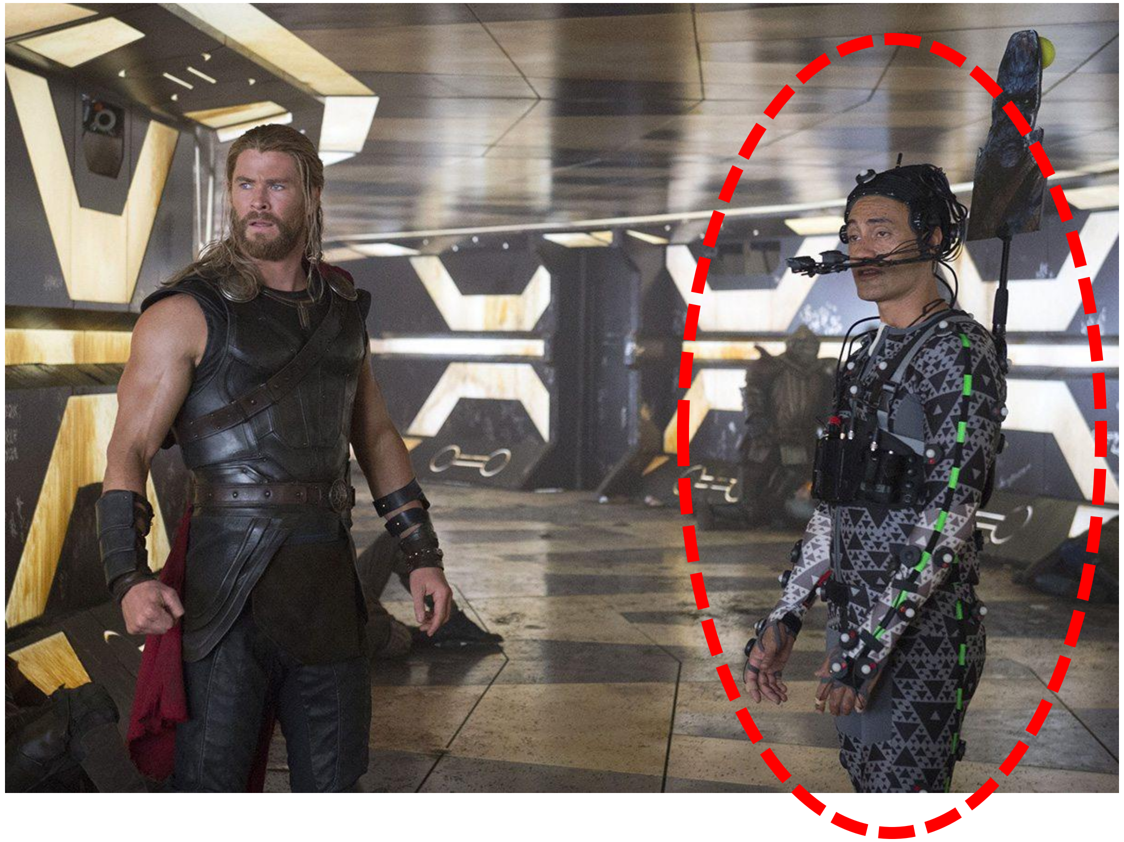





What is Sensing System?

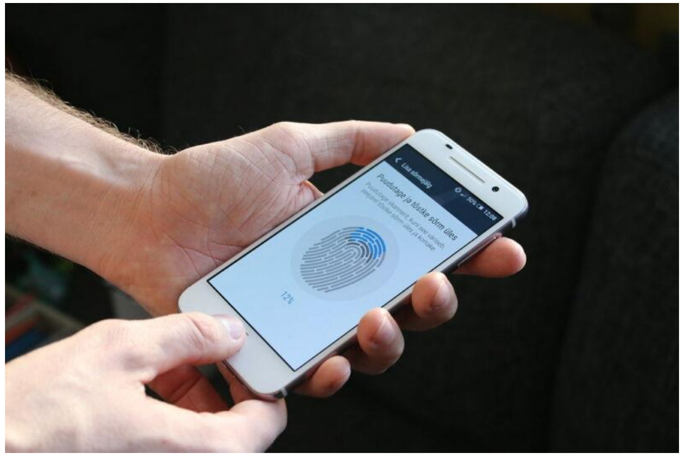
- Why sensing technologies are essential?



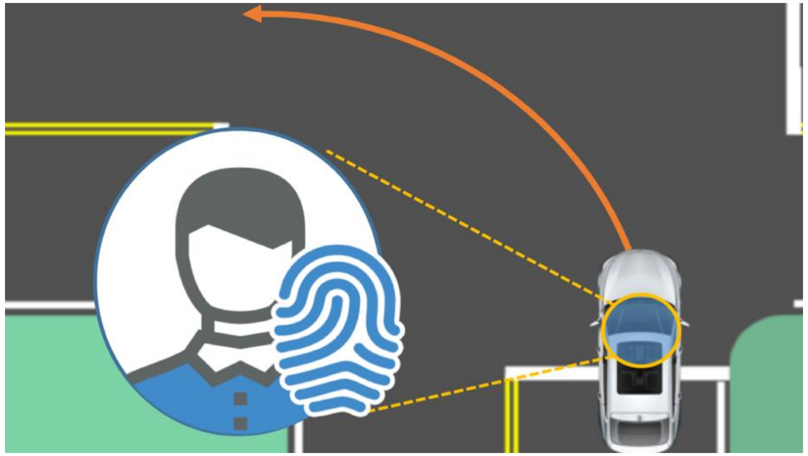
Sensing Systems are Changing Our Lives

- Authentication

Face recognition



Fingerprint scanner

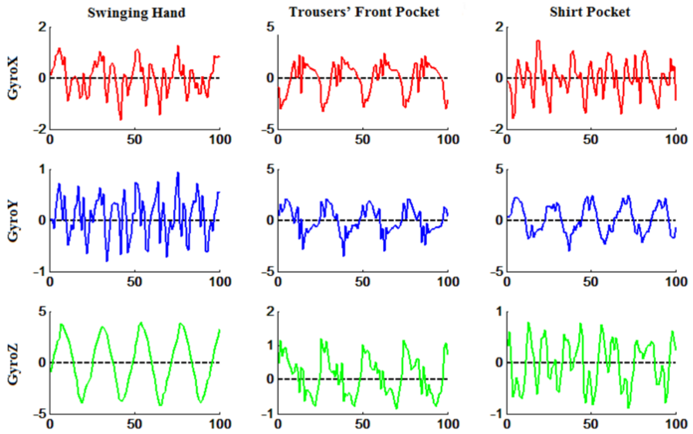


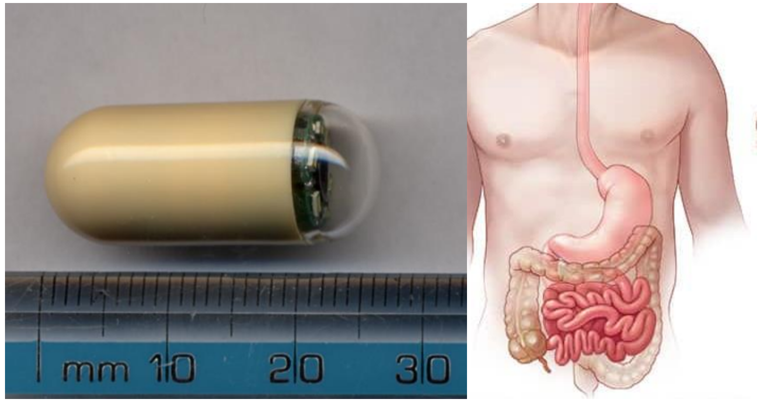
Behavioral biometrics
(行为生物信息)

Sensing Systems are Changing Our Lives

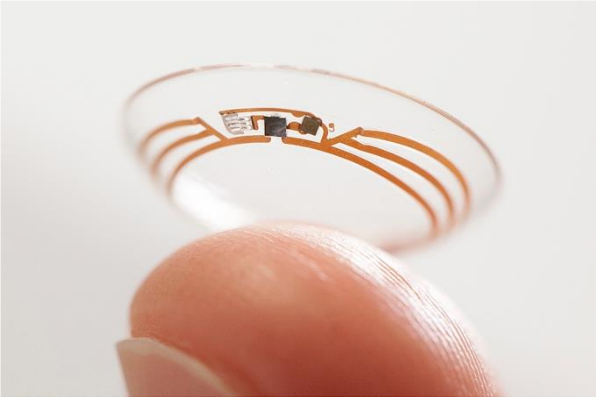
- Healthcare sensing

Step counter





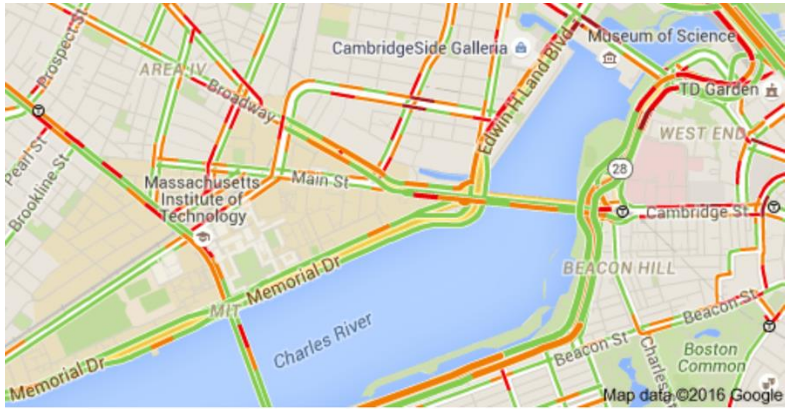
Capsule endoscopy
(胶囊胃镜)



Blood sugar analysis
隐形眼镜血糖仪 (e.g., Google lens, Mojo lens)

Sensing Systems are Changing Our Lives

- Smart transportation



Navigation system

Pothole detection

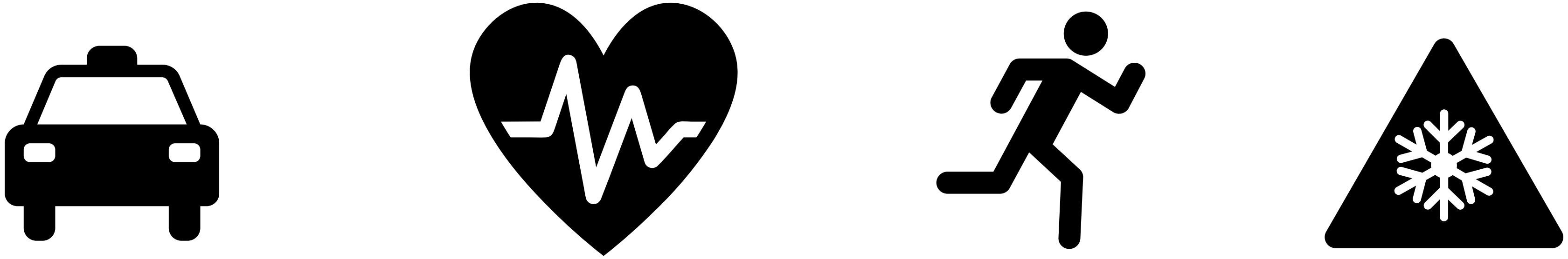
Self-driving cars

How to Design Your Sensing Application?

- Step 1: What problem you want to solve?

- Step 2: Examine the 4 key design principles

What Problem You Want to Solve?

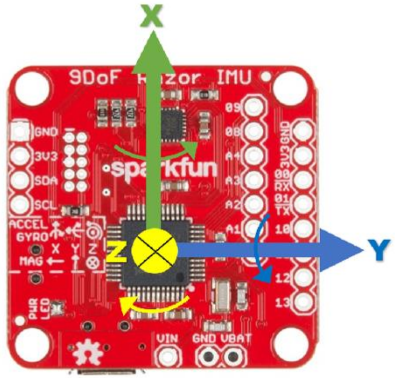


Is it a REAL problem?

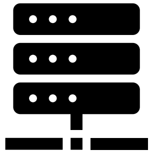
Is it a REAL problem?

Is it a REAL problem?

4 Key Principles for Designing Sensing Systems



Sensing Modalities

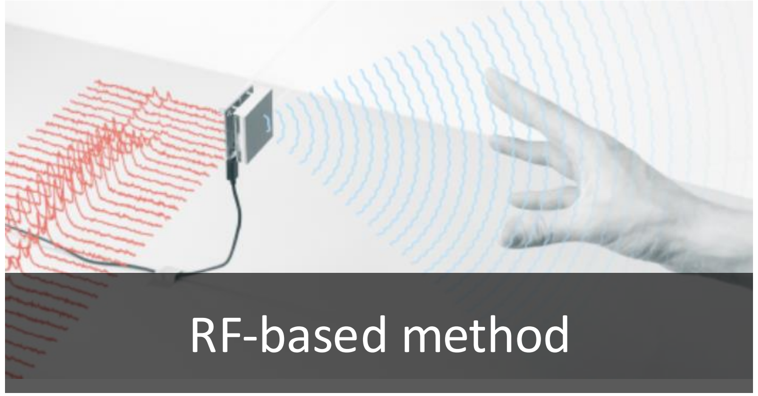


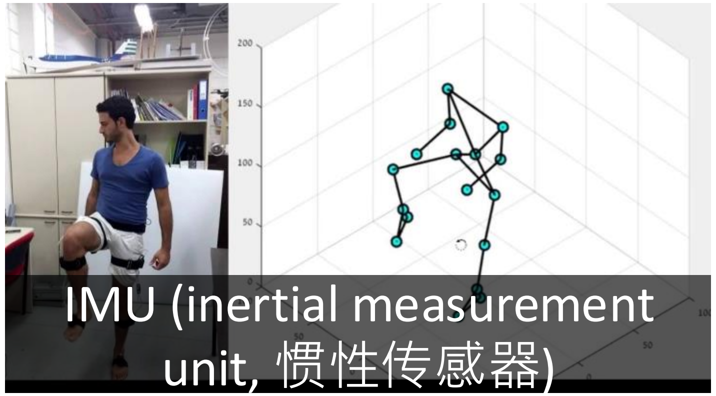
Computation

Power and Energy

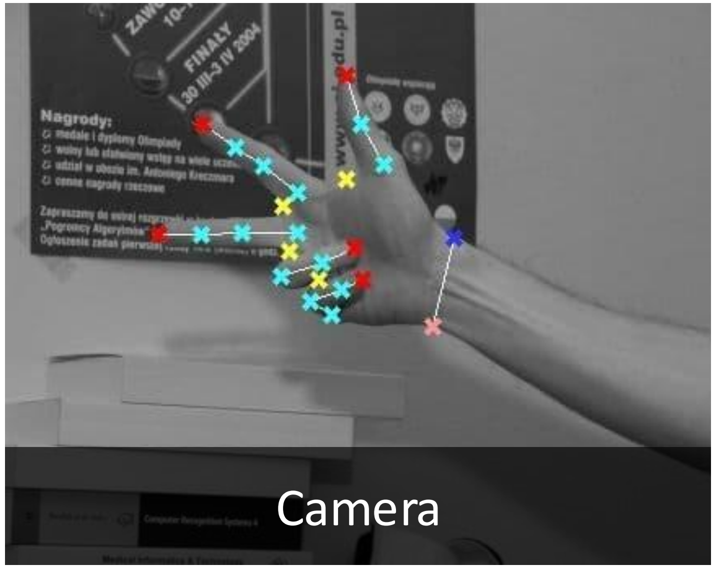
Connectivity

Sensing Modalities


RF-based method


IMU (inertial measurement unit, 惯性传感器)

Radar

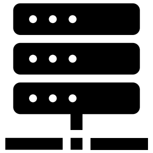

Camera

Computation

- How can we use the sensing modalities to achieve the goal

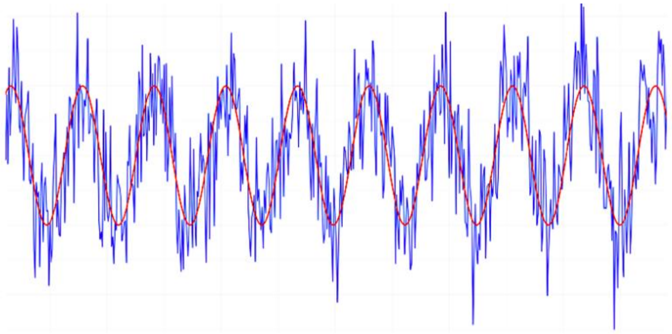
Programming model

- Embedded
- Mobile
- Edge/Cloud



Data management

- Storage
- Queries



Signal processing

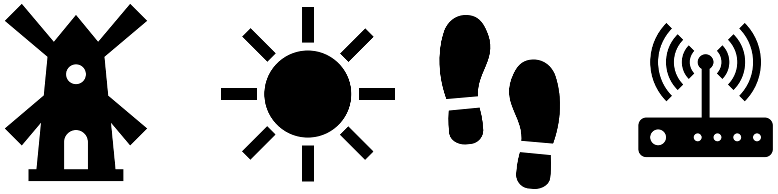
- Digitization
- Machine learning and inference

Security

- Digital, analog
- Privacy

Power/Energy

- How will we power nodes? What are the energy constraints?



Infrastructure

- Electricity power grid

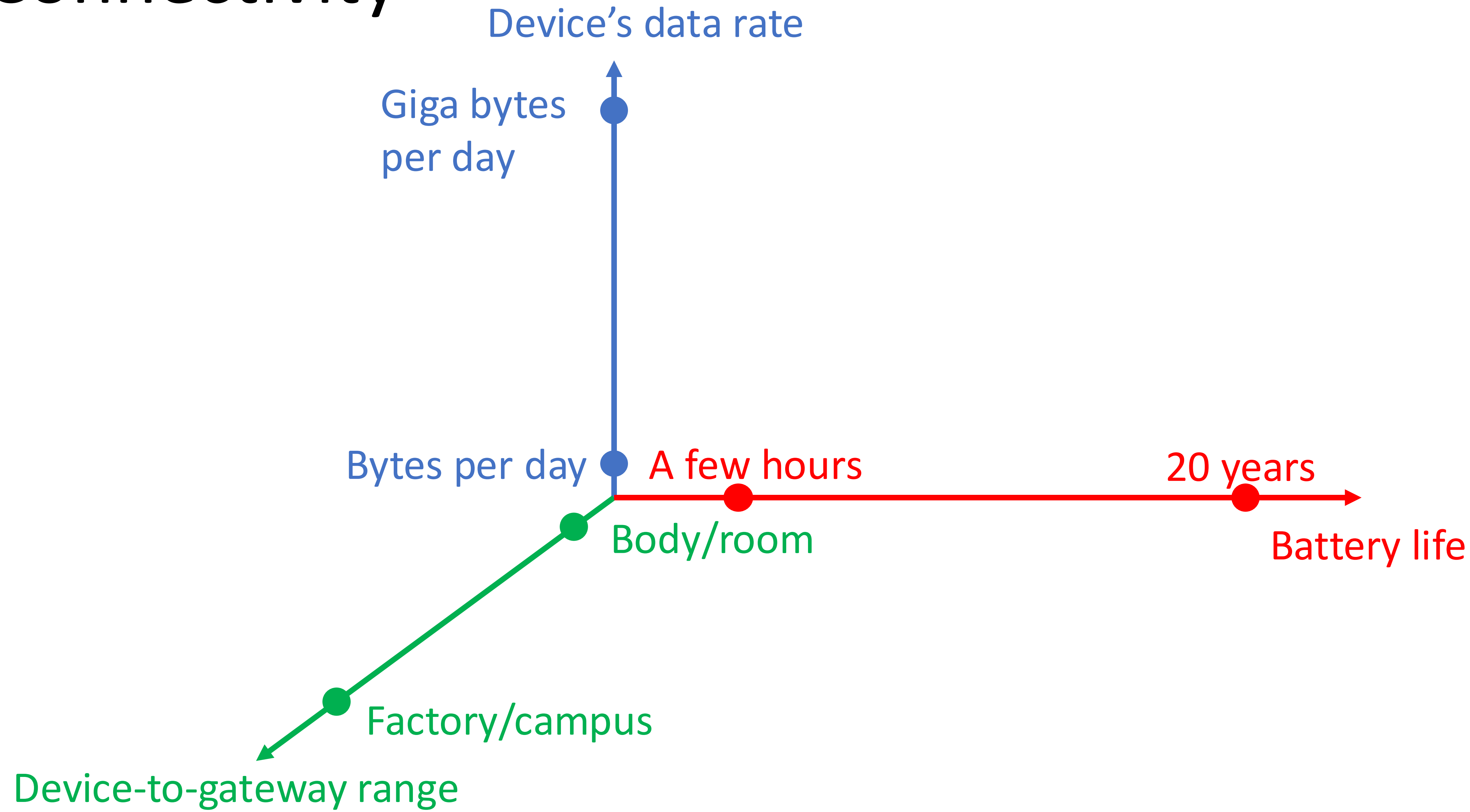
Battery

- Rechargable or not?

Energy harvest

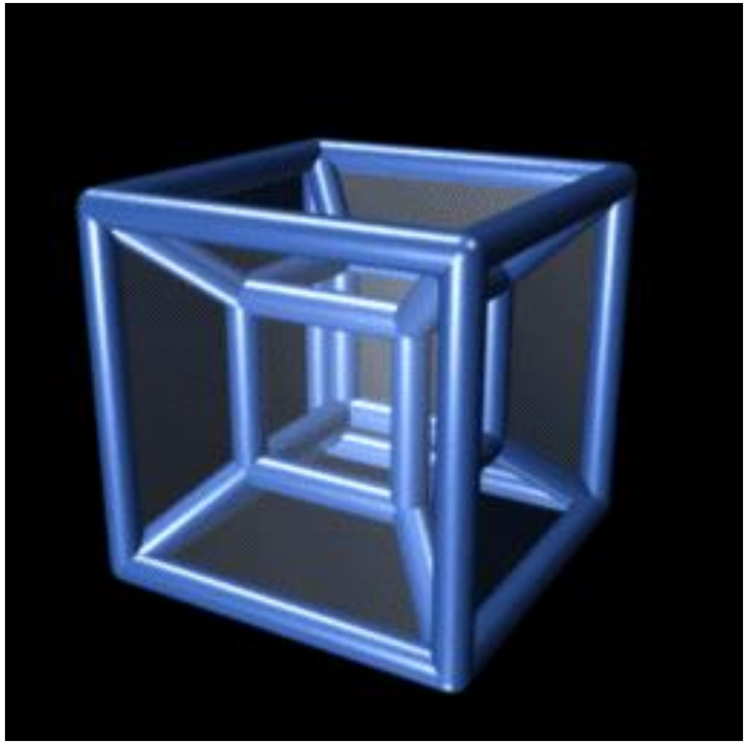
- Ambient, wireless power, e.g., wind, solar, waves, human activity, RF

Connectivity



So, how should I design my sensing system

- It is hard, think about optimizing your goal in a 4D dimension



For example, small sensing systems are usually resource constraint!

So, how should I build my sensing system

My suggestion:

- **Know your design goal**
- One thing at a time (you can only satisfy one design goal)
- Build the prototype as soon as possible
- Iterate a lot

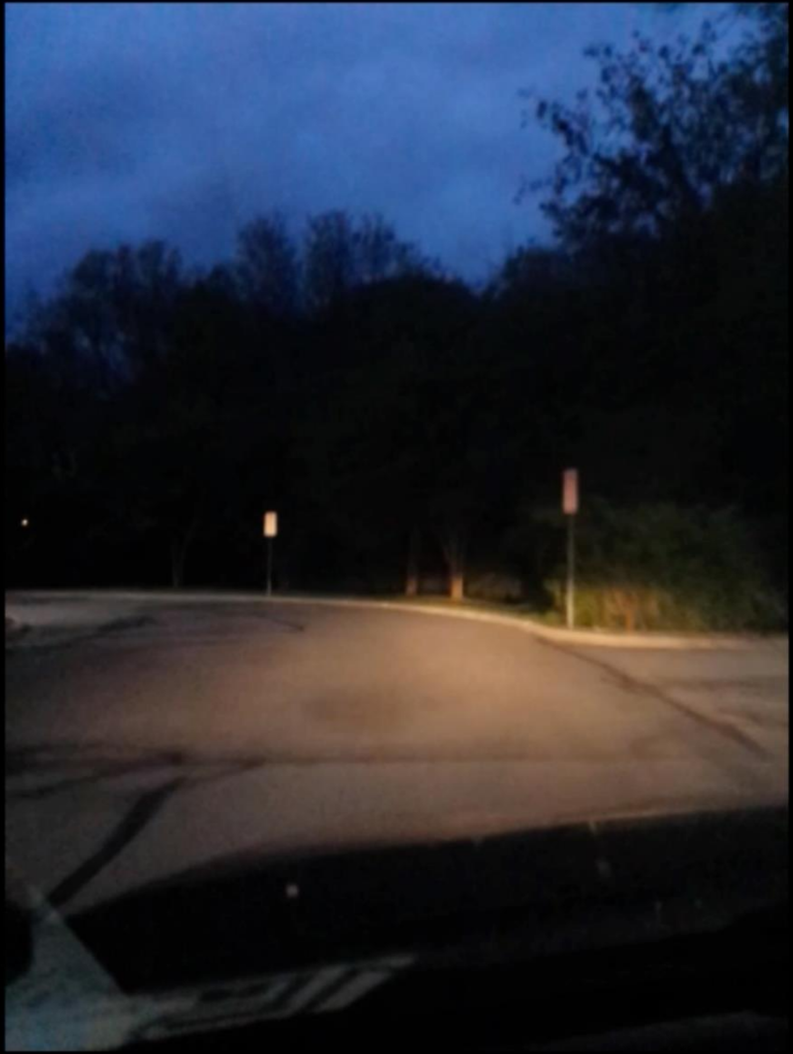
App1: Dashcam Application

- Goal:
  - Design a dashcam (行车记录仪) with only your phone
  - Collision warning system
- Design principles:
  - Use camera for detecting back of a car
  - Use embedded ML to detect cars

App2: Camera-free Driving Assistance System

- Goal:
  - Can we detect dangerous behaviors without using cameras? Because camera cannot “see” at night or bad weathers
- Design choice:
  - Use inertial measurement units (IMU) for detection


WLAN networks available
vsenselane
V-Sense II, 2015, RTCL, UM
magnetic X
System Log
18.8
mph
Waiting For Action
Turned angle: -2.9305122
Turned distance: 0.41673502

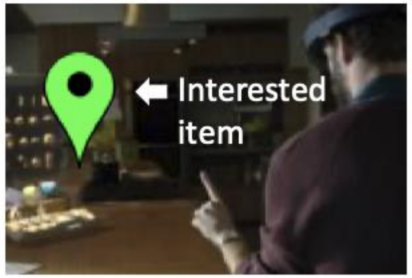


App3: Did You Turn On Your Turn Signal?

- Goal
  - Can we detect turn signal misuse by using accessible device(s)?
- Design choice
  - IMU is great, can we use it here?

App4: Finding Lost Items

(a) Finding item



(b) AR tagging

- Goal:
  - Can we find lost item easily?
- Design choice:
  - Using Bluetooth signal strength for indicating distance. Can we do it better?


9:41 AM
List of BLE Devices
Add
Estimote 1
unknown
Estimote 2
unknown
Estimote 3
unknown
Estimote 4
unknown
Estimote 5
unknown
Selected Beacon
Relative Location
Environment
Line of Sight
Press 'Start Measure' to Measure
Label
Measure
Navigation
STOP
440

App5: Hand Motion Capture

- Goal:
  - Motion capture is important; cameras are not idea due to the visibility issue. Can we do better?
  - The key challenge is the sensing accuracy. IMUs are not idea either
- Design choice
  - Leveraging magnetometers.


Magnetic Tracking

Miniature Robot

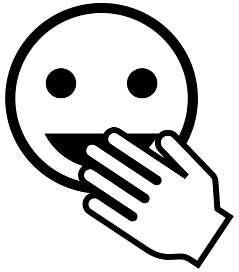
- How to lower energy cost while assuring accuracy?

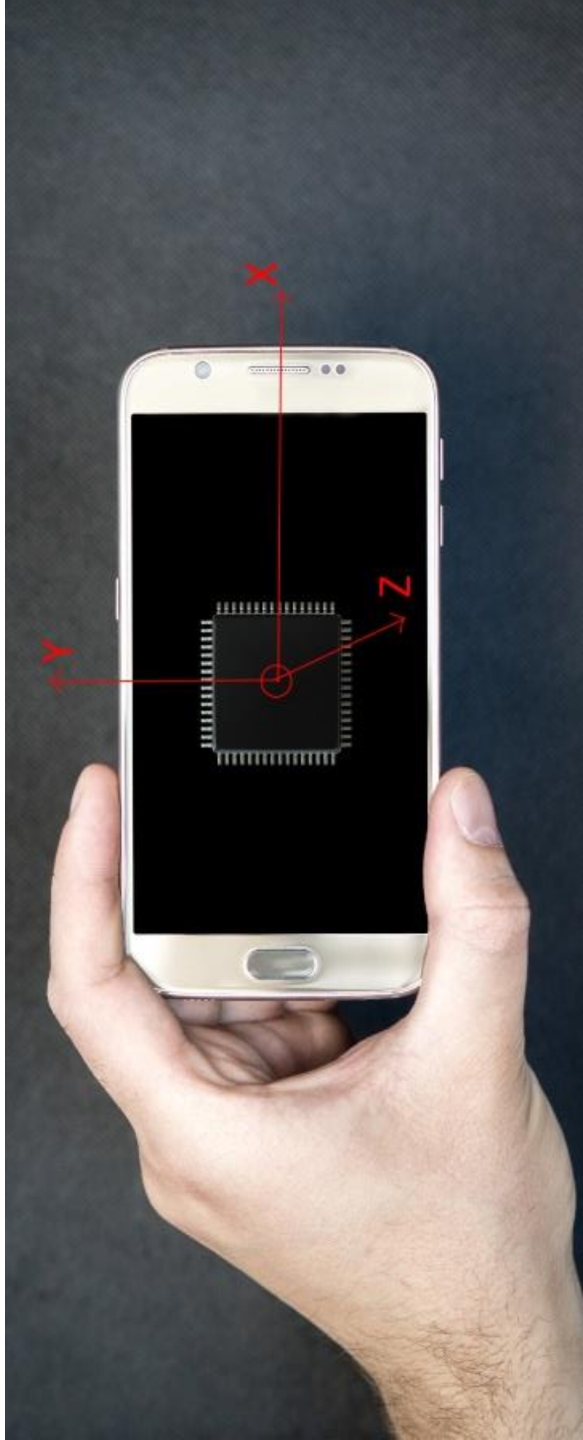
You Can Design Your Own Sensing Systems!

Exemplary Projects

- Safe driving analysis by using accelerometer and gyroscope

- Pervasive face touching detection method



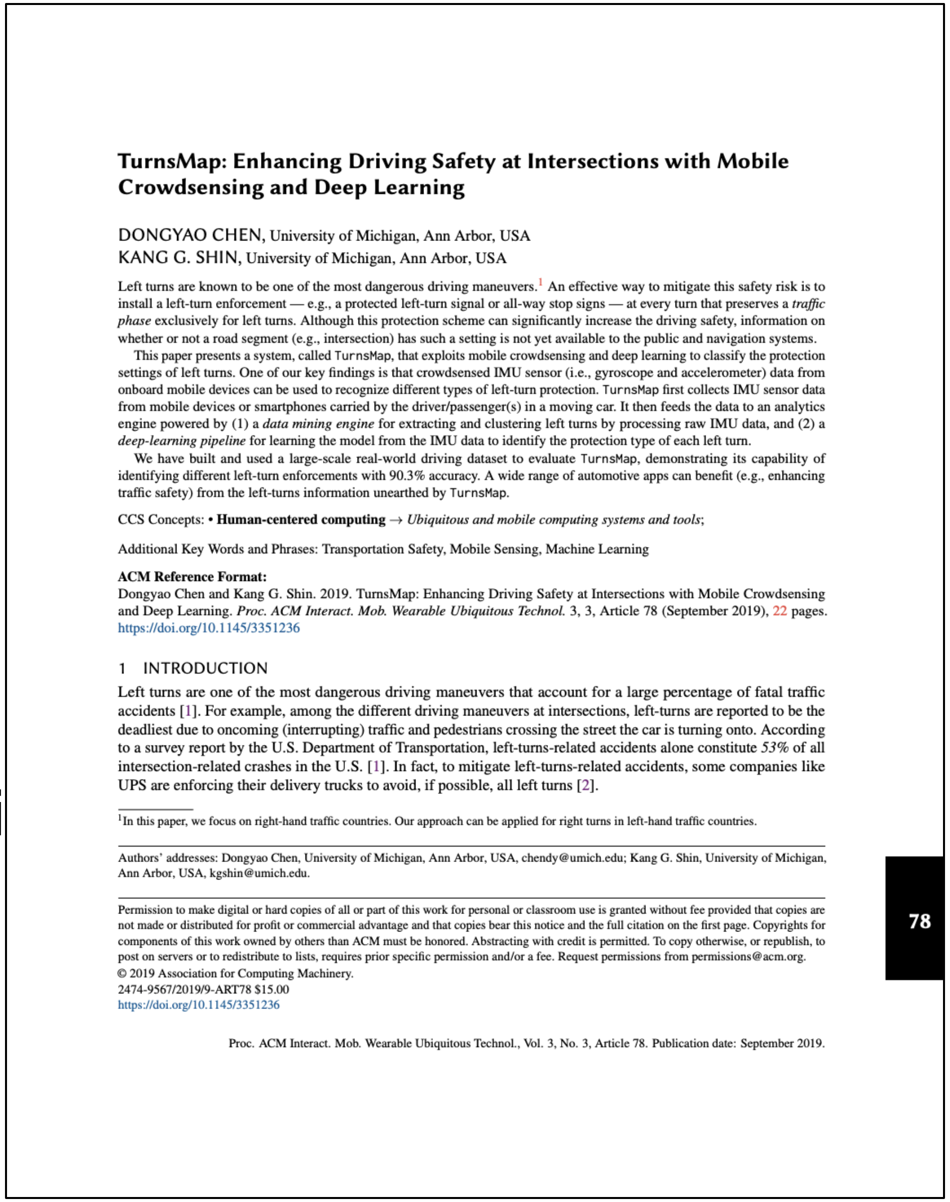


When you're confused, read papers

- Mobile and Sensing systems: MobiCom, MobiSys, SenSys
- Human-Computer Interaction: UbiComp, CHI, UIST, MobileHCI
- Communication protocol: SIGCOMM, NSDI, CoNEXT
- Security system: USENIX Security, CCS, NDSS, IEEE Security & Privacy (Oakland)
- Cross-disciplinary Fields: Nature Communications, Nature Sensors

How to Read a Paper

- First pass
  - Title, Abstract
  - Figures (illustrations? important results?)
  - Intro & conclusions
  - References
- Second pass
  - Overview, related work, or background secti
  - Figures in details
- Third pass
  - Read in detail
  - Mark references for future read



TurnsMap: Enhancing Driving Safety at Intersections with Mobile Crowdsensing and Deep Learning

DONGYAO CHEN, University of Michigan, Ann Arbor, USA
KANG G. SHIN, University of Michigan, Ann Arbor, USA

Left turns are known to be one of the most dangerous driving maneuvers.[1] An effective way to mitigate this safety risk is to install a left-turn enforcement — e.g., a protected left-turn signal or all-way stop signs — at every turn that preserves a *traffic phase* exclusively for left turns. Although this protection scheme can significantly increase the driving safety, information on whether or not a road segment (e.g., intersection) has such a setting is not yet available to the public and navigation systems.

This paper presents a system, called TurnsMap, that exploits mobile crowdsensing and deep learning to classify the protection settings of left turns. One of our key findings is that crowdsensed IMU sensor (i.e., gyroscope and accelerometer) data from onboard mobile devices can be used to recognize different types of left-turn protection. TurnsMap first collects IMU sensor data from mobile devices or smartphones carried by the driver/passenger(s) in a moving car. It then feeds the data to an analytics engine powered by (1) a *data mining engine* for extracting and clustering left turns by processing raw IMU data, and (2) a *deep-learning pipeline* for learning the model from the IMU data to identify the protection type of each left turn.

We have built and used a large-scale real-world driving dataset to evaluate TurnsMap, demonstrating its capability of identifying different left-turn enforcements with 90.3% accuracy. A wide range of automotive apps can benefit (e.g., enhancing traffic safety) from the left-turns information unearthed by TurnsMap.

CCS Concepts: • **Human-centered computing** → *Ubiquitous and mobile computing systems and tools*;

Additional Key Words and Phrases: Transportation Safety, Mobile Sensing, Machine Learning

ACM Reference Format:
Dongyao Chen and Kang G. Shin. 2019. TurnsMap: Enhancing Driving Safety at Intersections with Mobile Crowdsensing and Deep Learning. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 3, Article 78 (September 2019), 22 pages.
https://doi.org/10.1145/3351236

1 INTRODUCTION

Left turns are one of the most dangerous driving maneuvers that account for a large percentage of fatal traffic accidents [1]. For example, among the different driving maneuvers at intersections, left-turns are reported to be the deadliest due to oncoming (interrupting) traffic and pedestrians crossing the street the car is turning onto. According to a survey report by the U.S. Department of Transportation, left-turns-related accidents alone constitute *53%* of all intersection-related crashes in the U.S. [1]. In fact, to mitigate left-turns-related accidents, some companies like UPS are enforcing their delivery trucks to avoid, if possible, all left turns [2].

[1] In this paper, we focus on right-hand traffic countries. Our approach can be applied for right turns in left-hand traffic countries.

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