Lecture 9:
Liquid Sensing

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Lecture Outline

• Overview & Motivation for liquid sensing
• LiquID
• CapCam
• RFIQ
• Comparison between technologies
• Project updates
Liquid Sensing Applications

- Food safety (fake alcohol, baby formula, water)
- Product counterfeiting
- Fake Medicine
- Security (at airports)
How is food/liquid safety testing performed today?

**Electrochemical Tests**
- 1884, MIT, Chemist Ellen Swallow Richards

**RF Spectroscopy**

**Issues?**
Goal: Leverage low-cost, ubiquitous technologies to for liquid sensing (for everyone)

- Low-cost UWB radios: LiquiD [MobiSys’18]
- RFID near-field: RFIQ [HotNets’18]
- Sensor fusion (camera+vibrations): CapCam [MobiSys’19]
RFIQ Challenges

Challenge 1: How can we sense the material without even being in contact with it?

Challenge 2: How can we distinguish the impact of the material inside the bottle from that of multipat?
We developed a system that uses the RFID stickers already on hundreds of billions of items.
We developed a system that uses the RFID stickers already on hundreds of billions of items to sense properties of food in closed containers.
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RFID *wirelessly* interacts with material inside the bottle.
Challenge: Dielectric sensing requires measuring the response over a large bandwidth

RFIDs are designed to be narrowband (to optimize energy-harvesting)

Build on two-frequency excitation from RFind [MobiCom’17] which can sense a bandwidth 10,000x larger than their communication bandwidth without any hardware modification to the RFIDs
Prototype Implementation

Off-the-shelf RFID sticker

RFID reader implemented on software radios (USRP)

Two-frequency excitation setup (400-800MHz)
How can we distinguish the impact of the material inside the bottle from that of the environment?
Multipath vs. Near-field coupling

Multipath: Constructive & destructive interference across different frequencies

Near-field Coupling: Shifts the center frequency of operation
Multipath vs. Near-field coupling

Experiment: Measure the RFID’s response

Wide bandwidth enables to distinguish between multipath and near-field coupling

Train machine learning model to identify adulterants based on these features
Can RFIQ detect tainted alcohol?

Prepared alcohol mixtures with different compositions

- 150 experimental trials
- 10-fold cross-validation

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Average accuracy: 97%
Can RFIQ detect adulterated infant formula?

Prepared infant formula mixtures with different compositions

- 80 experimental trials
- 5-fold cross-validation

Average accuracy: 96%
Caveats (aka Open Questions)

- Testing and training were performed on similar compositions
  - How well would this perform on untrained mixture composition?

- Focused on fixed adulterant and fixed food of interest
  - Would like to generalize to different food and contaminants

- Demonstrated robustness to limited environmental changes
  - Can this really work with significant multipath changes?