MAS.S66
Computational Wireless Sensing

Lecture 4:
Wireless Sensing of Vitals & Backscatter Communication

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Ubiquitous Health & Comfort Monitoring

Can smart homes monitor and adapt to our breathing and heart rates?
Applications?

Personal Health

Baby Sleep

Elderly Health

Adapt Lighting and Music to Mood
But: today’s technologies for monitoring vital signs are cumbersome.

Breath Monitoring

Heart Rate Monitoring

Not suitable for elderly & babies
Can we monitor breathing and heart rate from a distance?
Vital-Radio

• Technology that monitors breathing and heart rate remotely with 97% accuracy

• Can monitor multiple users simultaneously

• Operates through walls and can cover multiple rooms
Idea: Use wireless reflections off the human body
Idea: Use wireless reflections off the human body
Problem: Localization accuracy is only 12cm and cannot capture vital signs.

Why? How did we compute the resolution?
Problem: Localization accuracy is only 12cm and cannot capture vital signs.

Why does phase allow us to get the distance at higher granularity?

Solution: Use the phase of the wireless reflection.
Wireless wave has a phase:

- Chest Motion changes distance
- Heartbeats also change distance

Distance to the body can be computed by analyzing the wireless reflections. However, localization accuracy is only 12cm and cannot capture vital signs.

Solution: Use the phase of the wireless reflection.

Why did we need FMCW if phase is so accurate?
Let’s zoom in on these signals
How do we get from here to extracting breathing rate and heart rate?
What happens when a person moves his limb?
What happens when a person moves his limb?

Band-pass filter the cleaned signals to extract breathing and heart rate.
What happens with multiple users in the environment?
Reflections from different objects collide

Problem: Phase becomes meaningless!
Solution: Use WiTrack as a filter to isolate reflections from different positions
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Recall Formulation with FMCW

- Output of FFT with reflectors
- Looked at the amplitude only
- Now will also look at phase

How do we deal with multipath?
Putting It Together

Step 1: Transmit a wireless signal and capture its reflections

Step 2: Isolate reflections from different objects based on their positions

Step 3: Zoom in on each object’s reflection to obtain phase variations due to vital signs
Vital-Radio Evaluation

Vital-Radio's antennas
Vital-Radio Evaluation

Baseline:
- FDA-approved breathing and heart rate monitor

Experiments:
- 200 experiments
- 14 participants
- 1 million measurements
Accuracy vs. Orientation

User is 4m from device, with different orientations

Accuracy (%)

Forward | Right | Backward | Left

Breathing Rate | Heart Rate

Why does it work when facing away?
Accuracy for Multi-User Scenario

Multiple users sit at different distances

Nearest (at 2m) | Middle (at 4m) | Furthest (at 6m)

Breathing Rate
- Nearest: 99.4%
- Middle: 97.3%
- Furthest: 98.2%

Heart Rate
- Nearest: 98.7%
- Middle: 98.9%
- Furthest: 98.7%
Accuracy for Tracking Heart Rate

Measure user’s heart rate after exercising

Vital-Radio accurately tracks changes in vital signs
Vital-Radio Limitations

- Minimum separation between users: 1-2m
- Monitoring range: 8m
- Collects measurements when users are quasi-static
Baby Monitoring

Works for multiple people and through walls
Rest of This Lecture

• Introduction to RFIDs

• WISP design and backscatter communication (Ian)

• RFID localization (Saad)
RFID (Radio Frequency IDentification)

Access Control

Security Sensitive Applications

Long-Range Payment Systems

Inventory control

Tracking & Localization
RFID (Radio Frequency IDentification)

Access Control

Inventory control

Largest and fastest growing market of networked devices by unit sale:
5 billion sold in 2016 alone

Long-Range Payment Systems
Basic Principle of Operation

RFID: cheap battery-free stickers

Reply to wireless reader with a unique identifier
History of RFIDs

- **WWII:** Aircraft IFF Transponder
  - Identify Friend or Foe, Transmitter-Responder
- **1945:** “The Thing” or “The Great Seal Bug”
  - “Gift” given by the Soviets to American ambassador
- **1980s:** development of E-Toll transponders
- **2004:** Auto-ID lab at MIT led to the birth of modern battery-free RFIDs
  - Goal: supply chain optimization
  - Paper: “Towards the 5 cent tag”
Types of RFIDs

Frequency Range

- UHF (~900MHz)
- HF (13.56MHz)
- LF (120-150kHz)

Range of Operation

- Long range (few m)
- Short range (few cm)

Power consumption

Where do these fall?

"Need to tap"
Types of RFIDs

- **Frequency Range**
  - UHF (~900MHz)
  - HF (13.56MHz)
  - LF (120-150kHz)
- **Passive (battery-free)**
- **Semi-Passive or Semi-Active**
- **Active (with battery)**
- Other less common versions: 2.4GHz, UWB (3-10GHz), etc.

- **Power consumption**
- **Cost**
  - few cents
  - 10s to 100s of $
How does an RFID power up?

Harvests Energy from Reader’s Signal

Inductive Coupling

- LF (120-150kHz)
- Magnetic (Near Field)
- Coil

HF (13.56MHz)

Backscatter

- UHF (~900MHz)
- Electromagnetic (Far Field)
- Antenna
Inductive Coupling

Mutual inductance?
Impedance switching?

Power Source  Oscillator  Rectifier  Load

Mutual inductance?
Impedance switching?