MAS.S60:

How to Wirelessly Sense Almost Anything

Lecturers

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Website

http://www.mit.edu/~fadel/courses/MAS.s60/index.html

Make sure you're on Slack

Let's start with some trivia

1. How many "connected" (IoT) devices are there today?

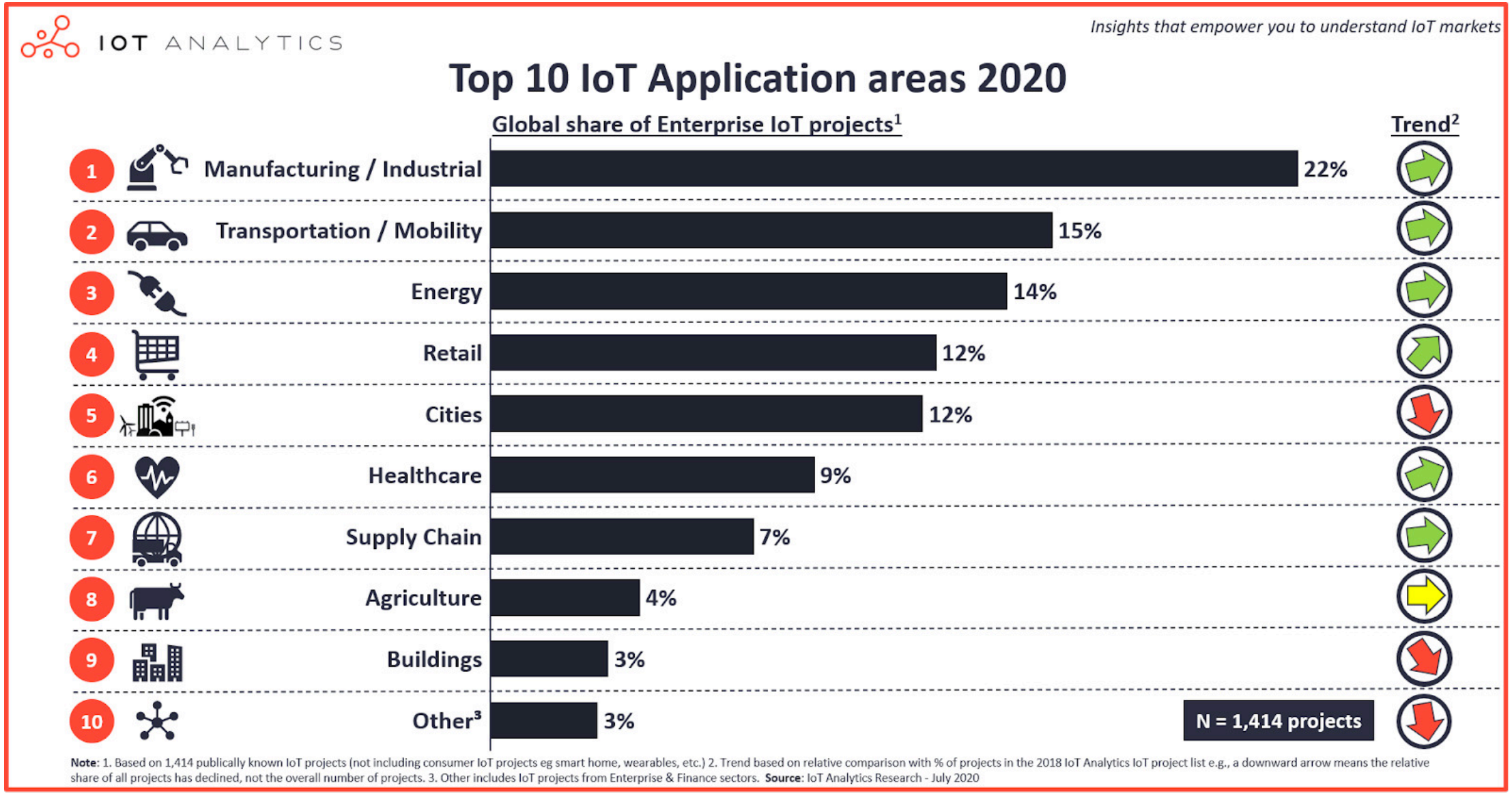
2. What is the most widely deployed IoT/ connected device?

3. Which company was listed on NYSE as IOT? (And when was it founded?)

4. How was radar discovered?

5. Why is there growing interest in LEO satellites (e.g., SpaceX, Blue Origin)?

Where is wireless used today? (Technologies, Applications)



Connected solutions bring increased vehicle uptime for our customers, better safety for drivers, operators and other road users and of course – less emissions of carbon dioxide.

– *Martin Lundstedt, CEO of the Volvo Group, Oct 2019*

How to Wirelessly Sense Almost Anything

sensing the physical world & transmitting data wirelessly

sensing via the wireless signals themselves

This class will cover both of these

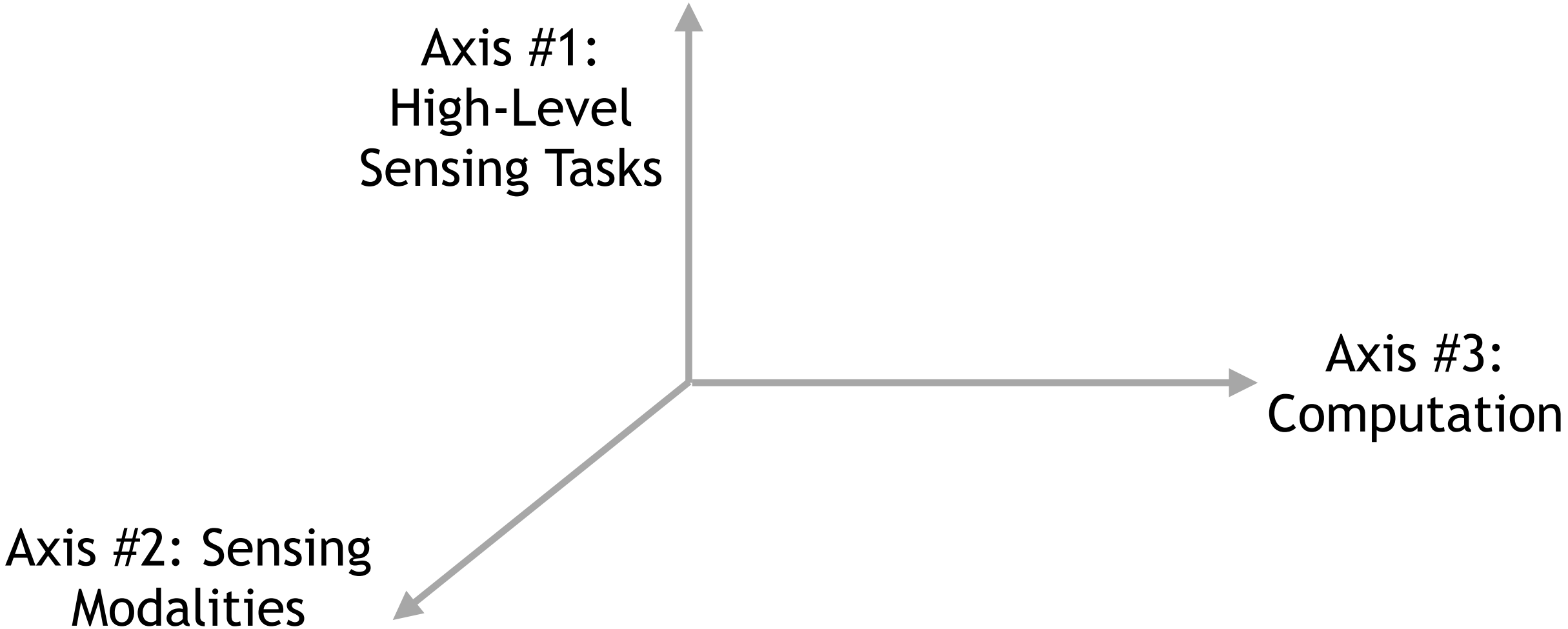
<u>Fundamental primitives</u>

- Signal propagation
- piezoelectricity
- energy harvesting
- …

<u>System design principles</u>

- localization
- networking
- storage
- …

Wireless Sensing Systems are designed along 3 axes



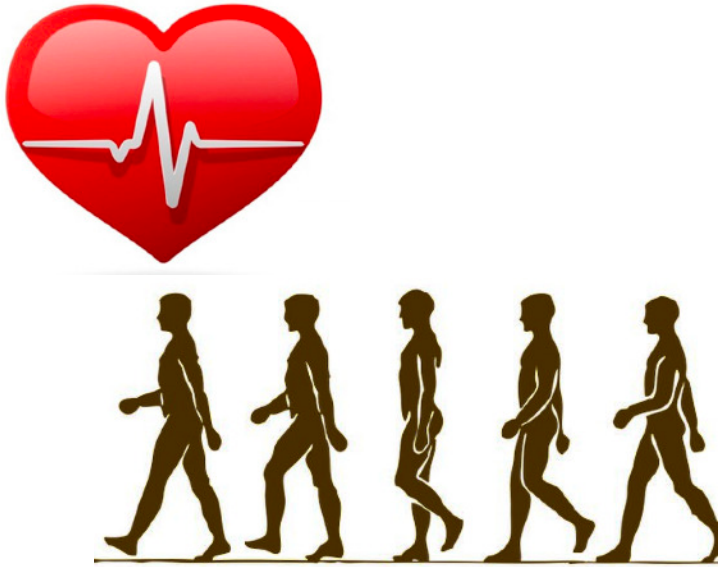
Axis #1: High-Level Sensing Tasks

WHAT do we want to sense?

(1) Location

- Outdoors, indoors
- Humans, objects

(2) Dynamics



- Velocity, Acceleration
- Activities, Monitoring

(3) Properties

- Identify, Characterize
- Environment, Humans

Axis #2: Sensing Modalities

HOW will we perform this sensing?

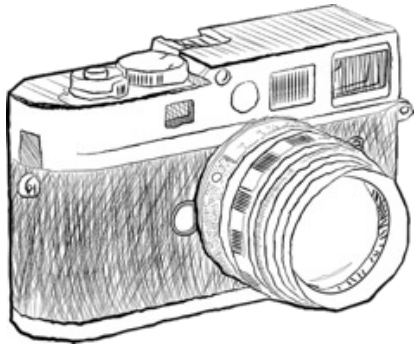
(1) Radio

- Wi-Fi
- Cellular
- Bluetooth

(2) Acoustic/ Ultrasonic

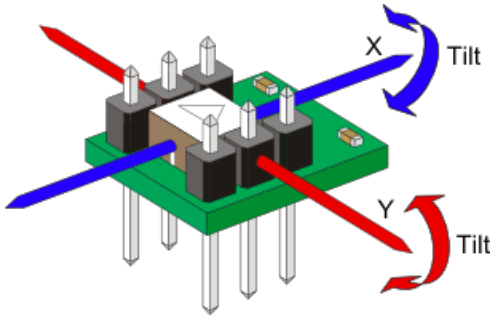
- Voices
- Engines
- Animals

(3) Visual



- Camera
- Infrared
- LIDAR

(4) Inertial



- Accelerometer
- Gyroscope
- Magnetometer

Axis #3: Computation

HOW can we use the sensing modalities to achieve the sensing task?

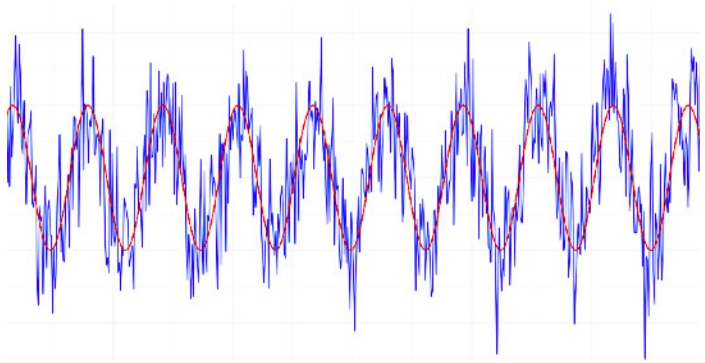
(1) Networking

- Connectivity
- Communication

(2) Data Management

- Storage
- Queries

(3) Signal Processing & Inference



- Digitization
- Inference & Machine Learning

(4) Security

- Digital, Analog
- Trust, Privacy

Wireless Sensing System Architecture

Axis #1: Sensing Tasks	(1) Location	(2) Dynamics	(3) Properties	
Axis #3: Computation	(1) Networking	(2) Data Management	(3) Signal Processing & Inference	(4) Security
Axis #2: Sensing Modalities	(1) Radio	(2) Acoustic/ Ultrasonic	(3) Visual	(4) Inertial

Will cover 11 topics.
One topic/lecture

1. Localization

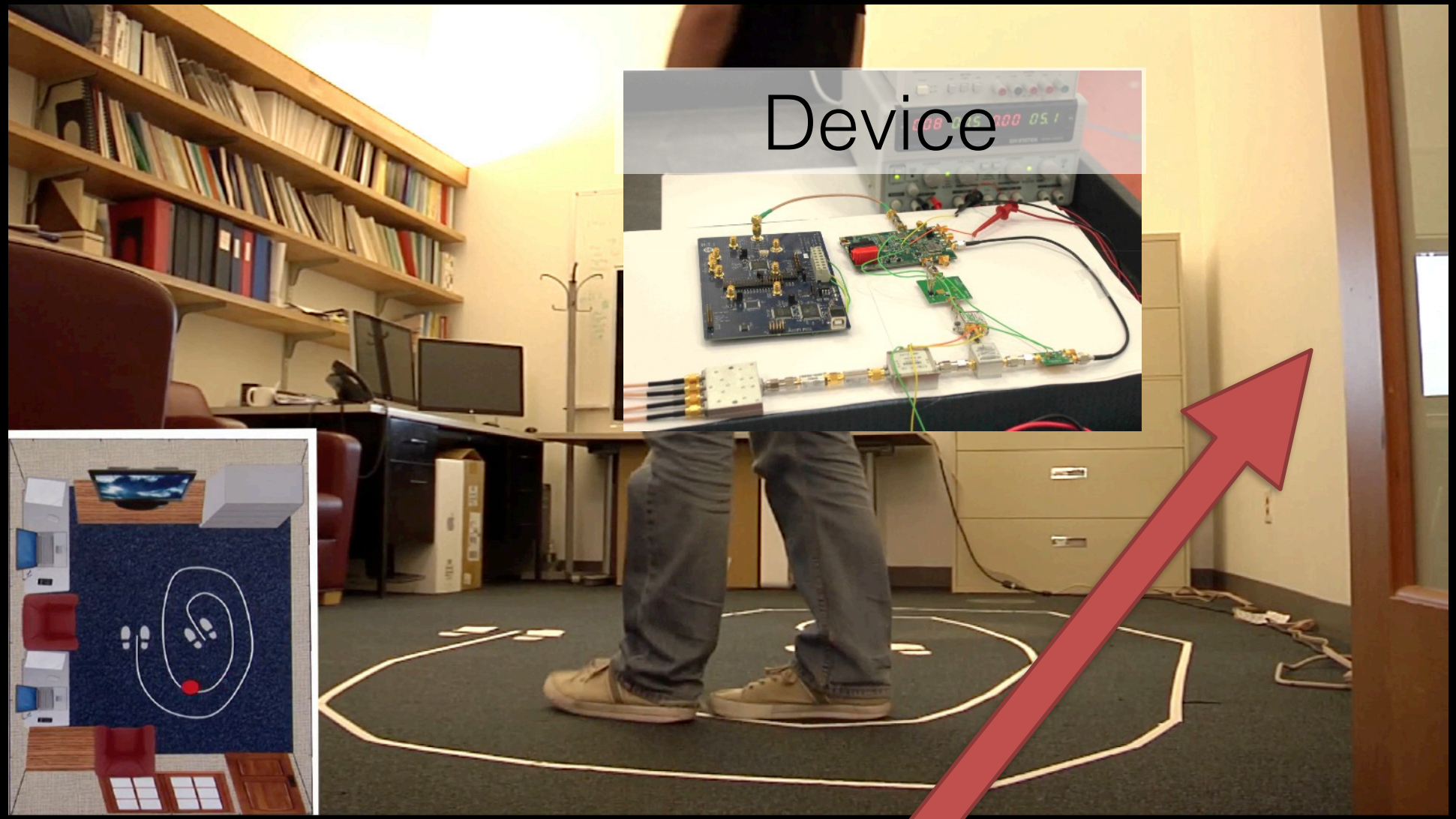
Indoor Positioning (Cricket, 2001)

Accurate Localization (Cricket, 2003)

Modern Example of Localization?

2. Contactless Sensing

Device-Free Localization (WiTrack, 2014)



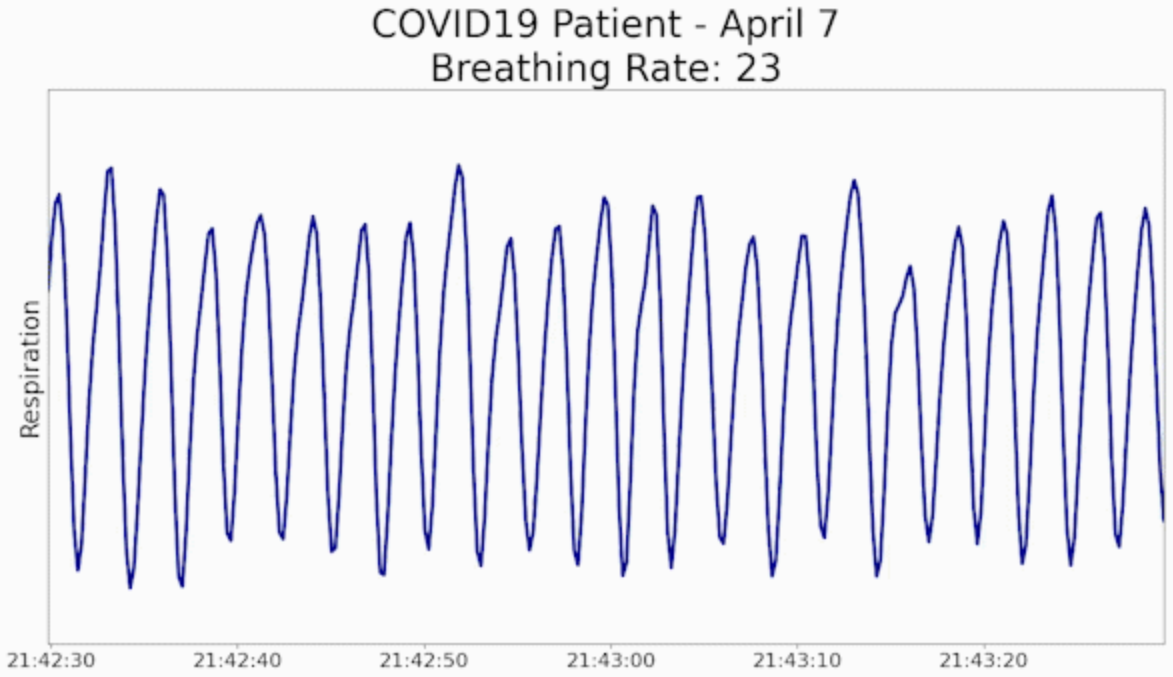
Seeing Through Walls (RF-Capture, 2015)

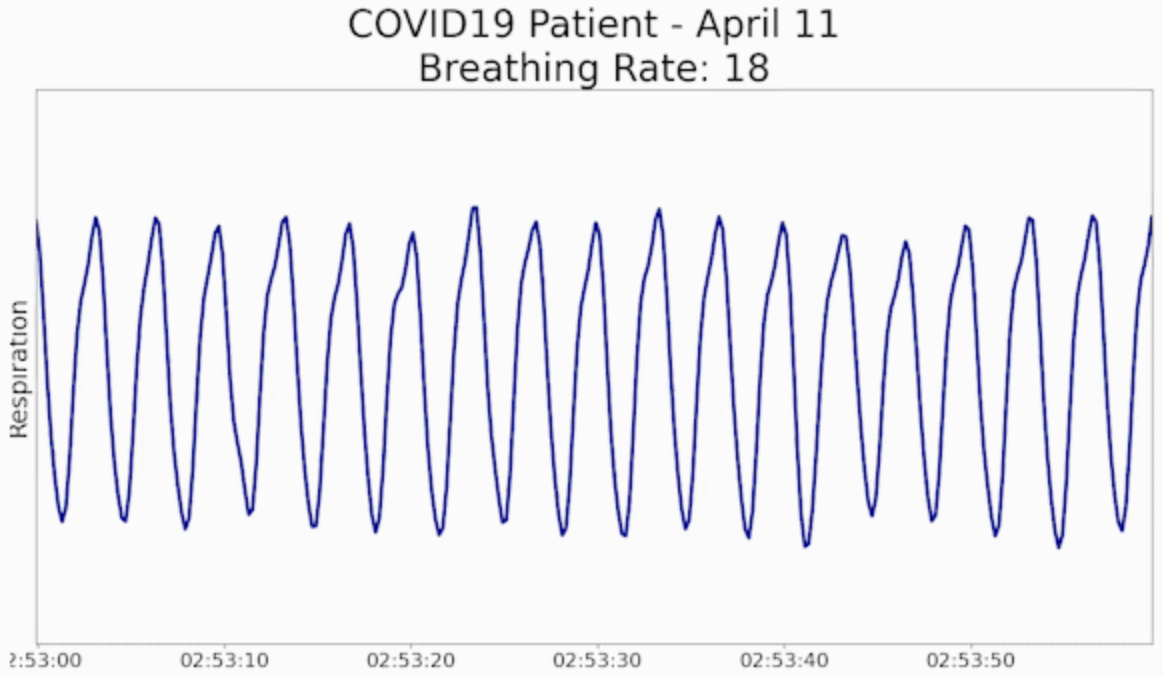
AI Senses People Through Walls

Breath Monitoring using Wireless (Vital-Radio, 2015)

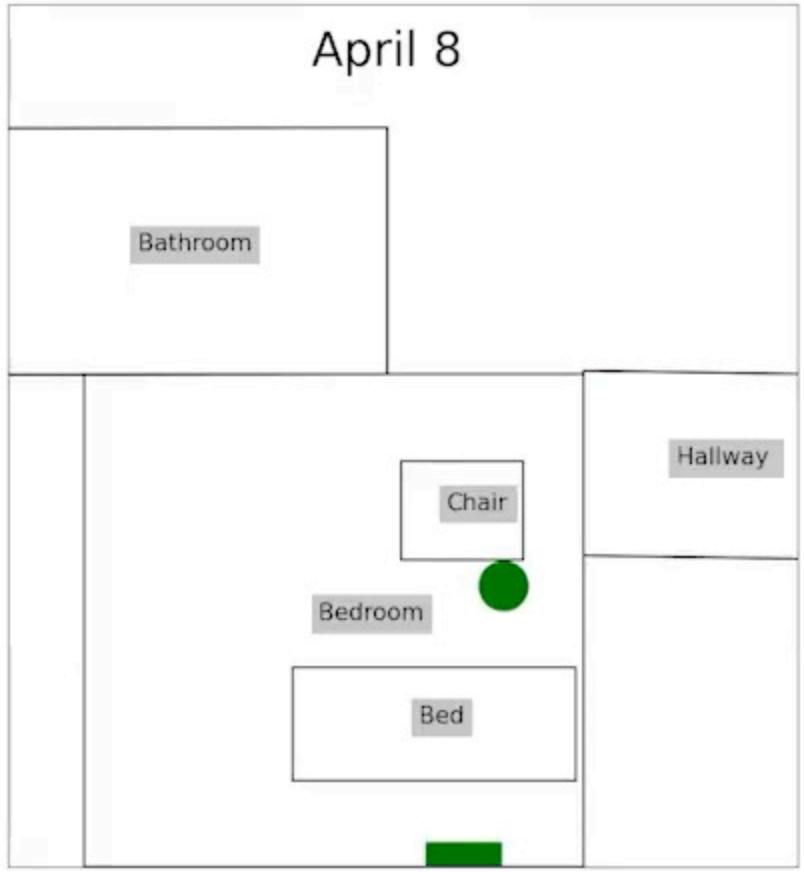
Where/when would it be helpful to monitor respiration?

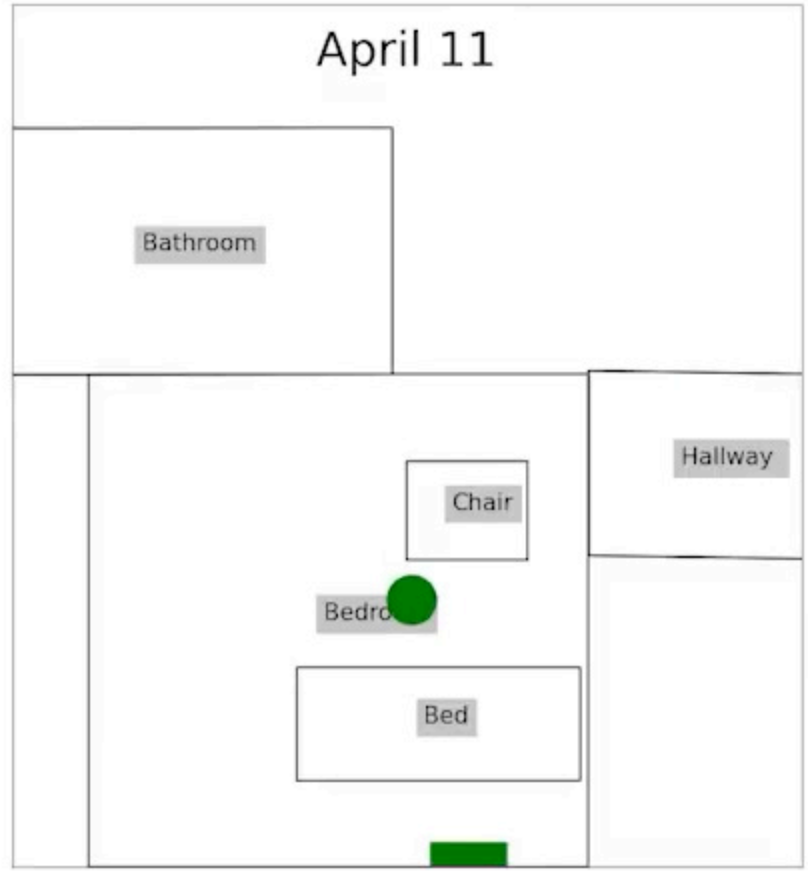
Monitoring COVID-19 Patient





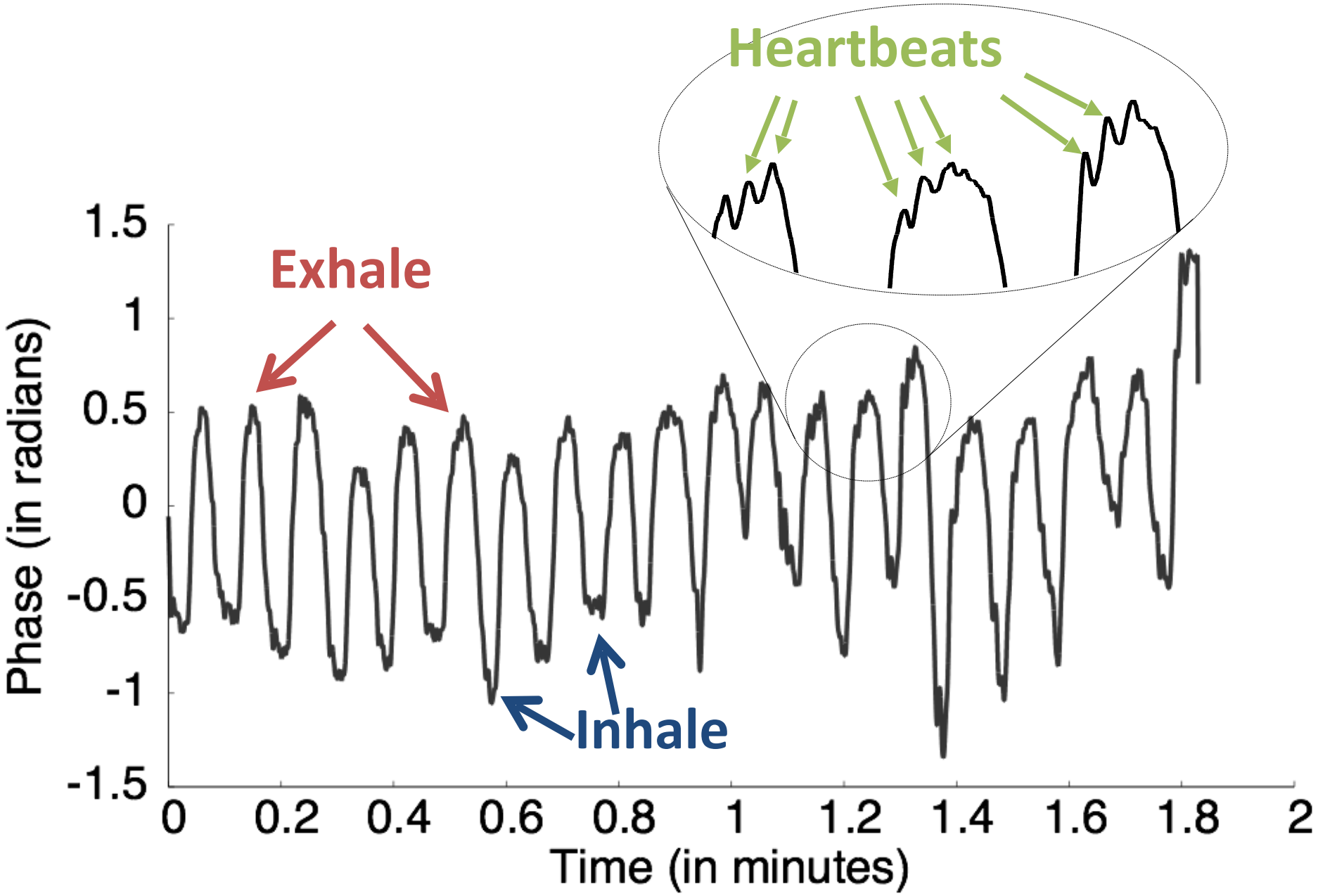
The patient's breathing decreased as it went back to normal





The patient's movements also demonstrate a marked improvement.

Let’s zoom in on respiration signals


Heartbeats
Exhale
Inhale
Phase (in radians)
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (in minutes)

Baby Monitoring

What else can we sense using the signals themselves?

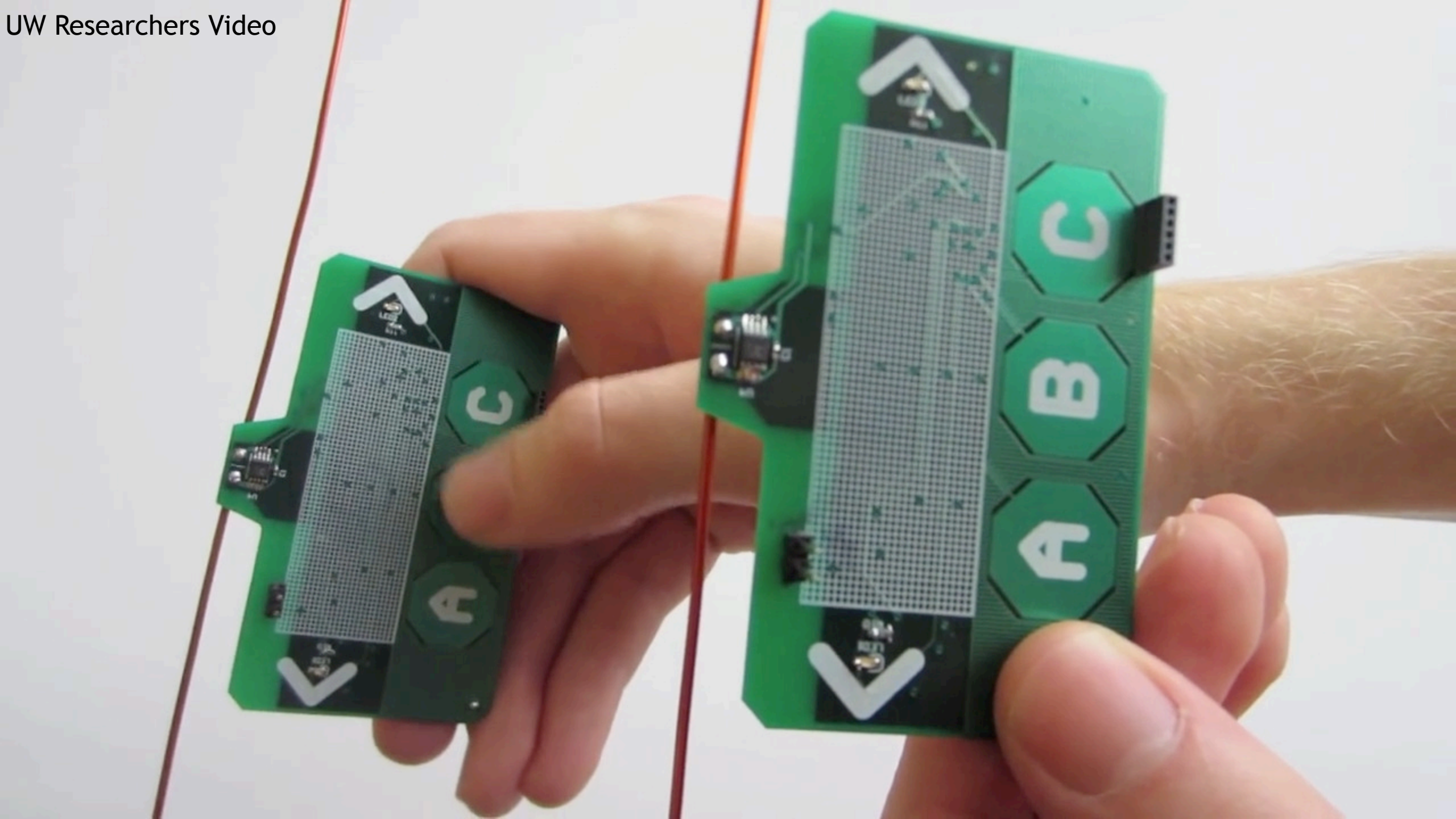
3. Communications

- Will cover fundamentals of comms (across Bluetooth, WiFi, cellular)
- These wireless technologies can work on Mars and the moon, but where can’t they work?

Did you know that a submerged submarine cannot wirelessly communicate with an airplane?

4. Battery-Free Computing

- What is battery-free computing?
- What's the most common battery-free computer?


UW Researchers Video
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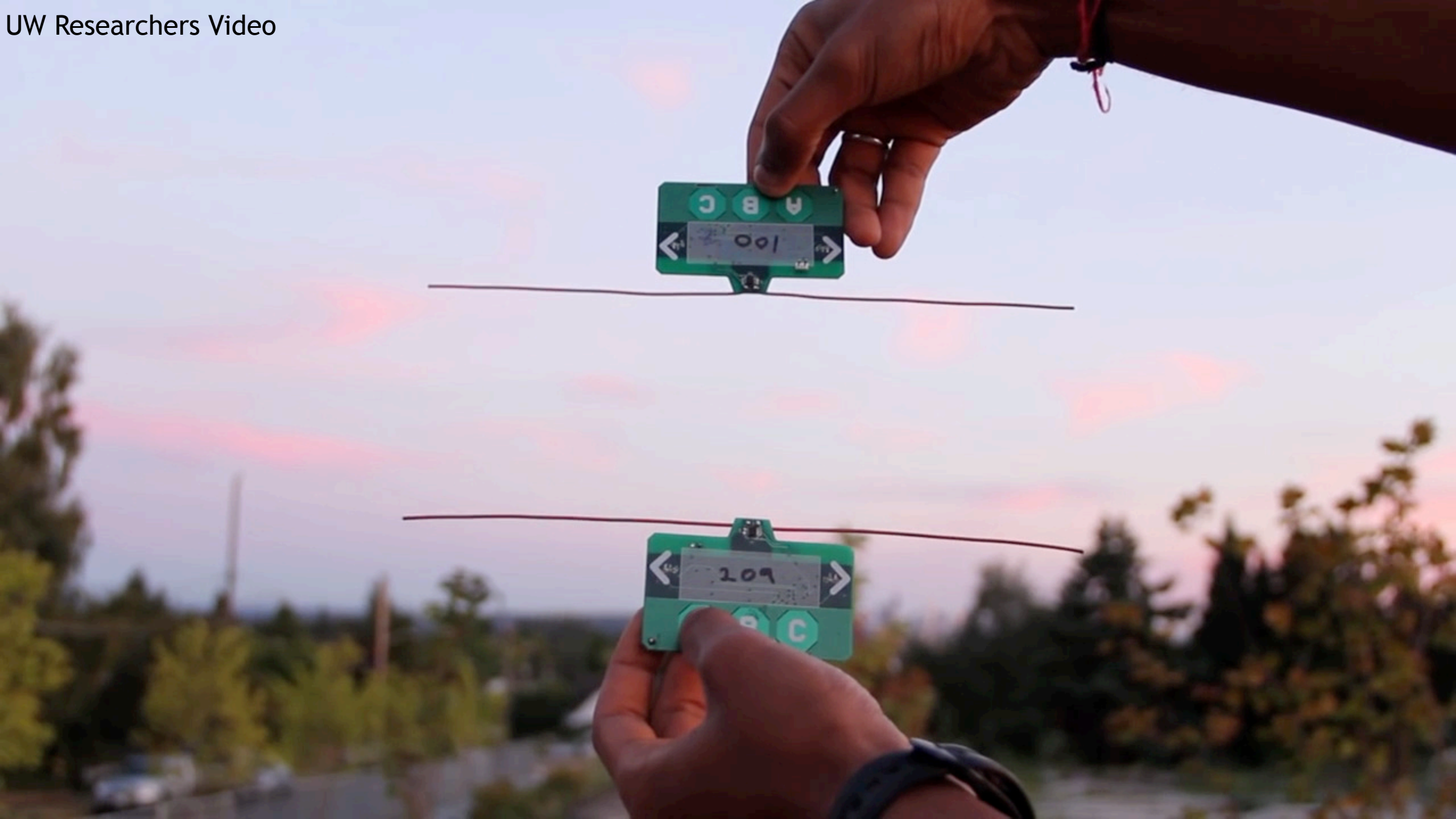
UW Researchers Video



5. Hacking Sensors

WIRED BACKCHANNEL BUSINESS CULTURE GEAR IDEAS SCIENCE MORE SIGN IN SUBSCRIBE

An Alexa Bug Could Have Exposed Your Voice History to Hackers

Amazon has patched the flaw, but its discovery underscores the importa
your voice assistant interactions.

BBC Sign in Home News Sport Reel Worklife Travel Future C

NEWS

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Tech

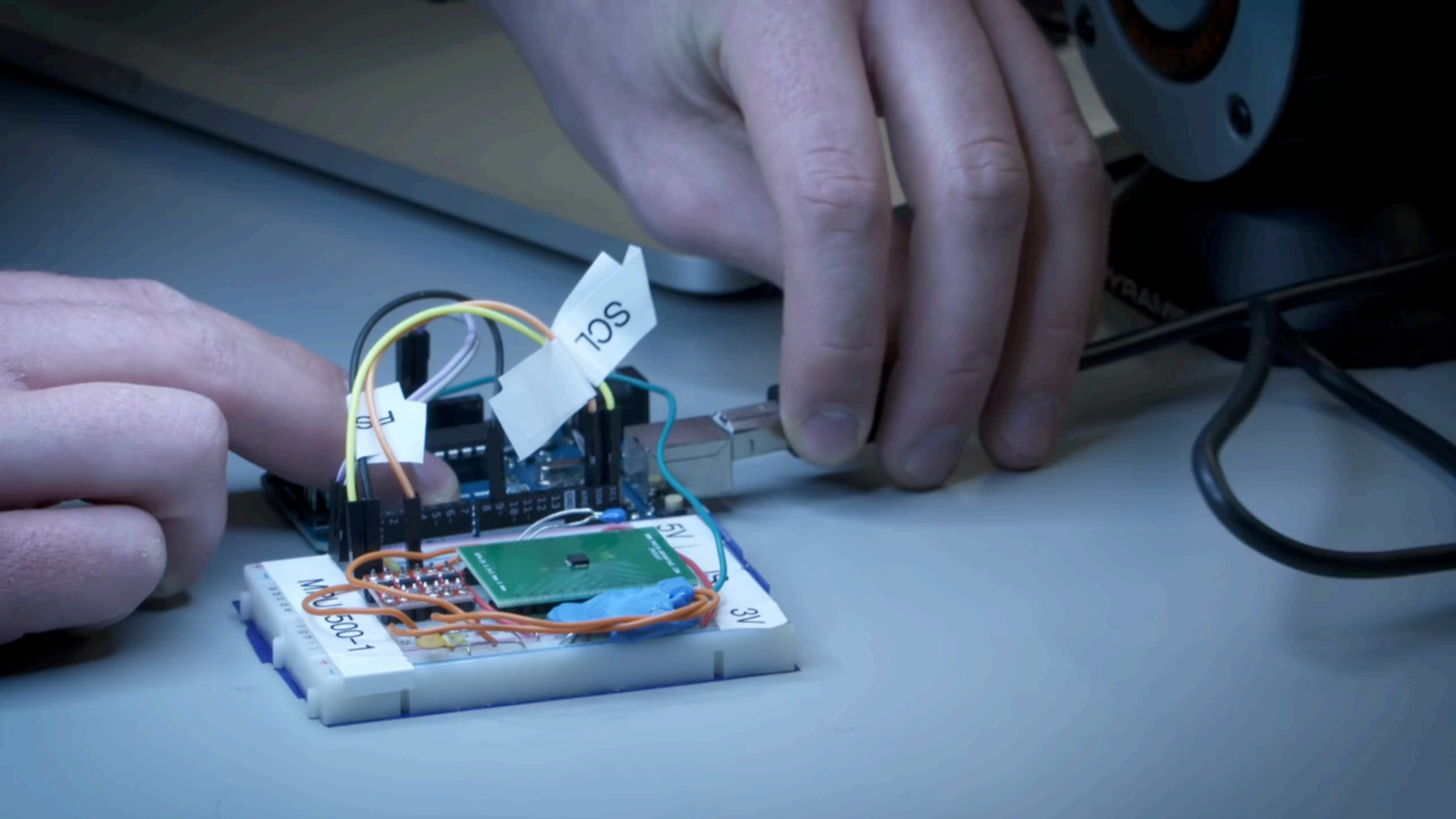
'Smart' home devices used as weapons in website attack

22 October 2016

ComputerWeekly.com IT Management Industry Sectors Technology Topics Search Computer Weekly

100,000 cheap wireless cameras vulnerable to hacking

TITANIUM BULLET TWEETER
PYRAMID


SCL
5V
3V
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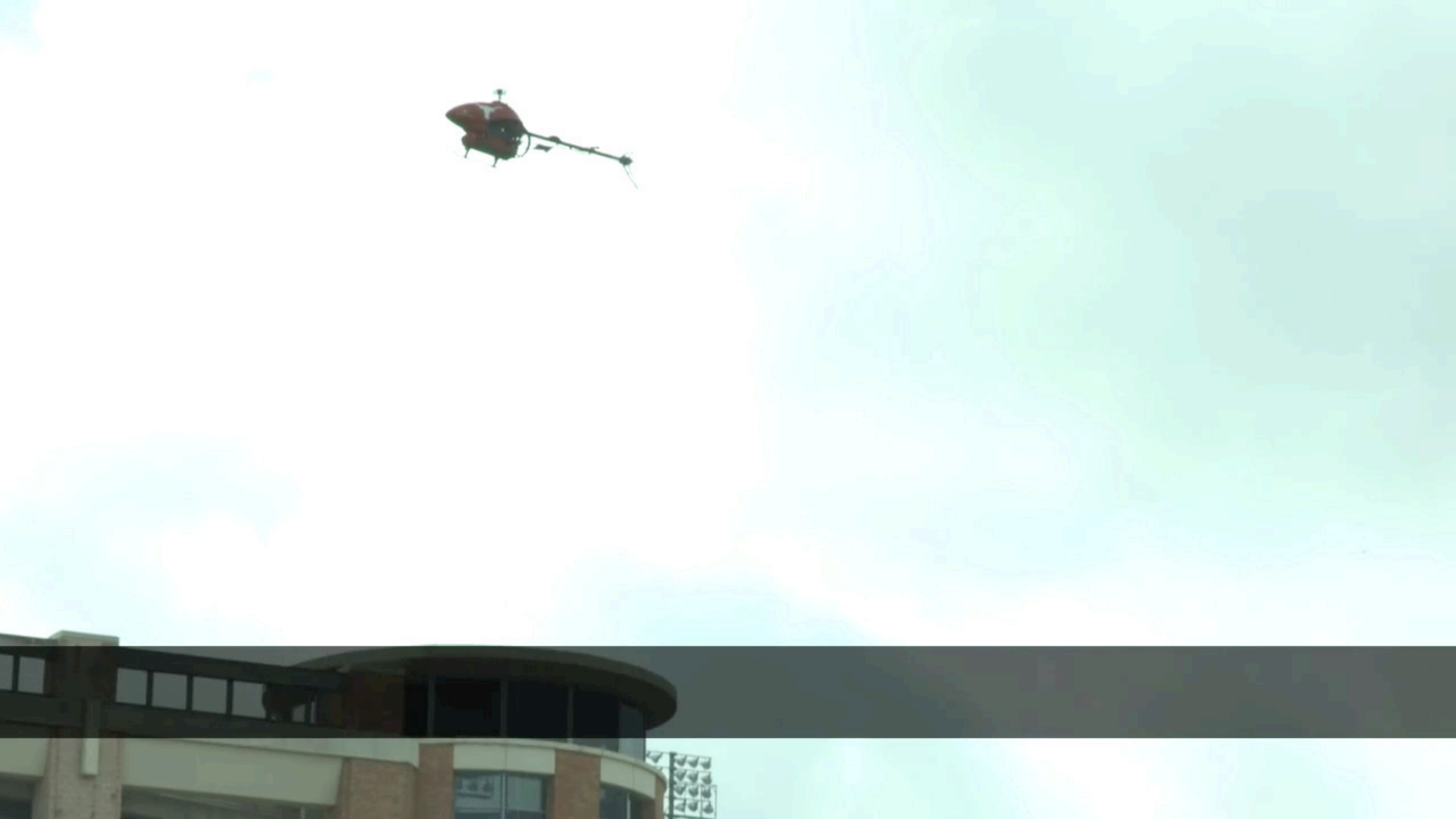
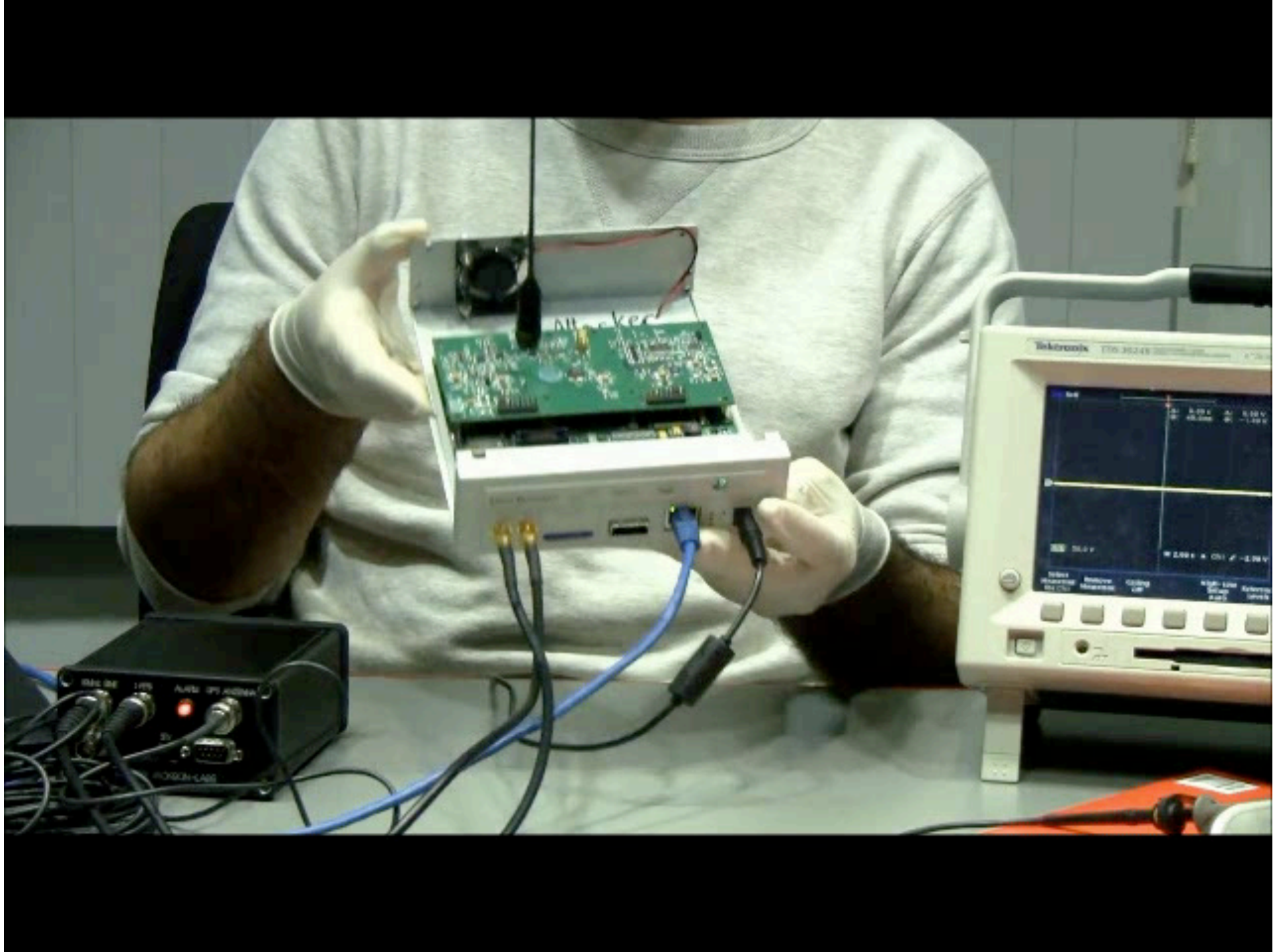
CSE COMPUTER SCIENCE AND ENGINEERING
UNIVERSITY OF MICHIGAN

LIGHT COMMANDS

Drone Security
Spoofing GPS Signals



Pacemaker Security
Wireless Control of Pacemaker

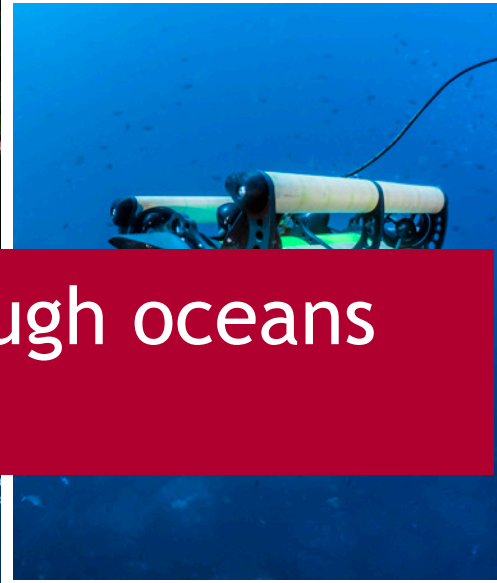

Tektronix

6. Ocean IoT

Taking the Internet of Things Underwater

"More than 95% of ocean remains unobserved and unexplored."

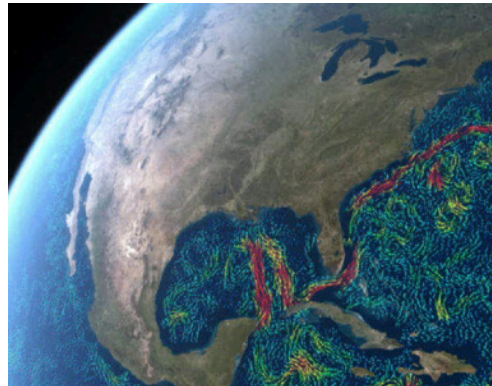
- NOAA, 2018

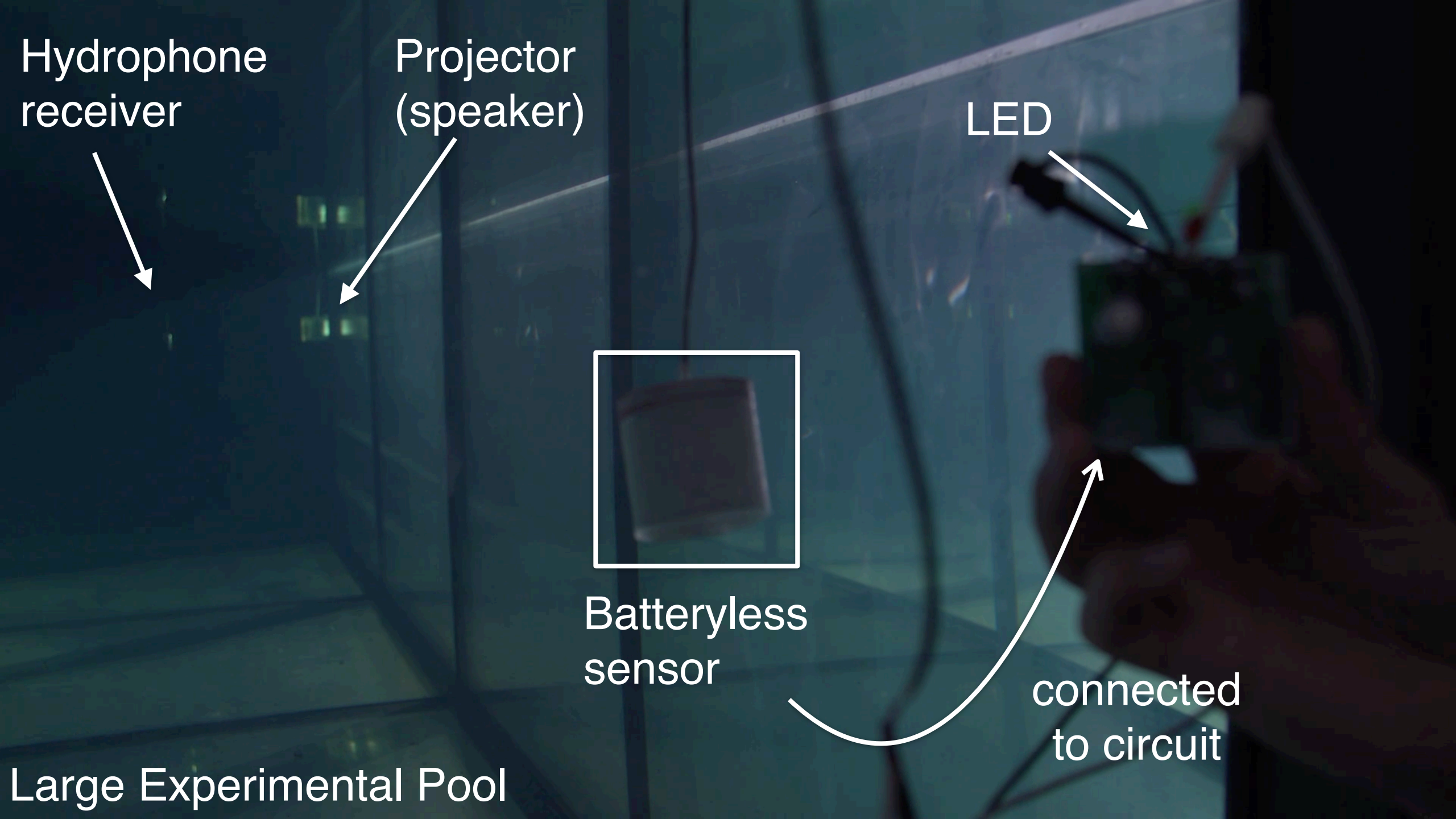


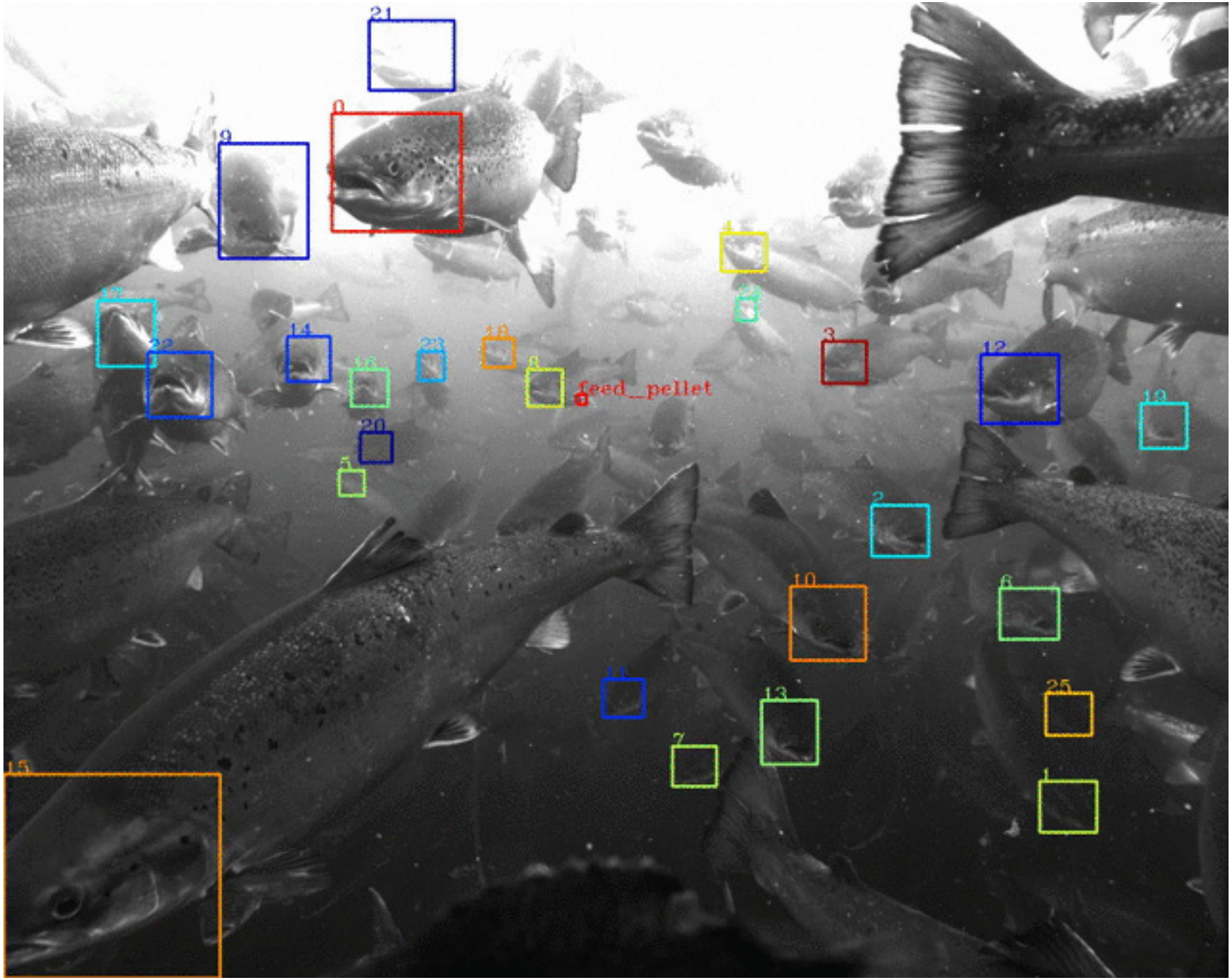
Less than 1 in a million of IoT is underwater, even though oceans cover more than 70% of the planet

Aquaculture is the "fastest growing food sector"

- UN Food & Ag org, 2022




Hydrophone receiver
Projector (speaker)
LED
Batteryless sensor
connected to circuit
Large Experimental Pool


feed_pellet

7. Millimeter Waves

- Where are millimeter waves being used?
- Comms/Sensing

Through Fog High Resolution Imaging Using Millimeter Wave Radar

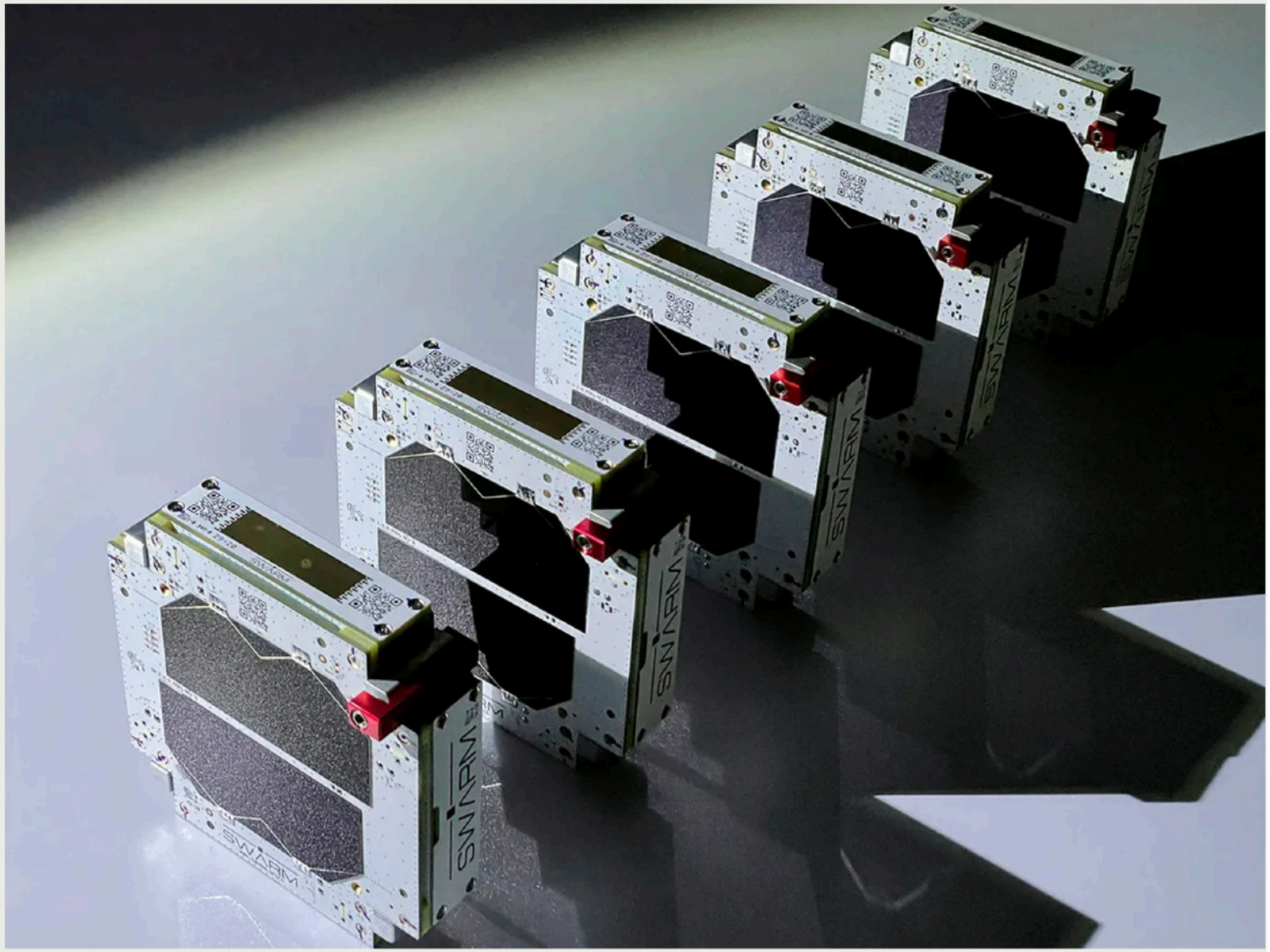
Junfeng Guan, Sohrab Madani, Suraj Jog,
Saurabh Gupta, Haitham Hassanieh
University of Illinois at Urbana-Champaign

8. Low-Power Wide-Area Networks

- How are they different from Bluetooth, WiFi, cellular?
- Where are they used?

Swarm Takes LoRa Sky-High ›The satellite company has adapted the popular IoT technology for use in its constellation

BY MICHAEL KOZIOL | 23 MAR 2021 | 4 MIN READ |



9. Smart Surfaces

What else do you envision
these metasurfaces can help?

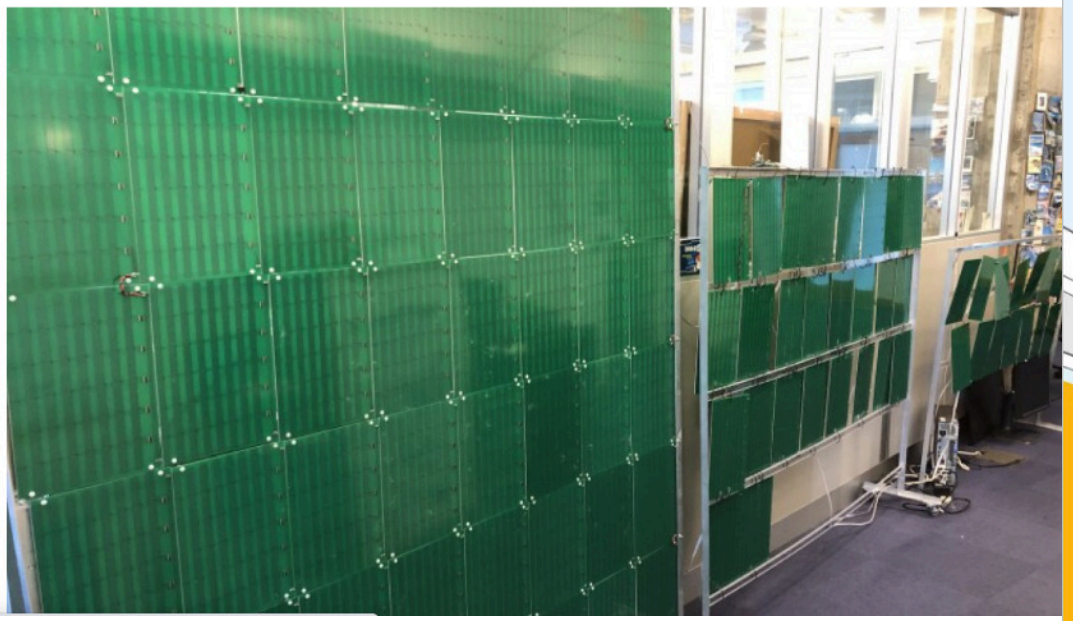
The 'smart wallpaper' that can boost Wi-Fi signals tenfold

The wallpaper, designed by engineers at the Massachusetts Institute of Technology, could solve the problem of "not-spots" in the home

By Matthew Field

3 February 2020 • 2:40pm

14

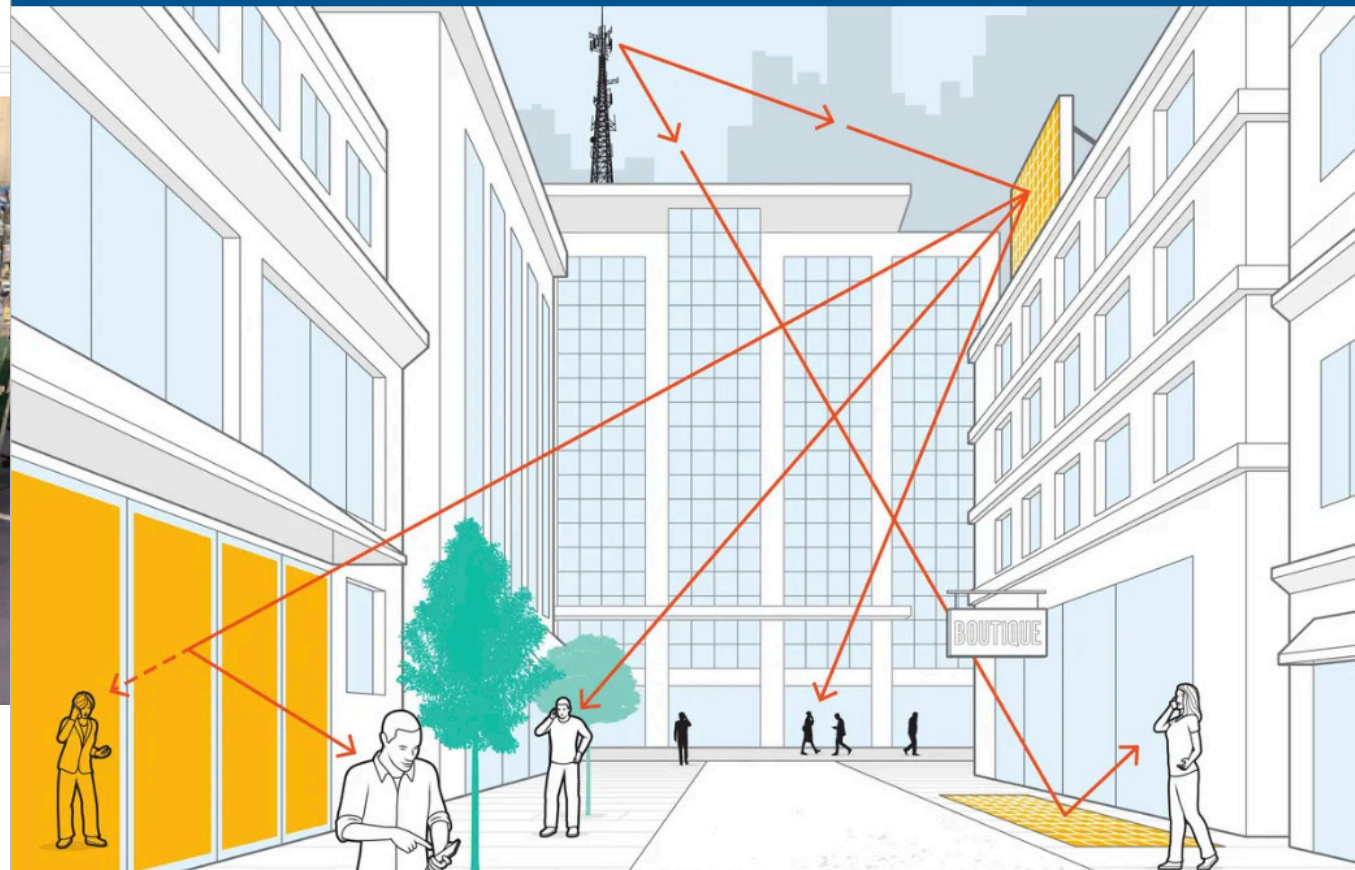


FEATURE | TELECOMMUNICATIONS

METAMATERIALS COULD SOLVE ONE OF 6G'S BIG PROBLEMS

There's plenty of bandwidth available if we use reconfigurable intelligent surfaces

BY MARIOS POULAKIS | 04 SEP 2022 | 12 MIN READ

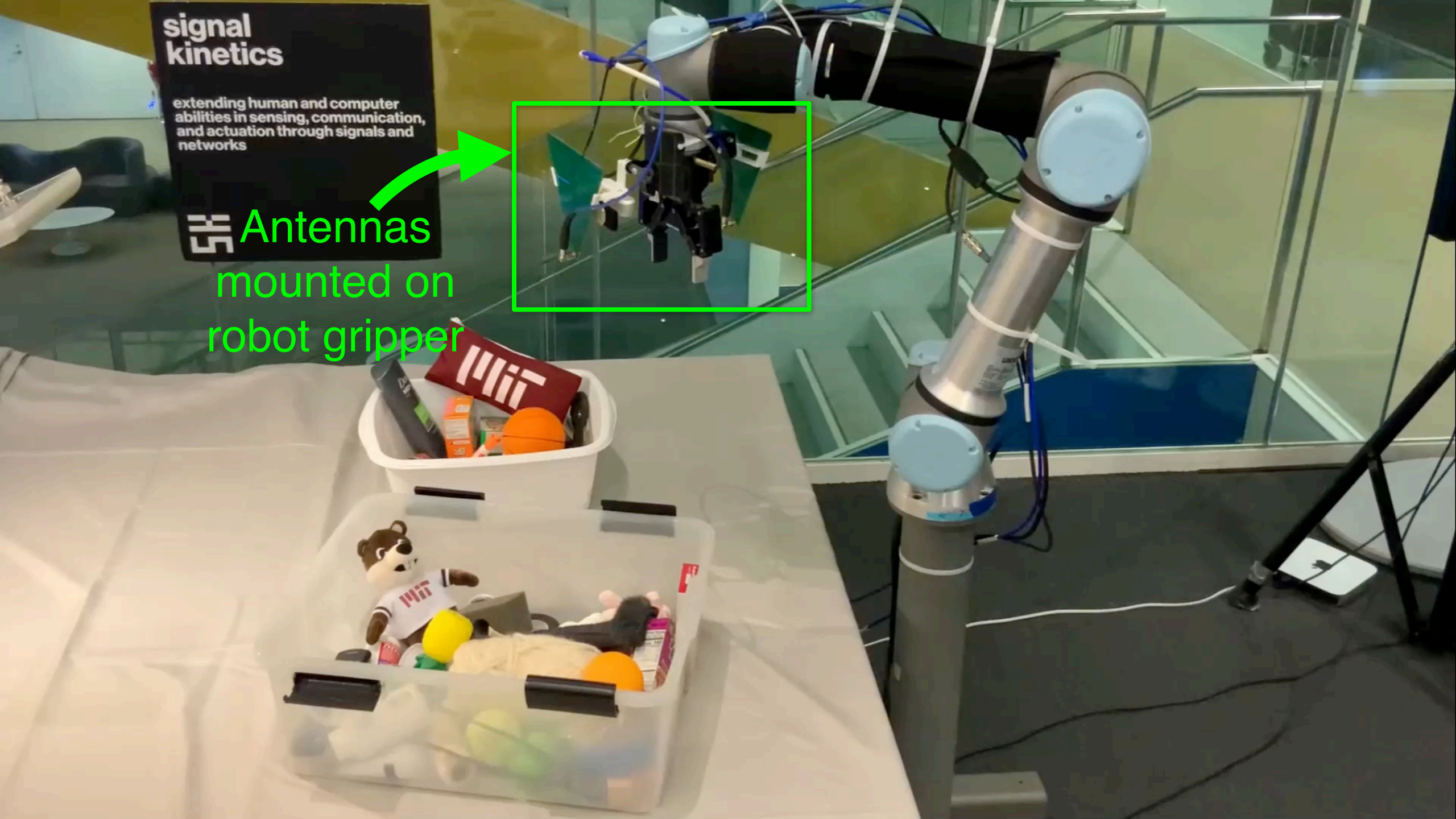


10. Sensor Fusion with ML for Robotics & AR

- What is sensor fusion?
- Why do we want sensor fusion?
- Where is it used and how?

Camera View
Camera's
line of sight is
blocked
Target item
under clutter

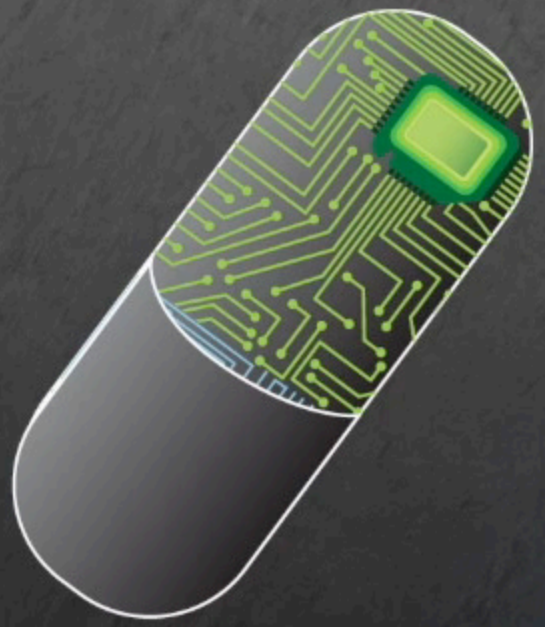
FOODS


signal
kinetics
extending human and computer abilities in sensing, communication, and actuation through signals and networks
Antennas
mounted on
robot gripper

11. In-Body IoT

- Why do we want it?
- Where is it already used now?

Continuous & Long-Term Drug Delivery



In-body Sensing and Diagnosis

Goal of This Class

1. Learn the fundamentals of wireless technologies for sensing and communications

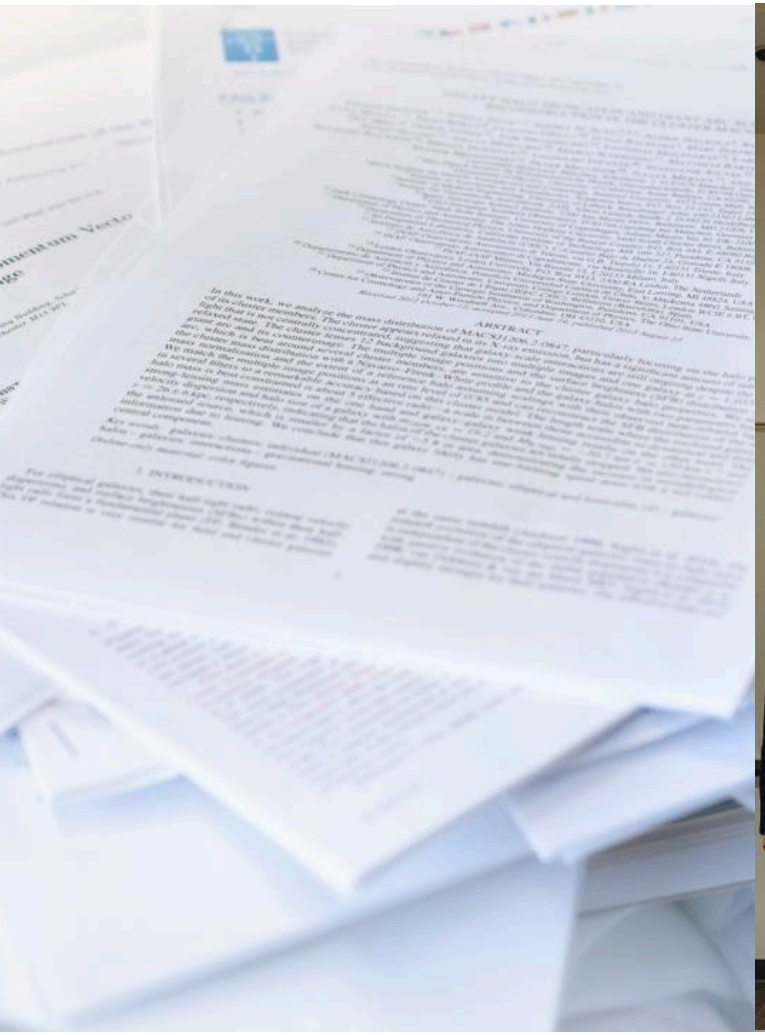
2. Discover about state-of-the-art systems and applications for wireless sensing

3. Develop an understanding of wireless systems and technologies at an intuitive and practical level

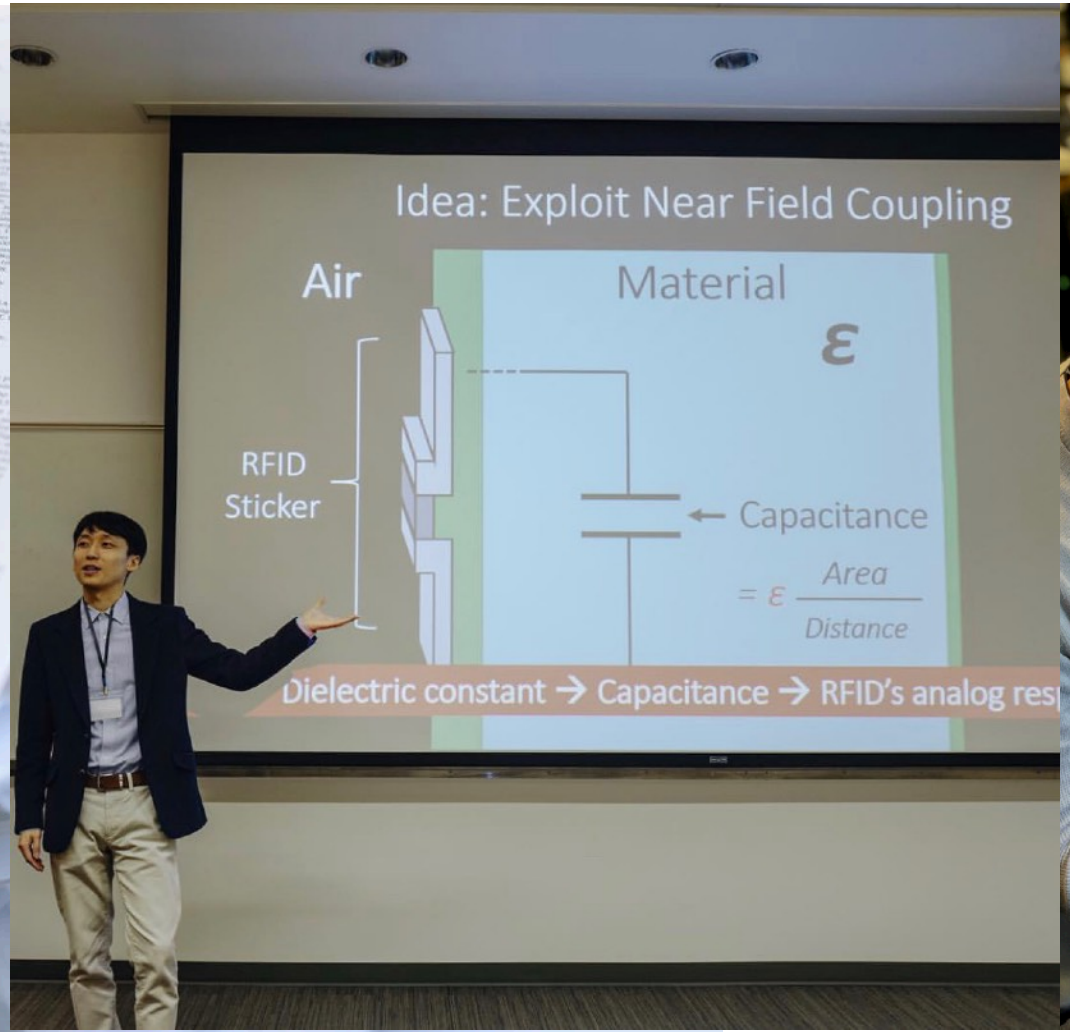
4. Learn how to reason about wireless systems with knowledge of technology, constraints, and applications

5. Design and build your own wireless sensing system project (budget/team)

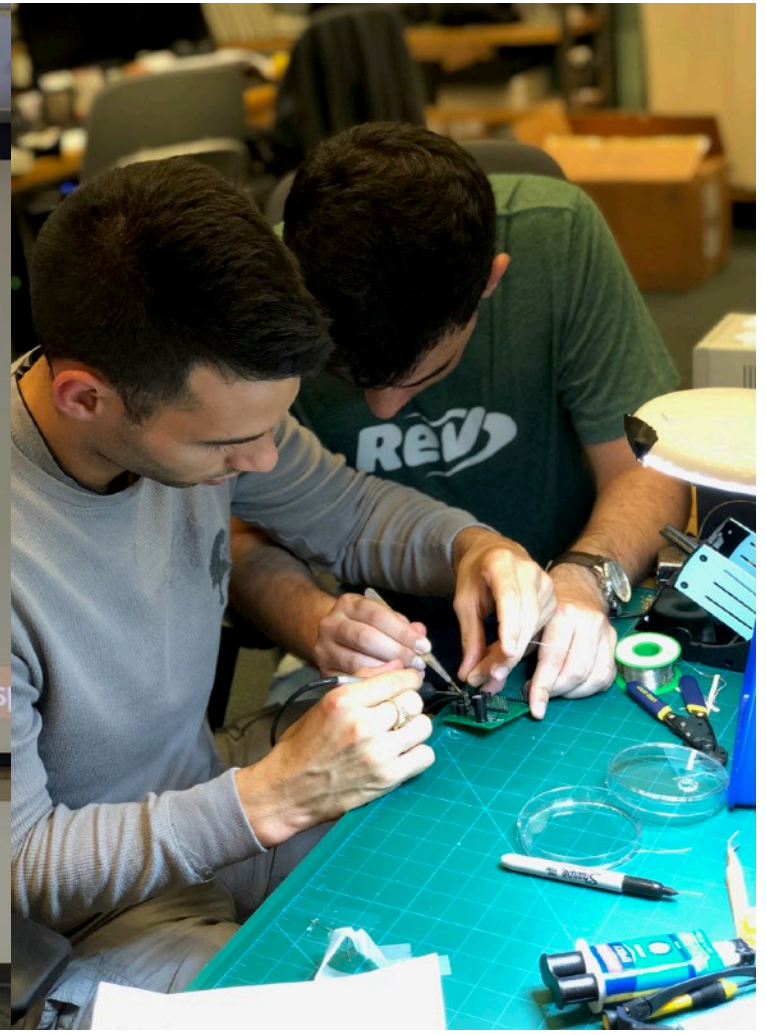
Course Organization



Reading & Reviewing Papers



Discussing Papers



Class Project

Each lecture =

Fundamentals + State-of-the-art system(s)

Necessary background?

advanced undergrad-level knowledge in engineering or computer science

Logistics

Grading:

- 1 Course Project (70%)
  - Proposal (10%); Progress Report 1 (10%); Progress Report 2 (10%); Presentation (20%); Final Report (20%)
- Reading Questions & Participation (30%)
  - Includes submitting reviews before every lecture (15%)
  - Participation via Attendance+Interaction (15%)
  - May skip one review without affecting grade

Website: http://www.mit.edu/~fadel/courses/MAS.s60/

Slack: Make sure you are on Slack (all should have been added)

Office hours will be posted soon (after survey)

Readings

We will read 1-2 papers/references per class:

- Everyone is expected to read the papers in advance
- Submit a short review of the required readings by midnight the night before the class
- Say something that is not in the paper

Submit Reviews here:

- http://www.mit.edu/~fadel/courses/MAS.s60/reviews.html

Projects

- All projects involve system implementation
- Work in groups of two (ideally)
- Will suggest project ideas; students can choose their own projects
- Can be (very) related to your research (come talk to me)

Timeline:

- Proposal (1-2 pages): October 14
- Progress Report 1: November 10
- Progress Report 2: December 2
- Final Presentation: December 12
- Final Report (6-8 pages): December 14

We will discuss project updates in class as time permits

How to Read a Paper

First Pass:

- Title, Abstract
- Figures (illustrations? important results?)
- skim intro & conclusions
- References

Second Pass

- Intro in details
- Overview, related work, or background sections
- Figures in details

Third pass:

- Read in detail
- Mark references for future read

How to Review a System Paper

How to think when reviewing a paper?

How to Review a System Paper

How to think when reviewing a paper?

1) Motivation
Is this an important problem?

- New problem? → Worthwhile or artificial?
- Existing problem? (i.e., have others worked on it) → Does it improve over prior work?

2) Related Work

- Does it really outperform prior work?
- Does it accurately represent prior work?
- Do you know past work? If not, search Google Scholar to get a sense of past work

3) Techniques

- Are they novel? intellectually interesting?
- Are they technically sound? Is there a key technical flaw?

How to Review a System Paper

How to think when reviewing a paper?

4) Implementation

- Significant effort?
- Matches the motivation?
- Simulation or real-world prototype?

5) Evaluation

- Comprehensive? Convincing?
- Does the system deliver what it promises?

How to Review a System Paper

How to think when reviewing a paper?

1) Motivation

2) Related Work

3) Techniques

4) Implementation

5) Evaluation

How to Review a System Paper

How to write a review?

1) Summary

2) Strengths & Weaknesses

3) Comments to authors

How to Review a System Paper

How to write a review?

1) Summary

- 5-10 sentences
- If someone hasn't read the paper at all, they should understand what it's about
- Should sound like a "brutally honest and straightforward abstract"

Rough structure:

This paper presents XXX, a system that does YYY. **The goal is to** XXX. The **main challenge** the authors try to address is YYY.

The key idea is to do XXX. The authors do this by introducing/proposing ZZZ

The authors implement (or simulate) their system and **demonstrated** (results) that it outperforms the baseline?

How to Review a System Paper

How to write a review?

1) Summary

- 5-10 sentences
- If someone hasn't read the paper at all, they should understand what it's about
- Should sound like a "brutally honest and straightforward abstracT"

2) Strengths & Weaknesses

- Use your answers to the questions of "How to think when reviewing"
- List 2-4 pros/cons
- Each should be a direct statement about the paper

<u>Rough structure:</u>

Pros:
+ Statement 1
+ Statement 2

Cons:
-
-
-

How to Review a System Paper

How to write a review?

1) Summary

2) Strengths & Weaknesses

3) Comments to authors

- Detailed comments to authors
- Elaborate on your pros/cons, areas for improvement, key concerns
- Ask questions about techniques, figures, results, etc.
- Based on the 5 points from how to think as well as technical details

Examples:

- If you listed a weaknesses small delta over prior work, specify in details why with references
- If experimental details are missing, state exactly what is missing and why it is problematic
- Include typos/grammar mistakes, potential suggestions to correct

How to Review a System Paper

How to write a review?

1) Summary

2) Strengths & Weaknesses

3) Comm… to authors

- Detailed c… …c…
- Elabor… …r pro…
- …s about t…
- …the 5 points…

Examples:

- If you liste… …mall delta o…
- If exper… …ng, state…
- Inclu… …amma… …, potent…

For the sake of this class, we will drop "comments to authors".

Instead, you should add a paragraph on "suggestions for improvement".

- If you could improve this paper, how would you do it?
- How do you envision your proposed technique will improve the work

How to Review a System Paper

How to write a review? (for this class)

1) Summary

2) Strengths & Weaknesses

3) Suggestions for Improvement

Next Class (Localization)

1) Required Readings

- **Chapter on Localization -** Covers fundamentals
- **ArrayTrack paper -** State-of-the-art localization system

What to submit? For localization paper: summary (2 paragraphs); for the ArrayTrack paper: a review

2) Optional Readings

- **Cricket -** More than 100,000 deployed (hospitals); Cited > 5,000 times
- **Radar paper** - Transitioned to real-world products (Microsoft, many startups); Started a new field; Cited > 10,000 times
- **SpotfFi paper** - another state-of-the-art localization paper
- **Chronos paper** - another state-of-the-art localization system
- **GPS** - how it works