UC San Diego
JACOBS SCHOOL OF ENGINEERING
Electrical and Computer Engineering

WCSNG
Wireless Communications Sensing and Networking

ForceSticker: Batteryless, Wireless Thin Sticker-Like Force Sensors

Agrim Gupta*, Daegue Park, Shayaun Bashar, Cedric Girerd, Nagarjun Bhat, Siddhi Mundhra

Tania K. Morimoto, Dinesh Bharadia

UBICOMP ISWC
2023 CANCUN, MEXICO

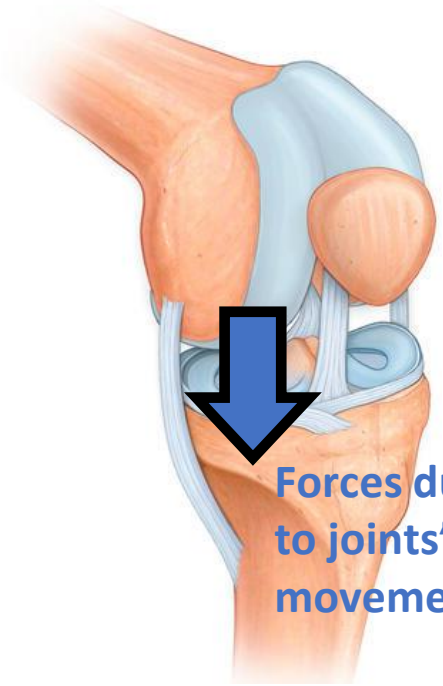
Forces are all around and within us!

Even static objects exert weight

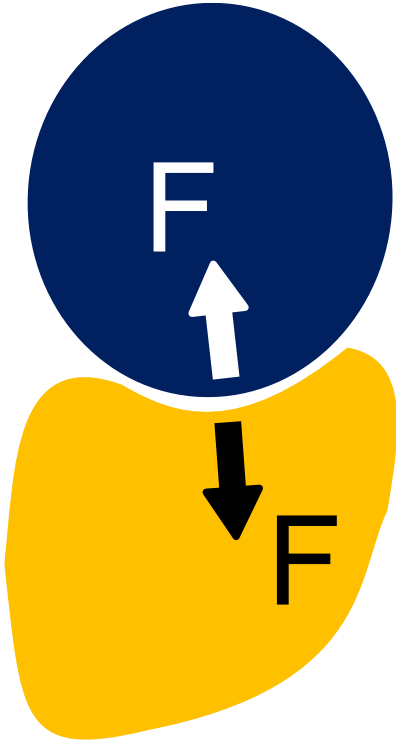
Interaction forces as we move

Force exerted by our feet as we walk

Forces within us (in-vivo)

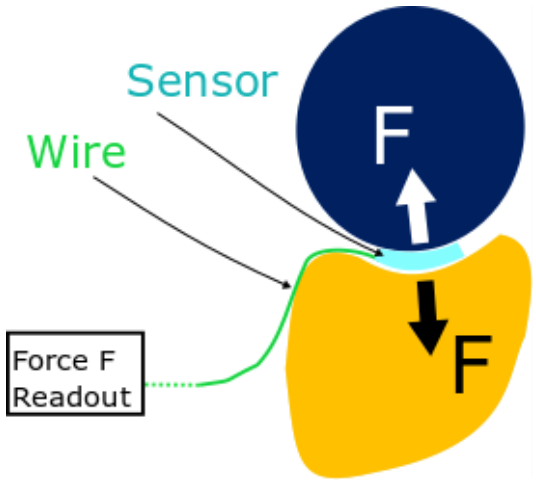


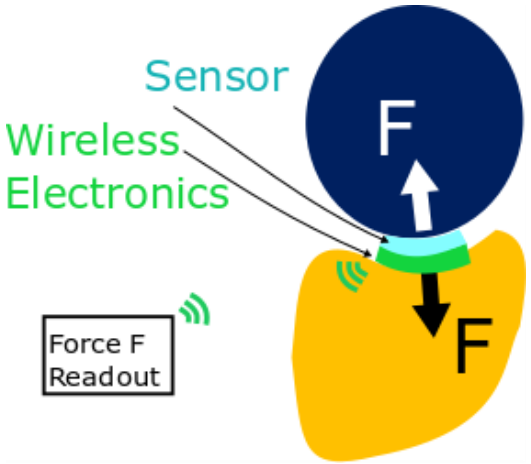
Forces due to joints' movement

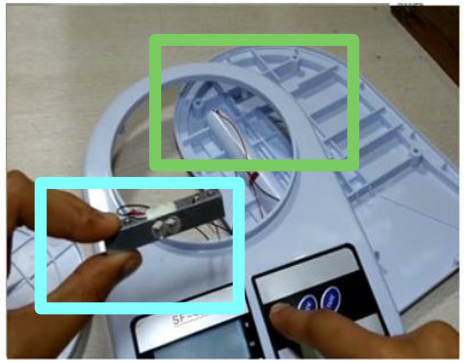


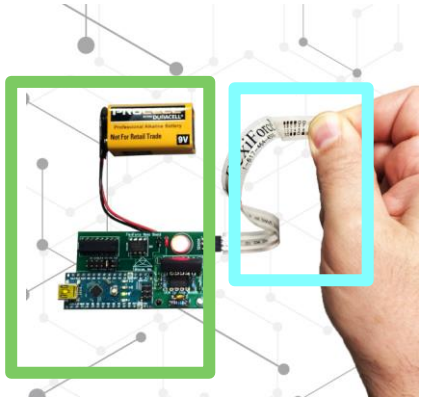
"Any two objects, in contact with each other, will exert forces onto each other"

How do we sense these forces today? Problem of Batteries and Wires



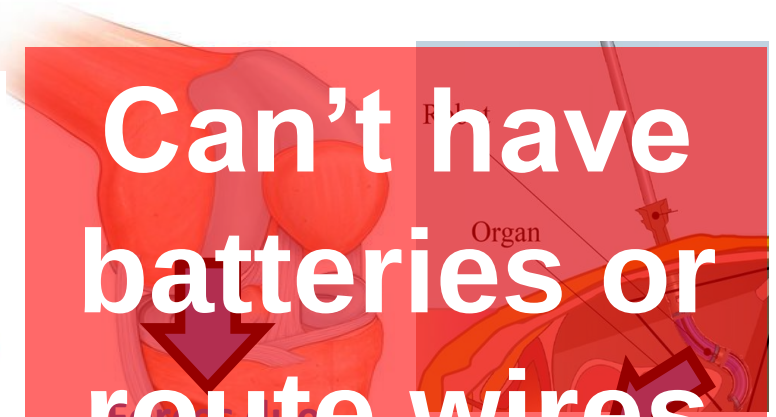






Wiring Hassle

Bulky Batteries

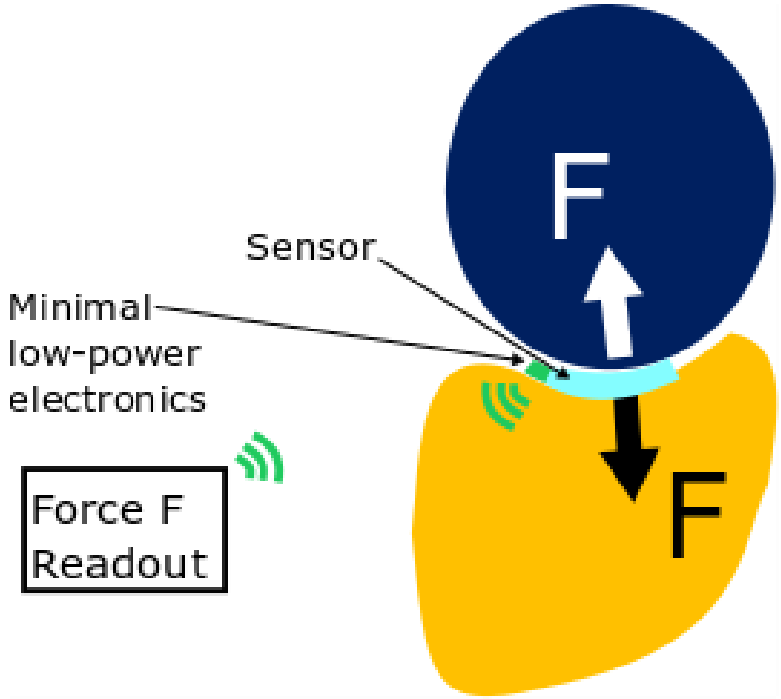


Can't have batteries or route wires in-vivo

Technology	Batteryless	Wireless Readout
Wired force sensors	✓	✗
Wireless force sensors	✗	✓

ForceSticker contribution summary: From Sticker Fabrication to Force testbeds

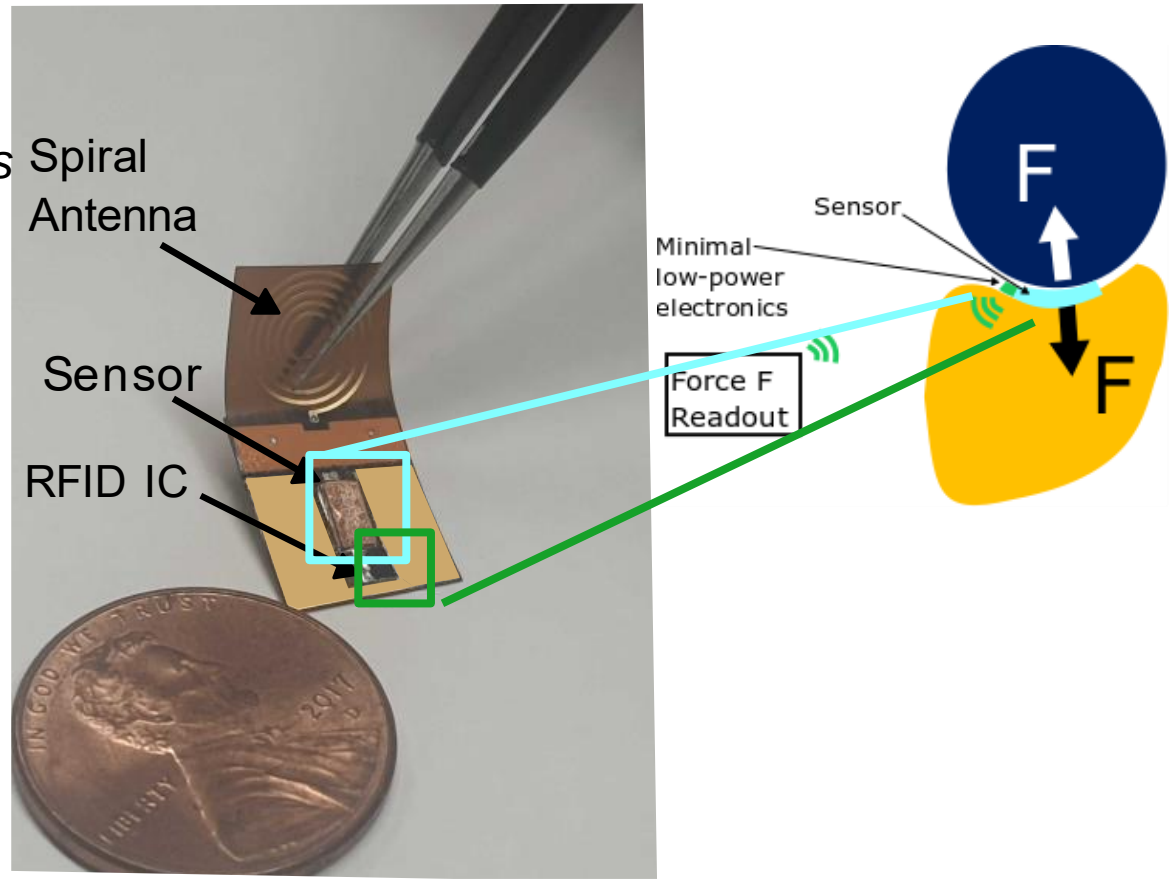
- **Solve for wires/battery-hassle in force sensors**
  Introduce a new class of sticker-like wireless force sensors



Technology	Batteryless	Wireless readout	In-Vivo applications
Wired force sensors	✓	✗	✗
Wireless force sensors	✗	✓	✗
Force``stickers”	✓	✓	✓

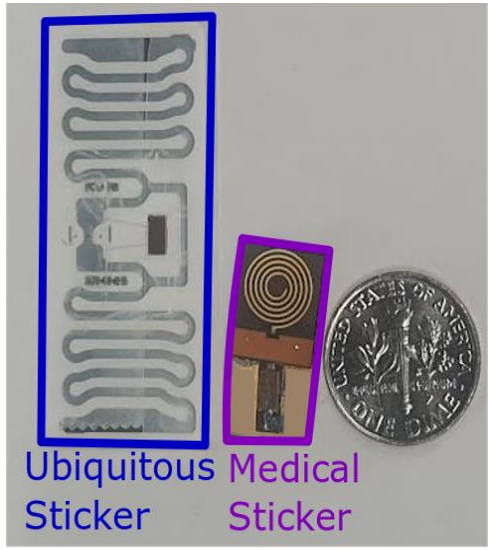
ForceSticker contribution summary: From Sticker Fabrication to Force testbeds

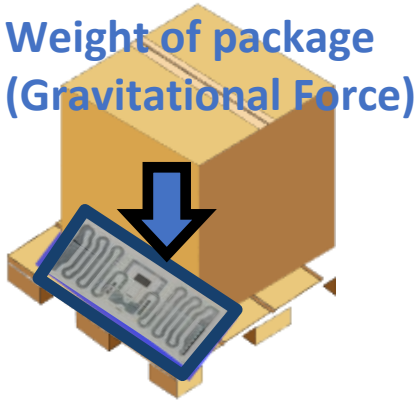
- **Solve for wires/battery-hassle in force sensors**
  Introduce a new class of sticker-like wireless force sensors
- **How do we create these force-stickers?**
  Amalgamation of capacitive force sensors and RFIDs



ForceSticker contribution summary: From Sticker Fabrication to Force testbeds

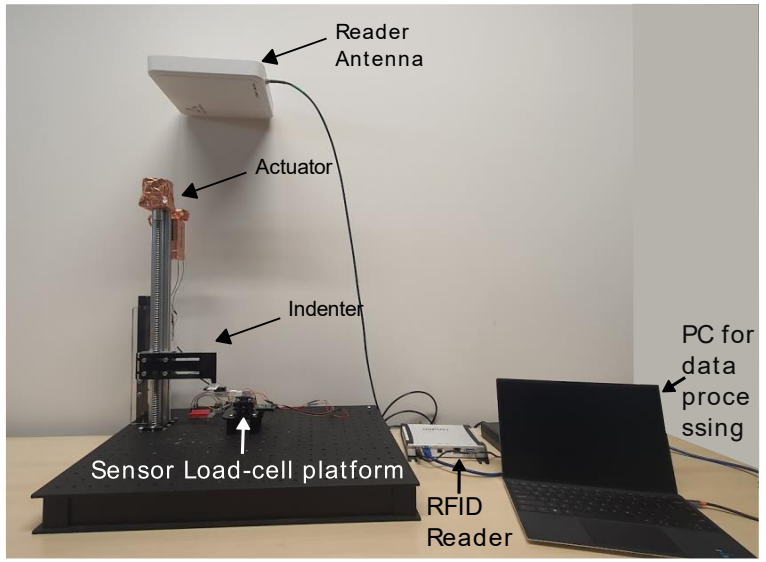
- **Solve for wires/battery-hassle in force sensors**
  Introduce a new class of sticker-like wireless force sensors
- **How do we create these force-stickers?**
  Amalgamation of capacitive force sensors and RFIDs
- **Enable diverse applications via different sticker-flavors**
  Stickers configurable to meet different size and force ranges

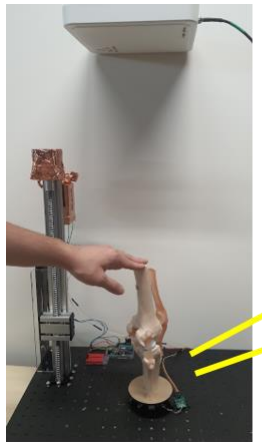


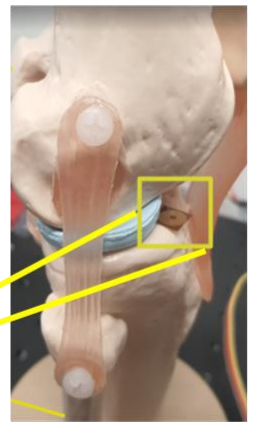


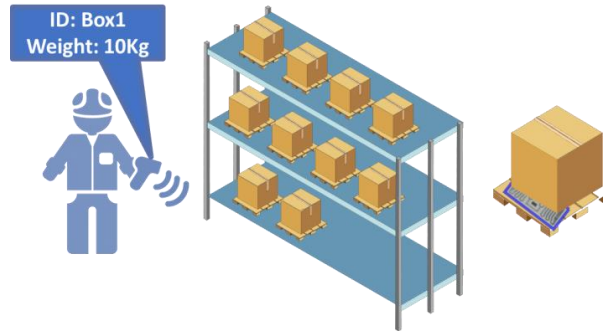
ForceSticker contribution summary: From Sticker Fabrication to Force testbeds

- **Solve for wires/battery-hassle in force sensors**
  Introduce a new class of sticker-like wireless force sensors
- **How do we create these force-stickers?**
  Amalgamation of capacitive force sensors and RFIDs
- **Enable diverse applications via different sticker-flavors**
  Stickers configurable to meet different size and force ranges
- **Research platform and case-study explorations**
  Force sensor test-bed, knee-implant, warehouse case-studies

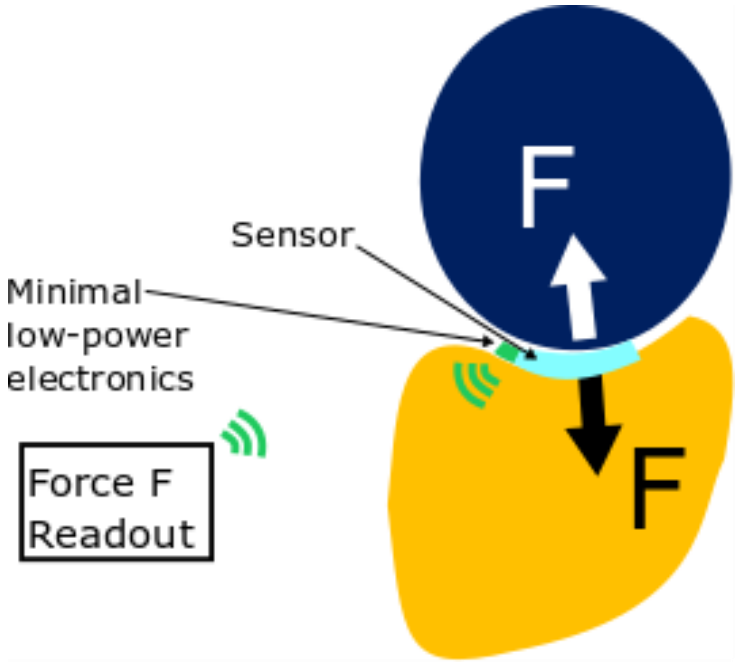


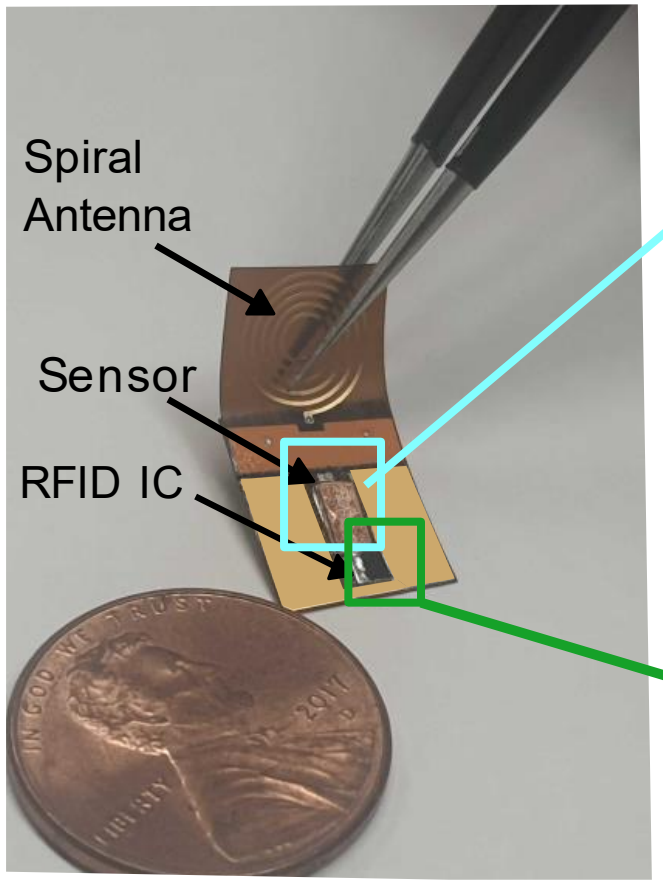


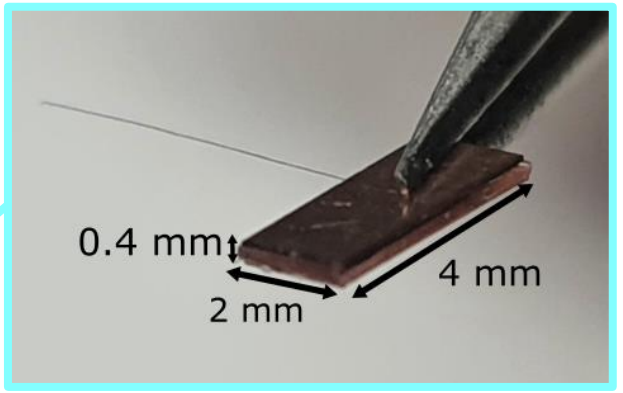


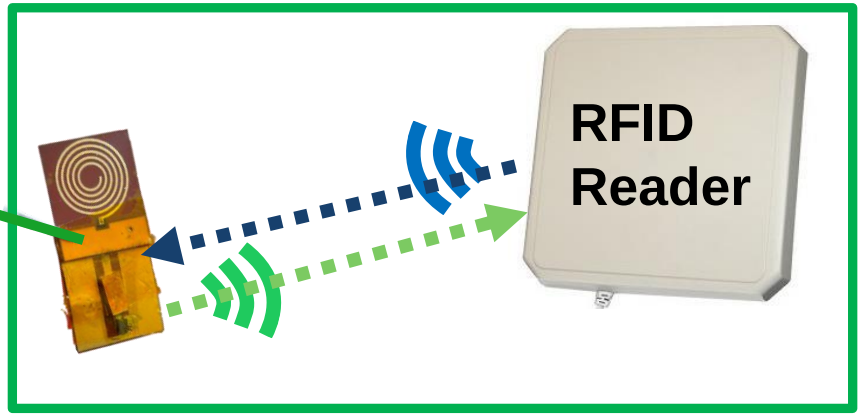


Two ingredients of the Forcestickers recipe: Capacitors and RFIDs!



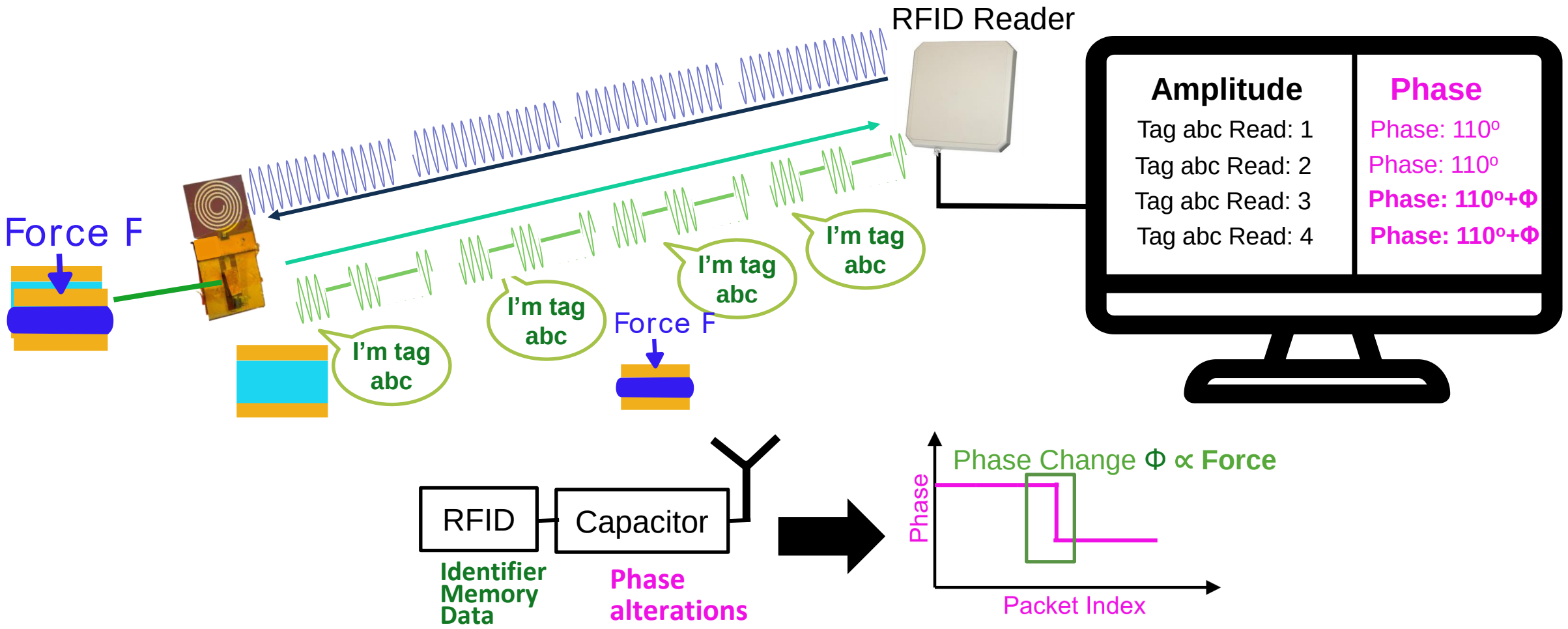






How does the capacitor communicate force readings to the RFID reader?

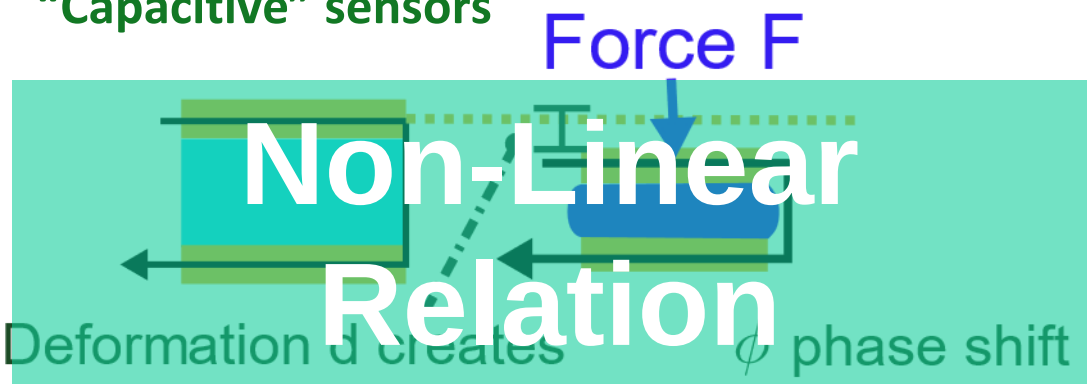
RFID Amplitude domain is dumb, but we can still use phase domain to communicate!



Using phases to communicate force limits provides smartness to the dumb repeating RFID communication

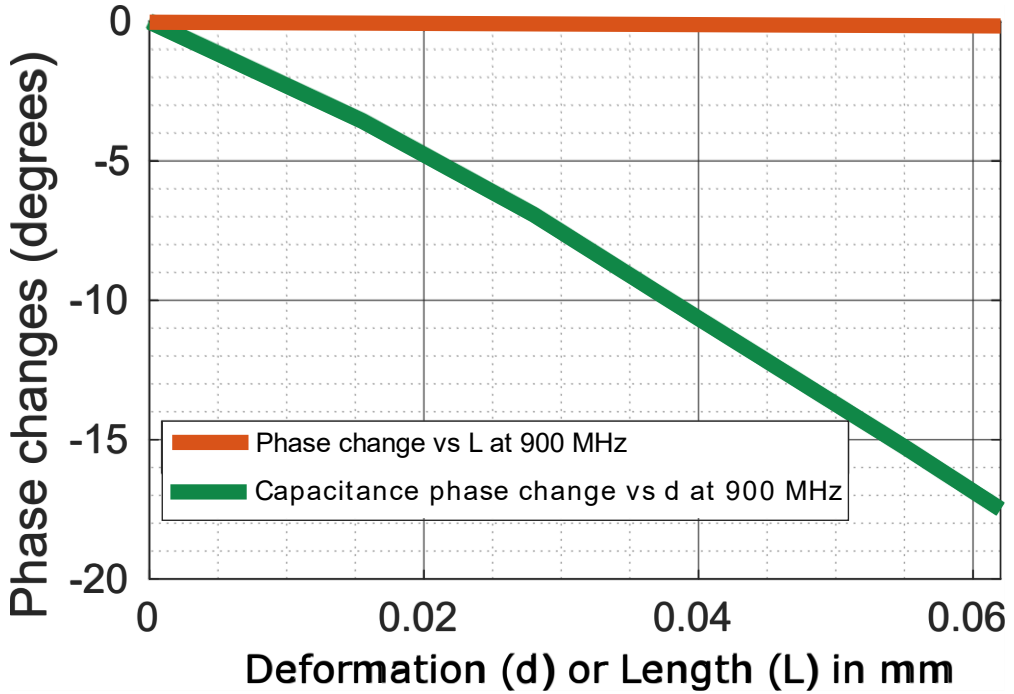
Can the mm-scale capacitor provide the required phase changes?

"Capacitive" sensors



$$\phi = 2tan^{-1}(1/50\omega C(F_{\max})) - 2tan^{-1}(1/50\omega C_0))$$

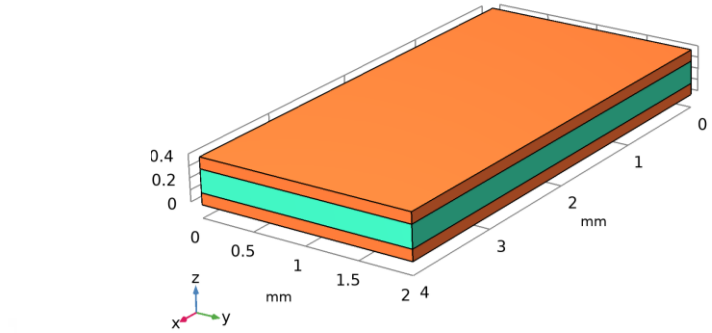
Past phase change sensors
WiForce, NSDI'21, Teng at al, SoRo'19

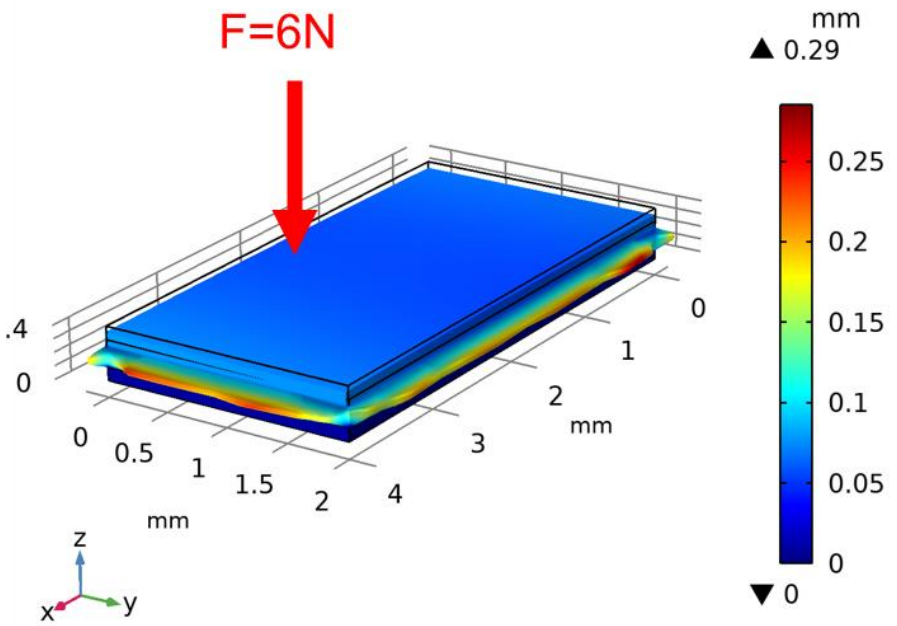


We optimize capacitance to maximize 900 MHz phase by leveraging non-linearity. More in poster/paper

Sensor Fabrication, Simulation Framework and Testing Setups

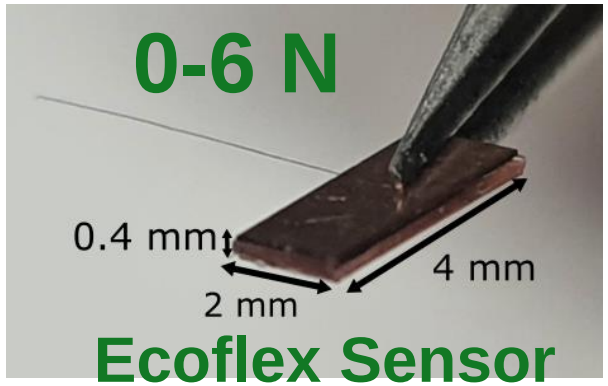
- **Multiphysics comsol simulation framework**

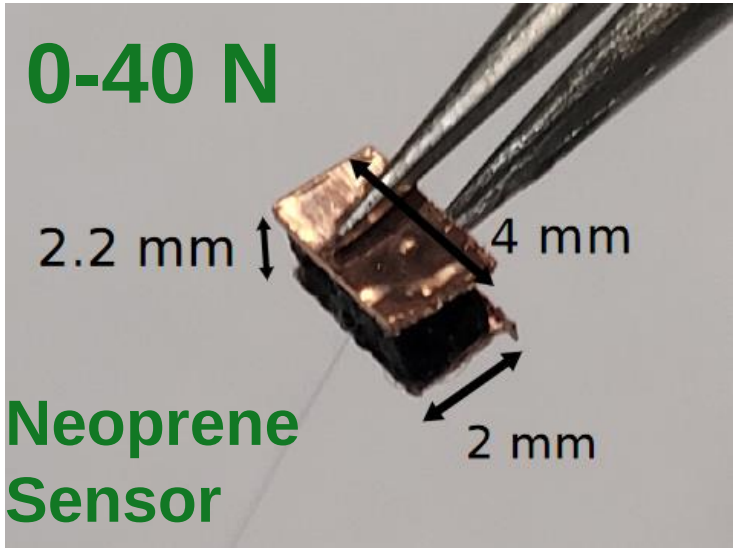




Sensor Fabrication, Simulation Framework and Testing Setups

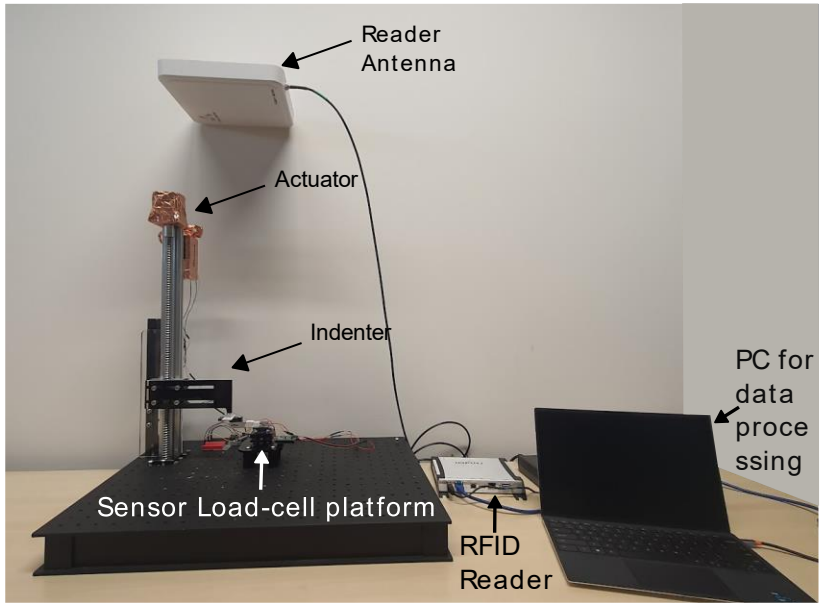
- Multiphysics comsol simulation framework
- **Utilizing different polymers for different force ranges**

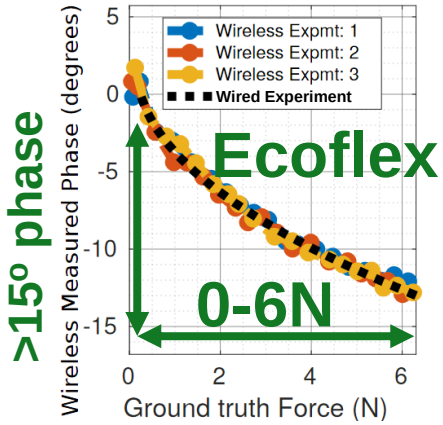


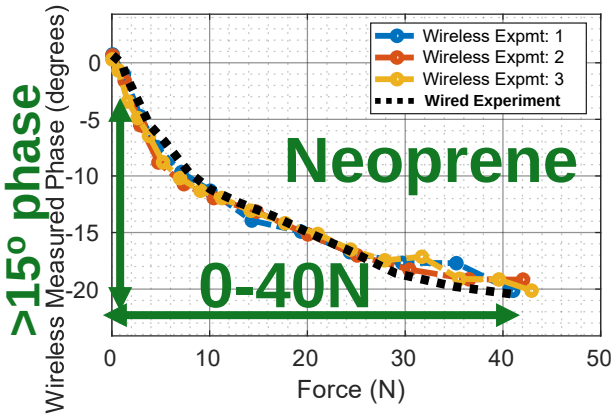


Sensor Fabrication, Simulation Framework and Testing Setups

- Multiphysics comsol simulation framework
- Utilizing different polymers for different force ranges
- **Cyclic testing setup to measure wireless phase change**

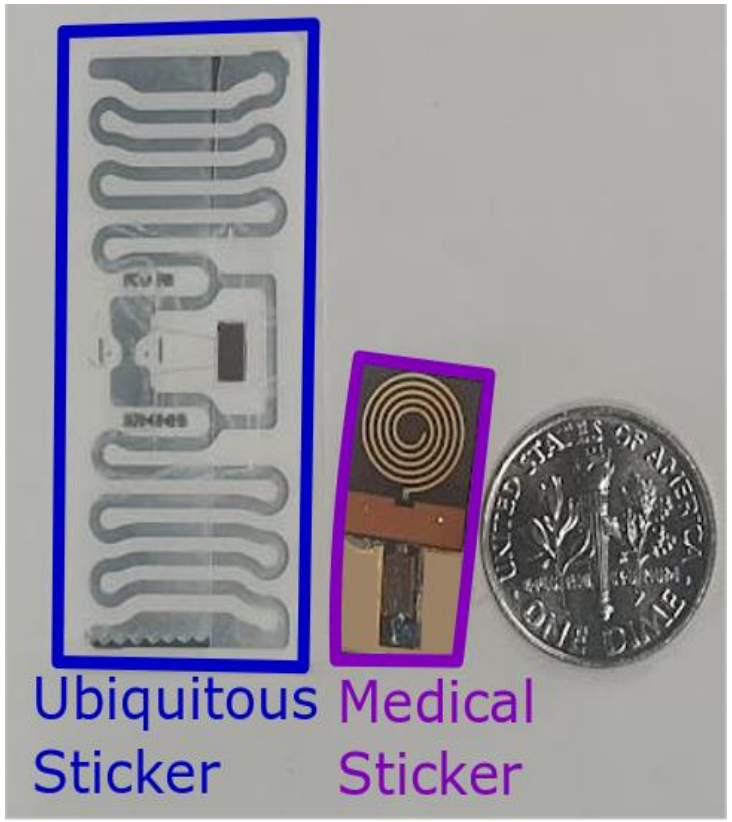






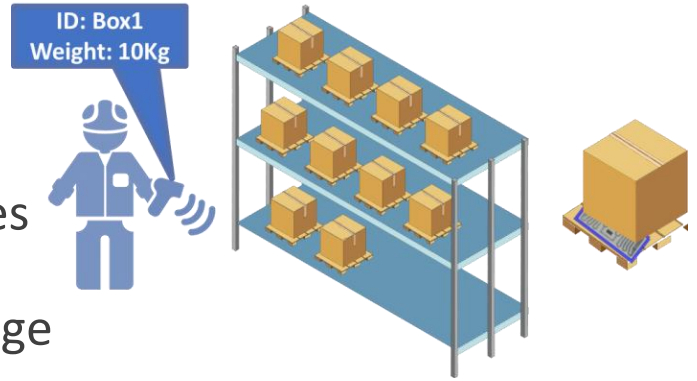
Sensor Fabrication, Simulation Framework and Testing Setups

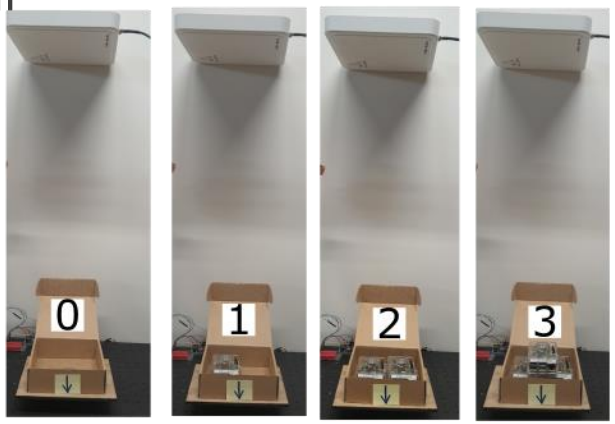
- Multiphysics comsol simulation framework
- Utilizing different polymers for different force ranges
- Cyclic testing setup to measure wireless phase change
- **Two flavors of ForceStickers: Ubiquitous and Medical**

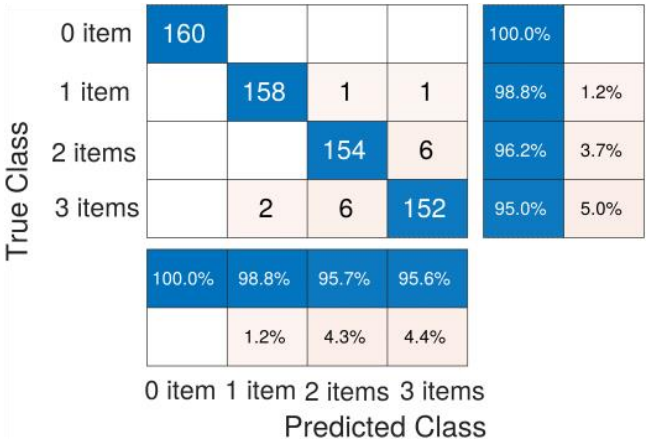


Sensor Fabrication, Simulation Framework and Testing Setups

- Multiphysics comsol simulation framework
- Utilizing different polymers for different force ranges
- Cyclic testing setup to measure wireless phase change
- Two flavors of ForceStickers: Ubiquitous and Medical
- **Warehouse case-study with ubiquitous stickers**

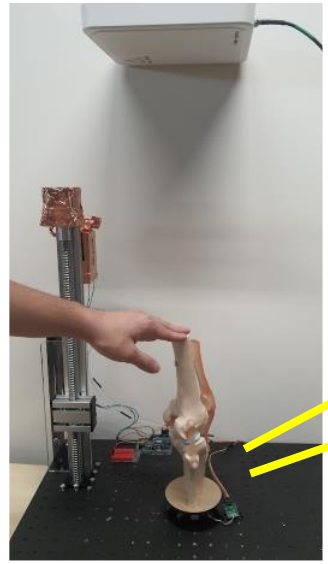


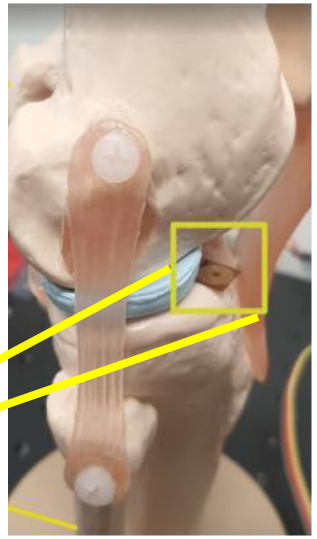


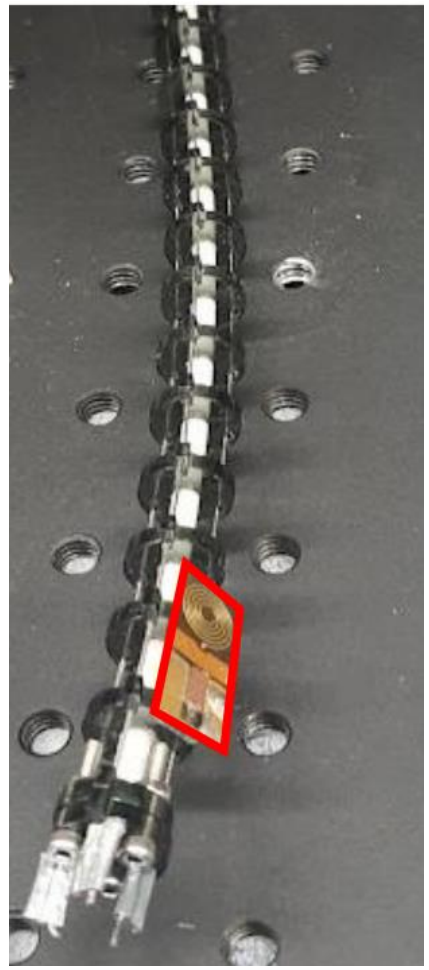


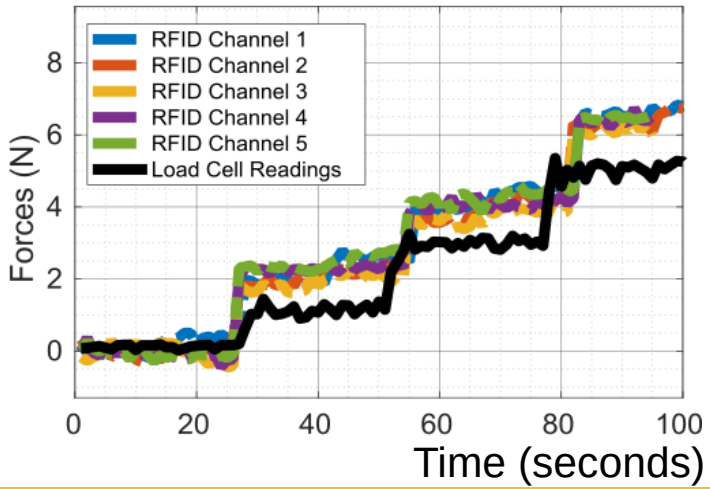
Sensor Fabrication, Simulation Framework and Testing Setups

- Multiphysics comsol simulation framework
- Utilizing different polymers for different force ranges
- Cyclic testing setup to measure wireless phase change
- Two flavors of ForceStickers: Ubiquitous and Medical
- Warehouse case-study with ubiquitous stickers
- **Knee-implant, surgical robot case-study with medical stickers**

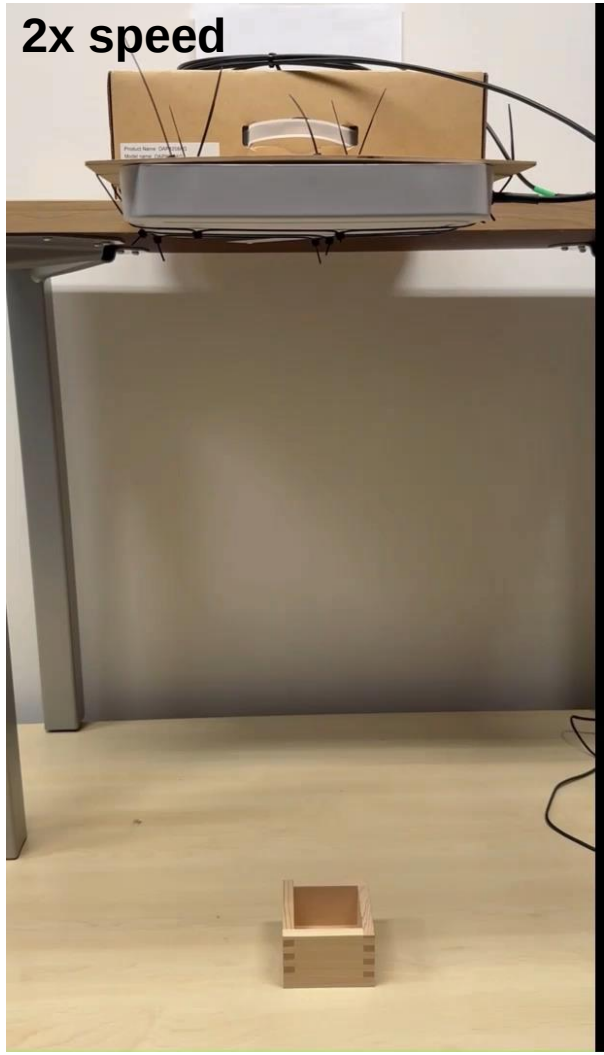




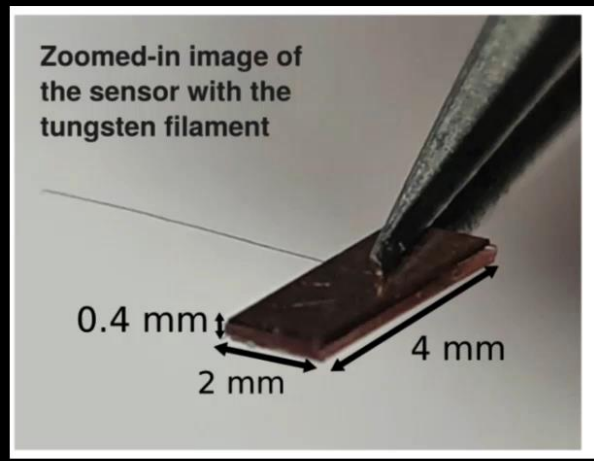


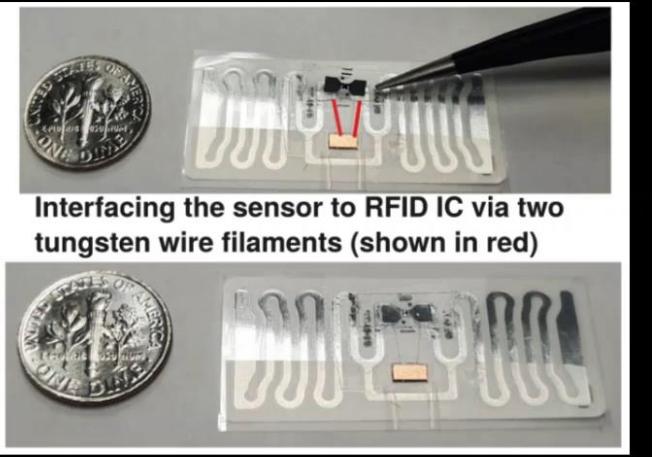


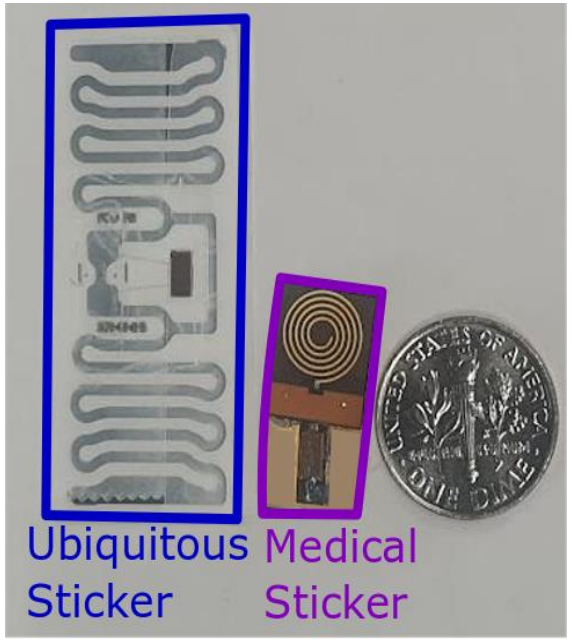
We can stick force-sticker to any simple object and start measuring forces!

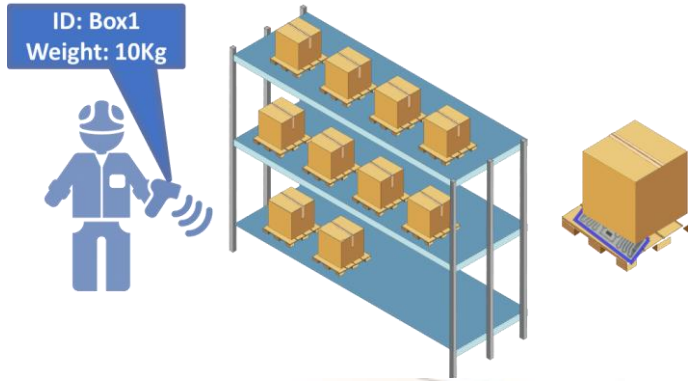


ForceSticker couples deformable capacitors to RFID tags, which allow measuring forces by estimating capacitance induced analog phase changes in the RFID's wireless channel









Technology	Batteryless	Wireless readout	In-Vivo applications
Wired force sensors	✓	✗	✗
Wireless force sensors	✗	✓	✗
Force``stickers”	✓	✓	✓

Thank you. Questions?

Email: agg003@ucsd.edu