FABRICATION

CSE 599 N1: Modern Mobile Systems

modernmobile.cs.washington.edu

Content borrowed from Vikram Iyer

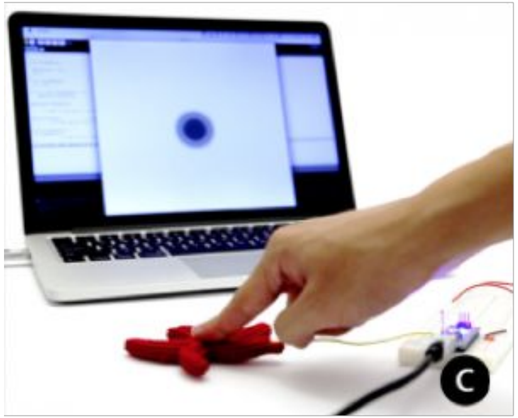
3D Printing Wireless Connected Objects

Can we **3D print** Wi-Fi connected objects?

3D Printed Interaction Devices

How can plastic objects **communicate**?

Challenge: Printing Connectivity



[CHI 2015]

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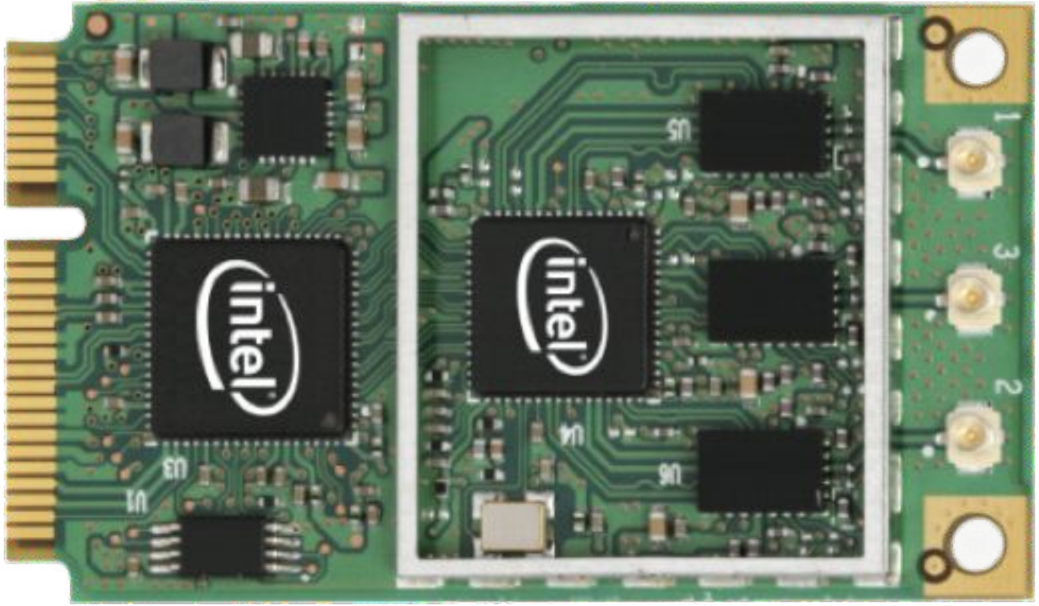
Need communication using only **plastic**

Fundamental Challenge: Wi-Fi operates at 2.4 GHz



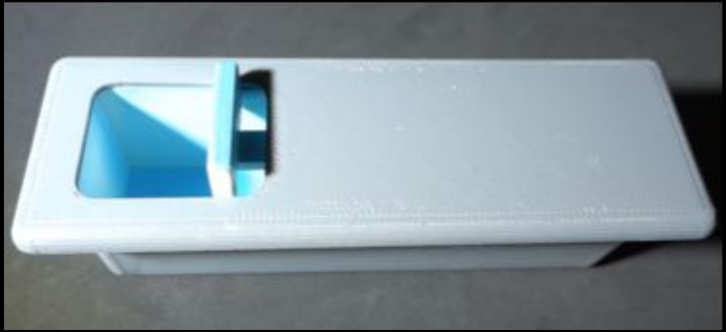
Can’t print **2.4 GHz oscillator** with **plastic**

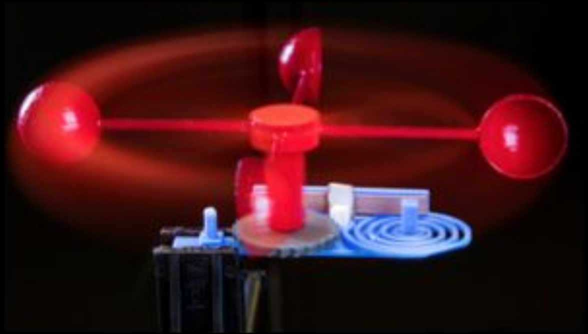
Our Solution: Reflect Wi-Fi Signals Instead

Key Idea: Use mechanical motion to send data

First **3D printed objects** that can connect with **Wi-Fi**

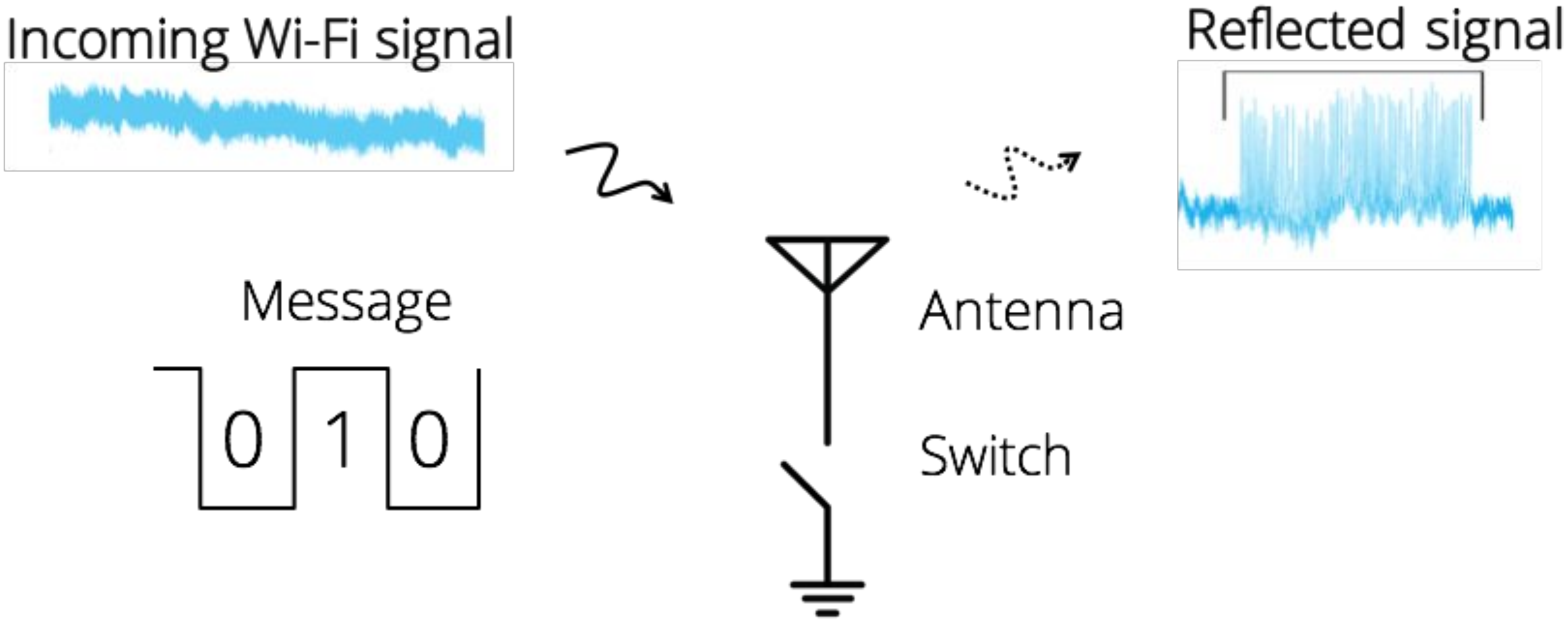
First 3D printed Wi-Fi input Gadgets and Sensors





How does printed Wi-Fi work?

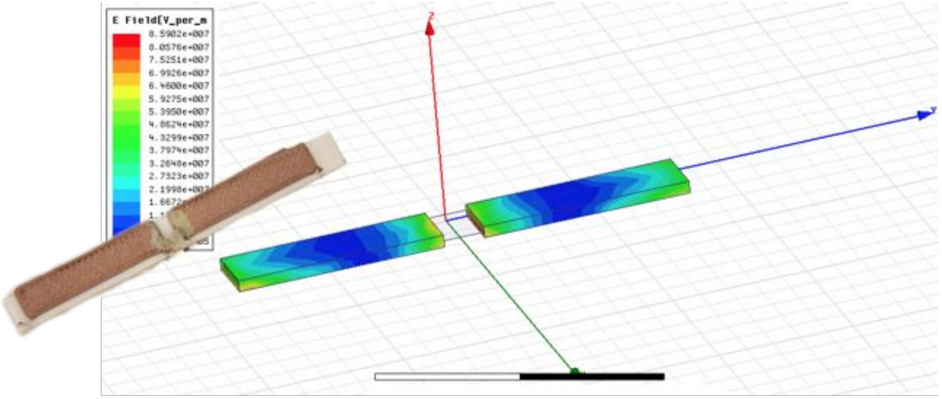
Printed Wi-Fi has Three Key Components

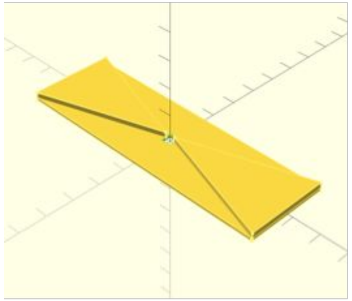


Switch produces changing reflections

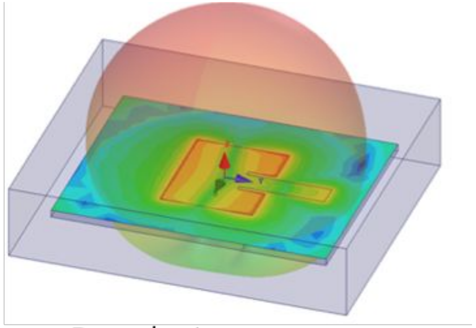
3D Printed Antenna Design

1. Start with **reference** metal antenna designs
2. Optimize **length, width, thickness** for printed materials
3. Integrate antennas into **3D printed** objects





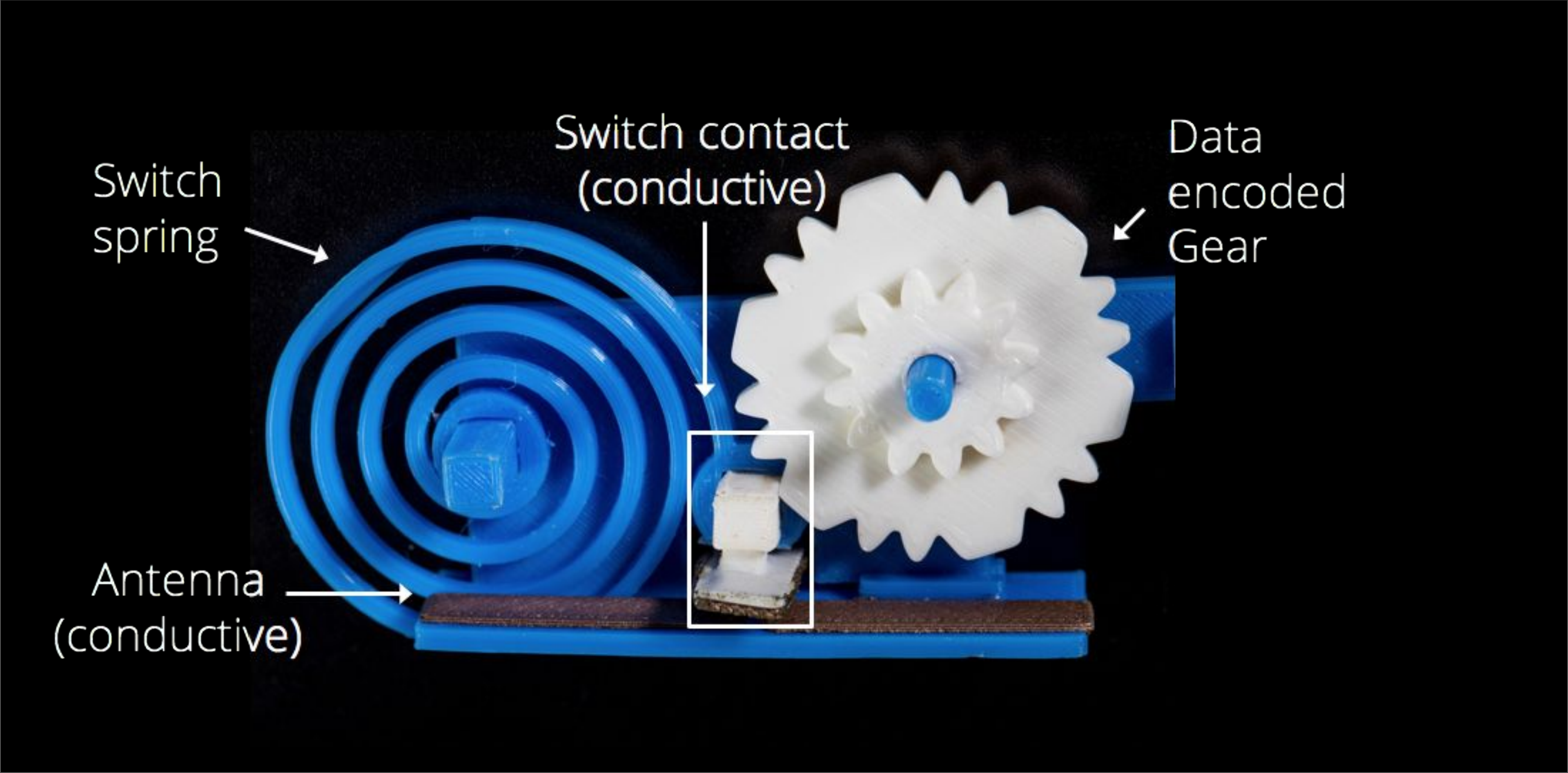
Bowtie Antenna



Patch Antenna

Dipole Antenna

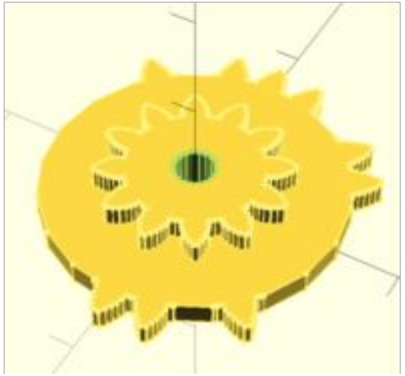
3D Printed Switch



Encoding Information on the Gear Teeth

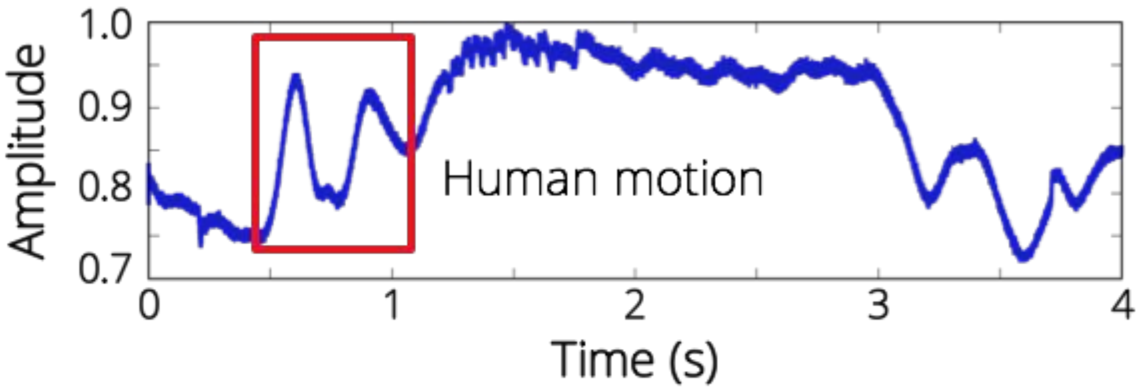
Choose Parameters → Generate 3D model → Printed Object

Encoding Message

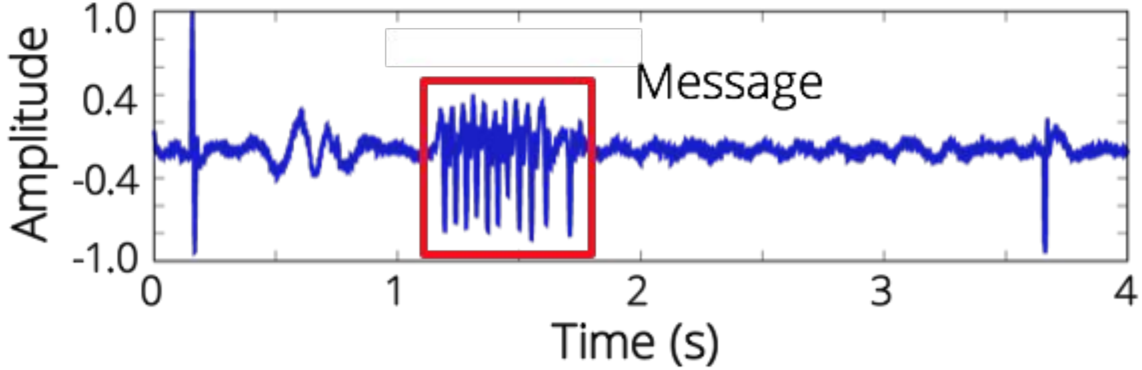


3D Printed Slider: An Inside Look

Separating human motion from printed objects



Raw signal with human motion



Filtered signal

3D Printed **Wireless** Sensors

3D Printed Wireless Sensors

3D Printed Wireless Sensors

Flow Rate Sensing

Performance Evaluation

45 bps data rates

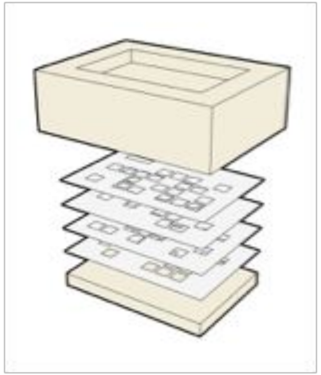
17 m Line of Sight Range

45 m^2 Non-line of sight Area

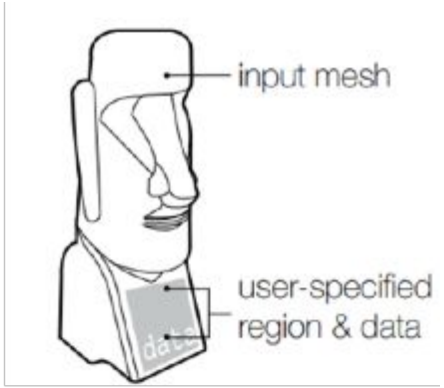
Can decode **multiple** printed objects **concurrently**

Can we embed **static information** in objects?

Embedding Information in 3D Prints



Infrastructs
SIGGRAPH '13



Aircode
UIST '17

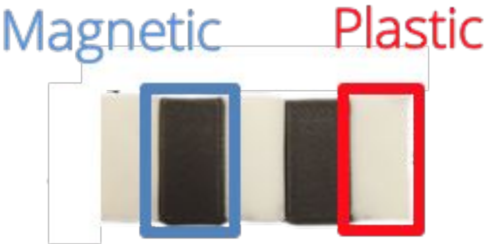
Read data on **smartphones**

Our Solution: Use Magnetic Materials

Read data using phone **magnetometer**

How do we encode data?

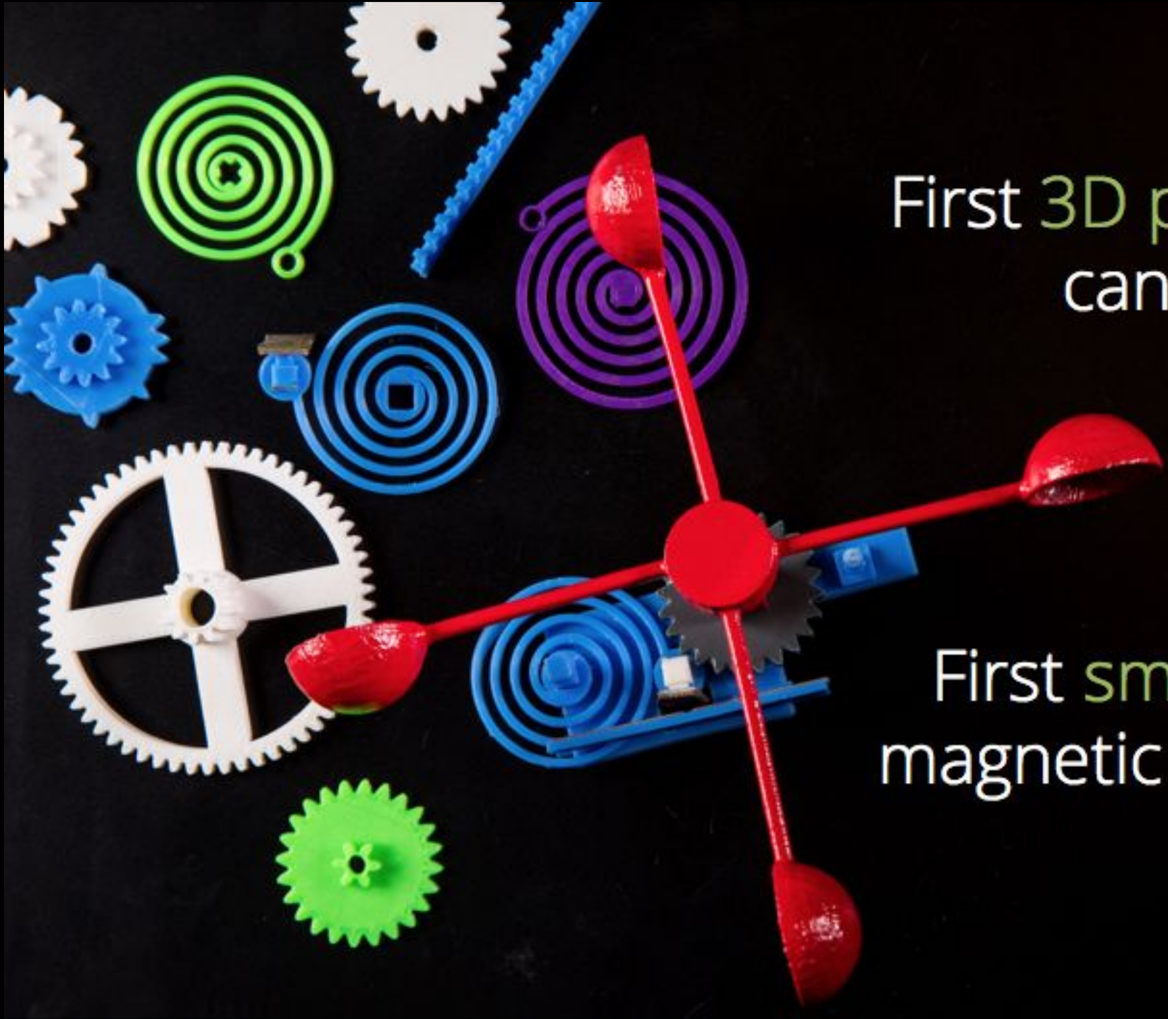
Original objects



Painted objects

Decoding Data on a Smartphone

Embedding Information in 2D



First 3D printed objects that can connect with Wi-Fi

First smartphone readable magnetic 3D printed objects

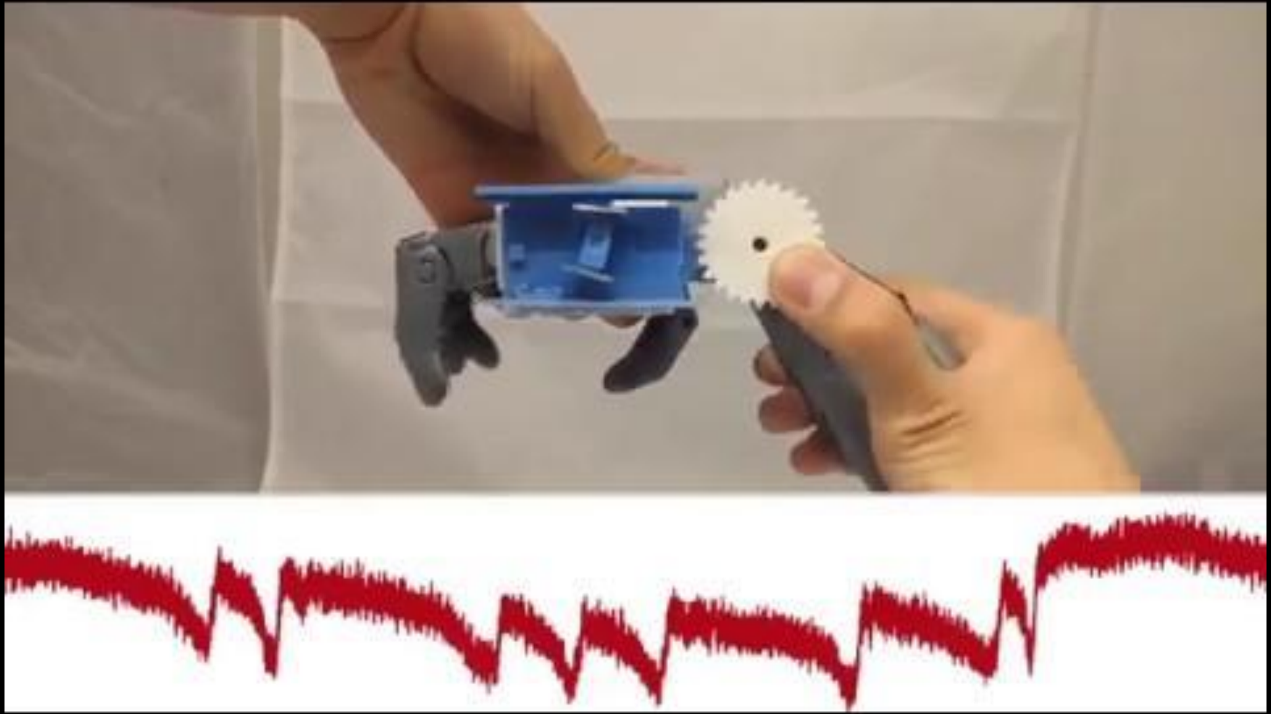
Wireless Analytics for 3D Printed Objects

What do we mean by analytics?

Track the use of printed objects over time

Embed **wireless sensing** in printed objects

What else could we do with wireless analytics?



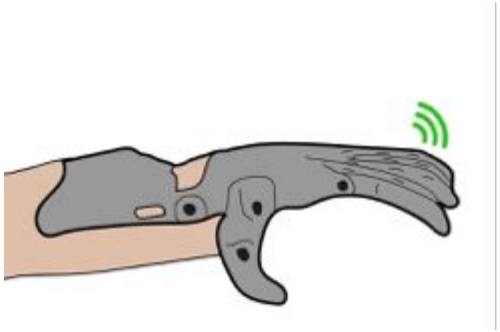
Why not use electronics?

- Requires designers to understand **electronics**
- Requires **power** source

Enable communication using **plastic** objects

Printed Analytics

Wireless, circuitless physical analytics capture for 3D printed objects



Printed prosthetics

Smart pill bottle

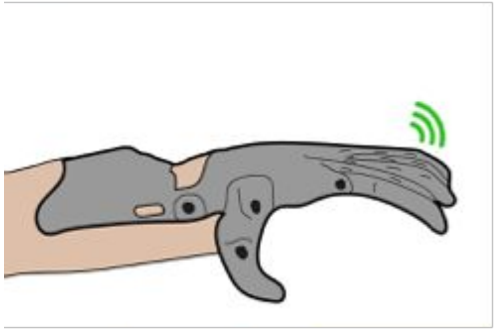
Wireless insulin pen

Our Contributions

- Backscatter communication **across a room** using conductive plastic

- 3D printed designs to sense **bi-directional linear** and **rotational** motion

- **Data storage** for printed objects for sensing beyond wireless range



3D Printing wireless devices

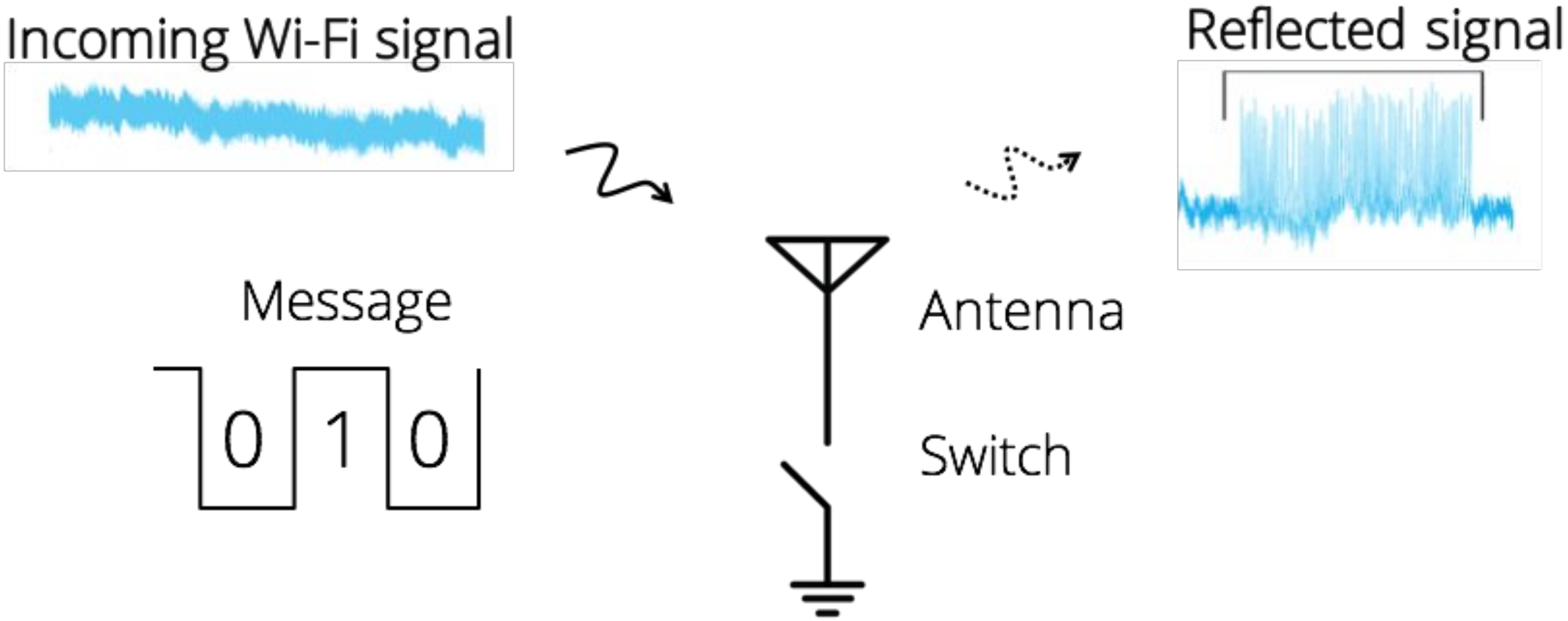
Decoding wireless signals

Tracking rotational motion

Analytics outside wireless range

How can plastic objects **communicate**?

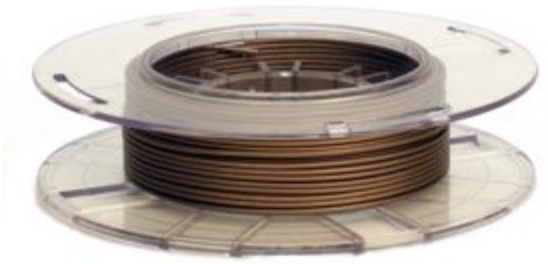
Printed objects communicate using **reflections**



Switch produces **changing reflections**

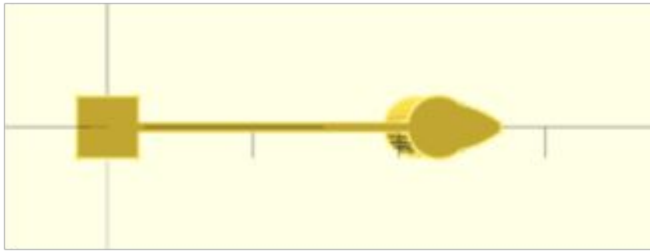
How do we build a switch?

1. Conductive contact



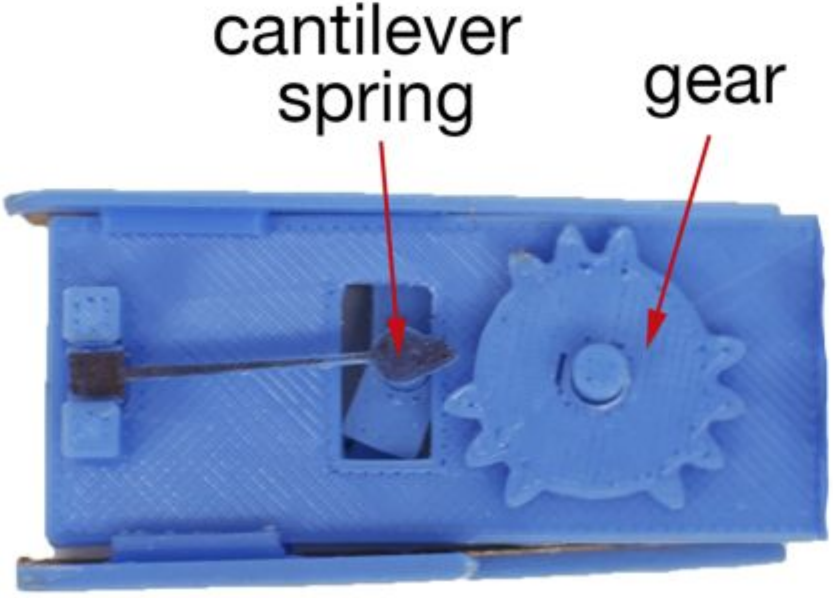
Conductive filament

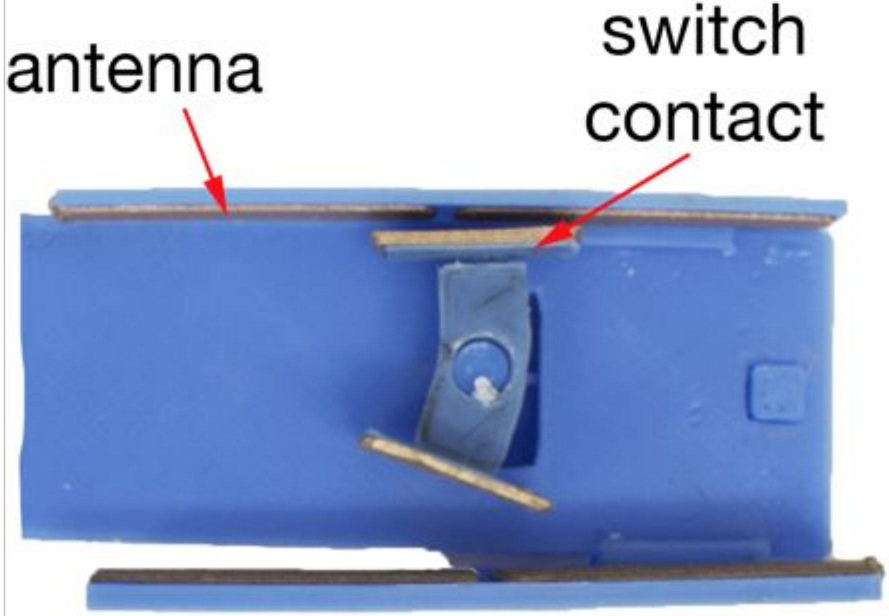
2. Bi-directional spring



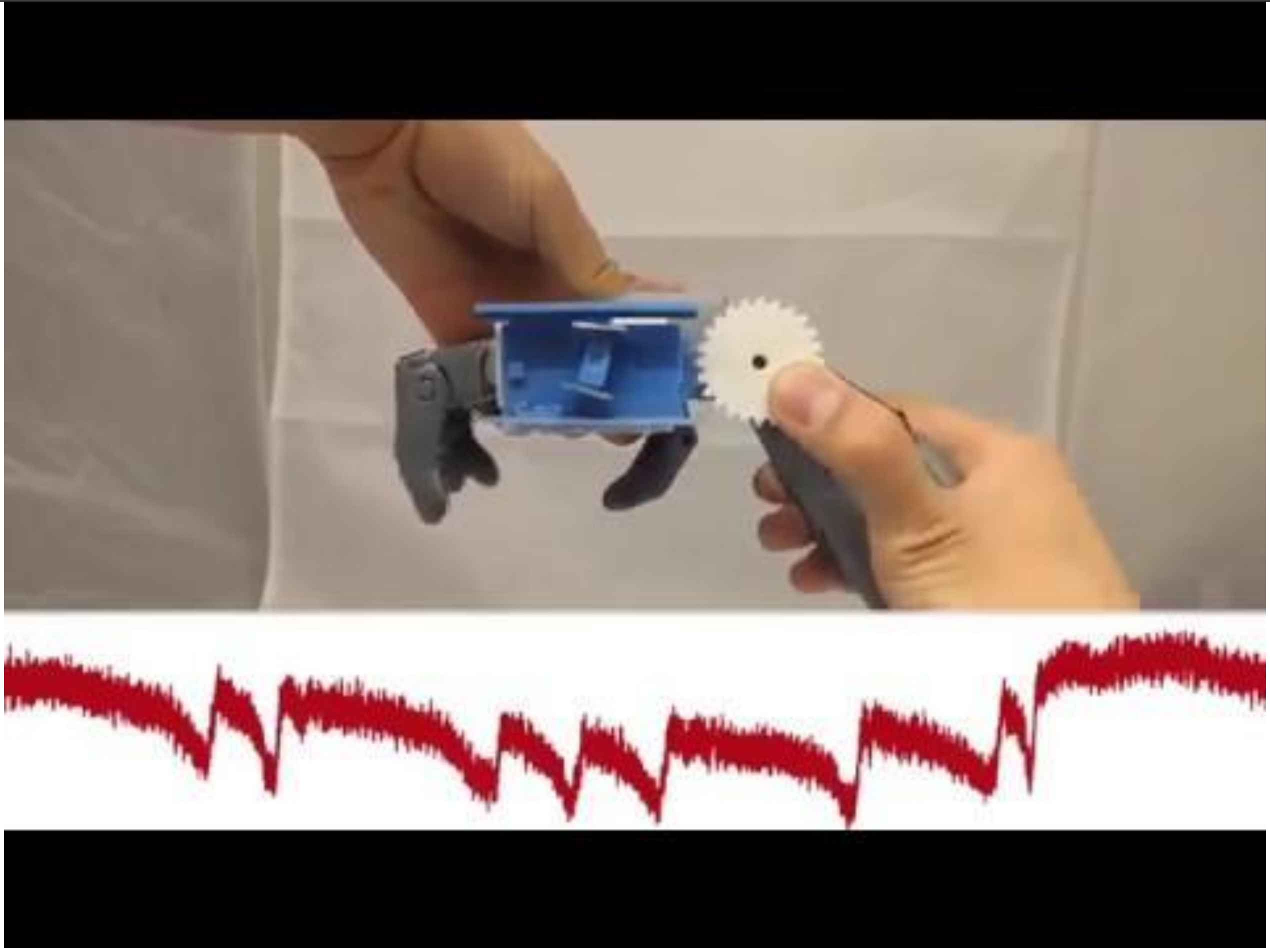
Cantilever spring

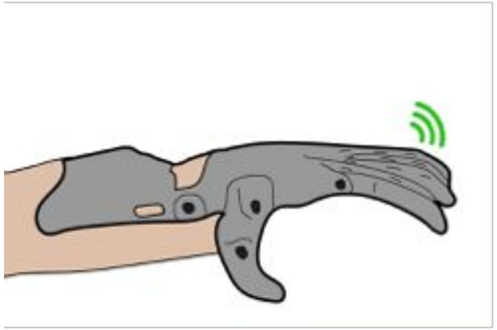
How do our switches work?





Switch in action: e-NABLE arm





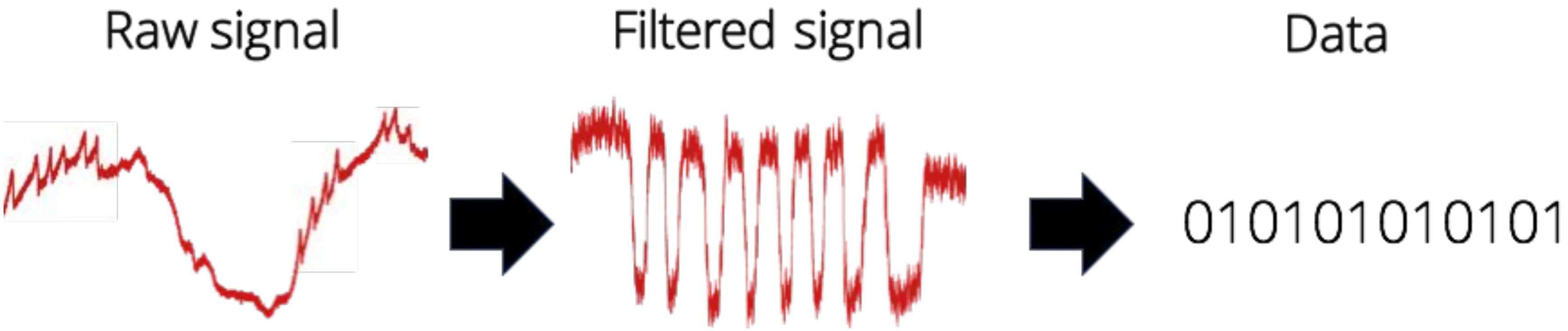
3D Printing wireless devices

Decoding wireless signals

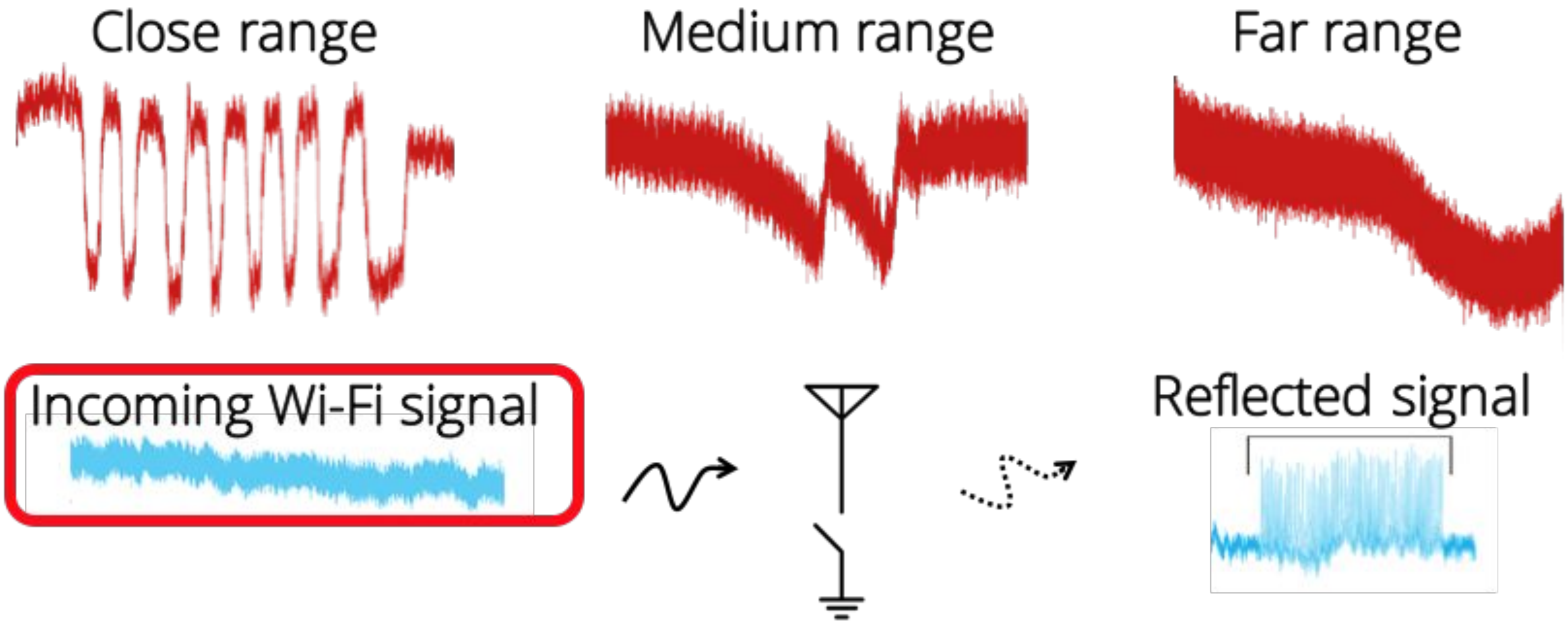
Tracking rotational motion

Analytics outside wireless range

How do we decode the data?



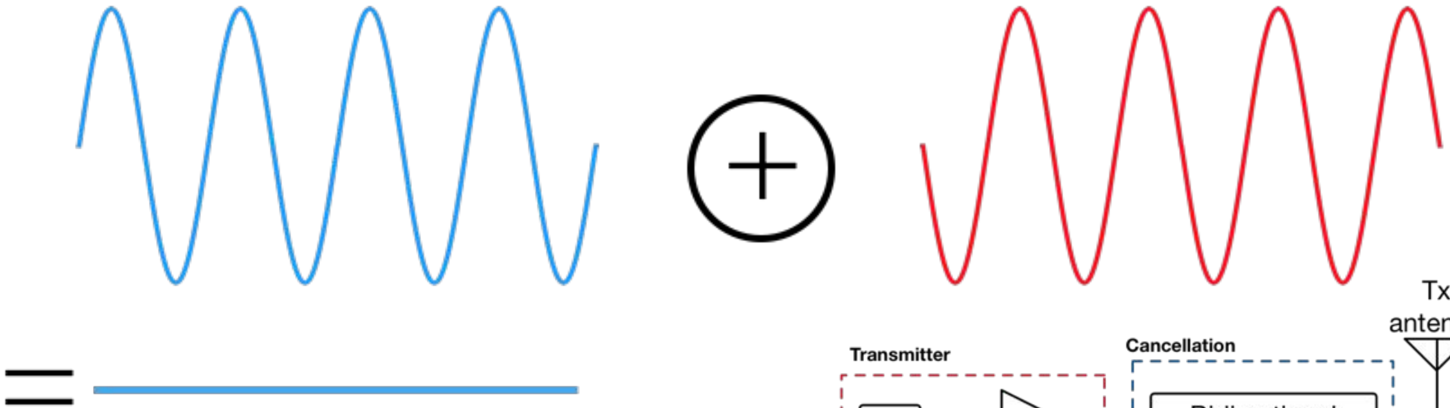
What happens at long range?

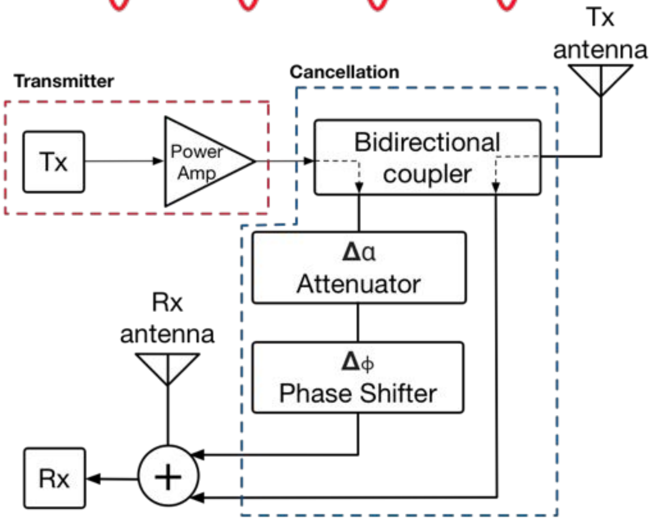


Self-interference limits range

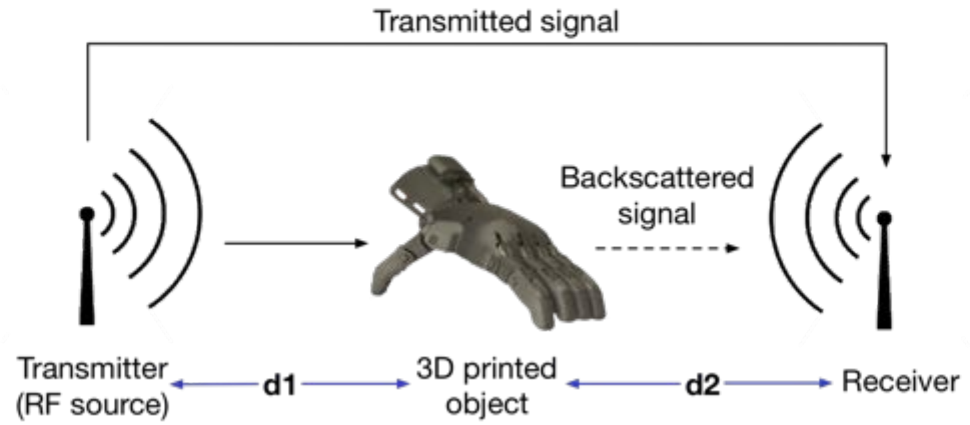
Solution: Cancel out the interference

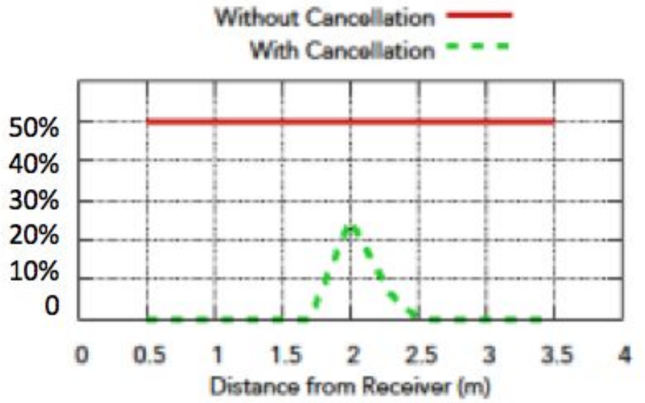
Transmitter signal Inverted signal



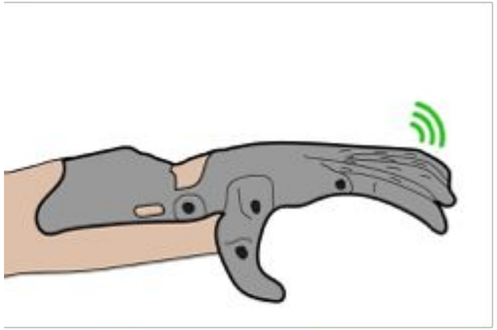


How well does cancellation work?





Works up to transmitter-receiver distances of **4 m**



3D Printing wireless devices

Decoding wireless signals

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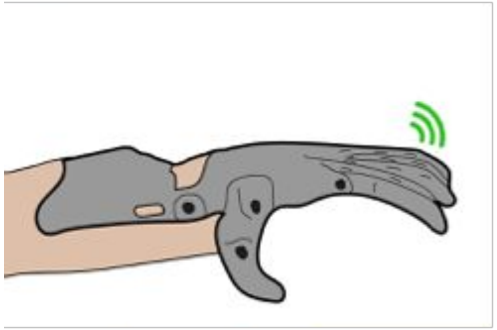
How do we measure angle?

How do we measure direction?

3D Printing wireless devices



Decoding wireless signals

Tracking rotational motion

Analytics outside wireless range

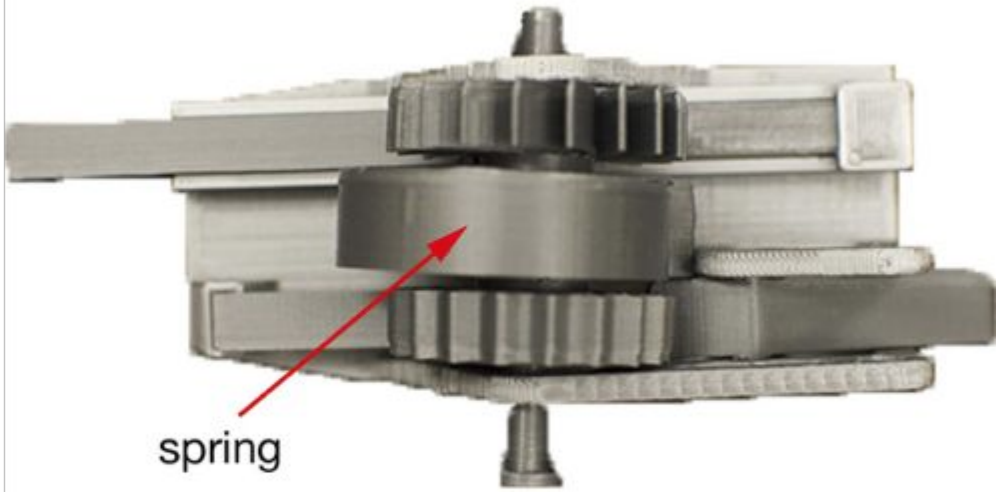
How do we read outside the wireless range?

- **Store** analytics outside range
- Wirelessly **upload** the data when back in range

Insulin pen requirements

- Store count of presses
- Accumulate each press
- Upload the data when back in range

Solution: Store information mechanically

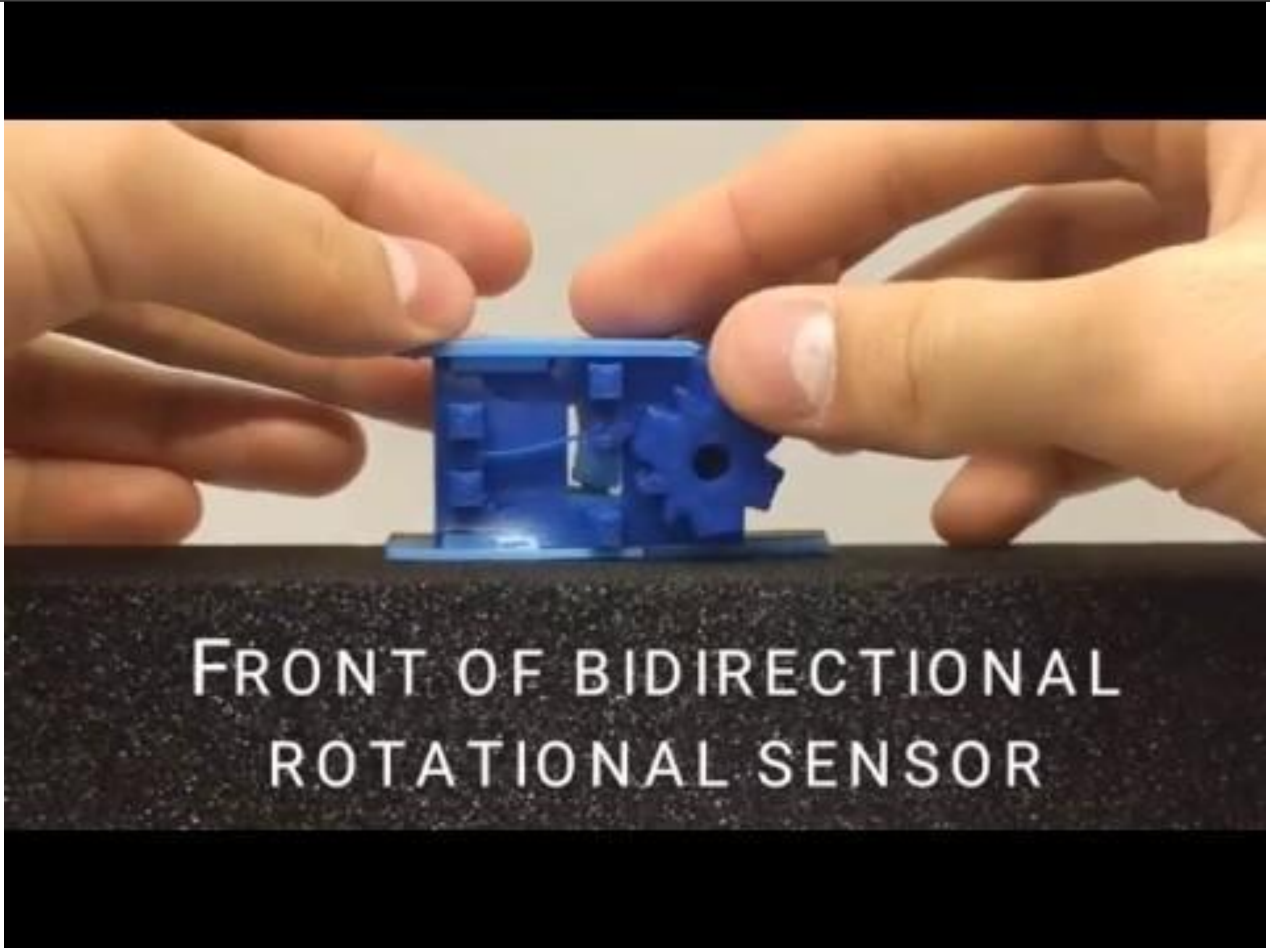


How do we keep the spring coiled?

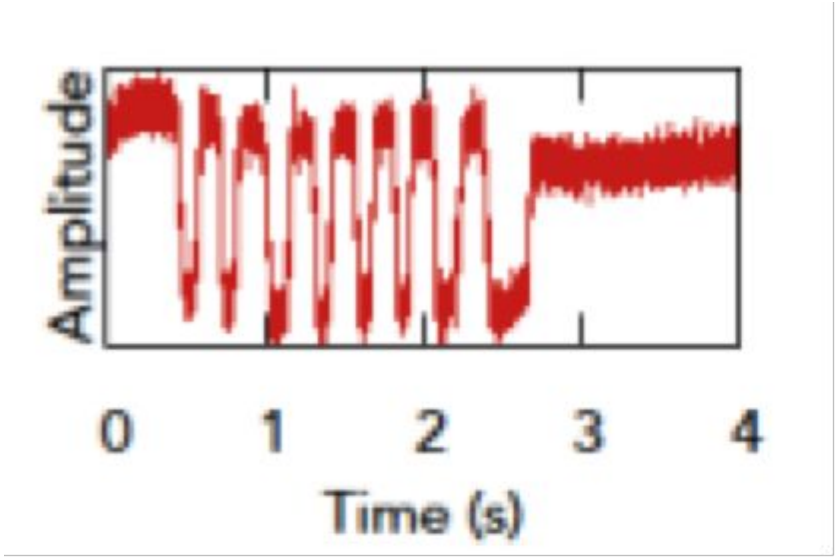
Key idea: Use a ratchet to coil the spring

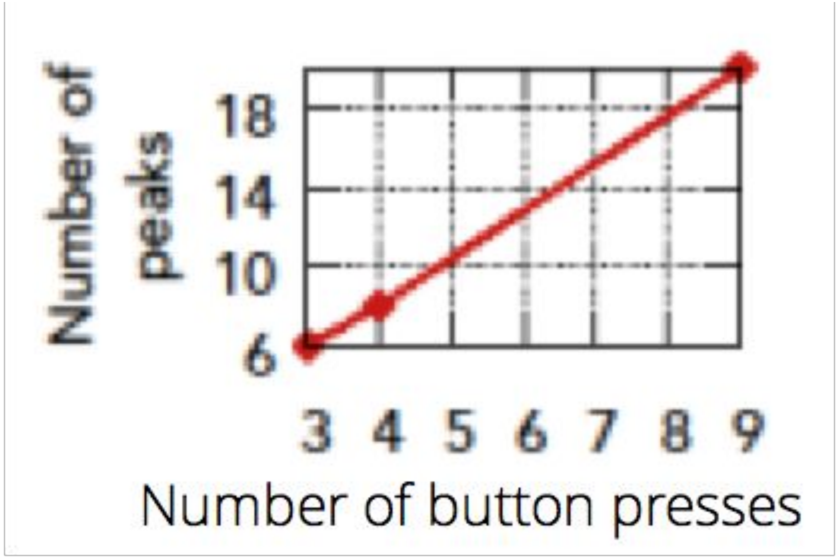
Ratchet **accumulates rotation** in spring

Storing and reading data from an insulin pen



Reading back the data





Future work

- Designing better form factor mechanism
- Recording timestamps of usage
- Increasing range to work across a whole home

Design and Fabrication by Example

Design and Fabrication by Example

Data driven approach for designing 3D models that are actually fabricable

Reality: When fabricating something beyond what can be produced by a 3D printed, one has to consider many complex requirements in particular the connectors like screws and connectors

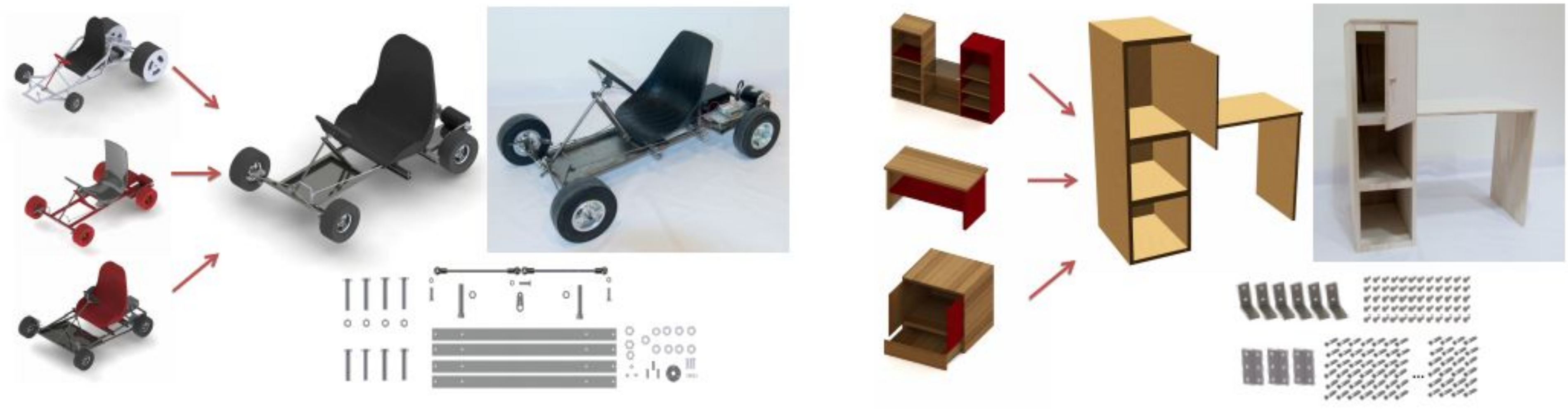
System creates a database of parameterized templates that were converted from expert designs.

Automatically extracts constraints/parameters

Guides users through the process of manipulation, positioning and stability analysis

Different
components from
expert database

Final
user-designed
prototype



Structural parts +
Mechanical joints

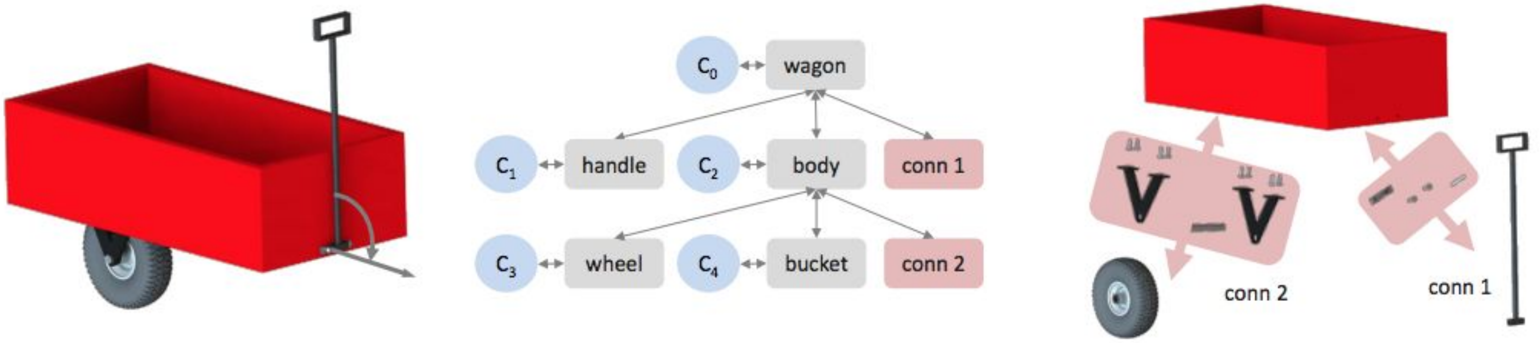
Output: bill of
materials

Hierarchical template representation

System creates a taxonomy that takes these complexities into account with categories for mechanical joints (prismatic, ball, hinge), structural parts (screws, hinges, brackets), principal parts (shelves, legs, wheels)

Geosemantic relationships are labelled by experts.

Leaves of tree are ‘least fabricable units’



Snapping method

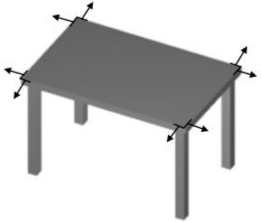
q^i: degrees of freedom

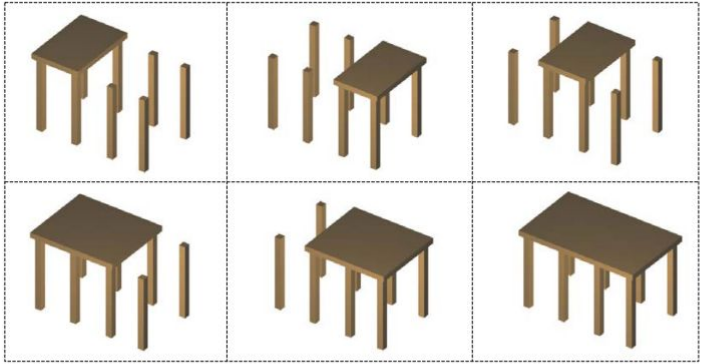
F^i: deformation function that computes new geometry

A^i: feasible space of q^i that is fabricable and collision free

Consider various geometric relationships:

Concentricity, coplanarity, symmetry, order



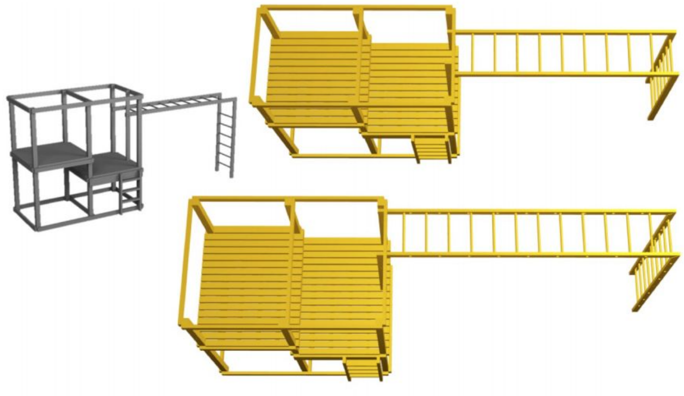


Snapping method

Constraint propagations are propagated through the hierarchy. Constraints remain intact when one principal component higher up in the hierarchy has changed.

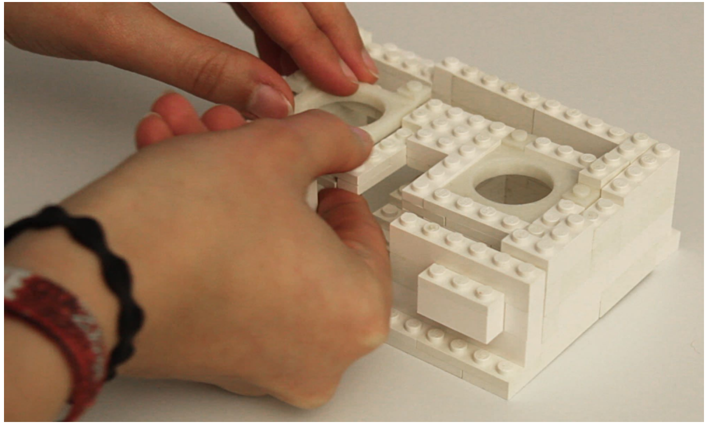
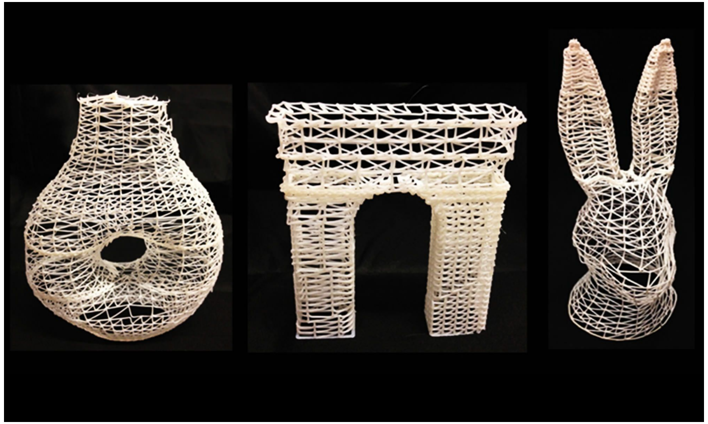
Fabrication:

Snapping - When dragging a new model, system automatically adjusts position and size to align with working model

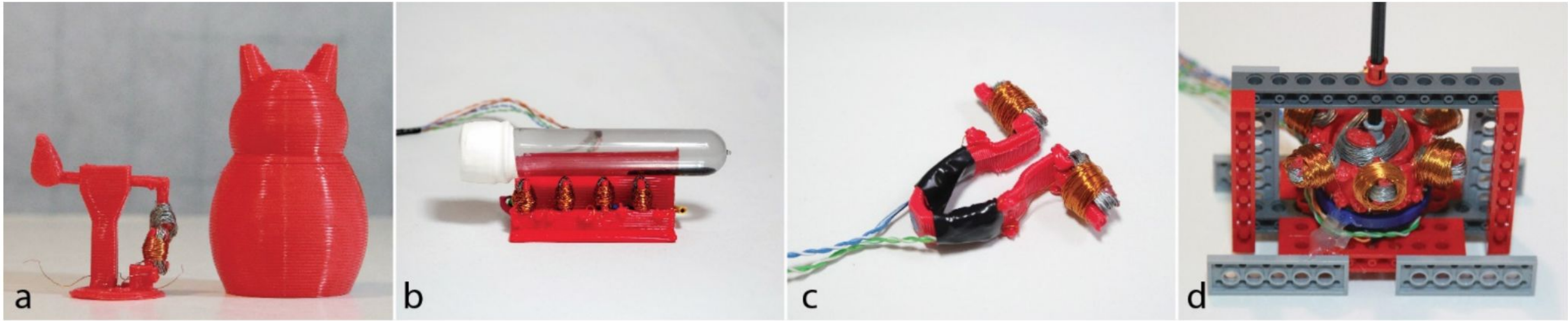


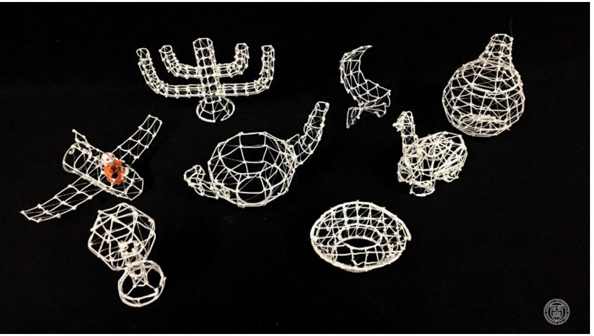
Connecting - Automatically retrieves new connecting elements and computes new geosemantic relationships

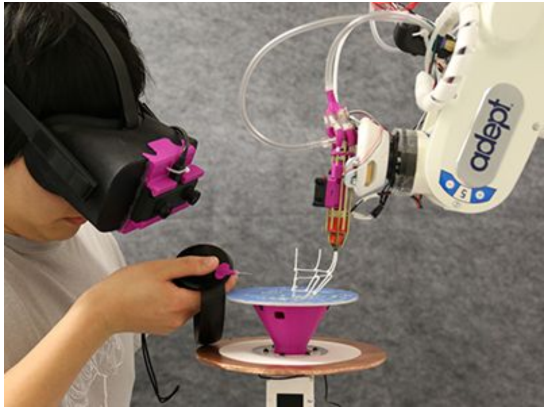
How can this be applied to Printed Wi-Fi?


fingers


a
b
c
d




adept


Soft Stanford Bunny
Research, Pittsburgh