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?
How can plastic objects communicate?
Challenge: Printing Connectivity

Need communication using only plastic
Fundamental Challenge: Wi-Fi operates at 2.4 GHz

Can’t print 2.4 GHz oscillator with plastic
Key Idea: Use mechanical motion to send data

Our Solution: Reflect Wi-Fi Signals Instead

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

Dipole Antenna

Bowtie Antenna

Patch Antenna
3D Printed Switch

Switch spring

Switch contact (conductive)

Antenna (conductive)

Data encoded Gear
Encoding Information on the Gear Teeth

Choose Parameters → Generate 3D model → Printed Object

Encoding Message
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

- Can decode multiple printed objects concurrently
- 45 bps data rates
- 17 m Line of Sight Range
- 45 m² 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

Magnetic  Plastic

Painted objects
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 \textit{communicate}?
Printed objects communicate using reflections

Switch produces changing reflections
How do we build a switch?

1. Conductive contact
2. Bi-directional spring

Conductive filament

Cantilever spring
How do our switches work?

cantilever spring

gear

antenna

switch contact
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
Tracking rotational motion
Analytics outside wireless range
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

Amplitude vs. Time (s):

- Amplitude graph shows variations over time.
- Time scale: 0 to 4 seconds.

Number of peaks vs. Number of button presses:

- Number of peaks graph shows an increasing trend.
- Number of button presses: 3 to 9.
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?