WiForce: Wireless Sensing and Localization of Contact Forces on a Space Continuum

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Need for a sensory layer like skin

Sensor Skins enable force sensing across the robot length
Emerging use-cases of sensor skins

Image Source: Highly dexterous 2-module soft robot for intra-organ navigation in minimally invasive surgery, Abidi et al.
Wired sensing of force profile

Sensing surface covered with discrete force sensors
Wired sensing of force profile

Force $F$

Voltage variation on sensors due to force $F$

$V_1$  $V_2$  $V_3$
Wired sensing of force profile

Current solutions have prohibitive wiring requirements
Problems with sensing wires

Image Source: Highly dexterous 2-module soft robot for intra-organ navigation in minimally invasive surgery, Abidi et al.
Need for wireless force sensing

Emerging applications necessitate wireless force sensing
WiForce designs a wireless force sensor that achieves sub-Newton force accuracy and mm accurate localization
Naïve wireless feedback solution

Can we design wireless force sensors without power hungry electronics?
Combining sensing and communication

Force $F$

Flexible skin-like layer

Encoding force onto the reflected signals doesn’t require power hungry electronics
Encoding force into wireless signal reflections

Mechanical perspective: Two parallel air-separated beams

Connecting the beams to antennas

\[ F_c = f(L_1, L_2), \quad l_c = g(L_1, L_2) \]

Contact lengths caused by applied force, gets encoded onto the reflected signals

Travel back a distance of L1, L2 respectively
How are contact lengths measured wirelessly?

Phase Accumulated $\propto$ Travelled Length

Phase Change $\propto L_1$
Handling interference caused by two-sided reflections

Without RF Switches

With RF Switches
Two swords in one sheath don’t fit together

How to give two frequency shifts without the switches being simultaneously ON?
Doing one at a time toggling

Measurements here, will only give $L_1$

Measurements here, will only give $L_2$

We can not measure lengths from the two ends simultaneously with this solution
Interleaving the off times creates continuous modulation
Interleaving the off times creates continuous modulation.

Measurements anywhere, gives both $L_1$ and $L_2$ simultaneously.
One antenna to sense them all

Two sided phases can be read with just one antenna reducing the form factor
Putting it all together: implementation of the reader

Slow Multipath Clutter

Sensor Freq. Shifts from the both ends

Power (dB)

500 Hz ≈ 70 mph

Doppler Frequencies (Hz)
Sensor implementation

Microstrip Line, with a soft polymer beam

Beam
Signal Trace
Ground Trace

VNA
(for Wired Phase Sensing benchmarks)

Linear actuator + indenter
Sensor
Load cell (for Force Ground Truth)
Sensor implementation

Microstrip Line, with a soft polymer beam

Beam
Signal Trace
Ground Trace

Phase (Degrees)

Force (N)

Wired Phases from VNA
Sensor implementation

Microstrip Line, with a soft polymer beam

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Phase (Degrees)

1  2  3  4  5  6  7  8

Force (N)

Wired Phases from VNA
Sensor implementation

Microstrip Line, with a soft polymer beam

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Phase (Degrees)

Forces:
- $F_1$
- $F_2$
- $F_3$

Wired Phases from VNA

Force (N)
Wireless experimental setup
Force magnitude and location CDFs

Median errors = 0.34, 0.56 N

Median errors = 0.59, 0.86 mm mm
Tissue phantom testing setup

![Image of tissue phantom setup with TX and RX labels, and a CDF graph showing similar median error for tissue phantom and over the air.

CDF

Force Error (N)
Multi-sensor and Fingertip touch force detection
Related works

Force Sensitive Resistors, Unmousepad: 2009

Electrode Resistance Tomography (ERT), Hyosang Lee et al. 2018-20

WiForce
Future directions

WiForce achieves sub-N, mm level accuracy in sensing & localizing forces, fully wireless, multi-sensors scalable

1. Designing creative communication+sensing solutions for related quantities to force
2. Enabling new HCI usecases for AR/VR with WiForce
3. Combined wireless tracking with WiForce can enable a new robotics wireless sensor suite

Feel free to contact me at agg003@eng.ucsd.edu for more information about our research!

http://wcsng.ucsd.edu/force_sensing