HERMA – Heartbeat Microwave Authentication

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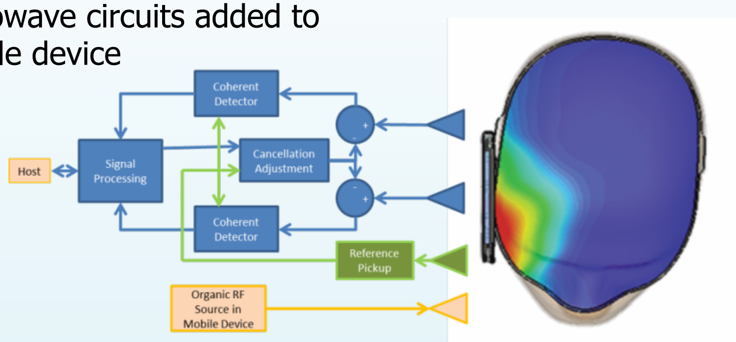
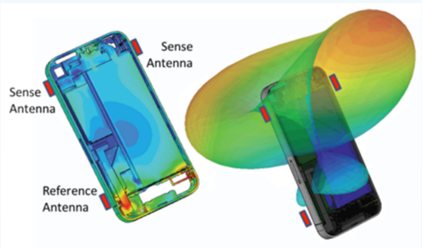
This research was developed with funding from the Defense Advanced Research Projects Agency(DARPA).

HERMA – Microwave Heartbeat Authentication

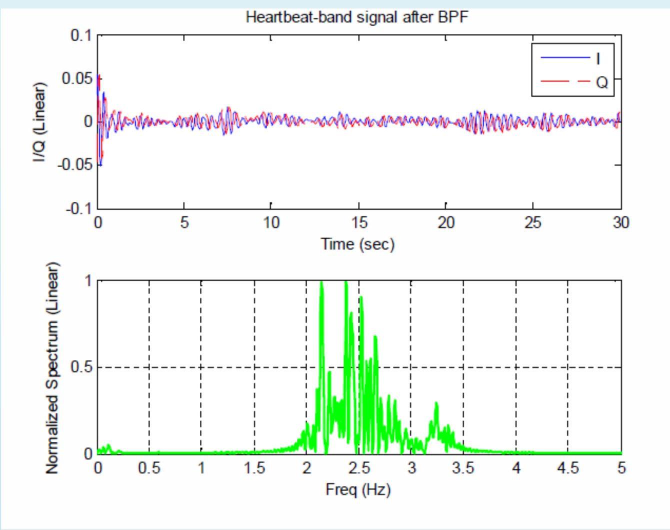
Microwave circuits added to mobile device



Antennas integrated into device sense motion due to heartbeat



Signal processing separates heartbeat features from background



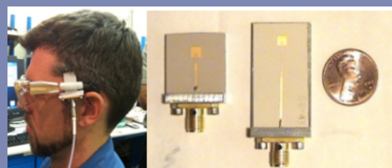
Features Extracted and Used for Authentication

Freq :	1.075	1.267	1.173
Amp :	0.00335	0.00314	0.00175
BW :	0.0335	0.0312	0.00534
Pk T :	5.93	5.03	2.54
FM f :	0.23	0.1	0.09
FM i :	0.35	0.4	0.75
FM p :	0	90	270

Background

JPL research demonstrated identification in laboratory

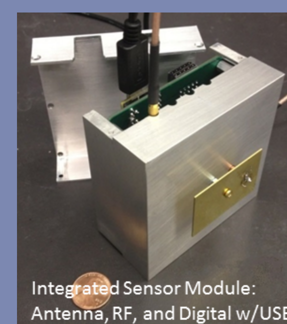
- 6 out of 6 subjects identified with sensor on temple over multiple trials



	S2	S4	S5	S7	S7	S8
S2	11					
S4		8				
S5			12			
S6				12		
S7					16	
S8						13

FINDER – Victim Detection Radar

- Detects multiple victims by sensing heartbeat through 30-40 ft of rubble
- DHS/JPL development from Lab bench to portable field unit in 1 year
- Leveraged microwave and computing from wireless industry


Integrated Sensor Module:
Antenna, RF, and Digital w/USB

Principle of Operation

Heartbeat pushes blood through body causing small motions of skin & tissue

Hardware addition to mobile device

Microwave Sensor detects motions

Software running on Mobile Device

Signal Processing Software extracts unique features

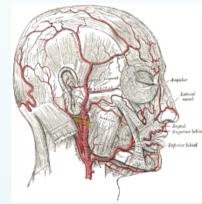
Software running on Mobile Device

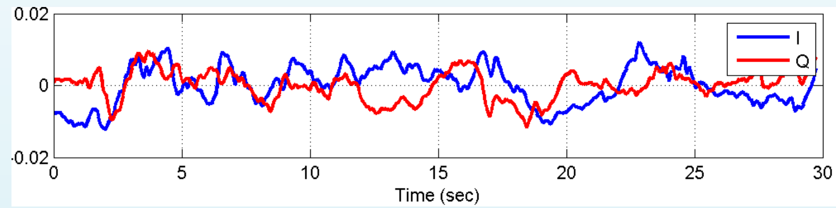
Features compared against database (with secure distribution)

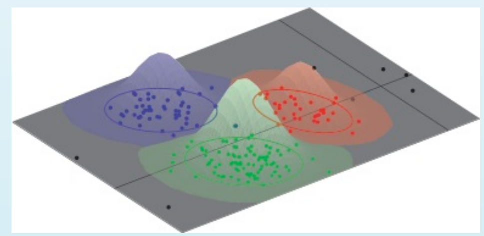
Authentication Decision

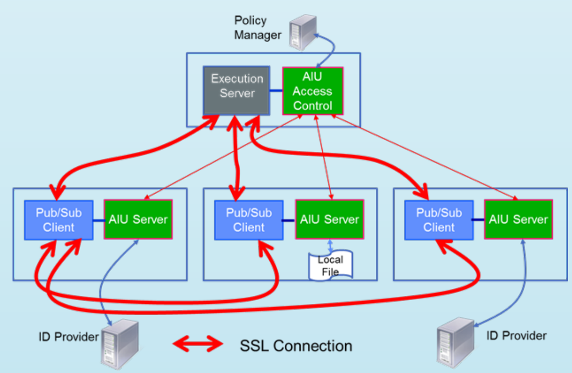
YES

NO





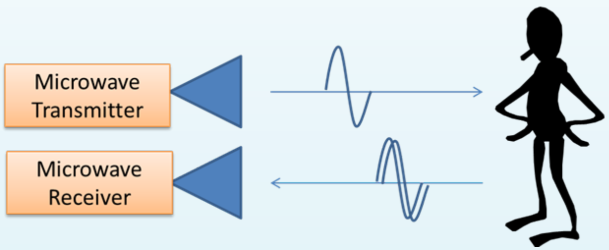


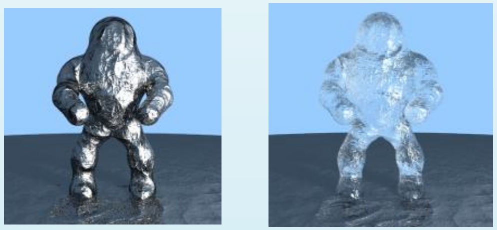


How the heartbeats are sensed

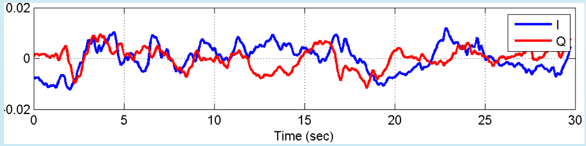
- A very low power radio signal illuminates the user
- The user's skin and tissues reflect most of the signal (at microwave frequencies, humans are shiny and slightly translucent!)
- As the skin and tissue moves (particularly due to the blood vessels expanding as the pulse moves through), the reflection changes.
- The motion pattern is unique for each person

- For HERMA, the radio illumination comes from the phone itself: the Bluetooth or WiFi signals illuminate the user, and we look for the changes in the reflections





Images from Rudy Knoerig
http://www.knoerig.de/lightflow_en.html



Hardware Implementation

- Ultimate objective is to integrate HERMA hardware with the phone, most likely in combination with existing Radio Frequency (RF) radio components.
- Intermediate step is to miniaturize to point it could fit in a hardshell case around the phone

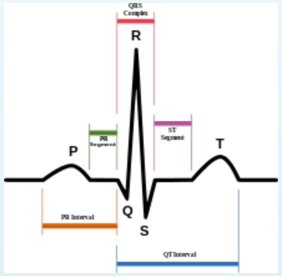
Which we've done:

- Design is small enough to fit in an off the shelf case with a Li-Ion battery
- Power consumption is low enough that the battery life is 10-20 hours, depending on duty cycle

Non-Fiducial Recognition Algorithms are the Focus

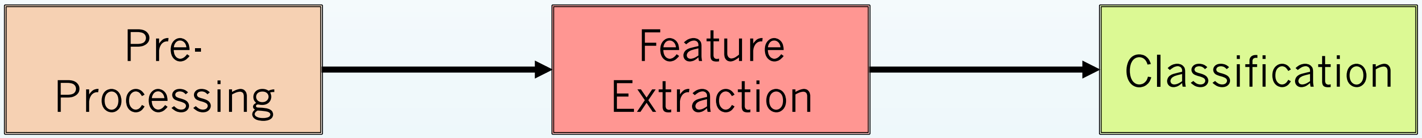
- Our algorithms focus on non-fiducial methods, because unlike ECG, the microwave signals don't have sharp peaks to use for time reference

- Initial implementation uses autocorrelation (AC) of non-overlapping windows coupled with the following feature extraction methods.
  - discrete cosine transform (DCT)
  - principal component analysis (PCA)
  - linear discriminant analysis (LDA)



- Initially started with ECG (electrical) data set
  - Physikalisch-Technische Bundesanstalt (PTB) Diagnostic ECG Database from PhysioNet, which has been used extensively in the literature.
    - 549 ECG recordings (each around 2 min and sampled at 1 kHz) obtained from 290 subjects.
  - Used 48 of the data sets

Processing Flow for ECG data

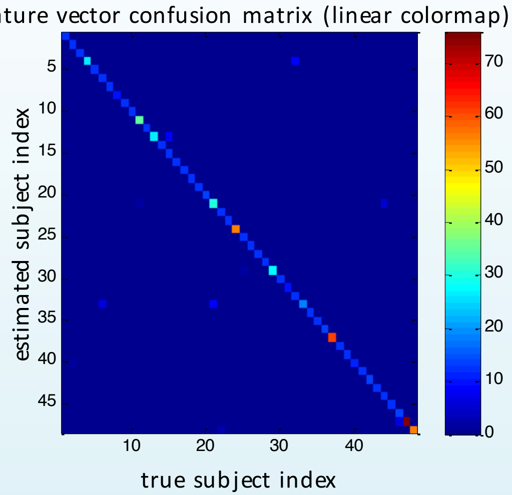


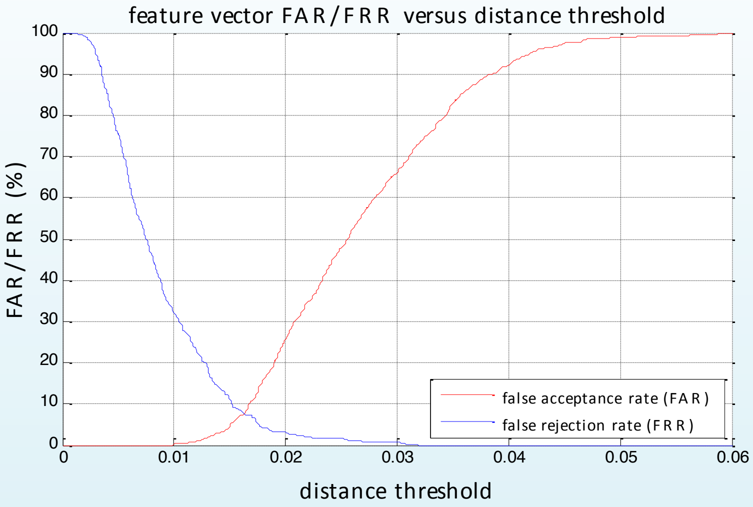
Pre-Processing:
- Lead I data was processed by a digital Butterworth filter (4^{th} order, cut-offs at 0.5 Hz and 40 Hz) to remove low frequency wander and high frequency noise.
- Optional resampling module implemented (for subsequent downsampling).

Feature Extraction:
- Data was segmented into 5 sec non-overlapping windows.
- Autocorrelation (AC) of each window was computed for lag values up to 180 msec. (features have this general time scale)
- Feature Vectors (FVs) formed from AC sequences using DCT, PCA, or PCLDA.

Classification:
- Training set was formed from 10 FVs per subject (50 sec worth of data).
- Test data was classified on an FV nearest-neighbor basis according to Euclidean distance. Records were classified according to the mode of the FV subject indices.

Excellent performance with EKG





Sample data for Autocorrelation/Principal Component Analysis(PCA)

- FV accuracy rate = 92.3%
- record accuracy rate = 98.4%
- # of FV dimensions = 20
- AC/Discrete Cosine Transform (DCT) is similar

Combined Principal Component/Linear Discriminant is better

- FV accuracy rate = 98.9%
- record accuracy rate = 100%
- # of PCA FV dimensions = 20, # of LDA FV dimensions = 15

As with most of these techniques, shifting threshold changes False Positive vs False Negative

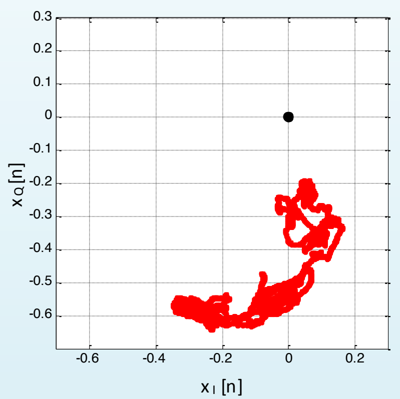
Recognition using Microwave Data

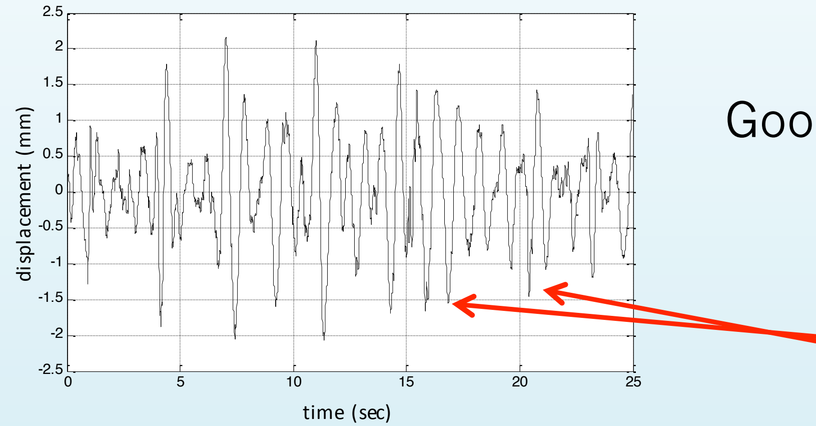
- Started with two MCG data sets collected by DHS FINDER program
  - 30 second captures, which can be segmented
  - Set #1
    - One subject, captured 30 seconds of data every 2 minutes for 4 hours
    - Single microwave channel, from 2 meters away (approx)
    - All the same subject, but from different angles
    - Out of 89 data sets, about 30 wind up being immediately usable, 9 are "pristine"
      - Software bugs corrupted data
      - Excessive motion artifacts
      - Subject not present in field of view
  - Set #2
    - One or two subjects (out of 4) in field of view
    - 3 channel recording (antennas displaced from each other)
    - Recorded from 5 meters away
    - 24 data sets

- Initial processing through recognizers found following:
  - Automated data editing is needed
  - Features are found allowing separation, but needs tuning

When you're not connected with wires in a lab…

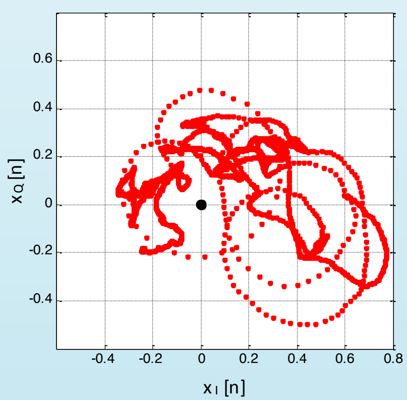
- Excision – not all of a data set is good data – motion transients can obscure the heartbeats

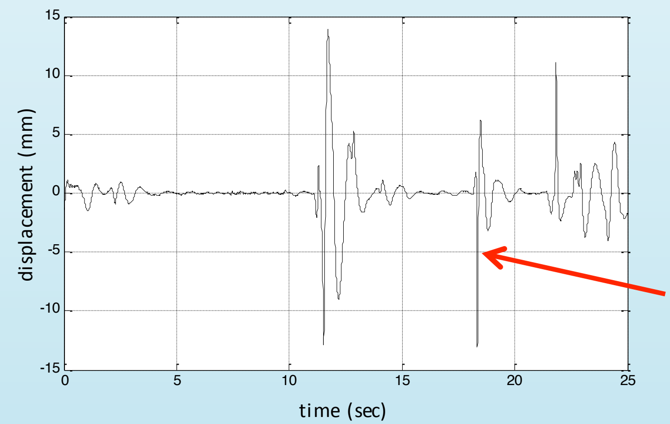




Good

Heartbeats





Not So Good

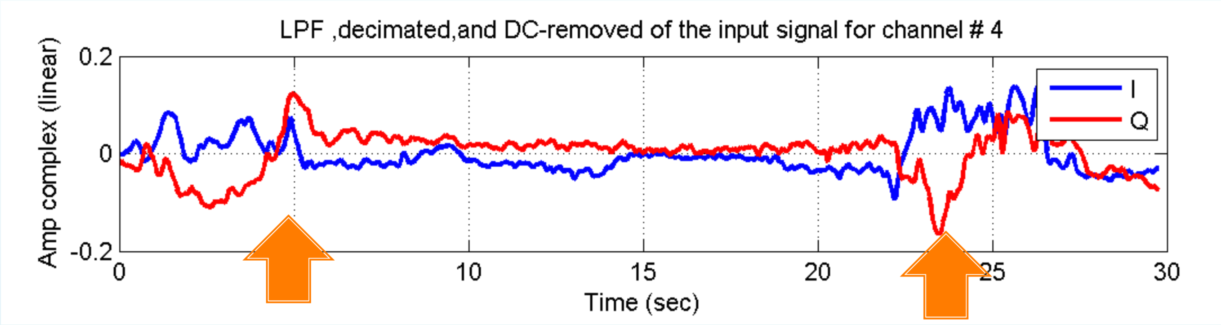
Note: Vert scale is different (15mm vs 2.5mm)

These are NOT heartbeats, they are 1cm movements

Raw I/Q data
(points should lie on an arc)

Extracted displacement

Excision and Transient Detection



- Two Approaches
  - For short transient (<1 heartbeat): Slice it out and use rest of segment
  - For long transient (> few heartbeats): Segment and process separatelyTwo alternatives: excise short transients; segment for big transients
- Transient Detection Algorithm
  - Needs to be something computationally simple that can be executed on the fly
  - Investigating simple "is rms amplitude bigger than it has been?" first
- Slicing Algorithm
  - Where do you start and end the excision: Slicing out a "whole beat" is preferable to slicing partial beats.
  - Particularly difficult for short captures with relatively few beats. Analysis finds "features" of the excision, not the underlying heartbeat.
  - No nice fiducial QRS complex to use.
- Or, real simple: If you authenticate every 30 seconds with a 5 second capture, and you get a bad capture, just skip it and go on. Depends on the higher level system requirements and transient statistics.

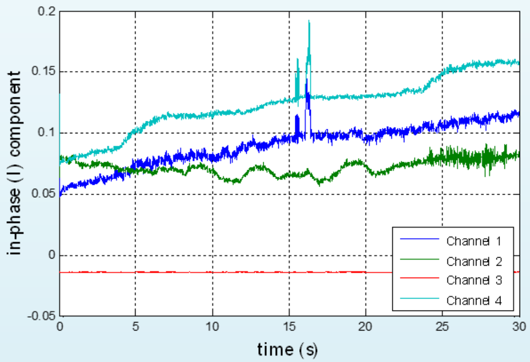
Mass Data Collection

- Collecting 4 simultaneous data sets
  - Wired ECG (3 lead) for "ground truth"
  - 2-3 microwave "standoff" (front, side, overhead) from >1 meter
  - Mobile device prototype microwave with 4 channels
  - Mobile device motion dynamics (gyro, accel, magnetic)
- Mobile device will be held in 5 positions
  - Calling
  - Texting/Emailing
  - Passively watching (e.g. video)
  - In pocket
  - On table in front of subject
- 3 captures of 30 seconds in each position
  - We can break 30 seconds up into shorter samples of 5-10 seconds
  - Each position takes about 4-5 minutes, if we do it repetitively
- Repeat measurements after 1 month delay
- 100 subjects will be recruited from JPL population
  - Found some identical twins – IRB being asked for change in protocol to allow recruitment and testing (we weren't lucky enough that both twins work at JPL)

Sample Data

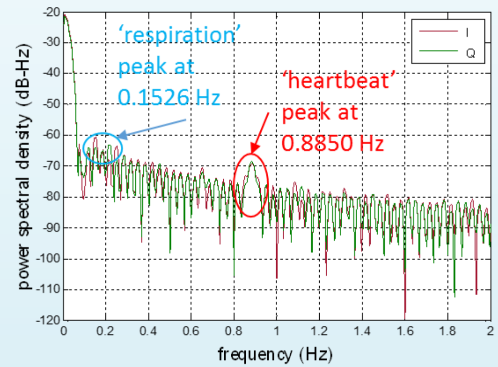
- Samsung Galaxy 3 cellphone with 4 antennas (one in each corner)

Raw Signals



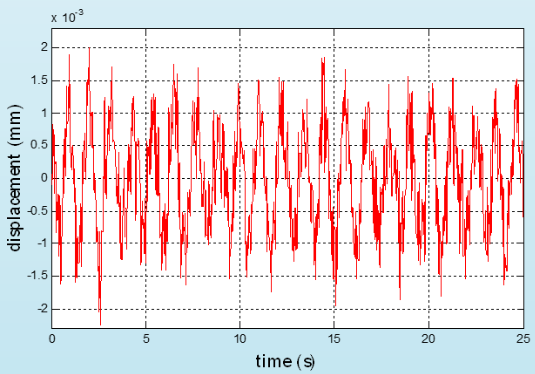
I, cell phone setup

Power Spectrum



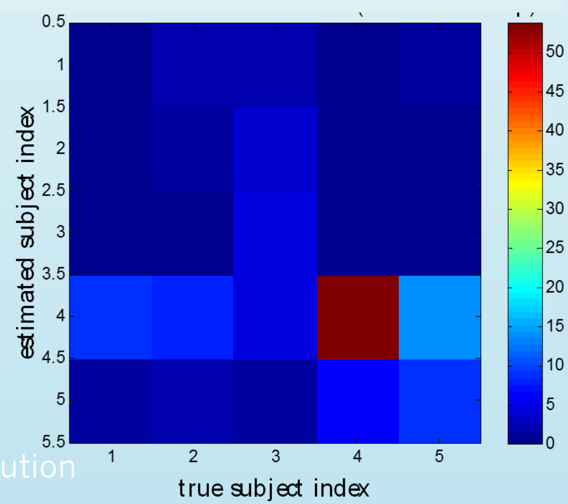
PSDs, cell phone setup

Extracted Motion



Channel 3, cell phone setup

Confusion Matrix



What's Next

- More Data Collection & Analysis
  - Input to actual authentication/recognition algorithms
- Improved Excision and Transient Detection
  - Needed for "good data"
- Revisit Software Architecture
  - How much processing in phone vs in central server