Performance Evaluation of Beacons for Indoor Localization in Smart Buildings

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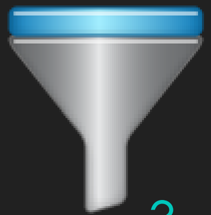
Agenda

- The Research
- The Motivations
- The Design
- The Results
- The Conclusion
- Q & A

The Research

- Testing feasibility of Bluetooth Low Energy beacon based indoor navigation
- BLE Beacon Comparison
  - Kontakt vs. Estimote vs. Glimworm
  - Proximity Accuracy
    - Using Received Signal Strength Indicator (RSSI) Techniques
    - Only accuracy, no other considerations
- RSSI Filtering
  - Kalman Filters
  - Fully Mobile



The Motivations

- IoT Growth
- Increased demand for interconnectivity
- Determine feasibility of; simple, fully wireless, indoor navigation using BLE
- Current Solutions:
  - Limited Indoor Location Services
  - Vision based solutions are expensive
- GPS does not work:
  - Physical obstructions (walls/roof)
  - Not accurate enough for requirements of indoor location services
  - Need alternate solution

The Motivations

Micro-localization scenarios

- Malls/shopping centers
  - Target & Walmart
  - Navigate stores
  - Location based promotions
- Museums
  - National Slate Museum, Wales
  - Brooklyn Museum, New York
  - Philips Museum, Eindhoven, The Netherlands

What Are Beacons?

- Small transmitting devices
- Fully wireless (Button cell power sources)
- Designed for low power consumption
  - Implement Bluetooth Low Energy Protocol
- Implement iBeacon/Eddystone packet layout
- Configurable
  - Transmission Power
  - Transmission Interval
- Additional Sensors
  - In only some cases

The Motivations: Why Beacons?

- Small
- Fully Wireless
- Cheap
- Longevity
- Scalable
- Configurability

https://locatify.com/blog/indoor-positioning-systems-ble-beacons/

The Design: Beacons

- 3 Beacons are utilized
  - Estimote
  - Kontakt
  - Glimworm

	Estimote	Kontakt	Glimworm
Power Supply	4 x CR2477 - 3.0V	2 x CR2477 -3.0V	1 x CR2450 – 3.0V
Radio	Bluetooth 4.2 LE	Bluetooth 4.0 LE	Bluetooth 4.0 LE
Size	Length: 62.7 mm Width: 41.2 mm Height: 23.6 mm	Length: 55 mm Width: 56 mm Height: 15 mm	Length: 85 mm Width: 64 mm Height: 15 mm
Appr. Price (USD)	$33	$20	$29

The Design: Beacons

Beacon Configurations

- Estimote & Kontakt
  - Transmit Power: -12dBm
  - Transmit Interval: 300ms
  - Apple's iBeacon protocol
- Glimworm
  - Transmit Power: -8dBm
  - Transmit Interval: 300ms
  - Apple's iBeacon protocol

- Trade-off between energy consumption & accuracy
  - Focus on accuracy
  - Focus on filtering improvements
- Ease of Implementation with Mobile Application
  - Mobile implemented Kalman filter

The Design: Test Environment

For the purposes of the experiment:

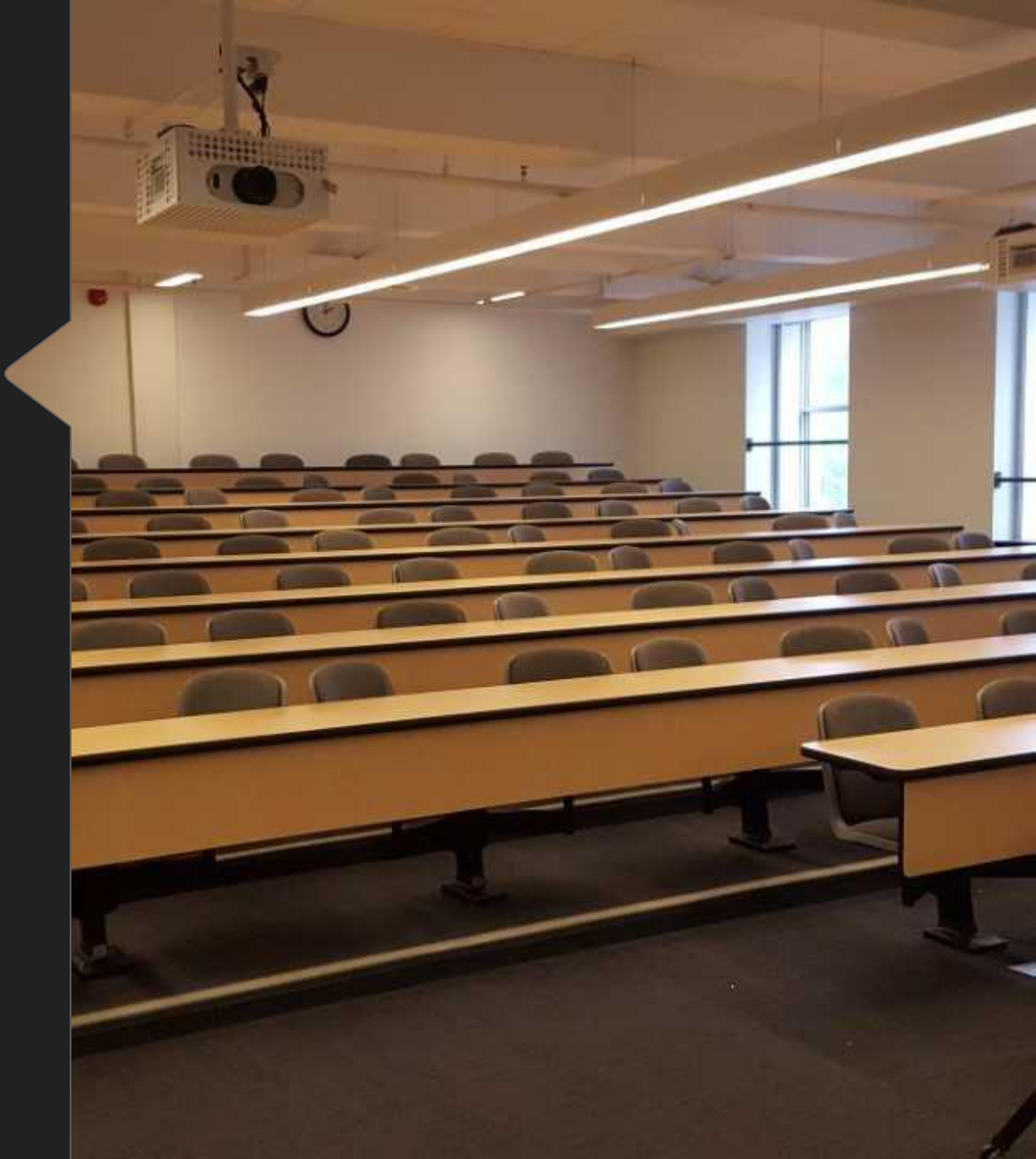
- Semi-controlled environment
  - 1 Beacon at a time
  - No people besides myself
  - No physical environmental changes
  - No control over other Bluetooth or Wi-Fi channels in the area

Reasoning:

- Want to see only the effects of room size on filtering parameters
- Eliminate variations in testing between beacons
- Have an understanding of the baseline/semi-ideal case

Test Environment: Lecture Hall

- University of Guelph: Richards Building
- 9m x 11m room
- Chosen for its simple configuration and layout
- Representative of average size room in a building
- Consistent environment
    - No physical changes in environment when empty



The Design: Receiver (Smartphone)

- The receiving device is Google Nexus 5
  - Running Android 6.0.1
  - Implements all distance calculations & filters on the phone itself
  - Makes use of "Beacon Scanner" application with changes to accommodate Kalman Filter

The Design: Mobile Application

- Fully mobile integration!
- Utilizes the open source AltBeacon Library
  - Enables phone to identify iBeacon and/or Eddystone protocols
- Available on Google Play store
  - Originally developed by Nicolas Bridoux

Application Screenshot

Beacon Scanner with UI changes and filter implementation

-Done with simple hash maps and math functions

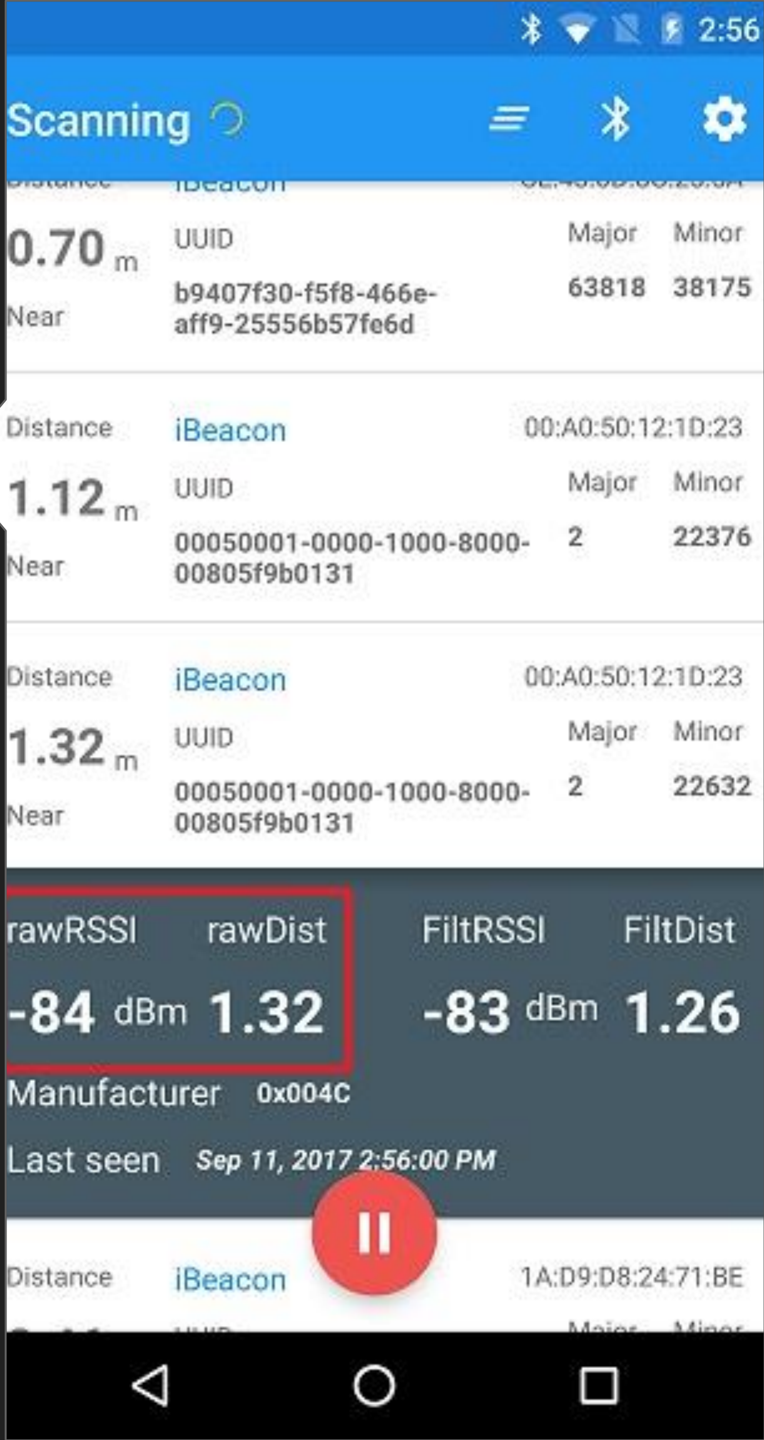
Shows RSSI and Distance

-Distance calculated with best curve fit algorithm

-Provided by AltBeacon Library

-Specific to each phone

Base Application w/o filters available on Google Play store



The Design: Kalman Filter

Prediction Stage

- State Prediction at Time k
  - x(k|k-1) = x(k-1|k-1)
- System Error & Noise Covariance Prediction at time k
  - P(k|k-1) = P(k-1|k-1)+Q

Q (process noise covariance) = zero in this system.

Assume environment is controlled with direct LOS.

Static measurements are taken, Hence Static Kalman

Update Stage

- Compute Kalman Gain
  - G(k) = P(k|k-1)/(P(k|k-1) + R)

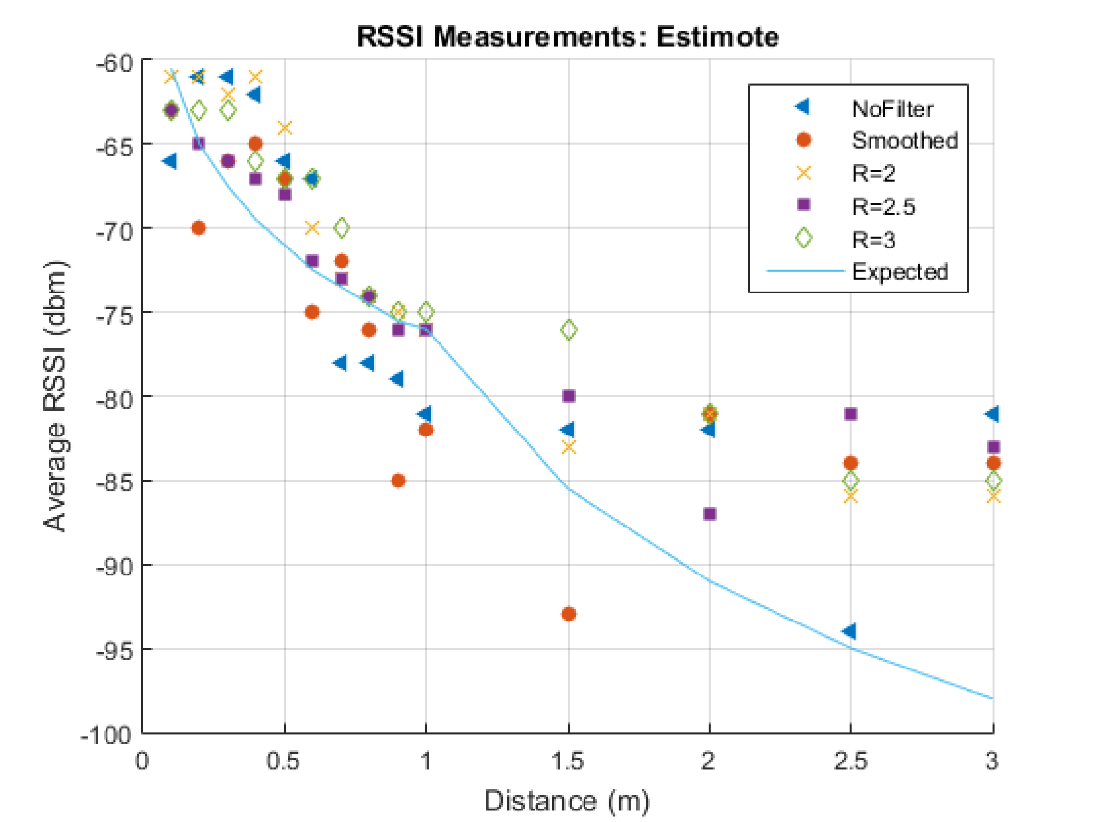
  R is the parameter optimized for the environment

  R = 2 for Estimote/ Kontakt. R =2.5 for Glimworm
- State Update at time k
  - X(k|k) = x(k|k-1) + G(k)*[y(k)-x(k|k-1)]

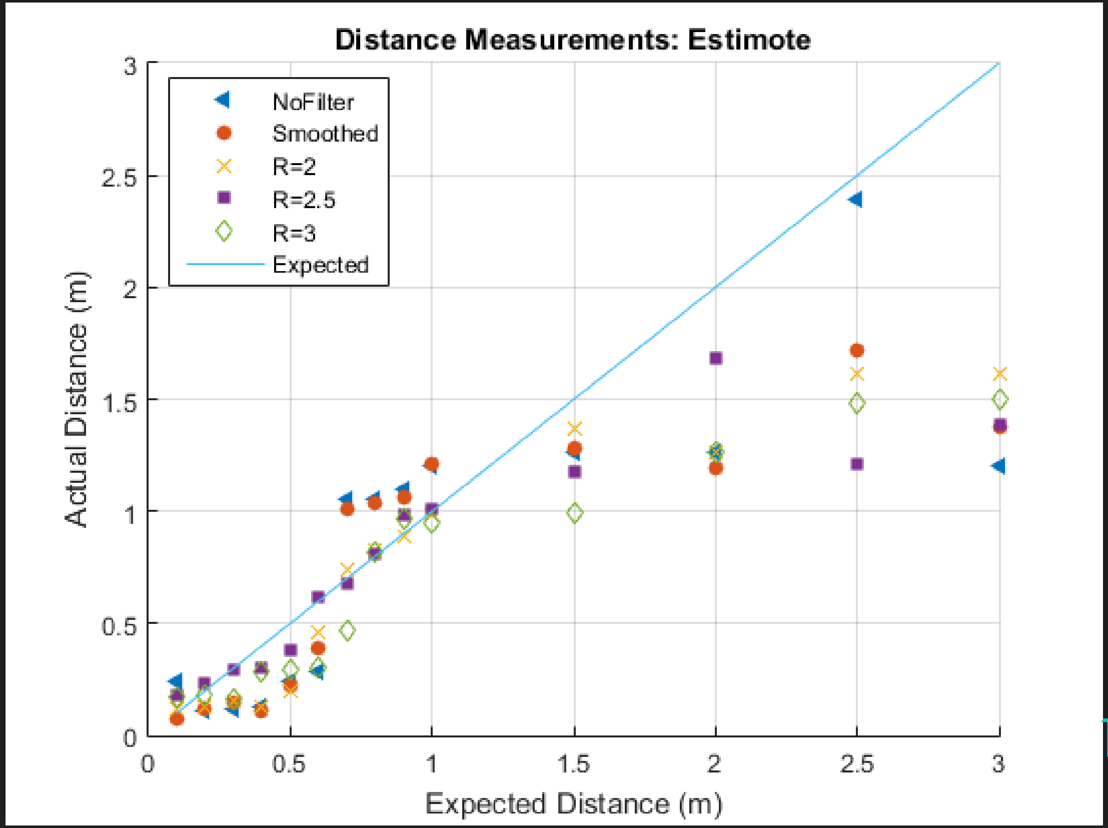
  y(k) is the new raw RSSI value at the current state
- System Error & Noise Covariance Update at time k
  - P(k|k) = [1-G(k)]*P(k|k-1)

The Results: Estimote

RSSI



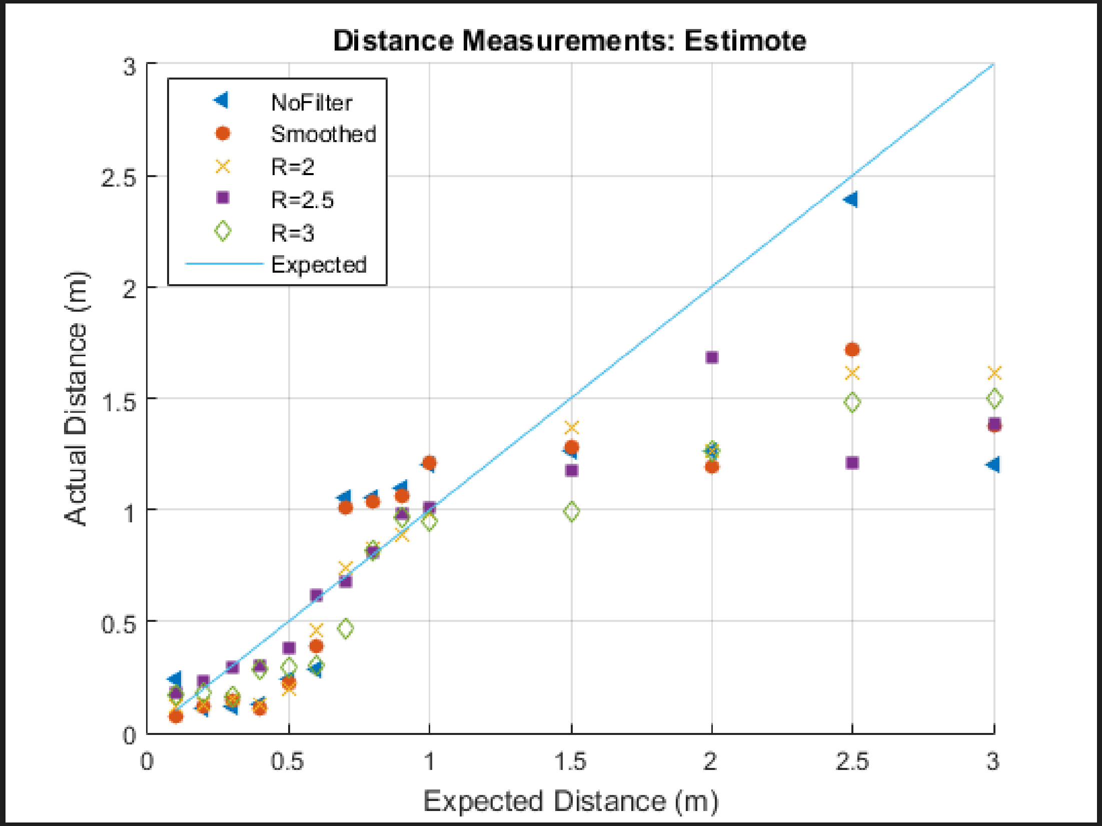
Distance



The Results: Estimote Discussion

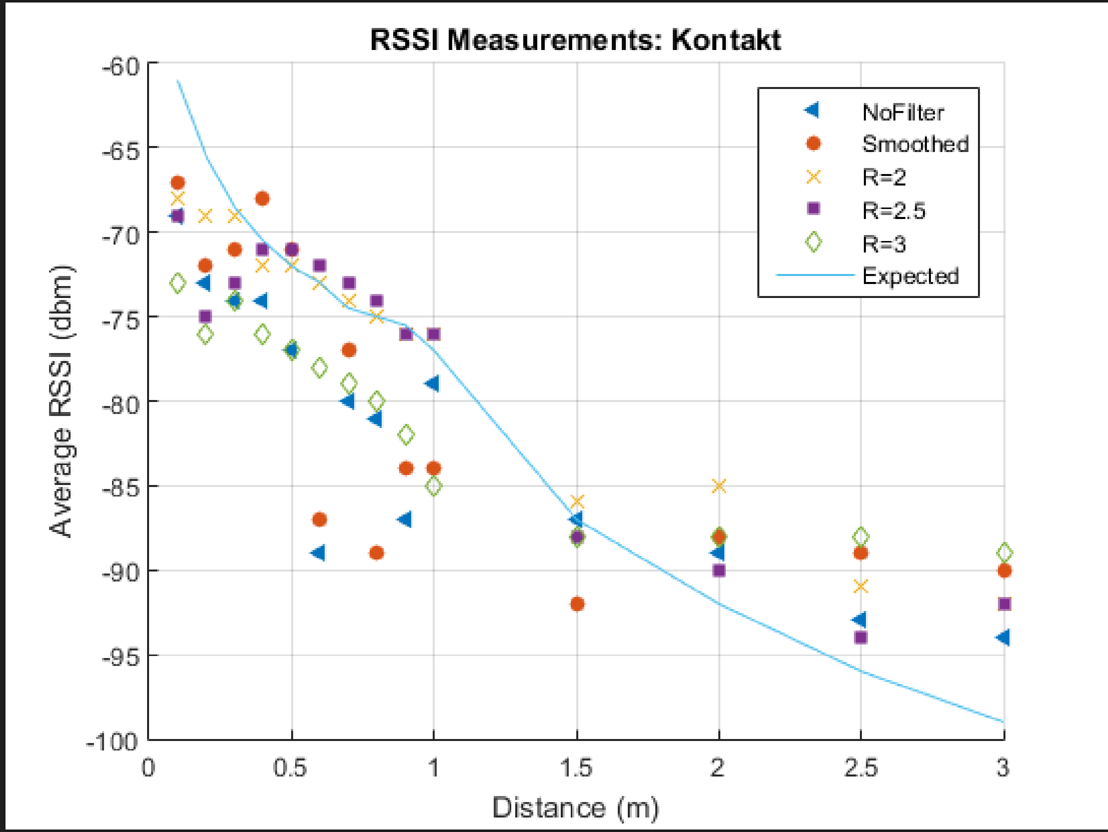
- Distance and RSSI accuracy for this environment fall after 1.5m
- This tends to be true for all the beacons
- Often underestimated for Estimote

Estimote Distance

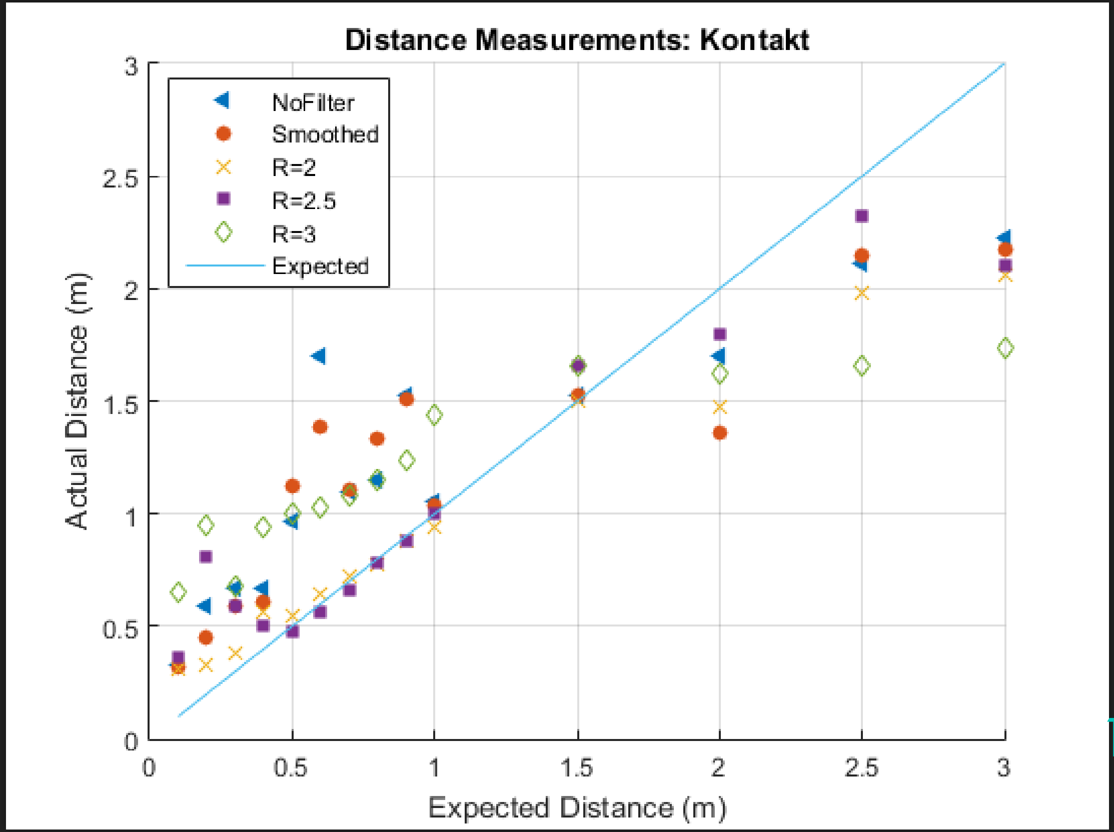


The Results: Kontakt

RSSI



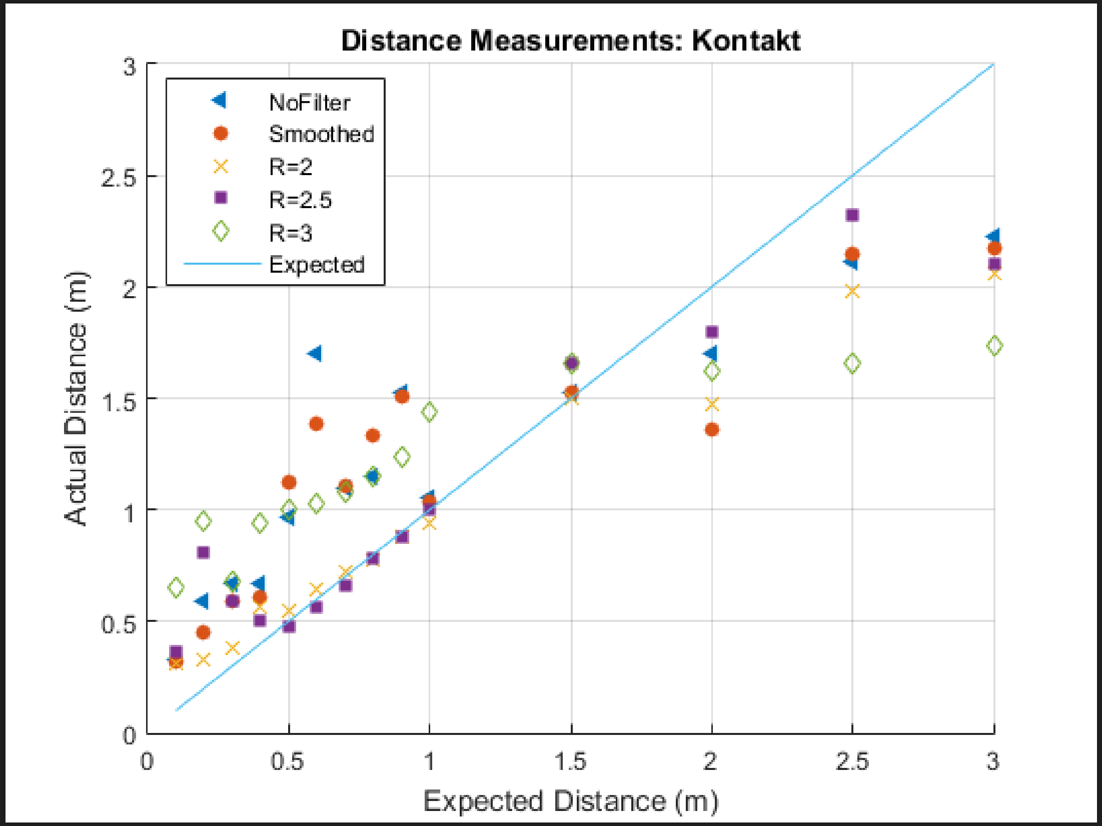
Distance



The Results: Kontakt Discussion

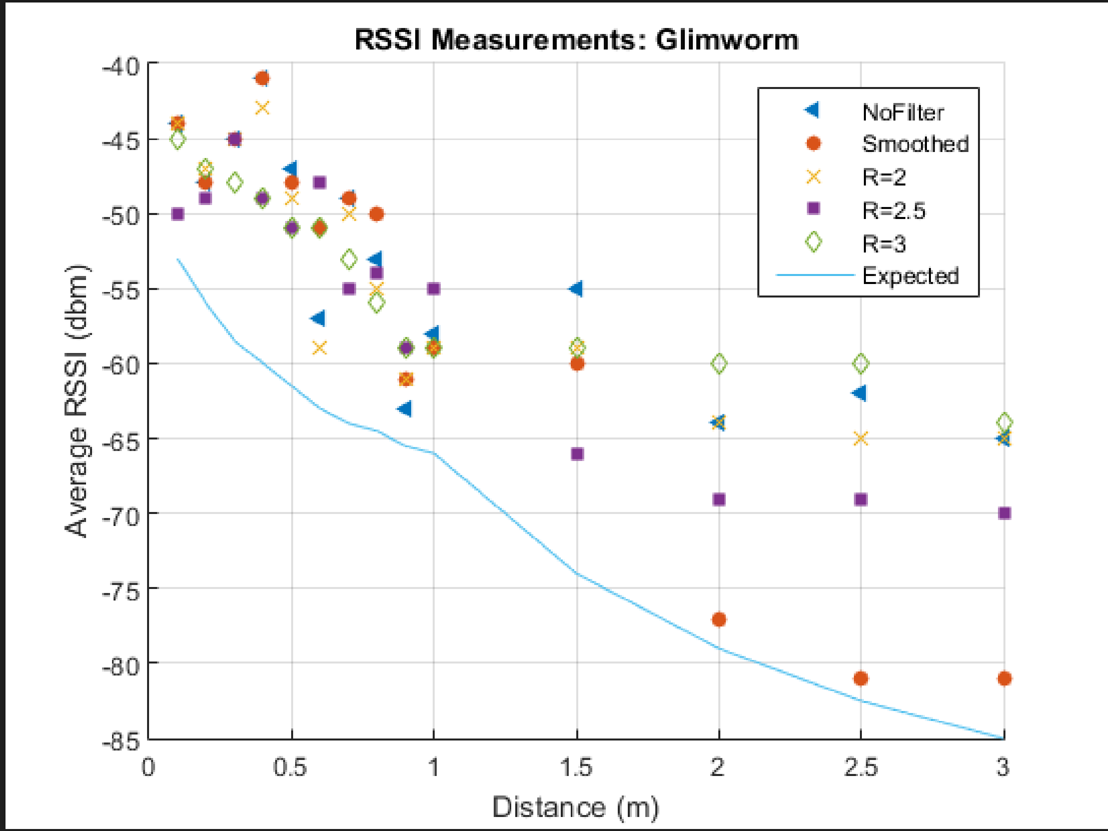
- Better estimation after 1.5 meters in comparison to Estimote beacon
  - Trend of accuracy falling still holds true
- Better distribution of results
  - Tends to overestimate at first
  - Underestimates at greater distances

Kontakt Distance

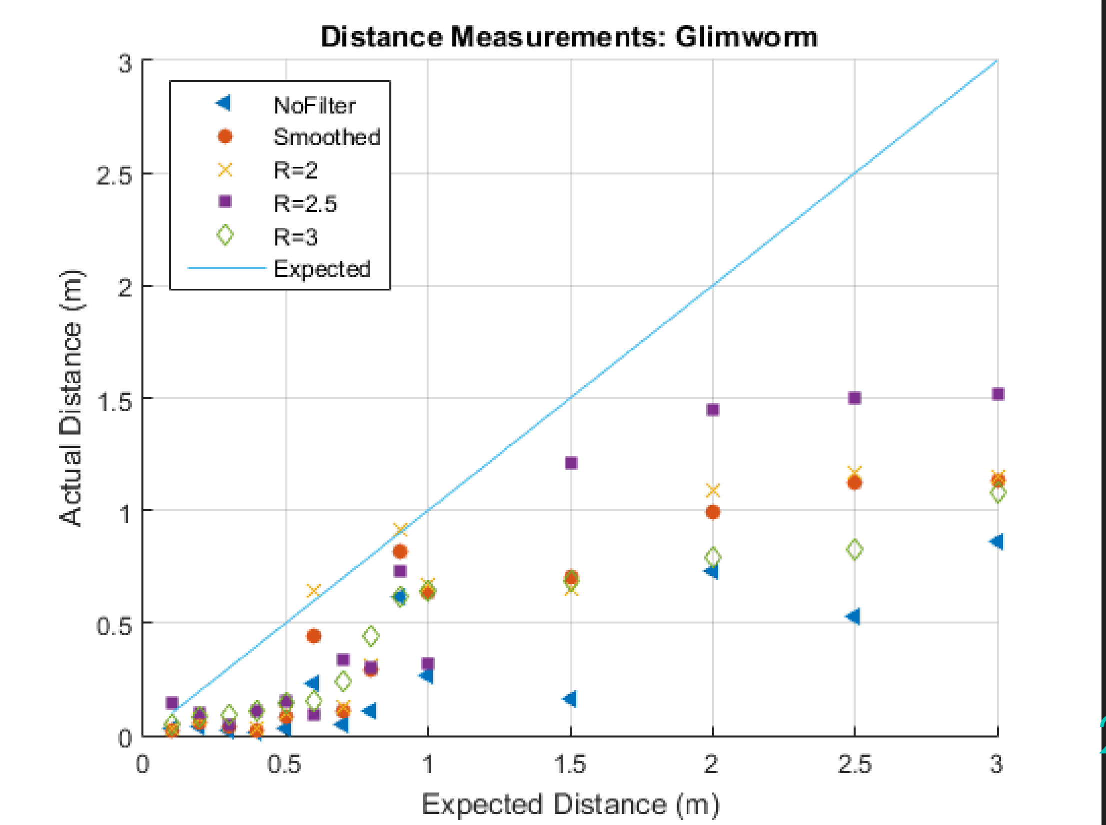


The Results: Glimworm

RSSI



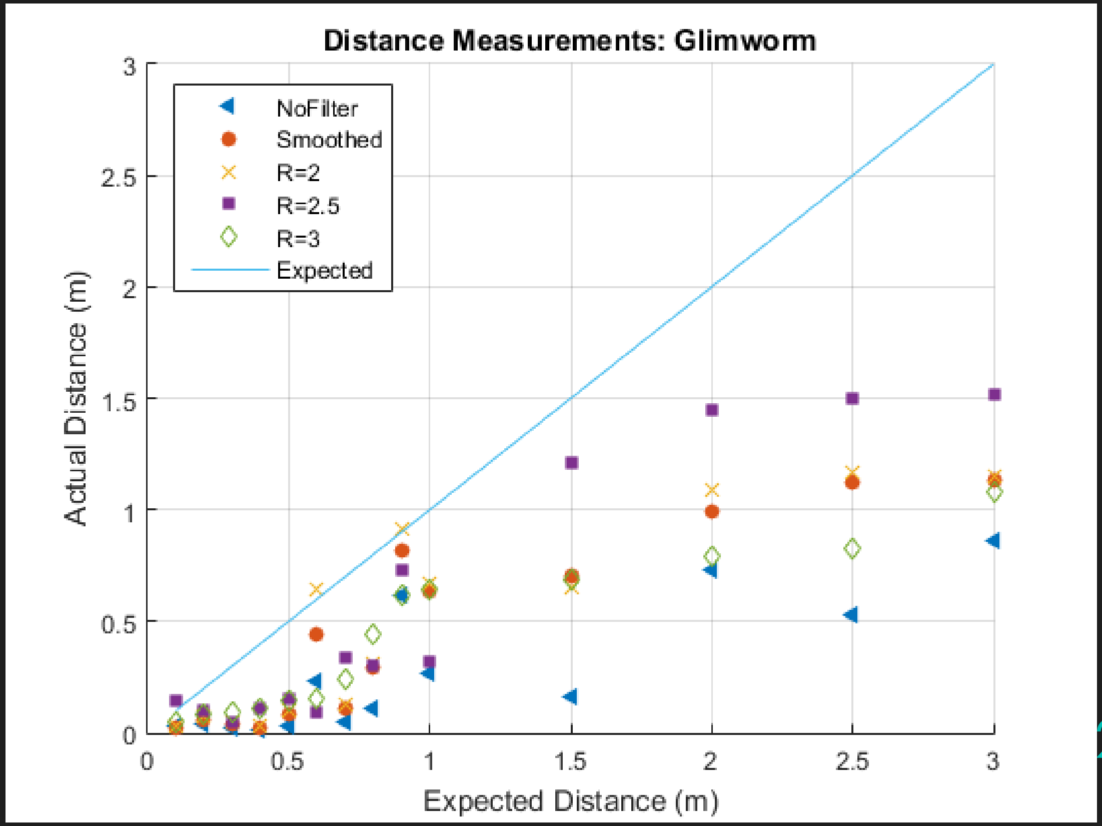
Distance



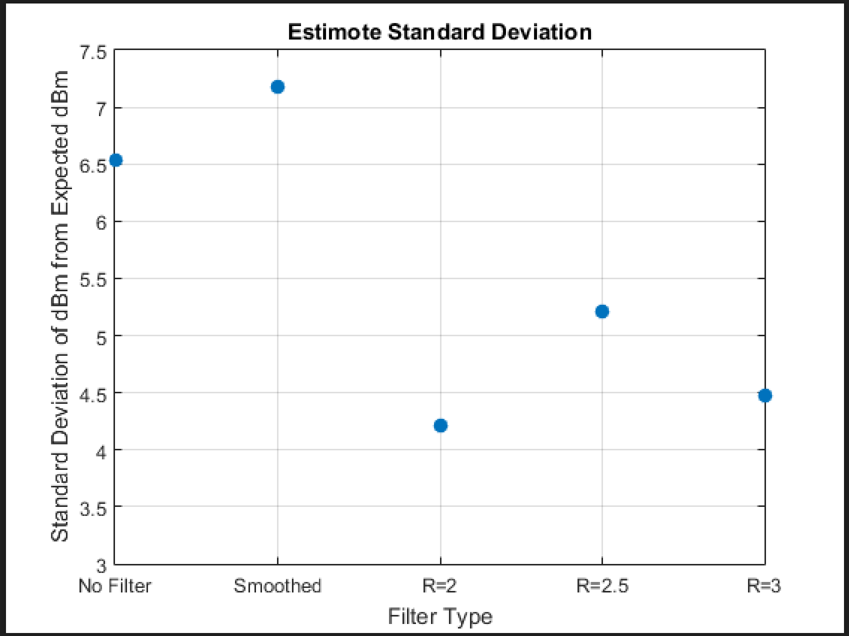
The Results: Glimworm

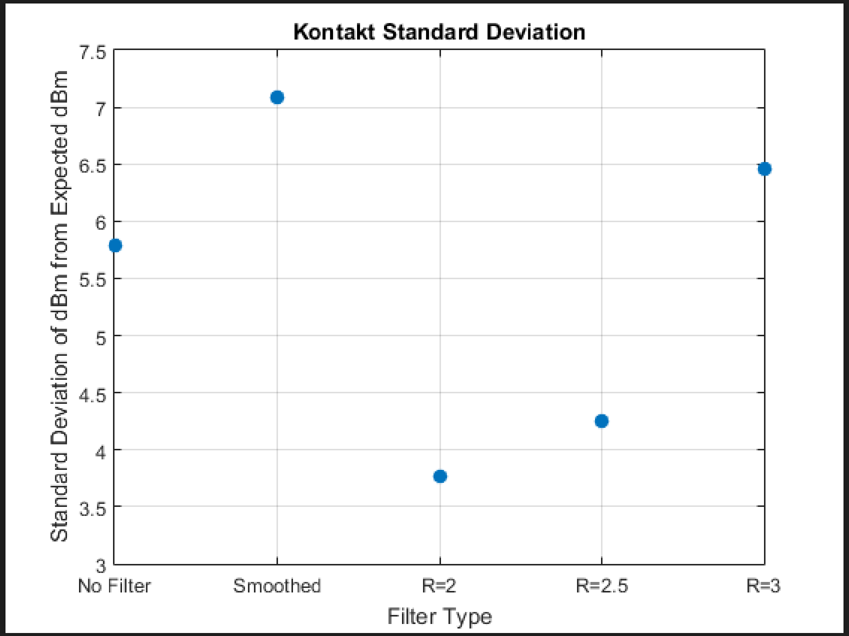
- Always underestimating
- Much less randomness in results
  - Each set follows its own curve
  - Especially falls short at greater distances
    - Even more without filtering

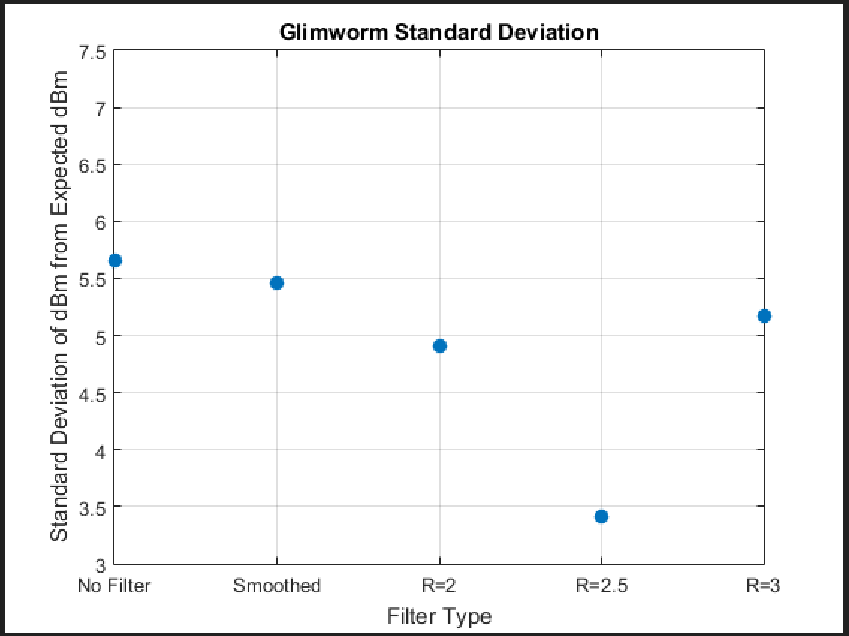
Glimworm Distance



The Results: Standard Deviation







The Results: Discussion

- Clear improvement in proximity estimation using Kalman filter
- Kalman filter parameter selection is vital to filter performance
- Beacons with same transmit power require same parameter selection
- Higher Transmission Power = higher R value for Kalman filter
  - *In this scenario

The Conclusion

- All filtering is implemented on the smartphone, in Android
- Each beacon benefits form filtering in indoor proximity applications
- Important to test the environment to select optimal Kalman filter parameters
- Glimworm & Kontakt achieved the best results in this environment
  - Kontakt very accurate close up
  - Glimworm achieves lowest standard deviation
  - Not definitive winner – an indication of available performance
  - Under these specific conditions! – Not guaranteed for all environments

- Future/current work:
  - Energy consumption comparison
  - Additional filtering techniques

Q & A

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