TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

Application of **Discriminant Analysis** for People Counting using **Radio Irregularity** in Wireless Sensor Networks

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Outline

- Introduction
- Related Work
- Radio Irregularity and RSS Fluctuations
- Motion Detection Algorithm
- Detect & Count People
- Standard Deviation Detection Algorithm
- Discriminant Analysis
- Conclusion

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Introduction

- Internet of Things (IoT)
  - Internet connects system, applications, devices which referred to as “Things”.
  - The technologies of IoT has extended to
    - Identification and Tracking
    - Sensing and Actuation
    - Intelligence and Cognition
- People counting – used for forecasting, resource allocation, facility management

Radio Irregularity

- Radio frequency (RF) signal propagates within a medium, it maybe
  - REFLECTED
  - DIFFRACTED
  - SCATTERED
- The phenomenon is known as **RADIO IRREGULARITY**
- **RECEIVE SIGNAL STRENGTH** fluctuates when the phenomenon of radio irregularity occurs.

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Related Work

- People Counting Methods
  - Infrared(IR) counter
  - Thermal Imaging
  - Video-based people counter
- Radio-based Detection
  - Woyach, *et al*., first reported the shadowing effect cased by objects moving between two communicating devices.

K. Woyach, D. Puccinelli, and M. Haenggi, “Sensorless sensing in wireless networks: Implementation and measurements,” Proc of WiNMee, Boston, MA, USA, April2006.

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Related Work

- Radio-based Detection and Counting
  - Puccinelli, *et al*., use Received Signal Strength (RSS) for outdoor people counting → major drawback: *RSS changes under different environment*.
  - Lee, *et al*., use fluctuation of RSS as detection indicator which reduces the impact of environmental factors.

D. Puccinelli, A. Foerster, A. Puiatti, and S. Giordano, "Radio-based trail usage monitoring with low-end motes," Proc of PerSeNS, Seattle, WA, USA, 21 March 2011.

P. Lee, W.K.G. Seah, H.-P. Tan, and Z. Yao, "Wireless sensing without sensors - An experimental approach," in Proc IEEE PIMRC, Tokyo, Japan, Sept. 2009.

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Related Work

- Radio-based Counting and Localization
  - Lin, *et al*., use RSS fluctuation to count multiple persons, up to two persons walking side-by-side along a corridor.
  - Patwari, *et al.*, measure the RSS of links between many pairs of nodes to infer the locations of people or objects moving in the network; utilizes complex signal processing.

W.C. Lin, W.K.G. Seah, and W. Li, "Exploiting Radio Irregularity in the Internet of Things for Automated People Counting," in Proc IEEE PIMRC, Ottawa, Canada, Sept. 2011.

N. Patwari and J. Wilson, "Spatial models for human motion-induced signal strength variance on static links," IEEE Transactions on Information Forensics and Security, vol. 6, no. 3, pp. 791–802, Sept 2011.

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Exploiting Radio Irregularity

- Received Signal Strength (RSS) level varies across different environments and over time.
- Our detection approach uses **RECEIVE SIGNAL FLUCTUATIONS** to determine the presence of moving objects.
- For each consecutive packet received, measure the RSS and compare it with the RSS of the previous packet.

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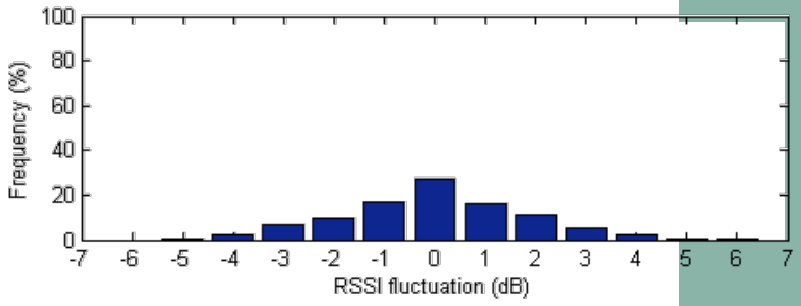
Receive Signal Fluctuations

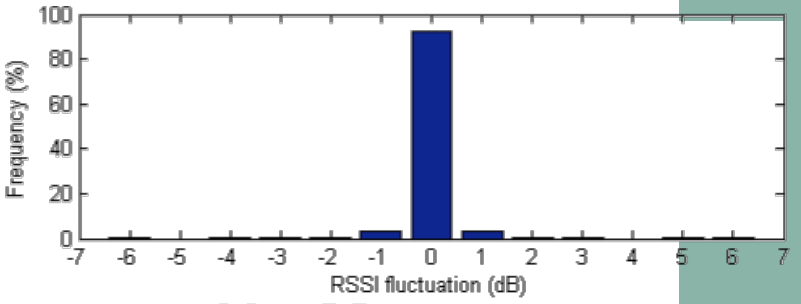
- For a given packet p_i, the RSSI fluctuation are calculated as:

$$F(p_i) = RSS(p_i) - RSS(p_{i-1})$$

- Certain patterns are associated with the existence of a moving object in the physical environment



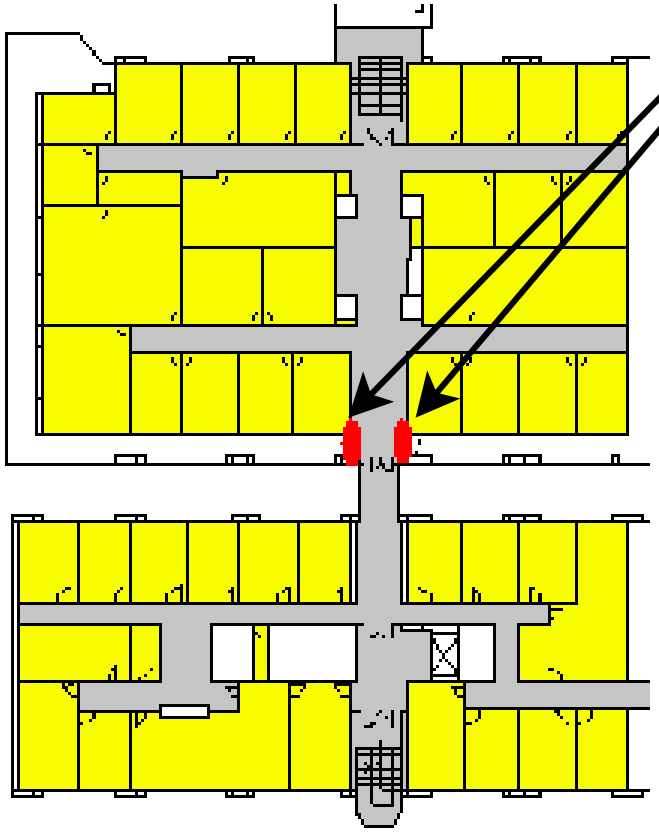
Movement



No Movement

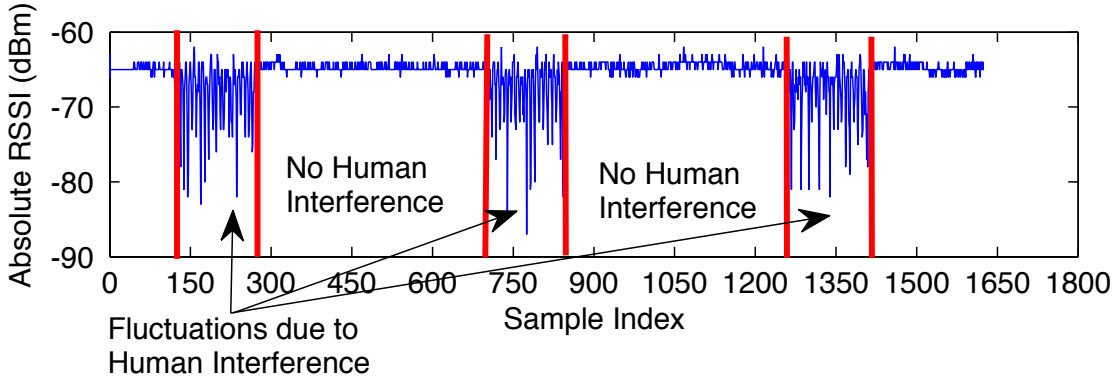
Detection of Pedestrian Traffic

- Corridor in building
- Single transmitter-receiver pair based on IEEE802.15.4
- 1.5m apart, 1.1m high
- Inter-packet interval 0.15 seconds

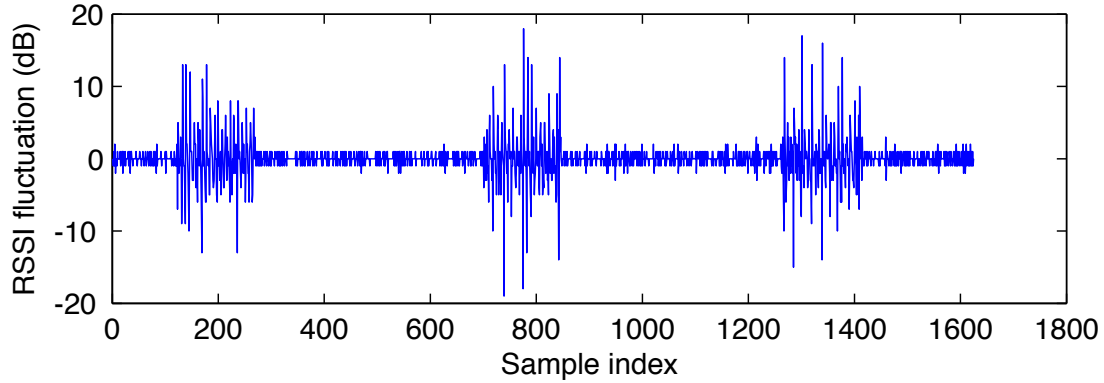


Motion Detection Algorithm

- Step 1: Data Collection



- Step 2: Calculate RSSI Fluctuations



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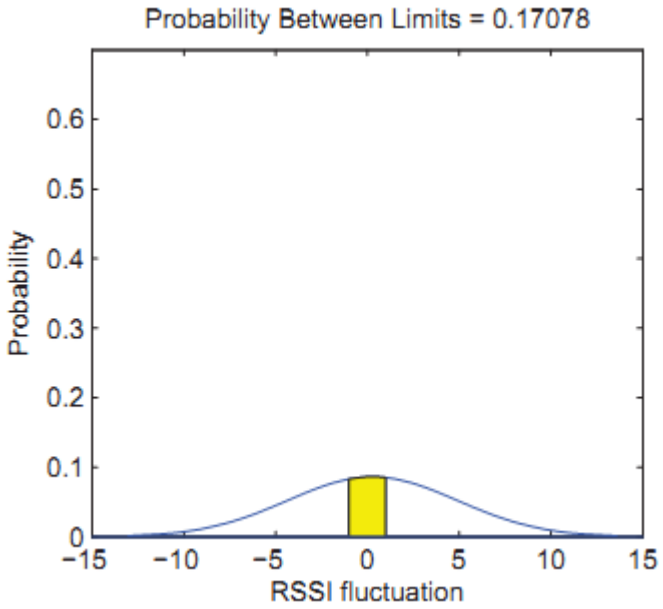
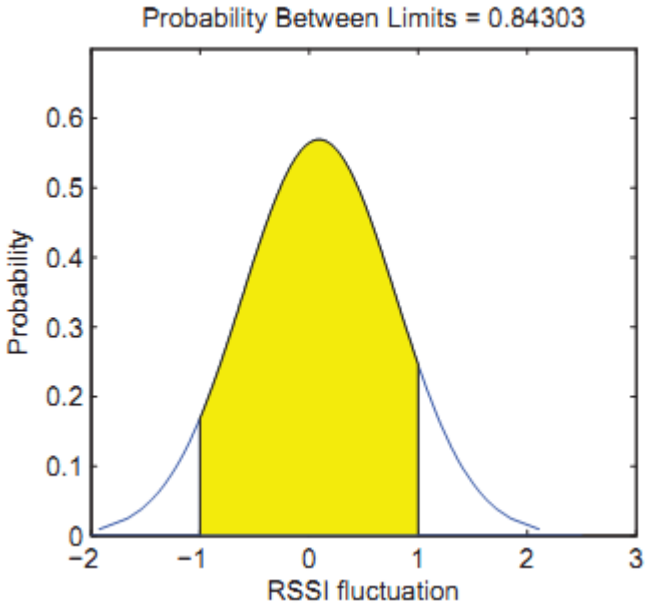
Motion Detection Algorithm

- Step 3: Compute probability of the RSSI fluctuations falling within the range [-1, 1]



Movement



No Movement

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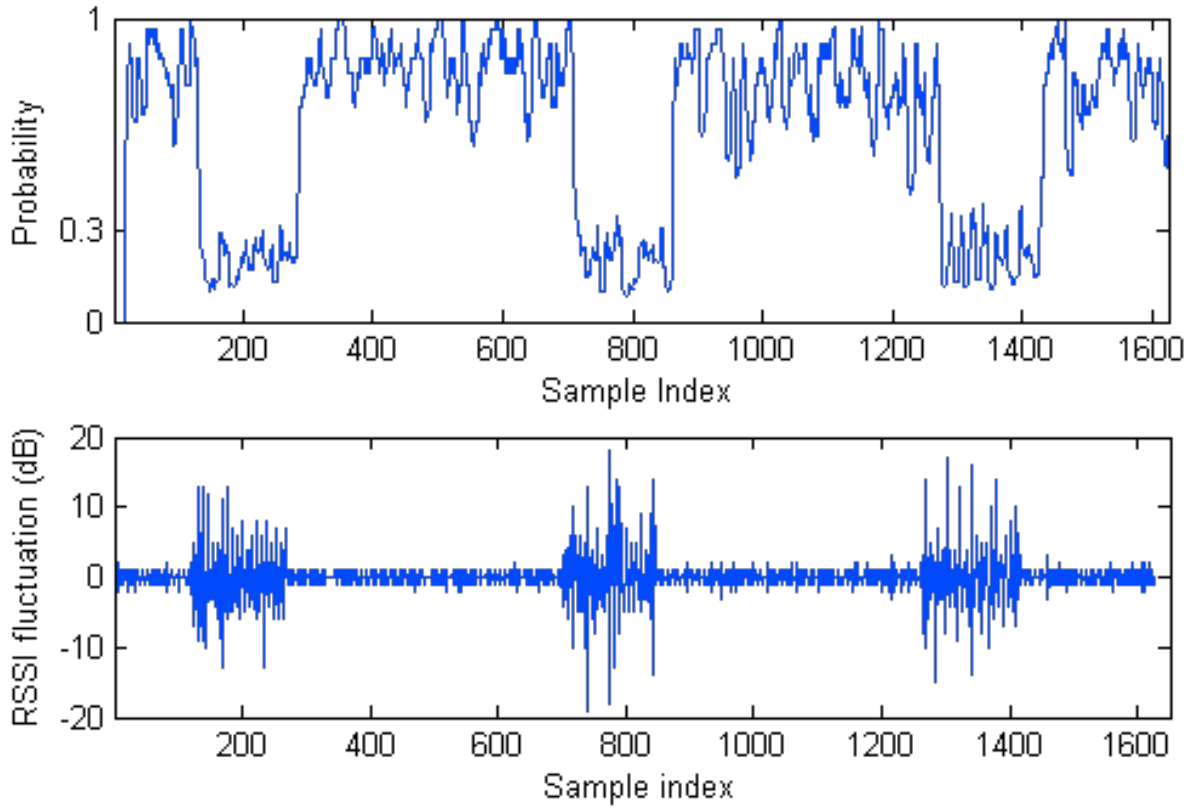
Motion Detection Algorithm

- Probability within [-1, 1]



Motion Detection Algorithm

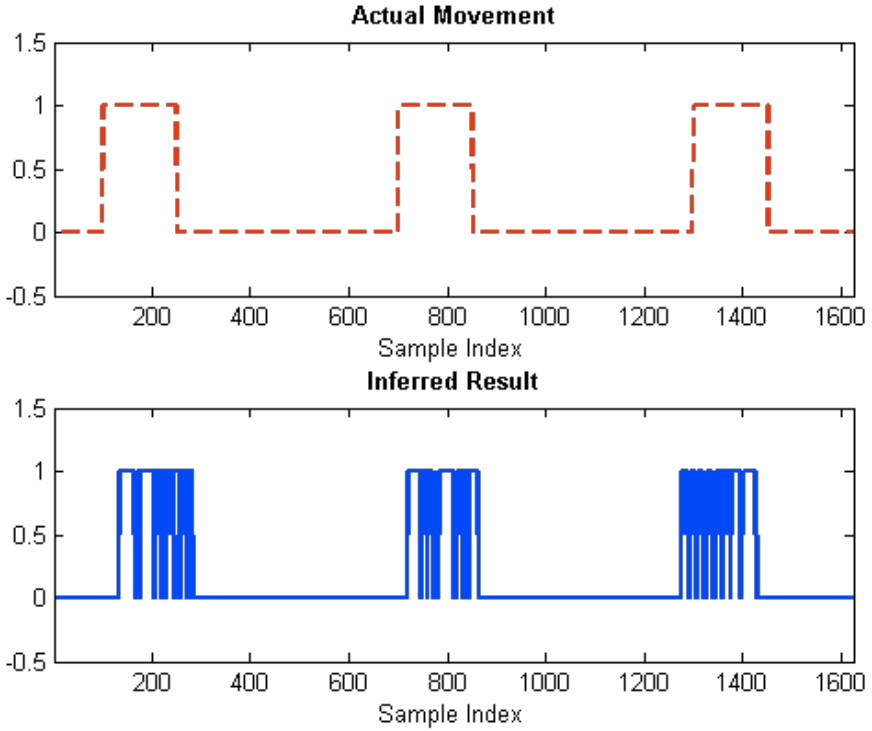
- Step 4: Making Decision

Probability > 0.3

→ NO MOVEMENT

Probability ≤ 0.3

→ MOVEMENT



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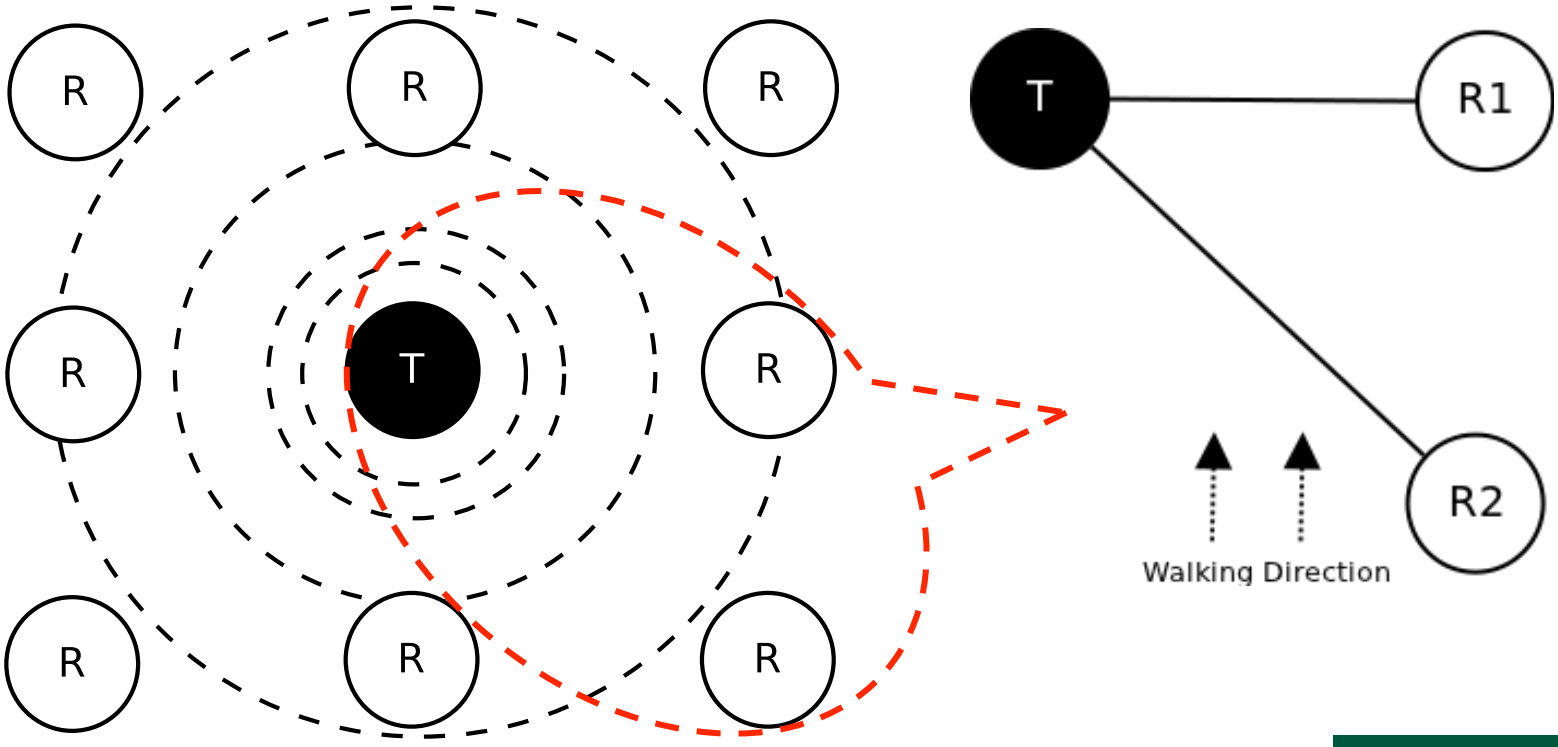
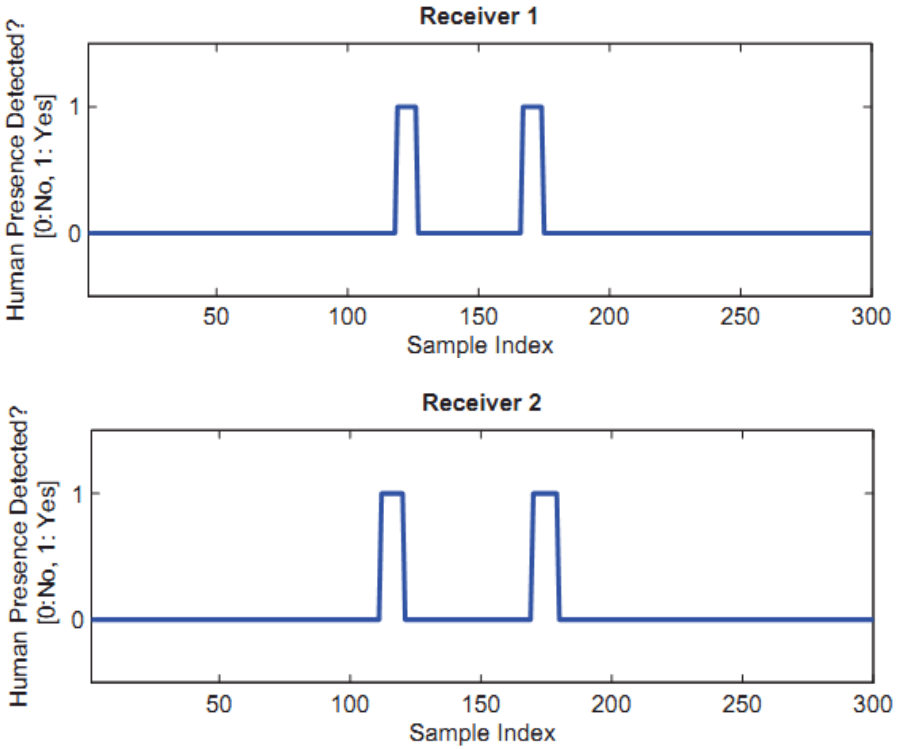
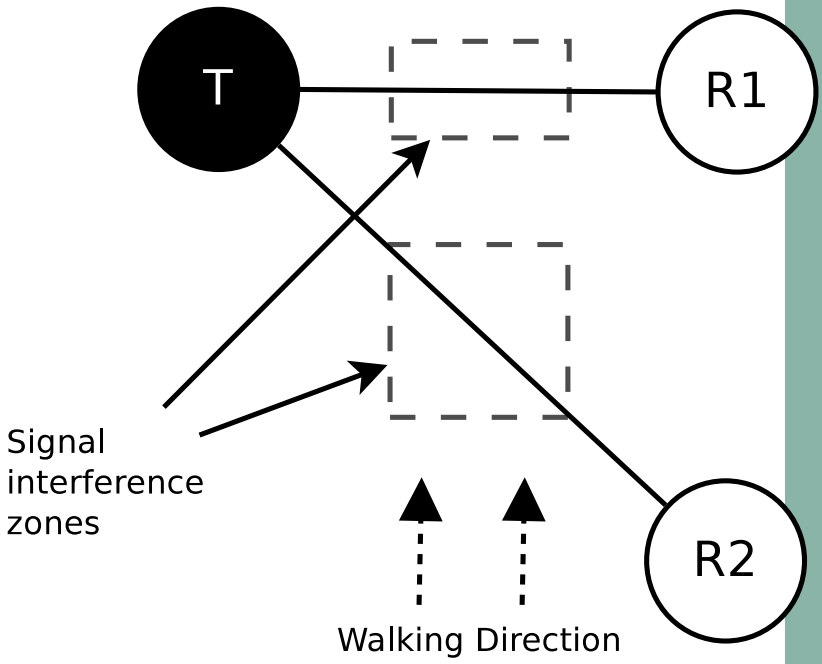
Detect & Count People

- Wireless Sensor Setup

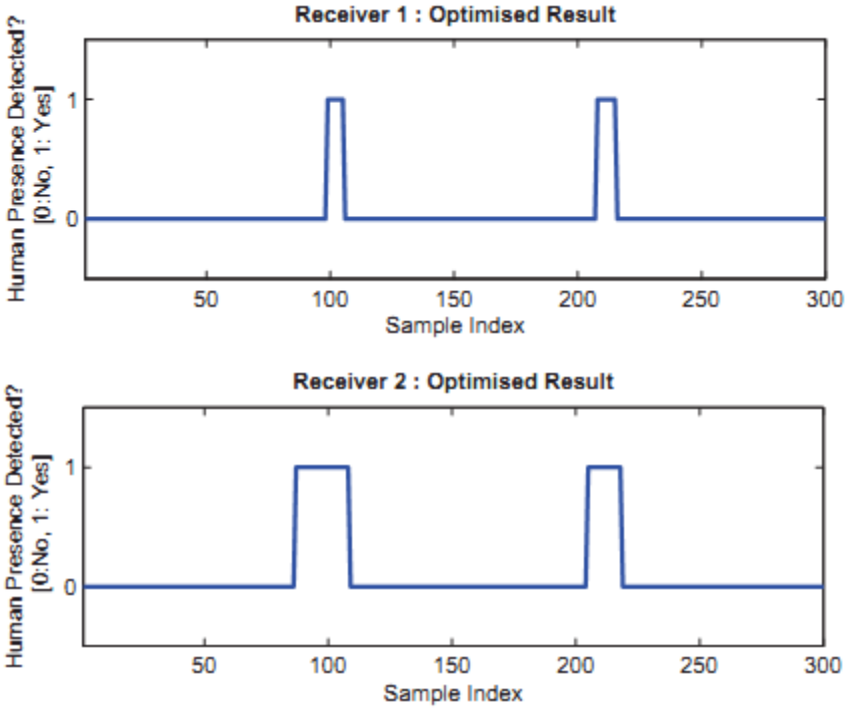


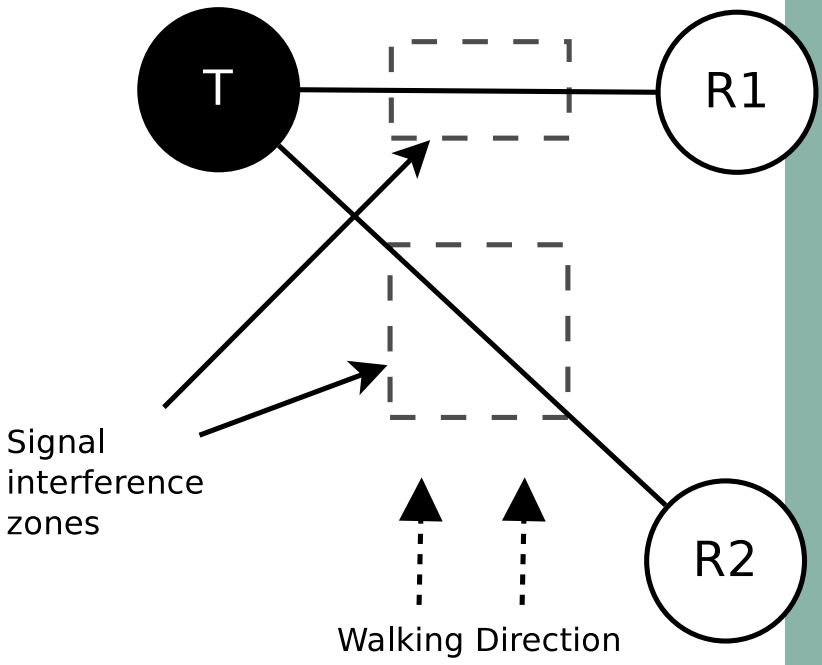
Detect & Count One People





Detect & Count Two People





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Detect & Count More People

- Standard Deviation Detection Algorithm
  - Enable us to derive more information from RSS data
- Discriminant Analysis
  - Perform discriminant analysis on information of positive detection to generate discriminant functions

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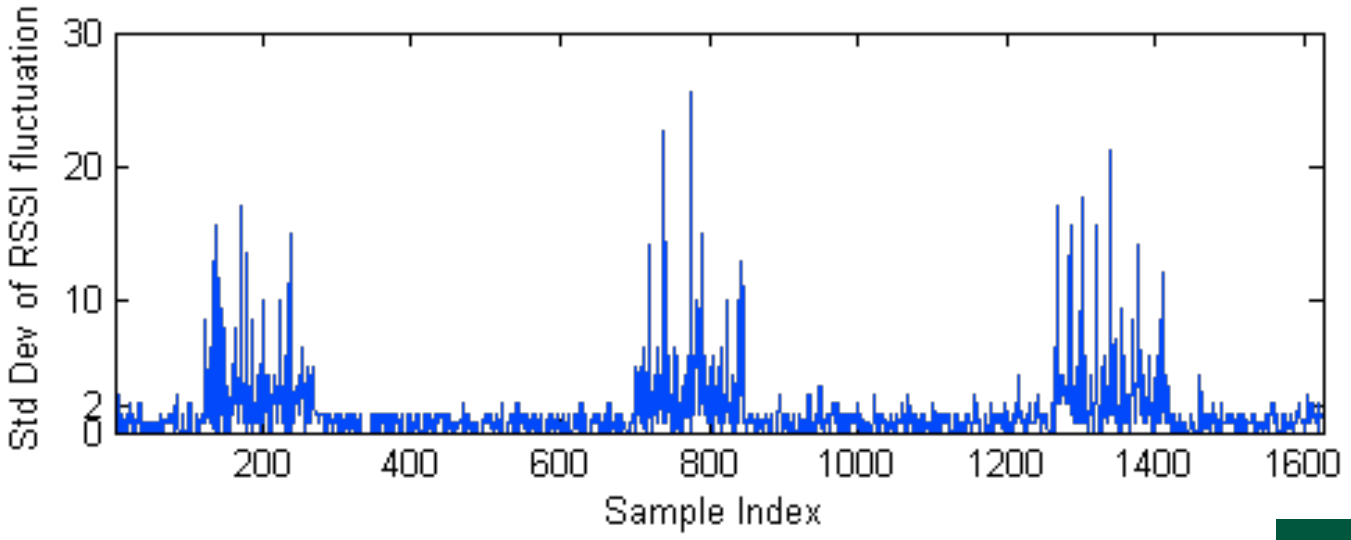
Std Dev Detection Algorithm

- We compute the standard deviation of RSSI fluctuation within a sliding window.
- Using same dataset before.



Std Dev Detection Algorithm

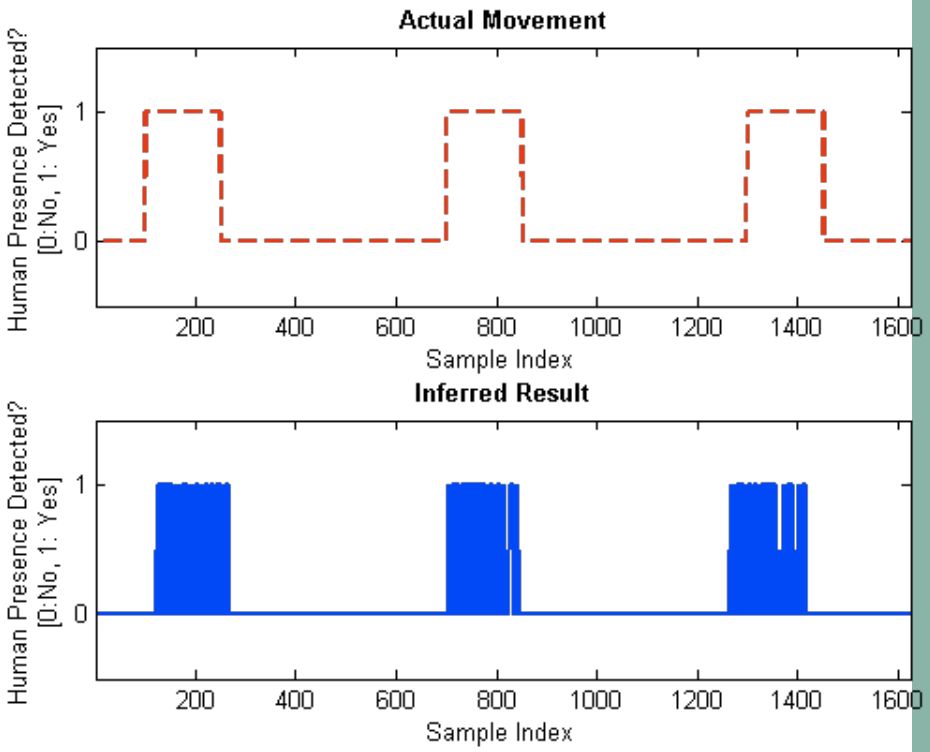
Detection Criteria

Std Dev ≤ 2

→ NO MOVEMENT

Std Dev > 2

→ MOVEMENT



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Applying Discriminant Analysis

- Find linear combination of measurements which characterize groups
  - Two phases: Training and Classification
- Use Std Dev of RSSI fluctuations of detected movement as primary dataset
- Utilize the information from each positive detection, namely, *Mean*, *Std Dev*, *Coefficient of Variation* (CV), *Duration* of fluctuations, and area under curve

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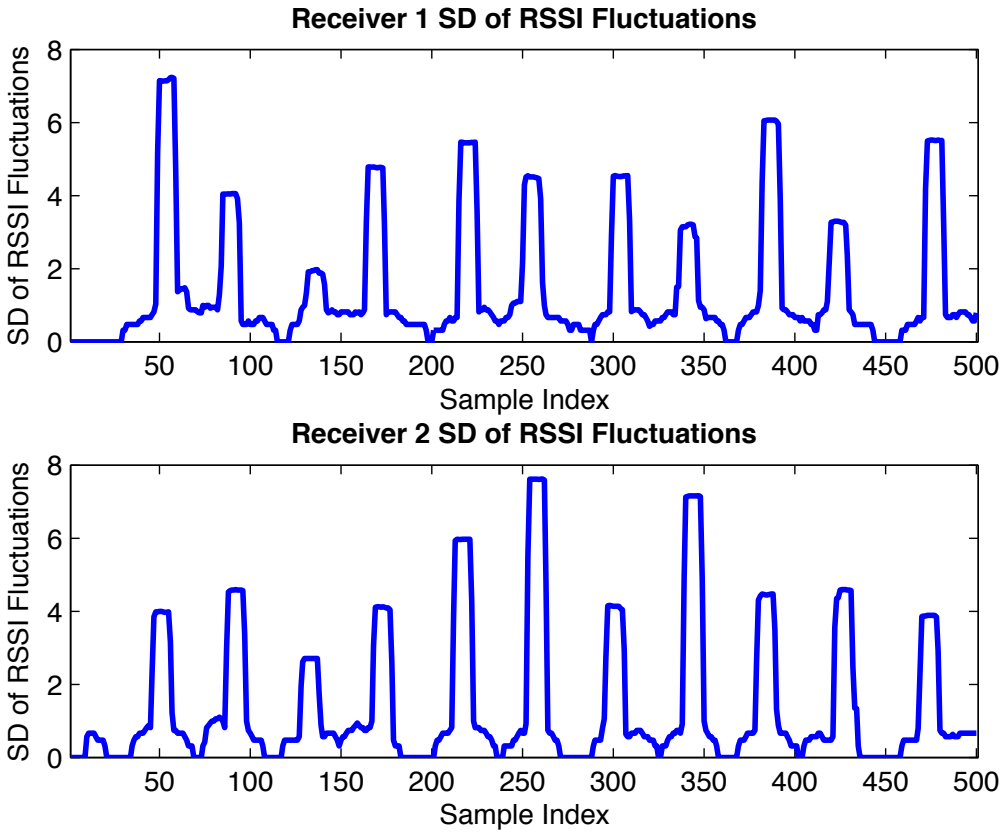
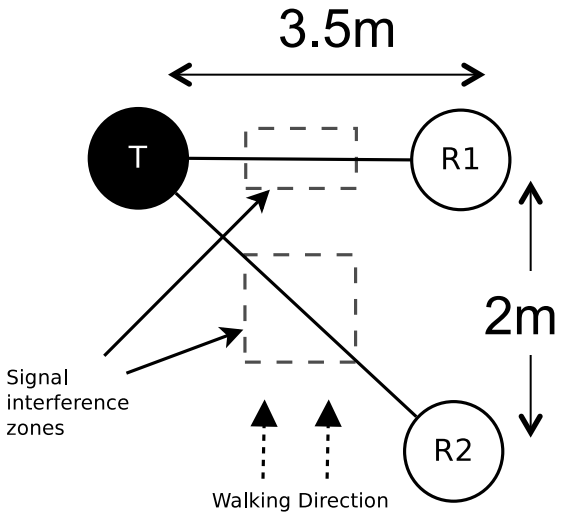
Applying Discriminant Analysis



Std Dev of RSS for 1 person



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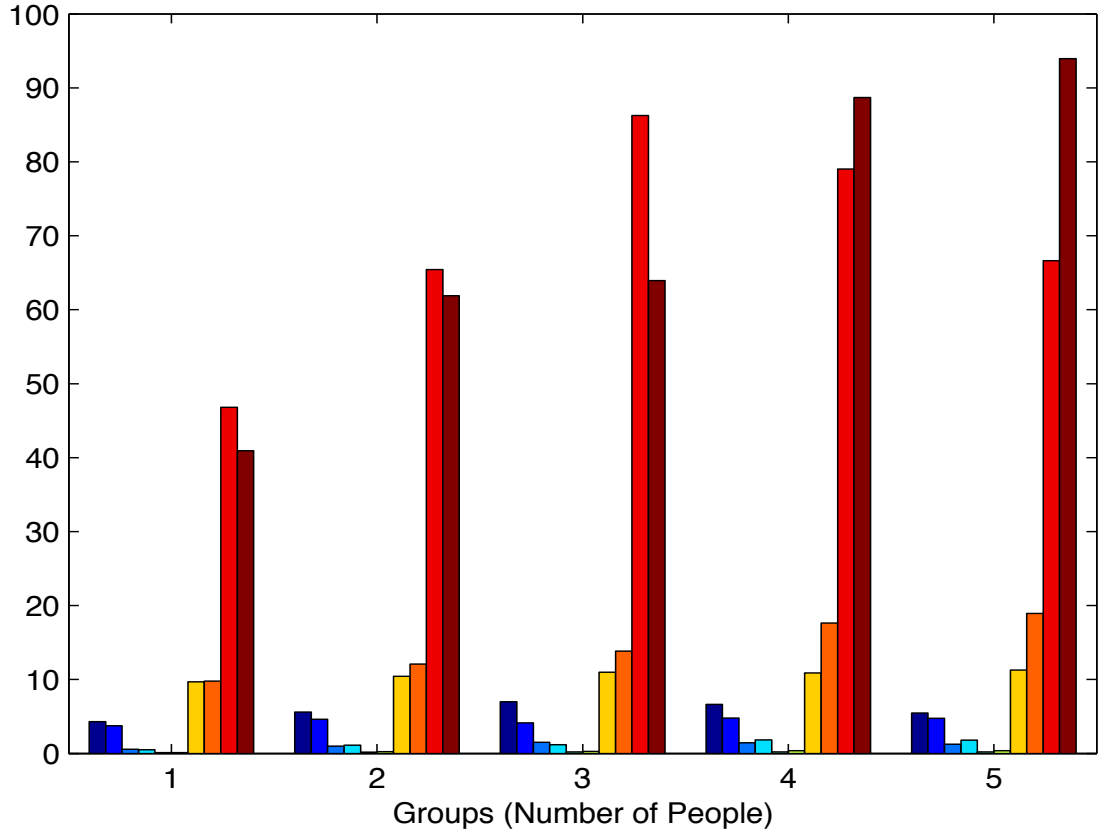
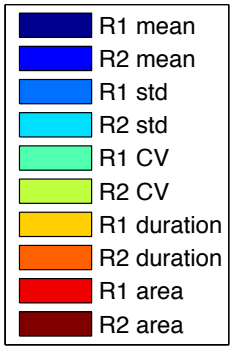
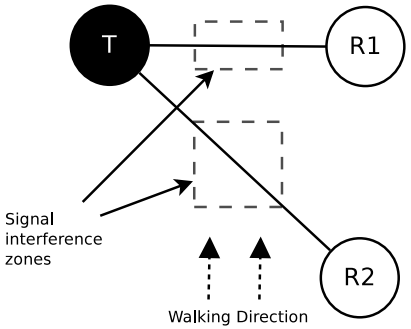
Applying Discriminant Analysis

50 samples of each group (1~5 people)







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Applying Discriminant Analysis

- Perform discriminant analysis on measurements of positive detection
  - Four Discriminant Functions are produced which are the functions that best separate between groups.
- Classify the positive detection using discriminant analysis.

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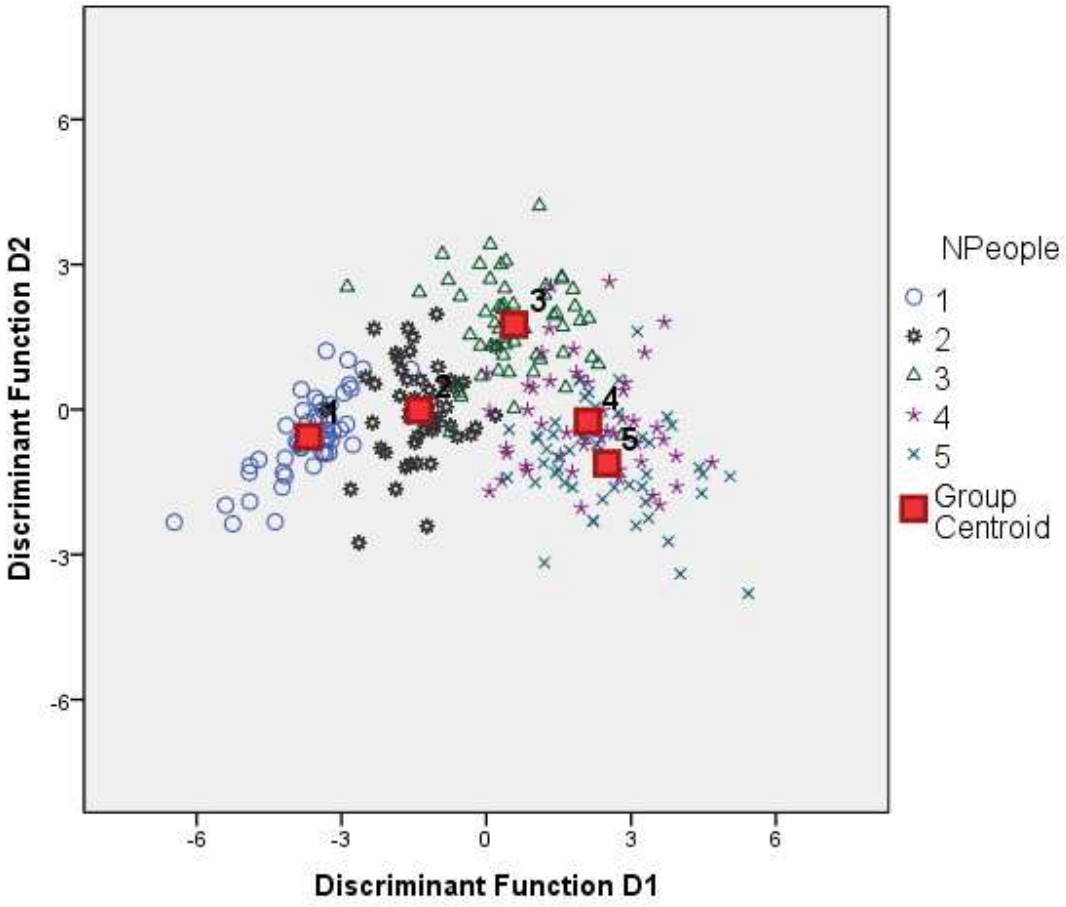
Classification Results



- Distinct clusters for groups of 1, 2 and 3 persons
- Accuracy drops as group size gets larger

Classification Results

- 81.6% (204/250) overall accuracy in detecting # of people comprising a group
- 97.9% (734/750) achieved in predicting individual head counts

	NPeople	Predicted Group Membership					
		1	2	3	4	5	Total
Count	1	47	3	0	0	0	50
	2	3	46	1	0	0	50
	3	0	3	44	2	1	50
	4	0	3	7	31	9	50
	5	0	0	0	14	36	50

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Conclusion

- Turn a problem (radio irregularity) into a tool
- Demonstrated the feasibility of using available wireless communication devices to detect and count people in the environment
- Signal fluctuation remain stable regardless of the environment; absolute signal level changes across different environments
- Able to successfully detect up to 5 people with overall accuracy of 81.6% in predicting group size and 97.9% in actual head counts

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What next?

- Practical limit of the scheme needs to be assessed; it is not a standalone system
- Extending the scheme to other wireless technologies, e.g. IEEE802.11 or WiFi
- Information fusion – integrating detection from more sensor-pairs in the network for target tracking
- Wireless sensor network protocol that combines both detection (using radio irregularity) and data delivery

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For more information

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