Th02C_5

Occupant Entry and Exit Event Extraction Using Continuous Wave Radar and Wavelet Analysis

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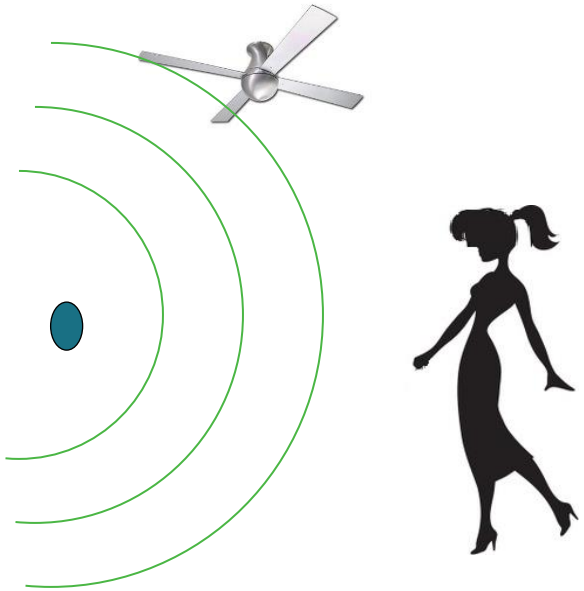
Overview

- Introduction
- Occupancy sensors
- Current Technology Drawbacks
- Proposed Solution
- Experimentation and Evaluation
- Results
- Conclusion

Introduction

- Lighting and climate control for unoccupied space accounts for energy waste and related financial burden.
- 50% of overall building energy consumption→ HVAC Systems
- Residential and commercial building→ 40% of total energy consumption
- Reliable occupancy estimation and entry/exit detection-> energy management

Occupancy Sensors



- Lighting & HVAC operation can be automatically controlled by sensors.
- These systems use PIR, ultrasonic, and camera-based technology.
- Currently various systems use sensors which detect a moving person.

Current Technology Challenges

- False alarms
  - Ultrasonics: Noise, rain, wind errors
  - PIR: heat (sun, pipes…), cold (AC).
- Missed detection
  - Blocked line of site errors
  - Missed stationary subjects (sitting, sleeping,…)
  - *Often results in nonuse*
- Advanced radar technology can avoid errors, while remaining competitive for cost and power consumption..

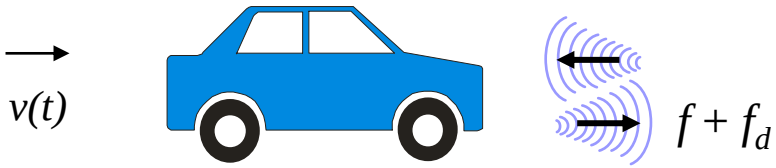
Potential Solution: Doppler Radar

- Medical radar→ respiration and heart rate
- Radar technology→ HVAC control and sensing
- Tracking, Localization→ FMCW radar
  - MIMO architecture→ DOA Estimation
- CW radar is simpler architecture than FMCW radar
- CW Radar→ RSS method→ estimating occupant's numbers
  - RSS method→ dependent on propagation environment
- Most of the Radar-based occupancy sensor→ number of occupants present in a room
  - Entry/exit event is measured→ supplementary sensors (camera, doorway sensor)
- This work is focused on extracting entry/exit events extractions→ CW Radar

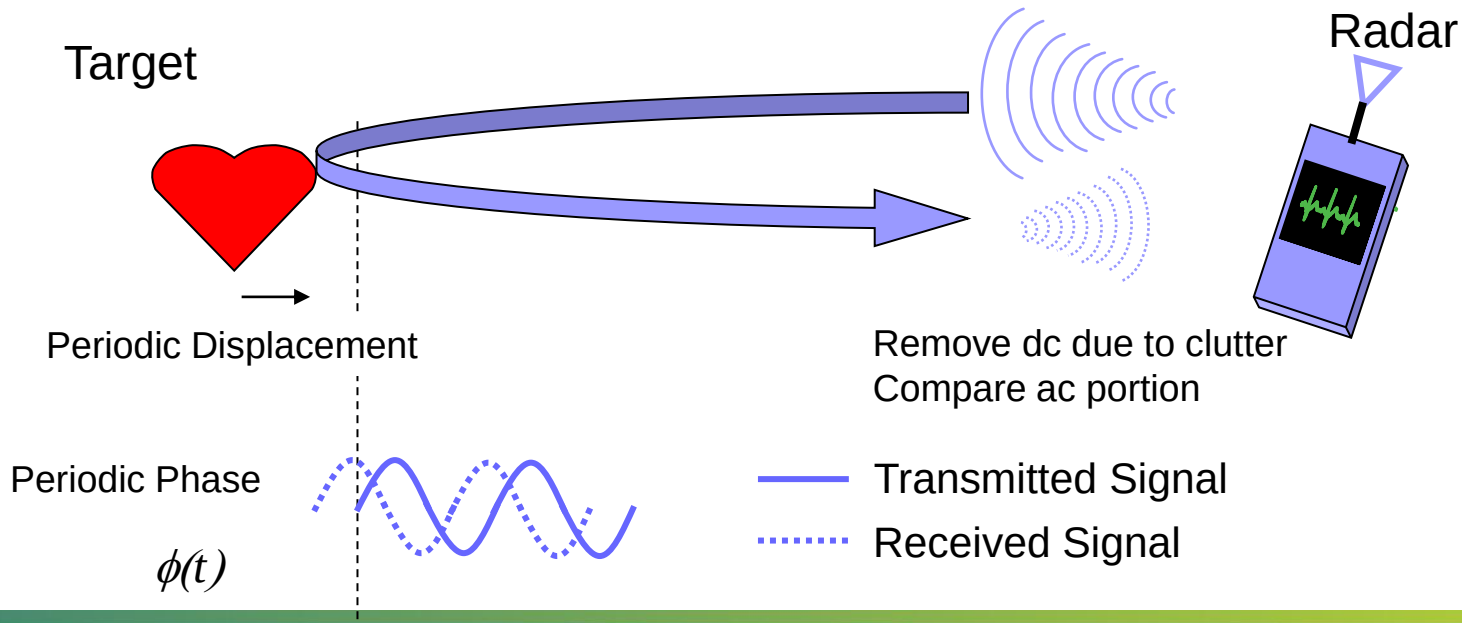
Theoretical Background

Doppler-CW Radar Motion Detection

Constant velocity → shift in f $f_d = 2f\,v(t)/c$



Periodic motion → shift in phase $\phi(t) = (4\pi/\lambda)\,x(t)$



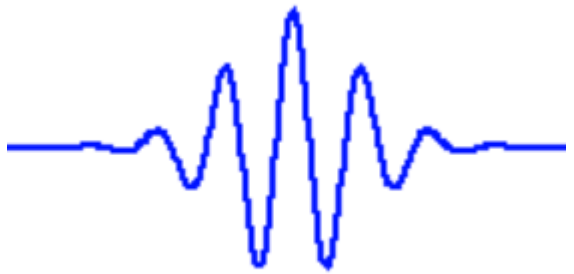
Wavelet Analysis

- Fast Fourier Transform (FFT)→ time domain into frequency domain
  - Stationary signal is well suited for finding maximum amplitude
- Fast Fourier Transform (FFT) is not suitable
  - Non-stationary Signal contains high frequency content short duration→ body movement
- The continuous WT of signal $x(t)$ is defined as:

$$x(\tau, a) = \frac{1}{\sqrt{a}} \int x(t) f^*\left(\frac{t-\tau}{a}\right) dt$$

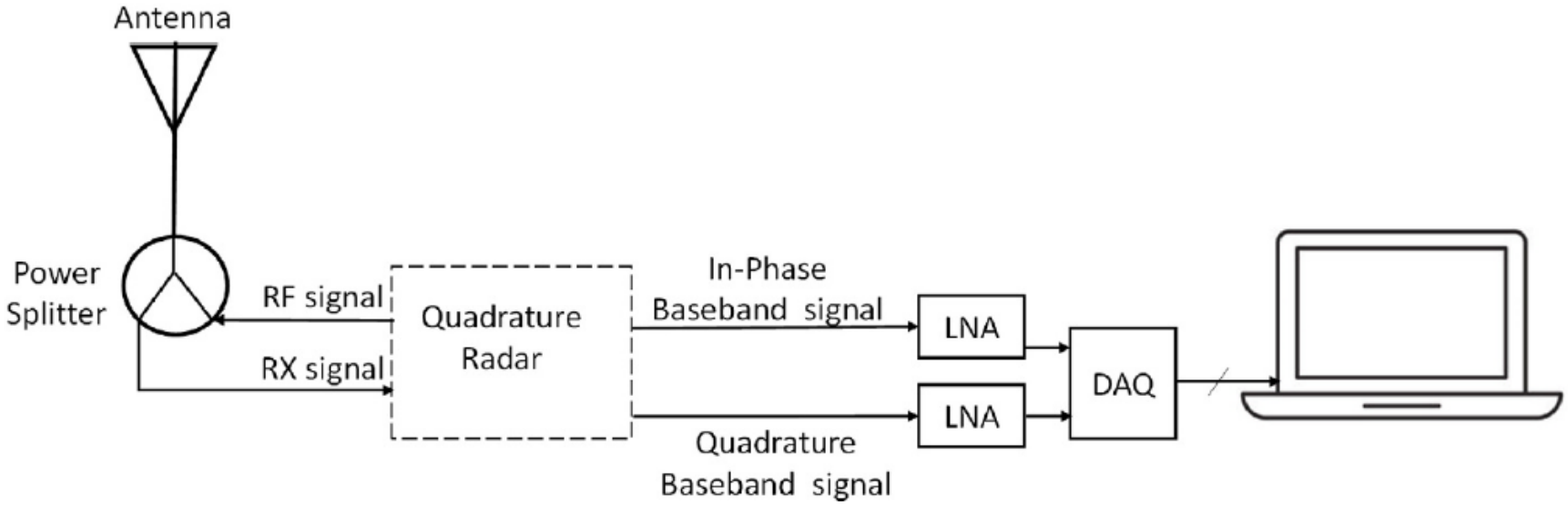
$x(t)$ is the continuous time signal
a is the scaling factor
$f^*\left(\frac{t-\tau}{a}\right)$ is the daughter wavelet

- Morlet wavelet is mostly used in physiological signal processing
- Two important parameters:
  - Maximum wavelet coefficient frequency (MWCF)
  - Wavelet coefficient energy (WCE)



$$WCE = \frac{1}{N} \sqrt{\left(\sum_{I=1}^{N} \left| x_{coeff} \right|^2\right)}$$

Hardware Specification

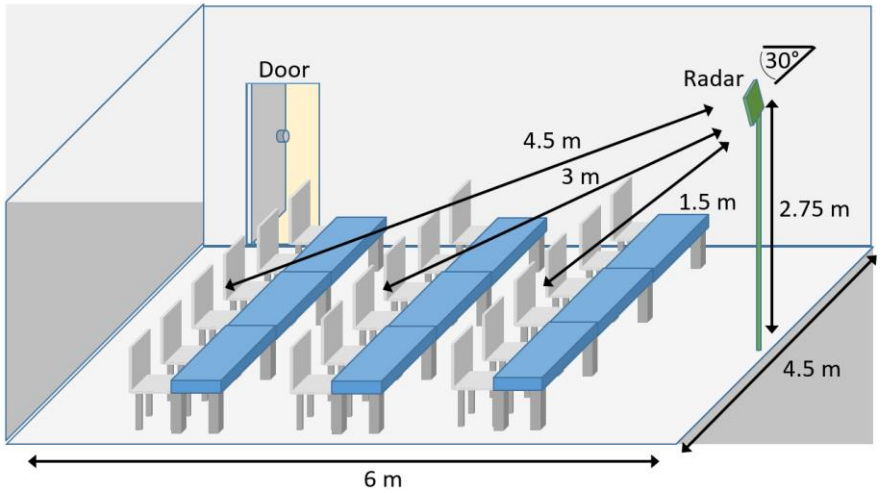


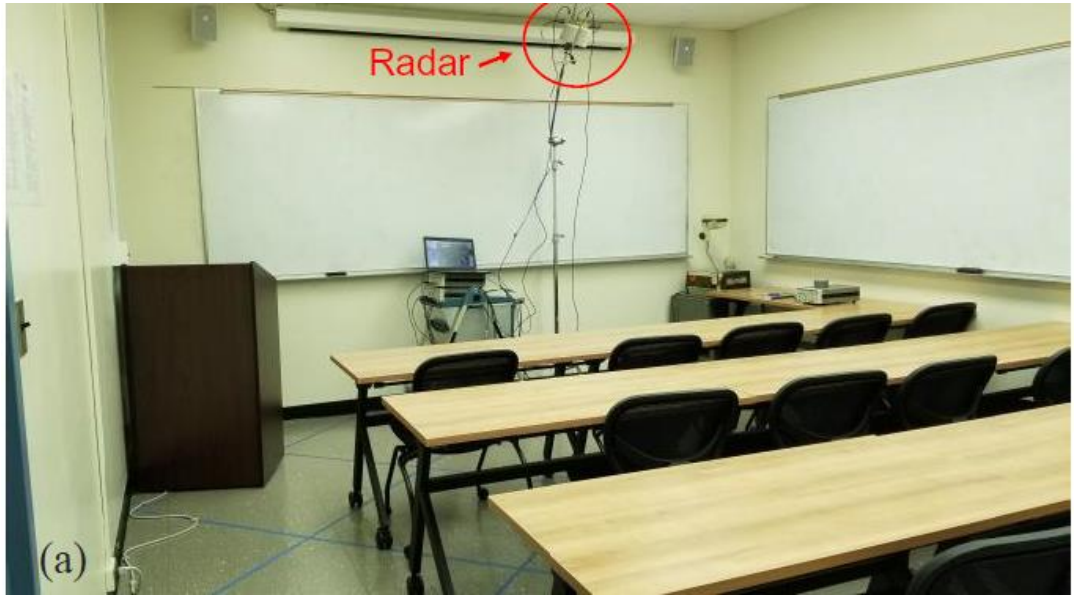
Hardware Specification:

- A 2.4-GHz Quadrature CW Radar System
- Antenna gain: 8 dBi, power: 7 dBm
- Sampling Frequency→ 100 Hz

Experimentation and Evaluation

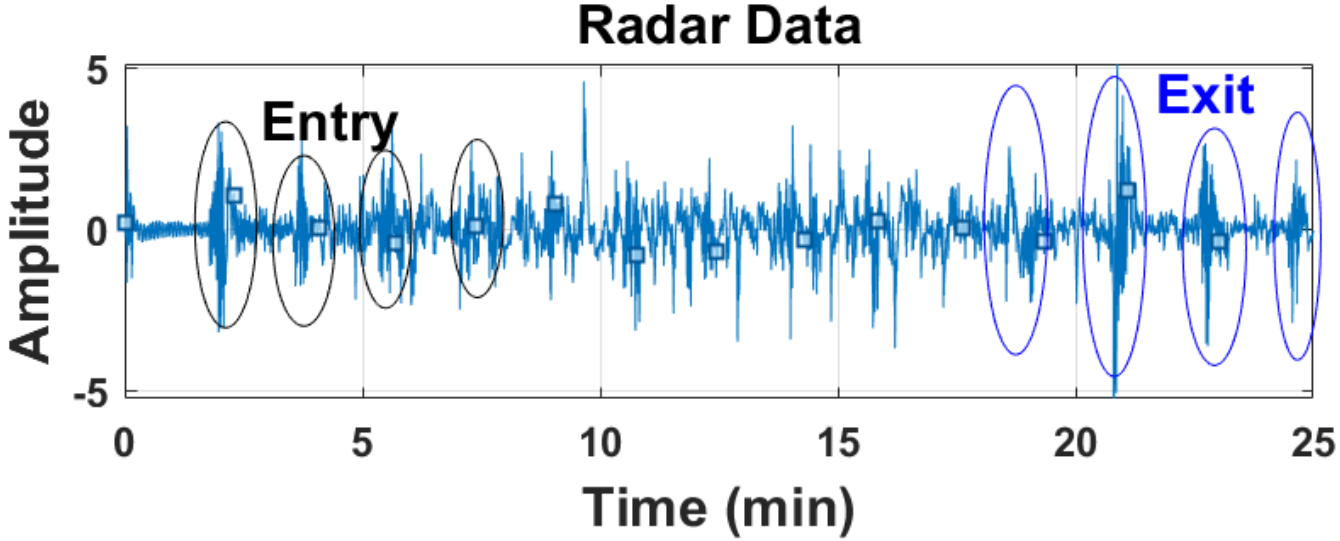
- The 2.4 GHz radar system
  - mounted 2.75 meters above the floor
  - Classroom dimension (6 × 4.5 m)

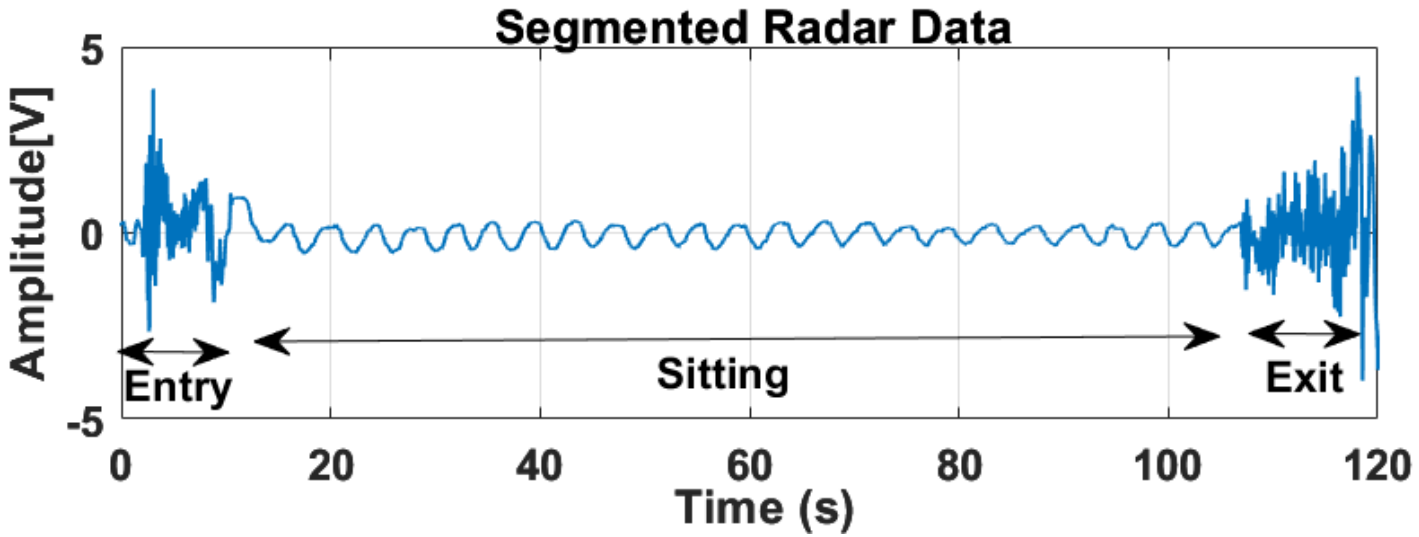




Results

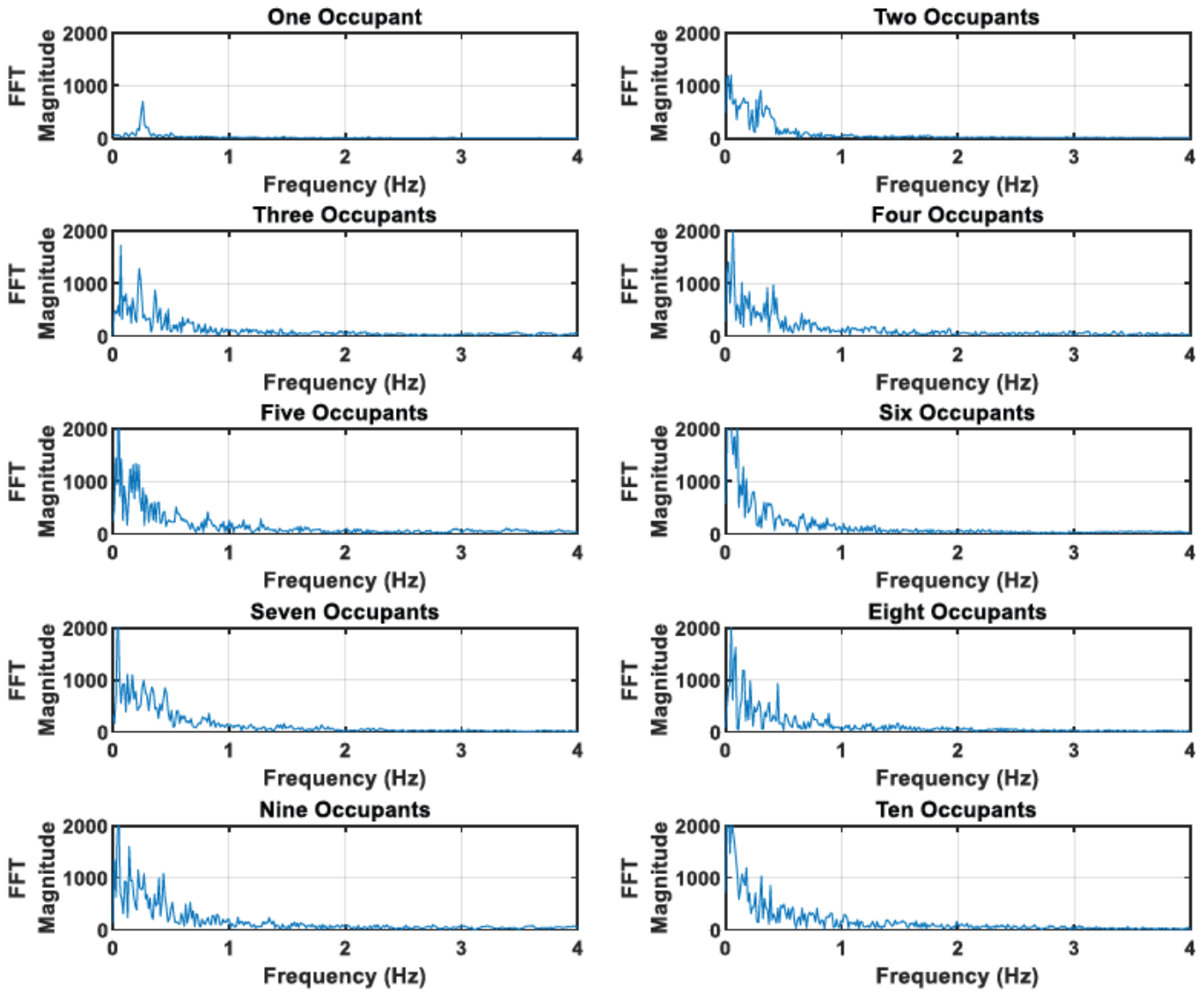
- After data acquisition
  - Filtering→ FIR filter
  - Cut off frequency→ 20 Hz



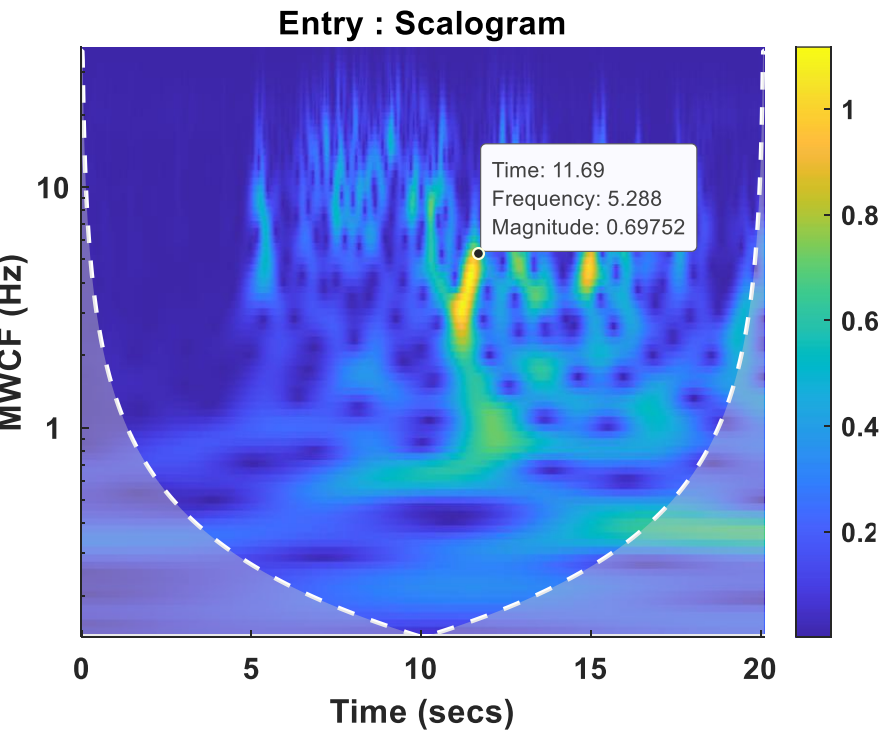


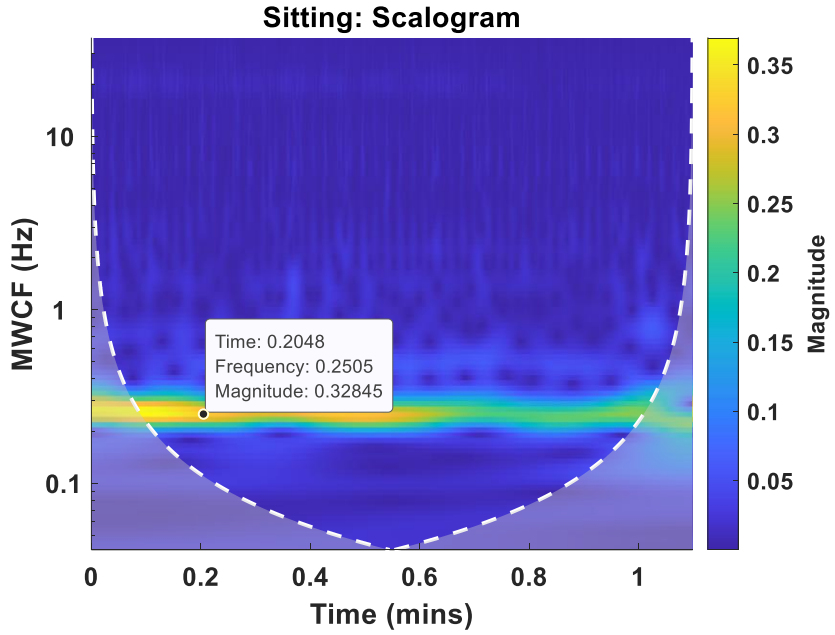
FFT of Segmentation

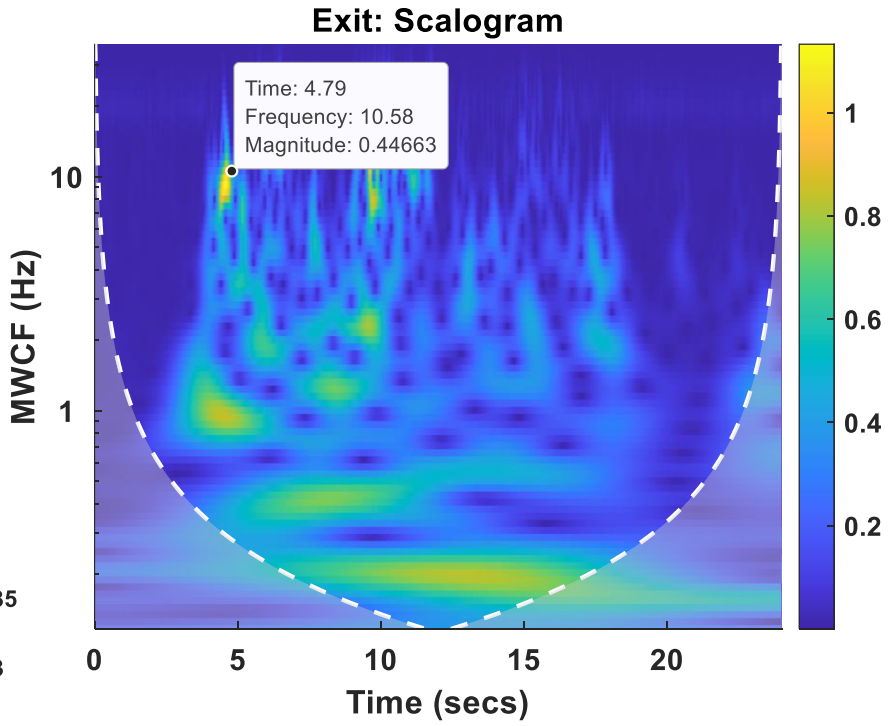
- Spectrum broadening→ with the number of occupants



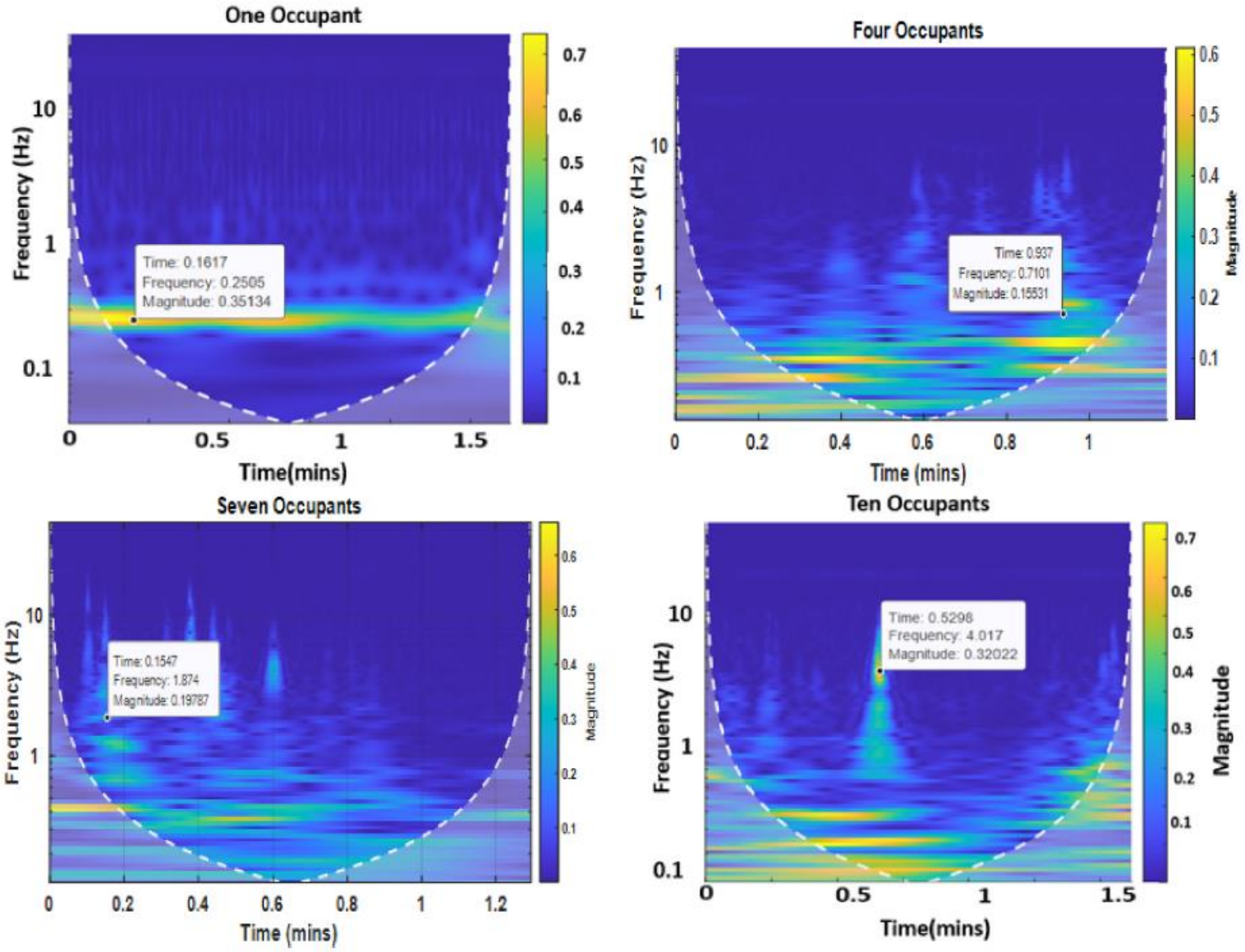
Wavelet: Scalogram





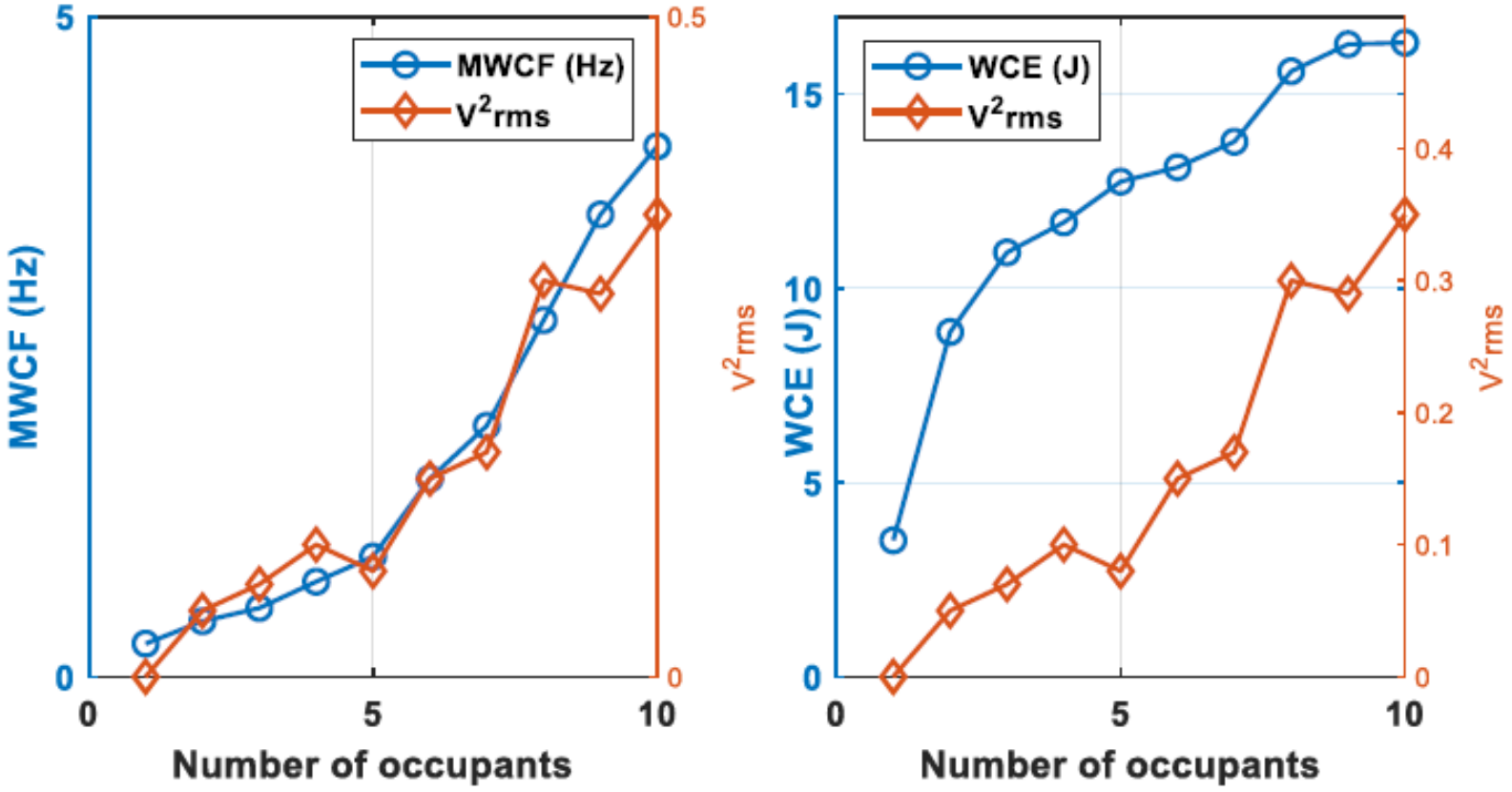


Wavelet Scalogram→ Occupants



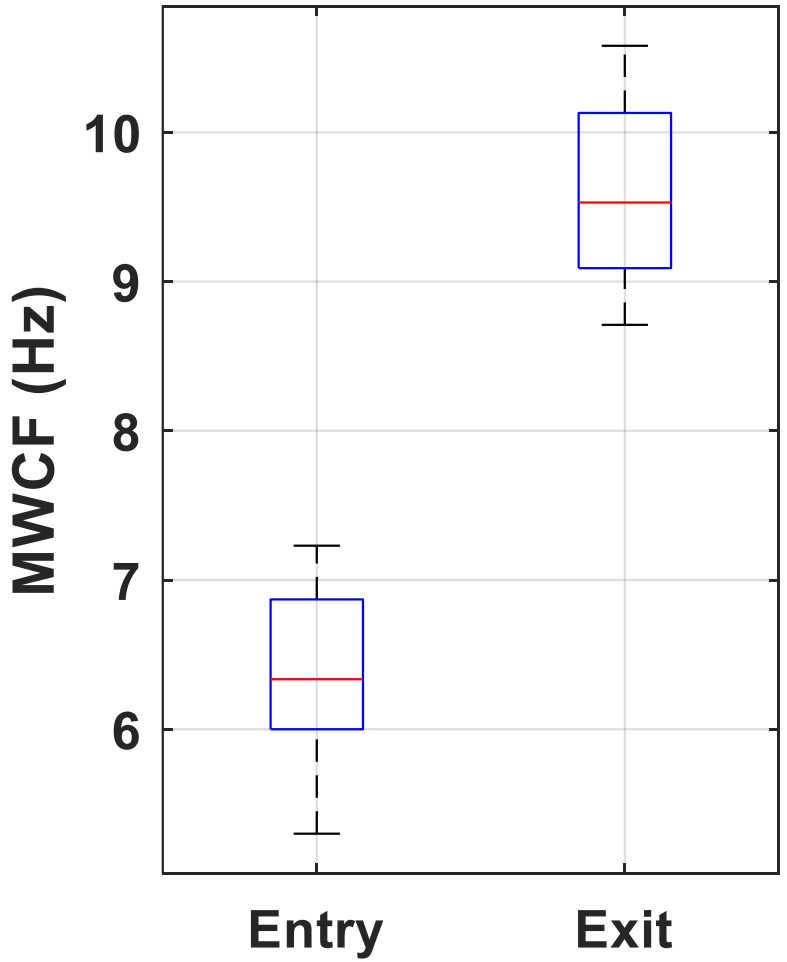
Comparative Analysis

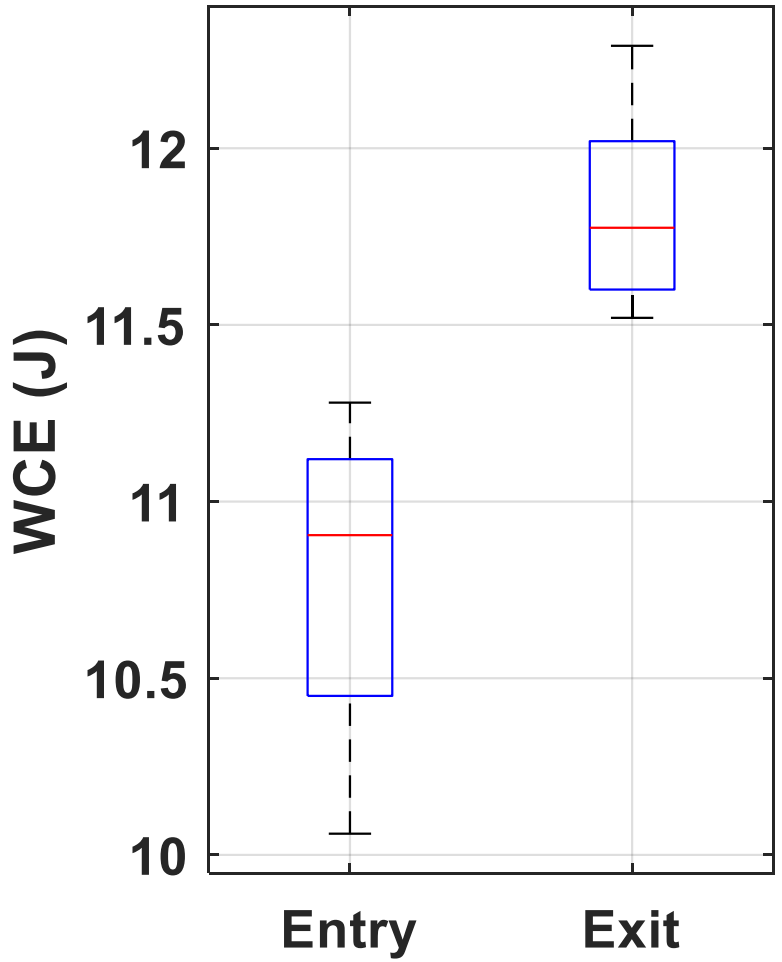
- Wavelet based method
  - Monotonically increasing→ with the occupants



Entry and Exit Event Extraction

- Box-plot of Entry and Exit Events→ MWCF and WCE





Conclusion

- This work explores the feasibility of utilizing single antenna CW Radar
  - Occupants' entry and exit event detection
  - Counting the number of occupants

- A new signal processing approach has been explored→ Wavelet analysis
  - MWCF and WCE shows significant variations→ entry and exit event detection
  - MWCF and WCE monotonically increases→ with the number of occupants

- Continued experimentation and algorithm development
  - Different room, larger number of occupants, and different occupant's patterns

- The proposed system has several potential applications
  - Efficient HVAC management, surveillance, and building evacuations