Continuous and Fine-grained Breathing Volume Monitoring during Sleep from Afar Using Wireless Signals

Phuc Nguyen, Xinyu Zhang, Ann Habower, and Tam Vu

University of Colorado, Denver, University of Wisconsin-Madison
University of Colorado School of Medicine
Sleep Study in Hospitals
Asked to sleep normally
Existing technologies

Noncontact Respiratory Measurement of Volume Change Using **Depth Camera** (Meng-Chieh Yu et. al.)

**Laser 3-D** measuring system and real-time visual feedback for teaching and correcting breathing (Klemen Povšič et. al.)

Smart Homes That Monitor **Breathing and Heart Rate** (Fadel Adib et. al.)
We proposed **WiSpiro**
WiSpiro works even with posture changes during sleep
**Idea**: WiSpiro analyzes the wireless reflection to compute *distance change* to the body

- **Phase information:**
  \[
  \varphi = 2\pi \frac{\text{distance}}{\text{wavelength}}
  \]
Challenges
Challenges: Body Movements

- Body movement causes inaccurate chest movement estimation
Challenges: Non-uniform movement

Different location on the chest move differently while reflecting the same breathing volume
Challenges: Occlusion

- The wireless signal might be blocked by human body part.
System Design
System Design

One-time Trainer

- Radar data
- Spirometer data

Chest movements → Breathing Volume

Movement patterns of each area on the chest

Correlation between chest movement and breathing volume

Volume Estimator

- Radar data

Chest movements → Estimated Breathing Volume

Radar Navigator

- Body Movement Detection
- Area Recognition Posture Detection

Navigating Radar to New Location
One-Time Trainer
Setup

Tx/Rx
Spirometer
One-Time Trainer

**Diagram**

- Radar
- Low pass filter
- DC Remover
- Peaks and Cross Zero Analyzer
- FFT
- Feature Extraction
- Breathing Signature
- Neural Network Training
- Correlation of chest movement and breathing volume

**Text**

- FFT Feature Extraction
- Breathing Signature
- Correlation of chest movement and breathing volume
- Neural Network Training
- Alignment
- Peaks and Cross Zero Analyzer
- DC Remover
- Peaks and Cross Zero Analyzer
- Low pass filter
- Low pass filter
- Radar
- Spirometer
Volume Estimator

Radar

Low pass filter

DC Remover

Chest & body movement tracker

Body movement?

Correlation Function from One-Time Trainer

Estimating Volume

To Radar Navigator

Breathing Volume
Radar Navigator

Small movement
Occlusion
Large movement

Machine Learning Technique (Focus on MFCC features)

Area Localization
Posture Detector

Navigation Controller

Analyze wireless signal from a scanning process
Radar Navigator: Posture Estimation

- Human posture can be approximated from angle between:
  - Human’s back and the bed surface
  - Human body and his legs

![Diagram showing scanning path with symbols for $\Delta d_0$ and $d_1$ and a top view of a human body]
Putting together
Putting together
System Performance
System Performance

Volume estimated in stationary case vs. spirometer measurement

Mean error of 0.021 l, max error of 0.051 l

Experiment Setup
System Performance
Sensitivity Analysis

The accuracy distribution of area localization technique
• Conclusion:
  • Infer breathing volume from chest movement using wireless signal
  • Estimate human posture using wireless signal
  • Localize where the radar is beaming to
  • Thoroughly evaluate the system

• Future Work
  • Improve the area localization and posture detection techniques
  • Conduct a clinical trial to verify the system performance
Thank You!