Non-contact Screening System with Two Microwave Radars in the Diagnosis of Sleep Apnea-Hypopnea Syndrome

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1. Introduction

Sleep Apnea-Hypopnea Syndrome (SAHS)

(1) Obstructive Sleep Apnea (OSA)
• the most common type
• Collapse of the upper airway in the presence of respiratory efforts

(2) Central Sleep Apnea (CSA)
• Failure of the brain to initiate a breath

(3) Mixed Sleep Apnea (MSA)

High prevalence: 2-4% of the adult population (still underdiagnosed)

Apnea (pauses in breathing)
Hypopnea (low breathing)

Low blood oxygen

SpO₂

Airflow

Chest

Abdomen
Polysomnography (PSG)

Overnight monitoring of sleep and a variety of body functions during sleep

Apnea-Hypopnea Index (AHI)

(the total number of apneic events per hour of sleep)
5–15/hr = mild; 15–30/hr = moderate; and > 30/h = severe

- brain (EEG)
- eye movements (EOG)
- muscle activity (EMG)
- ECG
- SpO2
- airflow
- chest
- abdomen
- snoring

The “gold standard” for diagnosis of SAHS
Motivation and Aim of the Project

» Motivation:
PSG with many electrodes restrain the patient and obtrusive inspection methods could disturb the measurement itself.
• Need for diagnostic alternatives

» Hypothesis: Displacements of respiratory movement measured by microwave radars have a linear relationship to tidal volumes.

» Main goal:
Developments of non-contact SAHS-diagnostic tools based on microwave radar sensors.
• Identify novel SAHS features based on the amplitude analysis of chest-abdominal radar signals.
2. Methods

(a) Measurement setup and block diagram

(b) Doppler-radar system and I/Q channels

Figure 1 Monitoring system setup

BPF : Band Pass Filter
AGC : Automatic Gain Control
FFT : Fast Fourier Transform
SSA : Spectrum Shape Analysis
(1) Characteristic of the radar

Microwave Doppler radars (NJR4262)

- Output power 7mW

Quadrupole plane antenna
(24.11GHz, 24.15GHz)

Compact microwave radar
(9.5×5.8×1.7cm)

Incident power density:
1.5×10^{-2} mW/cm^2 < 1 mW/cm^2

The electric wave of this radar is weaker than that of the mobile phone and PHS.

the Japanese electromagnetic wave safety guideline
(2) Heart Beat Measurement with Radars

Detecting the small vibration caused by pulse wave (heartbeats)

A: Arteries (Systole)

B: Arteries (Diastole)

Radar

Doppler detection
(3) Samples of radar output signals

(a) Slight vibrations due to heartbeat are superimposed on respiration and pulse waves.

(b) Apnea and hypopnea signal

Figure 2  Radar output signals

Tokyo Metropolitan University
Our original criteria in accordance with the clinical guidelines of AASM*

Apnea event:
- radar amplitude < 20% of the baseline*

Hypopnea event 1:
- radar amplitude < 50% of the baseline*

Hypopnea event 2:
- radar amplitude is 50% to 80% of the baseline* and rise of heart rates is accompanied.

※ All events last 10 seconds or more.
※ Baseline changes dynamically according to the mean value of the amplitudes of normal breathing radar signal in latest 60 seconds.

Figure 3 Criteria for Apnea and hypopnea events
(5) Flow of the signal processing

Figure 4  Block diagram of SAHS diagnosis

- **Four radar channel signals**
  - Sampling 100Hz
  - Band-Pass Filter
  - AGC: Automatic Gain Control
  - Peak Detection
  - SSA: Spectrum Shape Analysis

- **Respiratory signal**
  - AGC
  - SSA
  - Heartbeat signal
  - FFT
  - SSA: Spectrum Shape Analysis

- **Heart rates**
  - Rise of heart rate
  - Respiratory effort
  - Paradoxical movement

- **Apnea Hypopnea Event**

- **SAHS Diagnosis**
  - OSA
  - CSA
  - MSA: Mixed Sleep Apnea Hypopnea
(6) Prototype of the system

(a) Monitoring system setup

- Radars
- Control unit (12×12×6.5cm)
- LAN
- Remote monitoring

(b) Sample of monitoring display

Figure 5 Prototype of the monitoring system
3. Clinical tests

» Subjects: eight outpatients at the sleep disorder center (mean age 63; range 30-90, two females and six males)
» Overnight test: between 9 PM and 6 AM the following day
» PSG as reference data

![Monitoring PC](image)

Figure 6  The setup of the overnight test for SAHS

R1: Chest
R2: Abdomen
4. Results: OSA with paradoxical movements

(a) a typical central sleep apnea (CSA)

(b) an obstructive sleep apnea (OSA)

Figure 7  Features of CSA and OSA
Results: Hypopnea accompanied by rise of heart rates

Figure 8  Features of Hypopnea
Results: RDIs calculated with the radar and the PSG

**RDI**: the Respiratory Disturbance Index (the total number of apnea and hypopnea events **per hour of recording**)

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The difference of these is small.
Results: Linear association and Bland Altman analysis

RDIs obtained from radars and PSG correlated very closely, with a Pearson correlation coefficient of 0.98 (n=64).

**Fig. 9** Comparison between radar test and PSG
5. Conclusions and future work

(1) We have identified SAHS features based on the radar amplitude analysis. Developed SAHS diagnostic system can deal with body movement noises and positional changes in bed during sleep.

(2) In a practical test at the hospital, we achieved an accurate diagnosis with RDI of SAHS \( (r = 0.98) \).

Future work: Features abstraction of mixed sleep apnea, detection of consecutive hypopnea events.

Our non-contact diagnostic system for SAHS shows great promise as a new screening system.

Thank you for your attention!