Glasses for the Third Eye: Improving the Quality of Clinical Data Analysis with Motion Sensor-based Filtering

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김 미 정



1. INTRODUCTION

- 현재 임상 애플리케이션 문제점 제시
- Clinical applications represent one of the most accuracy-sensitive domains.
  - Unlike many applications where inaccurate predictions or error in the data can be treated simply as a "mistake"
- Patient movements
  - 1) Data collected from the hospitals are known to be noisy.
  - 2) Faulty measurements in physiological sensor readings
  - 3) Training a CDSS(임상의사결정지원시스템) from such noisy data can cause misleading predictions, directly leading to potentially dangerous clinical decisions.



1. INTRODUCTION

- 연구 목적: To design a system that addresses the aforementioned challenges.
- Prensent “MediSense” system.
- 주요 기능: A system to sense, classify, and identify noise-causing motions and activities that affect physiological signal when made by patients on their hospital beds.
- 시스템 구성: Combines a gyroscope sensor with an embedded board wirelessly connected to a gateway and a server.
- 기여: A system can be considered as “glasses" for the clinical third eye in correctly observing medical data.



1. INTRODUCTION

- MediSense 배치



Figure 1: Pictorial view of our target deployment site.
아주대 병원 외상센터 내 3개의 중환자실에 배치



2. MOTIVATION AND PROBLEM STATEMENT

- <2.1 Preliminary Studies>
- Collected real physiological signal traces from patients at an ICU.
- While analyzing the physiological signal data, irregular patterns in the signals.



2. MOTIVATION AND PROBLEM STATEMENT

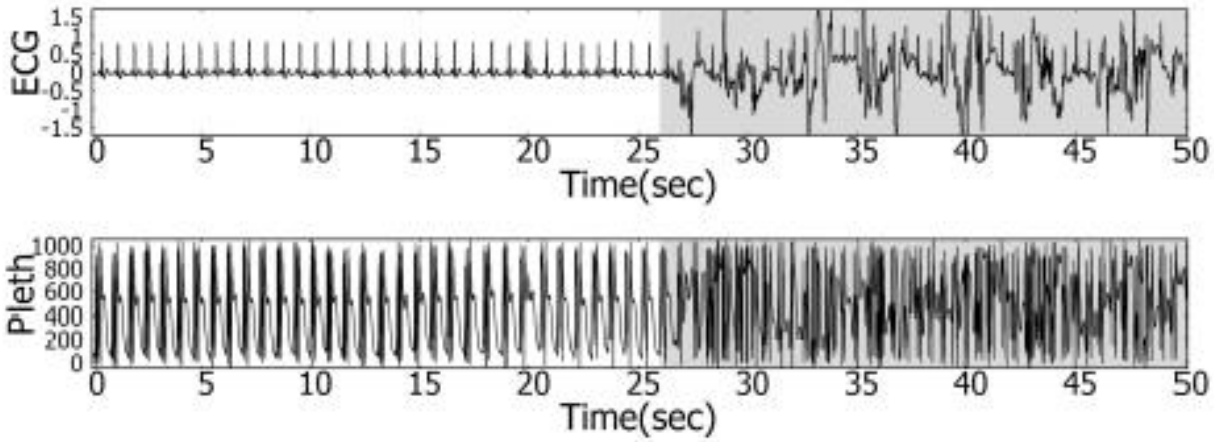


Figure 2: Sample ECG and plethysmograph signal traces collected from a real patient.

- The plethysmograph and ECG signal traces of a patient over time,
  - 1) Parts of the signal were noisy and corrupted (shaded region in Figure 2).
  - 2)An impact of patient movements on the ICU beds.

2. MOTIVATION AND PROBLEM STATEMENT

- 예비 연구를 통한 연구 목표 설정
  - 1. To identify when and how patients move on their beds
  - 2. Alert the data collection server

  -to closely examine and eliminate noisy physiological signal data from being part of the clinical learning system training set.



2. MOTIVATION AND PROBLEM STATEMENT

- <2.2 System Requirements>
- 예비 연구를 통한 시스템 요구사항 도출
  - 1) High Reliability
  - 2) Motion Classification & Physiological Signal Correlation
  - 3) Minimal Impact on Clinical Protocols
  - 4) Preserving Original Physiological Signals



3. MAIN SYSTEM COMPONENTS

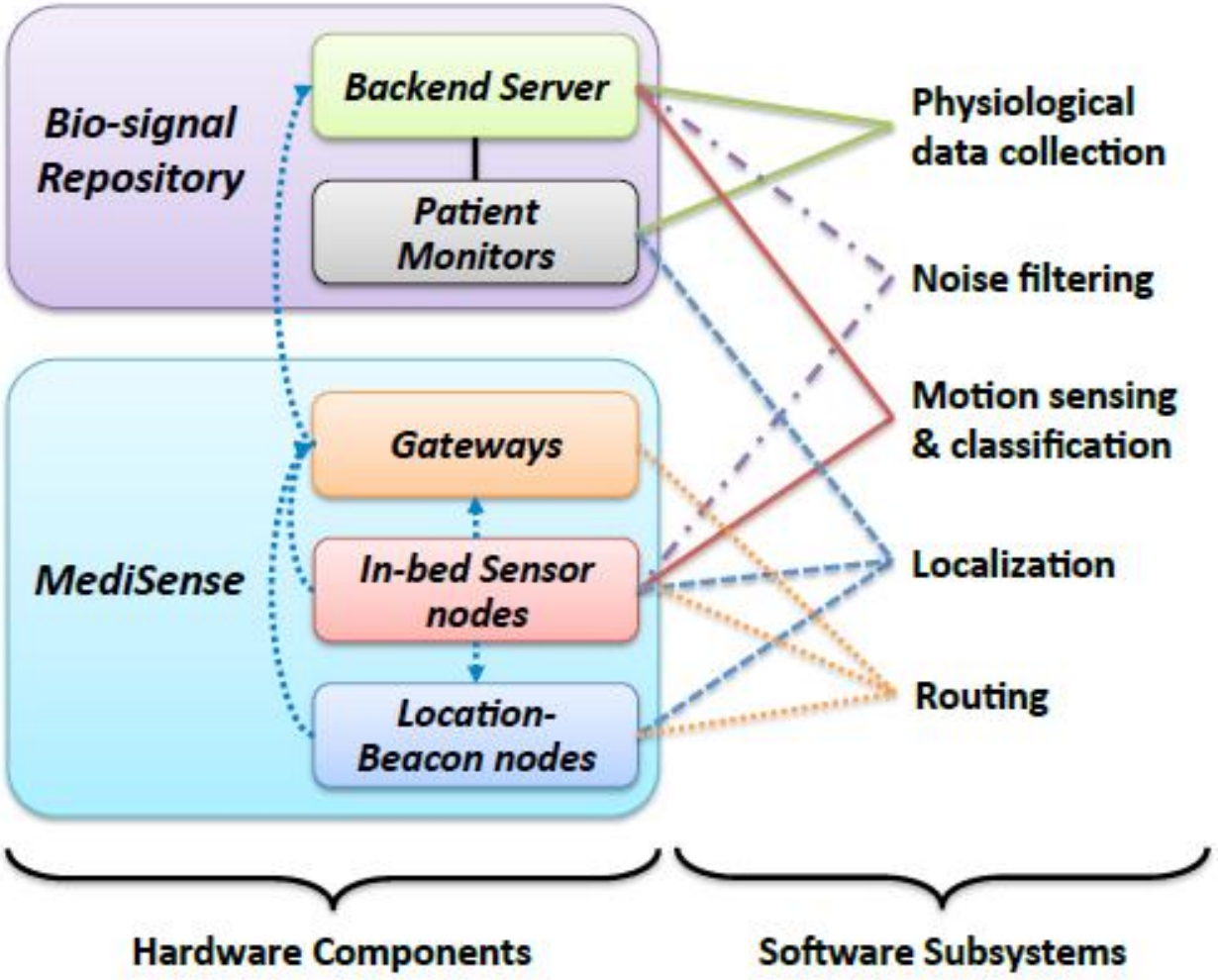


Figure 3

3. MAIN SYSTEM COMPONENTS

- <3.1 Biosignal Repository>
- "Backend Server" 설계
  - In three ICUs, 10 in each ICU, a total of 30 beds
- Additional physiological signal sensing equipments: (환자에게 부착 or 병원의 데이터베이스 조작하는 대신) Backend server directly to the "at-bed" patient monitors
- 수집하는 생리적 신호 데이터? at-bed patient monitors (ECG, plethysmograph, SpO2, heartrate, respiration, etc.)
- [Figure 3]



3. MAIN SYSTEM COMPONENTS

- <3.2 Hardware Platforms in MediSense>
- MediSense consists of three types of hardware platforms [Figure 3,4]
  - 1) In-Bed Sensor Node: 침대 아래에 설치. 환자의 움직임을 감지하여 게이트웨이에 보고
  - 2) Location-Beacon Node: 침대 옆 모니터 근처에 설치. 센서 노드의 위치 지정, 패킷 라우팅
  - 3) Gateway: 3개 ICU에 1개씩 설치. 이더넷 스위치와 연결



3. MAIN SYSTEM COMPONENTS







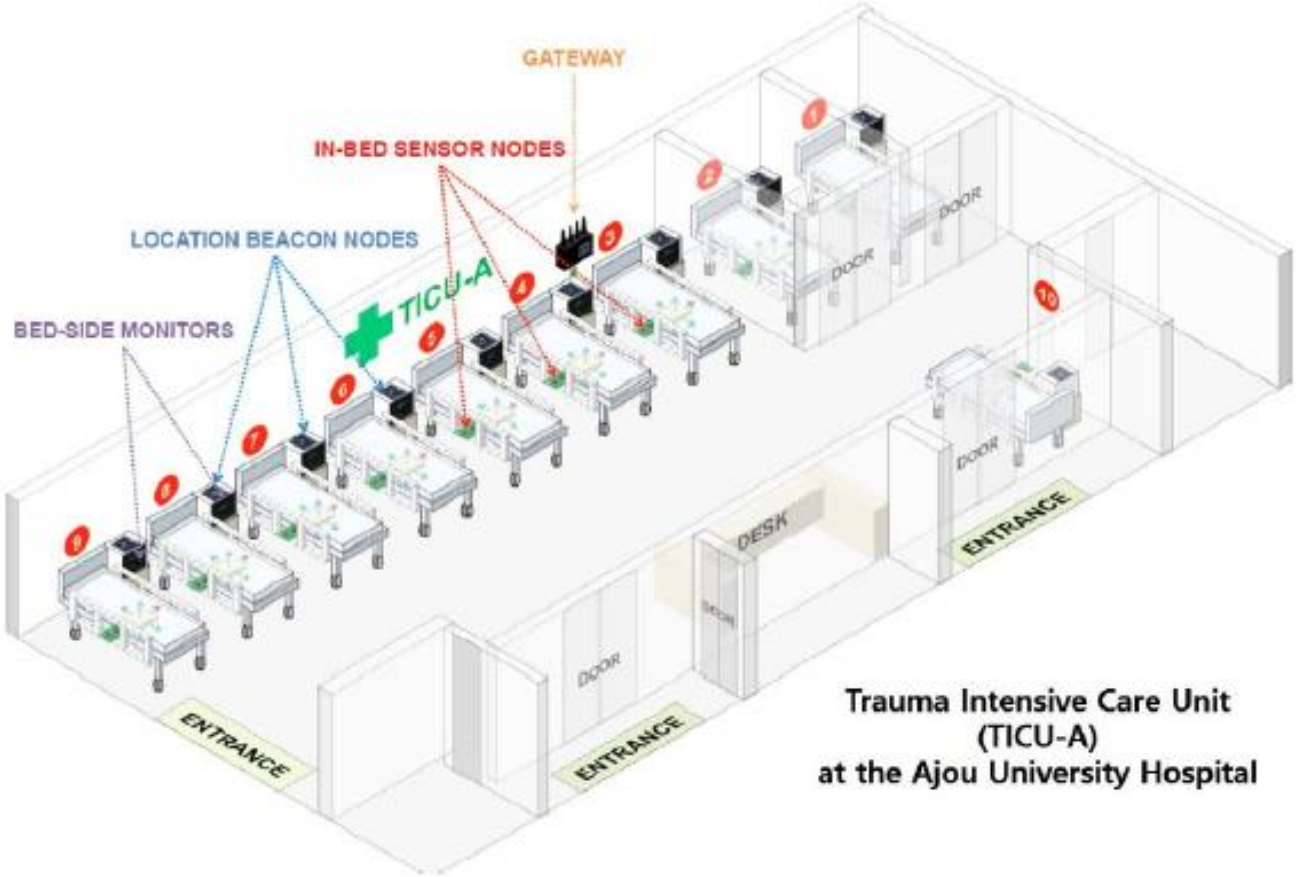


Figure 4. 아주대병원 TICU-A, MediSense 시스템 구성요소 평면도

4. PATIENT MOTION CLASSIFICATION

- <4.1 Physiological Signal Noise-causing Motions>
- 2주간 통제되지 않은 환경에서 10개의 침대에서 발생하는 환자의 동작 활동을 관찰 및 모니터링

- <table 1> 5가지 주요 움직임 유형과 발생

Motion Type	Occurrences/day/bed	Percentage (%)
Head Motion	56	7.77
Arm Motion	264	36.66
Full Body Motion	176	24.44
Chest Motion	112	15.56
Leg Motion	112	15.56



4. PATIENT MOTION CLASSIFICATION

- 환자들의 다양한 움직임 연구? plethysmograph, electrocardiograph (ECG), respiration patterns 등 생리적 신호 데이터의 변화와 관련
- Have the highest impact on the core physiological data used in the clinical routine.



4. PATIENT MOTION CLASSIFICATION

- <4.2 Sensor Selection and Configuration>
- 1) The motion sensors? 3-axis gyroscope
  (예비연구 결과: 가속도계는 환자 및 침대 자체의 움직임에 너무 민감, 자이로스코프 데이터는 보다 상관관계가 있는 측정값 제공)
- 2) gyroscope sensor의 장착위치? 침대 매트리스 아래(응급실 센터의 특성상 침대가 혈액으로 범람할 높은 가능성을 고려)
- 3) 매트리스의 어느 위치에 설치? 6명의 서로 다른 체중을 가진 "가짜 환자"를 통해 4가지 행동(누워있기, 팔 흔들기, 몸 회전, 몸 흔들기)을 흉내내는 통제된 실험 수행 => 3번 허리 부분에 설치 시 자이로스코프의 판독값이 구별가능한 패턴을 보임을 확인
  - [figure 5] 참조



4. PATIENT MOTION CLASSIFICATION

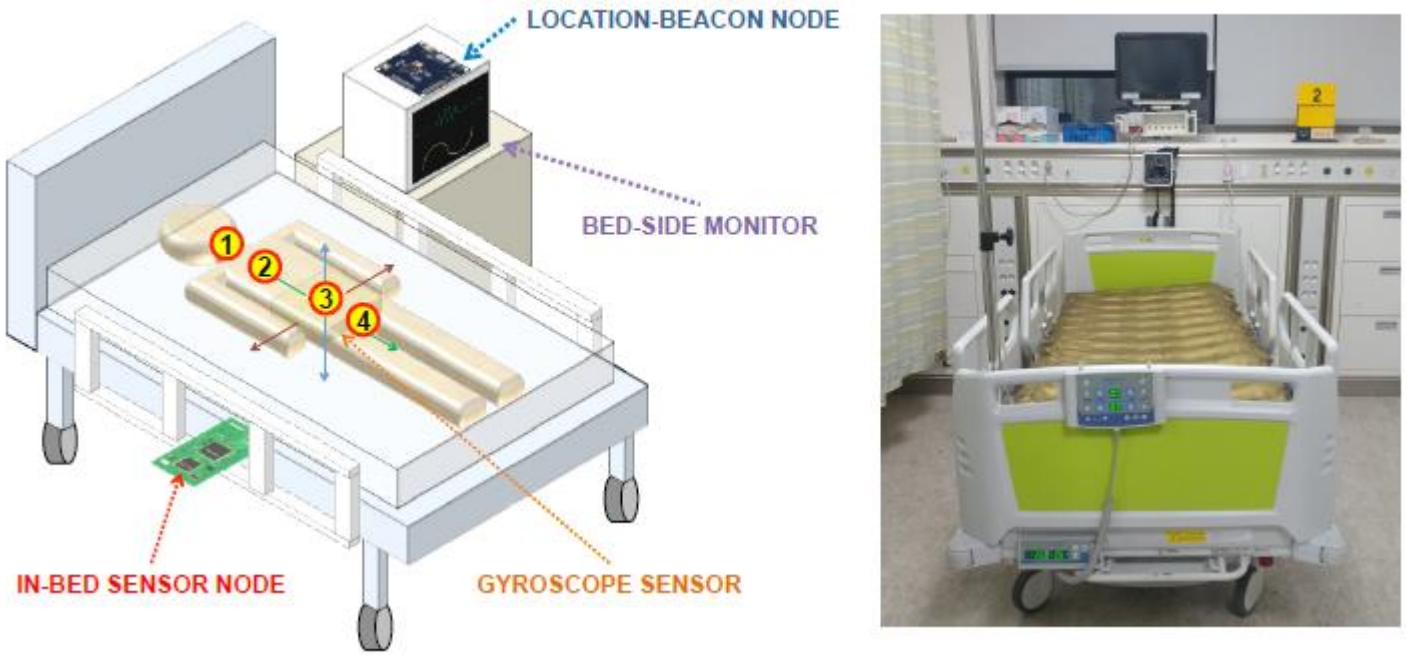
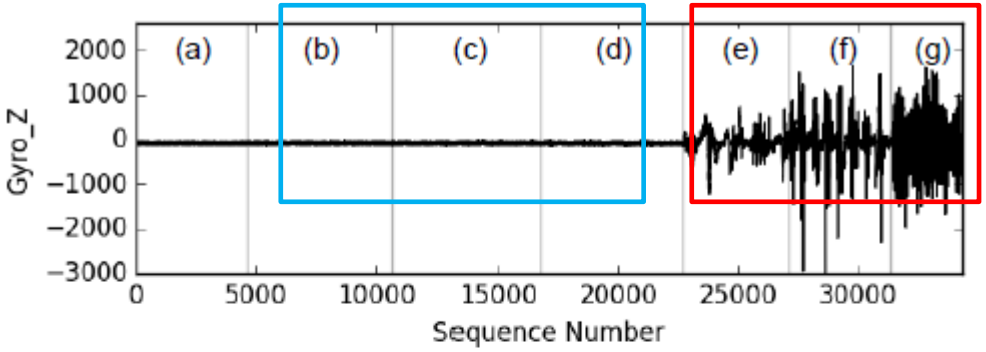


Figure 5

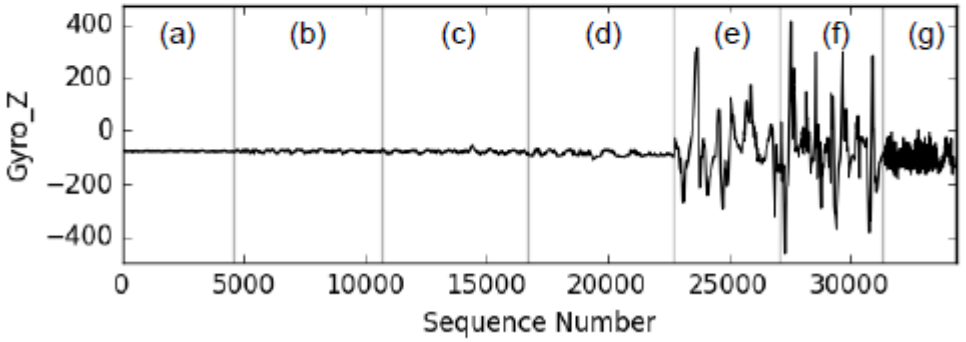
4. PATIENT MOTION CLASSIFICATION

- <4.3 Peak Detection & Classification>

(a) Stays Still
(b) Waves left arm
(c) Waves right arm
(d) Wave two arms
(e) Slowy rotates body
(f) Quickly rotates body
(g) Shakes body



(a) Raw values



(b) Low-pass filtered

- Figure 6. Raw and Low-pass filtered gyroscope Z-axis data.

4. PATIENT MOTION CLASSIFICATION

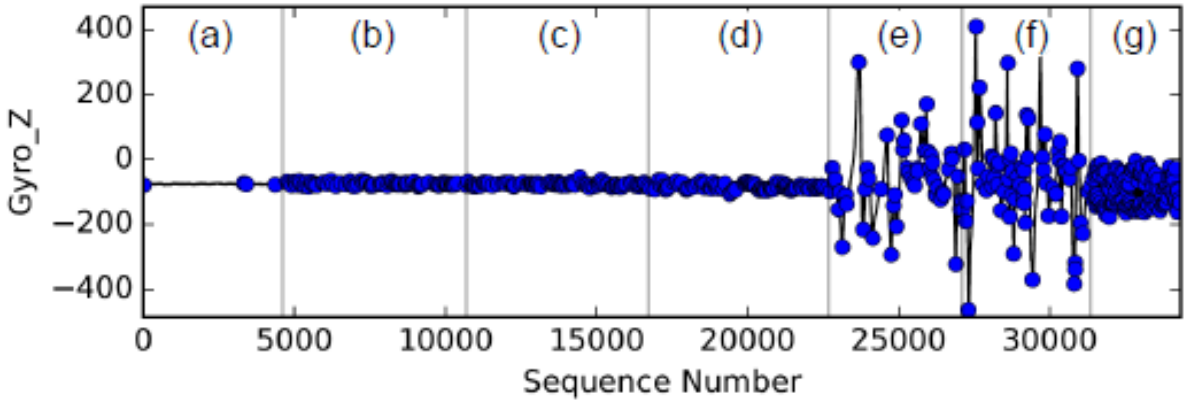


Figure 7. Peaks detected for our controlled data set.

- (a) If no peaks are detected => “Patient Still”



4. PATIENT MOTION CLASSIFICATION

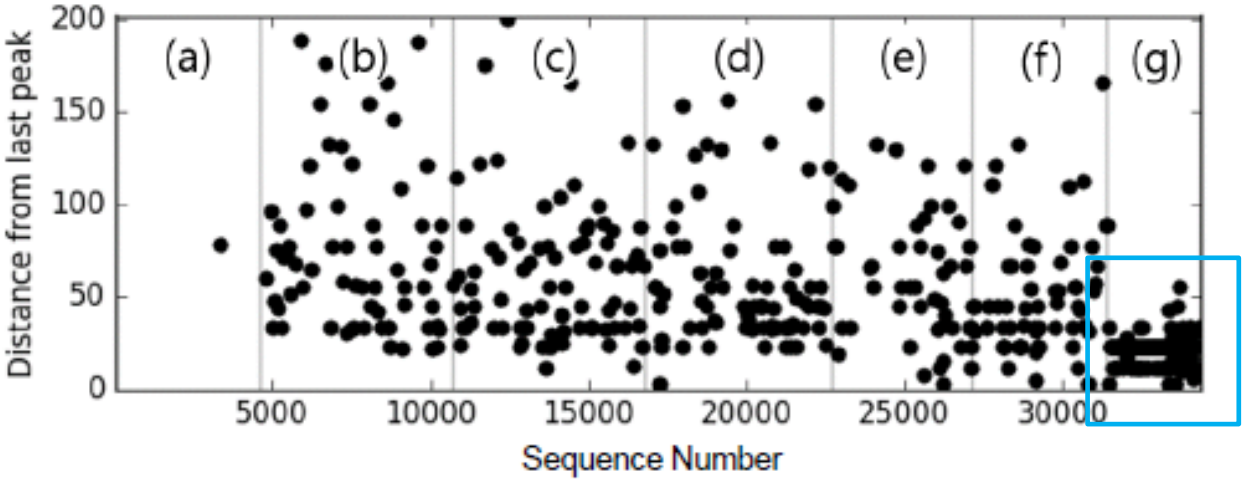


Figure 8. Peak time-distance scatter plots

- MediSense detects peaks in the data, it computes the time-distance between the peaks.
- (g) If the variance of peak time-distances within T is less than Vmin => "Body Shaking"
- Peak time-distance variances exceed Vmin => amplitude Nf **선택**
  - 1) The average signal amplitude < Nf => "Arm Waving"
  - 2) Else, "Body Rotation"

4. PATIENT MOTION CLASSIFICATION

- <4.4 Filter Evaluations>
- Evaluate the motion classifier
  - Collected: 2-month preliminary pilot study, 20 individuals summing up to ~500 minutes of data
  - Evaluated: 12 individuals (~370 minutes of data)



4. PATIENT MOTION CLASSIFICATION

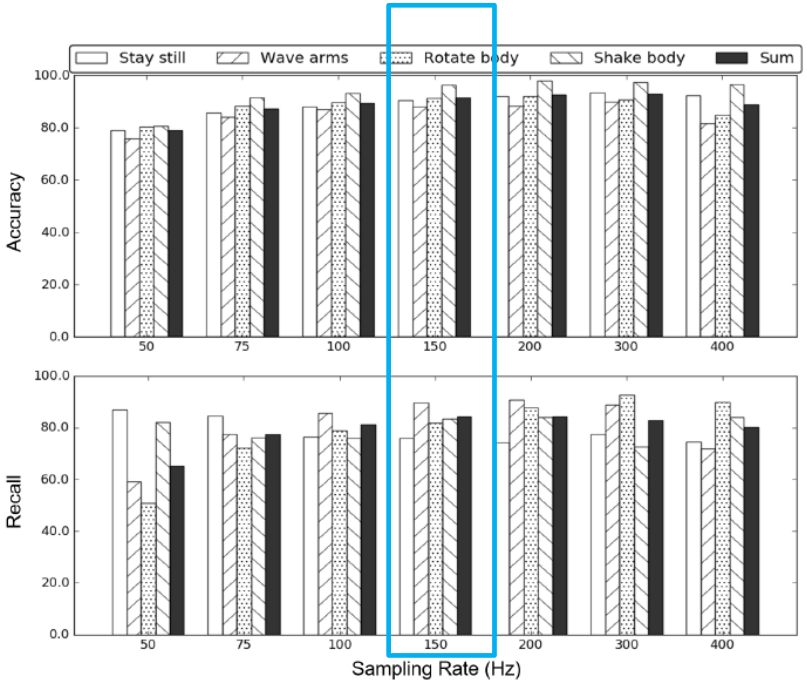


Figure 9. Accuracy and recall for our motion classification scheme with varying gyroscope sampling rates.

- The sampling rate exceeds 300 Hz => **성능 저하 (작은 진동 민감하게 반응)**
- 150Hz, 200Hz**의 분류 성능 거의 동일, 평균 정확도 > 90% 달성, 전력 소비 모두 유사**
- **정확도와 메모리, 프로세싱 오버헤드간의 균형을 맞추기 위해**
- 150Hz **자이로스코프를 샘플링하도록 결정**

5. SYSTEM ARCHITECTURE OF MEDISENSE

- <5.1 Device-to-Bed Localization>
- How MediSense maps each in-bed sensor to a patient monitor
- Main purpose of system: to filter out noisy physiological sensor measurements due to patient motion on the beds.
  - 1) Patient monitors
  - 2) In bed motion sensors
  - 3) location-beacon node: 비컨 패킷 방식
- A bed is outside of the ICU



5. SYSTEM ARCHITECTURE OF MEDISENSE

- <5.2 Routing>
- Routing system in MediSense
  - 1) Find a path from an in-bed sensor node to the gateway
  - 2) Have low latency for better time synchronization
  - 3) Routing state on the sensor nodes should be minimal and constant
  - 4) Achieve high packet delivery reliability and work effectively in ICU
- Combines “best-effort single-hop” delivery along with “beacon-as-backbone” routing



5. SYSTEM ARCHITECTURE OF MEDISENSE

- <5.3 Time Synchronization>
- Important issue
  - 1) Motion data is collected on MediSense's embedded platform
  - 2) Physiological data is gathered through a separate interface
- Do not require very tight time synchronization
  - 1) not correlating the two data streams directly
  - 2) only filtering out small portions of the physiological signal data
- A sub-second accuracy would suffice
- Time-stamp (the reception time)



5. SYSTEM ARCHITECTURE OF MEDISENSE

- <5.4 Power and Energy>
- Deployed in real clinical settings
  - The nodes (especially the battery powered in-bed sensors) maintain a sufficient enough life cycle
  - Clinical staff : at least one month
  - The lifetime of the in-bed sensors : to 33 days
- when transmitting a packet
  - No packet retransmissions, the in-bed sensor: 15.46 mA, 12,800 mAh rechargable battery = 34.50 days



6. EVALUATION

- <6.1 Motion Classification and Data Filtering>
- Using the in-bed sensors that were in operation for more than 30 days
- 375 motion events per day
  - 1) arm waving (91.51%)
  - 2) body rotation (7.66%)
  - 3) body shaking (0.83%)
- Within ±10 seconds, remove biosignals 2.417%
- The patient with the most amount of movements: 3,641 events, 9.71 days, remove 5.6 hours



6. EVALUATION

- <6.2 Bed Localization Performance>

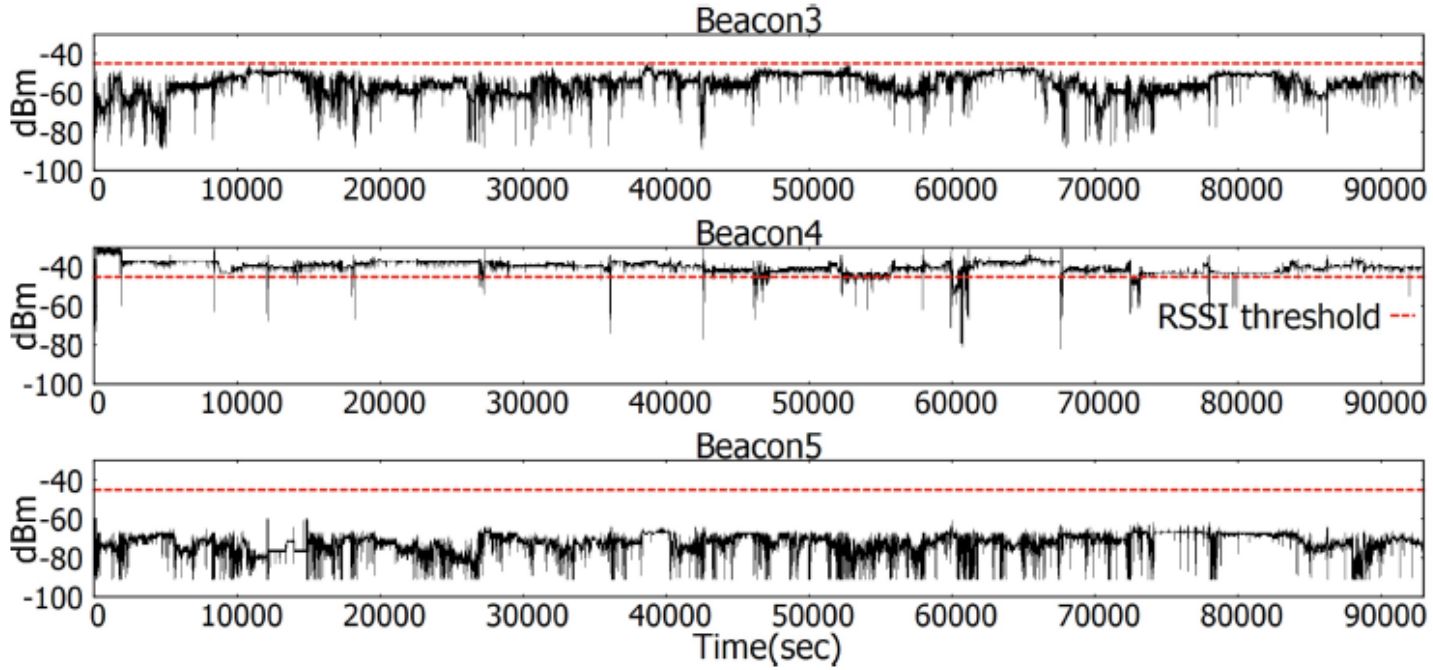


Figure 10. RSSI values captured for associated and neighboring location-beacon nodes. These are traces captured from in-bed sensor at location 4.

- RSSI-based localization scheme
- MediSense was able to correctly locate all in-bed sensor nodes with the bed-side monitors with 100% accuracy

6. EVALUATION

- <6.3 Packet Delivery and Routing Performance>
- packet reception ratio (PRR)
- average number of required transmissions per packet (ATX)
- successfully delivered to the gateway via 1-hop (In-Bed Sensor Node)
- a low ATX of <1.02 : 게이트웨이를 향한 모든 링크
- 매우 안정적인 성능



6. EVALUATION

- <6.4 Node Lifetime Distributions>

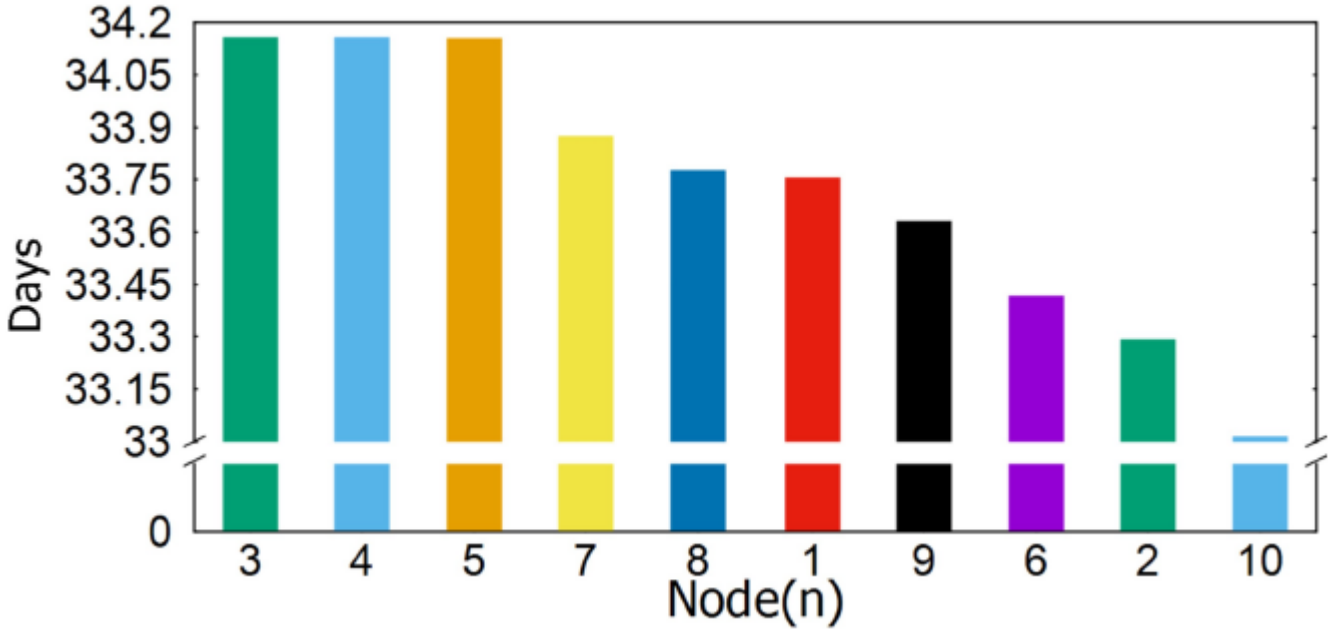


Figure 11. Lifetime distribution of nodes deployed at our deployment hospital

- achieving our goal of 33 days or more

6. EVALUATION

- <6.5 Deployment Experience>
- several non-technical challenges
  - 1) not interfering with the clinical protocols of the hospital.
  - 2) the time and access to the deployment site, the ICUs
  - 3) capturing ground truth data for our experiments itself was a challenge



7. CONCLUSION

- Results
  - 1) wellidentifies
  - 2) correlation
  - 3) arrhythmia patient data



비평

- 의료적으로 필요한 연구
- 1) 실제 임상 환경에서 구현 가능하도록 설계: 실제 의료진의 의견 반영, 실제 환자들의 데이터 수집 및 분석
- 2) 임상학습시스템의 정확도 향상에 도움을 줄 수 있는 시스템 설계
- 3) 의료진 요구 반영: 네트워킹 프로토콜이 단순하여 센서가 저전력 소비 가능 => 저전력 배터리로 충분한 수명 주기를 갖춤
- 배치 시 비기술적인 문제를 해결할 필요 있음

