Compressive Sensing Based ECG Monitoring with Effective AF Detection

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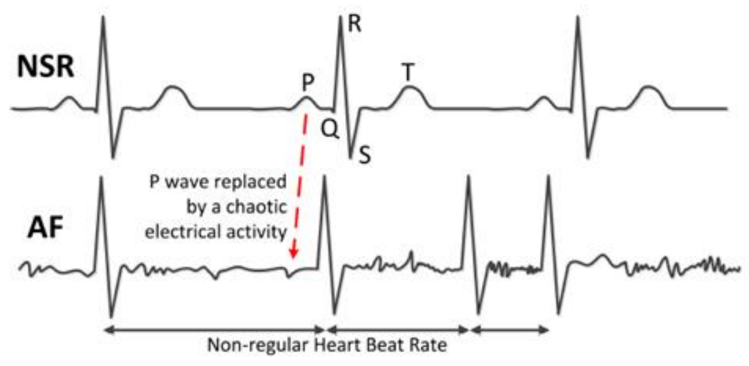
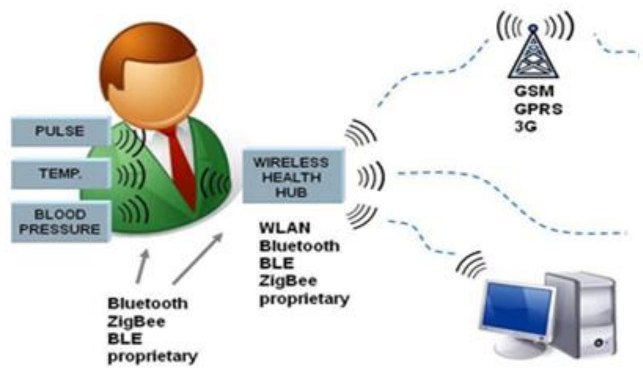
Atrial Fibrillation & ECG Monitoring

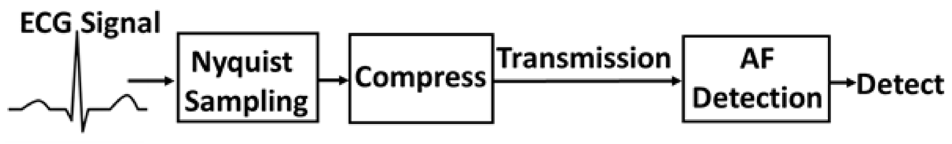
- Atrial Fibrillation (AF) is the most common cardiac arrhythmia
  - Increases the risk of stroke by 5-fold [1]
  - Electrocardiography (ECG) is used in AF detection
  - ECG-based AF detection algorithms [5][6]
- Wireless ECG monitoring system is the key of home care for AF patients
  - Wireless Sensors → Hub → Cloud & Doctor



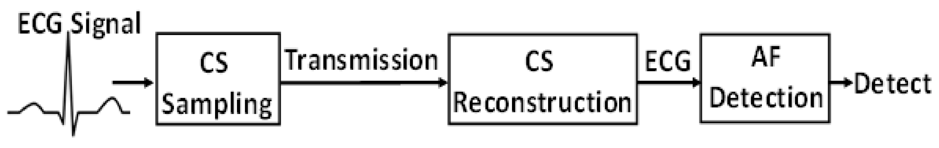


Compressive Sensing for ECG Monitoring

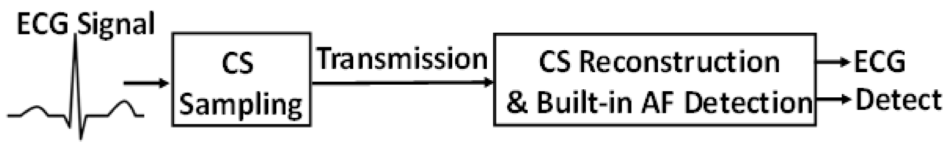
- Traditional measured-and-compressed ECG monitoring suffer from high power consumption



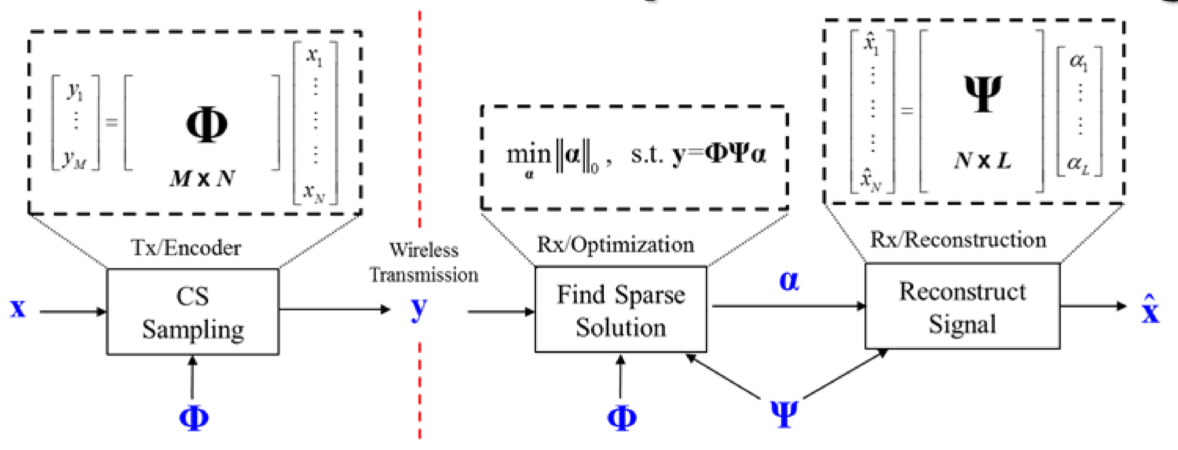
- Low-power compressive sensing (CS) based ECG monitoring system [4] for AF detection



- Proposed CS-based ECG monitoring system with built-in AF detection



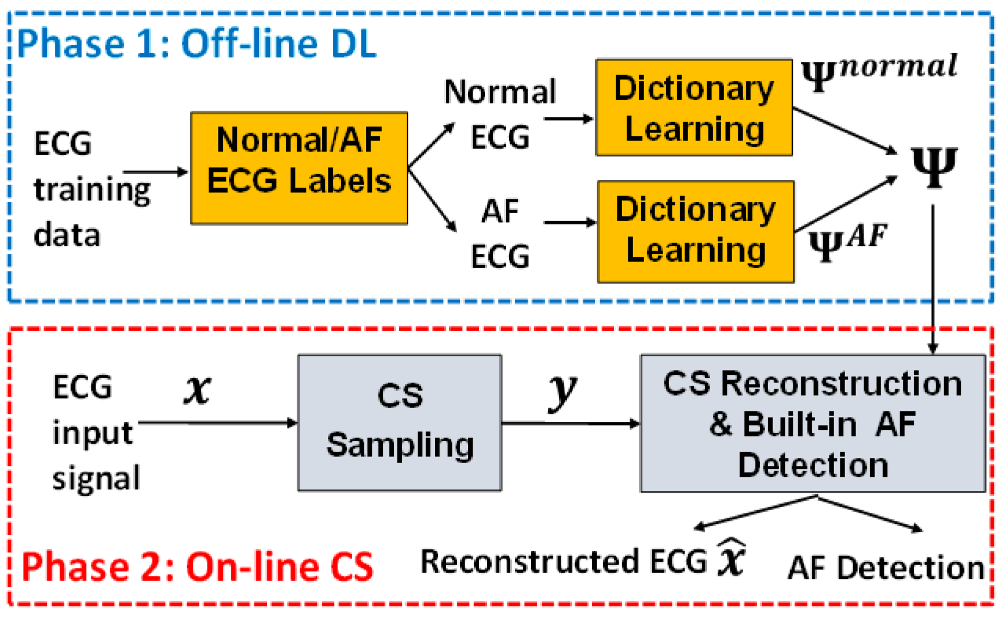
Introduction to Compressive Sensing



- Sensor: Random sampling N-dim $\boldsymbol{x}$ by sensing matrix $\boldsymbol{\Phi}$ → M-dim $\boldsymbol{y}$ (M < N)
- Receiver: Reconstruct signal $\boldsymbol{x}$ form measurement $\boldsymbol{y}$
  - l^1-Minimization: Basis Pursuit (BP) [8], Orthogonal Matching Pursuit (OMP)
  - $\boldsymbol{x}$ needs to be sparse in specific sparsifying basis $\boldsymbol{\Psi}$, $\boldsymbol{x}_{N\times 1} = \boldsymbol{\Psi}_{N\times P}\boldsymbol{\alpha}_{P\times 1}$
  - State-of-the-art takes Discrete Wavelet Transform (DWT) as sparsifying basis [4]
  - ECG on DWT is not sparse enough → K↑ → $M > O(K \cdot log(N/K))$ [2] → M↑ → Low compression ratio and bad energy efficiency

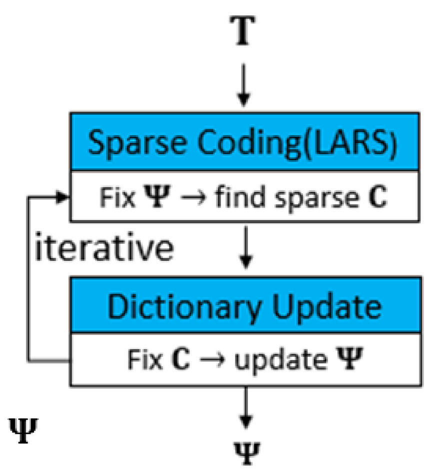
Proposed CS-based ECG Monitoring System with Built-in AF Detection

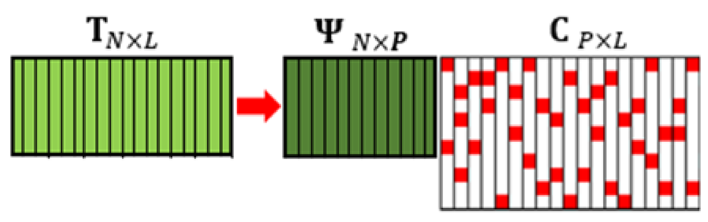
- Phase 1: Separate training data into AF and normal ECG waveform. Applied dictionary learning to generate $\boldsymbol{\Psi}_{N\times 2P} = \left[\boldsymbol{\Psi}^{Normal}_{N\times P}\ \boldsymbol{\Psi}^{AF}_{N\times P}\right]$
- Phase 2: AF detection in CS reconstruction stage



Dictionary Learning [7]

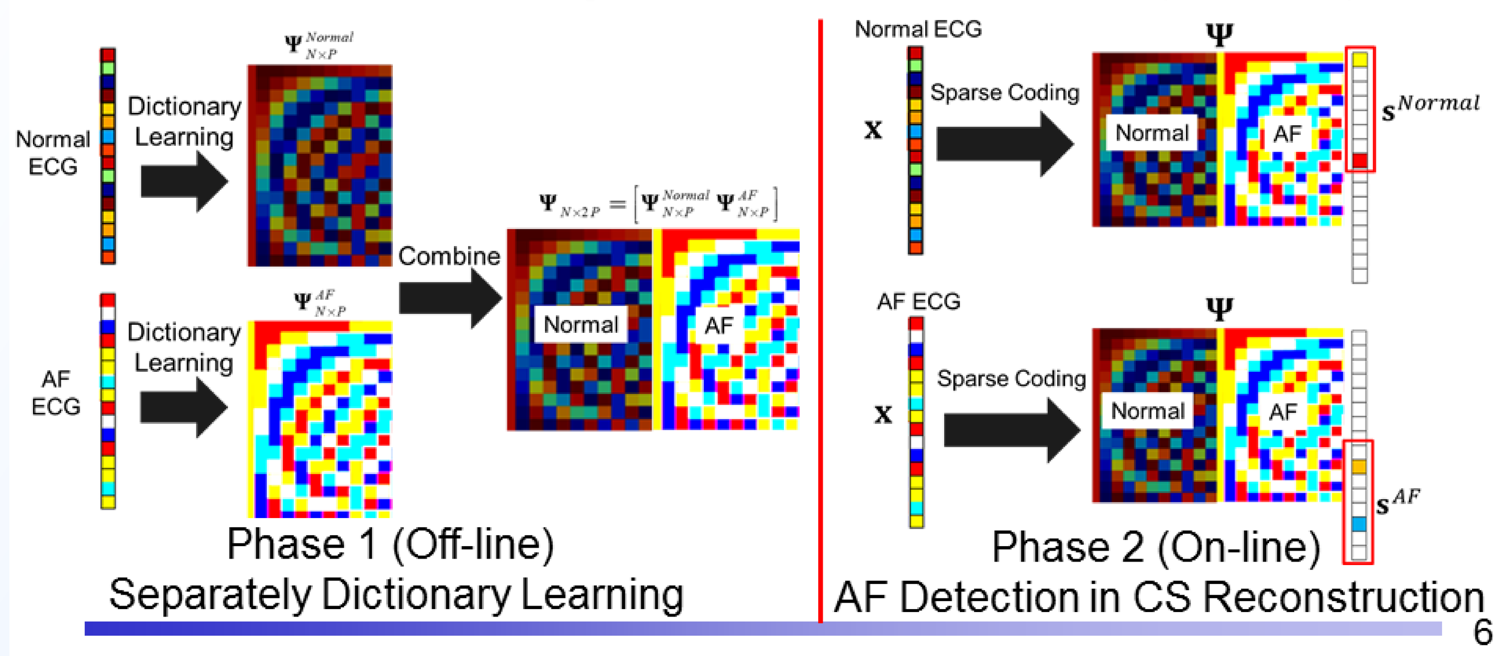
- Training data $\mathbf{T}$ can be represented by linear combination of dictionary $\boldsymbol{\Psi}$ with sparse coefficients $\mathbf{C}$
  - Solve $\min_{\boldsymbol{\Psi},\mathbf{c}} \frac{1}{L}\sum_{i=1}^{L}\left(\frac{1}{2}\|\mathbf{t}_i - \boldsymbol{\Psi}\mathbf{c}_i\|_2^2 + \lambda\|\mathbf{c}_i\|_1\right)$
- Two stage procedure
  - Sparse coding
    - Basis Pursuit Denoising (BPDN)
  - Dictionary update
    - Online updating
  - Iteratively applies two stages on $\mathbf{T}$ to generate $\boldsymbol{\Psi}$





Built-in AF Detection in CS Reconstruction

- Sparse Representation Classifier (SRC) in face recognition
  - Test sample as a sparse linear combination of trained dictionary
  - Sparse solution via l^1-Minimization
- CS reconstruction using l^1-Minimization → Detect AF (Classifier)

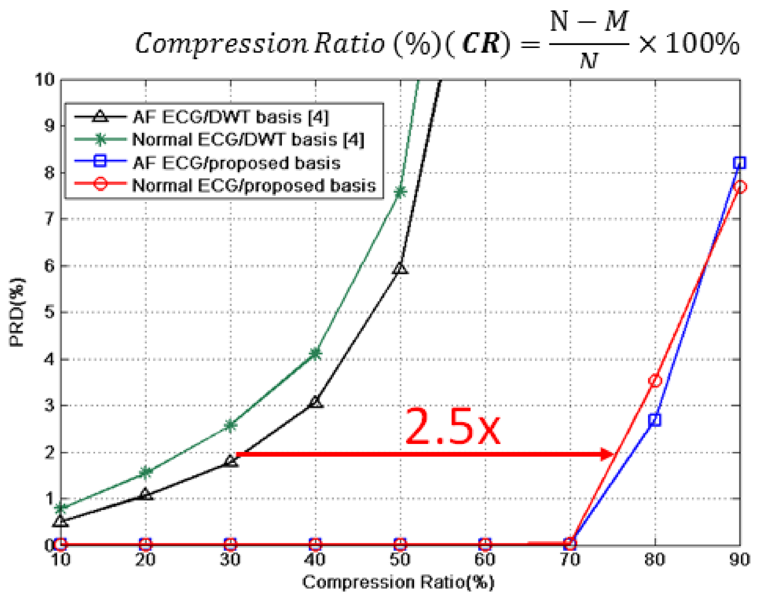


Reconstruction Performance of CS-based ECG Compression with Different Spasifying Basis

- Compare the proposed trained personalized basis with common predefined basis DWT [4]

$$Percantage\ Root\ mean\ square\ Distance\ (\boldsymbol{PRD}) = \frac{\|\mathbf{x}-\hat{\mathbf{x}}\|_2}{\|\mathbf{x}\|_2} \times 100\%\ [11]$$

$$Compression\ Ratio\ (\%)(\boldsymbol{CR}) = \frac{N-M}{N} \times 100\%$$



Parameter Settings	
Input Data Type	ECG from MIT-BIH Long-Term AF Database (LTAFDB) [10]
Sampling Frequency	256 Hz
# of Training Vectors (L)	2500
Input Dimension (N)	256
# of Dictionary Atoms (P)	512
Sampling Matrix	Random Gaussian Matrix
Trials	1000

Performance of Built-in AF Detection

- A paroxysmal AF patient in MIT-BIH Long-Term AF who has both normal ECG and AF ECG

$$Sensitivity = \frac{\#\ of\ AF\ segments\ detected\ as\ AF}{Total\ AF\ segments(labels\ in\ database)}$$

$$Specificity = \frac{\#\ of\ Normal\ segments\ detected\ as\ Normal}{Total\ Normal\ segments(labels\ in\ database)}$$

$$Detect(\mathbf{s}^{normal}, \mathbf{s}^{AF}) = \begin{cases} AF\ ECG, & if\ \|\mathbf{s}^{AF}\|_2 \geq \|\mathbf{s}^{normal}\|_2 \\ Normal\ ECG, & if\ \|\mathbf{s}^{AF}\|_2 < \|\mathbf{s}^{normal}\|_2 \end{cases}$$

CR	70%	80%	90%
Sensitivity	85.4%	92.4%	96.0%
Specificity	85.6%	86.0%	97.2%

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