DETERMINISTIC COMPRESSED DOMAIN ANALYSIS OF MULTI-CHANNEL ECG MEASUREMENTS

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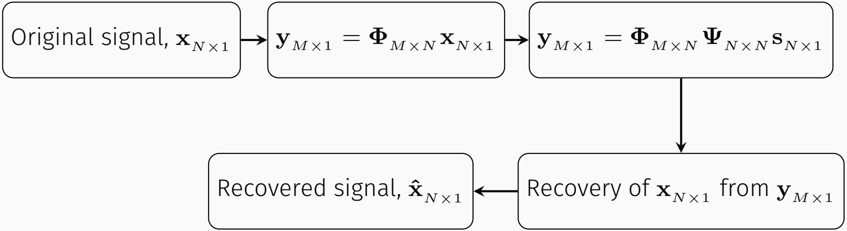
Content

BACKGROUND

Compressive Sensing (CS)



How to obtain the sparse solution of the linear system?

1. $\min ||\mathbf{s}||_0$ subject to $\mathbf{y} = \mathbf{\Phi\Psi s} \rightarrow$ NP hard problem.
2. $\min ||\mathbf{s}||_1$ subject to $\mathbf{y} = \mathbf{\Phi\Psi s} \rightarrow$ Solvable convex optimization problem leading to the same solution with ℓ_0 norm.

How to implement compressive sensing (CS) for J jointly sparse signals?

1. **Naive Approach:** Apply 1-D CS J times for J signals.
   - Does not exploit temporal sparsity between signals.
   - Recovery algorithm of complexity [1] $O(MN)$ is performed J times. $\longleftarrow$ Expensive Computationally

1. **Distributed CS Approach [2]:** Exploits temporal sparsity of J signals.
   - Decompose the signal into common and innovation components: $D = K_C + \sum_{j=1}^{J} K_j$
   - Recovery algorithm of complexity $O(JM^2N)$ is performed. $\longleftarrow$ Expensive Computationally

[1] H. Mohimani *et. al.*, "A fast approach for overcomplete sparse decomposition based on smoothed ℓ_0 norm," *IEEE Transactions on Signal Processing*, vol. 57, pp. 289–301, Jan 2009.

[2] D. Baron *et. al.*, "Distributed Compressive Sensing," *arxiv*, 2009.

CHALLENGES

Challenges:

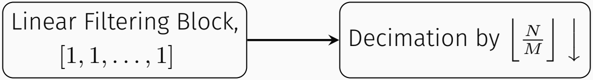
- Hardware implementation of measurement matrix ($\mathbf{\Phi}$).
- Computationally expensive recovery.

Goals:

- Easy to implement measurement matrix $\longleftarrow$ Deterministic matrix.
- Avoid computationally expensive recovery.

PROPOSED APPROACH

- To ensure easy realisation deterministic sensing is adopted.
- Linear filtering-based DBBD deterministic matrix[3] is used in this work.



- A matrix representation of DBBD deterministic matrix for $M = 4$ and $N = 16$.

$$\mathbf{\Phi}_{4\times 16} = \begin{bmatrix} [1111] & & & \\ & [1111] & & \\ & & [1111] & \\ & & & [1111] \end{bmatrix}$$

[3] A. Ravelomanantsoa *et. al.*, "Compressed sensing: A simple deterministic measurement matrix and a fast recovery algorithm," *IEEE Transactions on Instrumentation and Measurement*, vol. 64, pp. 3405–3413, Dec 2015

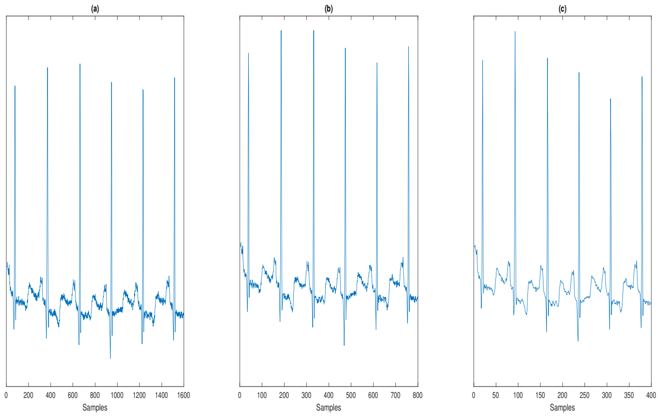


Figure: Compressed ECG signal at various compression levels. (a) Original signal, (b) compression ratio = 50%, (c) compression ratio = 75%.

QUANTIFYING FEATURE PRESERVATION

- Structural similarity $\longleftarrow$ Pearson's correlation coefficient.
  Structural similarity between two signals A and B: $corr(A, B) = \frac{cov(A,B)}{\sigma_A \sigma_B}$.
- Fiduciary Point Detection $\longleftarrow$ R-peak Detection.
  Pan Tompkins QRS detection[4] algorithm.

[4] J. Pan and W. J. Tompkins, "A real-time QRS detection algorithm," *IEEE Transactions on Biomedical Engineering*, vol. 32, no. 3, pp. 230-236, March 1985.

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- How to evaluate the performance of the QRS detection algorithm?

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Quality Evaluation Metrics

- Sensitivity (Se): $Se(\%) = \frac{TP}{TP+FN} \times 100\%$
- Positive predictivity (P_+): $P_+(\%) = \frac{TP}{TP+FP} \times 100\%$
- F measure (F): $F(\%) = \frac{2\times TP}{2\times TP+FN+FP} \times 100\%$
- Detection Error Rate (DER): $DER(\%) = \frac{FP+FN}{TP+TN+FP+FN} \times 100\%$

EXPERIMENTAL VALIDATION

Results

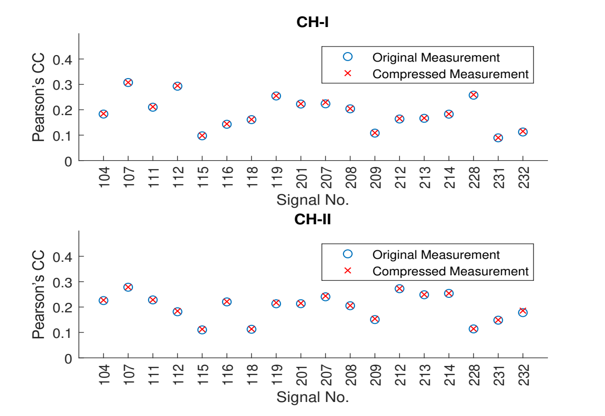


Figure: Structural similarity analysis at compression ratio = 50%

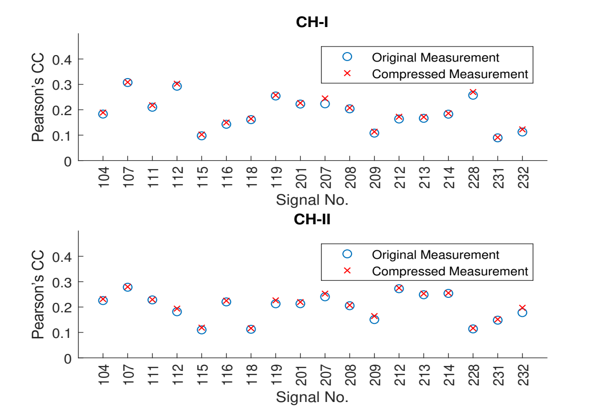


Figure: Structural similarity analysis at compression ratio = 75%

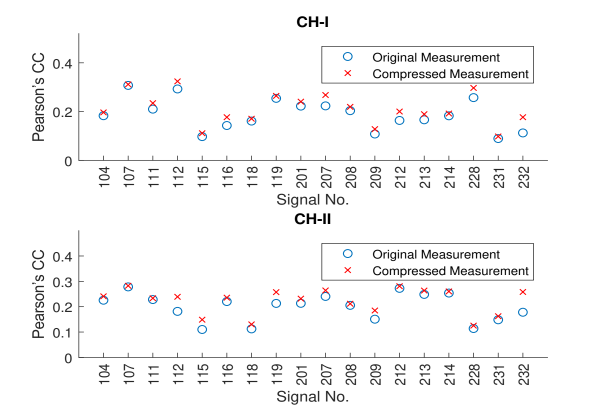
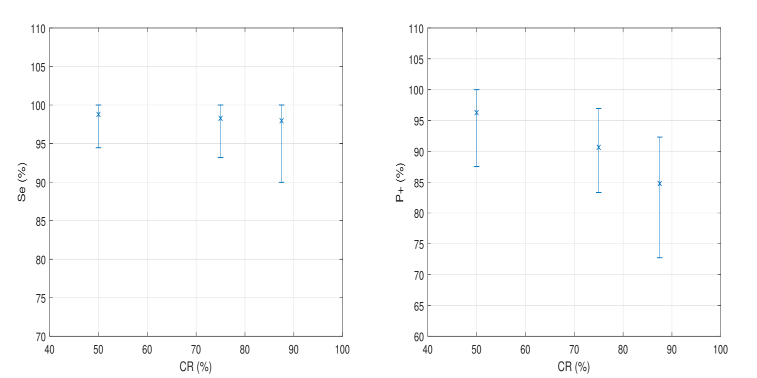


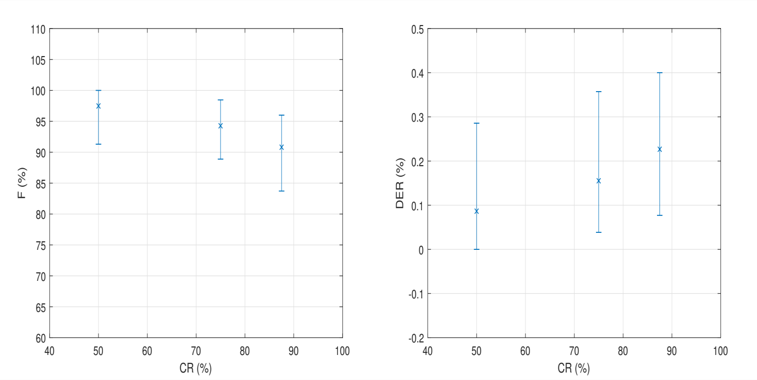
Figure: Structural similarity analysis at compression ratio = 87.5%

Results



(a) (b)

Figure: Performance of R-peak detection on the compressed measurements for compression ratio = 50%, 75% and 87.5%. (a) Sensitivity analysis, (b) Positive predictivity analysis



(a) (b)

Figure: Performance of R-peak detection on the compressed measurements for compression ratio = 50%, 75% and 87.5%. (a) F-measure and (b) DER analysis.

conclusions & future works

Conclusions

- Deterministic compressive sensing approach is presented for multi-channel ECG signal acquisition $\longleftarrow$ Easy to implement in hardware.
- Feature preserving DBBD sensing matrix is used $\longleftarrow$ Eliminating the need for computationally expensive recovery.
- Structural similarity and R-peak detection is performed $\longleftarrow$ To quantify compressed domain feature preservation.

Future Works

- Study of effectiveness of the proposed compressive sensing-based approach in presence of measurement artifacts.
- Study of measurement uncertainty associated with the approach.
- As an extension separation of fetus ECG from the mother's ECG in the compressed domain would be investigated.