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Contactless Monitoring of Human Vital Signs Via FMCW Radar Demo

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Motivation and Contributions

- The increase in cardiopulmonary morbidity, disease transmission and burden on medical staff has led to extensive investigation of non-contact monitoring approaches
- Remote technology such as radar do not require users to wear, carry, or interact with any additional electronic device
- We present an extended model for non-contact vital signs monitoring of multiple people (MP-NCVSM) via FMCW radar, in a realistic noisy scenario containing multiple objects
- Based on this model, we develop a complete methodology for human localization and estimation of their respiration rate (RR) and heart rate (HR), using only a single channel and a SISO setup
- We propose a dedicated phantom that simulates human thoracic motion through which realistic experiments can be performed, reducing the need for human trials.

Extended FMCW Model

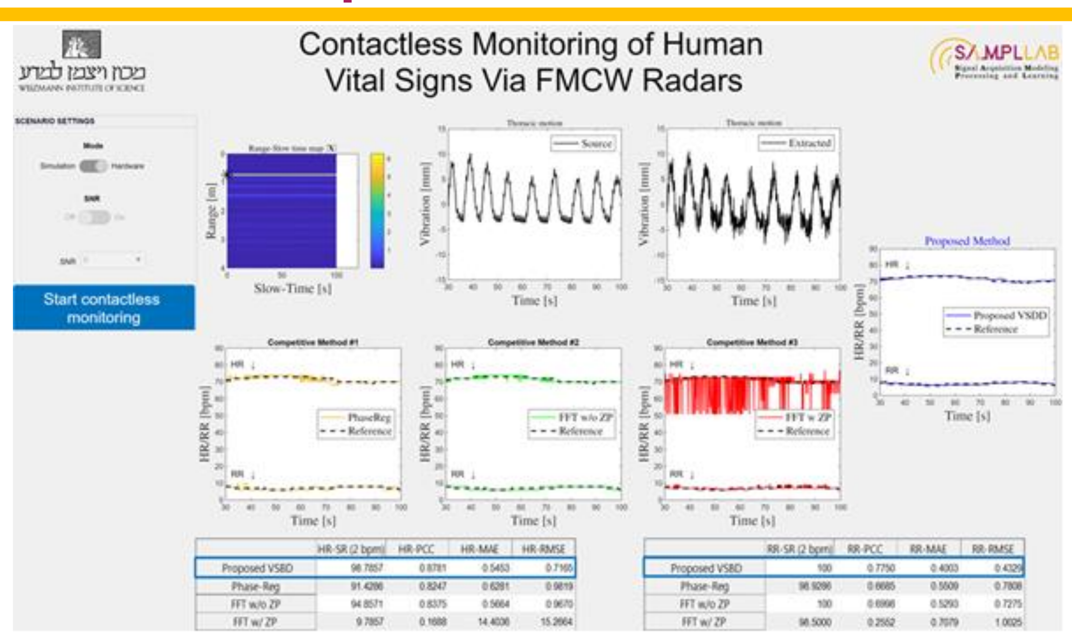
- Assume M different objects in the radar's FOV. The extended FMCW signal model for this case is given by

$$y[n,l]=\sum_{m=1}^{M} x_m \exp\left(j\left(2\pi f_m nT_f+\psi_m[l]\right)\right)+w[n,l],$$

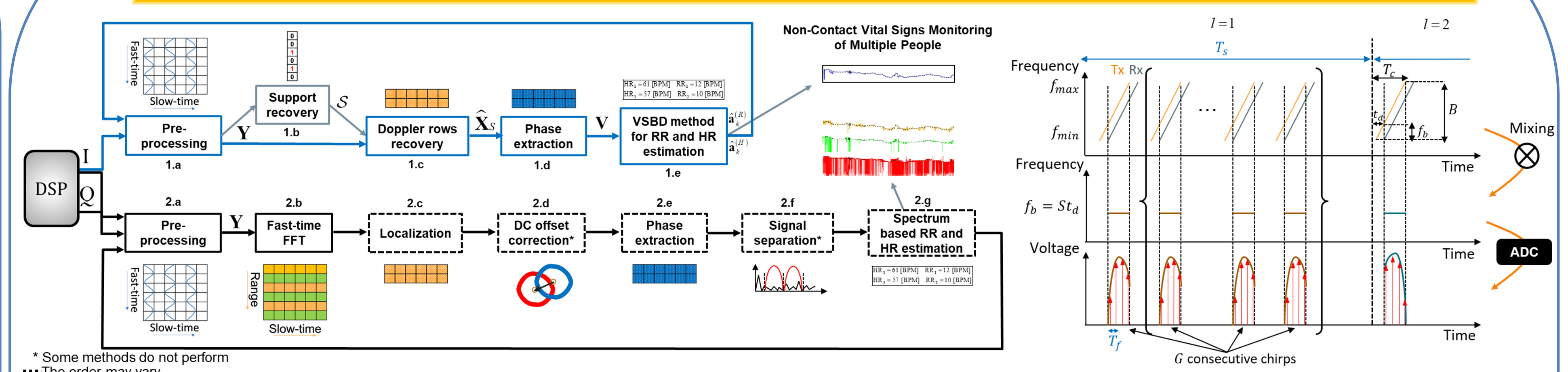
$$f_m \triangleq \frac{2S}{c}d_m \quad \psi_m[l]\triangleq\frac{4\pi}{\lambda_{\max}}\left(d_m+v_m[l]\right), \quad v_m[l]\triangleq\sum_{q=1}^{Q}a_{m,q}\cos\left(2\pi g_{m,q}lT_s\right),$$

- $\{v_m[l]\}$ models the vibration of each object.
- The set $\{g_{m,q}\}$ includes the RR and HR of each human, denoted by $f_r^{(k)}$ and $f_h^{(k)}$, $\forall k=1,\dots,K$ humans in the FOV.
- Reshaping $\{y[n,l]\}$ => $\mathbf{y}_l=\mathbf{A}\tilde{\mathbf{x}}_l+\mathbf{w}_l, \quad l=1,\dots,L$
- Matrix form for each monitoring window => $\mathbf{Y}=\mathbf{A}\tilde{\mathbf{X}}+\mathbf{W}$

Graphical User Interface



Sparsity Based MP-NCVSM



* Some methods do not perform
··· The order may vary

- Joint sparse recovery for human localization

Ideal window corresponding to normal breathing frequencies — *L-size DFT matrix*

$$\bar{\mathbf{Y}}=\frac{1}{L}\left(\mathbf{F}_L^H\left(\mathbf{\Pi}\odot\mathbf{F}_L\mathbf{Y}^T\right)\right)^T$$

$$\min_{\tilde{\mathbf{X}}\in\mathbb{C}^{M\times L}}\left\|\bar{\mathbf{Y}}-\mathbf{A}\tilde{\mathbf{X}}\right\|_F^2+\lambda\left\|\tilde{\mathbf{X}}\right\|_{2,1} \Rightarrow \mathcal{S} \qquad d_m, \quad \forall m\in\mathcal{S}$$

- Doppler rows recovery

$$\hat{\mathbf{X}}_S=\frac{1}{N}\mathbf{F}_S\mathbf{Y}$$

- Phase extraction

$$\mathbf{V}(l,k)\triangleq unwrap\left(\angle\left(\mathbf{X}_S\left(\mathcal{S}\{k\},l\right)\right)\right)^T, \begin{cases}k=1,\dots,K\\ l=1,\dots,L\end{cases},$$

- Vital-Signs based Dictionary (VSBD) method for MP-NCVSM
  - Assuming that

$$\mathbf{V}=\left[\mathbf{v}_1 \ \cdots \ \mathbf{v}_K\right], \quad \mathbf{v}_k=\mathbf{D}\mathbf{a}_k+\mathbf{n}_k$$

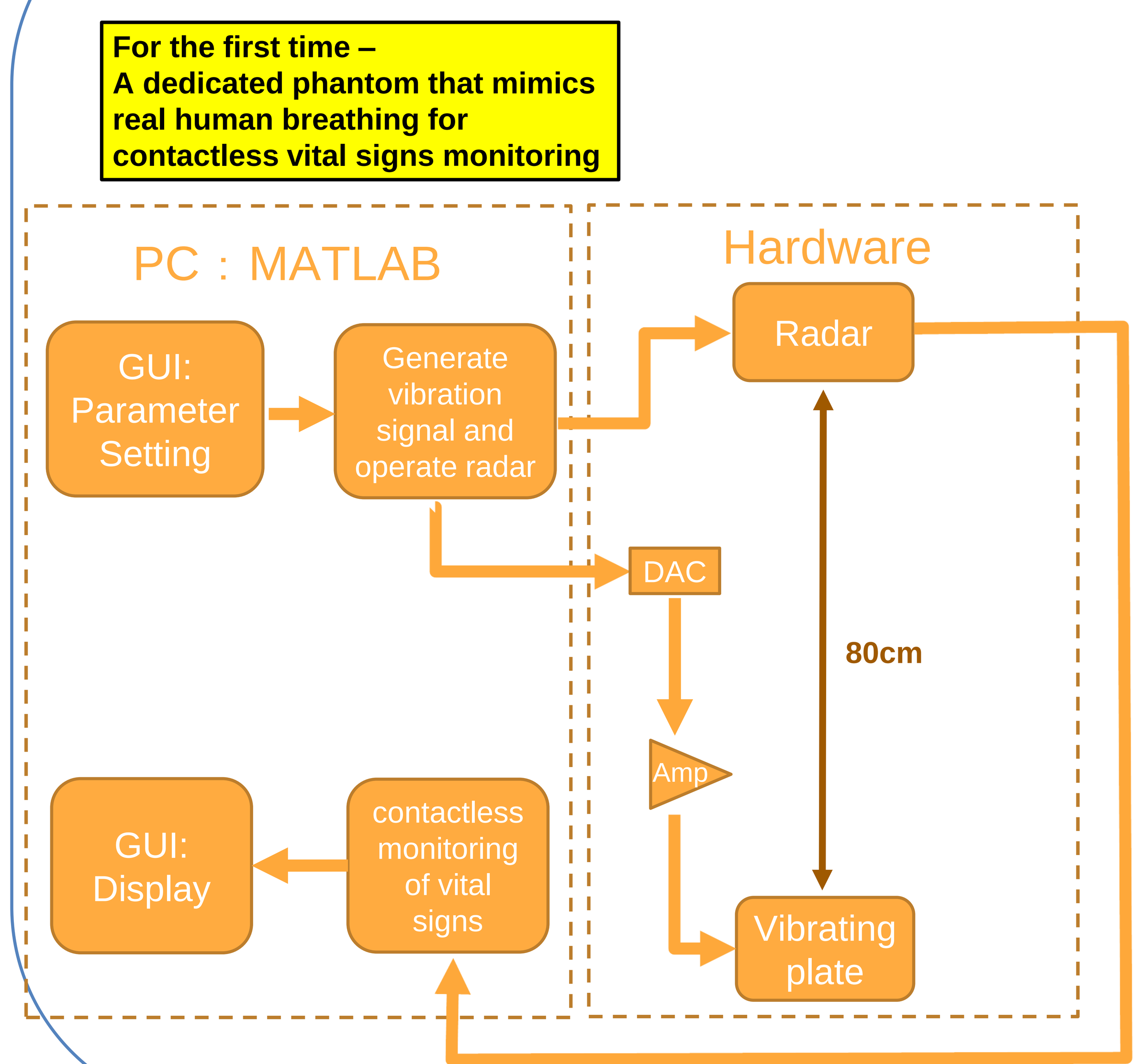
$$\mathbf{D}=\left[\mathbf{D}^{(R)},\mathbf{D}^{(H)}\right]$$

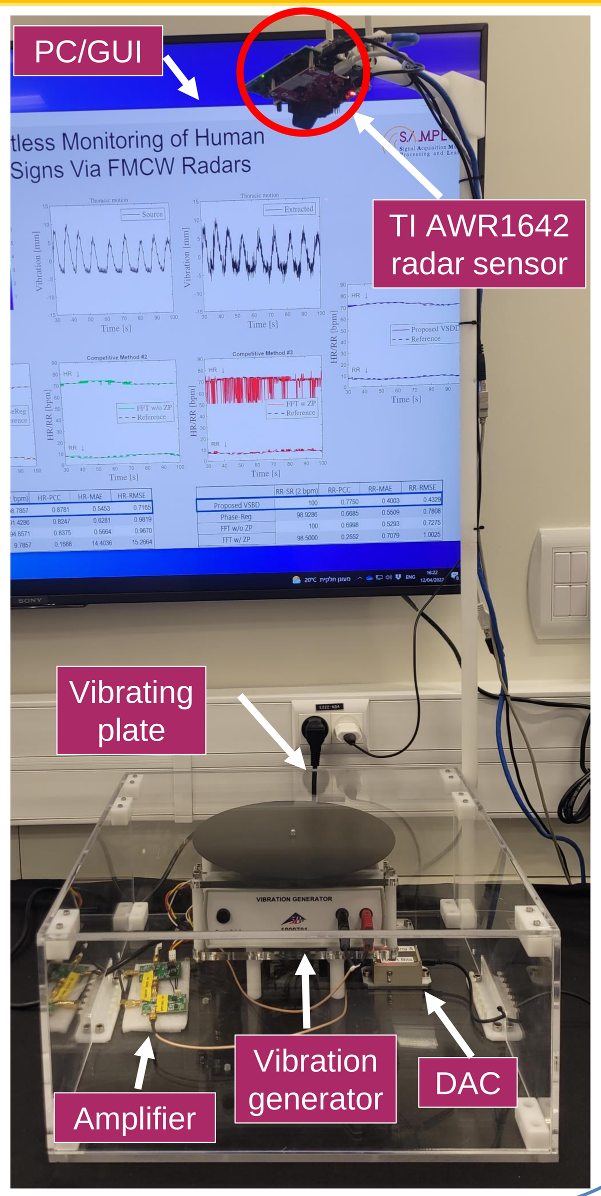
  - Then, the RR and HR estimates of each human are given by

$$\mathbf{v}_k=\mathbf{D}^{(R)}\mathbf{a}_k^{(R)}+\mathbf{D}^{(H)}\mathbf{a}_k^{(H)}+\mathbf{n}_k$$

$$\begin{cases}\hat{\mathbf{a}}_k^{(R)}=\mathbf{D}^{(R)\dagger}\mathbf{v}_k\\ \hat{\mathbf{a}}_k^{(H)}=\mathbf{D}^{(H)\dagger}\mathbf{v}_k\end{cases} \Rightarrow \boxed{\left\{\hat{f}_r^{(k)},\hat{f}_h^{(k)}\right\}_{k=1}^{K}}$$

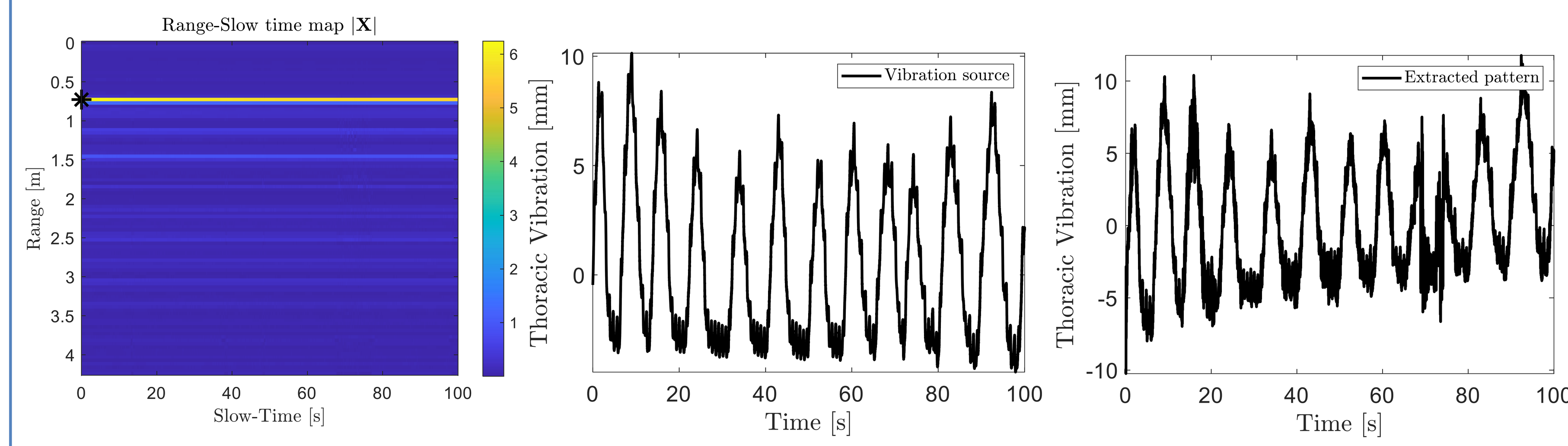
Hardware

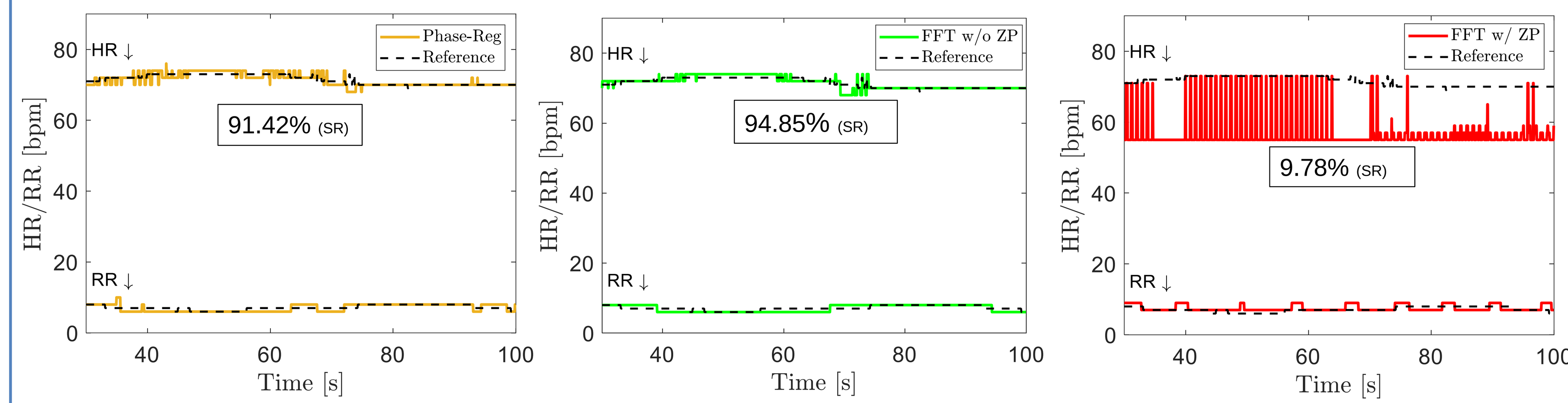




Results

- We perform 2 NCVSM experiments of a human located at 0.72 [m] from the radar, comparing our proposed method to other state-of-the-art techniques.
- The first experiment is based on a software simulation in which the SNR is controlled.
- The second experiment is based on a dedicated phantom that mimics the vibration source of the software simulation.
- In the following, one can observe the hardware based localization of the vibration source and its extraction, through which accurate monitoring of RR and HR is obtained, compared with other contemporary techniques.

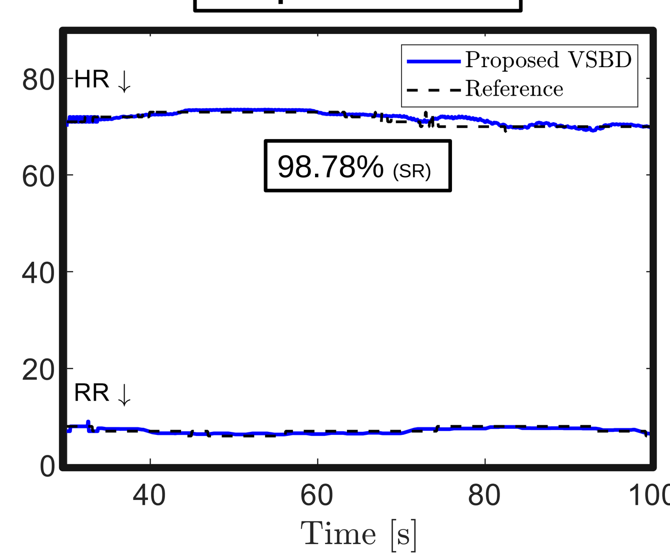




	HR-SR (2 bpm)	HR-PCC	HR-MAE	HR-RMSE
Proposed VSBD	98.7857	0.8781	0.5453	0.7165
Phase-Reg	91.4286	0.8247	0.6281	0.9819
FFT w/o ZP	94.8571	0.8375	0.5664	0.9670
FFT w/ ZP	9.7857	0.1688	14.4036	15.2664

	RR-SR (2 bpm)	RR-PCC	RR-MAE	RR-RMSE
Proposed VSBD	100	0.7750	0.4003	0.4329
Phase-Reg	98.9286	0.6685	0.5509	0.7808
FFT w/o ZP	100	0.6998	0.5293	0.7275
FFT w/ ZP	98.5000	0.2552	0.7079	1.0025

Proposed method



Superior HR and RR estimation results in 4 different metrics!