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Multi-Person Localization and Non-Contact Vital Signs Monitoring Via FMCW Radar

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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 does not require users to wear, carry, or interact with any additional electronic device
- We present a hardware phantom and method for multi-person non-contact vital signs monitoring (MP-NCVSM) in a noisy environment, via single-channel FMCW radar
- Our algorithmic approach is based on joint-sparse recovery (JSR) which accurately localizes humans in a cluttered scenario involving equidistant targets, where known techniques struggle
- Vital Signs-based Dictionary Recovery (VSDR) method is then used to estimate their vitals (Respiration Rate (RR) and Heart Rate (HR)) yielding superior results compared to current NCVSM approaches

Extended SIMO FMCW Model

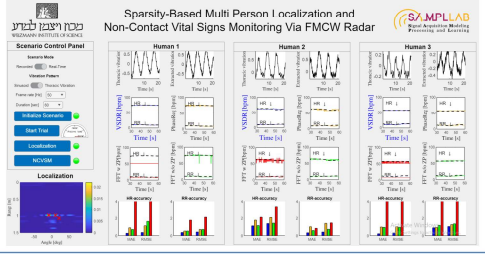
- We suggest the following signal model based on SIMO FMCW radar:

$$y[n,l,k]=\sum_{p=1}^{P}\sum_{m=1}^{M}x_{m,p}e^{j\left(2\pi f_m nT_f+\psi_{m,p}[l]+\phi_p[k]\right)}+w[n,l,k]$$

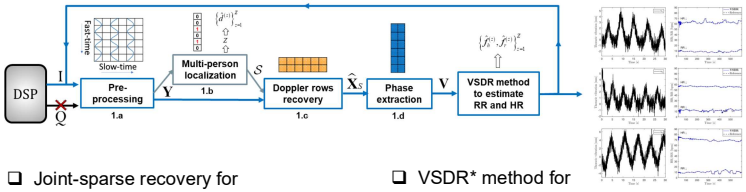
- $f_m \triangleq \frac{2S}{c}d_m$
- $v_{m,p}[l] \triangleq \sum_{q=1}^{Q} a_{m,p,q}\cos\left(2\pi g_{m,p,q} l T_s\right)$
- $\psi_{m,p}[l] \triangleq \frac{4\pi}{\lambda_{\max}}\left(d_m+v_{m,p}[l]\right)$
- $\phi_p[k] \triangleq \frac{2\pi}{\lambda} r_k \sin\theta_p$

- $\{v_{m,p}[l]\}$ models the possible vibration of each object.
- The set $\{g_{m,p,q}\}$ includes the RR and HR of each human, denoted by $\{f_h^{(z)}, f_r^{(z)}\}_{z=1}^{Z}$ for $Z \ll MP$ humans in the FOV.
- Reshaping each L frames => $\boxed{\mathbf{Y}=\mathbf{C}\tilde{\mathbf{X}}+\mathbf{W}}$

Graphical User Interface



Sparsity-Based Multi-Person Localization and NCVSM



- Joint-sparse recovery for multi-person localization

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

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

$$\min_{\tilde{\mathbf{X}}\in\mathbb{C}^{PM\times L}}\left\|\bar{\mathbf{Y}}-\mathbf{C}\tilde{\mathbf{X}}\right\|_F^2+\lambda\left\|\tilde{\mathbf{X}}\right\|_{2,1}$$

- Doppler rows recovery

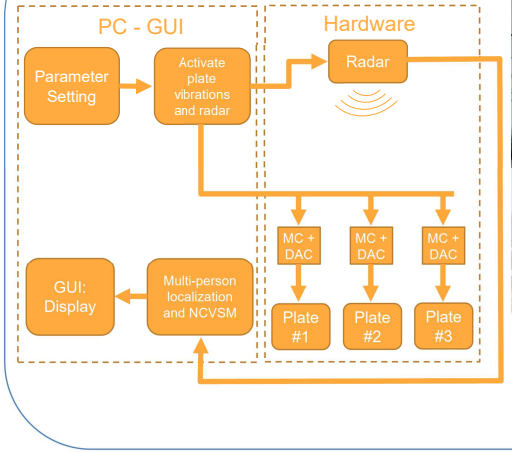
$$\mathbf{X}_S=\left(\mathbf{C}_S^H\mathbf{C}_S\right)^{-1}\mathbf{C}_S^H\mathbf{Y}$$

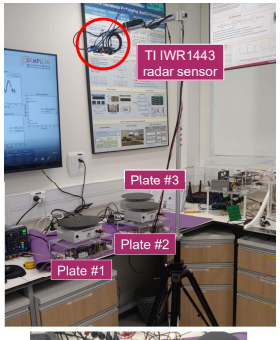
- Phase extraction

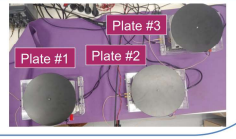
$$\mathbf{V}(l,z)\triangleq unwrap\left(\angle\left(\mathbf{X}_S(z,l)\right)\right)^T, \begin{cases} z=1,\ldots,Z \\ l=1,\ldots,L \end{cases}$$

- VSDR* method for estimating HR and RR given $\mathbf{V}=[\mathbf{v}_1,\ldots,\mathbf{v}_Z]$:
  - Assuming that $\mathbf{v}_z=\mathbf{D}^{(R)}\mathbf{a}_z^{(R)}+\mathbf{D}^{(H)}\mathbf{a}_z^{(H)}+\mathbf{n}_z$ with known $\mathbf{D}^{(R)}$ and $\mathbf{D}^{(H)}$
  - $\begin{cases}\hat{\mathbf{a}}_z^{(R)}=\mathbf{D}^{(R)T}\mathbf{v}_z \\ \hat{\mathbf{a}}_z^{(H)}=\mathbf{D}^{(H)T}\mathbf{v}_z\end{cases} \Rightarrow \boxed{\left\{\hat{f}_r^{(z)},\hat{f}_h^{(z)}\right\}_{z=1}^{Z}}$

Hardware



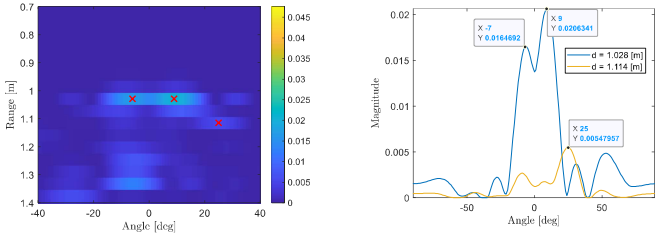




* Y. Eder, and Y.C. Eldar, "Sparsity-Based Multi-Person Non-Contact Vital Signs Monitoring Via FMCW Radar", to appear in IEEE Journal of Biomedical and Health Informatics, June 2023.

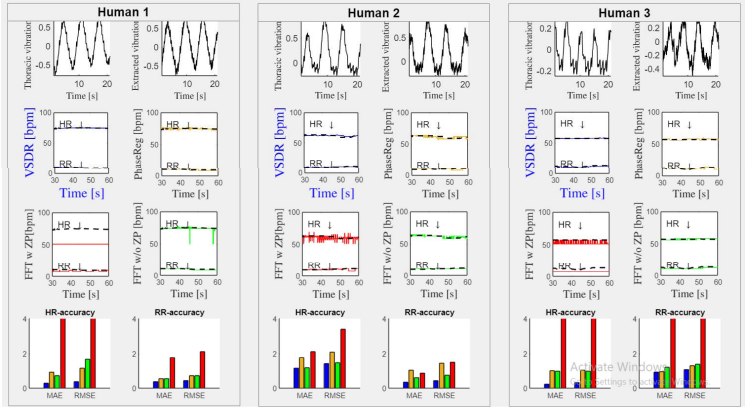
Localization and NCVSM Results

- Example of localization and NCVSM of 3 people simultaneously:
  - Two equidistant targets located approximately at 1 [m] from the radar and +-10 [deg]
  - Third target located approximately at 1.1 [m] from the radar and +25 [deg]
- The operator can choose between a trial of sinusoids or human thoracic vibrations as well as determining the frame rate and duration of trial
- Multi-person localization by the proposed JSR



JSR indicates the correct locations of the humans!

- Multi-person NCVSM by VSDR and other techniques



VSDR yields the best overall performance