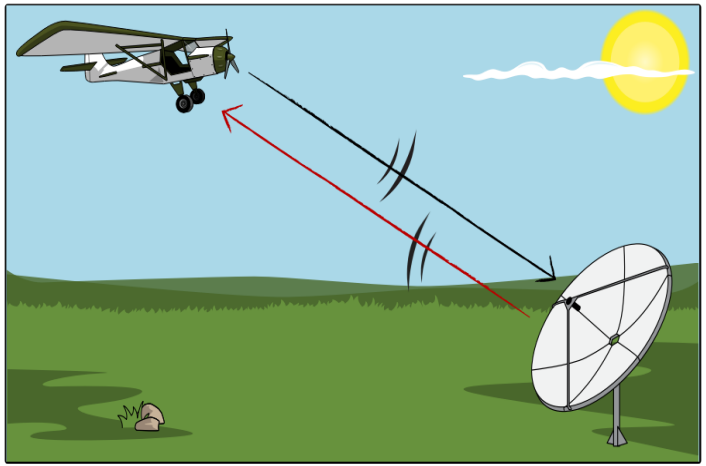
WEIZMANN INSTITUTE OF SCIENCE

Radar in The Service of Medicine

SAMPLLAB
Signal Acquisition Modeling Processing and Learning



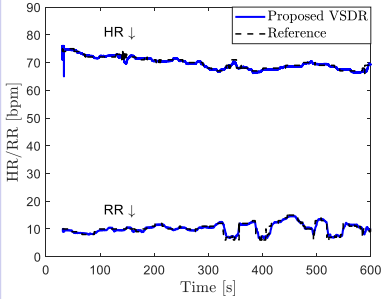
Radar in The Service of Medicine

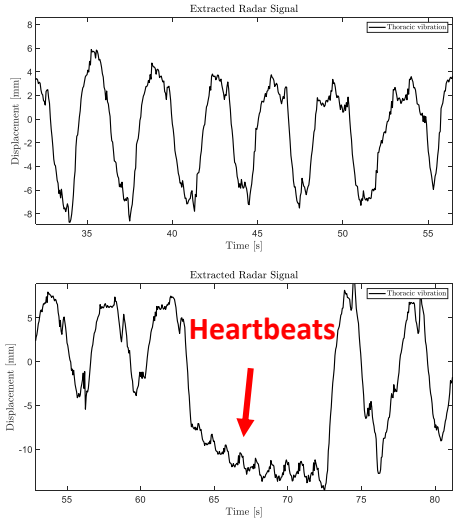
Outline:

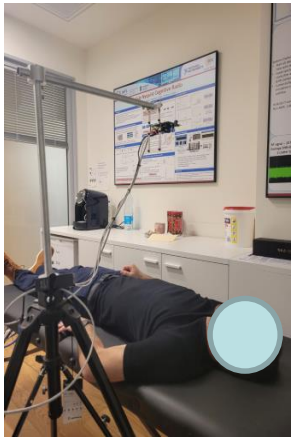
- Non-Contact Vital Signs Monitoring
- Hardware Demonstration
- Stroke Detection
- Targeted Drug Delivery

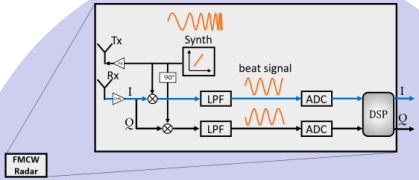
Non-Contact Vital Signs Monitoring Via FMCW Radar

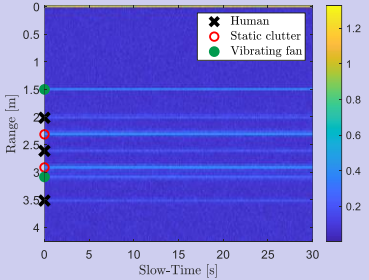
Sparsity Based Non-Contact Vital Signs Monitoring of Multiple People Via FMCW Radar

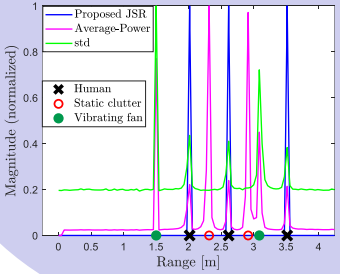












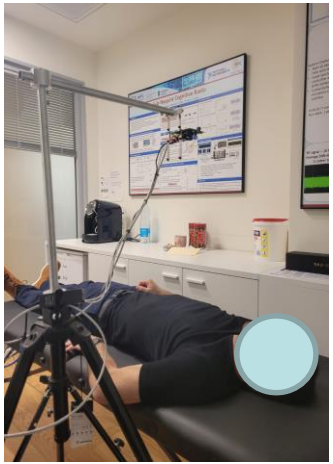
FMCW – Frequency Modulated Continuous Wave

Non-Contact Vital Signs Monitoring Via FMCW Radar

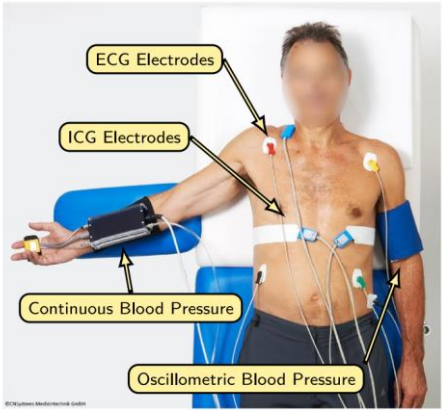
Problems with **contact** patient monitoring in healthcare

- Increases the risk of infections and **transmission of diseases** (e.g., COVID19)
- The connection **consumes valuable** time from medical staff
- May produce **discomfort** or irritations and can be easily detached
- **Privacy** concerns
- Patient unwillingness to **cooperate**
- Results are affected by the **manner of contact**

Non-Contact



Contact

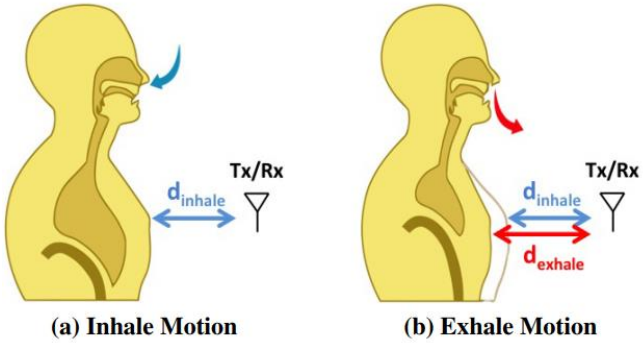


Schellenberger et al., Sci Data, 2020

Non-Contact Vital Signs Monitoring Via FMCW Radar

Incorporating radar in healthcare - challenges

- The radar should localize people in a **cluttered environment**
- Human cardiopulmonary activity should be **accurately** identified
- **Multiple-people monitoring** to alleviate loads
- Must operate at **low power** to meet safety requirements



(a) Inhale Motion (b) Exhale Motion

F. Adib, H. Mao, Z. Kabelac, D. Katabi, and R.C. Miller, "Smart homes that monitor breathing and heart rate," *In Proceedings of the 33rd annual ACM conference on human factors in computing systems*, pp. 837–846, 2015.

Non-Contact Vital Signs Monitoring Via FMCW Radar

Mathematical Modelling

Standard SISO FMCW model

$$y[n,l] \triangleq \tilde{x}_b \exp\left(j\left(2\pi f_b n T_f + \psi_b[l]\right)\right), \quad \begin{cases} n = 1,\ldots,N \\ l = 1,\ldots,L \end{cases}.$$

$$f_b \triangleq \frac{2S}{c} d \qquad \psi_b[l] \triangleq \frac{4\pi}{\lambda_{\max}}\left(d + v[l]\right),$$

Simplistic model for single person

Proposed SISO FMCW model

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

$$f_m \triangleq \frac{2S}{c} d_m \qquad \psi_m[l] \triangleq \frac{4\pi}{\lambda_{\max}}\left(d_m + v_m[l]\right),$$

$$v_m[l] \triangleq \sum_{q=1}^{Q} a_{m,q} \cos\left(2\pi g_{m,q} l T_s\right),$$

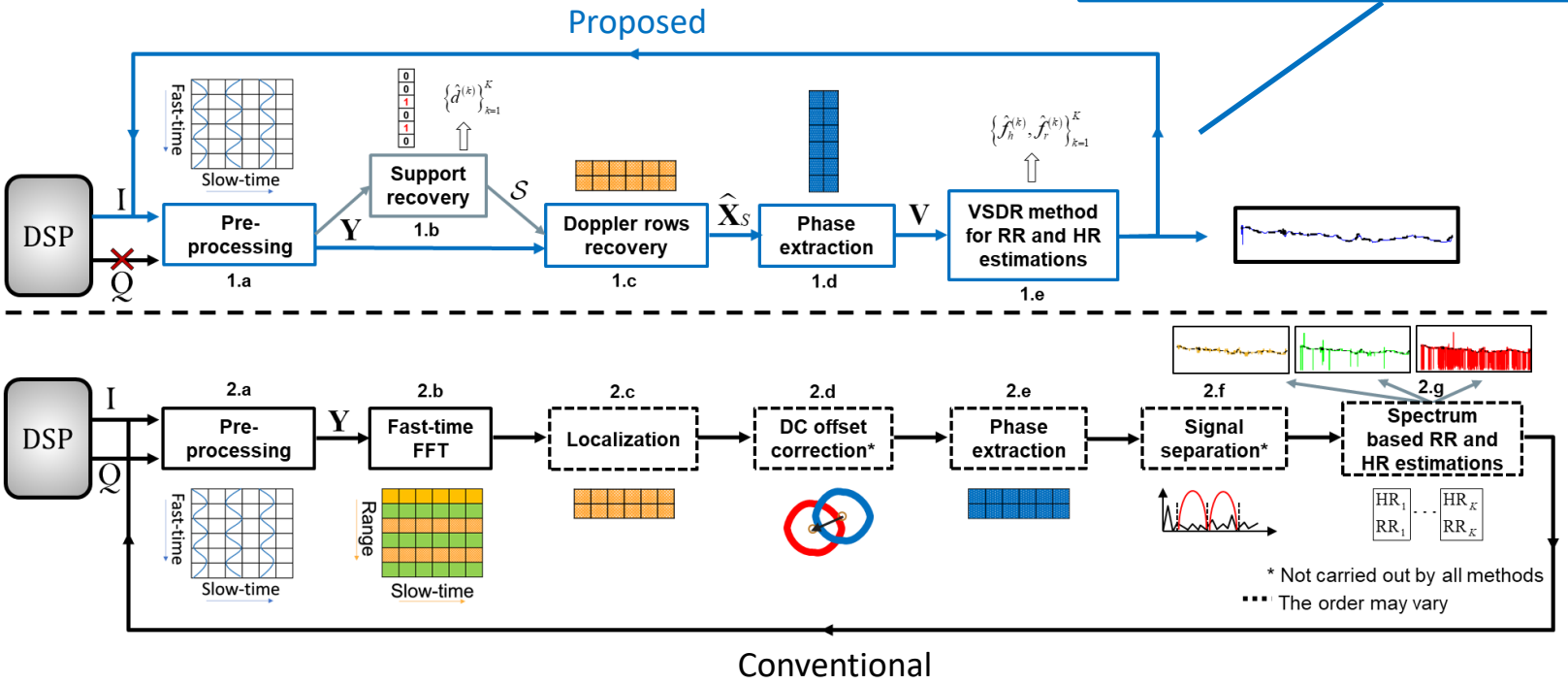
Extended model for multiple people!

Non-Contact Vital Signs Monitoring Via FMCW Radar

Sparsity-Based Localization and NCVSM of Multiple People

- Based only on a **single** channel
- Utilizing the **sparsity** of the modeled signals

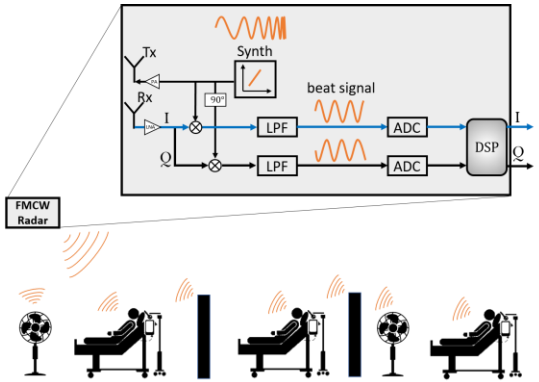
Accurate monitoring of multiple people without requiring many processing steps

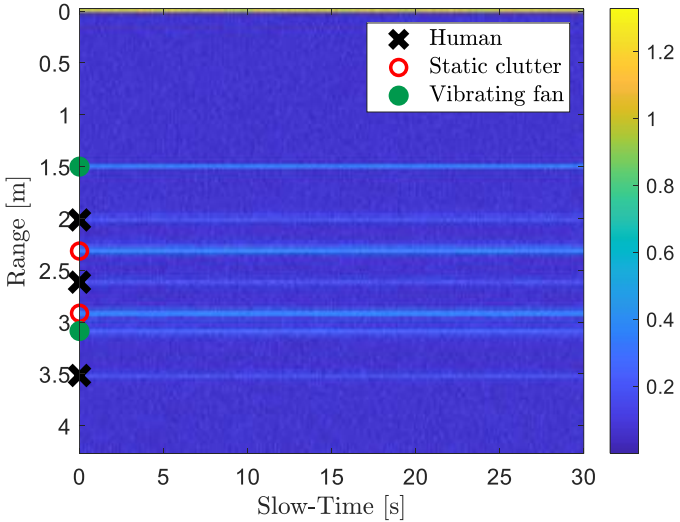


Non-Contact Vital Signs Monitoring Via FMCW Radar

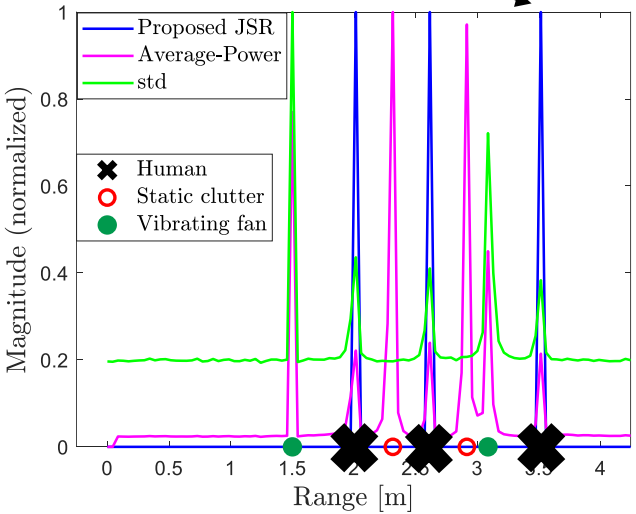
Multiple People Localization in A Cluttered Scenario

- Multiple objects in different radial distances
- Proposed localization based on Joint-Sparse Recovery



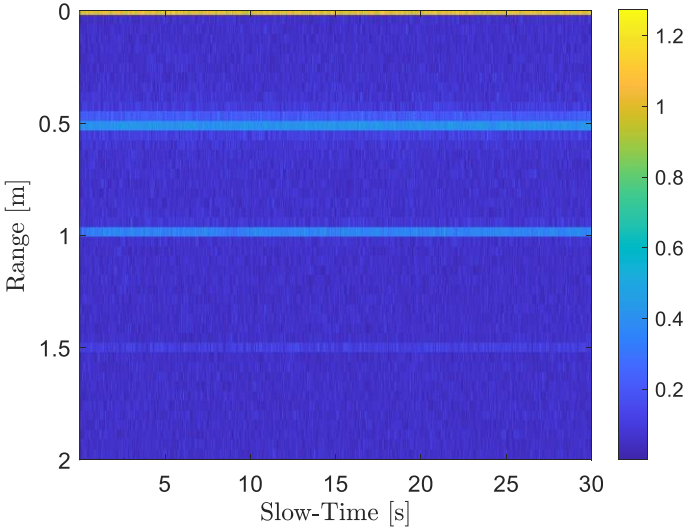


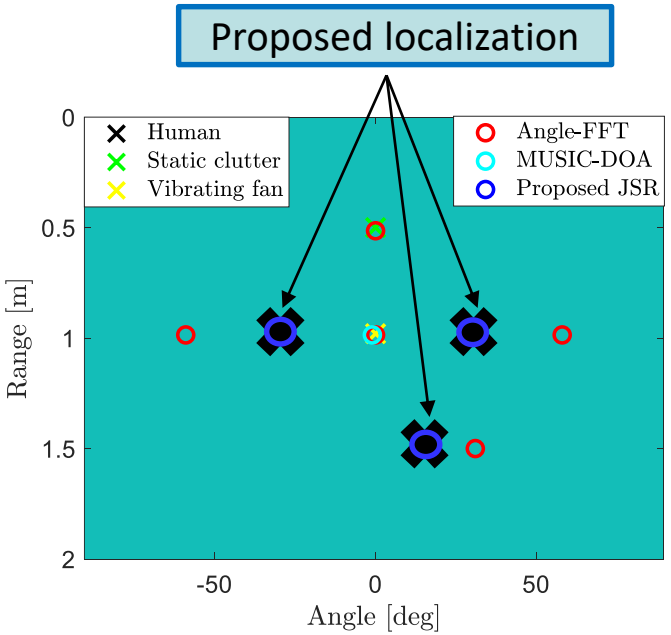
Only the proposed method correctly locates the people



Multiple people localization in a cluttered scenario

- Multiple objects in the same radial distances but different angles
- Proposed localization based on Joint-Sparse Recovery

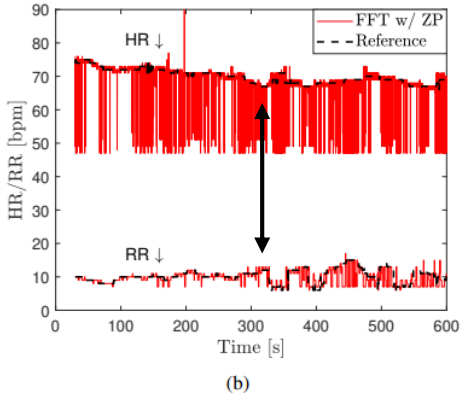




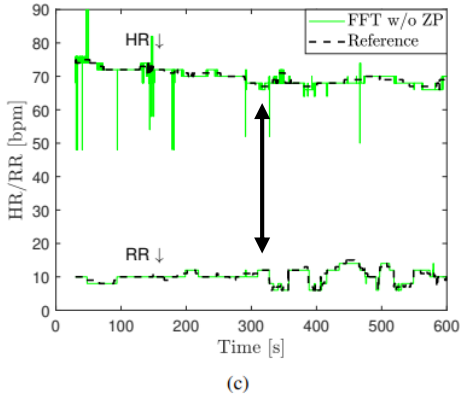
Non-Contact Vital Signs Monitoring Via FMCW Radar

10-minute NCVSM of a single subject (based on *)

FFT w/ ZP



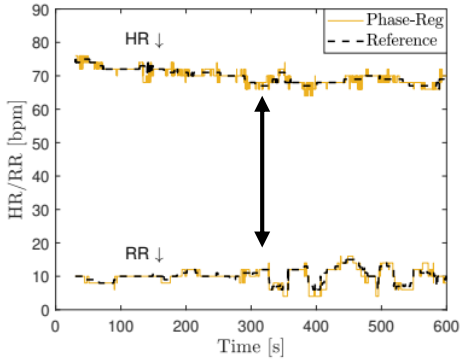
(b)

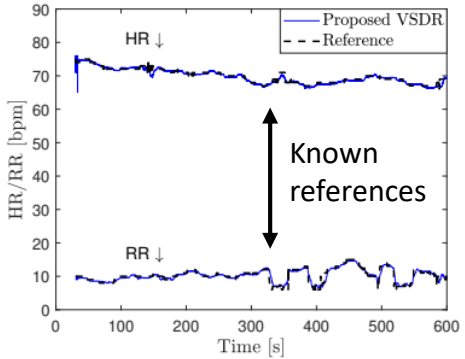


(c)

FFT w/o ZP

Phase-Reg





Proposed VSDR

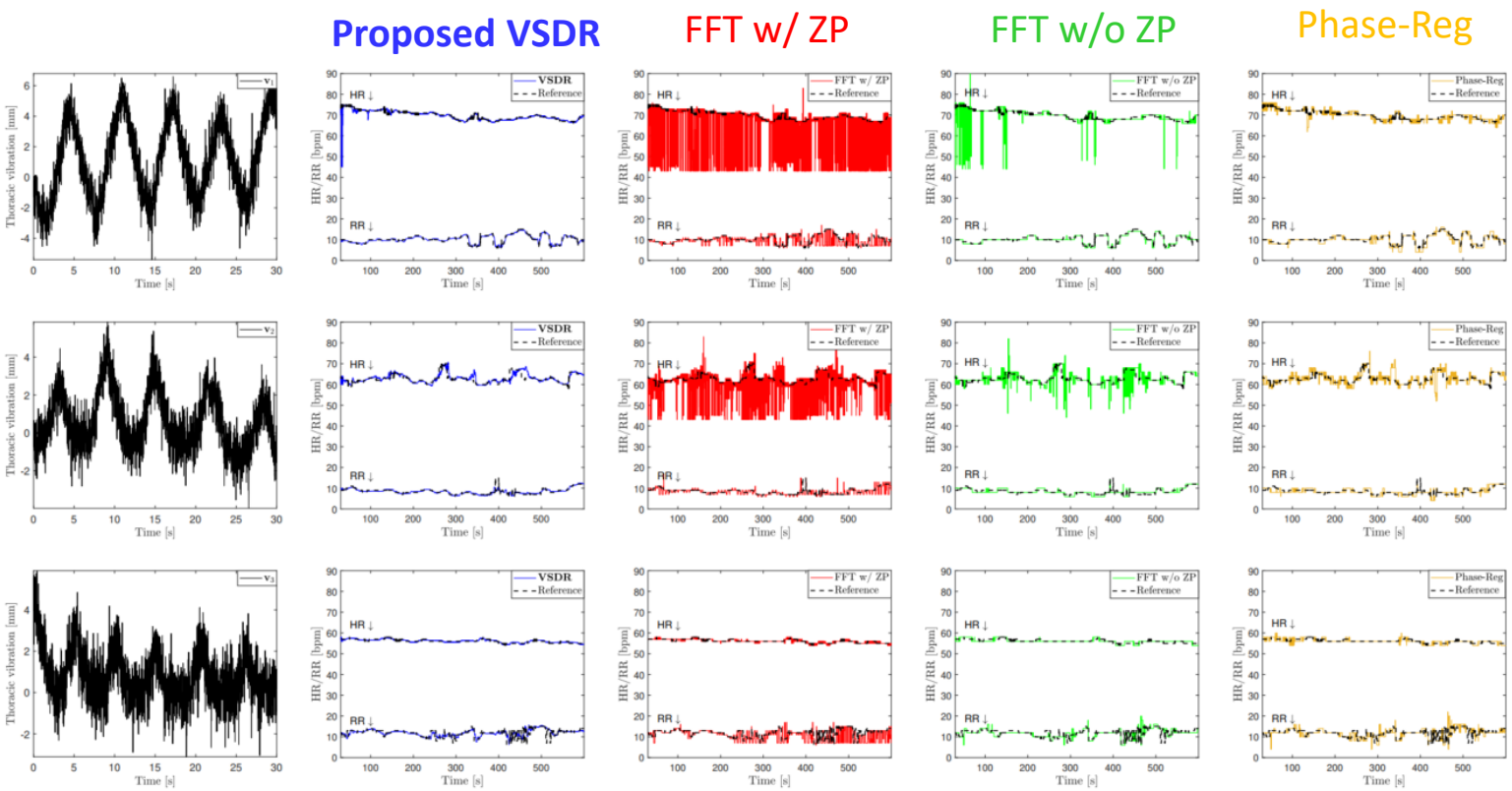
closest to the reference!

NCVSM - Non-Contact Vital Signs Monitoring

* Y. Eder, and Y. C. Eldar, "Sparsity Based Non-Contact Vital Signs Monitoring of Multiple People Via FMCW Radar," *arXiv preprint arXiv:2205.05152*, 2022.

Non-Contact Vital Signs Monitoring Via FMCW Radar

10-minute NCVSM of 3 subjects **simultaneously** (based on *)



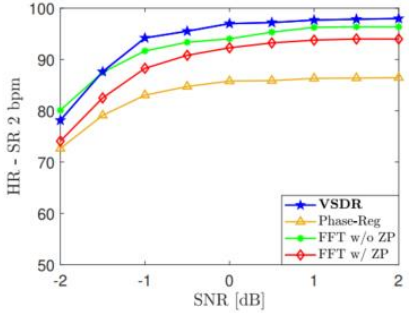
* Y. Eder, and Y. C. Eldar, "Sparsity Based Non-Contact Vital Signs Monitoring of Multiple People Via FMCW Radar," *arXiv preprint arXiv:2205.05152*, 2022.

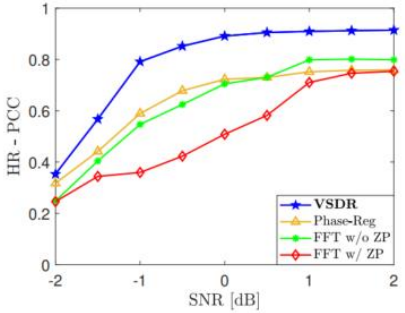
Non-Contact Vital Signs Monitoring Via FMCW Radar

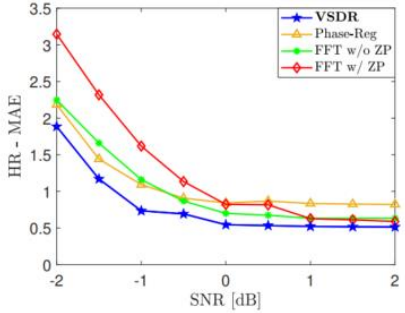
Median accuracy results of 30 monitored individuals

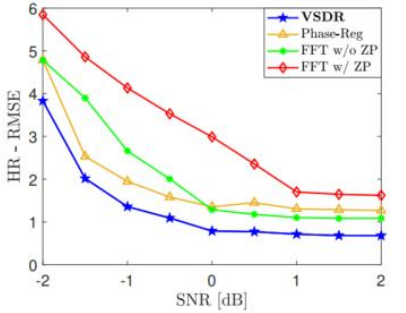
1. SR (2 bpm)
2. PCC
3. MAE
4. RMSE

HR

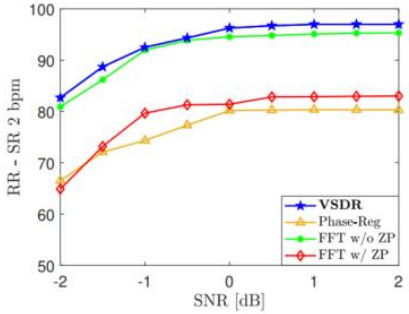


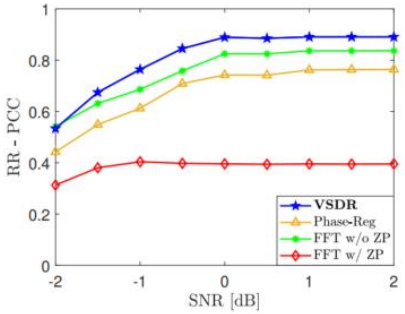


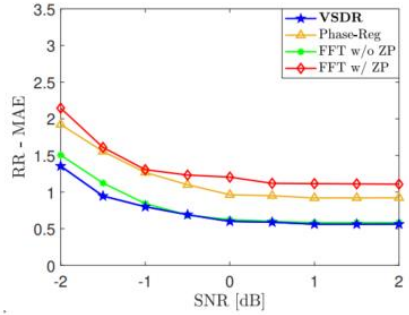


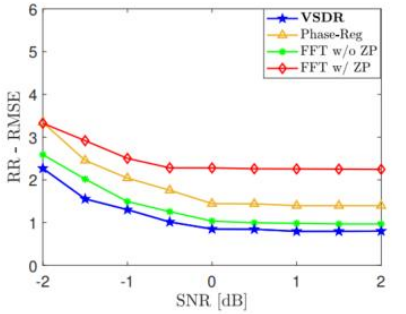


RR





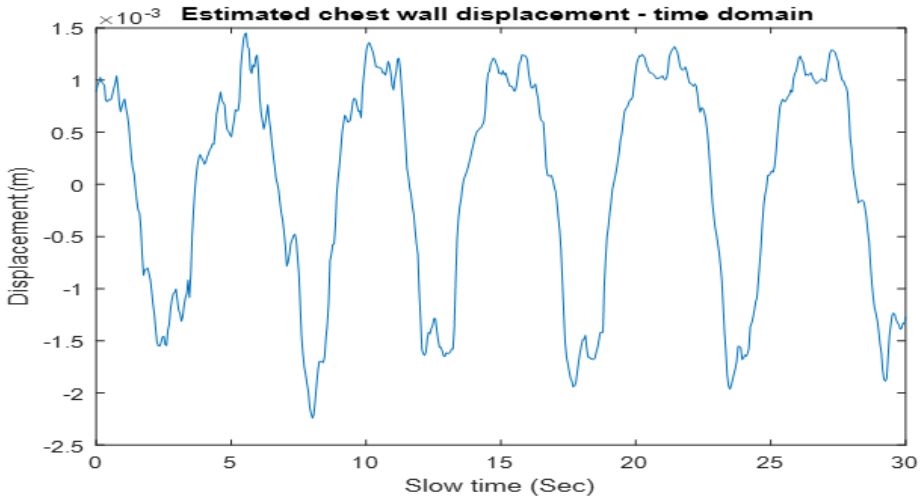




Best performance by 4 different metrics!

Non-Contact Vital Signs Monitoring Via FMCW Radar

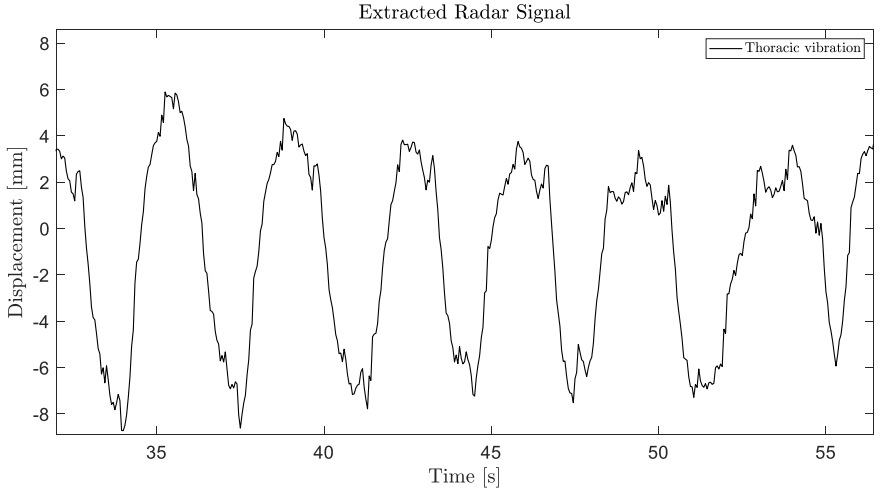
The extracted signal is rich in cardiopulmonary information



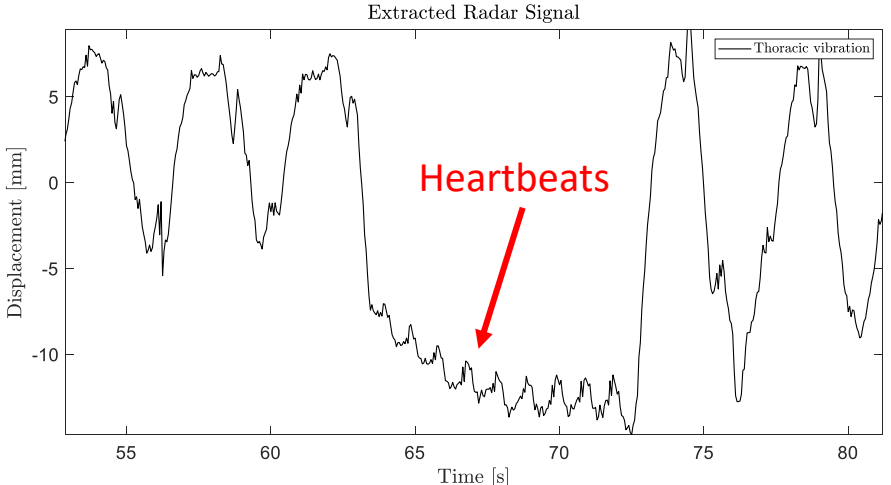
- Respiration rate
- Respiration depth
- Respiratory flow
- Inhale-exhale ratio
- Respiratory arrest
- Sleep monitoring
- Heart rate
- Blood Pressure
- Stress levels
- Inter-beat interval
- Atrial fibrillation
- Orientation

Non-Contact Vital Signs Monitoring Via FMCW Radar

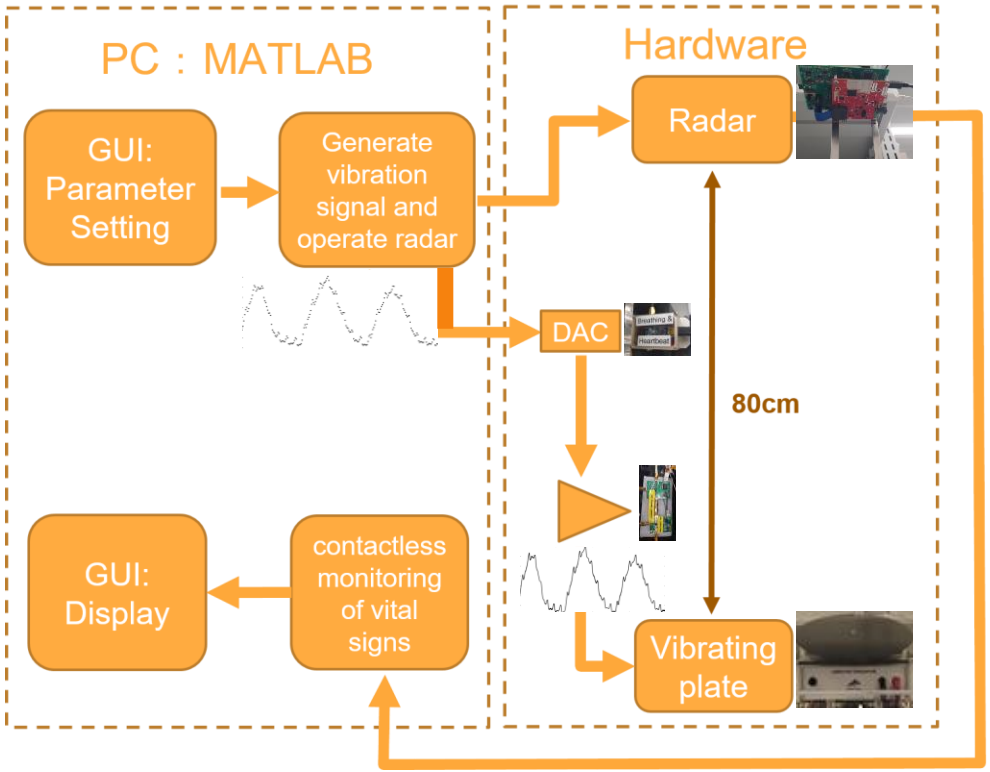
Normal breathing:

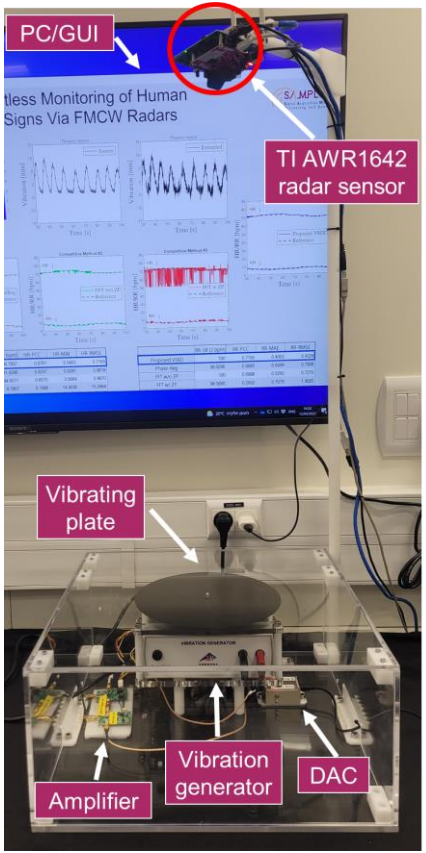


Apnea:



Hardware Demonstration

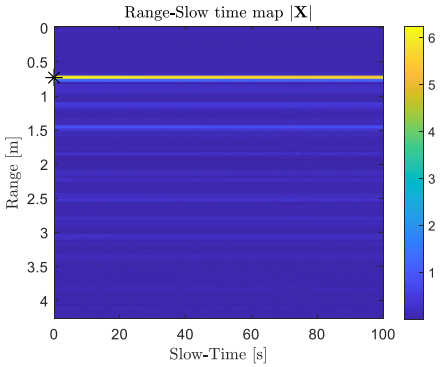




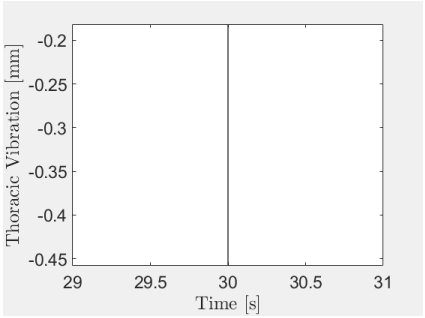
Hardware Demonstration

Hardware Demonstration

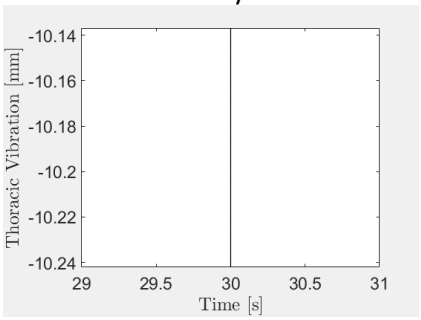
Real-time monitoring example using dedicated phantom

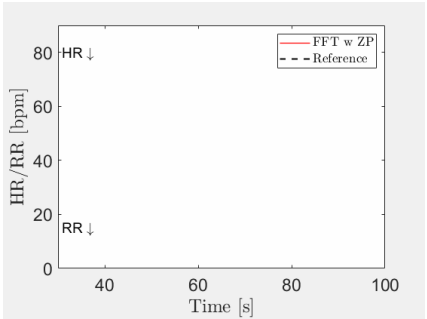


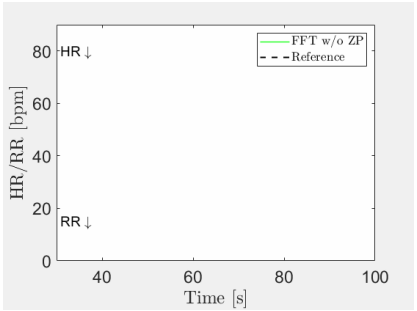
Vibration source

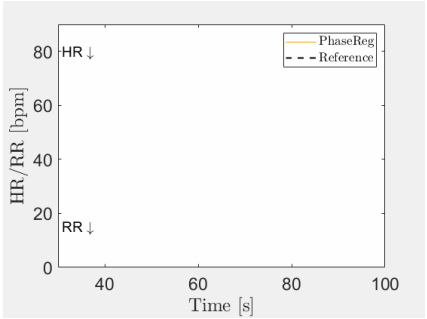


Extracted by radar

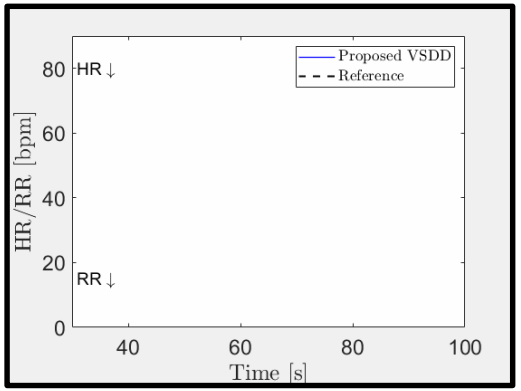








Proposed method

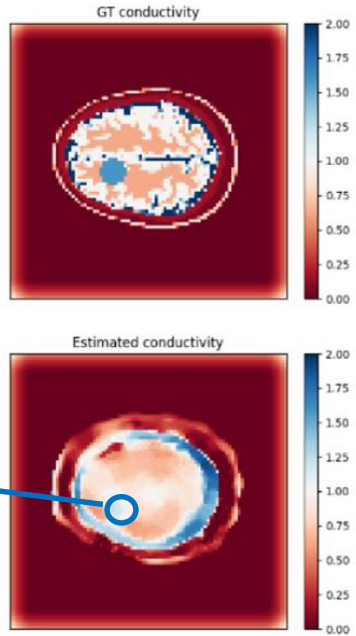


Experimental Demonstration

Radar for Stroke Detection

- Unique penetration properties of radar
- Based on dielectric properties of tissues and the wave equation

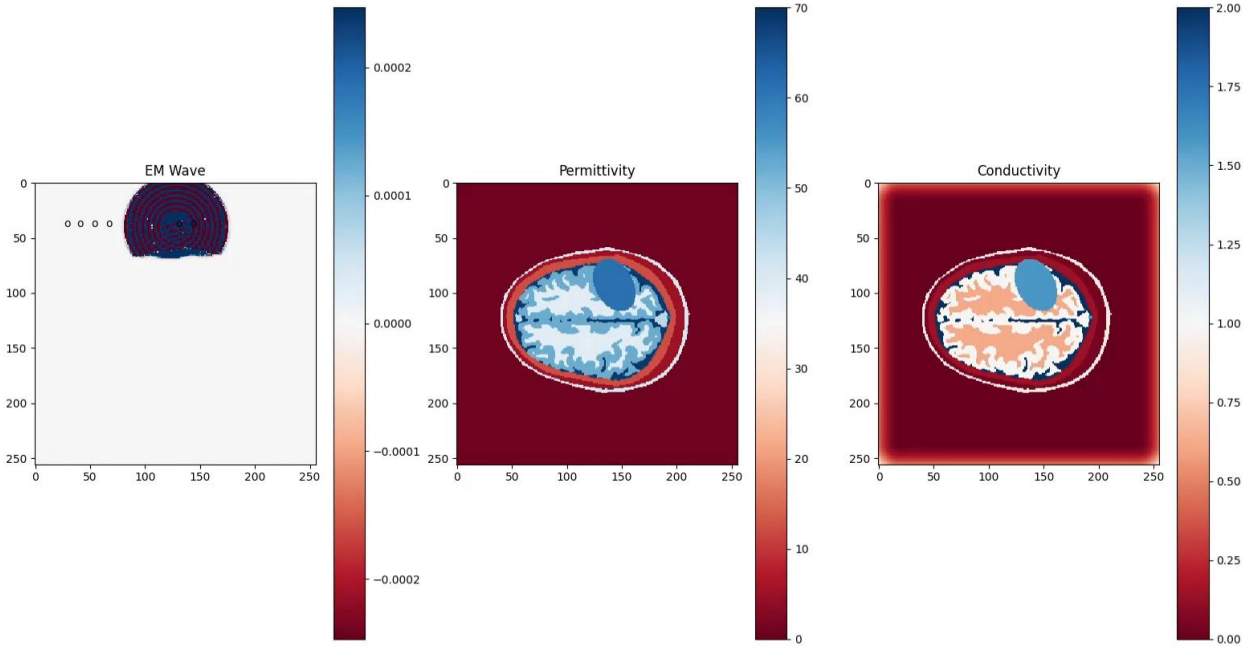
Simulation



Detecting the location and size of the stroke

Phantom

Radar for Stroke Detection

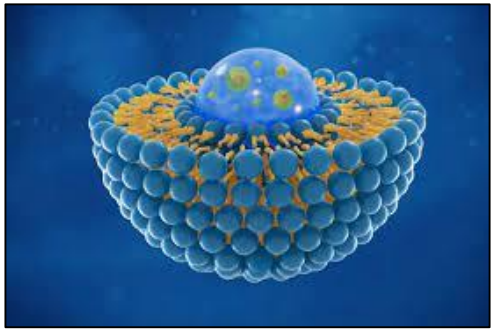


Radar for Personalized Medicine

Targeted drug delivery

Some of the benefits

- improvement of pharmaceutical activity
- Fewer side effects
- Lower doses
- Reducing the time, cost, and failure rate of clinical trials
- Contribute to better drug development



A major challenge

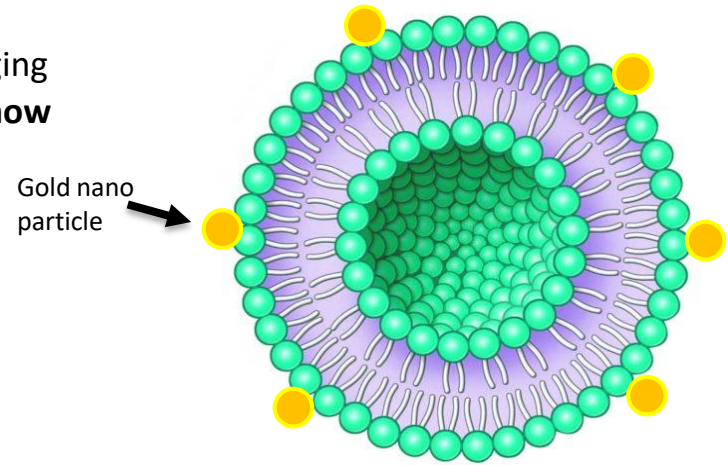
- Evaluating the drug performance is still a challenge, especially for organs beyond the bones (lungs, brain)

Collaborators: Avi Schroeder and Ravit Abel, Department of Chemical Engineering, Technion

Radar for Personalized Medicine

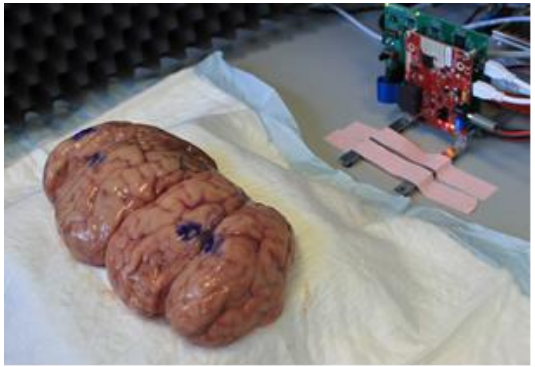
Imaging and Tracking of GNP using radar

- Metals are known as strong reflectors of EM waves
- Some EM waves are capable of penetrating rigid bodies include human bones
- As a result, using radar, it may be possible to detect and track a changing concentration of GNPs and liposomes to **non-invasively understand how the human body responds to treatment**



Radar for Personalized Medicine

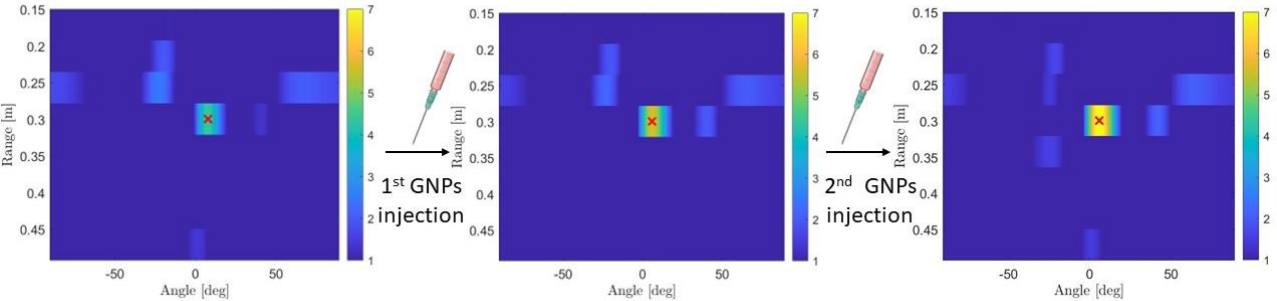
Ex-vivo Experiment

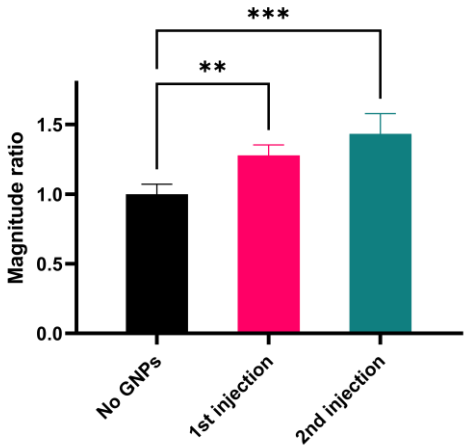


- SIMO FMCW signal model

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

- Amplification of the reflected signal due to the injection of GNPs





Radar in The Service of Medicine

To conclude:

- Radar systems have great potential in a variety of clinical applications
- From remote monitoring of vital signs to targeted drug delivery
- The aging population and the lack of manpower reinforce the need for automated personalized medicine which can be addressed using radars

Thank You

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