Signal Processing and Speech Communications Laboratory ▪ Inffeldgasse 16C/EG, 8010 Graz, Austria ▪ *jakob.moederl@tugraz.at*

Variational Message Passing-based Respiratory Motion Estimation and Detection Using Radar Signals

Jakob Möderl, Erik Leitinger, Franz Pernkopf and Klaus Witrisal

Abstract

- Detect **infants in cars** using UWB radar.
- Considering **multipath** propagation and clutter.
- Use **respiratory motion** to differentiate the target from the clutter.
- **Approximate model evidence** for the detection.

Conclusion

- **Multipath information boosts SNR!**
- **Channel**, **respiratory motion** and **model evidence** estimated by variational message passing (VMP).

Signal Model

Received signal can be modeled as outer product of respiratory motion and channel

$$\boldsymbol{R} = \boldsymbol{h}\boldsymbol{b}^{\mathsf{T}} + \text{AWGN} + \text{clutter}, \quad \boldsymbol{R} \in \mathbb{C}^{N\times M}.$$

- **Channels** $\boldsymbol{h}$ are modeled as independent Gaussian processes and cover the multipath propagation inside the car.
- **Respiratory motion** b is also modeled as Gaussian process.
- Additive white Gaussian **noise** (AWGN) with unknown precision λ.
- **Clutter** is assumed static and removed by subtracting the mean over slow time.

Detection

Bayes: compare model evidence

- $p(\text{occupied}) \lessgtr p(\text{empty})$.

Obtain $p(\text{occupied})$ by integrating out $\boldsymbol{b}$, $\boldsymbol{h}$ and the (unknown) noise precision λ

$$p(\text{occupied}) \propto \int \underbrace{p(\boldsymbol{R}|\boldsymbol{b},\boldsymbol{h},\lambda)\cdot p(\boldsymbol{b})p(\boldsymbol{h})p(\lambda)}_{\text{posterior } p(\boldsymbol{b},\boldsymbol{h},\lambda|\boldsymbol{R})} \, d\boldsymbol{b}\, d\boldsymbol{h}\, d\lambda.$$

Solving the integral is not feasible!
Solution: approximate posterior with simpler distribution to make integral tractable → VMP.

- $p(\boldsymbol{b},\boldsymbol{h},\lambda|\boldsymbol{R}) \approx q(\boldsymbol{b},\boldsymbol{h},\lambda)$
- $p(\text{occupied}) \approx \mathcal{L}(q)$

Message Passing

Maximize the evidence lower bound (ELBO) $\mathcal{L}(q)$ to approximate evidence

- $p(\text{occupied}) = \mathcal{L}(q) + \mathcal{D}_{\mathsf{KL}}(q||p)$

based on the approximating distribution

- $q(\boldsymbol{b},\boldsymbol{h},\lambda) = q_{\mathsf{b}}(\boldsymbol{b})\cdot q_{\mathsf{h}}(\boldsymbol{h})\cdot q_{\lambda}(\lambda)$.

Using conjugate priors results in distributions from well known families:

- $q_{\mathsf{b}}(\boldsymbol{b}) = \mathrm{N}(\boldsymbol{b}\,;\,\hat{\boldsymbol{b}},\hat{\boldsymbol{C}}_{\mathsf{b}})$
- $q_{\mathsf{h}}(\boldsymbol{h}) = \mathrm{CN}(\boldsymbol{h}\,;\,\hat{\boldsymbol{h}},\hat{\boldsymbol{C}}_{\mathsf{h}})$
- $q_{\lambda}(\lambda) = \mathrm{Ga}(\lambda\,;\,NM,\,NM/\hat{\lambda})$

Only update of parameters $\hat{\boldsymbol{b}}$, $\hat{\boldsymbol{C}}_{\mathsf{b}}$, $\hat{\boldsymbol{h}}$, $\hat{\boldsymbol{C}}_{\mathsf{h}}$ and $\hat{\lambda}$ needed in each iteration.

Illustrations

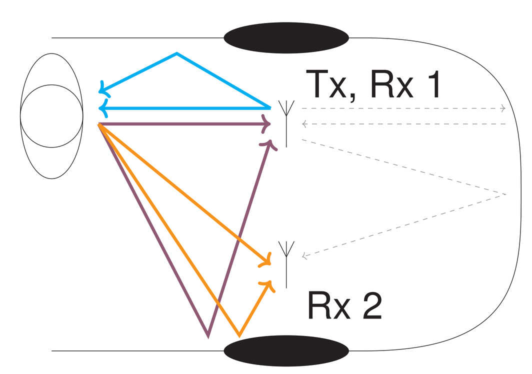
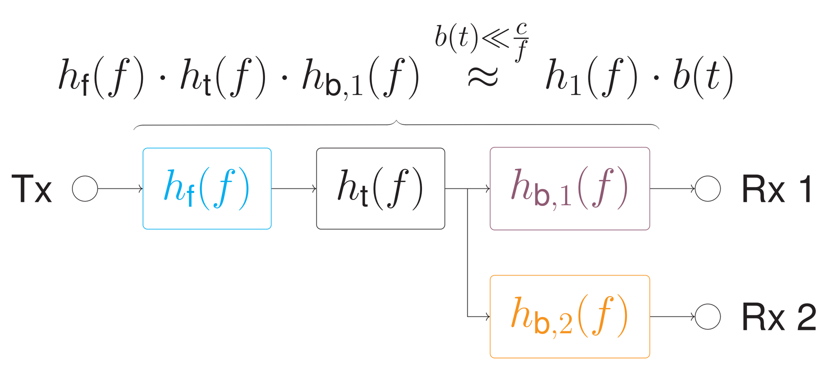
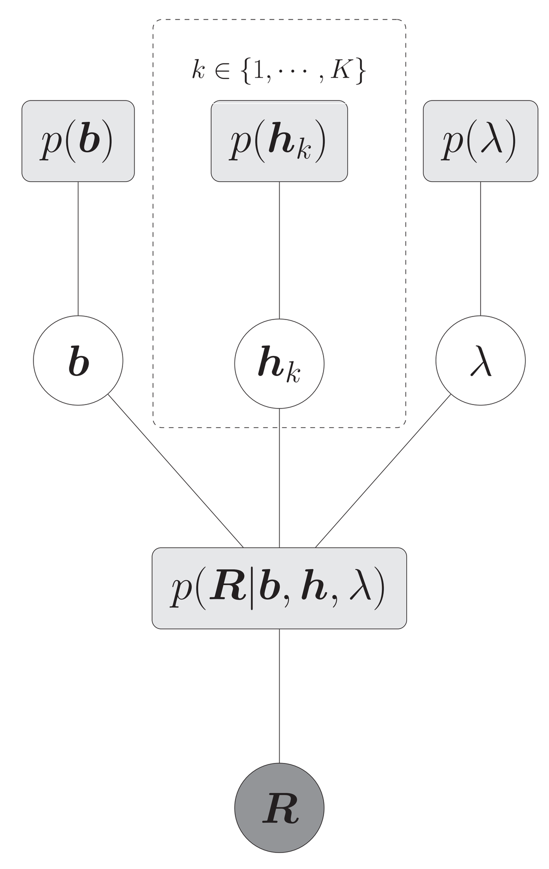


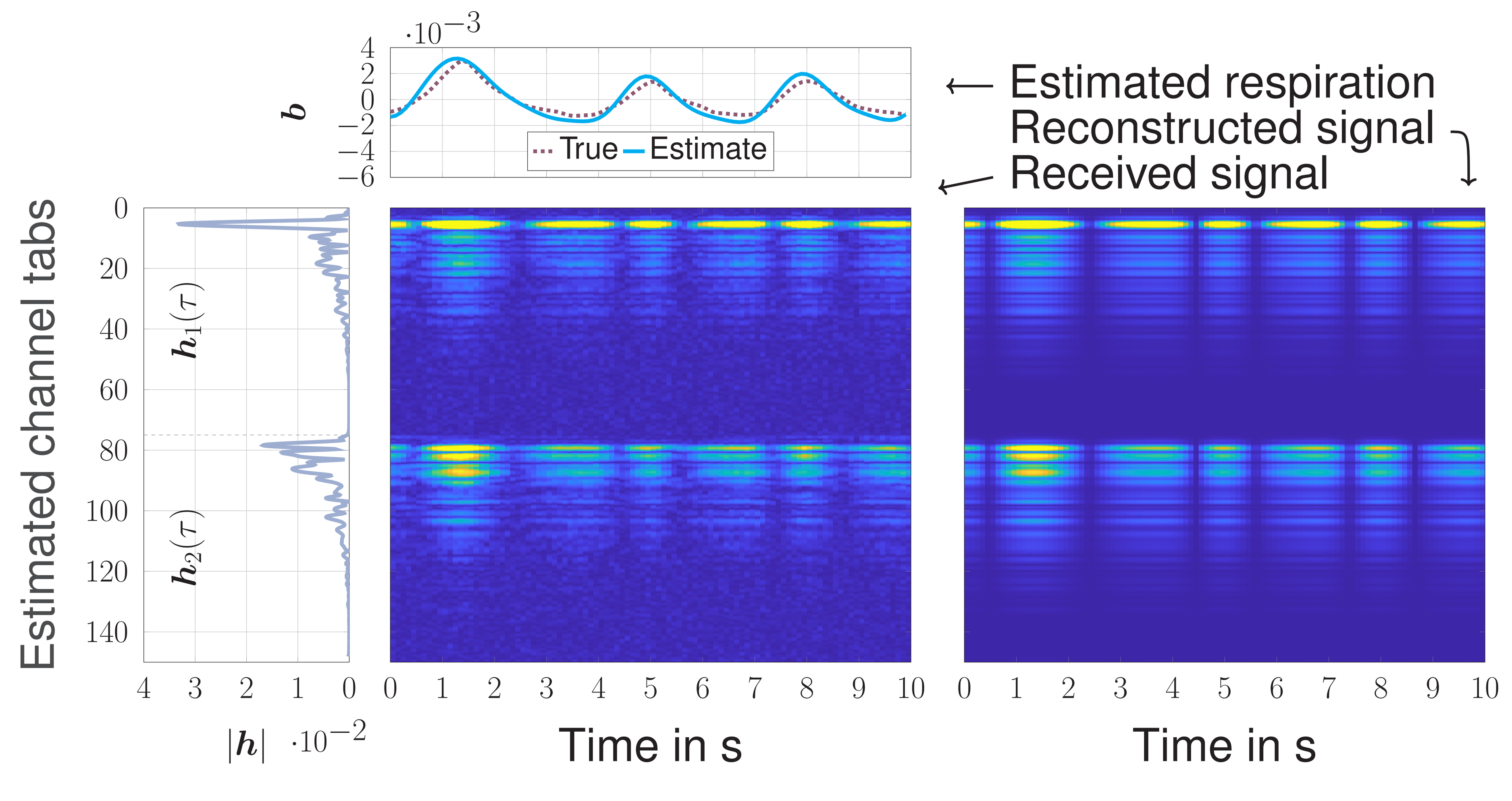
Illustration of the radar setup.



Pinhole channel model.



Factor graph.



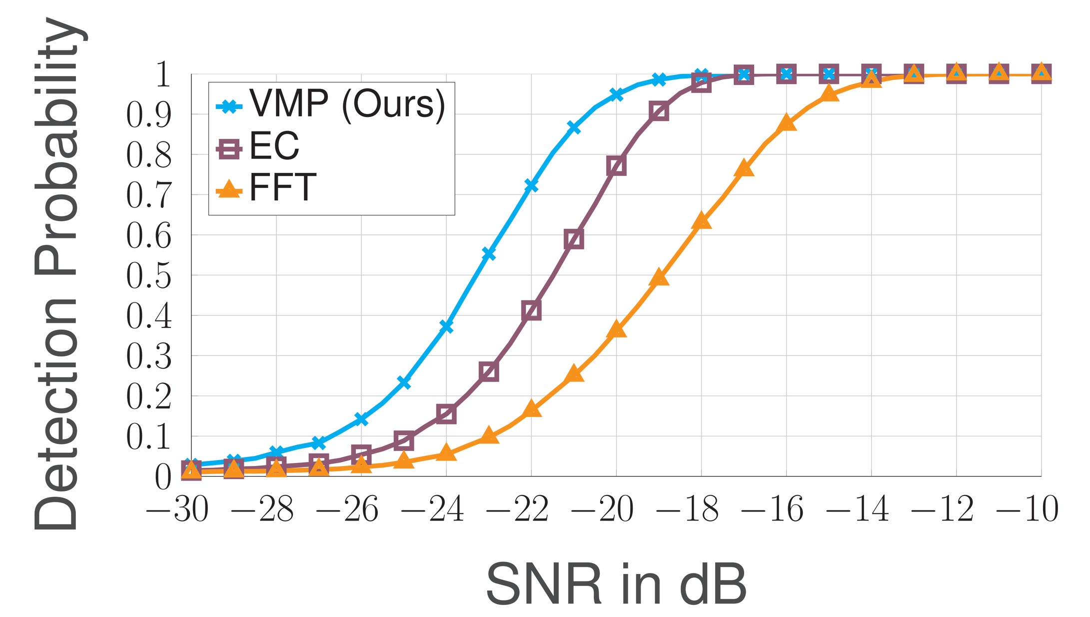
Radar measurement example (high SNR).

Results

- Measurement in 2 cars with 34 persons.
- 2 minutes per person, 10s frames.

Comparison approaches:

- FFT: maximum of FFT over slow time.
- Estimator-correlator (EC): based on factorized covariance $\boldsymbol{C}_{\mathsf{R}} = \boldsymbol{C}_{\mathsf{b}} \otimes \boldsymbol{C}_{\mathsf{h}}$.



This research was partly funded by the Austrian Research Promotion Agency (FFG) within the Project SEAMAL Front (project number: 880598).