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RFPose-OT: RF-based 3D human pose estimation via optimal transport theory

Key words: Radio frequency sensing; Human pose estimation; Optimal transport; Deep learning

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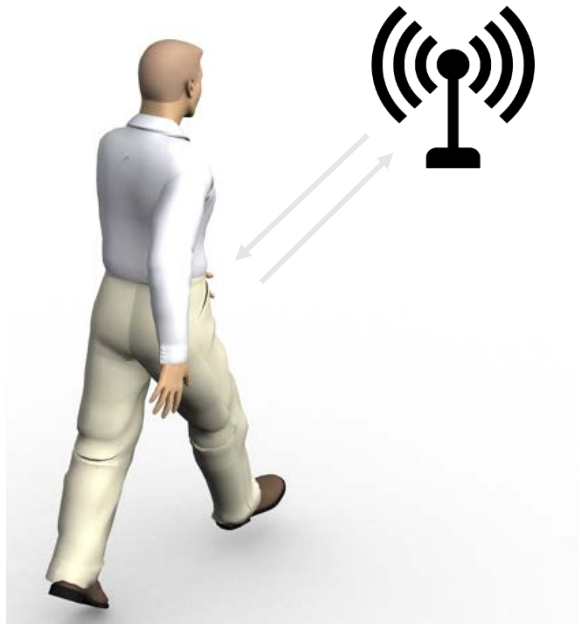
Motivation

Compared with camera-based and wearable-devices-based methods, radio frequency (RF) based human pose estimation can obtain human behavior and posture information with all-weather, non-contact, and non-line-of-sight characteristics.

Camera

Wearable devices

RF signals



Method

RF signals are transformed to the target pose feature domain based on the optimal transport (OT) theory, and then pose keypoints are generated from the transformed features.

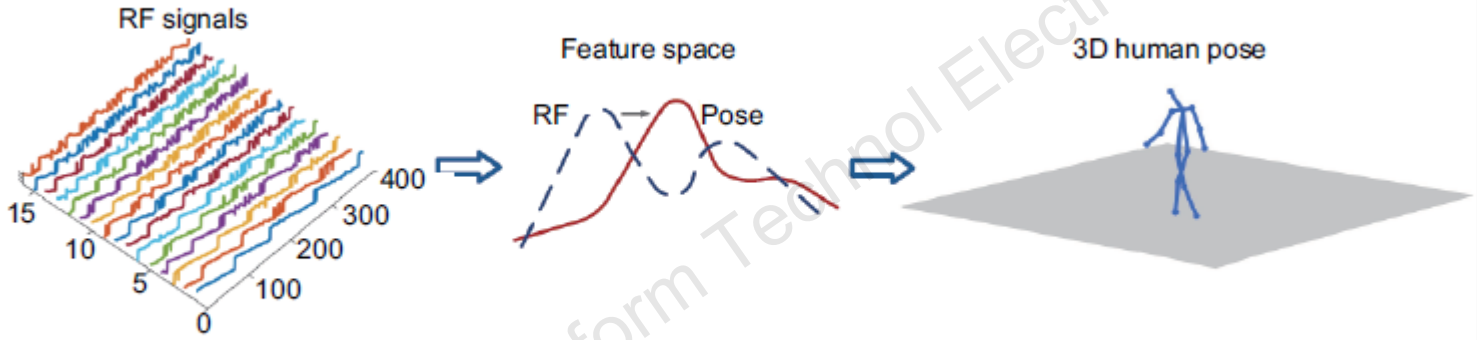


Fig. 1 RFPose-OT transforms the radio frequency (RF) signals to the pose domain to enable fine-grained three-dimensional (3D) human pose estimation

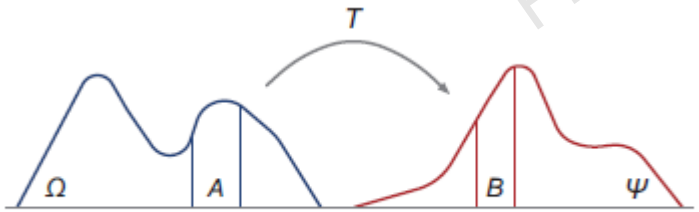


Fig. 2 Transport map

$$\mathcal{K}(\gamma) = \int_{\Omega \times \Psi} C(z, \hat{z}) \mathrm{d}\gamma(z, \hat{z})$$

$$\begin{cases} \gamma(A \times \Psi) = \mu(A), \\ \gamma(\Omega \times B) = \nu(B) \end{cases}$$

Method

The RFPose-OT architecture consists of a pose encoder, an RF encoder, and a keypoint predictor.

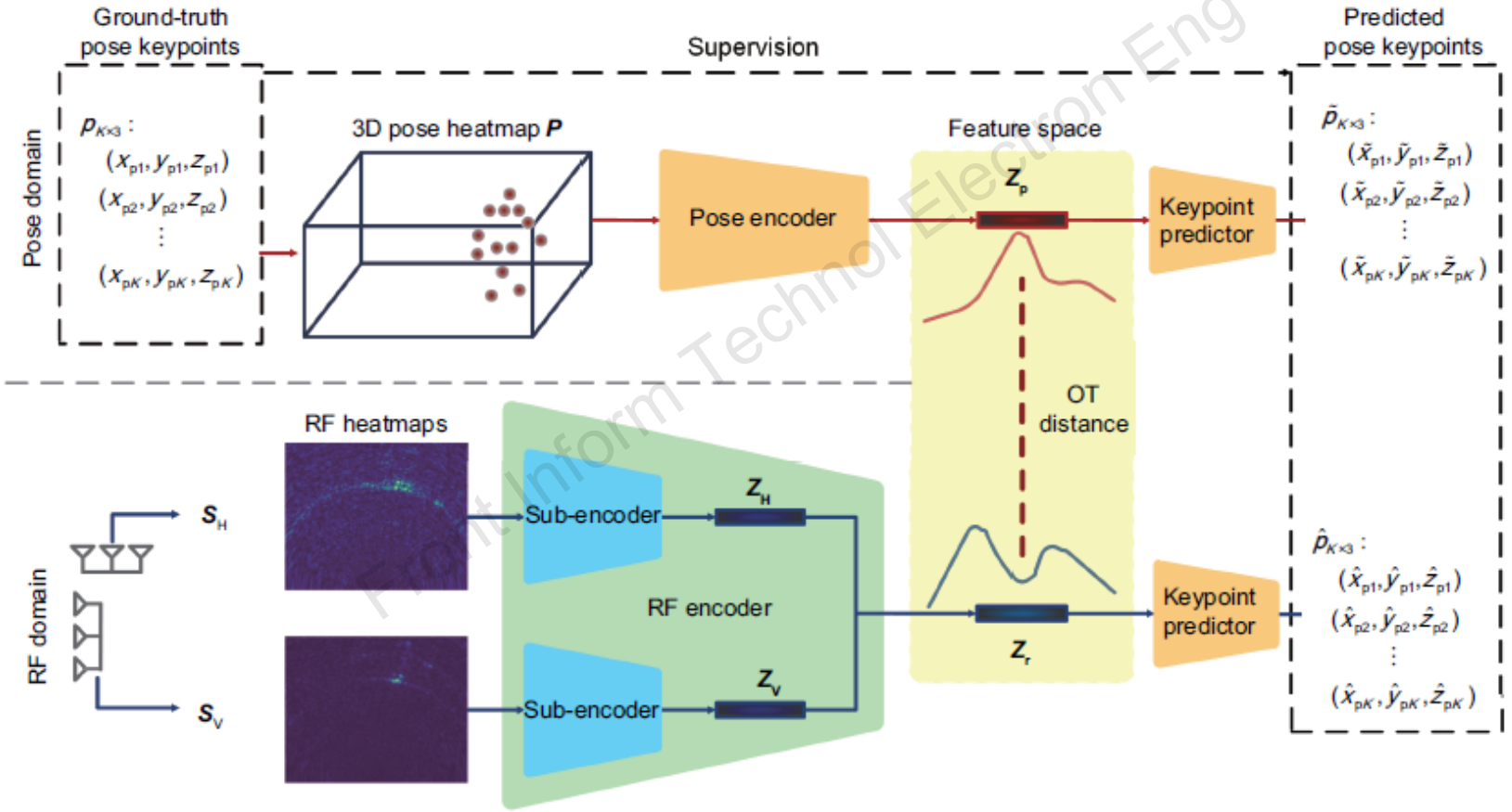


Fig. 4 The RFPose-OT architecture which consists of a pose encoder, a radio frequency (RF) encoder, and a keypoint predictor. Once trained, only the RF encoder and the keypoint predictor are retained to predict 3D human poses from RF heatmaps

Experiments

The spatial location error (SLE) between the predicted keypoints and the corresponding ground-truth keypoints is used as the metric:

$$\mathrm{SLE}_k = \frac{1}{U}\sum_{u=1}^{U}\left\|\hat{\boldsymbol{p}}_k^{(u)} - \boldsymbol{p}_k^{(u)}\right\|_2$$

Table 4 Quantitative evaluation results of different methods in the basic a and occlusion b indoor environments

Env	Method	SLE (cm)								
		Nose	Neck	Shoulders	Elbows	Wrists	Hips	Knees	Ankles	Overall
a	RF-Pose3D (Zhao et al., 2018a)	8.11	**5.21**	7.57	9.92	15.74	6.64	11.31	21.10	11.27
	mm-Pose (Sengupta et al., 2020)	8.19	5.30	7.23	9.67	15.29	**6.20**	10.83	19.04	10.72
	RFPose-OT	**7.90**	6.14	**6.76**	**7.99**	**11.67**	6.39	**8.34**	**12.60**	**8.68**
b	RF-Pose3D (Zhao et al., 2018a)	**6.53**	4.86	6.65	8.75	14.05	6.95	11.26	21.52	10.70
	mm-Pose (Sengupta et al., 2020)	6.64	**3.88**	**6.34**	9.16	14.84	6.98	11.28	19.28	10.45
	RFPose-OT	7.85	6.42	6.78	**7.90**	**11.41**	**6.82**	**9.35**	**14.05**	**9.07**

Bold numbers represent the minimum spatial location error (SLE) values. Env: environment

Experiments

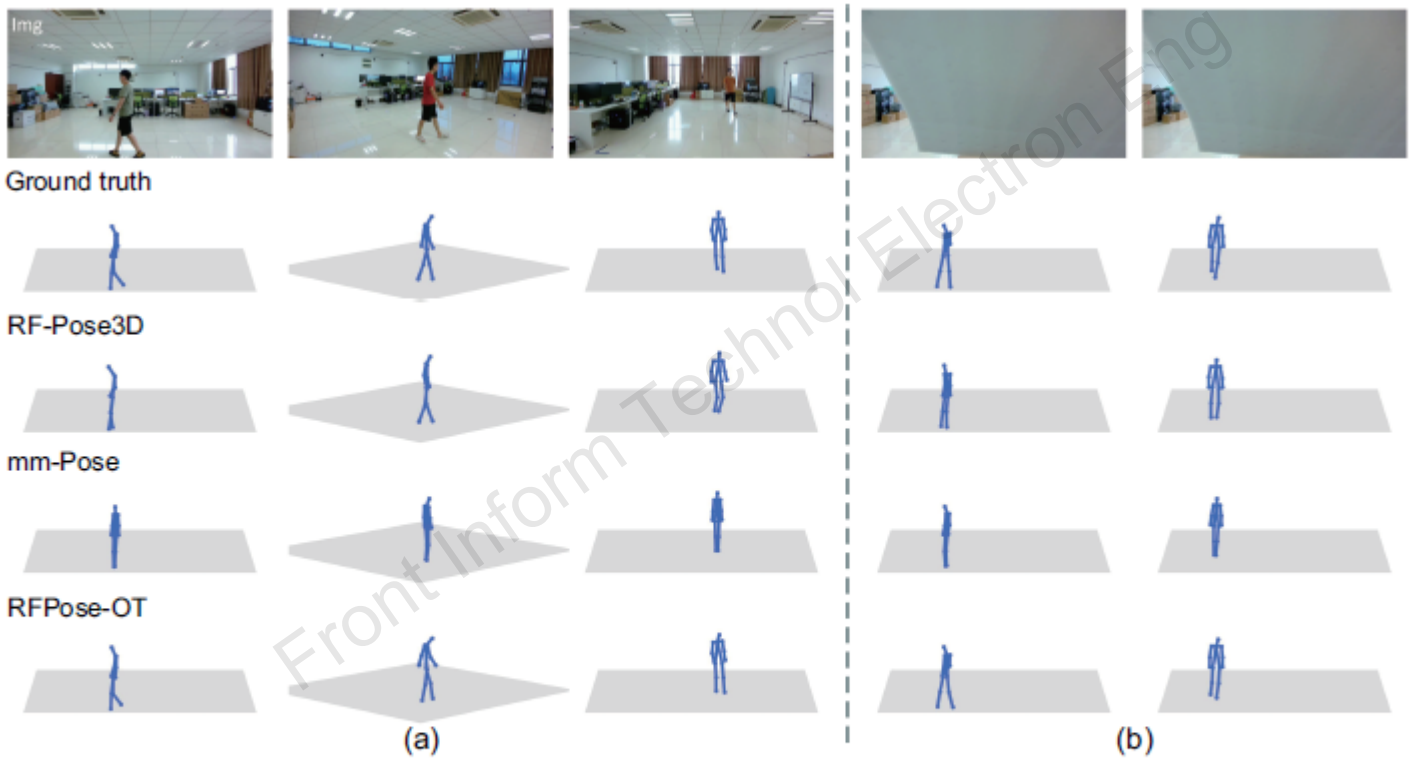
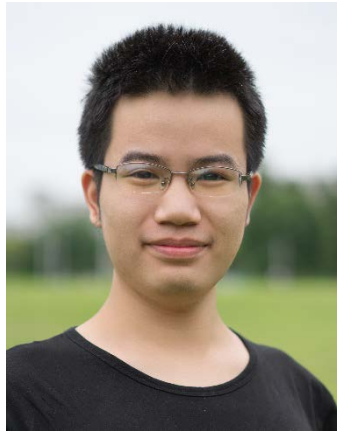


Fig. 5 Qualitative results of different methods in the basic (a) and occlusion (b) indoor environments

The 1st row shows the images captured by a camera that is attached to the radio system, the 2nd row shows the ground-truth 3D human poses, and the 3rd, 4th, and 5th rows show the 3D human poses estimated by RF-Pose3D (Zhao et al., 2018a), mm-Pose (Sengupta et al., 2020), and our proposed RFPose-OT, respectively

Conclusions

1. We propose an RF-based accurate human pose estimation method via the optimal transport theory.
2. The proposed RFPose-OT can be applied to a variety of scenarios.
3. RFPose-OT provides a new and valid framework to tackle related RF human sensing tasks.



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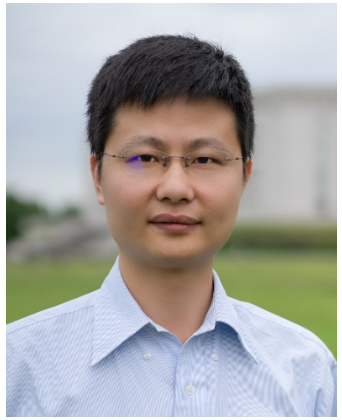

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