mmBody Benchmark: 3D Body Reconstruction Dataset and Analysis for MillimeterWave Radar

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Questions

- How **accurately** can the mmWave radar reconstruct 3D human body in **different scenarios**?
- Can the mmWave radar work **robustly** in severe environments?
- Can the mmWave radar achieve **comparable accuracy with RGB(D) cameras**?

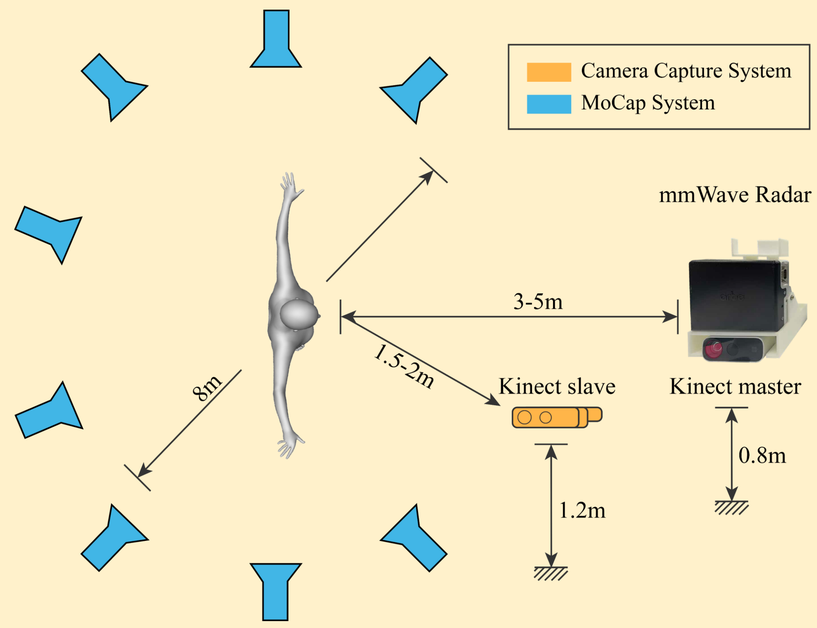
Dataset Comparison

mmWave point cloud + **SMPL-X body annotation** + **RGBD images**

100k frames & **100 motions** of 20 volunteers in **7 different scenes**

Dataset	Signals	Labels	No. Actions	Scenes					
				Public	Occlusion	Poor Lighting	Furnished	Rain	Smoke
RF-Pose [59]	RF Signal	2D Skeletons	/	×	✓	✓	×	×	×
RF-Pose3D [61]	RF Signal	3D Skeletons	/	×	✓	×	×	×	×
RF-MMD [27]	RF Signal	3D Skeletons	35	×	✓	✓	×	×	×
Person-in-WiFi [51]	Wi-Fi	2D Skeletons	/	×	×	×	×	×	×
RF-Avatar [60]	RF Signal	3D Mesh	/	×	✓	×	×	×	×
mmMesh [55]	mmWave	3D Mesh	8	×	✓	✓	✓	×	×
Ours	mmWave, RGB(D)	3D Skeletons/Mesh	100	✓	✓	✓	✓	✓	✓

Data Collection System



Phoenix Arbe mmWave Radar
2 Azure Kinects: synchronized and calibrated RGBD images
8 OptiTrack cameras: mesh annotation generated using MoSh++.

TSNE Visualization of Dataset Pose & Shape Space

- **Completeness** and **diversity** of scenarios, shapes, and poses
- **Coverage** of our dataset is **equal to or better** than popular datasets for human body reconstruction using MoCap or RGB(D) images.

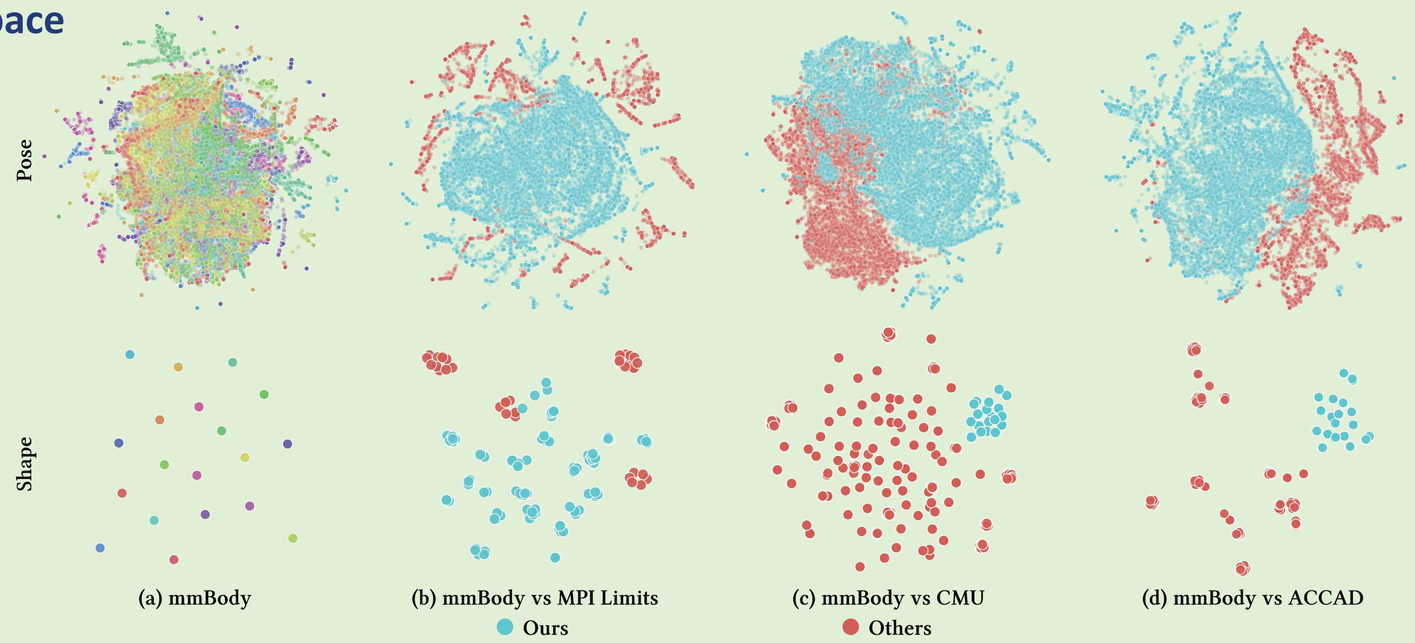
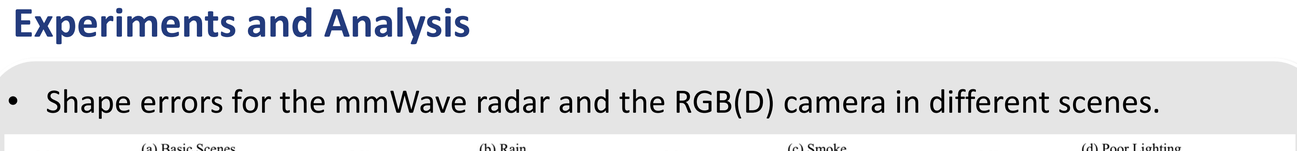


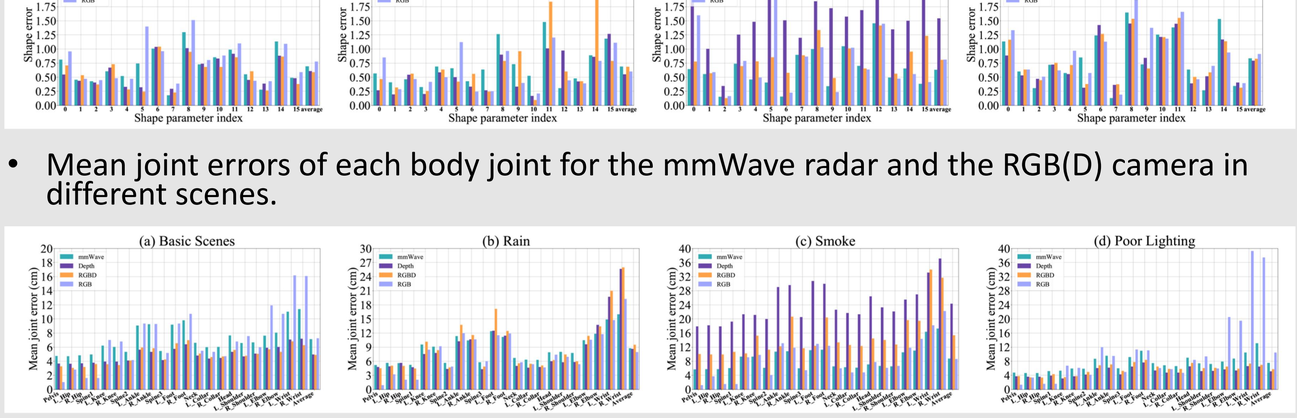
Fig. (a) Our mmBody pose and shape space
Fig. (b) Compares with the MPI Limits dataset.
Fig. (c) Compares with the CMU dataset.
Fig. (d) Compares with the ACCAD dataset.

Experiments and Analysis

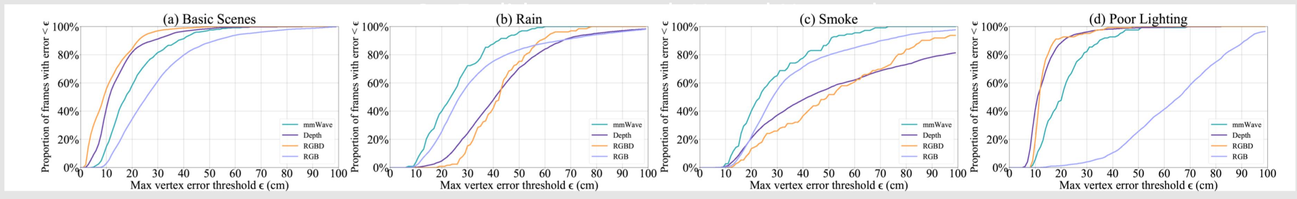
- Shape errors for the mmWave radar and the RGB(D) camera in different scenes.



- Mean joint errors of each body joint for the mmWave radar and the RGB(D) camera in different scenes.



- The proportion of frames with the max vertex errors within thresholds for different inputs in different scenes.



- Errors (cm) of 3D body reconstruction from the mmWave radar and the RGB(D) camera in different scenes. For each scene, the first column is for joint error and the second vertex error.

Scenes		Basic Scenes						Adverse Environments								Average	
		Lab1		Lab2		Furnished		Rain		Smoke		Poor Lighting		Occlusion			
Mean Error	mmWave	7.8	9.5	5.8	6.6	8.2	10.4	8.8	10.2	8.7	10.0	7.5	9.5	10.7	14.1	8.2	10.0
	Depth	5.5	6.5	3.9	4.3	5.5	6.9	8.6	10.9	24.3	28.0	5.1	6.5	/	/	8.8	10.5
	RGBD	5.8	7.0	3.4	3.9	5.4	6.8	9.5	11.6	15.4	18.3	5.8	7.2	/	/	7.5	9.1
	RGB	7.4	8.9	7.3	10.0	7.1	9.1	8.0	10.1	8.6	10.8	10.5	15.6	/	/	8.1	10.8
Max Error	mmWave	16.9	22.5	13.3	18.8	17.5	25.5	20.0	26.3	20.5	29.0	16.2	22.6	25.3	35.3	18.5	25.7
	Depth	12.6	17.2	8.8	12.7	11.3	16.4	29.8	44.6	49.4	61.7	10.3	14.4	/	/	20.3	27.8
	RGBD	12.2	16.5	7.5	10.9	10.1	14.1	29.0	43.7	38.8	53.4	11.2	14.5	/	/	18.1	25.5
	RGB	22.0	28.8	24.8	35.3	20.0	27.9	26.3	34.8	28.1	37.1	46.2	66.0	/	/	27.9	38.3

1. Naureen Mahmood, Nima Ghorbani, Nikolaus F Troje, Gerard Pons-Moll, and Michael J Black. AMASS: Archive of motion capture as surface shapes. In: ICCV (2019)
2. Ijaz Akhter and Michael J. Black. Pose-Conditioned Joint Angle Limits for 3D Human Pose Reconstruction. In: CVPR (2015)
3. CMU Graphics Lab. 2000. CMU Graphics Lab Motion Capture Database. http: //mocap.cs.cmu.edu/.
4. OSU ACCAD. 2022. ACCAD. https://accad.osu.edu/research/motion-lab/systemdata.
* Indicates equal contribution.

Conclusion

3D body reconstruction from mmWave radar can:

- **be well reconstructed from the noisy and sparse mmWave** radar signal, even **emulating the results of RGB images**;
- **be affected slightly by adverse environments** like rain and smoke;
- perform worse than depth camera in normal scenes but **robust in extreme scenes.**

Qualitative Results