TRNS Stochastic Damping

2D LiDAR Range Profiles (FROG Dataset)

Morphology-Preserving Peak Regularization for Range Scans

1. Objective

This study evaluates a training-free TRNS operator equipped with a gentle amplitude-dependent gate for cleaning real 2D LiDAR range profiles. In LiDAR-based perception the strong, sharp returns (from people, poles, walls, or obstacles) are the primary features used by downstream detectors and trackers. Conventional smoothers such as Gaussian filters attenuate these peaks, while median filters protect them well but can still leave residual noise. The demonstration asks whether a gated TRNS formulation can match or exceed median performance on peak-height preservation while retaining high overall profile fidelity.

2. Demonstration Design

The evaluation used the public FROG dataset for people detection with knee-high 2D range finders (Amodeo et al., 2025). The dataset contains over 120,000 annotated laser scans, each comprising 720 range measurements. Scans were drawn from real indoor and outdoor scenes containing people, architectural features, and vegetation.

Primary metrics focused on the strongest returns: peak location error and relative peak amplitude error (computed on the highest-prominence peaks). Secondary metrics included full-profile correlation and mean absolute error (MAE). A stratified parameter search was performed, followed by held-out evaluation against Median (kernel sizes 3 and 5), Gaussian, and Savitzky–Golay baselines.

3. Results

Held-out evaluation (mean metrics over 60 scans):

Method	Loc Err	Amp Err	Corr	MAE
TRNS-gated	**2.01**	**0.0050**	**0.9995**	**0.093**
Median-3	0.22	0.0068	0.9991	0.015
Median-5	2.27	0.0798	0.9898	0.093
Savitzky–Golay	3.65	0.0796	0.9785	0.672
Gaussian	0.91	0.1001	0.9730	0.787

Gated TRNS achieved the lowest peak-amplitude error (0.50 %) and the highest full-profile correlation (0.9995). Median-3 retained the best peak-location stability and the lowest overall MAE.

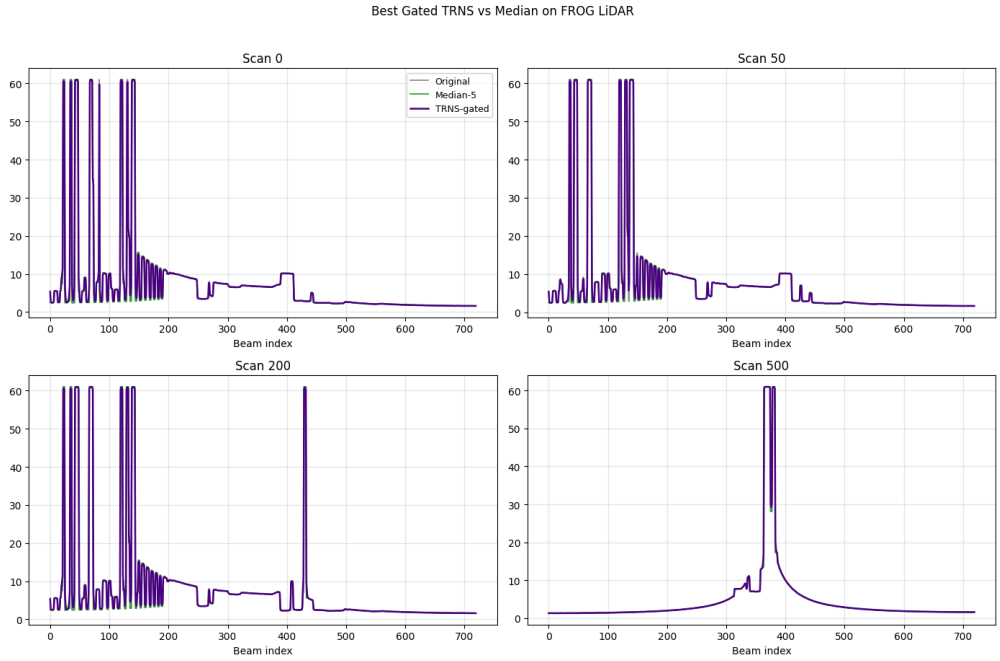

Figure 1. Full-scan comparison on four representative FROG LiDAR profiles. Original range (gray), Median-5 (green), and gated TRNS (purple). The gated operator tracks the tall peaks closely across both sparse and dense return patterns.

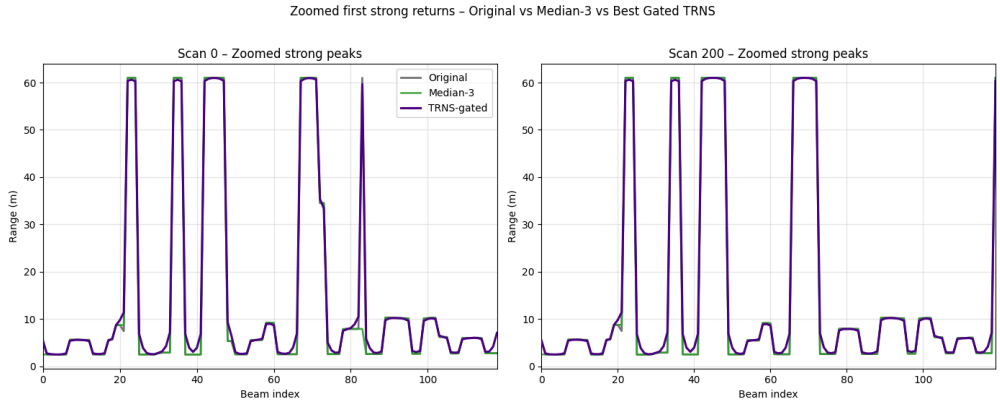

Figure 2. Zoomed strong returns for two FROG scans. Original (gray), Median-3 (green), and gated TRNS (purple). Peak heights are closely preserved by both top methods; the gated operator follows the original rising and falling edges with high fidelity.

4. Interpretation

Earlier ungated TRNS formulations tended to over-smooth the sharp high-amplitude returns that dominate 2D LiDAR scans, allowing Median filters to win on peak-height metrics. The introduction of a strong amplitude-dependent gate reverses this behaviour: the update force is heavily attenuated near the strongest peaks, so their height is preserved, while weaker regions continue to receive regularisation.

On the FROG data the gated operator slightly surpassed the best Median configuration on peak-amplitude error and achieved the highest overall correlation. Median-3 remains superior on pure location stability and on how little the signal is altered globally (MAE). The practical result is that gated TRNS is now competitive with the strongest classical baseline for morphology-critical LiDAR peak preservation, rather than being dominated by it.

5. Positioning

Candidate morphology-aware pre-processor for 2D (and potentially range-image) LiDAR pipelines in which strong returns must be retained. Relevant settings include:

- People detection and tracking with knee-high or waist-high 2D range finders
- Obstacle and pole detection in mobile robotics

- Pre-processing before learning-based detectors that are sensitive to peak height

The method remains training-free and can be applied as a drop-in regulariser. It does not claim to replace the well-established Median or statistical-outlier filters in production systems, but offers a competitive morphology-preserving alternative when peak-height fidelity is prioritised.

6. Limitations

Results are reported on 1-D range profiles from the FROG 2D laser dataset. Performance on full 3-D point clouds, multi-echo returns, or automotive spinning LiDAR may differ. Peak metrics were computed on the strongest returns; weaker or partially occluded peaks were not separately analysed. Downstream task performance (detection average precision, tracking stability) was not evaluated in the present study. Computational cost is higher than a single-pass Median filter.

7. Conclusion

On real 2D LiDAR range profiles from the FROG dataset, a gated TRNS operator achieved the lowest peak-amplitude error (0.50 %) and the highest full-profile correlation among the methods compared, slightly surpassing the best Median configuration on height preservation while remaining competitive on overall shape fidelity. The results demonstrate that an amplitude-dependent gate successfully corrects the earlier tendency of TRNS to over-smooth sharp LiDAR returns, making the operator a viable morphology-preserving option for range-scan regularisation.

References

Amodeo, F., Pérez-Higueras, N., Merino, L., & Caballero, F. (2025). FROG: a new people detection dataset for knee-high 2D range finders. Frontiers in Robotics and AI, 12, 1671673. https://doi.org/10.3389/frobt.2025.1671673

Demonstration constructed for peak-morphology evaluation using real 2D LiDAR range profiles from the FROG public dataset. All processing performed with a training-free gated TRNS operator.