

Introduction

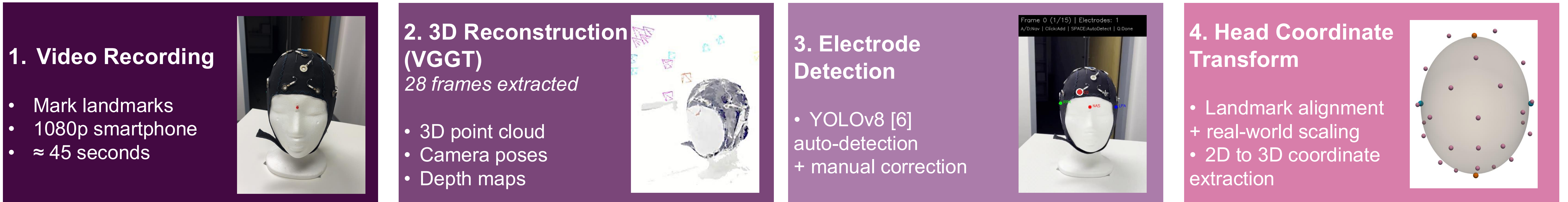
Accurate localization of EEG electrodes is essential for reliable source analysis. 5 mm sensor shift can introduce 2–12 mm of source localization error [2]. Traditional approaches such as electromagnetic digitizers and structured-light 3D scan are reliable methods but can require expensive equipment or complex setup [3] [4].

Project Goal:

The aim of this project is developing an open-source alternative to expensive traditional digitizing methods to make EEG electrode localization more accessible for every research laboratory via smartphone video recordings.

Method

Pipeline Workflow



Validation Study

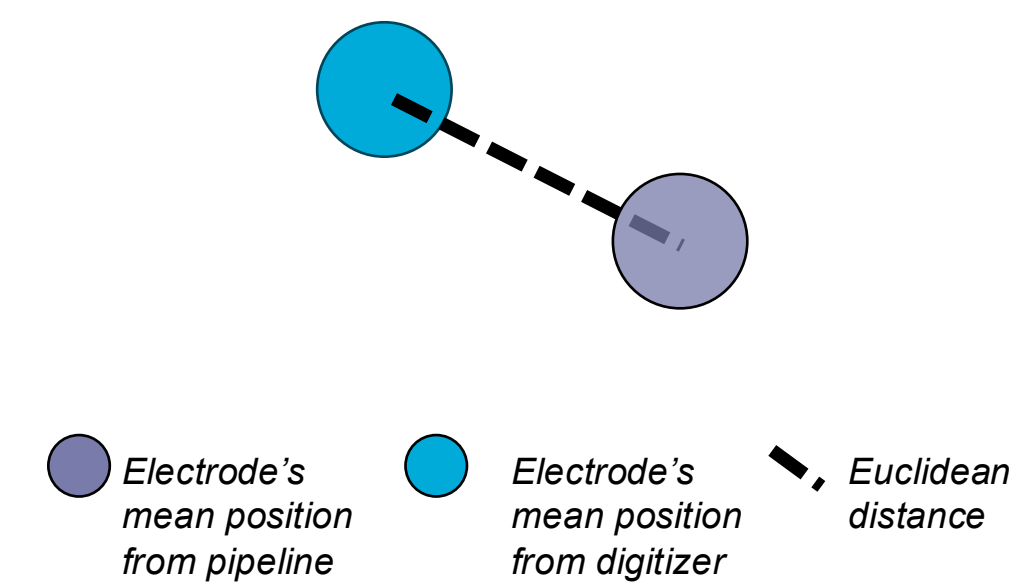
Setup

- Styrofoam Head Model
- 24 Channel EEG Cap
- 10 Digitizer Recording+10 Video Recording
- LPA → RPA distance in cm

Evaluation Metrics

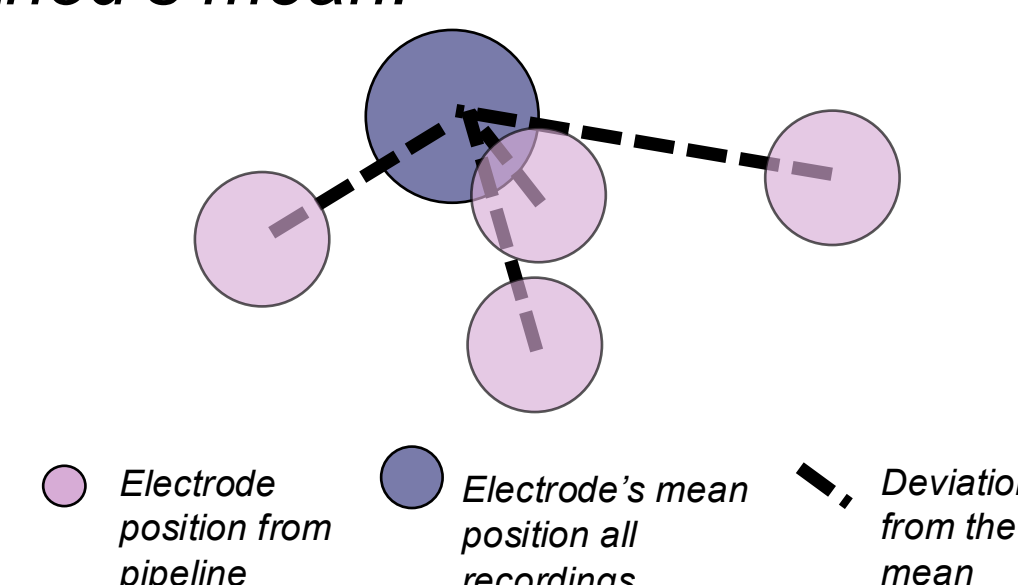
Inter-method Accuracy

Per-electrode Euclidean distance between mean positions.



Intra-Method Repeatability

Per-electrode deviation of each individual recording from its own method's mean.



Statistical Analysis

- **Inter-method accuracy:** ICC(2,1) on mean electrode coordinates between methods
- **Intra-method repeatability:** Wilcoxon signed-rank test comparing per-electrode variability between methods + ICC(2,1) across repeated recordings for each method

Results

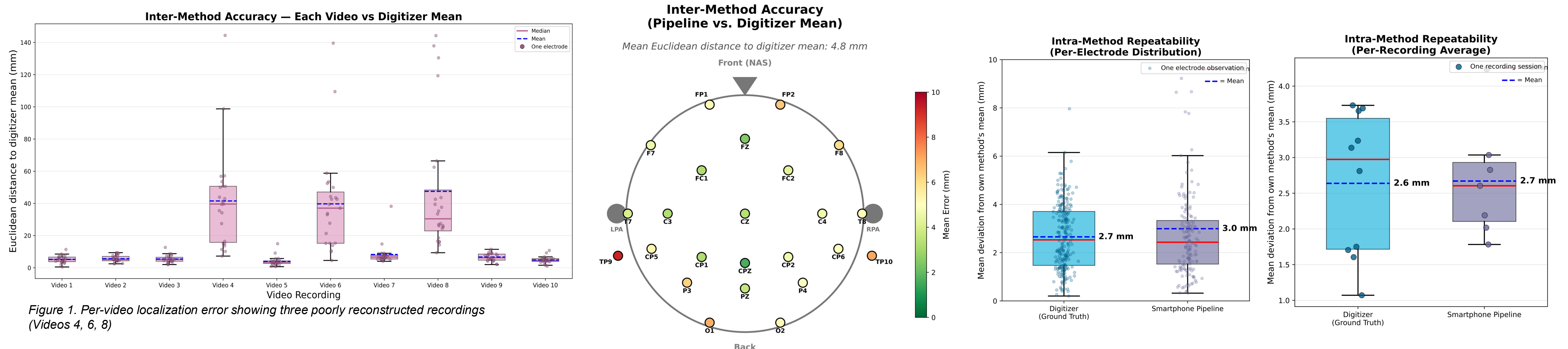


Figure 1. Per-video localization error showing three poorly reconstructed recordings (Videos 4, 6, 8)

1. Recording Quality

- Mean error across all 10 recordings was 12.5 mm, with per-video analysis (Figure 1) revealing a clear split between well-reconstructed (4–9 mm) and 3 poorly reconstructed recordings (40–48 mm) caused by camera drift.

2. Inter-Method Accuracy

- Excluding poorly reconstructed recordings: mean error 4.82 ± 1.67 mm.
- ICC(2,1) between methods = 0.998, indicating excellent agreement.

3. Intra-Method Repeatability

- Per-electrode variability: pipeline 2.98 ± 2.12 mm vs. digitizer 2.65 ± 0.35 mm, no significant difference (Wilcoxon $W = 127.0$, $p = 0.527$).
- Within-method ICC: digitizer 0.999 - pipeline 0.997, both excellent.

Discussion

- ICC showed excellent overall agreement between methods (0.998), confirming that the pipeline captures the correct electrode layout. The mean positional error of 4.82 mm reflects a small remaining offset at the individual electrode level, likely caused by depth estimation errors during rotational camera movement.
- The pipeline reproduces electrode positions as consistently as the digitizer, supporting its use as a repeatable localization tool.
- These results support the pipeline as a promising proof of concept for low-cost electrode localization, with recording quality and depth estimation identified as key areas for further improvement.

Limitations

- No standardized recording protocol
- Rigid head model only (no hair, no gel artifacts)
- Small YOLOv8 training dataset and single cap type
- Duplicate electrode ID issue

Outlook

- Standardized recording protocol
- Expanded validation with human subjects
- Retraining YOLOv8 on larger, multi-cap datasets to improve electrode detection

References

- [1] Homölle, S., & Oostenveld, R. (2019). Using a structured-light 3D scanner to improve EEG source modeling with more accurate electrode positions. *Journal of Neuroscience Methods*, 326, 108378.
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- [3] Shirazi, S. Y., & Huang, H. J. (2019). More reliable EEG electrode digitizing methods can reduce source estimation uncertainty, but current methods already accurately identify Brodmann areas. *Frontiers in Neuroscience*, 13, 1159.
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- [5] Wang, J., Chen, M., Karaev, N., Vedaldi, A., Rupprecht, C., & Novotny, D. (2025). VGGT: Visual Geometry Grounded Transformer. *arXiv*.
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