NeuSE: Neural SE(3)-Equivariant Embedding for Consistent Spatial Understanding with Objects

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Goals

Leverage neural implicit object representations for consistent long-term scene understanding.

What is NeuSE?

- A novel Neural SE(3)-Equivariant Embedding for objects
- A compact point cloud surrogate for complete object models, encoding full shape information while transforming SE(3) equivariantly with the object in the physical world.

Contributions

- NeuSE, a neural SE(3)-equivariant embedding for objects, encoding the full object shape and transforms SE(3)-equivariantly with the real-world object.
- A NeuSE-based object SLAM paradigm targeting long-term scene inconsistencies, enabling NeuSE-predicted object-level localization and change-aware mapping.

Experiments show:

- Synthetic and Real-world sequences with object changes
- Improved localization performance and flexible mapping capability when working standalone or jointly with a common SLAM pipeline.

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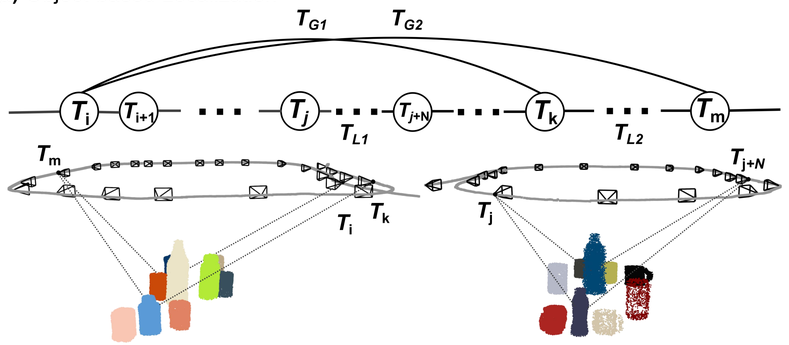
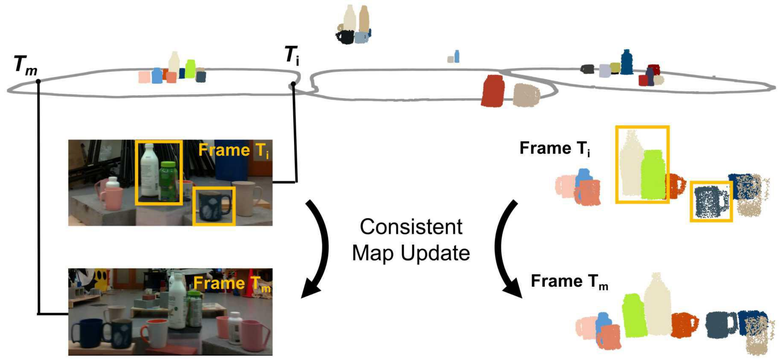
Methodology

(a) Object-based Localization



(b) Object-centric Change Detection and Mapping



(c) Category-level SE(3)-Equivariant Embeddings for Objects

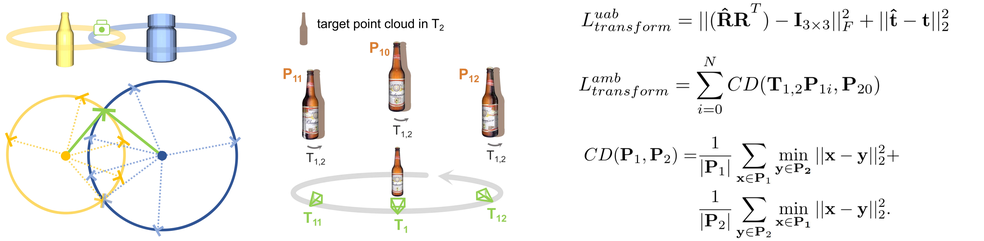
$$f_\theta(\mathbf{RP}) = \mathbf{Rz}, \mathbf{R} \in \mathbb{SO}(3)$$

$$f_\theta(\mathbf{P} - \overline{\mathbf{P}}) = \mathbf{z}_0 : \mathbb{R}^{n\times 3} \rightarrow \mathbb{R}^{k\times 3}$$

$$\mathbf{z} = \mathbf{z}_0 + \overline{\mathbf{P}}, \mathbf{z}' = \mathbf{z} - \overline{\mathbf{z}}$$

$$\Phi(\mathbf{x}, \mathbf{f}_\theta(\mathbf{P})) = \Phi(\mathbf{x} - \overline{\mathbf{z}}, \mathbf{z}') : \mathbb{R}^3 \times \mathbb{R}^{k\times 3} \rightarrow [0, 1]$$

(d) Training Objectives for Ambiguous and Unambigous Object Categories



$$L^{uab}_{transform} = ||(\hat{\mathbf{R}}\mathbf{R}^T) - \mathbf{I}_{3\times 3}||^2_F + ||\hat{\mathbf{t}} - \mathbf{t}||^2_2$$

$$L^{amb}_{transform} = \sum_{i=0}^{N} CD(\mathbf{T}_{1,2}\mathbf{P}_{1i}, \mathbf{P}_{20})$$

$$CD(\mathbf{P}_1, \mathbf{P}_2) = \frac{1}{|\mathbf{P}_1|}\sum_{\mathbf{x}\in\mathbf{P}_1}\min_{\mathbf{y}\in\mathbf{P}_2}||\mathbf{x}-\mathbf{y}||^2_2 + \frac{1}{|\mathbf{P}_2|}\sum_{\mathbf{y}\in\mathbf{P}_2}\min_{\mathbf{x}\in\mathbf{P}_1}||\mathbf{x}-\mathbf{y}||^2_2.$$

Results