SAIL-Recon: Large SfM by Augmenting Scene Regression with Localization

Junyuan Deng[1,2*] Heng Li[1*] Tao Xie[2,3] Weiqiang Ren[2] Qian Zhang[2]
Ping Tan[1†] Xiaoyang Guo[2†]
[1]The Hong Kong University of Science and Technology [2]Horizon Robotics [3]Zhejiang University

Abstract

Scene regression methods, such as VGGT [86], solve the Structure-from-Motion (SfM) problem by directly regressing camera poses and 3D scene structures from input images. They demonstrate impressive performance in handling images under extreme viewpoint changes. However, these methods struggle to handle a large number of input images. To address this problem, we introduce SAIL-Recon, a feed-forward Transformer for large scale SfM, by augmenting the scene regression network with visual localization capabilities. Specifically, our method first computes a neural scene representation tokens from a subset of anchor images. The regression network is then fine-tuned to reconstruct all input images conditioned on this neural scene representation. Comprehensive experiments show that our method not only scales efficiently to large-scale scenes, but also achieves state-of-the-art results on both camera pose estimation and novel view synthesis benchmarks, including TUM-RGBD, CO3Dv2, and Tanks & Temples. Code and models are publicly available here.

1. Introduction

Structure-from-Motion (SfM) algorithms simultaneously estimate camera poses and scene structures from a collection of unordered images. This problem underlies many computer vision applications, such as novel view synthesis with NeRFs [3, 44], 3DGS [31], multi-view stereo (MVS) reconstruction [96], and visual localization [7]. Traditional SfM methods work either in incremental [59, 64] or global [13, 48] approaches, which rely on crucial components such as feature detection [18], correspondence matching [56], triangulation, and bundle adjustment [77] for joint camera pose and scene structure optimization. However, these individual components are fragile to low-texture, blurred or repeated patterns, which could lead to catastrophic failures in the SfM process.

*Equal contribution.
†Corresponding authors.
E-mail: pingtan@ust.hk, xiaoyang.guo@horizon.auto

To overcome the limitation of conventional SfM methods, more recent works [45, 86, 88, 93] develop an end-to-end learning-based SfM pipeline to directly regress scene structures and camera poses from input images. DUSt3R [88] pioneers this scene regression-based approach by training a Transformer [80] to regress the scene coordinate maps (SCM) of two unposed images, which can be used to solve camera poses and correspondences. Some following works [22, 45, 93] extend DUSt3R to multiple input images with 3D constraints, such as scene graph optimization and global alignment. VGGT [86] develops the first large Transformer model to regress almost all 3D results end-to-end with a large dataset and multiple supervisions. Scene regression methods show impressive performance and robustness in handling unposed images with extreme viewpoint changes.

However, many scene regression methods, e.g., VGGT [86], cannot scale up to videos or a large number of input images, as GPU memory usage increases quickly with more images. Some methods [42, 82, 87] tackle video inputs using iteratively updated global memory tokens to fuse the features of each incoming frame, and regress scene coordinate maps conditioned on these memory tokens. Others [22, 43] divide the input video into segments, reconstruct each segment, and align different reconstructions using $Sim(3)$ or $SL(4)$. Both approaches suffer from pose drifting and are heavily dependent on subsequent global alignment to mitigate pose errors.

On the other hand, existing scene regression methods ignore visual localization, a fundamental 3D task to solve the pose of a query image. Localization can facilitate scaling up an SfM system, a principle commonly employed in simultaneous localization and mapping (SLAM) systems [91], where mapping is only performed at keyframes and localization is applied to non-keyframes for better memory and computation efficiency. Our work seeks to augment scene regression with localization to scale it up similarly.

Most existing learning-based visual localization works [7–9, 30] require time-consuming per-scene optimization and accurate camera pose annotations for the

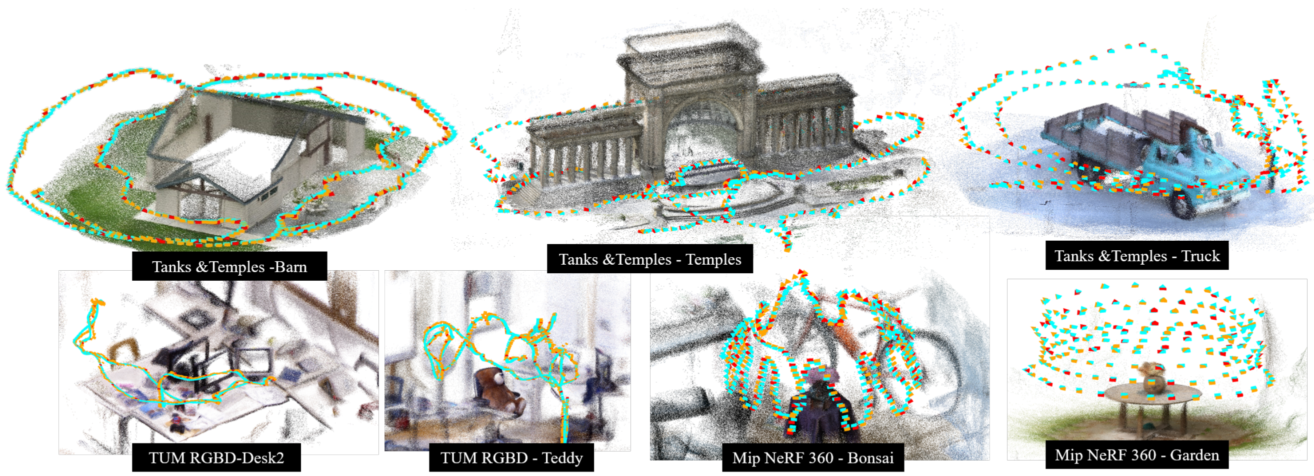

Figure 1. **Regressed Camera Poses and Point Clouds.** We visualize the camera poses and point clouds predicted by SAIL-Recon across various datasets. COLMAP or ground-truth camera poses are shown as blue frustums, while regressed camera poses are shown in yellow, with red indicating anchor images. As illustrated, SAIL-Recon estimates camera poses with accuracy comparable to COLMAP and produces high-quality, geometrically consistent point clouds.

reference frames. In contrast, we seek to fuse reconstruction and localization into a unified, annotation-free multitask framework for efficient scene regression. Specifically, given a large set of input images or video sequences, we first select a subset of anchor images to generate a global neural scene representation in a single forward pass, thereby avoiding the per-scene training required by previous localization methods. The neural scene representation serves as an implicit neural map of the scene, without relying on explicit 3D points or meshes. Subsequently, the neural scene representation, together with all remaining images, is fed into the same network to jointly recover scene coordinate maps and camera poses for each image. This approach allows for efficient reconstruction of thousands of images in just a few minutes. Unlike the localization process in SLAM systems, we regress map points for all images to produce a more complete 3D map that facilitates robust and dense reconstruction.

Our primary contributions are summarized as follows:

- We introduce SAIL-Recon, a novel feedforward SfM method that generalizes neural scene regression to include localization, resulting in precise and robust reconstruction for thousands of input images in a few minutes.
- We extract a neural scene representation from scene regression network as a global implicit map for localization.
- We demonstrate through extensive experiments that SAIL-Recon outperforms both traditional and learning-based baselines and achieves state-of-the-art results on SfM and visual localization benchmarks.

2. Related Works

Geometric Structure-from-Motion (SfM) is a classic computer vision problem [25], which aims to estimate camera poses and 3D scene structures from a collection of unposed images. Traditional SfM solutions are categorized into two main approaches: Incremental SfM [1, 64] initiates the reconstruction with a pair of images and progressively grows it by including images one by one; Global SfM methods [13, 29, 48, 90] determine the global pose of all images simultaneously by motion averaging. Both approaches rely on feature matching, triangulation, and bundle adjustment. Deep learning has significantly advanced these various components, especially in keypoint detection [17, 21, 79] and feature matching [12, 39, 56, 61]. Beyond individual modules, several methods [9, 63, 71, 75, 76, 85, 89] have explored end-to-end differentiable SfM by explicitly enforcing geometric constraints and minimizing reprojection or photometric errors.

Scene Regression-based SfM recovers 3D structures and camera poses from uncalibrated images directly without explicitly enforcing geometric constraints. DUSt3R [88] first employs a transformer model to predict the scene coordinate maps for a pair of images. Subsequent methods employ a global optimization step to expand its result to multiple images [45, 87, 88]. Recent advances have adapted DUSt3R to reconstruct multiple inputs directly [22, 74, 93, 99], and to deal with video inputs with incremental reconstruction [42, 43, 45, 82, 87]. VGGT [86] takes this endeavor further, which addresses nearly all 3D vision tasks in a comprehensive end-to-end fashion with minimum inductive biases while utilizing extensive training data. However, these methods often face challenges when scaling to a large number of input images and may suffer from driftings, even when equipped with additional global alignment.

Visual Localization often relies on a 3D map with reference images of known camera poses. Feature-based ap-

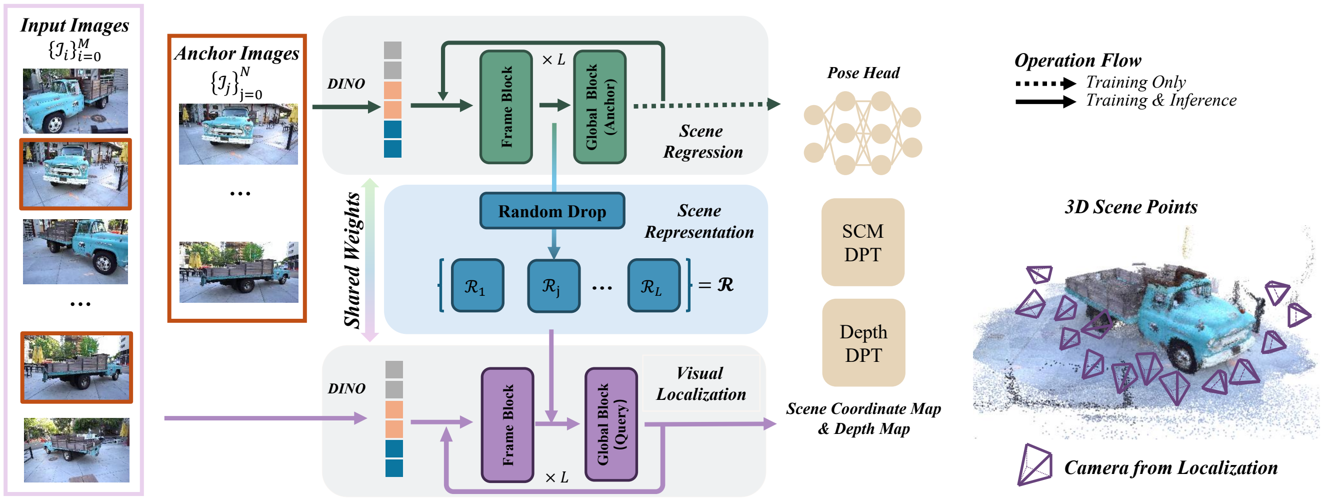

Figure 2. **Architecture Overview.** From a large set of unposed images, we first select a subset as anchor images, which are patchified by DINO [47] with appended camera tokens for scene regression. The *Scene Regression* block extracts a neural scene representation $\mathcal{R}$, which is then used by the *Visual Localization* block to compute the camera poses and 3D scene points for all images.

proaches extract 2D local features [18, 21, 57, 69] from a query image and match [39, 56] them to 3D points and estimate the query image pose using a perspective-n-point (PnP) algorithm [23]. For large-scale scenes, feature matching focuses on a subset of database images most relevant to the query, improving both accuracy and efficiency [28, 52, 55, 58]. Some learning-based approaches [2, 19, 30, 33, 73, 78, 95] encode the map into a neural network that directly predicts the pose of the query image. The scene coordinate regression approaches [6–8, 16, 62, 68] fit a scene-specific network to predict the 3D coordinates of the image pixels. Most of the localization methods require expensive per-scene training of the localization network. Only a few methods [72, 78, 94] estimate camera pose utilizing a network that simultaneously processes the 3D reconstruction and query image, thus bypassing the need for per-scene fitting. Unlike previous methods, SAIL-Recon circumvents expensive per-scene training by deriving a latent scene representation through scene regression, which is subsequently employed for visual localization.

3. Method

This section presents SAIL-Recon, a unified framework for robust and efficient SfM with thousands of input images from various indoor or outdoor scenes, as shown in Fig. 1. To handle such scenes, we augment *Neural Scene Regression* with *Visual Localization*, which significantly reduces computational costs. We first provide an overview of SAIL-Recon in Sec. 3.1. We then introduce and review the scene regression backbone in Sec. 3.2, which estimates camera parameters and 3D structures from unordered input images. Building upon neural scene regression, Sec. 3.3 details our approach for constructing a neural scene representation. This representation subsequently serves as the foundation for the visual localization introduced in Sec. 3.4. Sec. 3.5 presents the training methodology, while Sec. 3.6 describes an optional refinement stage.

3.1. Overview

The pipeline of our approach is illustrated in Fig. 2. The core contribution of SAIL-Recon lies in the construction of a neural scene representation from a sparse subset of input images. Instead of relying on explicit geometric prior (e.g., point clouds, posed images), we leverage a neural representation that jointly encodes local visual features and global scene geometry from unposed images. This compact representation enables efficient visual localization across the entire image collection.

Motivated by the impressive performance of VGGT [86], we adopt it as our backbone and augment its scene regression capability by the *Visual Localization* block in Fig. 2, to jointly compute a neural scene representation $\mathcal{R}$ as,

$$(\mathcal{R}, \{T_i, K_i, D_i, S_i\}_{i=1}^M) = \mathcal{T}_\theta(\{\mathcal{I}_i\}_{i=1}^M), \tag{1}$$

where $\{\mathcal{I}_i\}_{i=1}^M$ is the unordered input image set, M is the total number of input images. $\mathcal{T}_\theta$ is a transformer-based network with self-attention blocks parameterized by θ, and $\mathcal{R}$ is the neural scene representation for visual localization. The camera pose of $\mathcal{I}_i$ is specified by the extrinsic and intrinsic matrices $T_i \in \mathbb{R}^{4\times4}$ and $K_i \in \mathbb{R}^{3\times3}$. Furthermore, $D_i \in \mathbb{R}^{H\times W}$ and $S_i \in \mathbb{R}^{H\times W\times3}$ represent the depth map and the scene coordinate map (SCM) for $\mathcal{I}_i$, respectively.

The formulation in Eq. 1 is memory and time consuming. It typically cannot handle more than 100 input images on consumer GPUs. To address this, we use a subset of images, called *Anchor Images* in Fig. 2, to compute the neural scene representation $\mathcal{R}$. Without losing generality, we uniformly sample $N \in [50, 100]$ anchor frames $\{\mathcal{I}_i\}_{i=1}^N$ from the full set $\{\mathcal{I}_i\}_{i=1}^M$, where M often exceeds 1,000 in large-scale scenes. As illustrated by the *Visual Localization* block in Fig. 2, once we have the scene representation $\mathcal{R}$, we augment the scene regression network $\mathcal{T}_\theta$ to enable localization of a query image $\mathcal{I}^q$ as,

$$\{T^q, K^q, D^q, S^q\} = \mathcal{T}_\theta(\mathcal{I}^q, \mathcal{R}), \tag{2}$$

where T^q and K^q are the extrinsics and intrinsics matrices, and D^q and S^q are the depth and scene coordinate maps of the query image $\mathcal{I}^q$. $\mathcal{T}_\theta$ is the network for both scene regression and localization. We will provide details in Sec 3.4.

Note that we estimate camera parameters and 3D maps of anchor frames during **TRAINING ONLY**, as indicated by the *Operation Flow* in Fig. 2. During inference, we first extract $\mathcal{R}$ from the anchor frames and then process all input images conditioned on $\mathcal{R}$. Although all input images could be reconstructed in a single forward pass in principle, we process them in batches due to GPU memory constraints.

3.2. Neural Scene Regression

The scene regression network [86] takes a set of unposed anchor images $\{\mathcal{I}_i\}_{i=1}^N$ as input. Each anchor image $\mathcal{I}_i$ is fed into DINOv2 [47] to extract patchified feature tokens $t^{\mathcal{I}_i} \in \mathbb{R}^{K \times C}$, where $K = (W/14) \times (H/14)$. We follow VGGT [86] to augment $t^{\mathcal{I}_i}$ with an additional camera token $t_g^{\mathcal{I}_i} \in \mathbb{R}^{1 \times C}$ and four register tokens $t_r^{\mathcal{I}_i} \in \mathbb{R}^{4 \times C}$. The tokens from all anchor frames $\{t^{\mathcal{I}_i}\}$ are subsequently processed through $L = 24$ layers of frame-wise and global self-attention as,

$$\{t_j^{'\mathcal{I}_i}\} = \text{attn}_j^{\text{frame}}(\{t_j^{\mathcal{I}_i}\}), \tag{3}$$

$$t_{j+1}^{\mathcal{I}} = \text{attn}_j^{\text{global}}(t_j^{'\mathcal{I}}), \tag{4}$$

where j indexes the attention layers and $\{t_j^{'\mathcal{I}_i}\}$ is the output of frame-wise attention for $\mathcal{I}_i$. $t_j^{'\mathcal{I}} = [\{t_j^{'\mathcal{I}_i}\}_{i=1}^N]$ is the concatenation of all image tokens in the j-th layer. The global attention result $t_{j+1}^{\mathcal{I}}$ is then split along the view dimension into $\{t_{j+1}^{\mathcal{I}_i}\}$ for the frame-wise attention in the next layer.

The image tokens $\{t_L^{\mathcal{I}_i}\}$ in the last layer are then fed into DPT heads [51] to predict depth maps D_i and scene coordinate maps S_i for the input image $\mathcal{I}_i$ as follows,

$$\{D_i, C_i^D, S_i, C_i^S\} = \text{DPT}(\{t_L^{\mathcal{I}_i}\}), \tag{5}$$

where C_i^D and C_i^S are the confidence maps of depth and scene coordinate maps, respectively.

The camera tokens $t_g^{\mathcal{I}_i}$ associated with $\mathcal{I}_i$ on the last layer are processed by a camera head to estimate the intrinsic and extrinsic camera parameters as follows,

$$\{T_i, K_i\} = \text{PoseHead}(\{t_g^{\mathcal{I}_i}\}). \tag{6}$$

3.3. Neural Scene Representation

Scene representation is essential for visual localization. An effective scene representation should encode global 3D scene structure and facilitate correspondences between 3D map points and 2D image pixels. A straightforward choice is to use tokens $t_L^{\mathcal{I}}$ in the final attention layer as scene representation, as these tokens can be used to recover camera poses and dense 3D points map. In other words, we could set $\mathcal{R} = t_L^{\mathcal{I}}$ and then estimate the pose and 3D structure of a query image $\mathcal{I}^q$ by Eq. 2. However, the significant discrepancy between 2D and 3D feature tokens makes it difficult for the network $\mathcal{T}_\theta$ to correlate these feature tokens, even $\mathcal{T}_\theta$ contains a large number of parameters. We empirically find that this design leads to suboptimal results.

Ideally, the scene representation should effectively bridge the gap between 2D and 3D features. Inspired by the fact that the network $\mathcal{T}_\theta$ takes a set of 2D images as input and progressively enhances them to compute 3D structures, we extract intermediate feature tokens from each attention layer of $\mathcal{T}_\theta$ to form the scene representation $\mathcal{R}$. In this way, our scene representation $\mathcal{R}$ captures the gradual evolution from 2D appearance features to 3D coordinate descriptors. Specifically, we compute our scene representation as,

$$\mathcal{R} = [\{\Theta(t_j^{'\mathcal{I}})\}_{j=1}^L], \tag{7}$$

where Θ denotes a random downsampling operation applied to intermediate feature tokens $t_j^{'\mathcal{I}}$ to keep the scene representation compact. Specifically, for the anchor frame feature token $t_j^{'\mathcal{I}} \in \mathbb{R}^{N \times K \times C}$, we randomly select a ratio $r \in [0.2, 1.0]$ to sample a subset of tokens in each anchor frame to control the total size of $\Theta(t_j^{'\mathcal{I}}) \in \mathbb{R}^{(N \times \lfloor r \times K \rfloor) \times C}$ in a reasonable range during training. At testing time, we could choose an appropriate r based on the number of the anchor frames to balance between accuracy and efficency.

3.4. Neural Visual Localization

As described in Eq. 4, the global attention block in $\mathcal{T}_\theta$ aggregates tokens among all anchor frames via self-attention. For visual localization, given a query image $\mathcal{I}^q$, we introduce an attention mask in the global attention blocks, which essentially allows us to compute the cross attention between the query image $\mathcal{I}^q$ and the scene representation $\mathcal{R}_j = \Theta(t_j^{'\mathcal{I}})$:

$$t_{j+1}^q = \text{attn}_j^{\text{global}}(\{t_j^q, \mathcal{R}_j\}). \tag{8}$$

Specifically, tokens from query frames cannot attend to tokens from other query frames; they can only attend to tokens within the same frame and to the scene representation. More details are provided in the Supplementary.

During inference of visual localization, one choice is to compute the camera parameters by applying the PnP algorithm [23] with the scene coordinate map S^q from the DPT head. However, it takes a long time for DPT to up-sample tokens to a high-resolution scene coordinate map. To accelerate pose estimation, we leverage the pose head, which takes only a few camera tokens $t_g^{\mathcal{I}_i}$ as input and directly regresses the camera pose.

$$\{T^q, K^q\} = \text{PoseHead}(t_g^q, \{t_g^{\mathcal{I}_i}\}), \tag{9}$$

where t_g^q and $\{t_g^{\mathcal{I}_i}\}$ are the camera tokens of the query image and the anchor images, respectively. The attention mask is also applied in the pose head. Thus, we can formulate our visual localization for all images as follows,

$$\{T_i, K_i, D_i, S_i\}_{i=1}^M = \mathcal{T}_\theta(\{\mathcal{I}_i\}_{i=1}^M, \mathcal{R}). \tag{10}$$

Note that the anchor images are also processed by this localization block. The scene regression block only extracts the neural scene representation from anchor images.

3.5. Training

Training Losses. During training, we split the input images into the anchor image set and the query image set. We could forward all images in the anchor and query set in a single pass. To this end, we train the SAIL-Recon model $\mathcal{T}_\theta$ end-to-end using a multitask loss on each frame similar to VGGT [86] as,

$$\mathcal{L} = \mathcal{L}_{\text{camera}} + \mathcal{L}_{\text{depth}} + \mathcal{L}_{\text{scm}}. \tag{11}$$

The camera pose loss $\mathcal{L}_{\text{camera}}$ compares the predicted camera parameters $\hat{g}_i$ with the ground truth g_i as

$$\mathcal{L}_{\text{camera}} = \sum_{i=1}^{N} \|\hat{g}_i - g_i\|_1 , \tag{12}$$

where $g_i = [\mathbf{q}, \mathbf{t}, \mathbf{f}]$ includes the camera orientation encoded in a quaternion $\mathbf{q}$, the translation vector $\mathbf{t}$, and the field of view $\mathbf{f}$. We assume that the principal point is at the image center. The depth loss $\mathcal{L}_{\text{depth}}$ follows DUSt3R [88] to measure the discrepancy between the predicted depth $\hat{D}_i$ and the ground truth depth D_i with a predicted uncertainty map $\hat{C}_i^D$. We follow [86] to add a gradient-based smooth term on the depth loss,

$$\mathcal{L}_{\text{depth}} = \sum_{i=1}^{N} \|C_i^D \odot (\hat{D}_i - D_i)\| + \|(\nabla \hat{D}_i - \nabla D_i)\| - \alpha \log C_i^D,$$

where $\odot$ is an element-wise product. The loss of the scene coordinate map is defined similarly as,

$$\mathcal{L}_{\text{scm}} = \sum_{i=1}^{N} \|C_i^S \odot (\hat{S}_i - S_i)\| + \|(\nabla \hat{S}_i - \nabla S_i)\| - \alpha \log C_i^S.$$

Coordinate Normalization. During training, we randomly select an image $\mathcal{I}_r$ among the anchor images as the reference frame. We then compute the average Euclidean distance from the camera center of $\mathcal{I}_r$ to the 3D points of all anchor frames. We use this scale to normalize the 3D scene and the associated depth and scene coordinate maps.

Method	Align.	RRA@5 ↑	RTA@5 ↑	ATE ↓	Reg. ↑	Time [s] ↓
COLMAP [60]	OPT	GT	GT	GT	GT	-
GLOMAP [48]	OPT	75.8	76.7	0.010	100.0	1977
ACE0 [9]	OPT	56.9	57.9	0.015	100.0	5499
DF-SfM [26]	OPT	69.6	69.3	0.014	76.2	-
FlowMap [63]	OPT	31.7	35.7	0.017	66.7	-
VGGSfM [85]	OPT	-	-	-	0.0	2134
MASt3R-SfM [20]	OPT	49.2	54.0	0.011	100.0	2723
DROID-SLAM [76]	OPT	31.3	40.3	0.021	100.0	240
SAIL-Recon-OPT	OPT	71.5	77.7	0.008	100.0	233
Cut3R† [87]	FFD	18.8	25.8	0.017	100.0	42
Spann3R† [83]	FFD	22.1	30.7	0.016	100.0	116
SLAM3R† [42]	FFD	20.3	24.7	0.015	100.0	70
Light3R-SfM [22]	FFD	52.0	52.8	0.011	100.0	63
VGGT-SLAM*△ [43]	FFD	57.3	67.9	0.008	100.0	238
SAIL-Recon	FFD	70.4	74.7	0.008	100.0	81

Table 1. **Pose Estimation on Tanks & Temples. [32].** This dataset contains on average over 300 images per scene. We visualize the results using three colors: Best, Second, and Third. A '–' indicates cases where all scenes failed to converge or the running time is unavailable; † denotes that sequential input is required; * indicates evaluation on keyframes; and △ denotes that some sequences fail. 'OPT' stands for optimization-based and 'FFD' stands for feedforward-based.

3.6. Post Refinement

Employing a post-refinement step, such as bundle adjustment (BA) [77], can enhance reconstruction accuracy, particularly when the reconstruction is inferred directly from the network. Previous methods rely on global alignment using depth maps via gradient descent [45, 87, 88], while others use bundle adjustment with pixel correspondences [86]. Both methods are time-consuming and scale poorly to a large number of input images. Since our method provides accurate camera poses in a global coordinate system, we adopt BARF-like methods [37, 70] to optimize camera poses by minimizing a rendering loss. Although this optimization is weaker than bundle adjustment or global alignment, it scales to more than 10K frames and takes only 2-10 minutes. Note that this post-optimization is optional, since the camera poses and scene structures regressed by SAIL-Recon yield strong results for many applications. Further details are provided in Sec. 4.

4. Experiment

In this section, we present a comprehensive evaluation across diverse datasets, covering a wide range of scenarios. We also perform detailed ablation studies to identify the key factors determining the performance of our model. Additional implementation details for both training and inference are provided in the supplementary material.

Training Details. Our training is similar to the setup of VGGT [86]. We train our model by fine-tuning VGGT [86] pre-trained checkpoints. For each batch, we sample 4–48 images, randomly designating 2–24 as anchor frames and treating the remaining images as query frames. We train 30K iterations on 16 NVIDIA A800

Method	Sequence									Avg.
	`360`	`desk`	`desk2`	`floor`	`plant`	`room`	`rpy`	`teddy`	`xyz`	
DROID-SLAM* [76]	0.202	0.032	0.091	0.064	0.045	0.918	0.056	0.045	0.012	0.158
MASt3R-SLAM* [45]	0.070	0.035	0.055	0.056	0.035	0.118	0.041	0.114	0.020	0.060
VGGT-SLAM (Sim(3)) [43]	0.123	0.040	0.055	0.254	0.022	0.088	0.041	0.032	0.016	0.074
VGGT-SLAM (SL(4)) [43]	0.071	0.025	0.040	0.141	0.023	0.102	0.030	0.034	0.014	0.053
SAIL-Recon (Offline)	0.070	0.024	0.042	0.107	0.031	0.113	0.020	0.037	0.012	0.051

Table 2. **Root Mean Square Error (RMSE) of Absolute Trajectory Error (ATE) on the TUM RGB-D [66] dataset (unit: m)**. We evaluate methods under an uncalibrated configration following VGGT-SLAM [43], while methods marked with * indicate the intrinsic matrics are provided by GeoCalib [81]. We color result in: Best, Second, and Third.

GPUs, which takes about four days. We use a diverse mixture of synthetic and real-world datasets, including Co3Dv2 [53], BlendMVS [97], DL3DV [40], MegaDepth [35], WildRGB [92], ScanNet++ [98], HyperSim [54], Mapillary [46], Replica [67], MVS-Synth [27], Virtual KITTI [10], Aria Synthetic Environments, and Aria Digital Twin [49]. These datasets, which represent a subset of those in VGGT [86], are weighted according to their relative sizes to ensure that each dataset contributes proportionally to the overall training process. Please refer to the Supplemental Material for more training details.

4.1. Pose Accuracy Benchmark

We follow [9, 22, 43] to evaluate camera pose accuracy on three benchmarks: Tanks & Temples [32], TUM-RGBD [66], and 7-Scenes [62]. These datasets cover indoor and outdoor environments with image sets and video sequences ranging from 300 to 20k images per scene. We exclude comparisons with methods such as [45, 86, 88, 93] that cannot operate on datasets of this size within a reasonable resource budget. We compute our neural scene representation with 300 tokens from each anchor frame, with a downsample ratio $r \approx 0.2$. All runtime comparisons are conducted under similar GPU throughput conditions, using the Nvidia V100 as the reference hardware.

Tanks & Temples is a dataset includes 21 large-scale indoor and outdoor scenes, with 150–$1,100$ images per scene. We follow [20, 22] to compare our method with optimization-based (OPT) and feedforward-based (FFD) approaches, defined by whether they utilize an explicit optimization on the 3D structure and camera poses. In the OPT category, we compare against DF-SfM [26], GLOMAP [48], PixelSfM [38], VGGSfM [85], ACE-Zero [9], FlowMap [63], and MASt3R-SfM [20]. In the FFD category, we compare with Spann3R [83], Cut3R [87], SLAM3R [42], and Light3R-SfM [22]. We follow [22, 45] to report the proportion of camera pairs with relative rotation error (RRA@5) and relative translation error (RTA@5) below 5^o. The mean value of average translation error (ATE) is calculated between the estimated camera poses and the normalized ground truth poses after Procrustes alignment [24]. As shown in Tab. 1, our method (FFD), significantly outperforms all feedforward-based baselines, including Cut3R [87], Spann3R [83], and SLAM3R [42]. These methods suffer from pose drift due to their incremental reconstruction manner on sequential input. VGGT-SLAM [43] achieves the second best results in average, but only recovers keyframe camera poses and fails to reconstruct *Church*, *Courtroom* and *Palace* due to unstable numerical optimization in the $SL(4)$ manifold. Light3R-SfM [22] is more robust by minimizing pose error on the spanning-tree based scene graph, but with much lower accuracy. Our method achieves SOTA performance while incurring only a marginal computational overhead compared to Light3R-SfM. Furthermore, ours (OPT), which utilized 10K iterations of post-refinement, delivers superior performance in all metrics and is competitive with GLOMAP [48], with only a marginal increase in runtime.

TUM-RGBD is a widely used SLAM benchmark, where each video sequence contains 500–3,000 images. We uniformly select 50 frames as anchor images. Note that our method is an offline SfM method. Here, we show that our method achieves performance similar to that of some SOTA SLAM systems following the standard split in [15, 76]. We exclude Cut3R [87] and SLAM3R [42] from the evaluation because they fail on this benchmark. We evaluate the root mean square error (RMSE) of the absolute trajectory error (ATE) using the `evo` toolkit [24]. As shown in Tab. 2, our method achieves the best results in the uncalibrated setting, without any post-optimization. Results for the calibrated setting are provided in the Supplementary Files. In particular, compared to VGGT-SLAM [43], which employs nonlinear factor graph optimization to fuse multiple submaps, our approach achieves higher accuracy without optimization, demonstrating the effectiveness of augmenting scene regression by localization.

7 Scenes is a widely used localization benchmark that provides training and testing split with 2,000–12,000 images per scene. We follow ACE0 [9] to evaluate the localization accuracy. The visual localization methods [8, 9] will train a scene specific localization network with $1,000$-$4,000$ training images, which takes about 10 minutes to 2 hours depending on whether the ground truth camera poses are given. We report the total time of per scene training and localizing all images. We uniformly sample 50 images in the testing split as anchor frames and localize all images

Prior	ACE KinectFusion	ACE COLMAP	ACE0 OPT.	Ours FFD.
Chess	96.0%	100.0%	100.0%	98.8%
Fire	98.4%	99.5%	98.8%	100.0%
Heads	100.0%	100.0%	100.0%	100.0%
Office	36.9%	100.0%	99.1%	87.4%
Pumpkin	47.3%	100.0%	99.9%	92.8%
Redkitchen	47.8%	98.9%	98.1%	89.9%
Stairs	74.1%	85.0%	61.0%	87.9%
Average	74.1%	97.6%	93.8%	93.8%
Average Time	14min	14min	2h	8min

Table 3. **Localization on 7-Scenes.** Percentage of pose error under (5cm, 5°), compared to pseudo ground truth computed by COLMAP. ACE requires known camera poses during training. Our method achieves comparable localization accuracy to ACE0, where neither approach relies on camera poses in the training set. However, our method is significantly faster than ACE0, which performs self-supervised optimization.

in the same split. As shown in Tab. 3, ACE+COLMAP achieves the best performance since it uses ground truth camera poses in training. Without knowing ground truth camera poses, ACE0 and our method achieve the same average localization accuracy. However, ACE0 takes 2 hours to optimize a scene with $4,000$ frames, while SAIL-Recon uses only 8 minutes. We provide more results on 7-Scenes in Supplemantary Files.

4.2. Novel View Synthesis Benchmark

As observed in ACE0 [9], the evaluation of camera poses is sometimes unreliable, as the pseudo ground-truth from COLMAP is only an estimation. Thus, we follow ACE0 [9] to further evaluate camera pose quality through novel view synthesis. Specifically, for each method, we first estimate camera poses for all images of a scene. We then split these images into training and testing sets, and train a Nerfacto [70] model on the training set and render images in the testing view. The rendered images at the testing views are then compared with the ground truth testing images using the Peak Signal-to-Noise Ratio (PSNR) as an indicator of pose accuracy. This evaluation is carried out on the Mip-NeRF 360 [4] and Tanks & Temples [32] datasets. For this evaluation, we enable the post-refinement mentioned in Sec 3.6, since even slight pose noise can prevent the Nefacto model from converging, resulting in poor PSNR. Note that **ALL** baselines in this benchmark are optimization-based methods. Similarly to Sec 4.1, we exclude comparisons with methods [45, 86, 88, 93] that cannot operate on datasets of this size within a reasonable resource budget. We exclude [42, 82] due to poor performance.

Tanks & Temples has two sub-datasets: images and video sequences. For the image set, each scene contains 150–600 images. The video sequence contains $4,000$–$20,000$ frames. We use 100 anchor frames at each scene and evaluate our method in both subsets following ACE0 [9]. We report the results on the image set and leave the comparison on the video sequences in the Supplemantary. Results of compared methods are quoted from ACE0 [9].

		Frames	CMP (D)	Reality Capture	DROID-SLAM† [76]	ACE0 [9]	Ours
Training	Barn	410	24.0	21.2	19.0	16.5	23.5
	Catpr.	383	17.1	15.9	16.6	16.9	16.8
	Church	507	18.3	17.6	14.3	17.2	17.0
	Ignatius	264	20.1	17.7	17.8	19.8	19.5
	MtgRm.	371	18.6	18.1	15.6	18.0	19.5
	Truck	251	21.1	19.0	18.3	20.1	20.9
	Average	364	19.9	18.2	16.9	18.1	19.5
	Time		1h	3min	5min	1.1h	3.5min
Intermediate	Family	152	19.5	18.8	17.6	19.0	20.6
	Francis	302	21.6	20.7	20.7	20.1	21.8
	Horse	151	19.2	19.0	16.3	19.5	20.1
	LightH.	309	16.6	16.5	13.6	17.5	18.2
	PlayGd.	307	19.1	19.2	11.4	18.7	20.3
	Train	301	16.8	15.4	13.8	16.2	16.2
	Average	254	18.8	18.3	15.6	18.5	19.5
	Time		32min	2min	3min	1.3h	3min
Advanced	Audtrm.	302	19.6	12.2	16.7	18.7	20.3
	BallRm.	324	16.3	18.3	13.1	17.9	14.8
	CortRm.	301	18.2	17.2	12.3	17.1	17.4
	Palace	509	14.2	11.7	10.8	10.7	14.3
	Temple	302	18.1	15.7	11.8	9.7	17.8
	Average	348	17.3	15.0	12.9	14.8	16.9
	Time		1h	2min	4min	1h	3.5min

Table 4. **Tanks & Temples.** Pose accuracy via view synthesis with Nerfacto [70]. We report the PSNR in dB and the average reconstruction time. We color code in: Best, Second, and Third. † indicates methods needing sequential inputs.

	Pseudo GT COLMAP	DROID-SLAM†[76]	BARF [37]	Nope-NeRF[5]	ACE0 [9]	Ours
Bicycle	21.5	10.9	11.9	12.2	18.7	20.50
Bonsai	27.6	10.9	12.5	14.8	25.8	26.76
Counter	25.5	12.9	11.9	11.6	24.5	25.51
Garden	26.3	16.7	13.3	13.8	25.0	24.92
Kitchen	27.4	13.9	13.3	14.4	26.1	27.43
Room	28.0	11.3	11.9	14.3	19.8	27.46
Stump	16.8	13.9	15.0	13.9	20.5	20.83
Average	24.7	12.9	12.8	13.5	22.9	24.77
Average Time	1h	2min	4h	≥24h	8h	5min

Table 5. **Mip-NeRF 360.** Pose accuracy via view synthesis PSNR. Higher is better. We color code in: Best, Second, and Third. † indicates methods needing sequential inputs.

We use COLMAP with the *default* setting CMP (D) as a reference in Tab. 4. We enable post-refinement with 10K iterations. Our approach achieves the highest PSNR among all baselines, achieving COLMAP-level accuracy while recovering all camera poses in 3-4 minutes. This is significantly faster than COLMAP and ACE0, and is comparable to SLAM systems such as DROID-SLAM, which suffers from pose drifting and produces the lowest PSNR.

Mip-NeRF 360. Mip-NeRF 360 [4] is a small-scale dataset containing indoor and outdoor scenes with around 150–500

Method	Global Align.	Co3Dv2↑		
		RRA@15	RTA@15	mAA@30
Colmap [59]	OPT	31.6	27.3	25.3
Glomap [48]	OPT	45.9	40.3	37.3
PixSfM [38]	OPT	33.7	32.9	30.1
VGGSfM [85]	OPT	92.1	88.3	74.0
DUSt3R-GA [88]	OPT	96.2	86.8	76.7
MASt3R-SfM [20]	OPT	96.0	93.1	88.0
PoseDiff [84]	FFD	80.5	79.8	66.5
RelPose++ [36]	FFD	82.3	77.2	65.1
Spann3R [83]	FFD	89.5	83.2	70.3
MASt3R * [34]	FFD	94.5	80.9	68.7
Light3R-SfM [22]	FFD	94.7	85.8	72.8
VGGT [86]	FFD	98.4	94.8	88.2
SAIL-Recon $N = 10$	FFD	98.3	94.0	88.1
SAIL-Recon $N = 8$	FFD	98.2	93.6	87.3
SAIL-Recon $N = 5$	FFD	97.7	92.2	85.0
SAIL-Recon $N = 2$	FFD	96.4	89.7	78.5

Table 6. **Ablation on the number of anchor views for pose estimation performance on CO3Dv2 [53].** We evaluate pose estimation accuracy by varying the number of anchor views from 10 input images, randomly sampled from each sequence.

images per scene. We select 50 anchor images per scene and enable post-refinement with 10K iterations. The results are reported in Tab. 5. Again, results of all baseline methods are quoted from ACE0 [9]. Our approach surpasses all baselines, matching PSNR scores with pseudo ground-truth poses from COLMAP. NoPe-NeRF[5] and DROID-SLAM [76] struggle due to wide baselines between images, with NoPe-NeRF[5] needing two days of training. BARF [37] has difficulty starting from scratch. ACE0 [9] is inferior to SAIL-Recon in both accuracy and runtime.

4.3. Ablations

Number of Anchor Images. We evaluate the effect of the number of anchor images on the CO3Dv2 dataset [53]. For each 10 input images, we randomly select $N \in 2, 5, 8, 10$ anchor images to compute the neural scene representation and localize all 10 images. As shown in Tab. 6, our method maintains pose accuracy close to the original VGGT. Its performance drops slowly as the number of anchor images decreases. Remarkably, even with as few as two anchor images, our method still delivers strong performance, underscoring its robustness to sparse anchor images.

Number of Tokens/Downsample Ratio r. We investigate the impact of the number of downsampled tokens per anchor image on both pose accuracy and runtime with the number of anchor images fixed at $N = 5$, as shown in Fig. 3. Increasing the number of tokens improves pose accuracy, but also leads to a steady growth in processing time. We selected 300 tokens per image as a trade-off, since it achieves reasonable accuracy with low computation cost.

Training Strategy. We further evaluate the effect of our training strategy. Specifically, during training, our method selects a random number of tokens per image. We compare it with two alternatives: (i) using a fixed number of

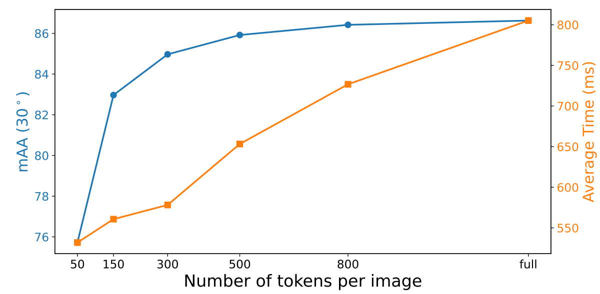

Figure 3. **Pose Accuracy & Runtime vs. Tokens per Image.** We choose 300 tokens per image to balance accuracy and efficiency.

Method	Co3Dv2↑			
	mAA@30	mAA@5	RRA@15	RTA@15
SAIL-Recon	**87.3**	**57.6**	**98.3**	**93.6**
Fixed token	86.5	53.6	98.2	93.6
Avg. Pooling	86.5	53.5	98.2	93.5

Table 7. **Ablation on Training Strategy.** We investigate the different training strategies on pose estimation accuracy.

tokens (300 per image) and (ii) applying average pooling over image tokens to achieve a $4\times$ downsampling (resulting in approximately 340 tokens per image). As shown in Tab. 7, our variant token strategy yields more accurate pose estimation. In particular, our method outperforms the average pooling baseline. We attribute it to dropout [65], where our random selection acts as a regularization mechanism, which improves generalization. Moreover, the variant token strategy offers greater flexibility than pooling, enabling an explicit trade-off between accuracy and efficiency.

5. Conclusion

We introduced SAIL-Recon, a feedforward SfM method that can scale up to thousands of input images. It is achieved by augmenting the scene regression Transformer with localization capabilities. By computing a neural scene representation from a subset of anchor images, we fine-tune the Transformer for localization conditioned on the neural scene representation. In this way, the fine-tuned Transformer can quickly reconstruct camera poses and scene points for all the input images. Experiments on various benchmarks show state-of-the-art results in both pose estimation and novel view synthesis, surpassing traditional and learning-based baselines in accuracy and efficiency.

Future Work & Limitation. While our model demonstrates strong performance, two key limitations remain. First, global pose estimation in a pre-fixed reference coordinate system might lead to a performance drop on some sequences. A better view selection criterion could improve results. Second, uniform anchor image sampling risks missing large or diverse scene regions. We could explore coverage-aware selection that maximizes visibility.

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