

# TinyVLA: Towards Fast, Data-Efficient Vision-Language-Action Models for Robotic Manipulation

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**Abstract**—Vision-Language-Action (VLA) models have shown remarkable potential in visuomotor control and instruction comprehension through end-to-end learning processes. However, current VLA models face significant challenges: they are slow during inference and require extensive pre-training on large amounts of robotic data, making real-world deployment difficult. In this paper, we introduce a new family of compact vision-language-action models, called TinyVLA, which offers two key advantages over existing VLA models: (1) faster inference speeds, and (2) improved data efficiency, eliminating the need for pre-training stage. Our framework incorporates two essential components to build TinyVLA: (1) initializing the policy backbone with robust, high-speed multimodal models, and (2) integrating a diffusion policy decoder during fine-tuning to enable precise robot actions. We conducted extensive evaluations of TinyVLA in both simulation and on real robots, demonstrating that our approach significantly outperforms the state-of-the-art VLA model, OpenVLA, in terms of speed and data efficiency, while delivering comparable or superior performance. Additionally, TinyVLA exhibits strong generalization capabilities across various dimensions, including language instructions, novel objects, unseen positions, changes in object appearance, background variations, and environmental shifts, often matching or exceeding the performance of OpenVLA. We believe that TinyVLA offers an interesting perspective on utilizing pre-trained multimodal models for policy learning. Our project is at <https://tiny-vla.github.io>.

## I. INTRODUCTION

Training multitasking robot imitators to operate in complex and uncertain environments faces considerable challenges due to limited data and the difficulty of learning physical motion [1], [2], [3], [4]. Moreover, traditional robot models struggle to adapt to new scenes and tasks and are easily affected by distractors, lighting conditions, and background changes [5], [6]. Modern methods typically leverage off-the-shelf Large Language Models (LLMs) [7], [8], [9], [10], [11], [12] for scene descriptions to generate object affordance, location, or heatmaps, followed by a predefined motion planner to complete the tasks [13], [14], [15], [16], [17], [18].

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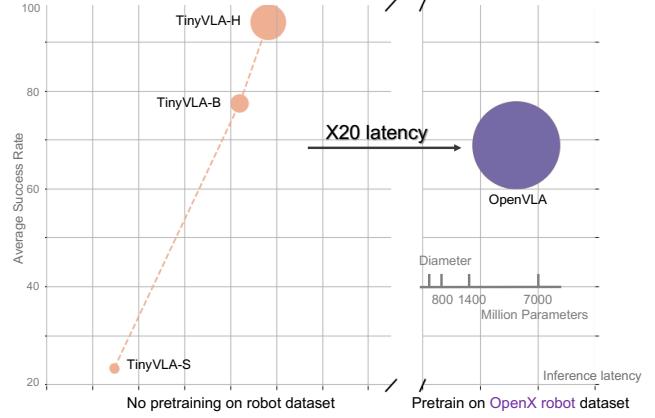


Fig. 1: **Inference Latency vs. Average Success Rate** for ◯ TinyVLA and ● OpenVLA in a single-arm, real-world Franka experiment. The y-axis represents the average success rate across five real-world tasks, with the bubble diameter indicating the number of model parameters. Inference latency was measured on the same A6000 GPU for both models. Our results show that TinyVLA-H outperforms OpenVLA, achieving superior performance with 20 times less inference latency.

Recently, vision-language-action (VLA) models have garnered significant attention for their ability to extend pre-trained vision-language models to robotics using a next-token prediction approach. Notable works, such as RT-2 [19] and OpenVLA [20], have demonstrated impressive performance in multi-task learning and generalization. However, these methods suffer from a critical drawback: extremely slow inference speeds, largely due to their dependence on large vision-language models and auto-regressive action token generation. In robotics, inference speed is crucial for enabling robots to respond instantly to user queries, directly impacting user experience and the robot’s overall effectiveness. In addition to the inference challenges, these models also require extensive pre-training on large-scale robotic datasets. For example, OpenVLA is pre-trained on the 970K-sample OpenX dataset [21], making the computational cost of training both expensive and resource-intensive. Given these challenges, a natural question arises:

**How can we build VLA models that retain the advantages of existing VLA models while being both fast and data-efficient?**

In this work, we propose TinyVLA, a compact vision-language-action model designed for fast inference. We identify two key factors in existing VLA models that contribute to

their high inference latency: (1) they are built on large vision-language models, often exceeding 7 billion parameters, and (2) they generate discrete action tokens autoregressively, requiring repetitive inference for each degree of freedom. To overcome these challenges, we first train and employ a family of small yet powerful vision-language models with fewer than 1 billion parameters. Then, instead of using the next token prediction technique to predict action tokens independently, we attach a diffusion-based head to the pre-trained multimodal model for direct robot action output. Consequently, we find that this combination enables TinyVLA to retain the prior knowledge and generalization capabilities gained from vision-language data pre-training, even without training on large-scale robot datasets like OpenX [21]. It efficiently adapts to new instruction and generalizes across various settings in a faster and more data-efficient manner.

In both simulations and real-world settings, our method demonstrates superior performance in multi-task learning compared to the baseline. For instance, in real-world experiments, TinyVLA-H achieves a 25.7% higher success rate than OpenVLA, while using 5.5 times fewer parameters. In bimanual real-robot experiments, we find that OpenVLA, which heavily relies on OpenX robot data pretraining, struggles to perform in bimanual settings due to OpenX consisting only of single-arm data. In contrast, TinyVLA-H significantly outperforms OpenVLA in these tasks. Additionally, we observed that TinyVLA generalizes well across diverse settings, including observational and spatial generalization, often matching or even surpassing OpenVLA in certain cases. We believe that TinyVLA offers a novel perspective to building vision-language-action models for embodied control.

## II. RELATED WORKS

Multimodal Models connect vision and language and extend the reasoning ability of LLMs to process with multimodal input. Numerous works have been proposed in this direction [22], [23], [24], [25], [26], [27], [28], [29], [30]. These MLLMs typically have parameters ranging from 7B to 70B, making the inference cost-prohibitive and limiting the accessibility of MLLMs to a wider audience. Recently, a select number of studies [31], [32], [33], [34], [35], [36], [37] have delved into the exploration of efficient multimodal, with a number of parameters less than 3B, from diverse angles. Robot learning [38], [39], [19], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61] is an crucial topic in the robotics. A number of works introduce vision-language models to the domain of embodied control, these representative works include RT-2 [19] and OpenVLA [20]. Our paper proposes a compact version of VLA models that does not require large-scale robot data pretraining and enables fast inference.

## III. METHOD

This section gives a comprehensive overview of our proposed TinyVLA. TinyVLA encompasses several crucial

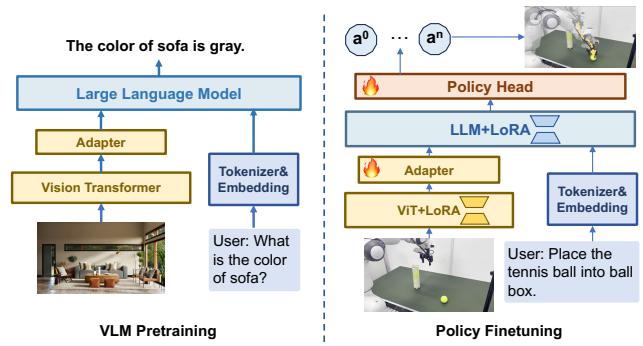


Fig. 2: **Model architecture.** The left image illustrates the VLM pretraining pipeline, whereas the right image demonstrates the process of training TinyVLA using robotic data.

designs: 1) We adopt a pre-trained Multimodal model as the initialization of a policy network; 2) During training the robot data, we freeze the pre-trained parts and utilize the parameter-efficient fine-tuning technique LoRA [62], where the trainable parameters account for only 5% of the entire model; 3) We introduce a policy decoder that concatenated to pre-trained multimodal model through a simple but efficient linear projection and output the executable action of the robot. An illustration of TinyVLA is given in Figure 2.

### A. Building TinyVLA with Efficient Vision-Language Models

The initial step involves acquiring pre-trained multimodal language models. While existing works typically focus on vision-language models with over three billion parameters, we trained a more compact vision-language model with parameters ranging from 40 million to 1.4 billion. Our model utilizes Pythia [63] as the language model backend. We then followed the training pipeline of LLaVA [25], using their vision-language dataset to train this family of VLMs. For robot data fine-tuning, we retained all modules from our VLM, including the visual backbone and the vision-language alignment module.

### B. Robot Data Finetuning for Manipulation

**Frozen weights and low-rank adaptation.** We employ the parameter-efficient training method, LoRA [62], which limits gradient updates to a low-dimensional space. This is achieved by modifying the weight matrix  $W \in \mathbb{R}^{d \times k}$  to  $W_0 + \Delta W = W_0 + BA$ , with  $B \in \mathbb{R}^{d \times r}$  and  $A \in \mathbb{R}^{r \times k}$ , where  $r$  is significantly smaller than either  $d$  or  $k$ . We incorporate low-rank matrices into the attention mechanisms' weights ( $Q, K, V$ ) while freezing the remaining weights of the Transformer.

Furthermore, the model must preserve the intrinsic knowledge of the language models. The trainable parameters constitute only 5.0% of the entire transformer's parameters. We posit that this approach enables the pre-trained model to process inputs with maximum linguistic fidelity while retaining flexibility. After training is completed, we apply re-parameterization techniques to integrate the LoRA module seamlessly into the standard language model, thereby enhancing inference speed.

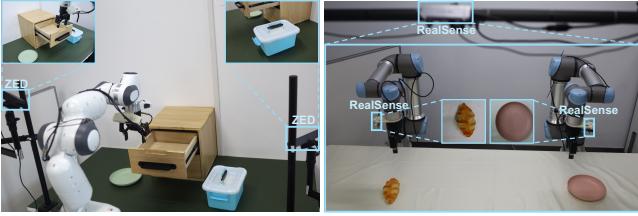


Fig. 3: **Real robot settings.** The real robot setup for the single-arm Franka and bimodal UR5.

**Learning action with diffusion policy decoder.** We need a way to represent the action space to control the robot. One method is to use discrete tokenization for the actions, as has been done in RT-2. However, using tokenization for continuous or high-dimensional data has proven to be extremely challenging for training [64], requires a huge amount of data [65], [66], and tends to converge to a single state [67]. Therefore, instead of converting actions into token space, we leverage a policy head to further learn the action space of the robot.

Specifically, we leverage the Diffusion Policy (DP) [5]. DP formulates robot policies using Denoising Diffusion Probabilistic Models (DDPMs) [68] which mainly involves two processes: adding noise and denoising. During training, a random value  $K$  is selected from 0 to  $N$ , indicating the number of times Gaussian noise is added to the original actions. Subsequently, DP denoises the noisy actions by predicting the added noise and minus it to acquire denoised actions. In the inference phase, starting from a pure noise  $a^N$  sampled from Gaussian distribution, DP generates a series of intermediate actions,  $\{a^n, a^{n-1}, \dots, a^1\}$ , until a desired noise-free output  $a^0$  is formed. The whole model structure is shown in Figure 2 right, we directly connect DP and multimodal model backbone through two simple Linear projections and one LayerNorm. The multimodal model backbone jointly encodes the current observations and language instructions to generate a multimodal embedding that controls the denoising process of DP as conditions.

#### IV. EXPERIMENTS

In our experiments, we aim to study the following questions:

- Does TinyVLA achieve a higher success rate in multi-tasking robotic manipulation compared to the baselines?
- Can TinyVLA interpret and follow novel instructions?
- Is TinyVLA capable of generalizing to unseen environments, adapting to new backgrounds, varying lighting conditions, changing camera view, and remaining robust against novel distractors?
- Does TinyVLA adhere to the scaling law, where a larger model size correlates with improved performance and better generalization?

##### A. Experimental Setup

To better distinguish the model sizes, we categorized TinyVLA into three sizes based on the scale of the multimodal model: TinyVLA-S (Small), TinyVLA-B (Base) and TinyVLA-H (Huge).

TABLE I: Comparing TinyVLA with Diffusion Policy in **simulation**. We report the average success rate on multiple tasks, We use TinyVLA-H as our method. **All methods are trained in a multi-task setting.**

| Model \ Tasks        | Metaworld (50 tasks) |             |             |               |             |
|----------------------|----------------------|-------------|-------------|---------------|-------------|
|                      | Easy (28)            | Medium (11) | Hard (6)    | Very Hard (5) | Avg.        |
| Diffusion Policy [5] | 23.1                 | 10.7        | 1.9         | 6.1           | 10.5        |
| <b>TinyVLA-H</b>     | <b>77.6</b>          | <b>21.5</b> | <b>11.4</b> | <b>15.8</b>   | <b>31.6</b> |

1) *Simulation Benchmark:* We evaluate our approach on MetaWorld. The 50 tasks in MetaWorld [69] can be categorized into multiple levels [70], i.e., easy, medium, hard, and very hard.

**Baseline.** We compare our approach with the Diffusion Policy [5]. We report the average success rate. All methods are trained in a multi-task learning fashion with 50 demonstrations. It is evaluated with 3 seeds, and for each seed, the success rate was averaged over five different iterations.

2) *Real Robot Setup:* TinyVLA is both evaluated on a single arm setup utilizing a Franka Panda 7Dof robot arms and a bimodal setup with two UR5 robotic arms as illustrated in Figure 3. The single-arm scene is perceived via two external ZED 2 stereo cameras fixed on both sides of the robot. The bimodal robot's scene is captured by two cameras on wrists with an extra camera at the top. These cameras are Realsense D435i.

**Tasks.** In the single-arm setting, there are five tasks: 1) closing the drawer (*CloseDrawer*), 2) stacking the pink cube on top of the blue cube (*StackCubes*), 3) opening the lid of the box (*OpenBox*), 4) placing a tennis ball into the ball box, and 5) uprighting a tipped-over mug (*FlipMug*). In the bimodal robot experiment, we set up three tasks that involved cooperation between two arms: 1) transferring bread to a plate (*TransferBread*), 2) unzipping the bag and placing a tennis ball inside it (*PlaceTennisBag*), and 3) stacking cubes on a plate (*StackCubes*). It is worth noting that the action spaces of tasks vary considerably. For instance, *flip mug* necessitates the robot to perform wide-ranging rotations to insert the gripper into the mug laterally, which is completely different from *stack cubes* which is pick&place type. The span of different trajectories within the same task varies markedly as well, e.g., the length of *stack cubes* trajectories ranges from 100 to 300. This provides TinyVLA with more challenges in learning to perform these tasks.

**Data collection.** We collect the dataset through teleoperation. We record the RGB stream from two camera views and robot states e.g., joint position during the whole robot control process. TinyVLA predicts the 6D pose, including position ( $x, y, z$ ) and rotation ( $roll, pitch, yaw$ ). For all the tasks we do not add additional distractors except in the *remove the lid of the box* task, in order to better evaluate the model's generalization capability to distractors. In total, we collected 100 trajectories for each task to balance data distribution across all 5 tasks.

**Baseline.** We evaluated our method against Diffusion Policy (DP) [5], Multimodal Diffusion [71] and OpenVLA [20]. We did a few modifications to ensure the comparison is fair.

TABLE II: **Quantitative results in real-world experiments.** We report the average success rate across multiple tasks and the count of trainable parameters for all models.

| Model \ Tasks            | Pre-trained Trajectory | Total Params | Trainable Params | RealWorld(5 tasks) |                 |                 |                 |                 | Avg.        |
|--------------------------|------------------------|--------------|------------------|--------------------|-----------------|-----------------|-----------------|-----------------|-------------|
|                          |                        |              |                  | PlaceTennis        | FlipMug         | StackCubes      | CloseDrawer     | OpenBox         |             |
| Diffusion Policy [5]     | N/A                    | 111M         | 111M             | 16.7±0.6           | 30±0.2          | 3.3±0.1         | 73.3±0.1        | 53.3±0.1        | 35.3        |
| Multimodal Diffusion[71] | N/A                    | 230M         | 230M             | 23.3±0.3           | 13.3±1.3        | 6.7±0.3         | 36.7±0.3        | 10.0±0          | 18.0        |
| OpenVLA[20]              | 970K                   | 7.2B         | 195M             | 83.3±1.1           | 51.7±3.1        | 40.0±0.1        | 85.0±1          | 81.7±0.6        | 68.3        |
| TinyVLA-S                | N/A                    | 422M         | 101M             | 8.3±0.1            | 6.7±0.1         | 6.7±0.1         | 60.0±0.2        | 35.0±0.3        | 23.3        |
| TinyVLA-B                | N/A                    | 740M         | 138M             | 76.7±0.6           | 76.7±0.1        | 71.7±0.1        | 81.7±0.1        | 80.0±0.2        | 77.4        |
| <b>TinyVLA-H</b>         | N/A                    | 1.3B         | 143M             | <b>90.0±0.2</b>    | <b>98.3±0.1</b> | <b>98.3±0.1</b> | <b>96.7±0.3</b> | <b>86.7±0.1</b> | <b>94.0</b> |

TABLE III: **Quantitative results for bimanual UR5 real robot experiments.** We report the average success rate over 10 trials. All models are trained in multi-task settings.

| Model \ Tasks    | Trainable Params | RealWorld(3 tasks) |                 |                | Avg. |
|------------------|------------------|--------------------|-----------------|----------------|------|
|                  |                  | PlaceBread         | StackCubes      | PlaceTennisBag |      |
| DP [5]           | 111M             | 40.3±1.7           | 31.3±1.3        | 43±2.3         |      |
| OpenVLA [20]     | 195M             | 0±0                | 0±0             | 0±0            |      |
| <b>TinyVLA-H</b> | 143M             | <b>76.7±2.3</b>    | <b>36.7±2.3</b> | <b>30±1</b>    |      |

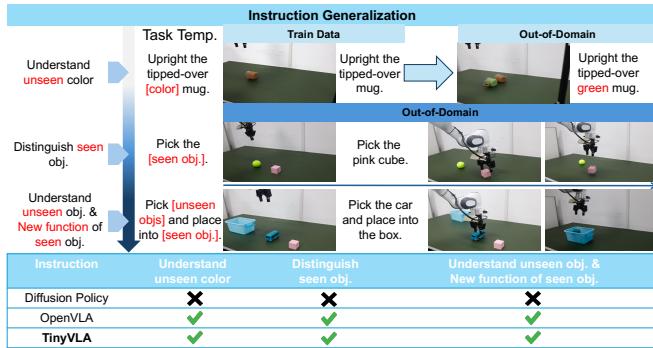


Fig. 4: **Instruction Generalization.** We conducted three different types of instruction generalization experiments with progressively increasing difficulty.

First of all, the vanilla OpenVLA is finetuned on a single view, which is incompatible with our approach. To ensure all camera views are utilized for OpenVLA, we process images from different views separately through the shared visual backbone, and then concatenate the visual tokens and feed them into the language models. Secondly, the vanilla DP does not incorporate language instructions. Therefore, following RT-1 [39] and YAY [72], we integrate language information into the visual backbone using FiLM [73].

### B. Experimental Results on Multi-Task Learning

**Simulation experimental results.** The experimental results are presented in Table I. Specifically, TinyVLA’s average success rate exceeds that of Diffusion Policy by 21.5%. Notably, the performance disparity widens in more complex tasks; for instance, on the MetaWorld Hard scenario, TinyVLA’s performance is sixfold better than that of Diffusion Policy. These results showcase the superiority of our proposed method.

**Real-world experimental results.** The experimental results are shown in Table II. We evaluate each model 20 trials per task in single arm setting. We report the mean and standard deviation of success rates across 3 checkpoints.

Notably, TinyVLA-H attained a 98.3% success rate in flipping a mug, stacking cubes, and a 90% success rate in place tennis, leading a large margin over other baselines. It is also worth mentioning that both place tennis and stack cubes are position-sensitive tasks. Also, both objects are rigid bodies, which makes the task challenging. Specifically, regarding the average success rate over five tasks, the result of TinyVLA-H surpasses OpenVLA by 25.7%.

### C. Generalization to Unseen Instructions

In this work, we investigate the generalization capabilities of TinyVLA-H, which demonstrates the best performance in both real-world scenarios and simulations. Since TinyVLA uses a pre-trained multimodal model as its backbone, we observe similar embodied capabilities driven by the rich world knowledge implicitly stored in these models, even though the fine-tuned version is not trained on question-answering pair data like RT-2 [19]. As demonstrated in Figure 4, we evaluated with a fixed list of instructions (i.e., “Pick the [object]”), where [object] are randomized objects that have not been seen in the training data. We use obj. as the abbreviation of objects in Figure 4. We test with three objects, a mug, a toy car, and a pink cube.

The first level challenges TinyVLA to differentiate between an object with a seen color and one with an unseen color. Specifically, we placed two mugs of seen and unseen colors on the table and instructed TinyVLA to flip the green mug. Note that the green color has not been seen in the training data. TinyVLA successfully completed the task, demonstrating its inherent understanding of different object attributes.

The second level involves grasping the object. Both objects presented have been part of the training data. We asked the model to “pick the cube”. Despite the environment and instruction not being part of the training data, TinyVLA successfully picked up the cube. This indicates that TinyVLA effectively maps textual descriptions to physical objects.

To further increase the difficulty of the test, we designed the third level, where the model is instructed to “pick a toy car” and “place it into the box”. The toy car is not in the training data. We placed a pink cube beside the toy car to assess whether the model could comprehend the instructions. Additionally, the command “place into the box” introduces a new skill-object combination, suggesting that even though the object is familiar, its function has been altered. Successfully completing this task indicates that

| View Generalization: Task A |             |             |            |             |             |  |  |
|-----------------------------|-------------|-------------|------------|-------------|-------------|--|--|
| Degrees                     | -30 degrees | -15 degrees | Train View | +15 degrees | +30 degrees |  |  |
| Left Camera                 |             |             |            |             |             |  |  |
| Right Camera                |             |             |            |             |             |  |  |
| View Generalization: Task B |             |             |            |             |             |  |  |
| Left Camera                 |             |             |            |             |             |  |  |
| Right Camera                |             |             |            |             |             |  |  |
| View Generalization: Task C |             |             |            |             |             |  |  |
| Left Camera                 |             |             |            |             |             |  |  |
| Right Camera                |             |             |            |             |             |  |  |

Fig. 5: **View Generalization.** We evaluated the view generalization capability of our model in a new environment, which we designed to be as consistent with the training environment as possible. We tested 3 tasks respectively, and the results under 8 viewing angle changes (the two cameras each correspond to 4 changes).

TinyVLA possesses the ability to recognize novel objects and identify new functionalities in familiar ones.

#### D. More Real-World Experiments: Bimodal Robot

We further conducted experiments on the Bimodal UR5 Robot, applying it to three distinct tasks: PlaceBread, Stack-Cube, and PlaceTennisBall. These tasks vary significantly in both duration and required skills, posing challenges for training a multi-task policy model. As shown in Table III, while the Diffusion Policy excels in the *PlaceTennisBall* task, our TinyVLA-H model achieved an average success rate of 44.5%, surpassing the Diffusion Policy’s 38.2%. Notably, the OpenVLA fails in every trial. We suspect this is because OpenVLA is pre-trained on the OpenX dataset, which consists entirely of single-arm robot data, making it ineffective when applied to bimodal robots.

#### E. Experiments on Generalization

In our approach, we integrate a pre-trained multimodal model with a Diffusion Policy head to generate robot actions. We demonstrate that leveraging a pre-trained multimodal model enhances the model’s generalization capabilities across various perspectives. This integration not only optimizes action output but also significantly boosts the system’s adaptability in diverse environments. For all experiments on generalization, we conduct one trial for each setting. Following DP3 [6], we use the same evaluation metrics. We use a cross mark to denote the failure of the model and a checkmark to indicate successful task completion.

**Generalization to new views.** Imitation learning, when trained on limited views, faces challenges in generalizing its learned capabilities to adapted views. In Figure 5, we compare the view generalization capabilities of TinyVLA and Diffusion Policy. It appears that the Diffusion Policy is extremely sensitive to changes in viewpoint; even a slight shift can cause the model to fail. In contrast, TinyVLA

| Task A   Close the drawer.                            |             |     |     |     |              |     |     |     |
|-------------------------------------------------------|-------------|-----|-----|-----|--------------|-----|-----|-----|
| View Generalization                                   | Left Camera |     |     |     | Right Camera |     |     |     |
|                                                       | -30         | -15 | +15 | +30 | -30          | -15 | +15 | +30 |
| Diffusion Policy                                      | ✗           | ✗   | ✗   | ✗   | ✗            | ✗   | ✗   | ✗   |
| OpenVLA                                               | ✗           | ✓   | ✓   | ✗   | ✗            | ✗   | ✓   | ✗   |
| TinyVLA                                               | ✓           | ✓   | ✓   | ✓   | ✓            | ✓   | ✓   | ✓   |
| Task B   Stack the pink cube on top of the blue cube. |             |     |     |     |              |     |     |     |
| View Generalization                                   | Left Camera |     |     |     | Right Camera |     |     |     |
|                                                       | -30         | -15 | +15 | +30 | -30          | -15 | +15 | +30 |
| Diffusion Policy                                      | ✗           | ✗   | ✗   | ✗   | ✗            | ✗   | ✗   | ✗   |
| OpenVLA                                               | ✗           | ✗   | ✗   | ✗   | ✗            | ✗   | ✗   | ✗   |
| TinyVLA                                               | ✓           | ✓   | ✓   | ✗   | ✗            | ✓   | ✓   | ✗   |
| Task C   Flip the mug over.                           |             |     |     |     |              |     |     |     |
| View Generalization                                   | Left Camera |     |     |     | Right Camera |     |     |     |
|                                                       | -30         | -15 | +15 | +30 | -30          | -15 | +15 | +30 |
| Diffusion Policy                                      | ✗           | ✗   | ✗   | ✗   | ✗            | ✗   | ✗   | ✗   |
| OpenVLA                                               | ✗           | ✗   | ✗   | ✗   | ✗            | ✗   | ✗   | ✗   |
| TinyVLA                                               | ✗           | ✓   | ✓   | ✓   | ✓            | ✓   | ✓   | ✗   |

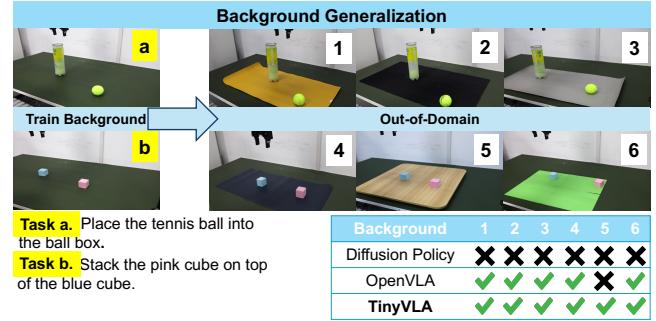


Fig. 6: **Background Generalization.** We utilized six different backgrounds, testing three of them on Task a and the remaining three on Task b.

demonstrates a certain degree of robustness in handling view generalization. For example, in tasks requiring high precision in object manipulation, such as Task B (StackCube) and Task C (FlipMug), our method can accommodate camera view shifts of up to 30 degrees to the left or right. Although it occasionally fails, TinyVLA still shows a significantly stronger view generalization compared to Diffusion Policy and OpenVLA, underscoring the benefits of using diffusion-based policy head.

**Background generalization:** We varied the background by using tablecloths of different colors and materials, including a wooden tabletop, mouse pad, desk mat, etc. In total, there are six distinct styles of backgrounds. We tested three of them on Task A and the remaining three on Task B. As shown in Figure 6, our model accurately locates objects and successfully completes tasks across various scenarios, including position-sensitive tasks like placing a tennis ball, demonstrating performance comparable to the OpenVLA.

**Generalization to different light conditions:** Regarding light conditions, conventional policy networks are sensitive to variations in lighting. As shown in Figure 7(bottom), we

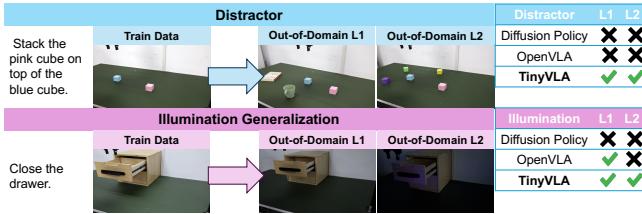


Fig. 7: **Distractor & Illumination Generalization.** In the distractor settings, Level L1 involves the addition of irrelevant objects such as books and cups, which are unrelated to the task. Level L2 involves the inclusion of identical cubes in various colors, adding complexity to the visual environment. Regarding illumination settings, Level L1 represents conditions with reduced lighting, while Level L2 describes scenarios with minimal lighting.

analyze the impact of three different lighting scenarios. The left image represents our training data. The middle image depicts the scenario when the overhead lights are turned off, and the right image shows conditions with all our lights turned off. We observe that TinyVLA remains unaffected by these variations in lighting, whereas the OpenVLA fails to complete the task under low light conditions. This reinforces our previous findings, confirming that our method is highly robust against changes in background lighting.

**Generalization to distractor:** It is known that the diffusion policy is sensitive to distractors, meaning that when objects not present in the collected data appear, the policy typically fails to complete the tasks. Indeed, adding strong augmentation could alleviate this problem. We aim to study whether the model, without data augmentation, could be robust to the appearance of distractors. In Figure 7 (top), we present the StackCube task featuring an additional distractor, categorized into two difficulty levels. Our model effectively manages both types of distractors at each difficulty level, whereas the Diffusion Policy and OpenVLA struggles with both. This demonstrates that utilizing a pre-trained multimodal model significantly enhances generalization capabilities in the presence of distractors.

#### F. Spatial Generalization

Spatial generalization [74], [75], [76], [77] refers to the generalization to unseen setup of objects (entities) locations in one task, which instead requires physical common sense about space and object. In Figure 9, we present the spatial generalization performance of our methods. Intriguingly, although our TinyVLA model was not trained on the specific locations of objects in the training dataset, it successfully completes tasks involving these objects. Furthermore, we have tested our method in locations significantly distant from those in our training data, as illustrated in Figure 9. We observe that OpenVLA performs slightly better than our approach, likely because it is trained on large-scale robotic data, allowing the model to "see" more diverse robot actions during pre-training. In contrast, the Diffusion Policy, which is trained on the same data as our model, consistently fails to generalize spatially across the tested locations.

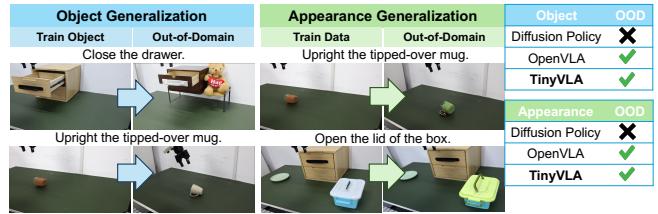


Fig. 8: **Object & Appearance generalization.** For object generalization, we replace the objects with previously unseen ones that have different shapes or colors. For appearance generalization, we only alter the colors of the objects.

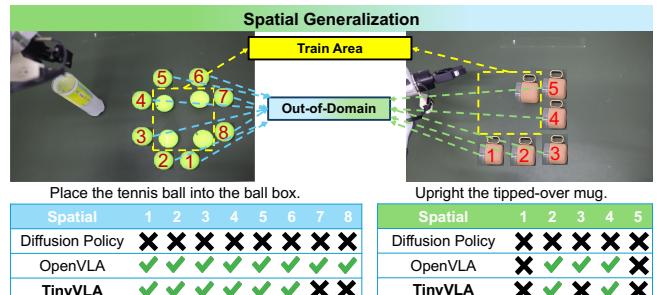


Fig. 9: **Spatial generalization.** We conducted evaluations at multiple positions thoroughly outside the training zone on two position-sensitive tasks: place tennis and flip mug.

#### G. Visual Generalization

Visual generalization pertains to the adaptation to novel visual textures. In robotic manipulation tasks, this type of generalization can be seen in variations in background color, object texture, or ambient lighting. These visual changes do not impact the fundamental task structure, such as the positioning of objects and targets. Instead, they necessitate that the robot accurately interpret the semantic meanings associated with these visual cues.

**Appearance generalization:** We altered the color of the target objects, as demonstrated in Figure 8 (right). Initially, the mug was brown, and the lid was white; we then modified their colors. We observe that TinyVLA successfully generalizes to objects with varying colors, demonstrating a capability similar to that of OpenVLA. Notably, our approach achieves appearance generalization without relying on data augmentation during training. This indicates that the generalization capability of our model stems from the pre-trained vision-language data.

## V. CONCLUSION

In this work, we explore the potential of leveraging pre-trained multimodal models for robotic manipulation. Our approach overcomes the limitations of previous methods by enabling fast inference and significantly reducing the computational resources required for training. We demonstrate the effectiveness of our method through both simulation and real-world experiments. We believe our approach offers a novel solution for building fast, data-efficient VLA models.

## REFERENCES

- [1] Z. Mandi, H. Bharadhwaj, V. Moens, S. Song, A. Rajeswaran, and V. Kumar, “Cacti: A framework for scalable multi-task multi-scene visual imitation learning,” *arXiv preprint arXiv:2212.05711*, 2022.
- [2] H. Bharadhwaj, J. Vakil, M. Sharma, A. Gupta, S. Tulsiani, and V. Kumar, “Roboagent: Generalization and efficiency in robot manipulation via semantic augmentations and action chunking,” in *2024 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2024, pp. 4788–4795.
- [3] A. Gupta, J. Yu, T. Z. Zhao, V. Kumar, A. Rovinsky, K. Xu, T. Devlin, and S. Levine, “Reset-free reinforcement learning via multi-task learning: Learning dexterous manipulation behaviors without human intervention,” in *2021 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2021, pp. 6664–6671.
- [4] F. Ebert, Y. Yang, K. Schmeckpeper, B. Bucher, G. Georgakis, K. Daniilidis, C. Finn, and S. Levine, “Bridge data: Boosting generalization of robotic skills with cross-domain datasets,” *arXiv preprint arXiv:2109.13396*, 2021.
- [5] C. Chi, S. Feng, Y. Du, Z. Xu, E. Cousineau, B. Burchfiel, and S. Song, “Diffusion policy: Visuomotor policy learning via action diffusion,” *arXiv preprint arXiv:2303.04137*, 2023.
- [6] Y. Ze, G. Zhang, K. Zhang, C. Hu, M. Wang, and H. Xu, “3d diffusion policy: Generalizable visuomotor policy learning via simple 3d representations,” in *Proceedings of Robotics: Science and Systems (RSS)*, 2024.
- [7] S. Biderman, H. Schoelkopf, Q. G. Anthony, H. Bradley, K. O’Brien, E. Hallahan, M. A. Khan, S. Purohit, U. S. Prashanth, E. Raff *et al.*, “Pythia: A suite for analyzing large language models across training and scaling,” in *International Conference on Machine Learning (PMLR)*, 2023, pp. 2397–2430.
- [8] H. Touvron, T. Lavril, G. Izacard, X. Martinet, M.-A. Lachaux, T. Lacroix, B. Rozière, N. Goyal, E. Hambro, F. Azhar *et al.*, “Llama: Open and efficient foundation language models,” *arXiv preprint arXiv:2302.13971*, 2023.
- [9] H. Touvron, L. Martin, K. Stone, P. Albert, A. Almahairi, Y. Babaei, N. Bashlykov, S. Batra, P. Bhargava, S. Bhosale *et al.*, “Llama 2: Open foundation and fine-tuned chat models,” *arXiv preprint arXiv:2307.09288*, 2023.
- [10] Z. Du, Y. Qian, X. Liu, M. Ding, J. Qiu, Z. Yang, and J. Tang, “Glm: General language model pretraining with autoregressive blank infilling,” *arXiv preprint arXiv:2103.10360*, 2021.
- [11] A. Q. Jiang, A. Sablayrolles, A. Mensch, C. Bamford, D. S. Chaplot, D. d. l. Casas, F. Bressand, G. Lengyel, G. Lample, L. Saulnier *et al.*, “Mistral 7b,” *arXiv preprint arXiv:2310.06825*, 2023.
- [12] S. Gunasekar, Y. Zhang, J. Aneja, C. C. T. Mendes, A. Del Giorno, S. Gopi, M. Javaheripi, P. Kauffmann, G. de Rosa, O. Saarikivi *et al.*, “Textbooks are all you need,” *arXiv preprint arXiv:2306.11644*, 2023.
- [13] M. Ahn, A. Brohan, N. Brown, Y. Chebotar, O. Cortes, B. David, C. Finn, C. Fu, K. Gopalakrishnan, K. Hausman *et al.*, “Do as i can, not as i say: Grounding language in robotic affordances,” *arXiv preprint arXiv:2204.01691*, 2022.
- [14] K. Rana, J. Haviland, S. Garg, J. Abou-Chakra, I. Reid, and N. Suenderhauf, “Sayplan: Grounding large language models using 3d scene graphs for scalable task planning,” in *7th Annual Conference on Robot Learning*, 2023. [Online]. Available: <https://openreview.net/forum?id=wMpOMOOSs7a>
- [15] R. Shi, Y. Liu, Y. Ze, S. S. Du, and H. Xu, “Unleashing the power of pre-trained language models for offline reinforcement learning,” *arXiv preprint arXiv:2310.20587*, 2023.
- [16] W. Huang, C. Wang, R. Zhang, Y. Li, J. Wu, and L. Fei-Fei, “Voxposer: Composable 3d value maps for robotic manipulation with language models,” *arXiv preprint arXiv:2307.05973*, 2023.
- [17] S. Cheng and D. Xu, “League: Guided skill learning and abstraction for long-horizon manipulation,” *IEEE Robotics and Automation Letters*, vol. 8, no. 10, pp. 6451–6458, 2023.
- [18] S. Bahl, R. Mendonca, L. Chen, U. Jain, and D. Pathak, “Affordances from human videos as a versatile representation for robotics,” in *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 2023, pp. 13 778–13 790.
- [19] A. Brohan, N. Brown, J. Carbajal, Y. Chebotar, X. Chen, K. Chormanski, T. Ding, D. Driess, A. Dubey, C. Finn *et al.*, “Rt-2: Vision-language-action models transfer web knowledge to robotic control,” *arXiv preprint arXiv:2307.15818*, 2023.
- [20] M. J. Kim, K. Pertsch, S. Karamcheti, T. Xiao, A. Balakrishna, S. Nair, R. Rafailov, E. Foster, G. Lam, P. Sanketi *et al.*, “Openvla: An open-source vision-language-action model.”
- [21] A. Padalkar, A. Pooley, A. Jain, A. Bewley, A. Herzog, A. Irpan, A. Khazatsky, A. Rai, A. Singh, A. Brohan *et al.*, “Open x-embodiment: Robotic learning datasets and rt-x models,” *arXiv preprint arXiv:2310.08864*, 2023.
- [22] J. Li, D. Li, S. Savarese, and S. Hoi, “Blip-2: Bootstrapping language-image pre-training with frozen image encoders and large language models,” *arXiv preprint arXiv:2301.12597*, 2023.
- [23] W. Dai, J. Li, D. Li, A. Tiong, J. Zhao, W. Wang, B. Li, P. Fung, and S. Hoi, “Instructblip: Towards general-purpose vision-language models with instruction tuning,” *arXiv preprint arXiv:2305.06500*, 2023.
- [24] D. Zhu, J. Chen, X. Shen, X. Li, and M. Elhoseiny, “MiniGPT-4: Enhancing vision-language understanding with advanced large language models,” in *The Twelfth International Conference on Learning Representations*, 2024. [Online]. Available: <https://openreview.net/forum?id=1Zbq88f27>
- [25] H. Liu, C. Li, Q. Wu, and Y. J. Lee, “Visual instruction tuning,” in *Thirty-seventh Conference on Neural Information Processing Systems*, 2023. [Online]. Available: <https://openreview.net/forum?id=w0H2xGHlkw>
- [26] G. Team, R. Anil, S. Borgeaud, Y. Wu, J.-B. Alayrac, J. Yu, R. Soricut, J. Schalkwyk, A. M. Dai, A. Hauth *et al.*, “Gemini: a family of highly capable multimodal models,” *arXiv preprint arXiv:2312.11805*, 2023.
- [27] J. Chen, D. Zhu, X. Shen, X. Li, Z. Liu, P. Zhang, R. Krishnamoorthi, V. Chandra, Y. Xiong, and M. Elhoseiny, “Minigpt-v2: large language model as a unified interface for vision-language multi-task learning,” *arXiv preprint arXiv:2310.09478*, 2023.
- [28] B. Li, Y. Zhang, L. Chen, J. Wang, J. Yang, and Z. Liu, “Otter: A multi-modal model with in-context instruction tuning,” *arXiv preprint arXiv:2305.03726*, 2023.
- [29] Z. Lin, C. Liu, R. Zhang, P. Gao, L. Qiu, H. Xiao, H. Qiu, C. Lin, W. Shao, K. Chen *et al.*, “Sphinx: The joint mixing of weights, tasks, and visual embeddings for multi-modal large language models,” *arXiv preprint arXiv:2311.07575*, 2023.
- [30] R. Bavishi, E. Elsen, C. Hawthorne, M. Nye, A. Odena, A. Soman, and S. Taşırılar, “Introducing our multimodal models,” 2023. [Online]. Available: <https://www.addept.ai/blog/fuyu-8b>
- [31] Z. Shao, X. Ouyang, Z. Yu, and J. Yu, “Imp: An empirical study of multimodal small language models,” 2024. [Online]. Available: <https://huggingface.co/MILVLG/imp-v1-3b>
- [32] M. He, Y. Liu, B. Wu, J. Yuan, Y. Wang, T. Huang, and B. Zhao, “Efficient multimodal learning from data-centric perspective,” *arXiv preprint arXiv:2402.11530*, 2024.
- [33] X. Chu, L. Qiao, X. Zhang, S. Xu, F. Wei, Y. Yang, X. Sun, Y. Hu, X. Lin, B. Zhang *et al.*, “Mobilevlm v2: Faster and stronger baseline for vision language model,” *arXiv preprint arXiv:2402.03766*, 2024.
- [34] Y. Zhu, M. Zhu, N. Liu, Z. Ou, X. Mou, and J. Tang, “Llava-phi: Efficient multi-modal assistant with small language model,” *arXiv preprint arXiv:2401.02330*, 2024.
- [35] B. Lin, Z. Tang, Y. Ye, J. Cui, B. Zhu, P. Jin, J. Zhang, M. Ning, and L. Yuan, “Moe-llava: Mixture of experts for large vision-language models,” *arXiv preprint arXiv:2401.15947*, 2024.
- [36] H. Wei, L. Kong, J. Chen, L. Zhao, Z. Ge, E. Yu, J. Sun, C. Han, and X. Zhang, “Small language model meets with reinforced vision vocabulary,” *arXiv preprint arXiv:2401.12503*, 2024.
- [37] S. Zhang, S. Roller, N. Goyal, M. Artetxe, M. Chen, S. Chen, C. Dewan, M. Diab, X. Li, X. V. Lin *et al.*, “Opt: Open pre-trained transformer language models,” *arXiv preprint arXiv:2205.01068*, 2022.
- [38] Octo Model Team, D. Ghosh, H. Walke, K. Pertsch, K. Black, O. Mees, S. Dasari, J. Hejna, C. Xu, J. Luo, T. Kreiman, Y. Tan, L. Y. Chen, P. Sanketi, Q. Vuong, T. Xiao, D. Sadigh, C. Finn, and S. Levine, “Octo: An open-source generalist robot policy,” in *Proceedings of Robotics: Science and Systems*, Delft, Netherlands, 2024.
- [39] A. Brohan, N. Brown, J. Carbajal, Y. Chebotar, J. Dabis, C. Finn, K. Gopalakrishnan, K. Hausman, A. Herzog, J. Hsu *et al.*, “Rt-1: Robotics transformer for real-world control at scale,” *arXiv preprint arXiv:2212.06817*, 2022.
- [40] Y. Ze, N. Hansen, Y. Chen, M. Jain, and X. Wang, “Visual reinforcement learning with self-supervised 3d representations,” *IEEE Robotics and Automation Letters*, vol. 8, no. 5, pp. 2890–2897, 2023.
- [41] Y. Ze, Y. Liu, R. Shi, J. Qin, Z. Yuan, J. Wang, and H. Xu, “H-index: Visual reinforcement learning with hand-informed representations for

- dexterous manipulation,” *Advances in Neural Information Processing Systems*, vol. 36, 2024.
- [42] S. Yang, Y. Ze, and H. Xu, “Movie: Visual model-based policy adaptation for view generalization,” *Advances in Neural Information Processing Systems*, vol. 36, 2024.
- [43] M. Zhu, Y. Zhu, J. Li, J. Wen, Z. Xu, Z. Che, C. Shen, Y. Peng, D. Liu, F. Feng *et al.*, “Language-conditioned robotic manipulation with fast and slow thinking,” *arXiv preprint arXiv:2401.04181*, 2024.
- [44] Y. Zhu, Z. Ou, X. Mou, and J. Tang, “Retrieval-augmented embodied agents,” in *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 2024, pp. 17 985–17 995.
- [45] M. Zawalski, W. Chen, K. Pertsch, O. Mees, C. Finn, and S. Levine, “Robotic control via embodied chain-of-thought reasoning,” *arXiv preprint arXiv:2407.08693*, 2024.
- [46] J. Wen, Y. Zhu, M. Zhu, J. Li, Z. Xu, Z. Che, C. Shen, Y. Peng, D. Liu, F. Feng *et al.*, “Object-centric instruction augmentation for robotic manipulation,” *arXiv preprint arXiv:2401.02814*, 2024.
- [47] H. Etukuru, N. Naka, Z. Hu, S. Lee, J. Mehru, A. Edsinger, C. Paxton, S. Chintala, L. Pinto, and N. M. M. Shafiuallah, “Robot utility models: General policies for zero-shot deployment in new environments,” *arXiv preprint arXiv:2409.05865*, 2024.
- [48] M. Chang, T. Gervet, M. Khanna, S. Yenamandra, D. Shah, S. Y. Min, K. Shah, C. Paxton, S. Gupta, D. Batra *et al.*, “Goat: Go to any thing,” *arXiv preprint arXiv:2311.06430*, 2023.
- [49] J. Aldaco, T. Armstrong, R. Baruch, J. Bingham, S. Chan, K. Draper, D. Dwibedi, C. Finn, P. Florence, S. Goodrich *et al.*, “Aloha 2: An enhanced low-cost hardware for bimanual teleoperation,” *arXiv preprint arXiv:2405.02292*, 2024.
- [50] S. Ge, B. Hou, W. Zhu, Y. Zhu, S. Lu, and Y. Zheng, “Pixel-level collision-free grasp prediction network for medical test tube sorting on cluttered trays,” *IEEE Robotics and Automation Letters*, vol. 8, no. 12, pp. 7897–7904, 2023.
- [51] T. Z. Zhao, J. Tompson, D. Driess, P. Florence, S. K. S. Ghasemipour, C. Finn, and A. Wahid, “Aloha unleashed: A simple recipe for robot dexterity,” in *8th Annual Conference on Robot Learning*.
- [52] Z. Fu, T. Z. Zhao, and C. Finn, “Mobile aloha: Learning bimanual mobile manipulation with low-cost whole-body teleoperation,” *arXiv preprint arXiv:2401.02117*, 2024.
- [53] K. Black, M. Nakamoto, P. Atreya, H. Walke, C. Finn, A. Kumar, and S. Levine, “Zero-shot robotic manipulation with pretrained image-editing diffusion models,” *arXiv preprint arXiv:2310.10639*, 2023.
- [54] T. Stouraitis and M. Gienger, “Predictive and robust robot assistance for sequential manipulation,” *IEEE Robotics and Automation Letters*, vol. 8, no. 12, pp. 8026–8033, 2023.
- [55] J. O. von Hartz, E. Chisari, T. Welschehold, W. Burgard, J. Boedecker, and A. Valada, “The treachery of images: Bayesian scene keypoints for deep policy learning in robotic manipulation,” *IEEE Robotics and Automation Letters*, vol. 8, no. 11, pp. 6931–6938, 2023.
- [56] C. E. Lin, M. Zhu, and M. Ghaffari, “Se3et: Se(3)-equivariant transformer for low-overlap point cloud registration,” *IEEE Robotics and Automation Letters*, vol. 9, no. 11, pp. 9526–9533, 2024.
- [57] Y. Wang, Y. Zhang, M. Huo, R. Tian, X. Zhang, Y. Xie, C. Xu, P. Ji, W. Zhan, M. Ding *et al.*, “Sparse diffusion policy: A sparse, reusable, and flexible policy for robot learning,” *arXiv preprint arXiv:2407.01531*, 2024.
- [58] X. Jia, Q. Wang, A. Donat, B. Xing, G. Li, H. Zhou, O. Celik, D. Blessing, R. Lioutikov, and G. Neumann, “Mail: Improving imitation learning with mamba,” *arXiv preprint arXiv:2406.08234*, 2024.
- [59] X. Li, C. Mata, J. Park, K. Kahatapitiya, Y. S. Jang, J. Shang, K. Ranasinghe, R. Burgert, M. Cai, Y. J. Lee *et al.*, “Llara: Supercharging robot learning data for vision-language policy,” *arXiv preprint arXiv:2406.20095*, 2024.
- [60] D. Niu, Y. Sharma, G. Biamby, J. Quenum, Y. Bai, B. Shi, T. Darrell, and R. Herzig, “Llarva: Vision-action instruction tuning enhances robot learning,” *arXiv preprint arXiv:2406.11815*, 2024.
- [61] K. Black, M. Janner, Y. Du, I. Kostrikov, and S. Levine, “Training diffusion models with reinforcement learning,” in *The Twelfth International Conference on Learning Representations*.
- [62] E. J. Hu, yelong shen, P. Wallis, Z. Allen-Zhu, Y. Li, S. Wang, L. Wang, and W. Chen, “LoRA: Low-rank adaptation of large language models,” in *International Conference on Learning Representations*, 2022. [Online]. Available: <https://openreview.net/forum?id=nZeV KeeFYf9>
- [63] S. Biderman, H. Schoelkopf, Q. G. Anthony, H. Bradley, K. O’Brien, E. Hallahan, M. A. Khan, S. Purohit, U. S. Prashanth, E. Raff *et al.*, “Pythia: A suite for analyzing large language models across training and scaling,” in *International Conference on Machine Learning*. PMLR, 2023, pp. 2397–2430.
- [64] J. Lu, C. Clark, R. Zellers, R. Mottaghi, and A. Kembhavi, “Unifiedio: A unified model for vision, language, and multi-modal tasks,” in *The Eleventh International Conference on Learning Representations*, 2022.
- [65] T. Chen, S. Saxena, L. Li, T.-Y. Lin, D. J. Fleet, and G. E. Hinton, “A unified sequence interface for vision tasks,” *Advances in Neural Information Processing Systems*, vol. 35, pp. 31 333–31 346, 2022.
- [66] T. Chen, L. Li, S. Saxena, G. Hinton, and D. J. Fleet, “A generalist framework for panoptic segmentation of images and videos,” in *Proceedings of the IEEE/CVF International Conference on Computer Vision*, 2023, pp. 909–919.
- [67] T. Chen, S. Saxena, L. Li, D. J. Fleet, and G. Hinton, “Pix2seq: A language modeling framework for object detection,” *arXiv preprint arXiv:2109.10852*, 2021.
- [68] J. Ho, A. Jain, and P. Abbeel, “Denoising diffusion probabilistic models,” *Advances in neural information processing systems*, vol. 33, pp. 6840–6851, 2020.
- [69] T. Yu, D. Quillen, Z. He, R. Julian, K. Hausman, C. Finn, and S. Levine, “Meta-world: A benchmark and evaluation for multi-task and meta reinforcement learning,” in *Conference on robot learning*. PMLR, 2020, pp. 1094–1100.
- [70] Y. Seo, D. Hafner, H. Liu, F. Liu, S. James, K. Lee, and P. Abbeel, “Masked world models for visual control,” in *Conference on Robot Learning*. PMLR, 2023, pp. 1332–1344.
- [71] M. Reuss, Ö. E. Yağmurlu, F. Wenzel, and R. Lioutikov, “Multimodal diffusion transformer: Learning versatile behavior from multimodal goals,” 2024.
- [72] L. X. Shi, Z. Hu, T. Z. Zhao, A. Sharma, K. Pertsch, J. Luo, S. Levine, and C. Finn, “Yell at your robot: Improving on-the-fly from language corrections,” *arXiv preprint arXiv:2403.12910*, 2024.
- [73] E. Perez, F. Strub, H. De Vries, V. Dumoulin, and A. Courville, “Film: Visual reasoning with a general conditioning layer,” in *Proceedings of the AAAI conference on artificial intelligence*, vol. 32, no. 1, 2018.
- [74] L. A. Doumas, G. Puebla, A. E. Martin, and J. E. Hummel, “A theory of relation learning and cross-domain generalization.” *Psychological review*, vol. 129, no. 5, p. 999, 2022.
- [75] S. Toyer, R. Shah, A. Critch, and S. Russell, “The magical benchmark for robust imitation,” *Advances in Neural Information Processing Systems*, vol. 33, pp. 18 284–18 295, 2020.
- [76] Z.-H. Yin, Y. Gao, and Q. Chen, “Spatial generalization of visual imitation learning with position-invariant regularization,” in *RSS 2023 Workshop on Symmetries in Robot Learning*, 2023.
- [77] D. Yarats, I. Kostrikov, and R. Fergus, “Image augmentation is all you need: Regularizing deep reinforcement learning from pixels,” in *International conference on learning representations*, 2020.