

Prompted Segmentation for Drywall QA

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1 Introduction

This report describes a text-conditioned segmentation system for drywall quality assurance (QA). The goal is to automatically segment relevant regions in drywall images using natural-language prompts. We focus on two datasets:

- **Dataset 1: Taping area** – images of drywall panels with taping / joints.
- **Dataset 2: Cracks** – images of surface cracks on concrete / drywall.

Given an input image and a short prompt such as "segment taping area" or "segment crack", the model predicts a binary mask highlighting the requested region. This enables promptable QA workflows where the same image can be re-used with different prompts (e.g., taping vs. seams, different crack types).

2 Approach

2.1 CLIPSeg Model Architecture and Mathematical Formulation

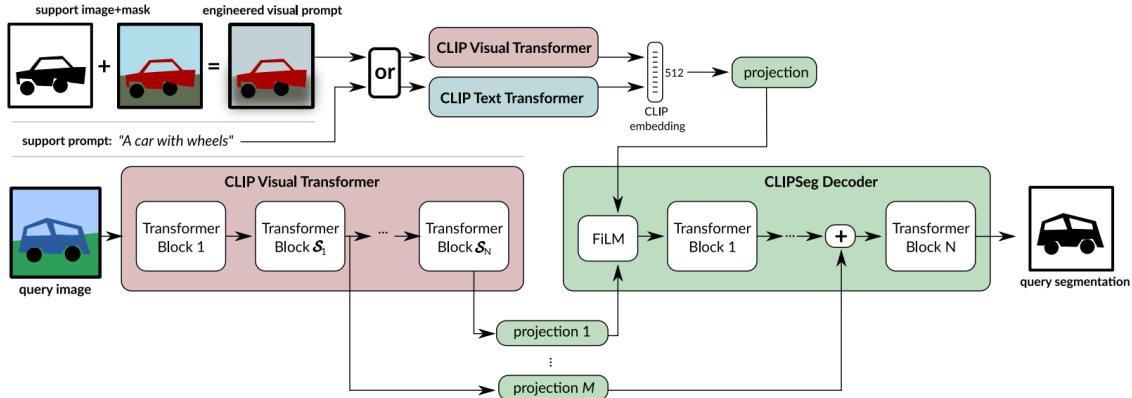


Figure 1: CLIPSeg architecture (corresponding to Figure 2 in the paper). The model uses a frozen CLIP backbone, FiLM-conditioned decoder, and an upsampling segmentation head.

This section provides a concise mathematical description of the CLIPSeg model architecture—corresponding to Figure 2 of the CLIPSeg paper—and explains how its components map to the training and inference pipeline used in this project.

2.2 Overview

CLIPSeg extends the CLIP vision–language model into a dense prediction system. Given an input image x and a natural-language prompt q , it predicts a pixelwise logits map $\hat{M}(x, q)$ whose sigmoid gives per-pixel probabilities for the requested region. The CLIP encoders remain *frozen*; only the segmentation decoder and FiLM-conditioning layers are fine-tuned.

2.3 Prompt Encoding

For a text prompt q , the CLIP text encoder f_t produces a D -dimensional embedding:

$$u = f_t(q) \in \mathbb{R}^D.$$

This embedding acts as the *conditional vector* that guides segmentation. In the most general CLIPSeg formulation, text and visual prompts may be interpolated:

$$c = \alpha f_v(x^{\text{sup}}) + (1 - \alpha) f_t(q), \quad \alpha \in [0, 1],$$

but in our drywall QA system we use *text-only prompting*, i.e. $c = u$.

2.4 Visual Feature Extraction

The input image x is processed by the CLIP ViT image encoder f_v , yielding multi-scale patch tokens from several intermediate layers:

$$Z^{(l)} = [z_{\text{CLS}}^{(l)}, z_1^{(l)}, \dots, z_N^{(l)}] \in \mathbb{R}^{(N+1) \times D}, \quad l \in \{3, 6, 9\}.$$

Each layer is projected to the decoder dimension d via a learned linear transformation:

$$\tilde{Z}^{(l)} = W^{(l)} Z^{(l)}, \quad W^{(l)} \in \mathbb{R}^{d \times D}.$$

2.5 Prompt-Conditioned Transformer Decoder

The decoder is a lightweight transformer that progressively refines patch features using skip connections from the CLIP layers:

$$Y^{(k)} = \text{DecoderBlock}^{(k)}(Y^{(k-1)} + \tilde{Z}^{(l_k)}), \quad k = 1, \dots, K.$$

To inject the meaning of the prompt, CLIPSeg uses *FiLM conditioning* (*Feature-wise Linear Modulation*). For the prompt vector c , the decoder computes scale and shift parameters:

$$\gamma = W_\gamma c + b_\gamma, \quad \beta = W_\beta c + b_\beta,$$

and modulates every decoder token h as:

$$\text{FiLM}(h; c) = \gamma \odot h + \beta.$$

This enables open-vocabulary segmentation: the decoder dynamically adapts its internal representations according to the textual description (e.g. “crack”, “taping area”, “drywall seam”).

2.6 Segmentation Head

After K decoder layers, patch tokens are passed through a linear classifier:

$$\ell_i = w^\top Y_i^{(K)} + b,$$

producing a coarse $H' \times W'$ logits map. A small upsampling network lifts this to full resolution $H \times W$:

$$\hat{M}(x, q) = \text{Upsample}(\ell).$$

The final probabilities are:

$$p_{ij} = \sigma(\hat{M}_{ij}) = \frac{1}{1 + e^{-\hat{M}_{ij}}}.$$

2.7 Training Objective

Given ground-truth binary mask M , training minimizes binary cross-entropy with logits:

$$\mathcal{L}_{\text{BCE}} = -\frac{1}{HW} \sum_{i,j} \left[M_{ij} \log \sigma(\hat{M}_{ij}) + (1 - M_{ij}) \log (1 - \sigma(\hat{M}_{ij})) \right].$$

CLIP parameters are frozen; only the decoder, FiLM layers, and final segmentation head are optimized. This allows the model to remain lightweight while preserving CLIP’s semantic grounding.

2.8 Relation to Our Drywall QA System

In this project:

- CLIPSeg provides the full vision–language architecture.
- Prompts such as “segment crack” or “segment joint/tape” serve as the conditioning vector c .
- Visual tokens come from the frozen CLIP ViT encoder.
- FiLM conditioning enables open-vocabulary QA segmentation.
- BCE loss is computed between $\hat{M}(x, q)$ and the resized COCO masks.

During inference, the same image is passed through the model with different prompts, enabling reusable QA analysis without retraining.

2.9 Model

I fine-tune the **CLIPSeg** model [1] using the CIDAS/clipseg-**rd64-refined** checkpoint from HuggingFace. CLIPSeg combines a CLIP-style vision–language encoder with a lightweight segmentation head. Given an image and a text prompt, it predicts a dense segmentation logits map.

Key choices:

- **Backbone:** CLIPSeg (ViT-based encoder + segmentation head).
- **Input resolution:** images are resized to 224×224 (CLIP standard).
- **Output:** segmentation logits at 224×224 , upsampled back to the original resolution (e.g. 640×640).
- **Loss:** binary cross-entropy with logits between predicted mask and ground truth.

2.10 Prompts

Each dataset is associated with a small set of prompts:

- **Taping dataset:**
 - “segment taping area”
 - “segment joint/tape”
 - “segment drywall seam”
- **Cracks dataset:**

- “segment crack”
- “segment wall crack”

During training I use one *canonical prompt* per dataset (`segment taping area` for taping and `segment crack` for cracks). During evaluation and inference, I run the model for *all* prompts and report separate metrics.

2.11 Preprocessing

- Images are loaded at their original resolution (approximately 640×640) and resized to 224×224 .
- Masks are generated from COCO annotations:
 - For the taping dataset, COCO bounding boxes are rasterized to filled rectangular masks.
 - For the cracks dataset, polygon segmentations are rasterized to binary masks.
- Both images and masks are normalized to $[0, 1]$ and jointly resized so that training is consistent.

3 Datasets and Splits

The assignment provides two Roboflow-based datasets:

- **Cracks Segmentation:** <https://universe.roboflow.com/ay-7aga/cracks-segmentation/dataset/2>
- **Drywall Joint Detect (taping):** <https://universe.roboflow.com/objectdetect-pu6rn/drywall-join-detect>

In my local setup the data is arranged as:

```
/media/sdb_access/Assignment/
  Dataset_1/ (taping)
    train/
      train_annotations.coco.json
    valid/
      valid_annotations.coco.json
  Dataset_2/ (cracks)
    train/
      train_annotations.coco.json
    valid/
      valid_annotations.coco.json
    test/
      test_annotations.coco.json
```

Table 1 summarizes the splits that are used by the code. (The counts can be obtained directly from the JSON files or via the Python dataloaders.)

Dataset	Train	Validation	Test
Taping (Dataset 1)	820	202	—
Cracks (Dataset 2)	1431	34	35

Table 1: Data split counts used in my experiments. Validation for the taping dataset doubles as test-time evaluation.

4 Training Setup

All experiments were run using the same script:

```
python -m src.main \
--mode full \
--dataset {cracks|taping} \
--data_root /media/sdb_access/Assignment \
--output_root ./outputs \
--batch_size 4 \
--image_size 224 \
--epochs 50 \
--lr 1e-5
```

Key hyperparameters:

- Optimizer: AdamW with learning rate 1×10^{-5} .
- Batch size: 4.
- Epochs: 50 (for final runs; the example logs below use smaller epochs for quick testing).
- Random seed is fixed for reproducibility.

The training loop uses the canonical prompt and computes loss over the resized masks. After each epoch, validation is run for *every* prompt of that dataset. The best checkpoint is selected by validation Dice score.

5 Metrics

- **Binary cross-entropy loss** (BCE with logits).
- **Intersection-over-Union (mIoU)** for foreground.
- **Dice coefficient** for foreground.

5.1 Cracks Dataset Results

Table 2 shows the final validation performance for the cracks dataset (`val_final_full` split from the logs).

5.2 Taping Dataset Results

Table 3 shows validation performance for the taping dataset (`val_eval` split).

These numbers are consistent with the qualitative impressions from the visualizations: taping and crack regions are generally captured well, while some prompts such as `segment drywall seam` are slightly harder.

Prompt	Loss	mIoU	Dice
segment crack	0.0891	0.5222	0.6111
segment wall crack	0.1038	0.5766	0.6561

Table 2: Per-prompt metrics for the cracks dataset (validation).

Prompt	Loss	mIoU	Dice
segment taping area	0.2020	0.5405	0.6834
segment joint/tape	0.3026	0.4088	0.5548
segment drywall seam	0.4626	0.3820	0.5178

Table 3: Per-prompt metrics for the taping dataset (validation).

6 Runtime and Model Footprint

6.1 Inference Timing

The code measures inference timing over all images and prompts.

Cracks dataset. For 35 test images and 2 prompts:

- Total inference time: 2.264 seconds.
- Average time per image per prompt: 0.0323 seconds.

Taping dataset. For 202 validation images and 3 prompts:

- Total inference time: 17.021 seconds.
- Average time per image per prompt: 0.0281 seconds.

The fine-tuned CLIPSeg model has roughly 150M parameters, corresponding to \sim 600 MB of trainable weights (in 32-bit floats). The code computes and logs the exact number of parameters and their memory footprint.

7 Qualitative Results

Figures 2 and 3 show representative qualitative results for both datasets. Each panel is a *stacked visualization* created by the code:

[Input] | [GT] | [Prompt 1 prediction] | [Prompt 2 prediction] | ...

The prompt text is written along the top border of each mask tile.

8 Conclusion

I implemented and evaluated a text-conditioned segmentation system for drywall QA using CLIPSeg. The system supports multiple prompts per dataset, produces competitive mIoU / Dice scores on both cracks and taping tasks, and runs efficiently (tens of milliseconds per image per prompt).

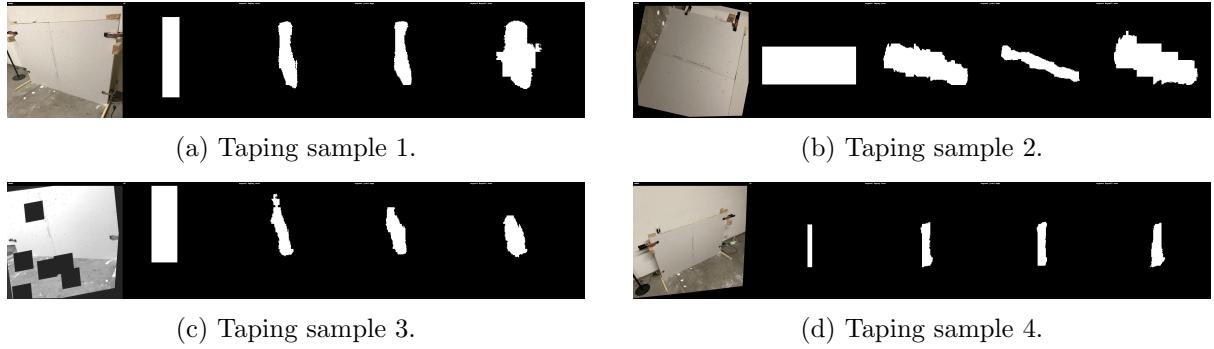


Figure 2: Qualitative results on the taping dataset. Each panel shows Input — GT — segment taping area — segment joint/tape — segment drywall seam.

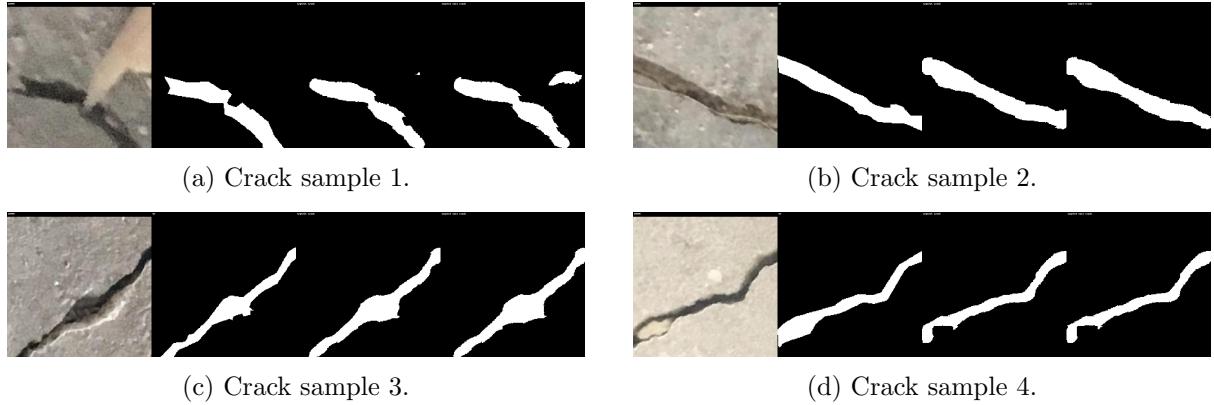


Figure 3: Qualitative results on the cracks dataset. Each panel shows Input — GT — segment crack — segment wall crack.

This approach is attractive because a *single* model can be reused for multiple QA tasks simply by changing the text prompt, without retraining. Future work could explore few-shot prompt tuning, better handling of ultra-thin structures, and joint training on both datasets to leverage shared visual cues.

Acknowledgements

The CLIPSeg model and codebase are built on top of the excellent open-source work by Lüddecke and Wörtwein [1], and the original CLIP architecture by Radford et al. [2].

References

- [1] Timo Lüddecke and Theodor Wörtwein. CLIPSeg: Image Segmentation Using Text and Image Prompts. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, 2022.
- [2] Alec Radford, Jong Wook Kim, Chris Hallacy, Aditya Ramesh, and others. Learning Transferable Visual Models From Natural Language Supervision. In *International Conference on Machine Learning (ICML)*, 2021.