



Your Smart Guide to Surf Conditions

SwellSight

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Review and refine project definition

Motivation & Definition

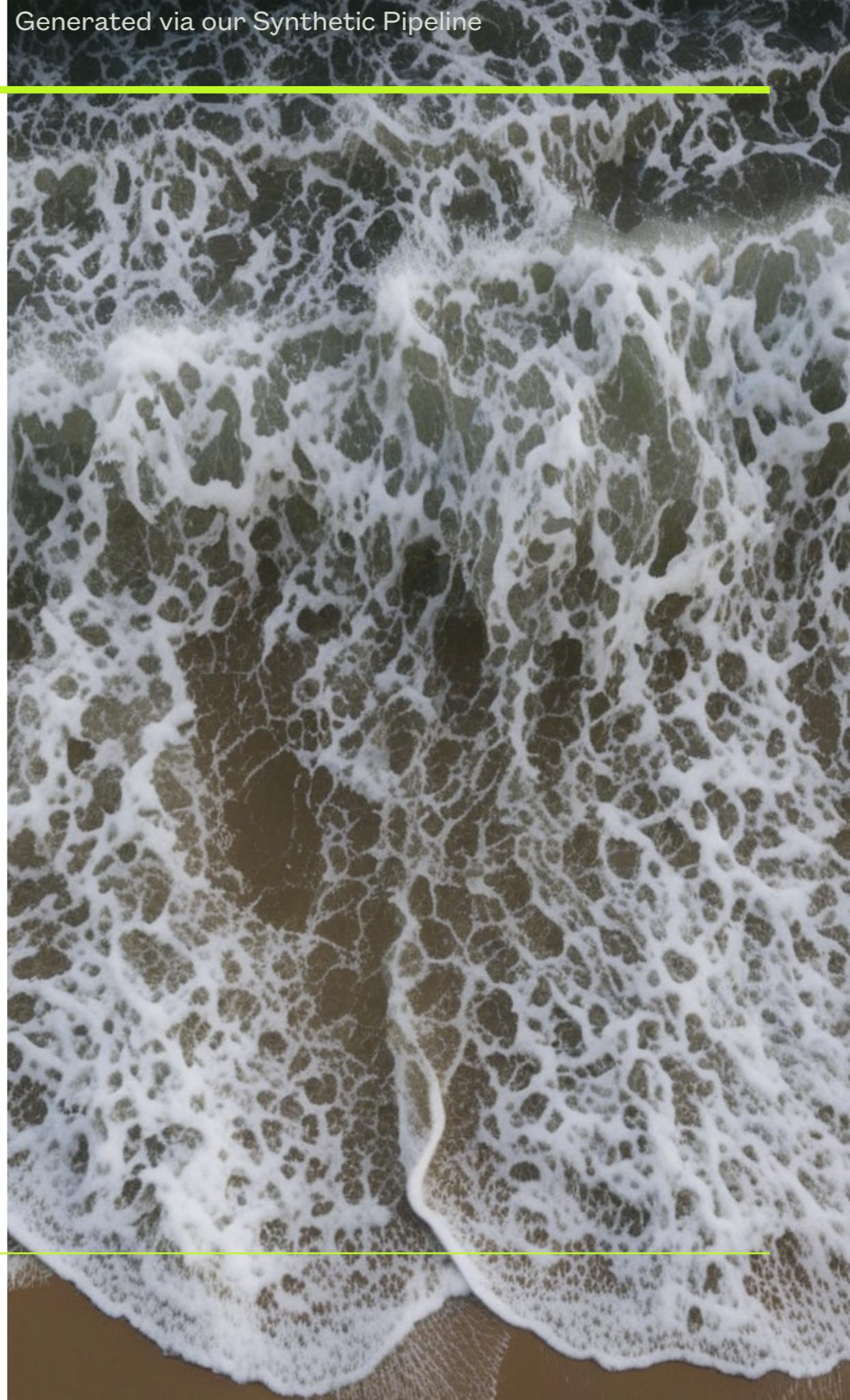
- **Motivation:** Surfers need accurate wave metrics from distant beach cams but rely on manual visual assessment
- **Problem:** Manual assessment is time-consuming, inconsistent, and weather-dependent
- **Solution:** AI system that analyzes beach cam footage to provide critical wave metrics

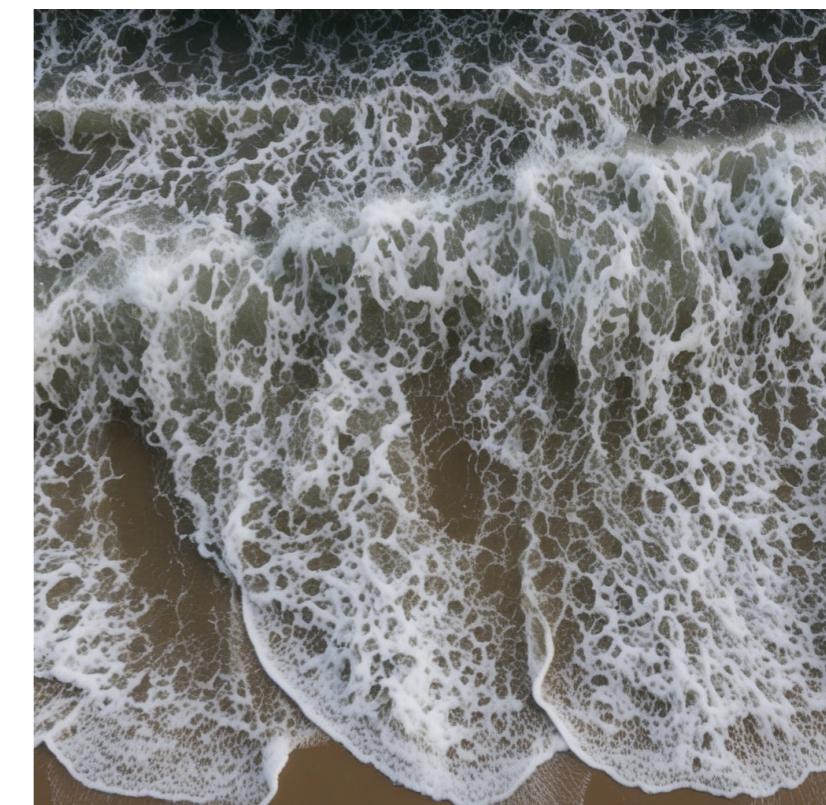
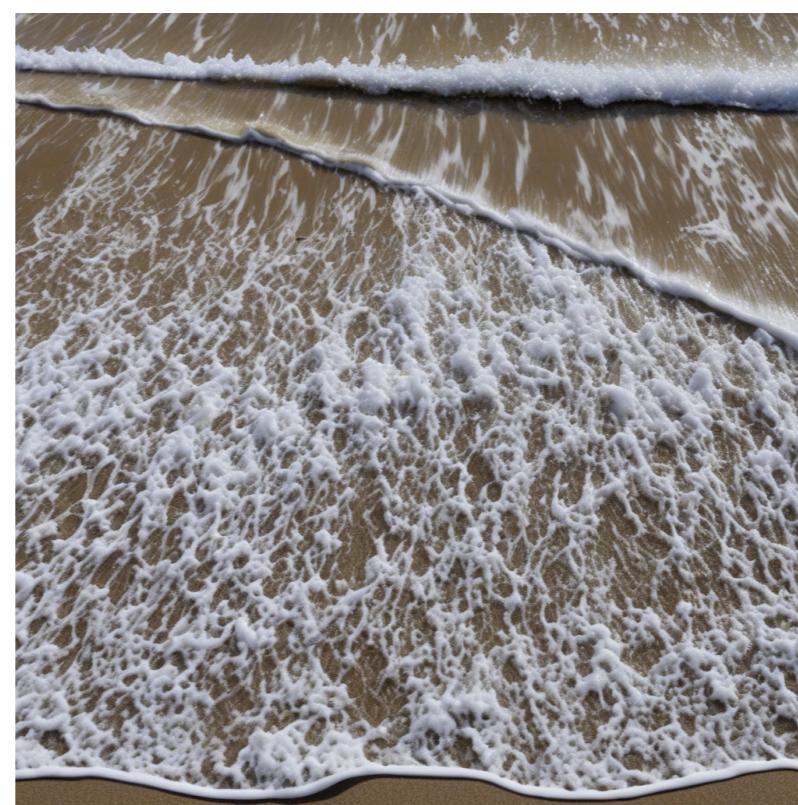
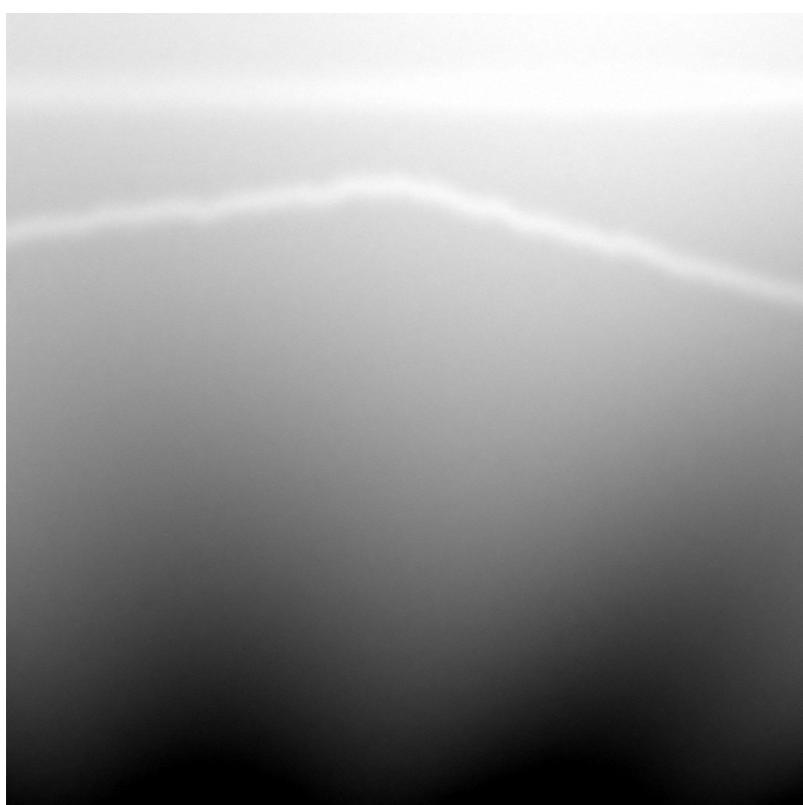
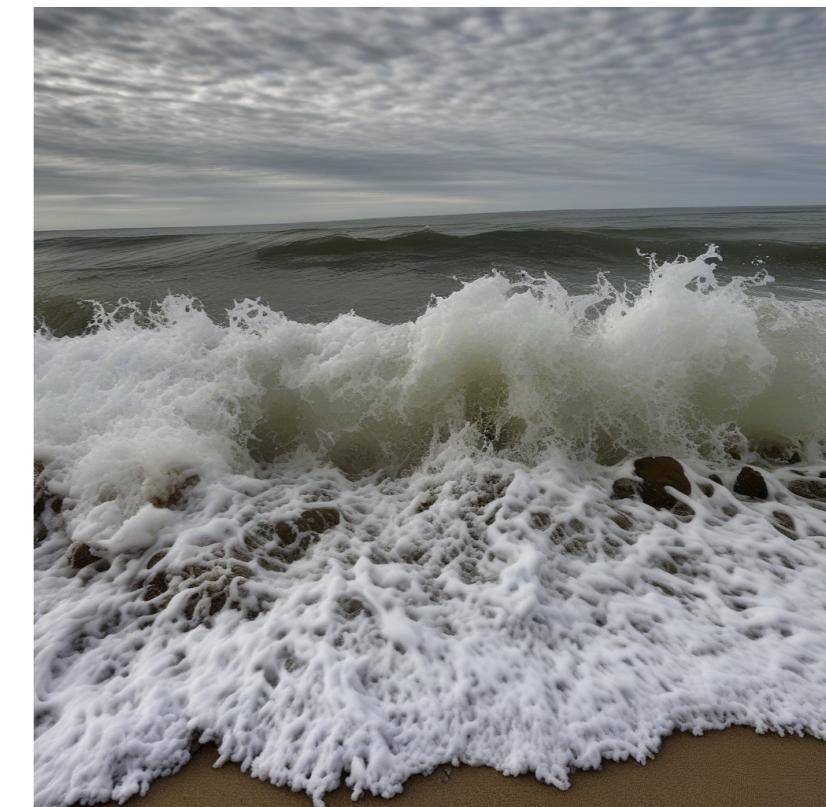
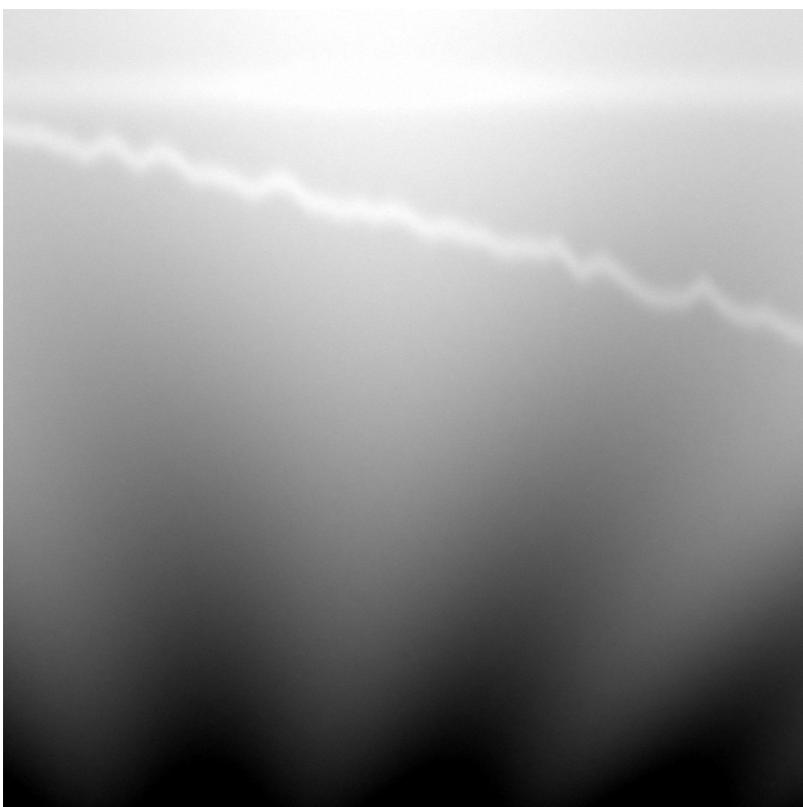
Dataset & Models

- **Depth-Anything-V2** for high-frequency wave texture capture
- **FLUX.1-dev + ControlNet** for physics-accurate synthetic waves
- **DINOv2 backbone** for geometric wave understanding
- **Data:** Beach cam images (RGB + Depth), synthetic labeled dataset **through generation pipeline.**
- **Metrics:** **MAE/RMSE for height, Accuracy/F1 for classifications.**

Key Achievements

- **End-to-end AI pipeline** from raw beach cam footage to actionable wave metrics.
- **Real-time processing capability** (<2000ms per image).
- **Solved manual labeling challenge** through synthetic data generation.



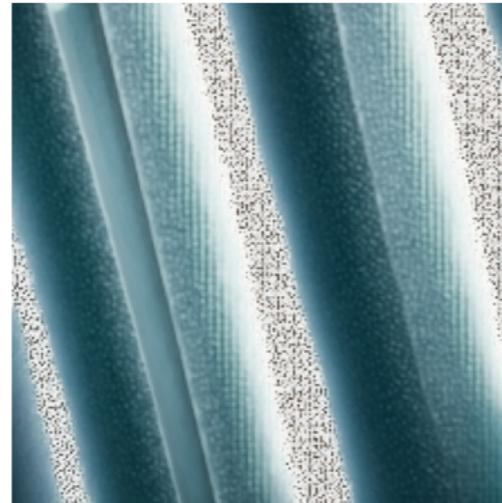


Synthetic Examples Generated During Our Work

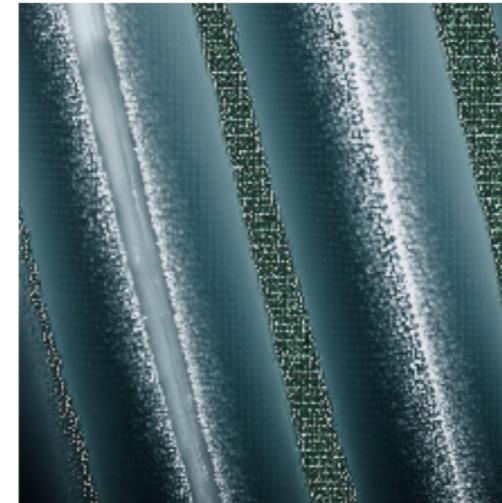
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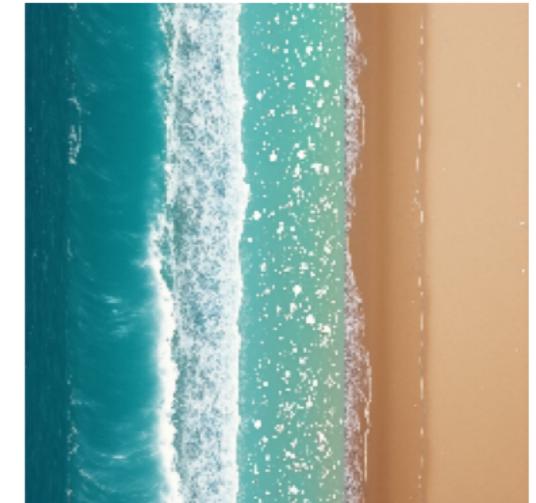
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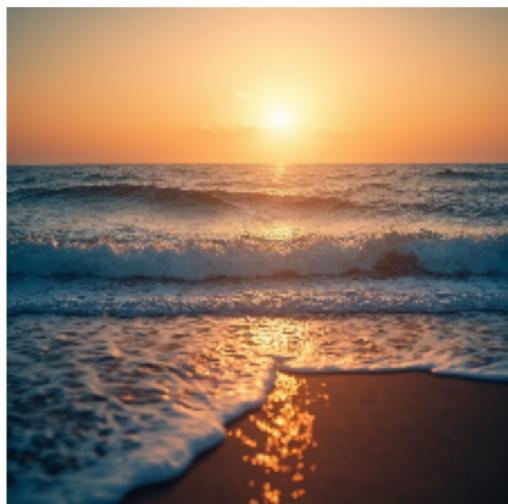
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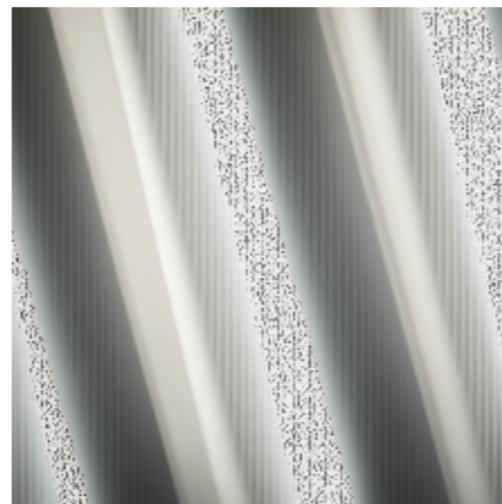
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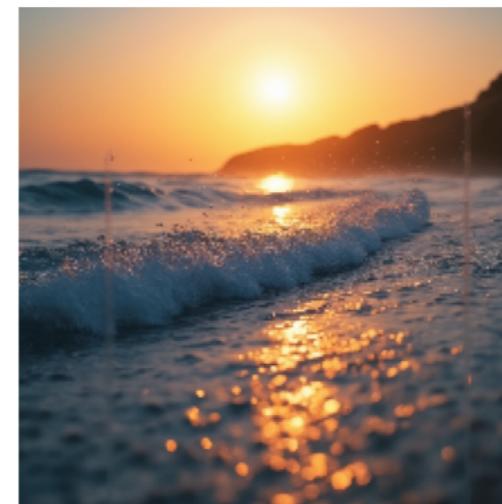
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H: 0.00->-0.30
D: 2->0 B: 2->0



H: 0.00->-0.36
D: 2->1 B: 2->1



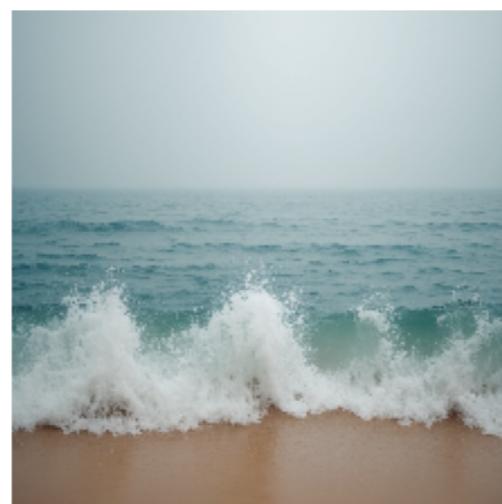
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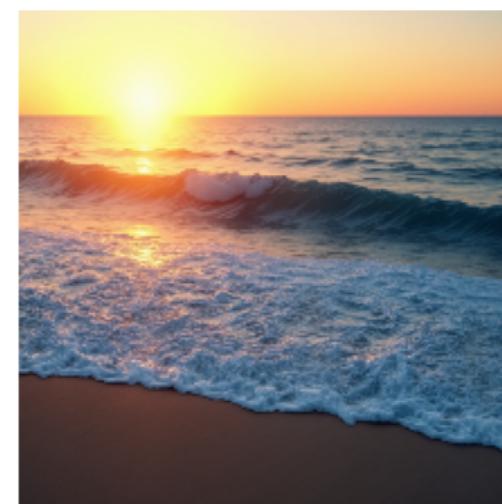
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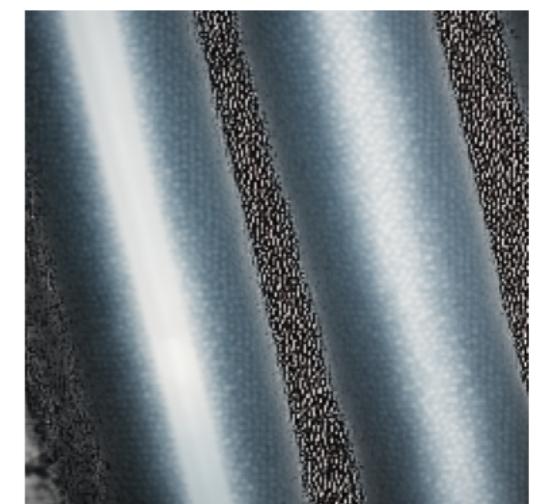
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H: 0.00->0.20
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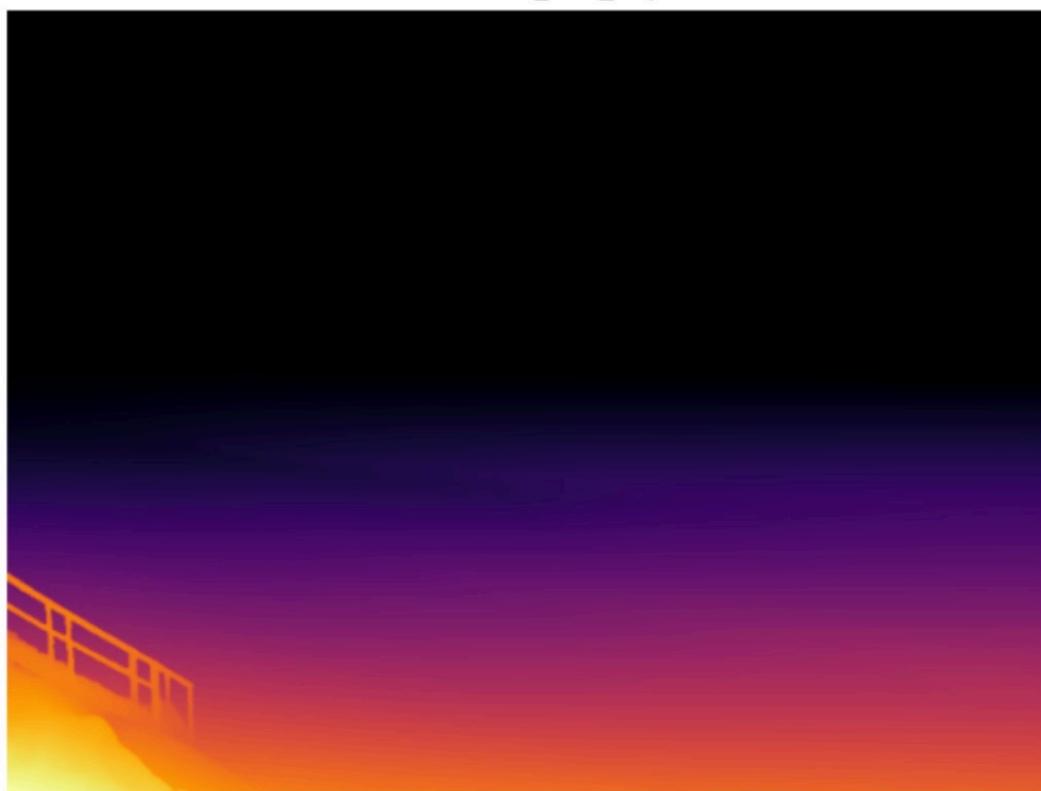
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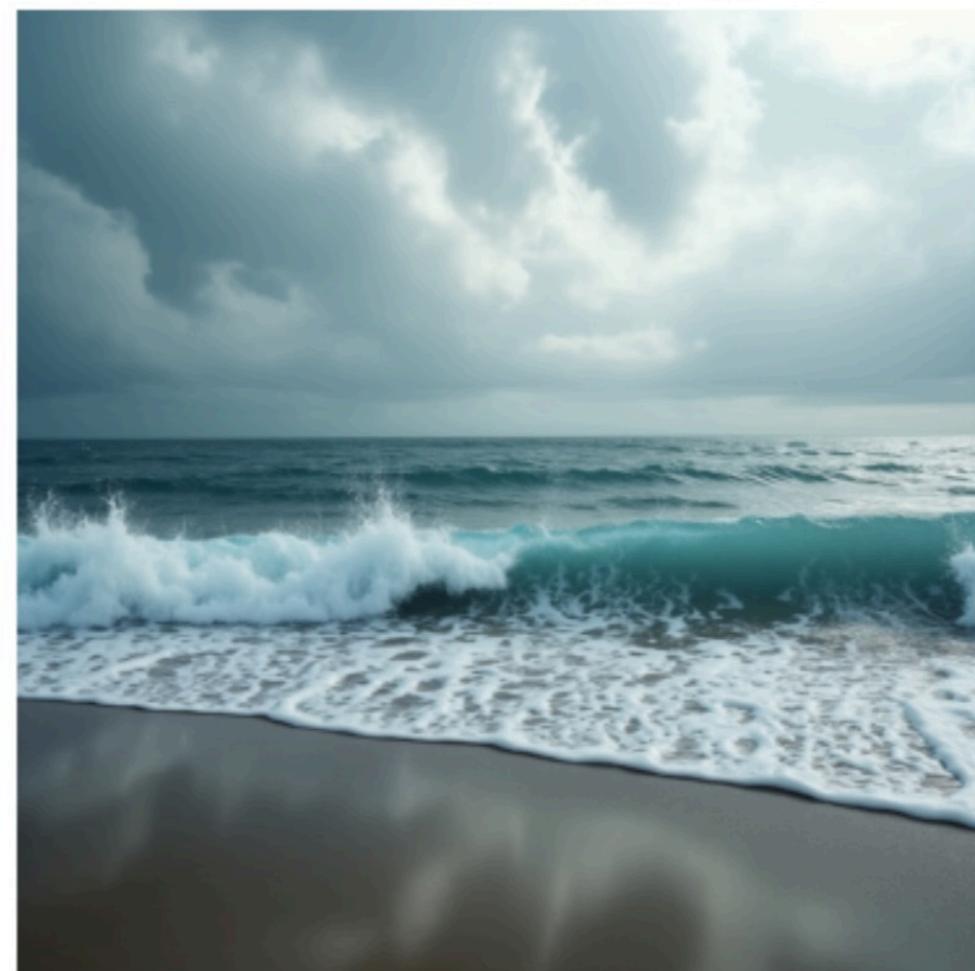
The original photo



Source: beach_220_depth...



Generated: synthetic_0025.npy

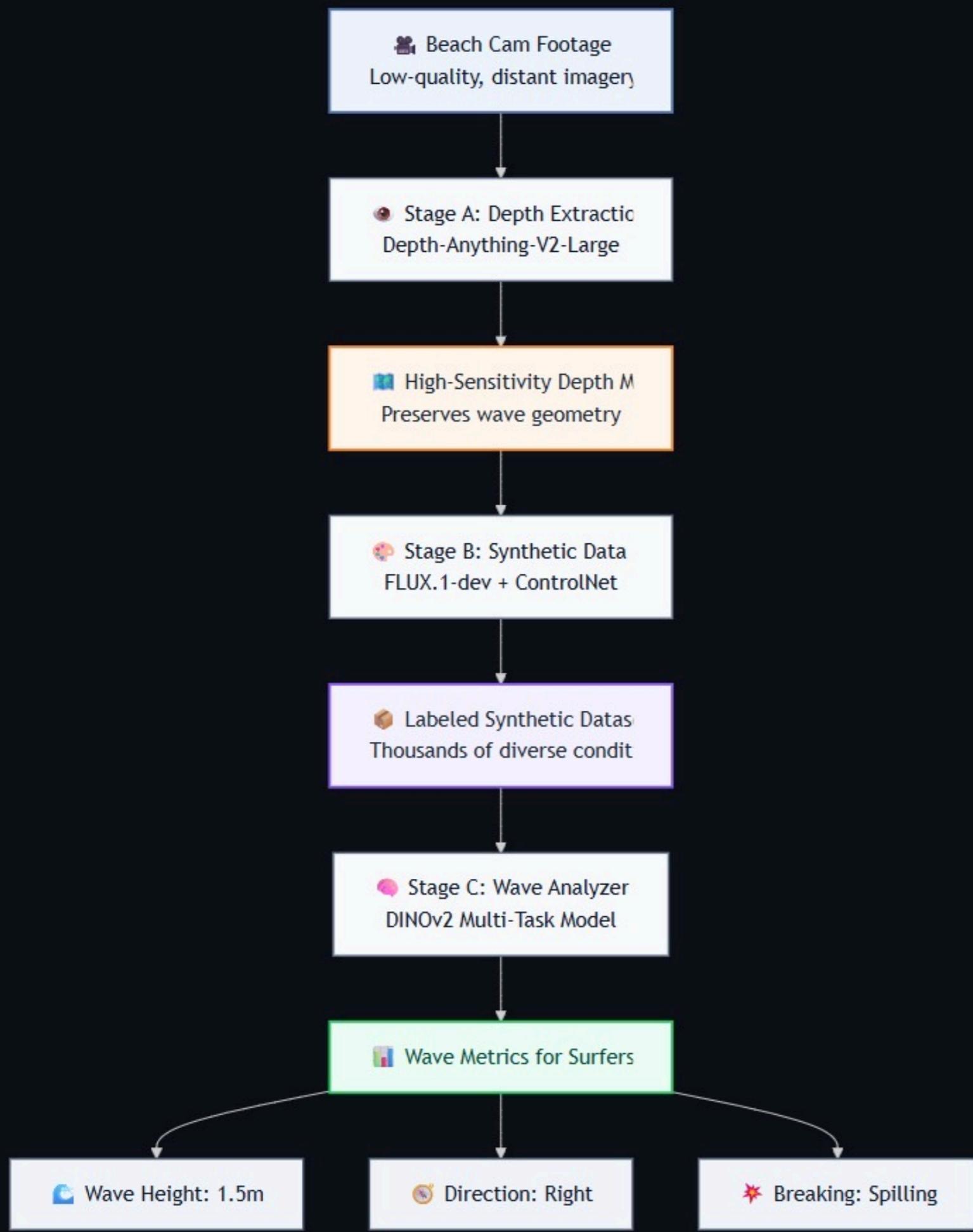




Novel Contributions

- **Hybrid Pipeline Architecture:** Generative AI trains Analytical AI (sim-to-real approach).
- **Advanced Depth Sensing:** Depth-Anything-V2 for high-frequency wave texture capture.
- **Physics-Accurate Synthesis:** FLUX.1-dev + ControlNet for photorealistic wave generation.
- **Geometric Intelligence:** DINOv2 self-supervised backbone for superior wave understanding.
- **Multi-Task Learning:** Single model predicting three metrics simultaneously with shared representations.

Data Generation Pipeline and Models Used



Review methodology- Three Stage Pipeline

Stage A: Depth

Extraction (The "Eye")

- **Model:** Depth-Anything-V2-Large (518×518 resolution)
- Extracts high-sensitivity depth maps preserving wave texture and distant shapes
- **Output:** Normalized grayscale depth maps

Stage B: Synthetic Data

Factory (The "Simulator")

- **Model:** FLUX.1-dev + Shakker-Labs ControlNet-Depth
- Generates 500+ photorealistic synthetic images with perfect labels
- Creates diverse weather/lighting conditions while preserving wave geometry

Stage C: Wave Analyzer (The "Brain")

- **Backbone:** DINoV2-ViT-B/14 (frozen, 768-dim features)
- Input: 4-channel (RGB + Depth) beach cam images
- **Architecture:** Multi-task model with three specialized prediction heads
- **Training:** Sim-to-real strategy (50 epochs pre-training + 150 epochs fine-tuning)



Review methodology

Quality Efforts:

- Multi-level validation (image, depth, generation quality)
- Confidence calibration (isotonic/Platt/temperature scaling)
- Data augmentation preserving scale (critical for height measurement)



Efforts and Challenges

Problem Faced:

Using MiDaS model produced low precision depth maps.

Solution provided:

Implemented Depth-Anything-V2 model to ensure better precision and small details sensitivity.

Problem Faced:

Synthetic images generated have low quality and unlogical details

Solution provided:

Implemented FLUX.1-dev + Shakker-Labs ControlNet-Depth to improve data generation.

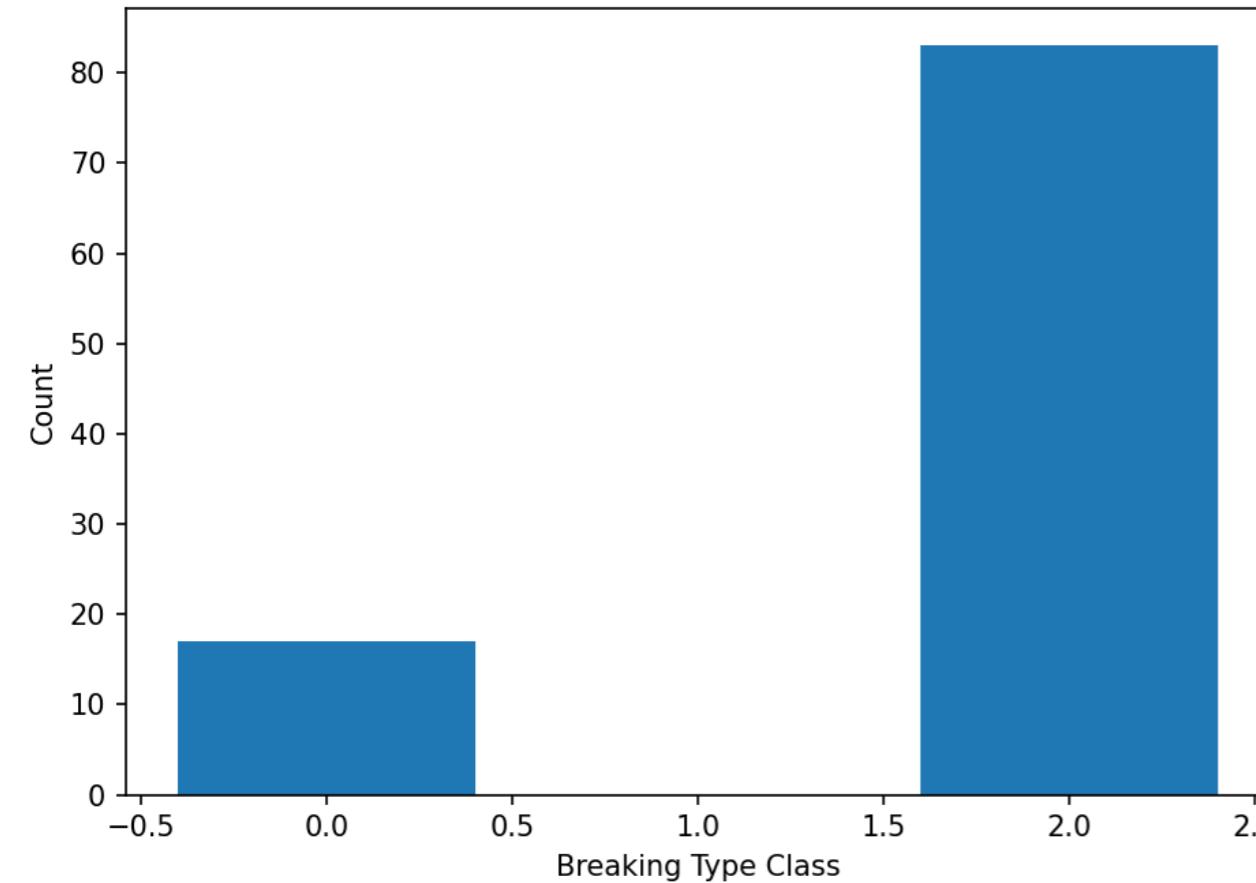
Results – Model Evaluation

Task	Metric	Value	Interpretation
Wave Height	MAE	0.181m	Precise; strong predictive performance.
Wave Height	RMSE	0.218m	Dependable; few large errors.
Wave Type	Accuracy	42.0%	Weak; barely beats chance.
Wave Type	Macro F1	0.276	Poor class-wise balance.
Direction	Accuracy	4.0%	Critically broken; likely bug.
Direction	Macro F1	0.026	Complete model failure.

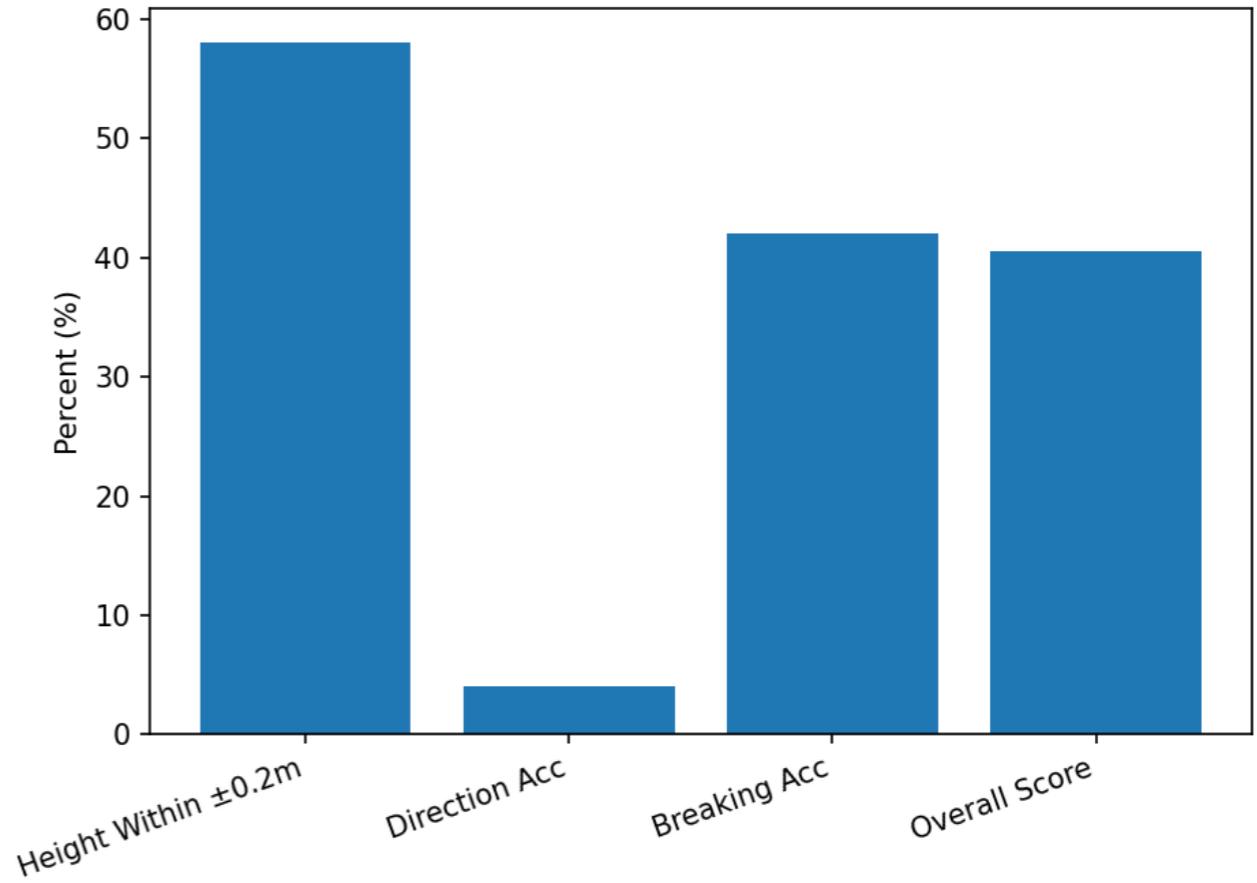
Performance Insights

- Wave height regression is highly effective, achieving a precise mean absolute error of just 18 centimeters.
- Direction prediction is broken with near-zero accuracy, confirming a critical mismatch between labels and predictions.
- Breaking type classification remains weak, struggling to capture the fine textural details required for accurate distinction.

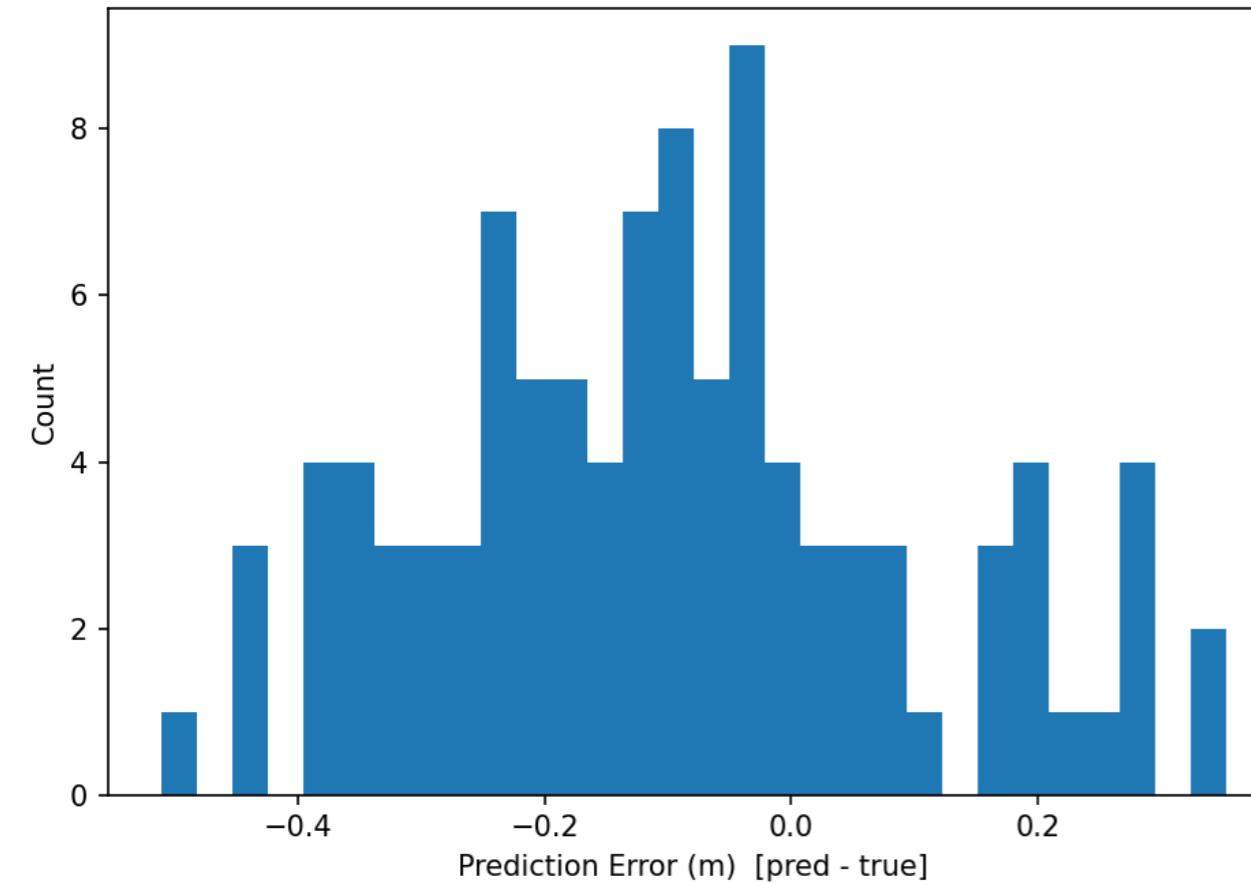
Breaking Type Distribution (Ground Truth)



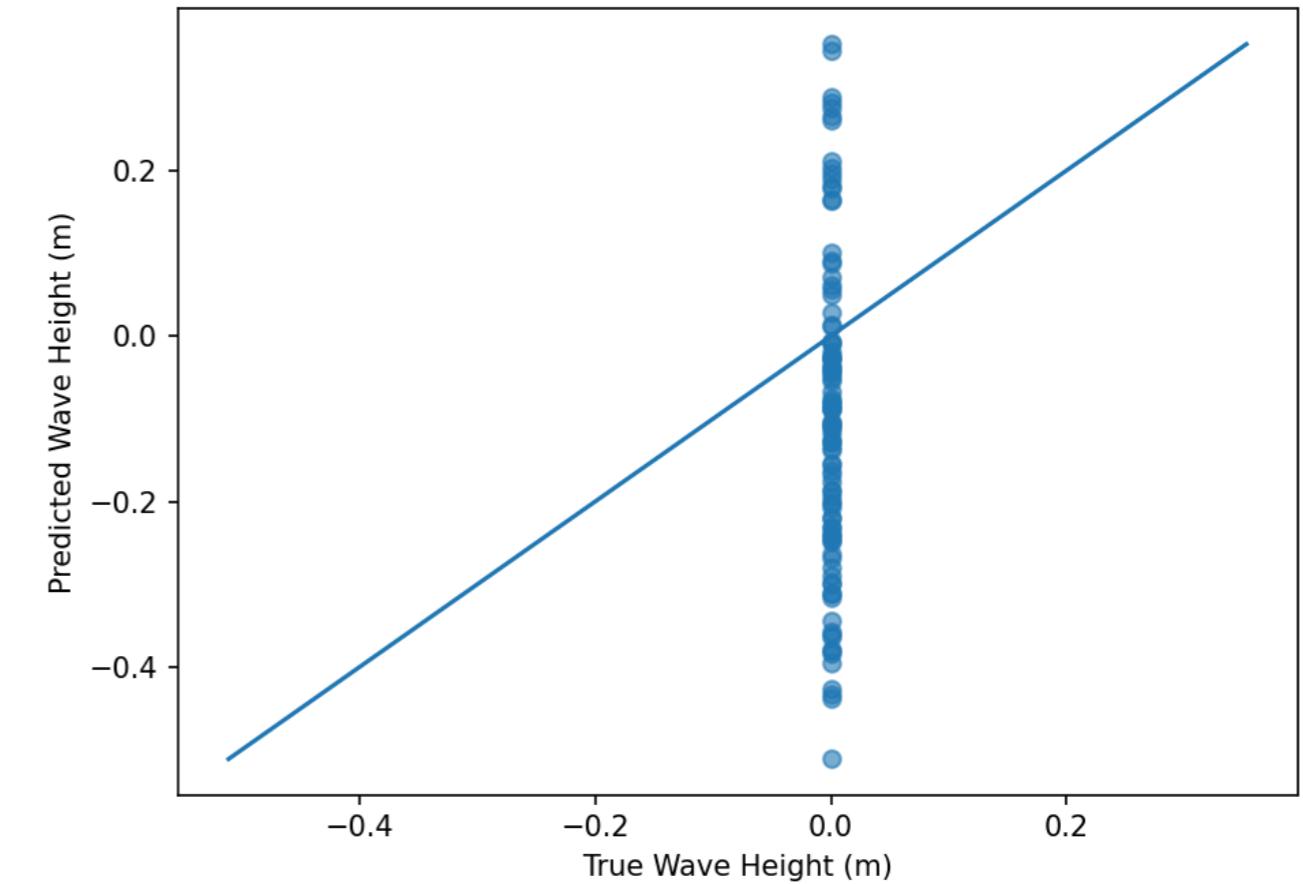
Evaluation Metrics Summary



Wave Height Error Distribution



Wave Height: Predicted vs True



Conclusion

Measuring Results

- **Yes.** Delivered a functional, multi-task system capable of height estimation and wave classification.
- Successfully completed e2e pipeline of data processing, generation, augmentation, and model training.

Learnings & Future Work

- **Limitation:** The real dataset (729 images) is sufficient for a Proof-of-Concept but too small for broad global generalization.
- **Plan & Research:** It is crucial to perform deep research of the best model available for each necessary task, along with organized plan and architecture of the model.
- **Future Experiment 1 (Video):** Move from single-frame to temporal analysis (video) to capture wave period and dynamics.
- **Future Experiment 2 (Deployment):** Optimize the model (ONNX/TensorRT) for mobile deployment to allow surfers to analyze waves directly from the beach.