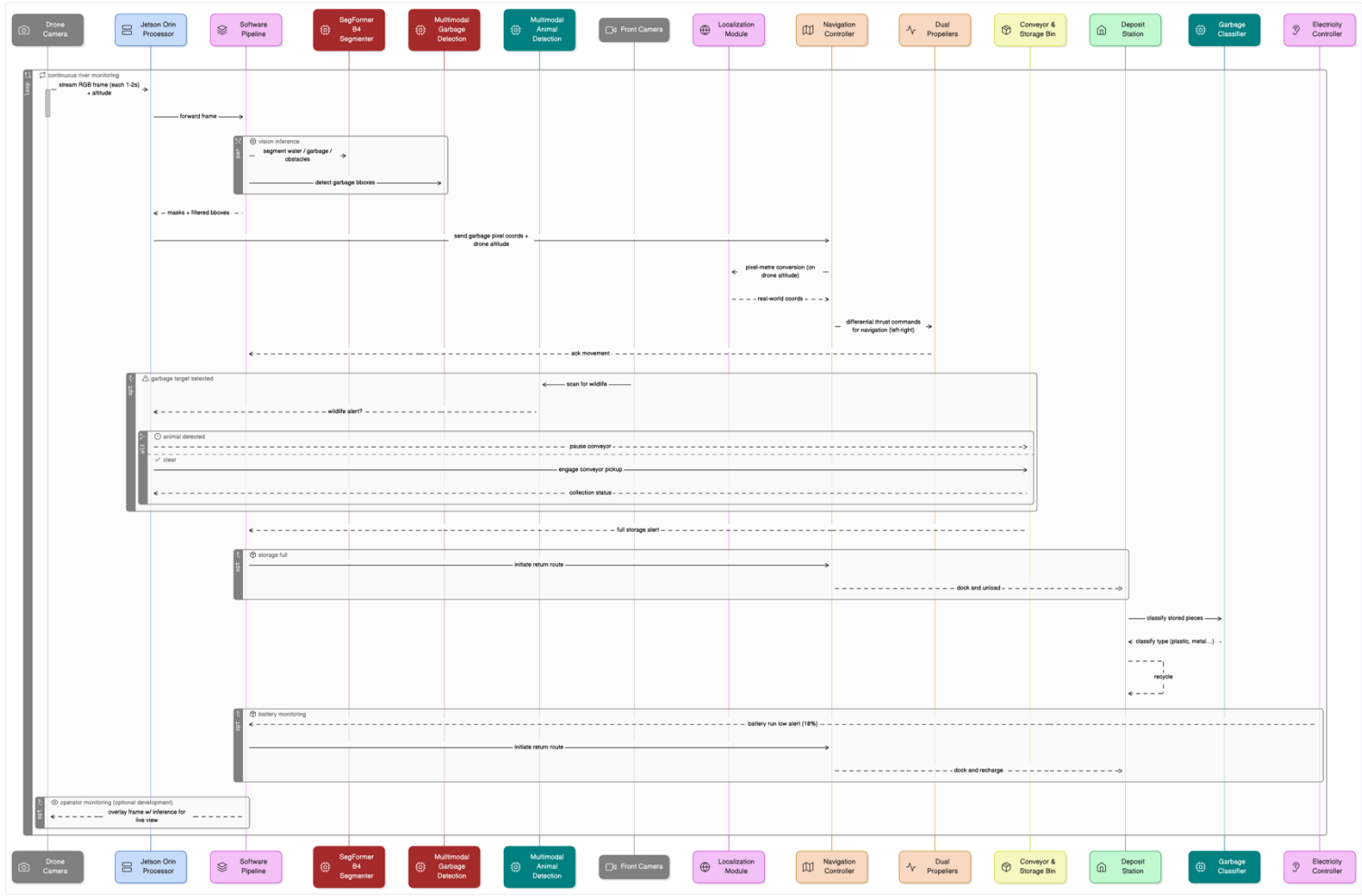
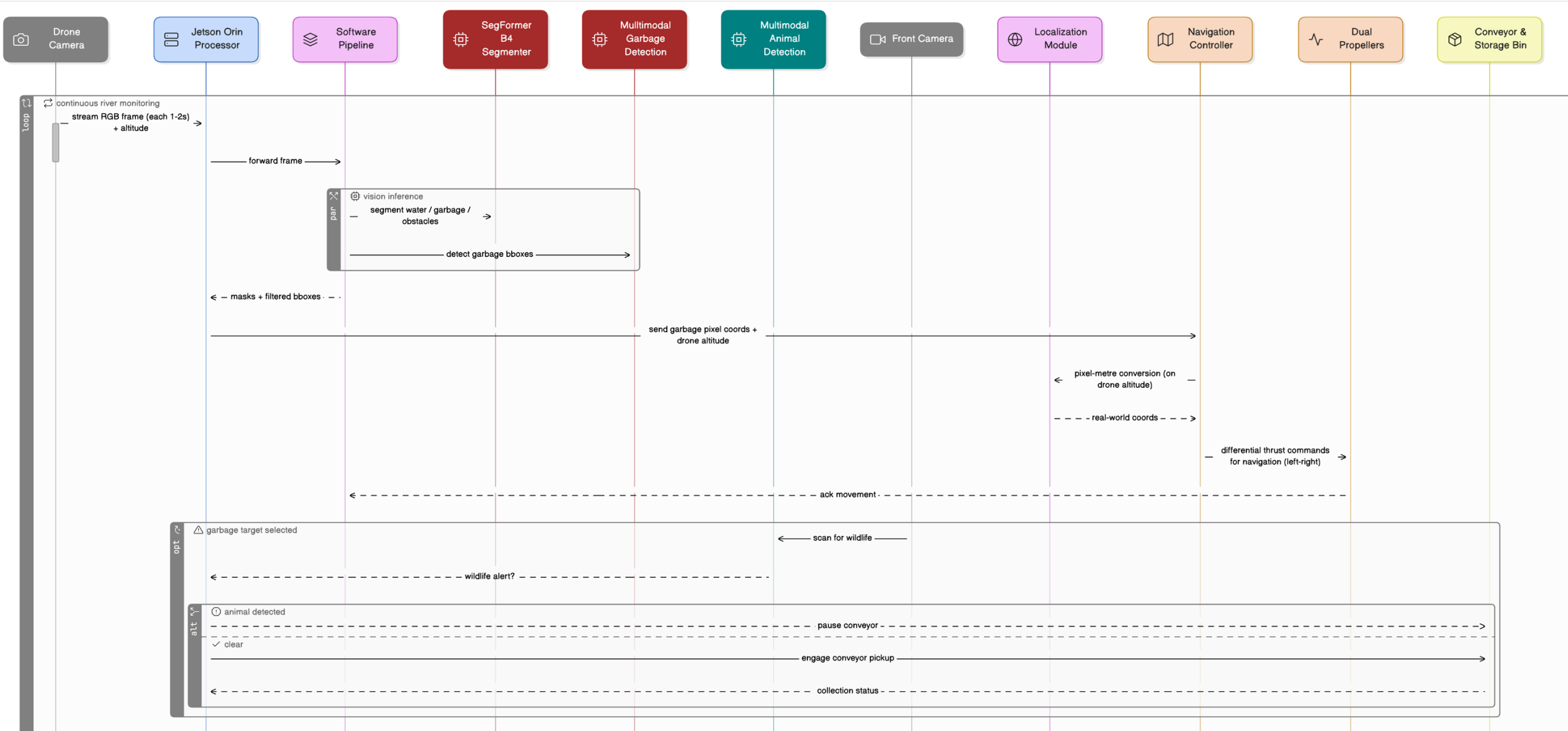
System Architecture

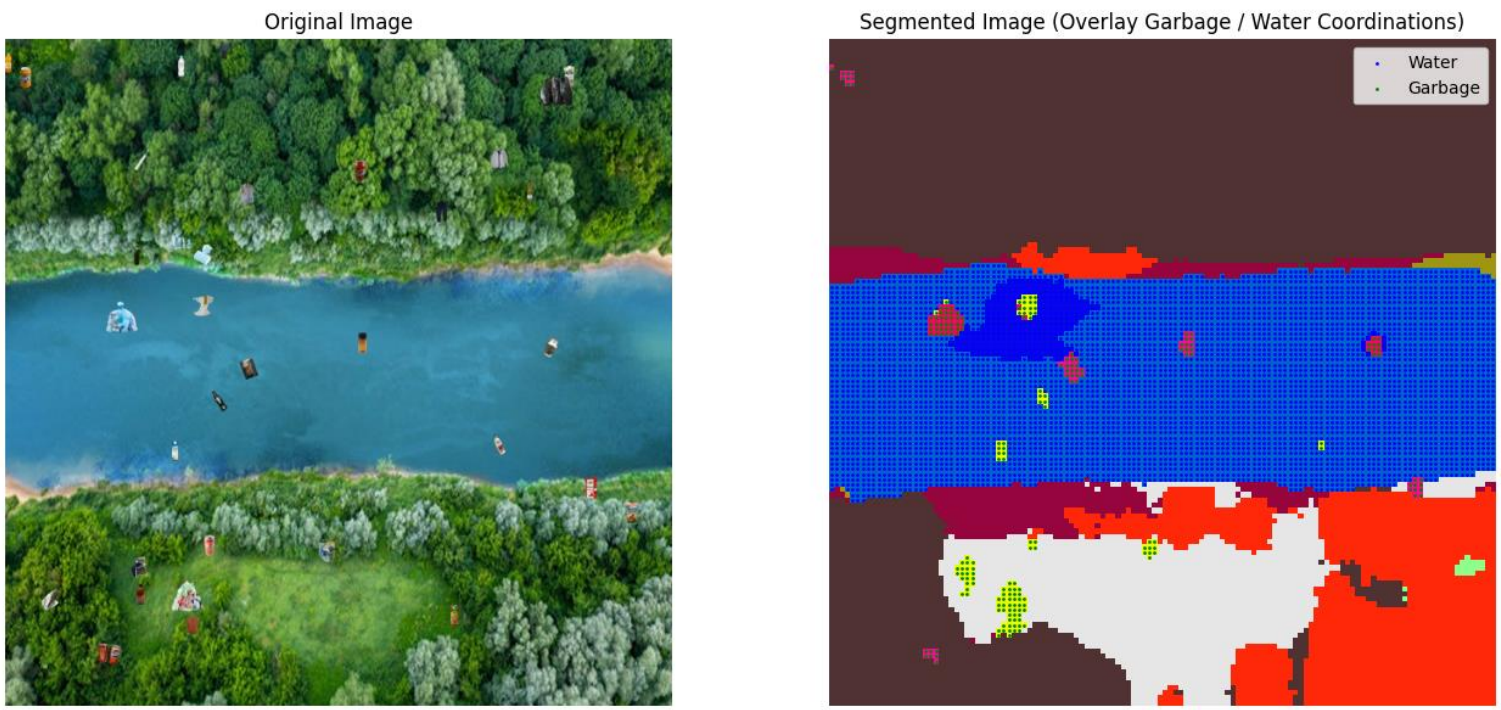


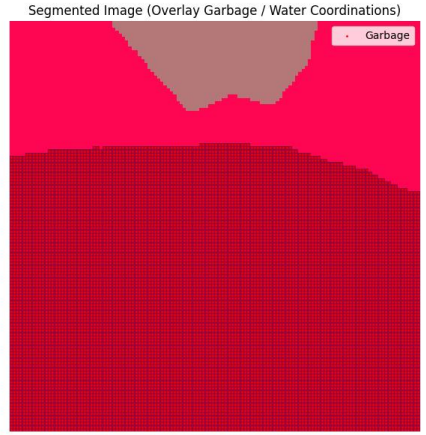
Operation Workflow



Segmentation

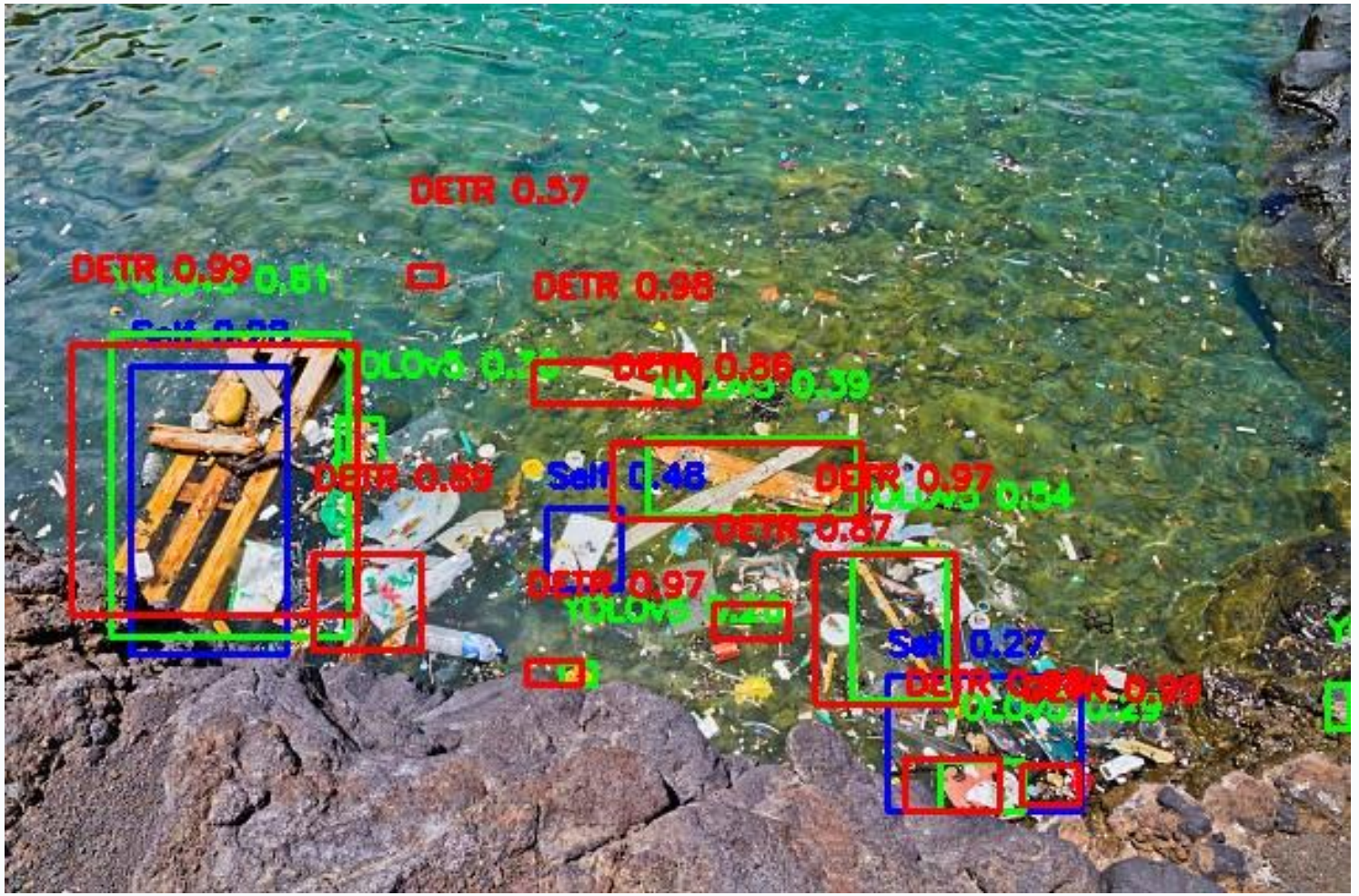
- Model: nvidia/segformer-b4-finetuned-ade-512-512
- Detects: Water, Garbage, Trees, Sand, Structures





Garbage Detection

- YOLOv11l (self-trained)
- YOLOv5 (CNN)
- DETR (Transformer-based)



YOLO+DETR multimodal system is well-designed architecture (Fahim Rustamy, PhD, 2023)

Navigation

Debris Removal

Debris only flagged as collectable collectable in movable zones

Path Optimization

A* + KNN reduces total path by path by 22% over baseline BFS BFS (Cui et al., 2017)

Navigation Formula

A-star algorithm
f(n) = g(n) + h(n)

- f(n): is the estimated cost of the path from the starting node to the goal node through node n.
- g(n): is the actual cost of the path from the starting node to node n.
- h(n): is the heuristic estimate of the cost from node n to the goal node. In Manhattan heuristic, this is calculated as h(n) = |x1 - x2| + |y1 - y2|.

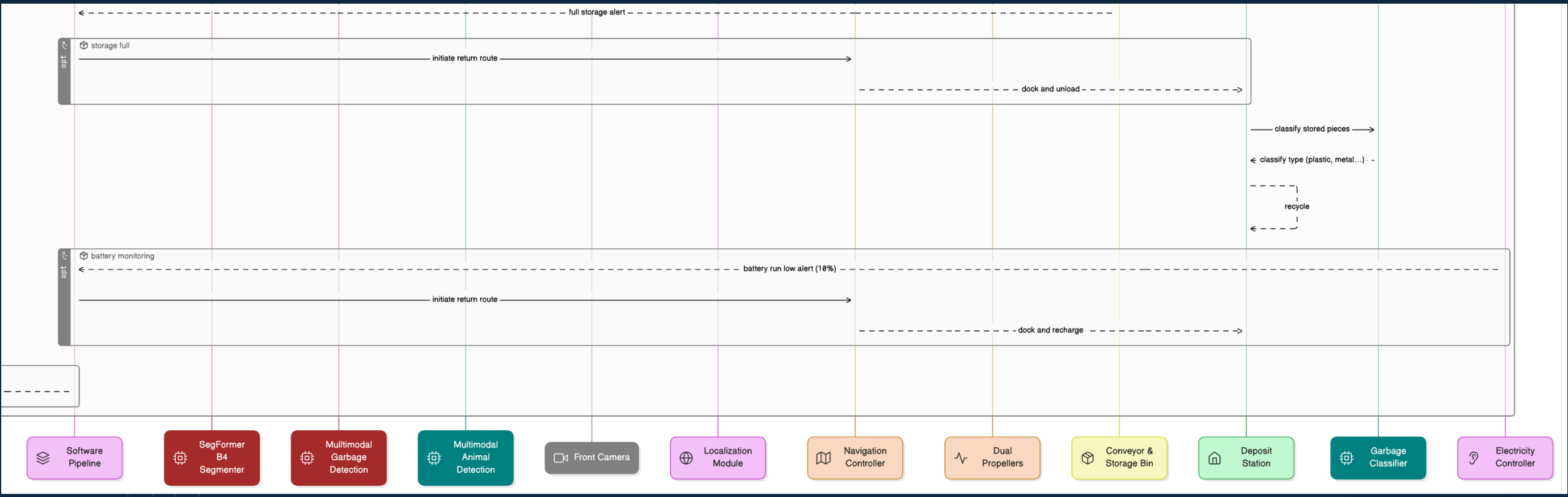
Deployment Stage

Apply mathematical program localizing pixel to meter-based coordination with drone' s altitude.

$$D = \frac{H \cdot \sqrt{(x - x_c)^2 + (y - y_c)^2} \cdot s}{f \cdot R}$$

- **H:** Drone altitude (meters)
- **f:** Focal length of camera (mm)
- **s:** Sensor height or width (mm)
- **R:** Image resolution height or width (pixels)
- (x,y): pixel coordinates of the detected object
- (xc,yc): pixel coordinates of the image center

Retrieval Trigger Mechanism



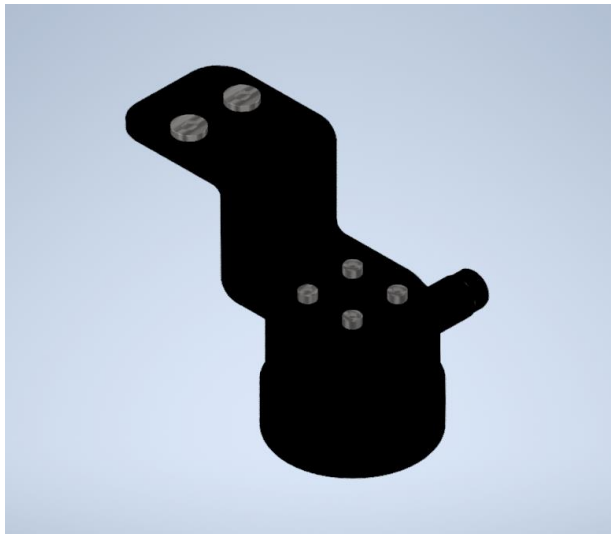
Wildlife Detection

Model Stack:
- **YOLOv8n** → mammals and birds (80+ COCO classes)
- **Fish model** → small fish in garbage areas
- **Bird model** → birds perched on floating debris

Control Behaviour:
- Frames with any valid detection halt conveyor pickup
- Resume only when clear — updated each frame

YOLOv8n chosen for its low-latency inference (<20 ms/frame) and edge compatibility.

Sonar Sensor: Underwater Detection

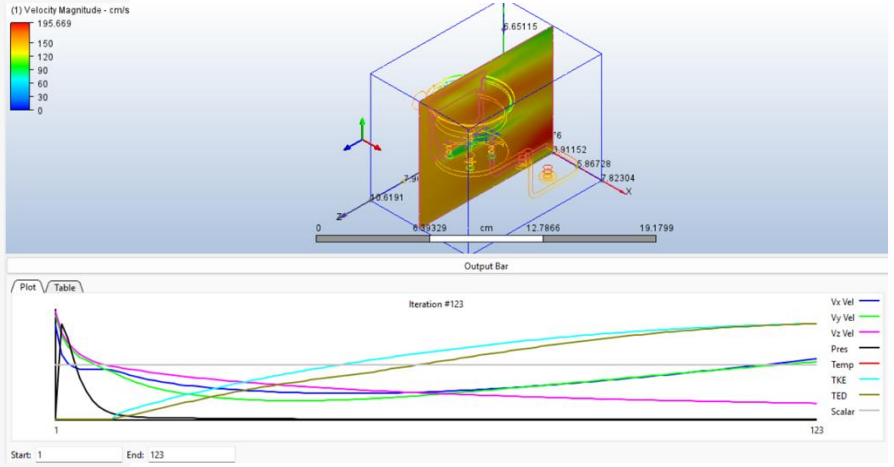


Blue Robotics Ping Sonar Altimeter and Echosounder

- Submergible waterproof sensor
- Range: 0.5 - 30 m
- Beam angle: 30 degrees

CFD Simulation:

- Water speed: 1.5 m/s - modelled from observed storm water speeds in area



CFD Hydrodynamic Flow Results:

- Smooth, laminar flow
- Negligible turbulence over sensor
- Total force: < 1N
- Flow does not interfere with sonar performance

Runtime Performance

Hardware:

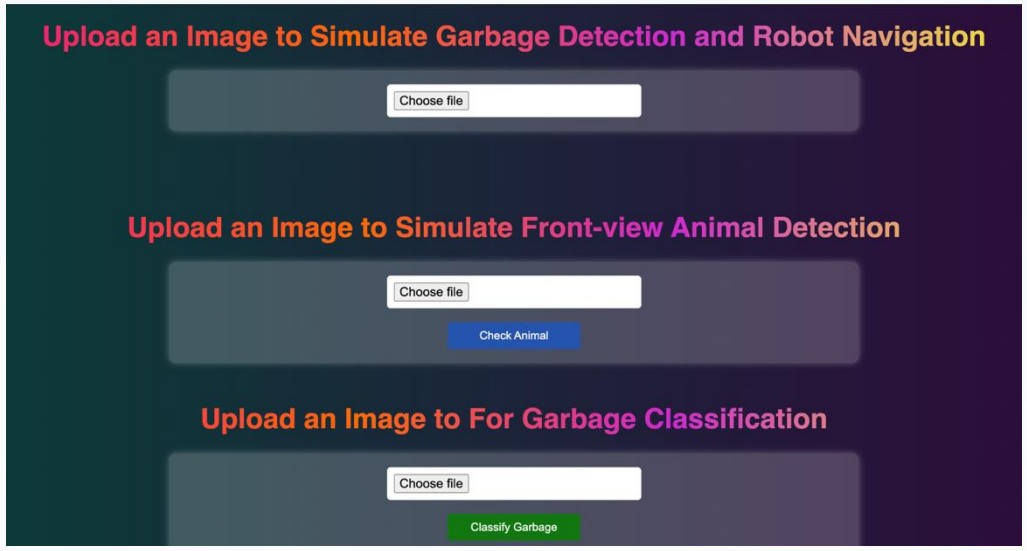
•Jetson Orin 64 GB (35W TDP)
•Drone video streaming service

Metrics:

•Segmentation: ~40 ms
•Detection: ~35 ms
•Total processing: < 100 ms per frame

Simulation

- Simulating full software pipelines on web-inference.
- 10 FPS video streaming (H.264)



Access Web Simulation at:
https://binkhoale1812-sall-egarbagedetection.hf.space/ui

Recycle Classifier

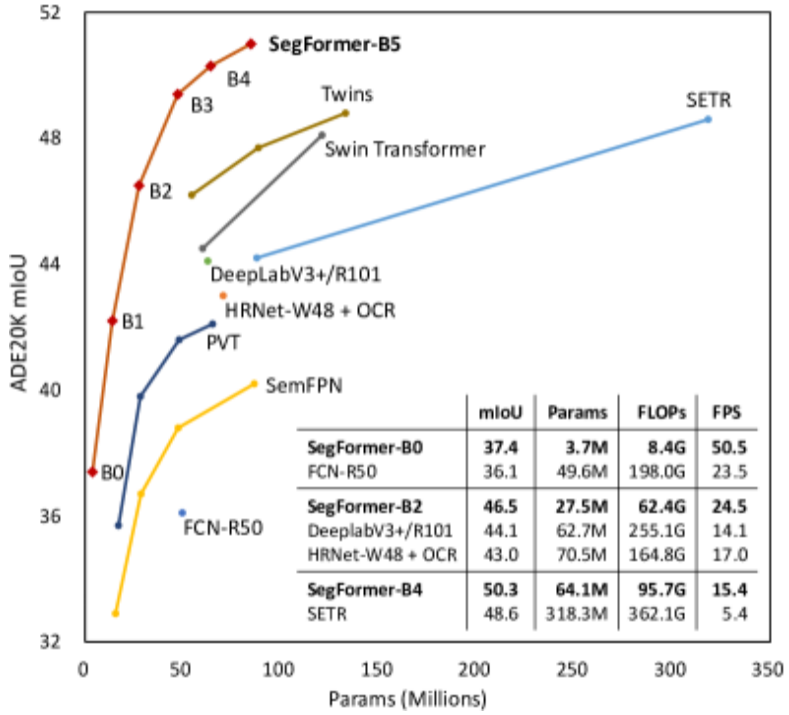
Post-collection, we leverage a **YOLOv8s classifier** (custom trained on 10 distinct garbage categories) to enable precise waste segregation, driving efficient recycling and greener downstream processing.

Key Implementation:

- **Model Stack**: Custom-trained YOLOv8s waste classification.
- **Outcome:** Model return with 97% accuracy on test-set while stay minimizing with 3-4% loss.
- **Impact**: Critical for automating recycling workflows and reducing environmental harm.

Software Deliverables

SegFormer-B4 achieves 50.3% mIoU (max 84.0%) on ADE20K only with 64M parameters, proving performance under terrain variation (NVIDIA 2021).



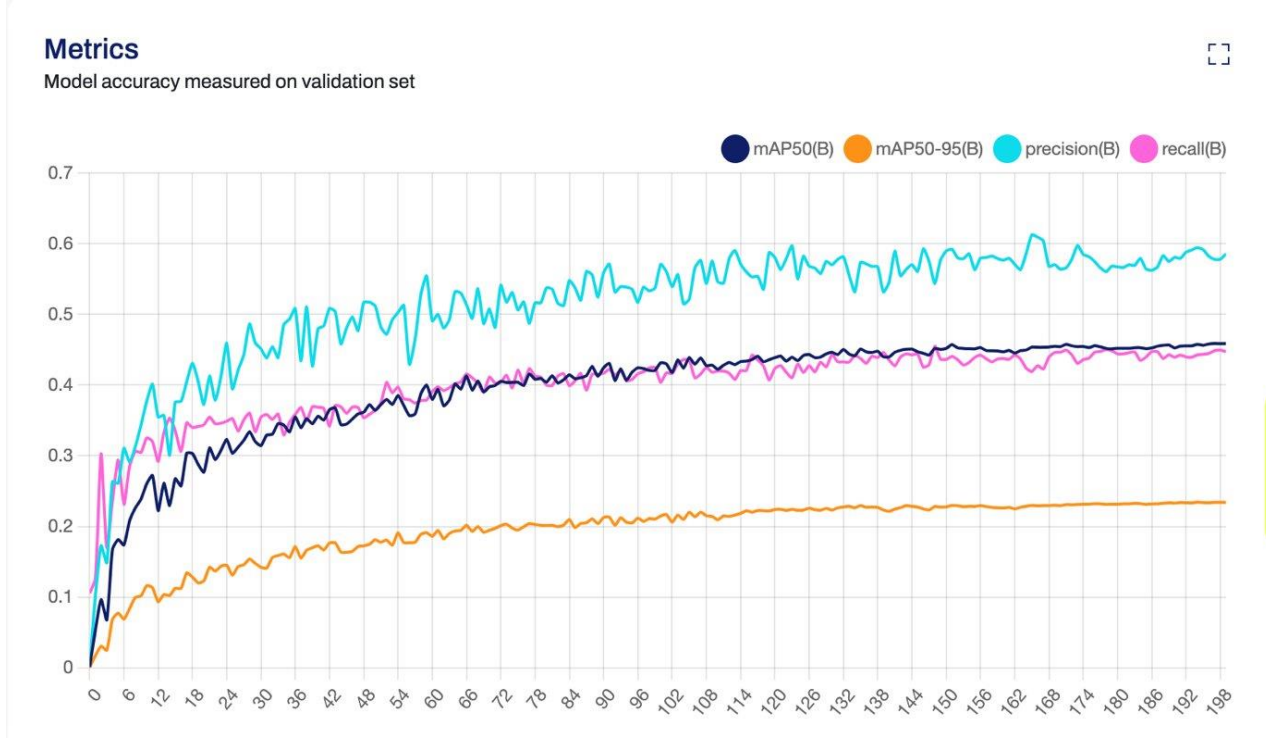
	mIoU	Params	FLOPs	FPS
SegFormer-B0	**37.4**	**3.7M**	**8.4G**	**50.5**
FCN-R50	36.1	49.6M	198.0G	23.5
SegFormer-B2	**46.5**	**27.5M**	**62.4G**	**24.5**
DeeplabV3+/R101	44.1	62.7M	255.1G	14.1
HRNet-W48 + OCR	43.0	70.5M	164.8G	17.0
SegFormer-B4	**50.3**	**64.1M**	**95.7G**	**15.4**
SETR	48.6	318.3M	362.1G	5.4

Garbage Classification

- ~92% across10 distinct garbage categories.
- *Maximum accuracy reaching 97%.*

Navigation Success

96% average successful collection rate across 10 simulation tests



- *Under complex environment, custom-trained reaches 60% percision with stabilized mAP indicate low false positive and overfitting.*
- *Multimodal detection architecture reutns 91–93% accuracy on test-sets.*