MICHIGAN STATE UNIVERSITY
College of Engineering

Soft Pressure Sensing System with Application to Underwater Sea Lamprey Detection

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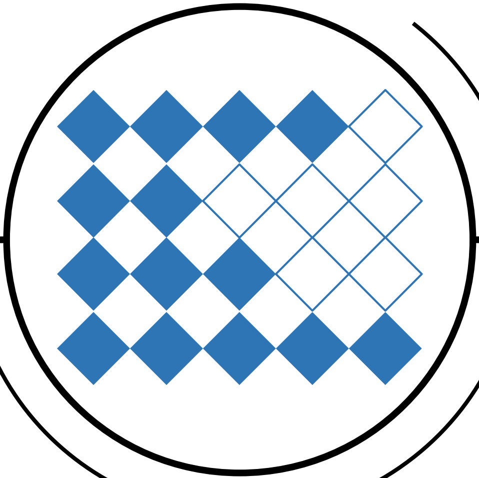
OVERVIEW



Sea Lampreys

Invasive species with a specific suction trait

Soft Pressure Sensors

Mapping pressure distribution of sea lamprey’s attachment

Automated Detection

Smart sensing panel with machine learning

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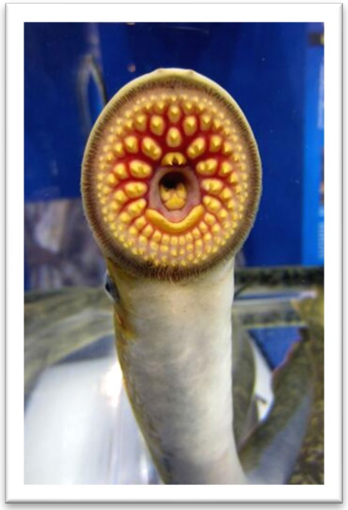
1. Introduction: sea lampreys



[1]

[2]

[3]

- Sea lamprey, a parasitic invasive fish species that invaded the Great Lakes in the 1930s.
- Each sea lamprey can kill up to 40 lbs. of host fish in its lifetime.
- Contribute to collapse of the major fish stocks in the Great Lakes (valued $4.5 billion annually).
- Sea lampreys rest during upstream migration for spawning, when they suck and attach to a surface.
- Distinct pressure pattern: positive on the mouth rim, negative inside the rim.

[1] https://www.usgs.gov/news/national-news-release/sea-lamprey-mating-pheromone-registered-us-environmental-protection
[2] https://www.michiganseagrant.org/lessons/lessons/by-broad-concept/life-science/sea-lamprey/
[3] https://seas.umich.edu/news/great-lakes-invasive-species-controlling-sea-lamprey-populations

1. Introduction: sea lamprey control program

GREAT LAKES FISHERY COMMISSION
PROTECTING OUR FISHERY

- Lampricides
- Sterile-male-release technique
- Migratory barriers and traps
- Selective fishway
  - Allow native or desired fishes to pass
  - Prevent passage of sea lampreys

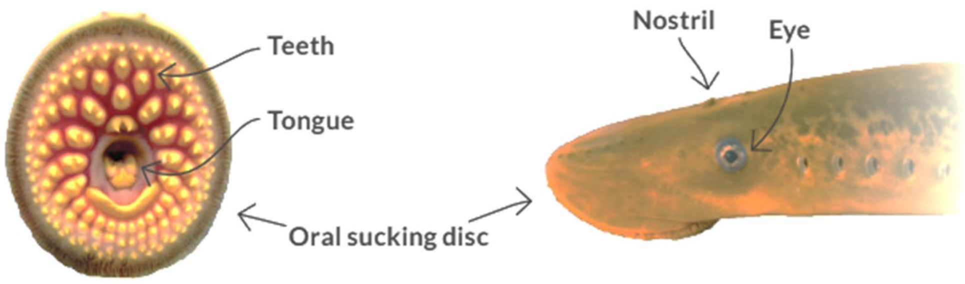
When to trigger the fishway operation?

Sea lamprey detection

1. Introduction: sea lamprey detection

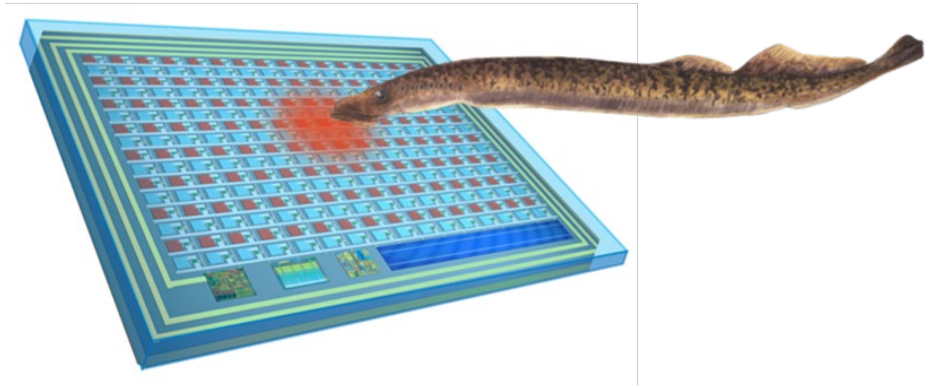
01 Video analysis

- Species morphological differences
- Image quality (water, light, …)
- Massive quantities of data
- Computationally intensive algorithms



02 Pressure Sensing

- the prominent suction trait
- Not affected by light conditions
- Less data required
- Pressure mapping visualization



CONTENTS

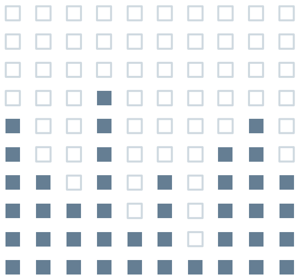
5.1 Sea Lamprey Detection With Machine Learning

Objectives:

- Automatically recognize patterns in the measured data;
- Accomplish proper classification of patterns and estimation of location & size;
- Provide information for the decision of a selective fishway operation;
- Support assessment of sea lamprey populations…

Approaches:

- Learning features from the data *vs.* from the generated mapping contour images;
- Utilize suitable object detection algorithms.



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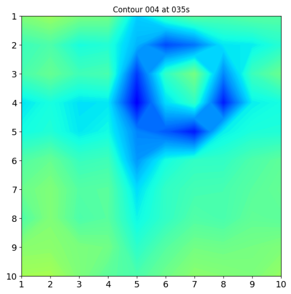


Data

Image

Feature detection

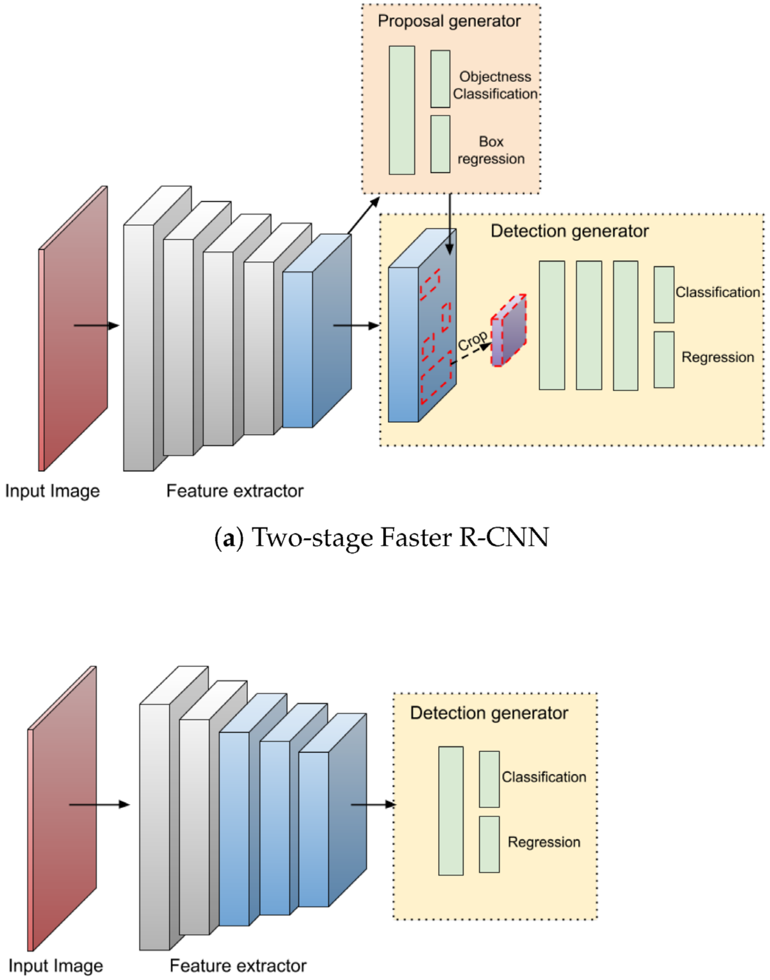
classification

bounding box regression

5.2 Object Detection Frameworks

Object detection methods:

- Non-neural approaches:
  - Viola-Jones Detector (2001)
  - HOG Detector (Histogram of Oriented Gradients,2006)
- Neural network approaches:
  - Two-stage object detectors:
    - R-CNN (Region proposal with CNNs, 2013)
    - Fast R-CNN and Faster R-CNN (2015)
    - Mask R-CNN (2017)
  - One-stage object detectors:
    - SSD (Single Shot MultiBox Detector, 2016)
    - RetinaNet (2017)
    - YOLO (You only look once, 2016)



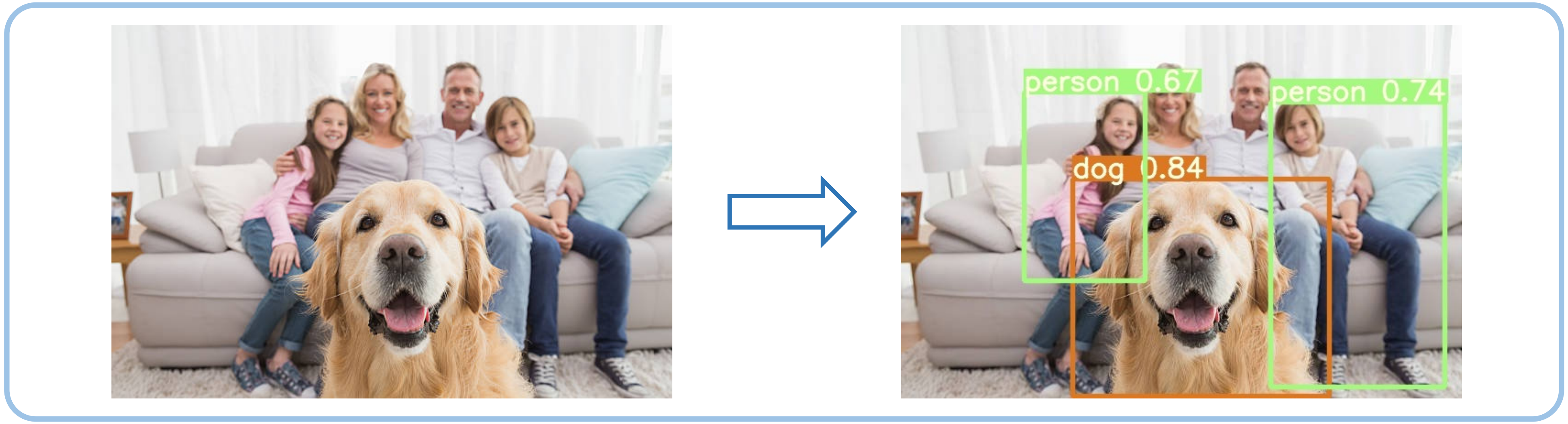
(a) Two-stage Faster R-CNN

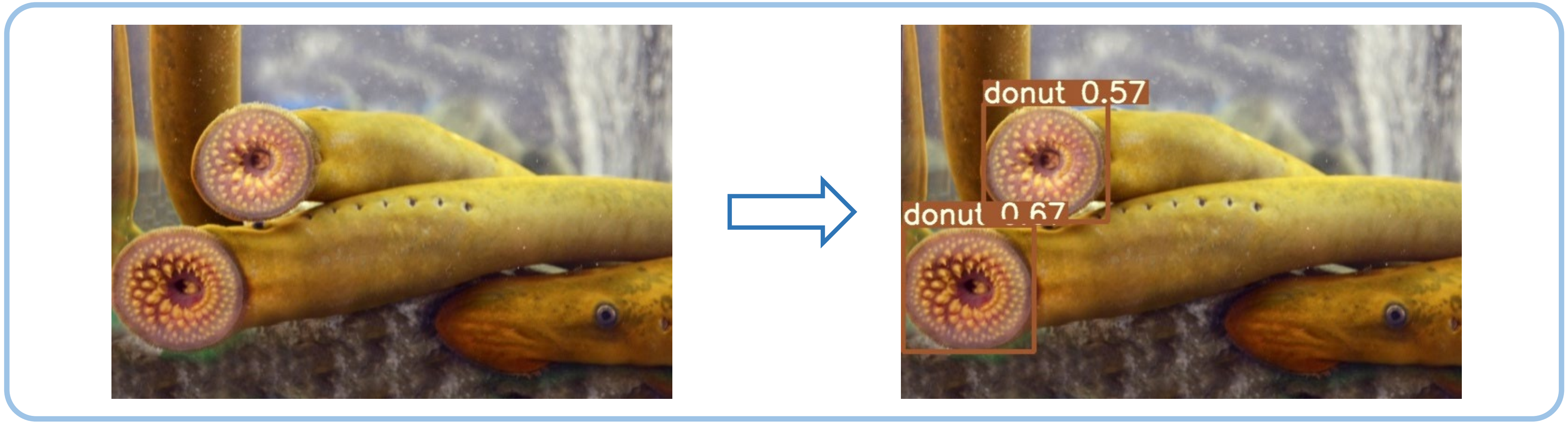
(b) One-stage RetinaNet

https://stackoverflow.com/questions/65942471/one-stage-vs-two-stage-object-detection

5.2 Object Detection Frameworks

A quick test of the YOLOv5 detection networks.



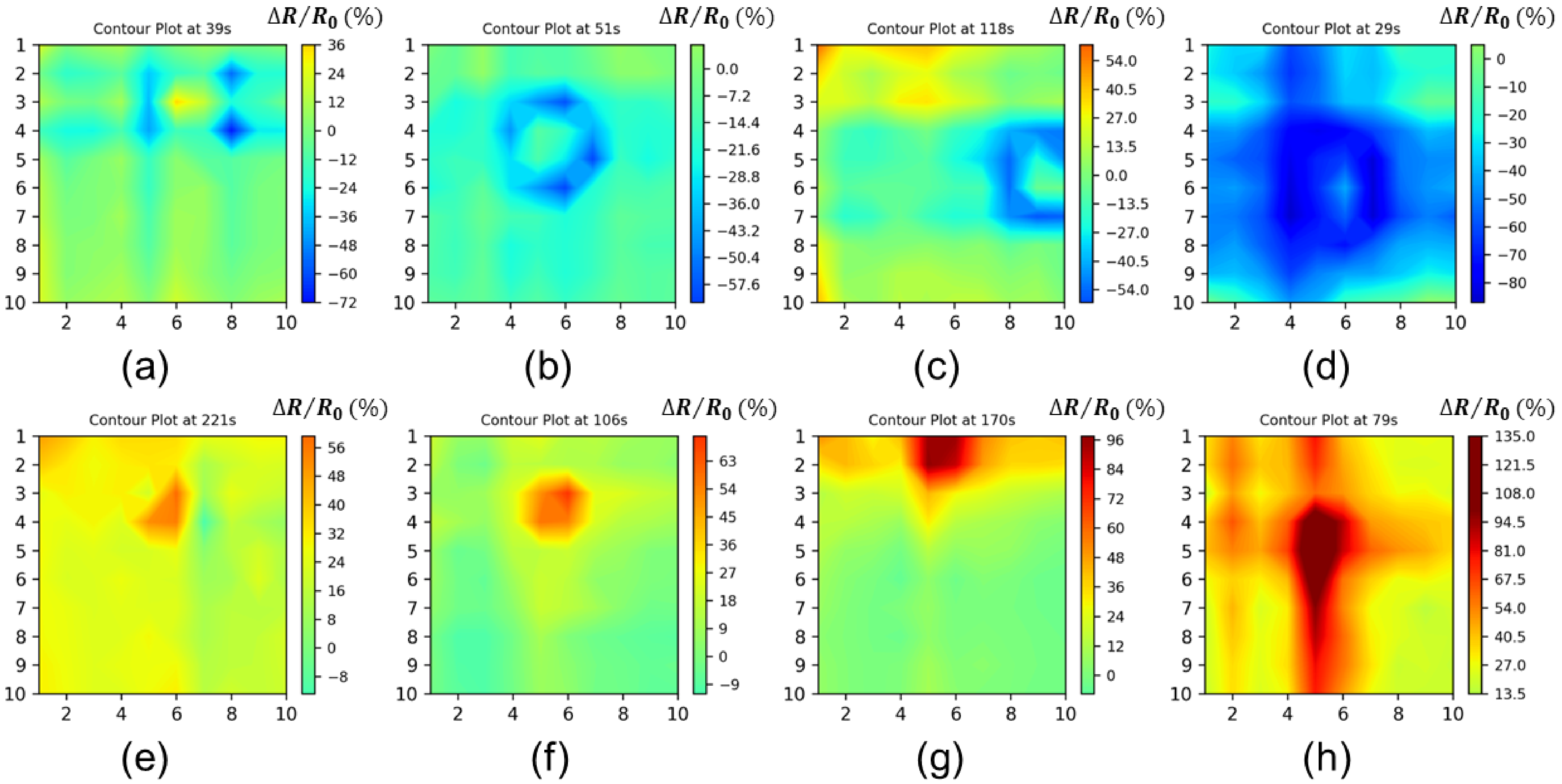


5.3 Dataset: Mapping Contour Patterns

- Relative change in measured resistance:

Compression

Suction



5.4 Image Annotation

- **RetinaNet** label format: $(class, x_{min}, y_{min}, x_{max}, y_{max})$

$$x_{min} = \left(\frac{Col_{min} - 1}{10 - 1} \cdot r_w + r_{lm}\right) \cdot Fig_w \quad (2)$$

$$x_{max} = \left(\frac{Col_{max} - 1}{10 - 1} \cdot r_w + r_{lm}\right) \cdot Fig_w \quad (3)$$

$$y_{min} = \left(\frac{Row_{min} - 1}{10 - 1} \cdot r_h + r_{tm}\right) \cdot Fig_h \quad (4)$$

$$y_{max} = \left(\frac{Row_{max} - 1}{10 - 1} \cdot r_h + r_{tm}\right) \cdot Fig_h \quad (5)$$

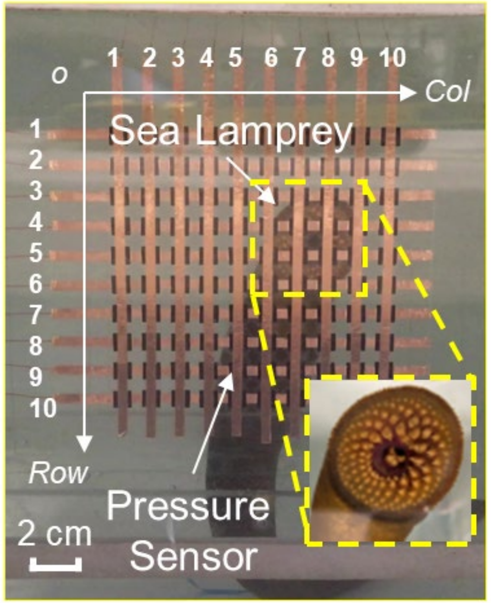
- **SSD** & **YOLO**: $(class, x_{center}, y_{center}, w_{bbox}, h_{bbox})$

$$x_{center} = \left(\frac{\frac{Col_{min} + Col_{max}}{2} - 1}{10 - 1} \cdot r_w + r_{lm}\right) \quad (6)$$

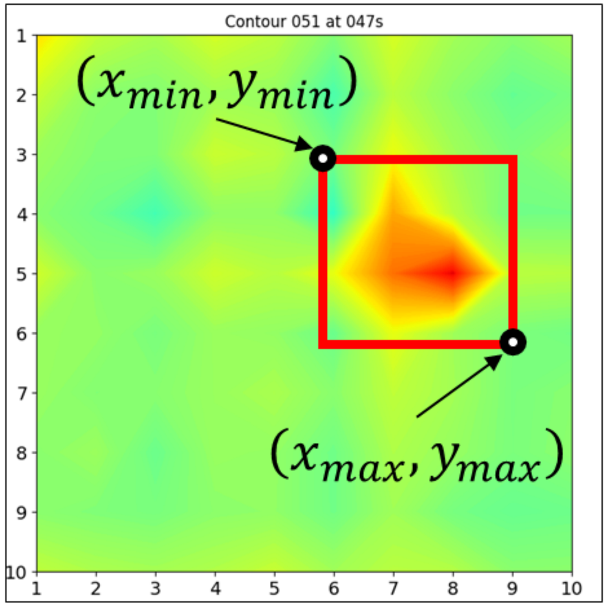
$$y_{center} = \left(\frac{\frac{Row_{min} + Row_{max}}{2} - 1}{10 - 1} \cdot r_h + r_{tm}\right) \quad (7)$$

$$w_{bbox} = \frac{Col_{max} - Col_{min} - 1}{10 - 1} \cdot r_w \quad (8)$$

$$h_{bbox} = \frac{Row_{max} - Row_{min} - 1}{10 - 1} \cdot r_h \quad (9)$$



(a)



(b)

5.5 Assessment of Three Object Detectors

Table 5.1. Statistics of the Sea Lamprey Dataset.

Dataset	Compression Pattern	Suction Pattern	Total
Training	498	1,976	2,474
Validation	125	495	620
Testing	685	453	3,875

Table 5.2. Hyperparameters for Training the Sea Lamprey Detection Networks.

Parameter	Value
Learning rate	0.005
Momentum	0.9
Weight decay	0.0005
Score threshold	0.050
NMS threshold	0.5

5.5 Assessment of Three Object Detectors

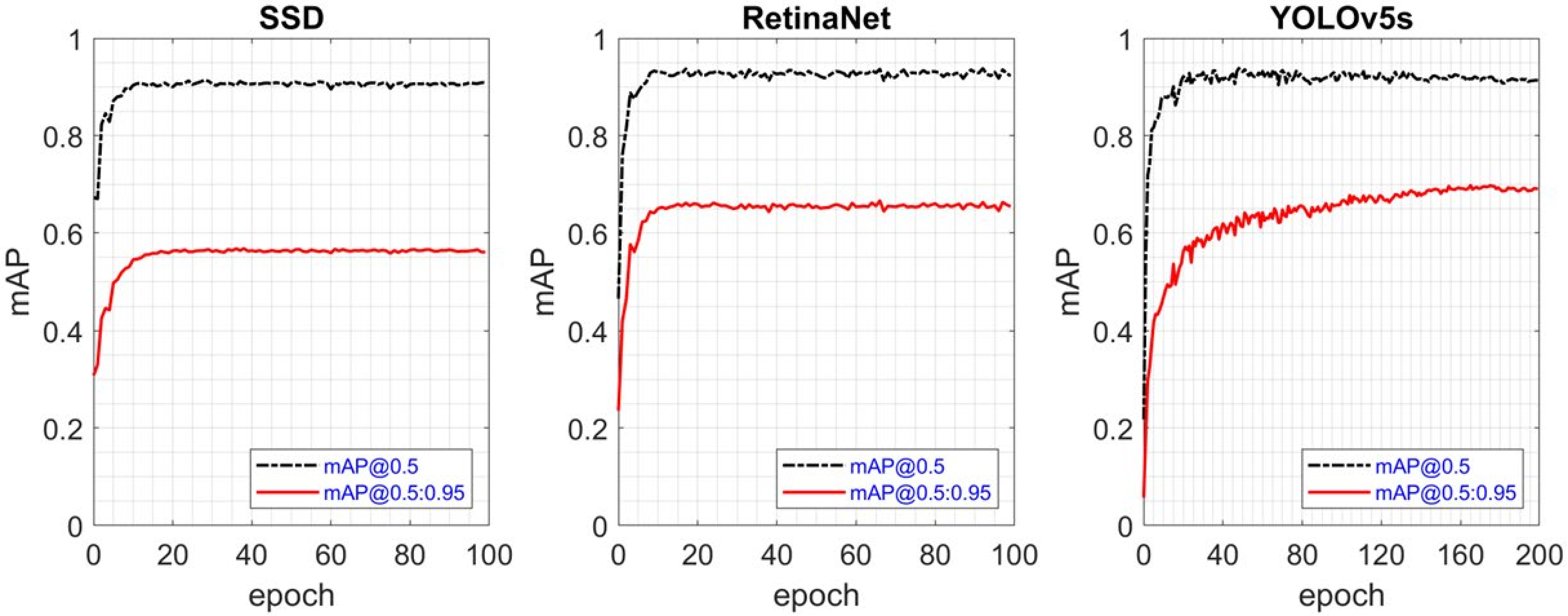


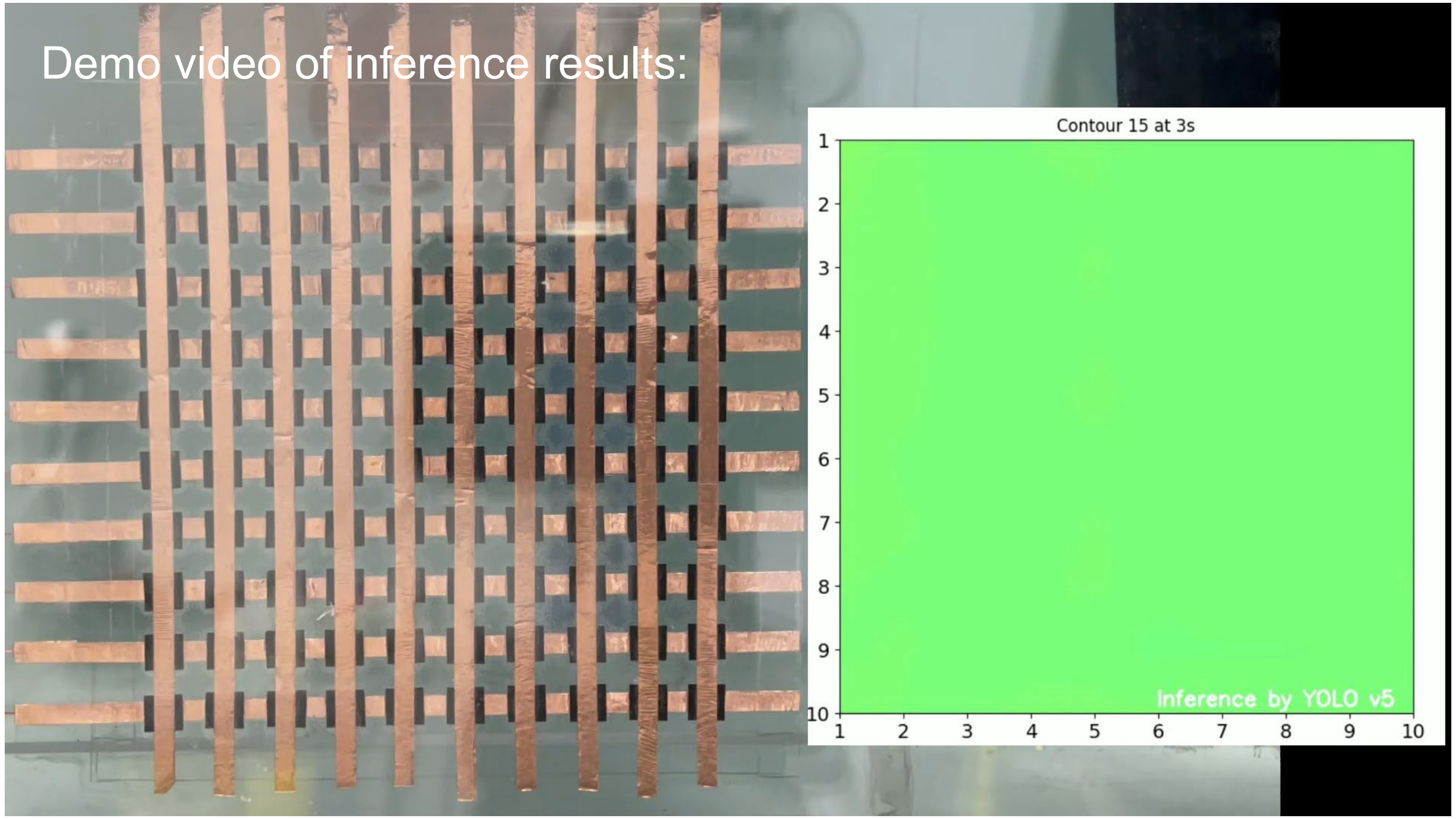
Table 5.3. Comparison of Validation Results of Different Algorithms for Sea Lamprey Detection.

Framework	mAP(val) @ 0.5	mAP(val) @ 0.5:0.95	GPU Speed [ms / img]
SSD	90.79 %	56.81 %	11.4
RetinaNet	93.68 %	66.63 %	55.0
YOLOv5s	92.11 %	69.77 %	8.4

5.6 Inference Using Trained YOLOv5s Model

Soft pressure sensor's **memory effect**:

- The detection network will view the leftover patterns following the detachment as a normal suction pattern;
- Cause false positive in prediction.



5.7 Filtered YOLOv5s for Mitigation of Sensor Memory Effect

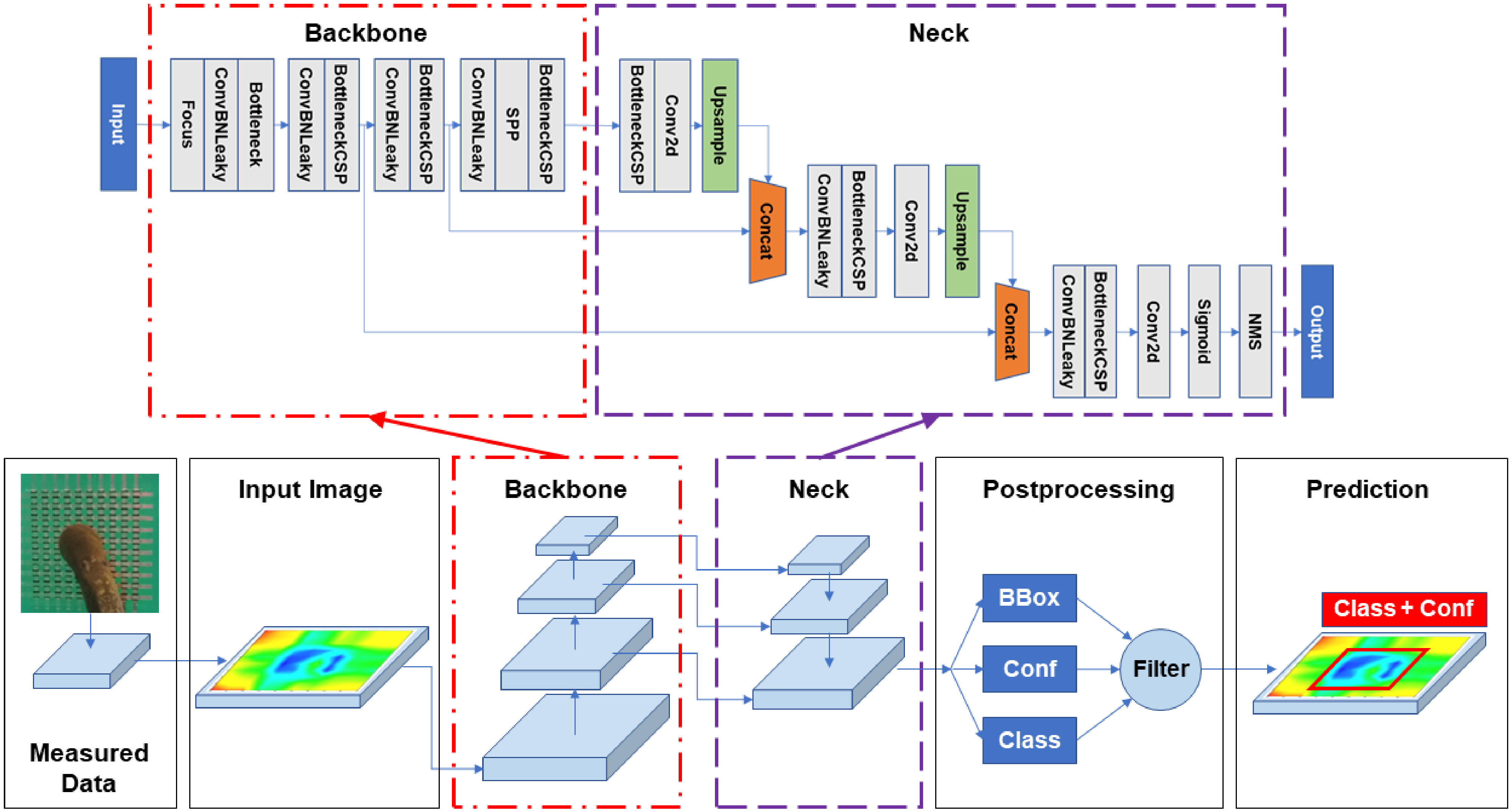


Figure 5.5. Diagram of the soft pressure sensor and YOLOv5s model-based sea lamprey detection approach.

5.7 Filtered YOLOv5s for Mitigation of Sensor Memory Effect

- YOLOv5's confidence output:

$$IoU_{pred}^{g-t} = \frac{\text{Area of Intersection}}{\text{Area of Union}} \quad (13)$$

$$Pr_{obj} = \begin{cases} 0, & \text{if } IoU_{pred}^{g-t} = 0 \\ 1, & \text{otherwise} \end{cases} \quad (14)$$

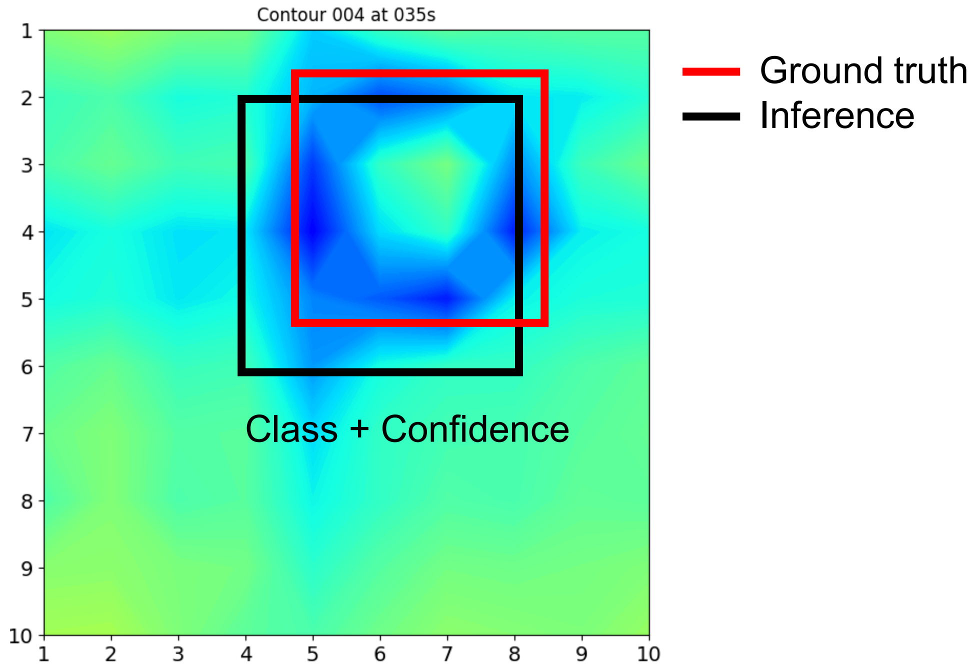
$$Conf_{obj} = Pr_{obj} \cdot IoU_{pred}^{g-t} \quad (15)$$

The class confidence is a conditional probability of the class when there is an object being predicted at that cell:

$$Conf_{cls} = Pr_{cls|obj} \quad (16)$$

So the final confidence score can be written as

$$Conf = Conf_{cls} \cdot Conf_{obj} = Pr_{cls|obj} \cdot Pr_{obj} \cdot IoU_{pred}^{g-t} \quad (17)$$



- Filter with a designed confidence threshold θ:

$$\text{Output} = \begin{cases} \text{BBox}_{\text{compression}}, & \text{if } class = 0 \text{ and } Conf \geq \theta_C \\ \text{BBox}_{\text{suction}}, & \text{if } class = 1 \text{ and } Conf \geq \theta_S \\ \text{None}, & \text{otherwise} \end{cases}$$

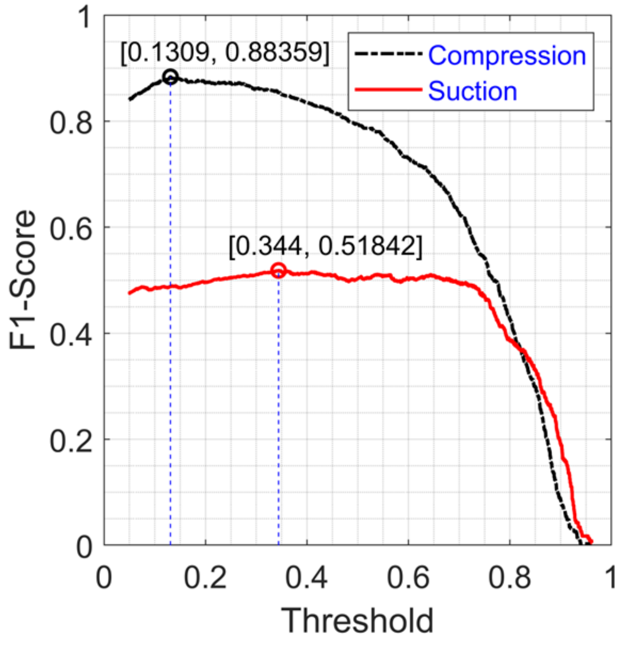
5.8 Postprocessing on the Testing Dataset

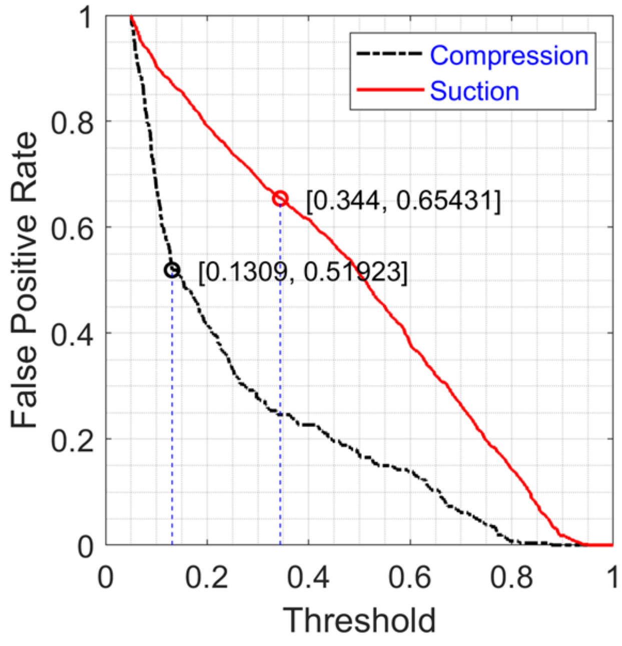
		Ground Truth	
		Positive	Negative
Prediction	Positive	True Positive (TP)	False Positive (FP)
	Negative	False Negative (FN)	True Negative (TN)

$$P_C(\theta_C) = \frac{TPRC(\theta_C)}{TPRC(\theta_C) + FPRC(\theta_C)} \quad (19)$$

$$R_C(\theta_C) = \frac{TPRC(\theta_C)}{TPRC(\theta_C) + FNRC(\theta_C)} \quad (20)$$

$$F1_C(\theta_C) = \frac{2 \cdot P_C(\theta_C) \cdot R_C(\theta_C)}{P_C(\theta_C) + R_C(\theta_C)} \quad (21)$$





- The higher the confidence threshold, the lower the false positive rate.
- The F-1 score would be reduced when the threshold is too high.

$$L_C(\theta_C) = F1_C(\theta_C) - \lambda \cdot FPRC(\theta_C) \quad (22)$$

$$\hat{\theta}_C = \arg\max_{\theta_C} L_C(\theta_C) \quad (23)$$

5.8 Postprocessing on the Testing Dataset

- The filtering process with a pair of selected confidence thresholds proves to be simple and effective to this sea lamprey detection.

Table 5.4. Inference During a Sample Memory Effect Interval.

Time [s]	Class	Confidence	True or False
231	Compression	0.80	True
232	Suction	0.46	True
233	Suction	0.18	False
234	Suction	0.27	False
235	Suction	0.33	False
236	Suction	0.16	False
237	Suction	0.27	False
238	Suction	0.31	False

(a)

(b)

$$\begin{cases}\theta_C = 0.05 \\ \theta_S = 0.05\end{cases}$$

(c)

$$\begin{cases}\theta_C = 0.131 \\ \theta_S = 0.344\end{cases}$$

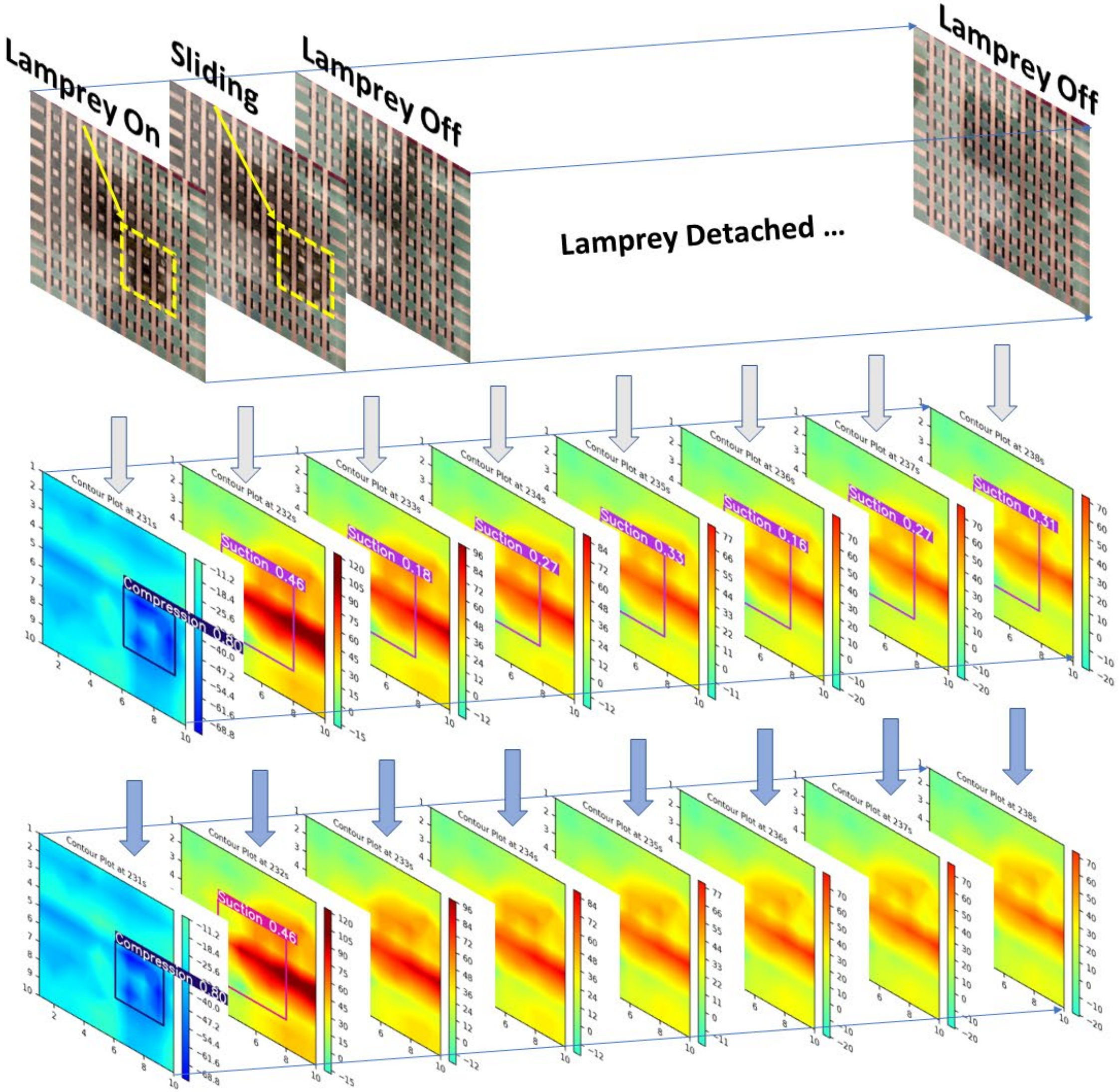
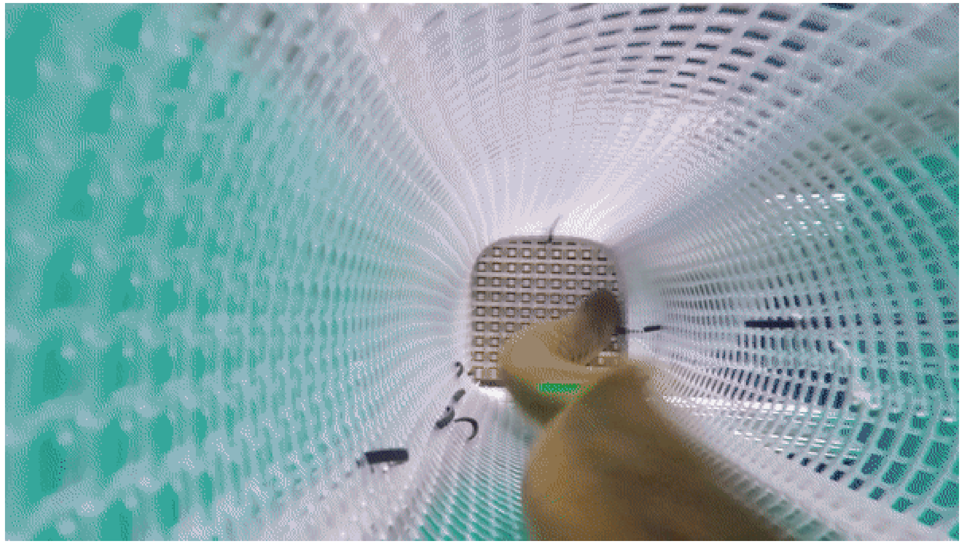
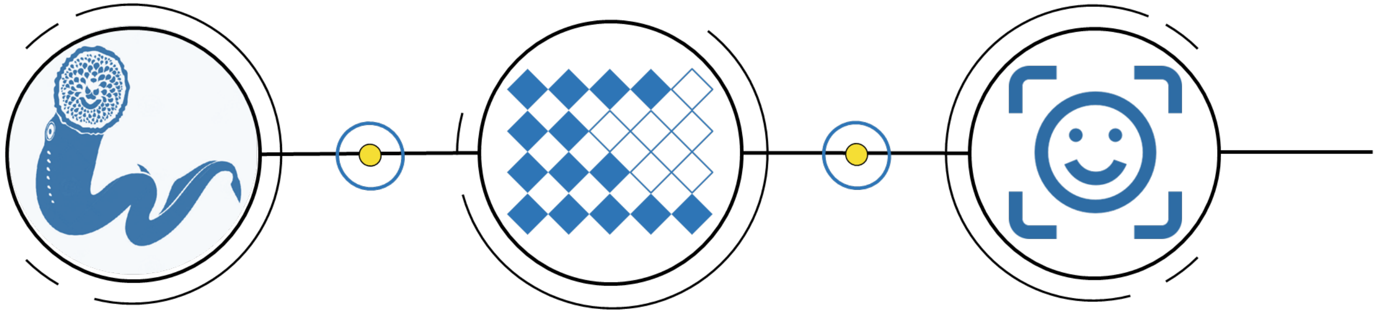


Figure 5.7. Illustration of the faulty detection problem due to the sensor's memory effect.

THANKS!

Do you have any questions?





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