A METHOD FOR NOISE-ROBUST FISH BIOMASS ESTIMATION IN POND AQUACULTURE USING DYNAMIC IMAGING SONAR

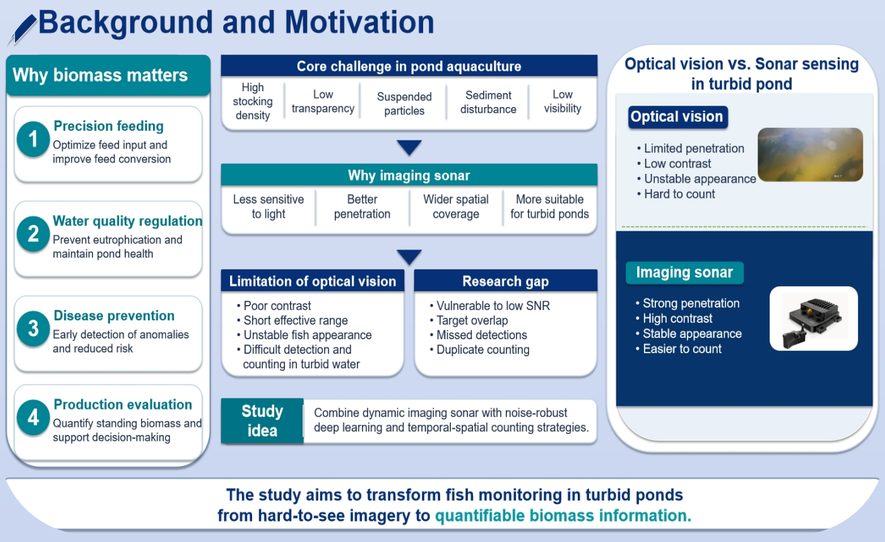
GAO Xin[1], YUAN Yu-Tian[1], WU Yu-Long[2], TANG Rong[1], LI Da-Peng[1]and WANG Huan[2]
(1. College of Fisheries, Hubei Provincial Engineering Laboratory for Pond Aquaculture, Key Laboratory of Aquaculture Facilities Engineering, Ministry of Agriculture and Rural Affairs, Huazhong Agricultural University, Wuhan 430070, China; 2. College of Informatics, Huazhong Agricultural University, Wuhan 430070, China)

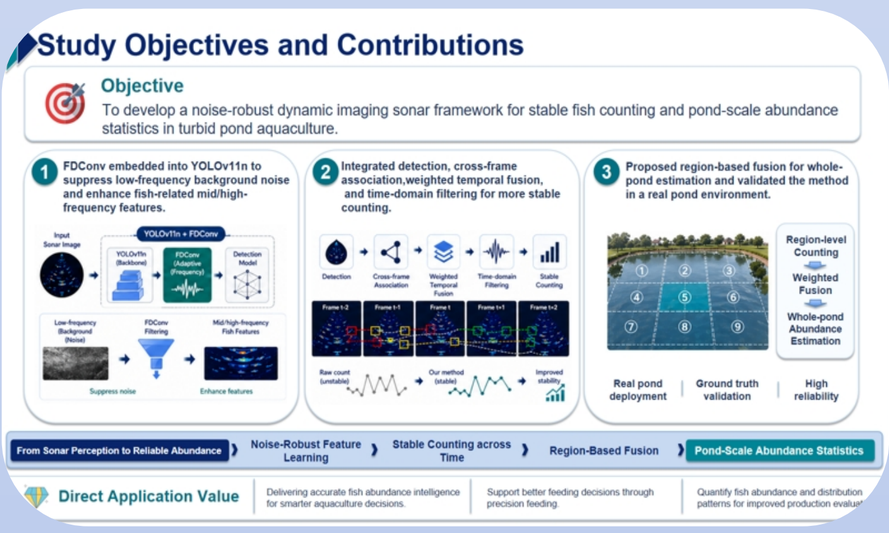
Abstract

Real-time estimation of fish biomass at the pond-wide scale is critical for precision aquaculture management. However, the low water transparency commonly observed in pond aquaculture environments severely limits the effectiveness of vision-based fish detection methods. To address this challenge, this study proposes a dynamic imaging sonar–based noise-robust fish biomass estimation method tailored for pond aquaculture scenarios. Dynamic sonar image data were collected using an imaging sonar system (Lowrance HDS-9) under typical pond conditions, and a benchmark dataset was constructed for model training, calibration, and validation. A frequency-dynamic convolution (FDConv) module was embedded into the backbone of the YOLOv11n architecture to enable multi-band sonar feature modeling and noise suppression. Fish counting was performed through an integrated pipeline consisting of detection, tracking, and region-based fusion, and the proposed method was further validated in real pond environments. In the model evaluation stage, the proposed method achieved favorable detection performance, with a precision (P) of 0.886, an F1-score of 0.891, and an mAP@0.5 of 0.897, representing improvements of 2.5%, 1.2%, and 1.8%, respectively, over the baseline model. In field experiments conducted at typical pond observation points, the frame-level counting deviation ranged from 10.13% to 17.65%, with an average deviation of 13.98%, while the overall counting deviation was 15.5%. The results demonstrate that the proposed method enables stable perception and reliable estimation of fish abundance in turbid pond waters, achieving effective pond-scale fish population statistics under visually degraded conditions. This study provides a practical solution for fish biomass monitoring in precision pond aquaculture management.

Introduction

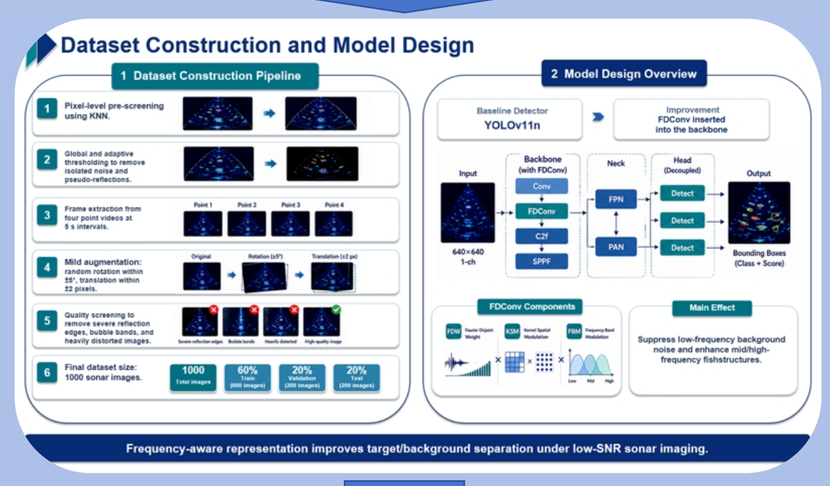
Real-time monitoring of fish biomass is critical for precision feeding, water quality control, and disease prevention in smart pond aquaculture. However, high turbidity and low visibility in dense culture ponds severely degrade optical signals, making visible-light imaging ineffective for fish detection. Imaging sonar offers strong penetration and light independence, making it suitable for turbid water. Yet low signal-to-noise ratio, target overlap, and strong background scattering cause frequent false detection and unstable counting. This study presents a dynamic anti-noise sonar imaging method for full-pond biomass estimation. By integrating frequency-domain decomposition into YOLOv11 and using cross-frame target association, the approach suppresses noise, enhances fish features, and improves counting stability. It provides a reliable technical solution for real-time biomass assessment in smart aquaculture.

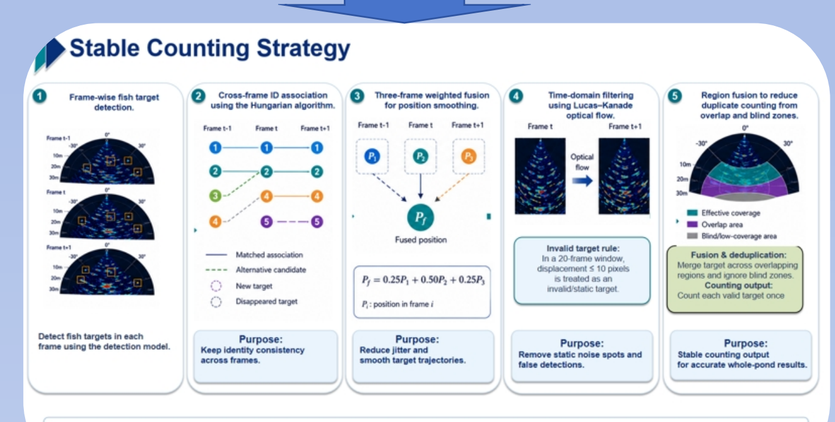




Methods

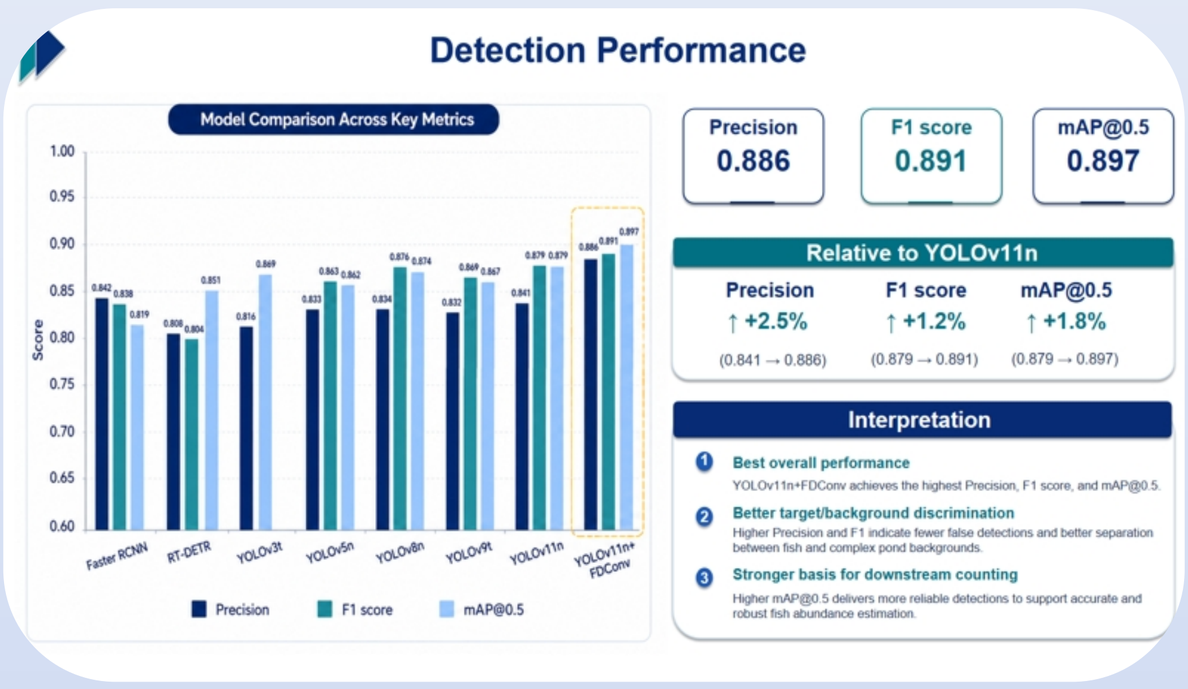




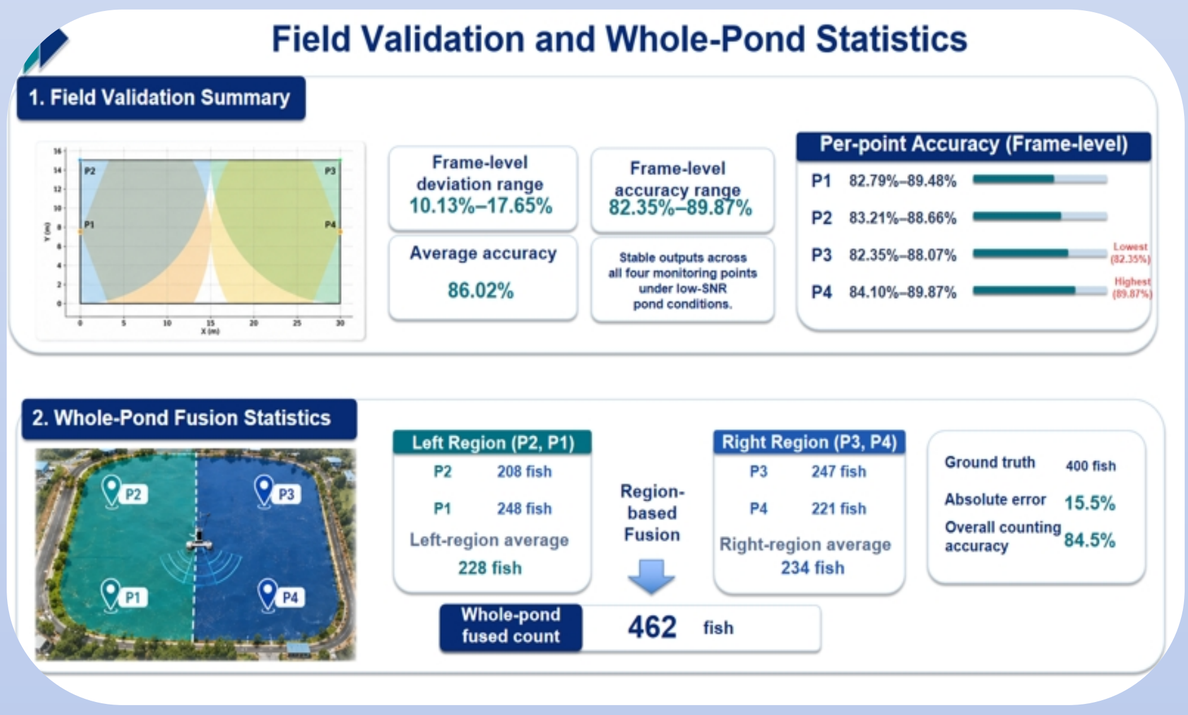


This study collected sonar data in a turbid aquaculture pond using a Lowrance HDS-9 system, building a 1000-image dataset via preprocessing and augmentation. An improved YOLOv11n with FDConv was trained to suppress background noise and enhance fish features. A multi-stage tracking and fusion strategy then enabled stable fish detection and full-pond biomass estimation under low-SNR conditions.

Results



The proposed YOLOv11n+FDConv model outperforms other detectors, achieving the highest precision (0.886), F1 score (0.891), and mAP@0.5 (0.897), representing respective improvements of 2.5%, 1.2%, and 1.8% over the baseline YOLOv11n. These gains demonstrate enhanced fish-background discrimination and more reliable detections, laying a stronger foundation for stable pond fish counting.

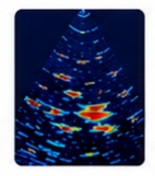


Field validation across four monitoring points achieved stable frame-level accuracy of 82.35–89.87%, averaging 86.02%. After region-based fusion, the whole-pond count reached 462 fish, with an absolute error of 15.5% and overall counting accuracy of 84.5% against the ground truth of 400 fish, demonstrating the method's reliable biomass estimation under low-SNR pond conditions.

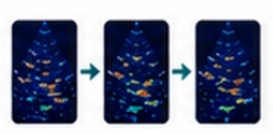
Discussion

Why the Method Works

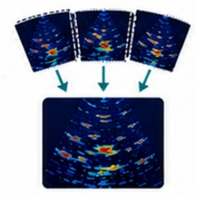
1. **FDConv enhances fish-related mid/high-frequency features while suppressing low-frequency background noise.**



2. **Temporal strategies improve consistency and reduce false accumulation from transient noise or static bright spots.**



3. **Region-based fusion helpsmitigate overlap, blind zones, and cross-region duplicatecounting.**



Conclusions

- **The proposed method enablesstable fish perception and abundance estimation in turbid pond water.**
- **It turns visually degradedpond scenes into quantifiablefish abundance information.**
- **It provides a practical technicalpath for precision feeding,production evaluation, and smart aquaculture management.**