Deep learning based laser dot detection for orientation estimation of indoor radiation monitoring robot

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Introduction

Indoor localization and path planning are dire requirements in the field of robotics, where autonomous robots are substituting human beings in hazardous and hostile environments. For the purpose of nuclear radiation field mapping inside a cyclotron vault, we have developed a pan-tilt camera and laser dot detection-based localization system. The next step, path planning of the autonomous robot, is greatly dependent upon accurate orientation information of the robot. The odometry information is erroneous due to dead-reckoning errors, and the IMU (Inertial Measurement Unit) becomes unreliable due to the presence of high electromagnetic field, and ferromagnetic materials inside a cyclotron vault. In this paper we are reporting a deep learning-based laser dot detection method to encounter the orientation estimation problem for an indoor radiation monitoring autonomous mobile robot.

Methodology

Two green and red type III lasers have been attached to the wheeled mobile robot. Through the use of bounding boxes to isolate the lasers, the algorithm was able to distinguish between the two laser colors with high accuracy. By constructing a vector connecting the centroids of the bounding boxes, the algorithm was able to determine the robot's orientation.

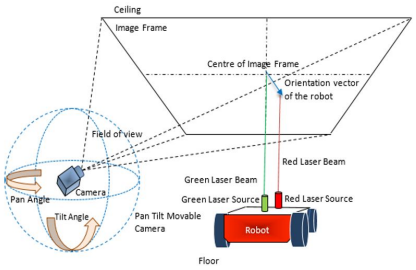

FIG. 1: Schematic diagram of the of the system

Experimental Results

For our robot orientation estimation task, we have chosen the YOLOv8 (You Look Only Once) [1]algorithm . YOLOv8 is a state-of-the-art architecture object detection model . The architecture uses a Cross-stage Partial (CSP) Connection block as the backbone for a better gradient flow to reduce computational cost. YOLOv8 features an enhanced version of the PANet neck. This enhancement optimizes the flow of feature information, which improves the model's ability to detect objects across various scales and contexts

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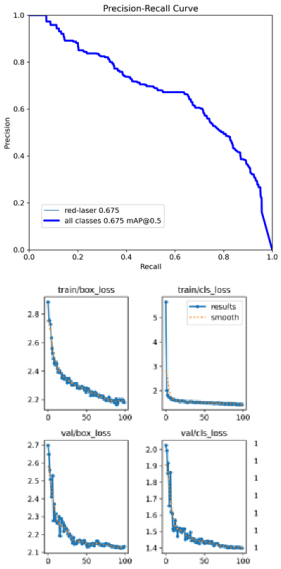

FIG. 2: YOLOv8 small with 100 epochs

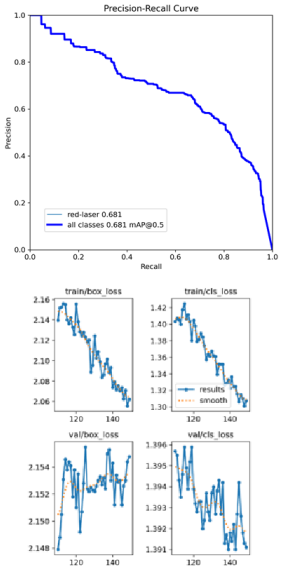

FIG. 3: YOLOv8 small with 150 epochs

. The first step of training the model began by developing a comprehensive dataset. This was accomplished by extracting frames are captured using a pan-tilt camera system. Prior to data collection, careful calibration of the camera was done to mitigate potential errors. Our rigorous extraction process yielded a substantial dataset. To ensure accurate identification and labelling of objects of interest within the images, data annotation was performed. Image augmentation techniques were employed to enhance the diversity of our dataset. The augmented dataset was used to train multiple YOLO models. Previously we have successfully demonstrated the detection using YOLOv8 nano model with 150 epochs. Here in this paper the detection of red laser dot has been done using YOLO v8 small with 150 epoches and YOLOv8 small with 100 epoches . The precision-recall curve and training graphs collectively indicate a effective model for detection of red laser dot, with an mAP(mean average precision) of 0.681 at 0.5 IoU (intersection over union) for YOLOv8 small with 150 epochs(FIG.2) and map value of 0.675 at 0.5 IoU for YOLOv8 small with 100 epochs (FIG.3). The orientation detection error is found to be 10 degrees and 14 degrees for 100 epoches and 150 epoches models respectively at a distance of 3 meters.

Conclusion and future outlook

The models show good precision at lower recall values and performs well on confident predictions. Training and validation losses decrease over time, suggesting improvement. The balanced performance across metrics depicts the two model's satisfactory learning progression and accuracy.This technique can be successfully used to detect laser dot for orientation estimation of autonomous robots. The performance can be improved by using more exhaustive dataset .The method functions optimally with high-resolution imagery.

References

[1] Yaseen, Muhammad. (2024). What is YOLOv8: An In-Depth Exploration of the Internal Features of the Next-Generation Object Detector. 10.48550/arXiv.2408.15857.