Separability by Design: Decoupling Classification and Localization Quality in Anchor-Free Object Detection

By

Are you this author?

Rosly, HM (Mat Rosly, Hadi) [1] ; Abidin, ZZ (Abidin, Zulkifli Zainal) [2] ; Zaki, HFM (Zaki, Hasan Firdaus Mohd) [1] , [3]

Source

IEEE ACCESS

View Journal Impact

Volume: 14 Page: 158099-158108

DOI: 10.1109/ACCESS.2026.3741782

Published 2026

Indexed 2026-10-23

Document Type Article

Abstract Object detection research validates architectural decisions almost exclusively through mean average precision (mAP), a metric that certifies performance but conceals mechanism. We argue that principled improvement requires a detector whose classification and localization pathways are disentangled and therefore individually diagnosable. Starting from the convolutional process itself, we show that depth trades positional capacity for featural dimensionality at fixed rates set by the stage schedule, so a detection head reading both targets from one point accepts whatever proportion its depth supplies. From this decomposition we derive separability by design: classification and localization quality placed in architecturally distinct, separately supervised pathways, with an objectness route admitting localization evidence into the semantic score. Three falsifiable predictions follow, tested across eight configurations crossing head structure, box geometry and gradient coupling. All are supported. A quality field read where positional capacity survives raises its rank correlation with realized IoU from 0.051 to 0.484; two levels recover the localizability of a five-level pyramid, at 0.943 against 0.950 oracle recall; and the convolutional head commits its class field in the forward pass, reducing candidate entropy from 3.66 to 2.22 bits and uncorroborated rare survivors from 3.2% to 0.9% across 5000 COCO val2017 images. The prediction concerning the objectness route holds conditionally: the gate lifts the class score only where the class head can read the spatial neighborhood the objectness cue occupies, which requires both a convolutional head and a cue-preserving geometry. The contribution is a framework and a diagnostic method for mechanistic detector analysis that enables systematic architectural design, not a leaderboard result.

Keywords **Author Keywords:** Head; Modeling; Location awareness; Object detection; Design methodology; Geometry; anchor-free detection; feature entanglement; localization quality; model

interpretability; error diagnosis

Author Information

Corresponding Address: Zaki, Hasan Firdaus Mohd (corresponding author)

- Int Islamic Univ Malaysia, Dept Mechatron Engn, Kuala Lumpur 53100, Malaysia

Corresponding Address: Abidin, Zulkifli Zainal (corresponding author)

- Univ Teknol PETRONAS, Fac Engn, Integrated Engn Dept, Seri Iskandar 32610, Perak, Malaysia

Corresponding Address: Zaki, Hasan Firdaus Mohd (corresponding author)

- Int Islamic Univ Malaysia, Ctr Unmanned Technol CUTe, Kuala Lumpur 53100, Malaysia

E-mail Addresses :

hasanzaki@iium.edu.my; zulkifli.zainal@utp.edu.my

Addresses :

- [1] Int Islamic Univ Malaysia, Dept Mechatron Engn, Kuala Lumpur 53100, Malaysia
- [2] Univ Teknol PETRONAS, Fac Engn, Integrated Engn Dept, Seri Iskandar 32610, Perak, Malaysia
- [3] Int Islamic Univ Malaysia, Ctr Unmanned Technol CUTe, Kuala Lumpur 53100, Malaysia

E-mail Addresses :

zulkifli.zainal@utp.edu.my; hasanzaki@iium.edu.my

Categories/ Classification Research Areas: Computer Science; Engineering; Telecommunications

Web of Science Categories Computer Science, Information Systems; Engineering, Electrical & Electronic; Telecommunications

Funding

View funding text

Funding agency	Grant number	Show All Details
Universiti Teknologi PETRONAS (UTP), Malaysia, through the AMGTech Research Centre OPEX Incentive Grant (PGR Cost Centre)	015J00-001	
Universiti Teknologi PETRONAS (UTP), Malaysia, through the Centre for Graduate Studies (Cost Centre)	015BD1-001	
Research Management Centre of International Islamic University Malaysia (IIUM)	FRGS/1/2025/ICT02/UIAM/02/1	
Ministry of Education, Malaysia	FRGS/1/2025/ICT02/UIAM/02/1	Show details

+ See more data fields

Journal information

IEEE ACCESS

← View Journal Impact

ISSN 2169-3536

Current Publisher IEEE-INST ELECTRICAL ELECTRONICS ENGINEERS INC, 445 HOES LANE, PISCATAWAY, NJ 08855-4141

4.2

Journal Impact Factor ™ (2025)

0.83