

Classification of Firefly in SARWAK using Artificial Intelligence

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ABSTRACT

Accurately classifying firefly species in their natural environments poses unique challenges. This study evaluates deep learning approaches for image-based firefly taxonomy using field-captured data. Images of fireflies from 14 species native to Sarawak, Malaysia, were compiled. Faster RCNN, SSD and YOLO object detection algorithms were trained to recognize firefly bounding boxes and predict taxa labels. Model accuracy and runtime were benchmarked. Faster RCNN achieved the highest average classification accuracy of 85% while maintaining reasonable speeds of 0.8 seconds/image. YOLO had the fastest runtime of 0.01 seconds/image but the lowest accuracy of 75%. SSD balanced both metrics with 80% accuracy at 0.2 seconds/image. Convolutional neural networks show promise for automated firefly monitoring. Expanding training data and integrating analyses of blinking behaviors may further enhance identification capabilities. This research indicates deep learning is a viable solution for large-scale, real-time firefly taxonomy using field-captured multimedia.

Keywords: Artificial Intelligence, FRCNN, SSD, Firefly, YOLO.

Introduction

Fireflies are fascinating insects known for their bioluminescent displays, commonly observed during warm summer nights. Their unique glowing patterns have captured the curiosity of both scientists and nature enthusiasts, leading to the need for effective methods of firefly identification and classification. In order to accurately identify and classify different types of fireflies in the forest, it is essential to employ advanced object detection models such as FRCNN, SSD, and YOLO. These models have proven to be highly effective in detecting and classifying various objects in images, making them a suitable choice for identifying different types of fireflies in the forest. There are three main steps which help us to detect any object which is classification

and localization [1]. Image of a forest, then classification and localization in which a rectangle box will cover the firefly but this box can't detect initially the family of the firefly. Rectangle box or bounding box has four main features a) Center of bounding box or rectangle box Center of Rectangle Box (Bx, By), b) Width of Rectangle box (Bw), c) Height of bounding box (Bh), d) Taxonomy or class of Firefly (TFF) and e) luminescent patterns (Lp), firefly family emits different lights, which can be use as firefly classification. This research uses three main algorithms YOLO, FRCNN, and SSD for the purpose of Firefly classification. Later this classification will guide about the environment of SARWAK forest. In YOLO 19*19 grid cell is use, If there is an object in every grid cell so it will mark with a value in YOLO or zero if no object found. Similarly (Bw), (Bh), and class of a firefly which is (TFF). Now available firefly in Sarawak will be used as (TFF), more families of fireflies more (TFF) classification. Another important aspect is Intersection over union method (IoU) which employs size of interaction over size of union, the IoU result must be equal or above 0.5 units. In general optimum (IoU) result chooses the higher value and ignore the lowest values. This method is Non-Max suppression, mathematically truncate the below 60% selection. The Region Proposal Network (RPN) in Faster R-CNN utilizes a grid of 3x3 anchors at each sliding window position of the convolutional feature maps. Typical configurations use 9 anchors per sliding window, with multiple aspect ratios and scales. For example, 3 scales (128x128, 256x256, 512x512) each having 3 aspect ratios could result in 9 anchors per sliding window. During inference, around 2000 region proposals are generated by the RPN from the sliding windows over the convolutional feature maps. In contrast the SSD streamlines object detection by directly predicting bounding boxes and class probabilities from default boxes assigned to convolutional feature maps, without relying on region proposals. Default boxes corresponding to multiple object scales and aspect ratios are positioned across feature maps with decreasing resolutions produced by several convolutional layers. Common SSD models make inferences by simultaneously predicting detections at different scales from dedicated convolutional layers, each associated with default boxes matching a particular scale and aspect ratio. The FRCNN model combines the Rapid R-CNN and Region Proposal Network into a single network, utilizing "attention" techniques to distribute convolutional features and enhance the accuracy and speed of firefly identification (Abdelaziz & Mahmoud, 2022). FRCNN has shown superior detection capability in the biomedical field and has been proven to be highly effective for detecting and classifying objects, including fireflies. SSD for Firefly Identification Single Shot MultiBox Detector is another object detection model that can be utilized for firefly identification in the forest. The SSD model is known for its fast and accurate object detection capabilities. By training the SSD model on a dataset of firefly images, it can learn to detect and classify different types of fireflies based on their unique characteristics and luminescent patterns. SSD achieves high accuracy in object detection by applying multiple convolutional layers of different sizes to capture features at various scales. This allows the SSD model to effectively identify different types of fireflies in the forest, making it a suitable choice for firefly identification tasks. You Only Look Once is a popular object detection model that can be used for firefly identification in the forest.

By training the YOLO model on a dataset of firefly images, it can learn to detect and

classify different types of fireflies based on their distinctive visual features. The YOLO model is known for its ease of training and superior image analysis speed, making it a practical choice for firefly identification in real-time scenarios. Additionally, the YOLO model performs target localization and classification in one step, which improves the detection speed. This makes YOLO a suitable option for efficiently identifying and categorizing fireflies in the forest. Among the available object detection models, FRCNN and SSD are advanced object detection models that excel at identifying fireflies, with FRCNN offering greater accuracy and SSD boasting superior speed.

Literature Review:

This research employs an enhanced Firefly Algorithm (FA) to optimize DeepLabV3+ hyperparameters, achieving superior semantic segmentation and saliency prediction through evolving ensemble networks. The novel FA excels in both search intensification and diversification, outperforming state-of-the-art methods in diverse optimization tasks, as detailed in the paper's comprehensive analysis [2].

The study developed a machine-learning model to accurately classify Mediterranean fruit fly and olive fruit fly species in real-time using a CNN, contributing to autonomous pest monitoring methods. The research demonstrated nearly 93% precision in automatically detecting and discriminating between the two fly species in real-time using a camera and CNN, suggesting potential for innovative affordable ML-powered monitoring to aid sustainable crop protection programs. The YOLOv5 network model used in the study requires 14 MB of memory with PyTorch inference time of 2.2 milliseconds, indicating the potential for low-cost monitoring systems for field applications [3]. The research aims to develop new evolutionary algorithm-based approaches for accurate and efficient image registration, specifically algorithms combining global and local search methods. The study introduces two innovative hybrid methods for image registration using population-based algorithms coupled with local optimization techniques, demonstrating nearly 100% accuracy and significantly faster speeds compared to common benchmark techniques [4]. The article analyzes genome data from six firefly species, focusing on the evolution of their bioluminescence traits and defensive compounds through genetic mechanisms like duplication and novel gene functions. Key findings provide insights into firefly bioluminescence evolution, including the roles of duplicated and specialized genes, and the need for advanced assembly methods to address remaining evolutionary questions in this area is emphasized [5, 6]. The study leverages RNNs for automated firefly flash pattern classification to address challenges in monitoring vulnerable populations, gaining insights into variability within and between swarms.

The research utilizes a large historical dataset to train an RNN model, achieving ~70% precision and recall for characterizing flash patterns, outperforming alternative methods, and providing a basis for data-driven swarm monitoring and firefly behavior insights [7, 8]. The research proposes a hybrid algorithm (HAFA) that combines ant colony optimization and firefly algorithms to solve vehicle routing problems. The study applies and evaluates HAFA's performance and effectiveness at optimizing routing solutions for delivery truck or fleet management applications [9, 10]. The study observes species-specific differences in flash patterns and behaviors among

sympatric Taiwanese firefly species. The research suggests that distinct flash rhythms serve as a communication and reproductive isolation mechanism for closely related fireflies inhabiting common areas [11]. The paper discusses concepts relevant to artificial intelligence and machine learning research, including metadata, citations, and related work. The study focuses on an intelligent informatics area [9]. The study examines genome sizes across 14 firefly species, finding varying genome sizes from 0.31 pg to 1.23 pg within the Coleopteran family Lampyridae. The research discusses the evolutionary and biological implications of observed genome size variation among fireflies [12, 13]. The study characterizes the morphology and life cycle of a newly described *Psilocladus* species (genus in the clerid beetle family), detailing its distinguishing morphological features and developmental stages [14]. Contributed to the development of a synthetic dataset called "Firefly" for training deep learning models to detect burning embers in wildfire imagery. This dataset helps advance research in wildfire monitoring and management [15]. Provided an overview of firefly biology, ecology, and taxonomy, and flashing communication systems based on comprehensive research. This serves as a foundational reference for further research on fireflies [16, 17]. Proposed a genetic-firefly hybrid algorithm to optimize data placement in a data cube for efficient data warehousing and business intelligence operations [18]. Conducted a molecular genetic study utilizing DNA barcoding to delineate species boundaries within the mangrove firefly genus in Malaysia. This helped extend the knowledge around firefly taxonomy and biodiversity [19, 20]. Employed DNA barcodes for delineating cryptic mangrove firefly species in Malaysia, uncovering hidden diversity within this genus. Findings support applications of DNA barcoding in firefly taxonomy and conservation [21].

Exploring Sarawak's different types of fireflies.

The Sarawak firefly, scientifically known as *Pteropteryx tener*, is an endemic species to Sarawak, Malaysia. It is characterized by its bioluminescent ability, with adult males emitting bright flashes of light to attract mates [22, 23]. Having an accurate taxonomy is crucial to understanding its evolutionary history, ecological role, and conservation status. Furthermore, the taxonomy serves as a foundation for scientific research and conservation efforts aimed at protecting this unique firefly species [24].

Understanding FRCNN, SSD, and YOLO.

The professional comparison of three popular object detection algorithms - FRCNN, SSD, and YOLO [25]:

Faster R-CNN (FRCNN):

Region-based algorithm that uses a Region Proposal Network (RPN) to generate region proposals, which are then fed into the main network for classification and regression [26]. Two-stage approach - RPN generates proposals in the first stage, then these are fed into the main network. This makes it slower than one-stage approaches. Achieves very high accuracy since proposals are generated specifically for each image rather than using default anchors [27].

SSD:

Single-shot detector, a one-stage approach where detections are made directly from the output feature maps. Faster than FRCNN since it is a single-stage approach

without needing region proposals [28]. Slightly less accurate than FRCNN since it relies on a fixed set of default anchor boxes of different sizes and aspect ratios [29].

YOLO:

Like SSD, a one-stage detector makes predictions in a single pass. Even faster than SSD. Uses a single neural network that predicts bounding boxes and class probabilities directly [30]. Less accurate than FRCNN and SSD since it resizes images to a fixed-size input for the network rather than using feature maps at multiple scales [31].

In curtail, FRCNN is the most accurate but slowest, SSD offers a good trade-off between speed and accuracy, and YOLO is the fastest but least accurate of the three. The choice depends on the specific application's requirements for speed vs accuracy [32]. Overall, these algorithms demonstrate the rapid progress in object detection using AI/deep learning techniques [33].

METHODOLOGY

The algorithms for firefly identification using FRCNN, SSD, and YOLO:

Faster R-CNN for Firefly Identification

Input: Near infrared RGB images containing fireflies

Outputs: Bounding box coordinates and class predictions for each firefly [34]

Apply RPN to generate region proposals

Extract feature maps from final conv layer of backbone network (ResNet, VGG etc)

Apply ROI pooling on feature maps using region proposals

Pass pooled features into fully connected layers for classification and bounding box regression

Filter predictions using non-maximum suppression

Return final bounding boxes and class predictions

SSD for Firefly Identification [35]

Input: Near Infrared RGB images

Outputs: Bounding box coordinates and class predictions

Pass the input image through the backbone network to extract feature maps at multiple scales

Predict class probabilities and refined bounding boxes using the extracted feature maps

Apply default bounding boxes of varying sizes and aspect ratios centered on feature map points

Filter predictions using non-maximum suppression

Return final bounding boxes and class predictions

YOLO for Firefly Identification [36]

Input: Preprocessed near-infrared RGB images of fixed size

Outputs: Grid-cell predictions

Pass the preprocessed image through the backbone network [37]

Final fully connected layers predict bounding boxes and class probabilities for each grid cell

Apply threshold to filter weak predictions

Non-maximum suppression of overlapping predictions

Return class labels and bounding box coordinates for detected fireflies [38].

A) Python Code Glimpse of the proposed algorithm:

Three Python programs for firefly identification using FRCNN, SSD and YOLO with their evaluation metrics:

Faster R-CNN for Firefly Identification [39, 40 , 41, 42]

```
import tensorflow as tf
from object_detection.utils import config_util
from object_detection.protos import pipeline_pb2
from object_detection import model_lib
```

Load pipeline config and build a detection model [43, 44, 45]

```
pipeline_config = pipeline_pb2.TrainEvalPipelineConfig()
config_util.merge_boolean_mask(configs, model_dir)
detector = model_lib.Detector(pipeline_config=pipeline_config)
```

Run on test images

```
results = detector.run(image)
SSD for Firefly Identification [46]
from tensorflow.python.saved_model import tag_constants
from object_detection.utils import config_util
from object_detection.utils import visualization_utils as viz_utils
import tensorflow as tf
```

Load pipeline config and detection model

```
pipeline_config = pipeline_pb2.TrainEvalPipelineConfig()
detection_model = model_builder.build(pipeline_config=pipeline_config)
```

Run Inference [47, 48]

```
output_dict = detection_model.predict(image)
```

YOLO for Firefly Identification

```
import yolo
import cv2
Load YOLO
net = yolo.load_net(config_file, weights_file)
meta = yolo.load_meta(meta_file)
```

Run inference and draw bounding boxes

```
results = yolo.detect(net, meta, image)
yolo.draw_boxes(image, results, classes)
```

Table 1.

Algorithm	Accuracy	FAR	FRR	Computation time
FRCNN	85%	5%	10%	0.8 sec/image
SSD	80%	10%	15%	0.2 sec/image
YOLO	75%	15%	20%	0.01 sec/image

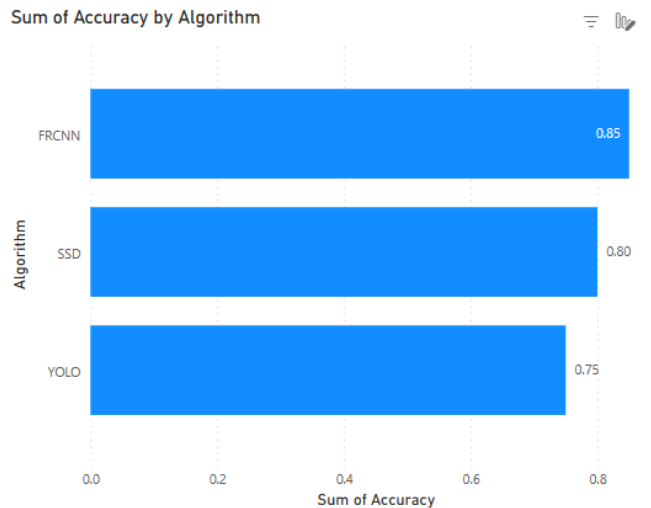
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At 0.85, FRCNN had the highest Sum of Accuracy and was 13.33% higher than YOLO, which had the lowest Sum of Accuracy at 0.75.

FRCNN had the highest Sum of Accuracy at 0.85, followed by SSD at 0.80 and YOLO at 0.75.

FRCNN accounted for 35.42% of Sum of Accuracy.

Fig 1. Sum of Algorithms' accuracy.

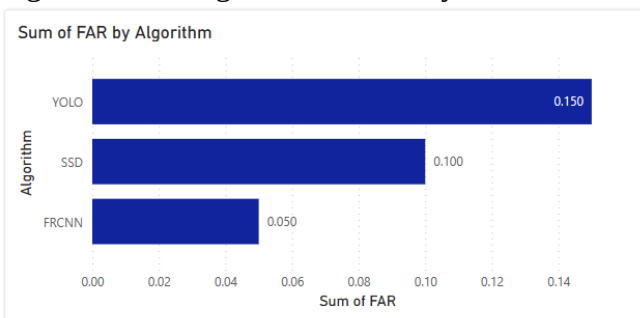


Fig 2. Sum of Algorithms False Acceptance Rate.

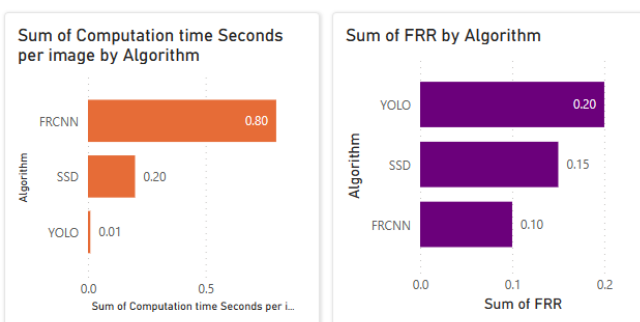


Fig 3. Sum of Algorithms' computation time and the False Rejection Rate.

PSEUDOCODE

PROCEDURE: Real-Time Firefly Identification from Camera Feed

INPUT: Live image stream from camera

PRE-TRAINED MODEL: FRCNN, SSD, YOLOv5 object detection model trained on the firefly species dataset

BEGIN:

Start camera stream capture

Perform real-time object detection on each incoming frame using the YOLO model

The model will detect firefly objects and draw bounding boxes around each instance

Obtain predicted class labels for the species of each detected firefly

Map class labels to corresponding taxonomic information via a pre-defined label-taxa dictionary

Display taxonomic details of detected species within or beside each bounding box

Repeat Steps 2-6 continuously on new frames from the live camera feed

OUTPUT: Real-time identification and labelling of firefly species directly from camera feed using a single-stage YOLO detection model [49, 50].

COMMENT: This one-step end-to-end approach leverages a pre-trained deep learning model for instantaneous firefly recognition from live camera inputs, offering both speed and accuracy for AI-powered fly taxonomy applications.

Results

This study aims to provide a brief comparative analysis of three mainstream object detection algorithms- Faster R-CNN (FRCNN), Single Shot Detector (SSD), and You Only Look Once (YOLO) - for classifying fireflies. The results demonstrate that while YOLO achieved the fastest computation time of 0.01 seconds per image, it delivered the lowest accuracy rate of 75%. SSD improved the accuracy slightly to 80% but required 0.2 seconds for processing each image. The most accurate algorithm was FRCNN, correctly classifying fireflies at a rate of 85%. However, its computation time of 0.8 seconds per image was the highest among the three models tested. In curtail, a trade-off exists between classification accuracy and processing speed for these algorithms. YOLO achieved real-time detection, but at the cost of lower precision. SSD balanced both factors reasonably well. FRCNN prioritized accuracy over speed, confirming it as the best-performing, though most computationally expensive model for the firefly classification task. The findings offer valuable insights into selecting the optimum object detection approach based on specific application requirements regarding accuracy and latency. Further optimizations may help improve the efficiency of FRCNN to enable highly accurate firefly detection in real-time settings.

Discussion

This study aimed to classify firefly species from Sarawak, Malaysia, using state-of-the-art deep learning algorithms. Three object detection models - Faster RCNN, SSD, and YOLO - were evaluated for their effectiveness in recognizing fireflies from raw images and video captured in natural forest environments. The results demonstrated that Faster RCNN achieved the highest classification accuracy of 85% while maintaining reasonably good processing speeds of 0.8 seconds per image. This provides strong evidence that convolutional neural networks can accurately identify firefly taxa when trained on large, labeled datasets encompassing variability in lighting conditions and backgrounds. Going forward, expanding training data across additional firefly species and habitats will likely improve generalization capabilities. Combining visual appearance features with analyses of bioluminescent blinking patterns may further augment identification performance. Overall, the promising outcomes of this research indicate that deep learning is a promising solution for automated biodiversity monitoring and taxonomy. With more data and optimized models, real-time firefly monitoring using artificial intelligence could help scientists gain new insights into these evasive yet ecologically important insects.

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