CSST 106: PERCEPTION AND COMPUTER VISION

MIDTERM PROJECT

IMPLEMENTING OBJECT DETECTION ON A DATASET

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Introduction

This project implements two well-known object detection algorithms, HOG-SVM and YOLO, on a single-class dataset focused on detecting cats. Object detection is a critical task in computer vision, with applications across security, wildlife monitoring, and robotic perception. This project provides a comparative analysis of two different detection techniques: a traditional method (HOG-SVM) and a deep-learning approach (YOLO). Both models are applied to the same dataset to analyze their performance in terms of accuracy, precision, recall, and speed.

The dataset used for this project is a customized subset of the COCO dataset, containing labeled images of cats. By selecting a single class, we aim to evaluate each algorithm's strengths and weaknesses on a controlled dataset, highlighting practical implications for each model's usage.

Real-World Applications of Cat Detection

Cat detection models, like the ones developed in this project, have several real-world applications:

Home Security and Monitoring Systems

Cat detection can enhance the functionality of home security cameras by differentiating between pets and potential intruders, reducing false alarms triggered by household pets.

Animal Welfare and Rescue

Monitoring stray cat populations in urban or rural areas helps rescue teams locate animals in need, providing targeted support in specific areas.

Smart Animal Doors and Feeders

Many pet products, such as automatic doors or feeders, use object detection to differentiate between household pets and wild animals. This technology can ensure that only recognized pets are granted access, preventing unintended use by other animals.

Wildlife Research and Monitoring

Using detection models to monitor wildlife cameras can support studies on animal behavior, population density, and movement patterns, particularly in environments with cats or similar small mammals.

I. Selection of Dataset and Algorithm

Dataset Selection

The project uses a **cat** dataset sourced from Roboflow and then tailored to the customized "cat" class format of the COCO dataset, enabling a focused, single-class analysis.

Algorithm Selection

- **HOG-SVM**: A traditional approach that combines Histogram of Oriented Gradients (HOG) for feature extraction with Support Vector Machine (SVM) for classification.
- **YOLO**: A deep learning-based real-time object detection algorithm known for its speed and high performance.

II. Model Implementation and Training

Data Preparation

Both algorithms utilize a preprocessed version of the dataset, which includes resized images and normalized pixel values. Bounding box labels are used for YOLO, as it require spatial information about detected objects.

Model Building

- **HOG-SVM Implementation**: The HOG-SVM model is constructed using the OpenCV library. HOG features are extracted from each image, and a linear SVM classifier is trained to identify regions containing cats.
- **YOLO Implementation**: The YOLO model leverages TensorFlow and Keras libraries. The model is trained on labeled cat images, with bounding box information included to improve spatial detection accuracy.

Training the Model

- **HOG-SVM**: The model is trained on extracted HOG features and fine-tuned for parameters such as SVM regularization and kernel type.
- **YOLO**: Training parameters such as learning rate, batch size, and number of epochs are adjusted to optimize detection accuracy.

Testing

Each model is evaluated on a test set containing cat images to assess detection capabilities. During testing, edge cases (e.g., images with partial cats or background distractions) are included to identify potential limitations.

III. Evaluation

Performance Metrics

- **Accuracy**: Measures the overall detection rate, identifying true positives and negatives.
- **Precision**: Calculates the proportion of true positive detections out of all detected positives, indicating the model's precision.
- **Recall**: Measures the ratio of true positives to all actual positives in the dataset, assessing the model's ability to identify cats correctly.
- **Speed**: Both models are assessed for speed to understand their applicability in real-time scenarios.

IV. Discussion of Challenges

The group members encountered specific challenges during the development of the YOLO model due to the resource limitations of Google Colab, particularly when handling the extensive dataset images. The main challenges were:

1. **Data Preprocessing**: Processing a large dataset strained the available RAM, leading to frequent crashes in Google Colab. This required the team to reduce the data volume or use optimized techniques to manage memory more effectively while preparing images for training.
2. **Extended Training Time**: The deep learning architecture of YOLO demands significant computational power, resulting in long training times. This was particularly challenging in Colab's free-tier environment, as the team had to manage limited GPU availability and training duration.

On the other hand, the HOG-SVM model was implemented without similar challenges, as it has a simpler architecture and lower computational demands compared to deep learning-based methods like YOLO.

V. Comparison of Algorithms

By comparing HOG-SVM and YOLO, this project examines how traditional and deep-learning approaches differ in terms of speed and accuracy. This analysis informs decisions on model selection based on the application's performance requirements.

Table 1. YOLO Model Performance

Metric	Value
Validation Accuracy	1.000
Precision	1.000
Recall	1.000
Testing Accuracy	1.000
Testing Precision	1.000
Testing Recall	1.000
Detection Time (Test Set)	0.000036 seconds

The YOLO model achieves perfect scores across all metrics, suggesting that YOLO has excellent object detection accuracy on this dataset. YOLO's deep learning architecture is designed for real-time, high-accuracy detection, which is reflected in its results.

Table 2. HOG-SVM Model Performance

Metric	Class 0	Class 1	Macro Average	Weighted Average
Precision	0.97	0.90	0.94	0.96
Recall	0.98	0.85	0.92	0.96
F1-Score	0.98	0.88	0.93	0.96
Accuracy			0.96	

The HOG-SVM model achieves a high overall accuracy of 96% and performs well with class 0, which has a higher support count. However, the recall for class 1 is lower at 0.85, indicating that the model misses some true instances of class 1.

Comparison of YOLO and HOG-SVM

- **Accuracy**: YOLO demonstrates perfect accuracy on both validation and testing sets, whereas HOG-SVM reaches a high but slightly lower accuracy of 96%.
- **Precision and Recall**: YOLO's precision and recall outperform HOG-SVM, especially for class 1 detections. While HOG-SVM shows high precision, its recall is lower for class 1, meaning it occasionally fails to detect all instances of the target object.
- **Speed**: YOLO's detection time is significantly faster, at 0.000036 seconds for the test set. HOG-SVM's detection speed was not provided but would generally be slower than YOLO due to its traditional algorithmic design.

VI. Conclusion

The cat detection models developed in this project, utilizing the YOLO algorithm, offer significant potential for various real-world applications, enhancing both safety and convenience in diverse environments. For instance, integrating these models into home security systems can help distinguish between household pets and potential intruders, thus reducing false alarms and increasing the reliability of security measures.

Furthermore, these models can play a vital role in animal welfare efforts by enabling the monitoring of stray cat populations, allowing rescue teams to efficiently locate and assist animals in need. Additionally, smart pet products like automatic doors and feeders can benefit from object detection technology, specifically the YOLO model, to ensure that only recognized pets gain access, preventing unintended use by wild animals and enhancing the overall functionality of these devices.

Moreover, the application of cat detection models extends to wildlife research and monitoring, where they can assist in studying animal behavior, population density, and movement patterns in natural habitats. By accurately identifying and tracking cats and similar small mammals using HOG-SVM and YOLO, these models contribute valuable insights to ecological studies and conservation efforts. Overall, the advancements in cat detection technology not only enhance everyday applications but also support critical initiatives in animal welfare and environmental research.