Capstone Proposal

Inventory Monitoring at Distribution Centers

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1 Domain Background:

Distribution centers are very important in the supply chain. They support the storage, sorting and dispatching the products. The efficient operations of these centers are paramount to ensure timely deliveries, minimize costs and maintain inventory accuracy. Before, inventory management based on manual process, which are prone to errors and inefficiencies. Now, with automation and robotics, distribution centers can adopt robotic system to handle tasks such as moving objects or managing bins etc..., and robots can automatically handle repetitive task than humans

But can do that, the integration robotics requires the inventory monitoring systems can track and detect objects perfectly. Beside, accurate inventory tracking is needed to maintain stock levels, avoid the overstocking or stock-outs and ensure bins contains the correct number of items.

With the development of machine learning and computer vision, we can offer many solution promising for automating inventory monitoring. With the resources is image data captured by robotic systems, machine learning models can be trained to recognize and count objects accurately. The academic research has demonstrated the effectiveness of convocational neural networks (CNNs) in object detection and classification [1], [2]. That why it is suitable candidates for this application.

2 Problem Statement:

Maintaining accurate inventory is a challenge for distribution centers. Without the robotic supports, the counting and sorting are manually. They are very take time and susceptible to errors, leading to differences between actual and recoded inventory levels

The primary problem is we don't have an automated, reliable system for counting the objects within each bin managed by robots in distribution centers. This project aim to solve that problem. We will focus on develop a machine learning model that can accurately classify the objects based on images data using the provided Amazon Bin Image Dataset.

3 Solution Statement:

The proposed solution is developing a machine learning based on the image classification system that accurately counts the objects. The system will use the AWS SageMaker for model development, training and deployment.

The solution will follow an end-to-end machine learning pipeline:

- **Data Acquisition:** Utilize the Amazon Bin Image Dataset (more 500.000 bins images with varying numbers of objects, along with corresponding metadata)
- **Data Prepocessing:** Clean and preprocessing the images to enhance the model robustness (resizing, normalization and augmentation, etc)
- **Model Selection and Training:** Apply a pre-trained convolutional neural network (e.g., Restnet-50) fine-turn on the image dataset to leverage transfer, reducing the training time and improve the accuracy.
- **Model Evaluation:** Assess the model's performance using appropriate metrics and validate its generalizability on a separate test set.
- **Deployment:** Deploy the trained model as a SageMaker endpoint for real-time inference.

Use metrics like accuracy, precision and F1 score, etc, we can evaluate on test data, and replicable by using the standard procedures and SageMaker's reproducible training environment

4 Datasets and Inputs:

The primary dataset for this project is the **Amazon Bin Image Dataset** which contains half a million bin's images containing objects. Each image is paired with metadata file detailing the number of objects, their dimensions and types.

Data Collection: The dataset is sourced from Amazon, one of biggest distribution center and retail in the world. That ensures relevance and applicability to real-world scenarios.
Dataset Characteristics:

- **Volume:** 536,434 images, providing rich data to train powerful models
- **Variety:** Images show bins with varying numbers and types of objects, enhancing the model's ability to generalize across different scenarios
- **Annotations:** Metadata includes precise counts of objects, facilitating supervised learning.

Usage in the Project:

- **Training Set:** 70% of the dataset
- **Validation Set:** 20% for hyperparameter tuning and model validation
- **Test Set:** 10% to evaluate final model performance.

5 Benchmark Model:

Suitable model for this project is a pre-trained **ResNet-50** convolutional neural network . ResNet-50 is very famous for its performance in image classification tasks.

Benchmark Characteristics:

- **Architecture:** 50-layer deep residual network.
- **Pre-training:** Trained on ImageNet, providing a strong foundation for feature extraction.
- **Fine-tuning:** Fit in with the bin image dataset by retraining the final layers to classify the object's number in bins.

This benchmark provides a solid performance, so we can compare with other models (more sophisticated or customized). It is measurable through standard classification metrics and aligns with the domain's requirements for accuracy and reliability.

6 Evaluation Metrics:

Evaluations metrics bellow will be ussed for quantifying the performance of benchmark and proposed model.

- **Accuracy:** a metric that measures how often a machine learning model correctly predicts the outcome.

$$Accuracy = \frac{CorrectPredictions}{AllPredictions}$$

- **Precision:** the quality of a positive prediction made by the model

$$Precision = \frac{TruePositives}{TruePositives + FalsePositives}$$

- **Sensitivity:** measures how well a machine learning model can detect positive instances

$$Recall = \frac{TruePositives}{TruePositives + FalseNegatives}$$

- **F1-Score:** the harmonic mean of the precision and recall of a classification model

$$F1 - Score = 2 \times \frac{Precision \times Recall}{Precision + Recall}$$

7 Project Design:

The project will follow a structured workflow encompassing data handling, model development, evaluation, and deployment

1. **Data Ingestion and Storage:**
   - Use AWS SageMaker to access and manage and store the Amazon Bin Image Dataset to AWS S3
2. **Data Preprocessing:**
   - Resize image to standardize input dimensions.
   - Normalize pixel values to enhance model convergence.
   - Apply data augmentation techniques (e.g., rotation, flipping) to increase dataset diversity and prevent overfitting.
   - Split the dataset into training, validation, and test sets to ensure unbiased evaluation.
3. **Exploratory Data Analysis (EDA):**
   - Analyze the distribution of object in bins.
   - Visualize sample images to understand variability and complexity.
   - Identify and handle anomalies data .
4. **Model Selection and Training:**
   - **Benchmark Model:** Fine-tune ResNet-50 on the dataset, leveraging transfer learning to expedite training and improve performance.
   - **Proposed Models:** Experiment with some alternative architectures e.g EfficientNet or custom CNNs tailored to the specific characteristics of bin images.
   - **Implement hyperparameter:** Using SageMaker's Hyperparameter Optimization (HPO) to identify the optimal training configurations.
5. **Model Evaluation:**
   - Calcuate evaluation metrics (accuracy, precision, recall, etc) on the test set to ensure model is perfect on general data
   - Compare the benchmark model performance with proposed models to identify improvements.
6. **Deployment:**
   - Deploy the best-performing model as an endpoint in SageMaker for real-time inference.
7. **Monitoring:**
   - Implement monitoring to track model performance over time.

References

[1] Ramachandra A.C Viswanatha V Chandana R K. *Real Time Object Detection System with YOLO and CNN Models: A Review.* URL: `https://arxiv.org/pdf/2208.00773`.

[2] Mustapha Amrouch Ayoub Benali Amjoud. "Object Detection Using Deep Learning, CNNs and Vision transformers: A Review". In: *IEEE* 11 (2023), pp. 35478–35516. DOI: `https://doi.org/10.1109/ACCESS.2023.3266093`.