

Smart Agriculture: CNN-Based Potato Disease Detection System

Using Dual-Branch CNN with Attention Mechanism

```
In [ ]: import kagglehub  
path = kagglehub.dataset_download("aarishasifkhan/plantvillage-potato-disease-dataset")  
print("Dataset downloaded to:", path)
```

Dataset downloaded to: /kaggle/input/plantvillage-potato-disease-dataset

```
In [ ]: import os  
print(os.listdir(path))  
  
['PlantVillage']
```

```
In [ ]: base_path = os.path.join(path, "PlantVillage")
```

```
In [ ]: print(os.listdir(base_path))  
  
['Potato__healthy', 'Potato__Late_blight', 'Potato__Early_blight']
```

```
In [ ]: categories = os.listdir(base_path)  
categories
```

```
Out[ ]: ['Potato__healthy', 'Potato__Late_blight', 'Potato__Early_blight']
```

```
In [ ]: image_paths = []  
labels = []  
  
for category in categories:  
    category_path = os.path.join(base_path, category)  
    for image_name in os.listdir(category_path):  
        image_path = os.path.join(category_path, image_name)  
        image_paths.append(image_path)  
        labels.append(category)  
  
print(len(image_paths))  
print(len(labels))
```

2152

2152

```
In [ ]: import pandas as pd
```

```
df = pd.DataFrame({  
    "image_path": image_paths,  
    "label": labels  
})  
  
df.head()
```

Out[]:

	image_path	label
0	/kaggle/input/plantvillage-potato-disease-data.../0/0_0.jpg	Potato__healthy
1	/kaggle/input/plantvillage-potato-disease-data.../0/0_1.jpg	Potato__healthy
2	/kaggle/input/plantvillage-potato-disease-data.../0/0_2.jpg	Potato__healthy
3	/kaggle/input/plantvillage-potato-disease-data.../0/0_3.jpg	Potato__healthy
4	/kaggle/input/plantvillage-potato-disease-data.../0/0_4.jpg	Potato__healthy

In []:

```
df.tail()
```

Out[]:

	image_path	label
2147	/kaggle/input/plantvillage-potato-disease-data.../2147/2147_0.jpg	Potato__Early_blight
2148	/kaggle/input/plantvillage-potato-disease-data.../2148/2148_0.jpg	Potato__Early_blight
2149	/kaggle/input/plantvillage-potato-disease-data.../2149/2149_0.jpg	Potato__Early_blight
2150	/kaggle/input/plantvillage-potato-disease-data.../2150/2150_0.jpg	Potato__Early_blight
2151	/kaggle/input/plantvillage-potato-disease-data.../2151/2151_0.jpg	Potato__Early_blight

In []:

```
print(df.shape)  
print(df.columns)  
print(df.duplicated().sum())  
print(df.isnull().sum())
```

(2152, 2)
Index(['image_path', 'label'], dtype='object')
0
image_path 0
label 0
dtype: int64

In []:

```
df.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 2152 entries, 0 to 2151
Data columns (total 2 columns):
 #   Column      Non-Null Count  Dtype  
--- 
 0   image_path  2152 non-null   object  
 1   label        2152 non-null   object  
dtypes: object(2)
memory usage: 33.8+ KB
```

```
In [ ]: df['label'].value_counts()
```

```
Out[ ]:
```

label	count
Potato__Late_blight	1000
Potato__Early_blight	1000
Potato__healthy	152

dtype: int64

```
In [ ]:
```

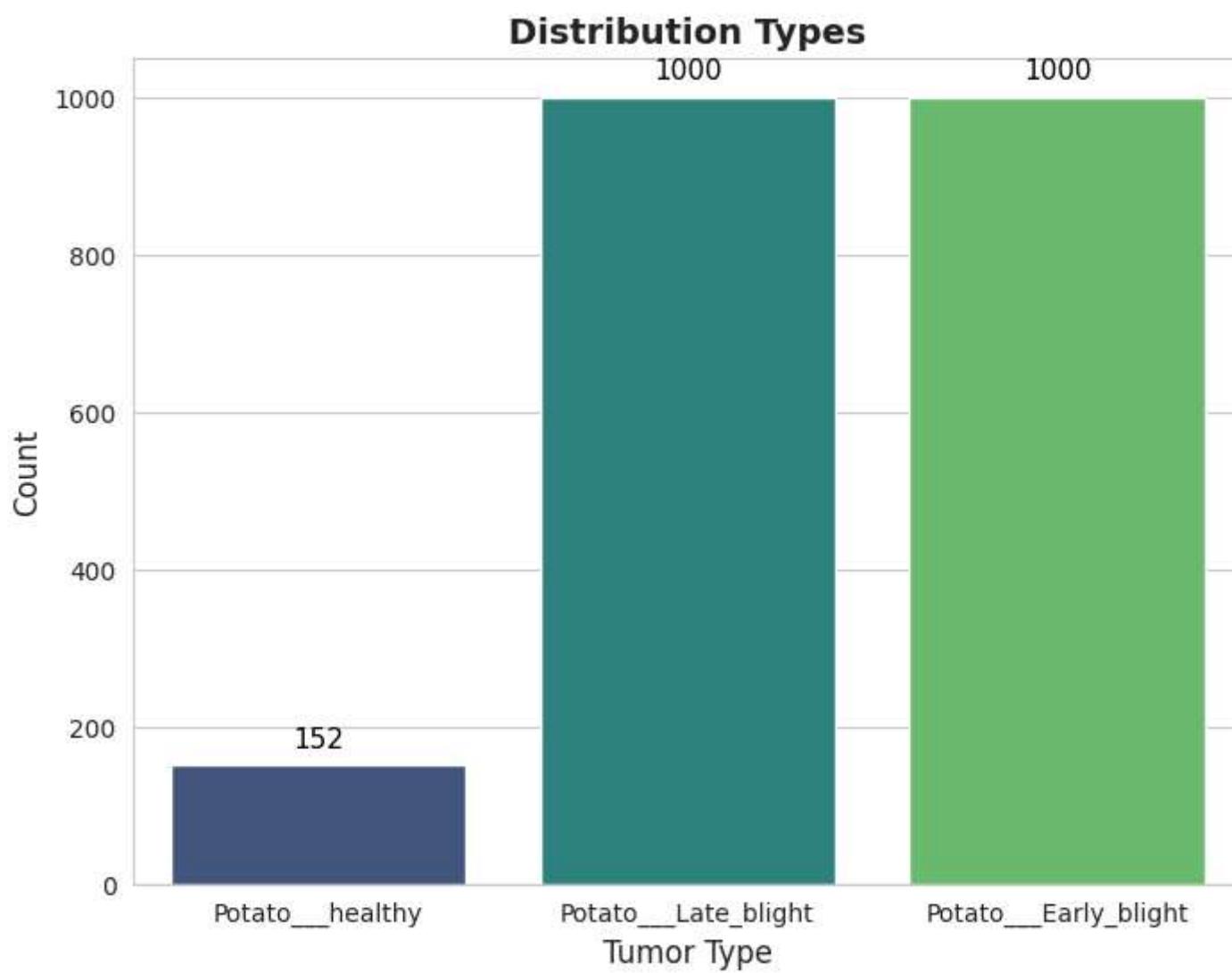
```
import seaborn as sns
import matplotlib.pyplot as plt

import warnings
warnings.filterwarnings("ignore")

sns.set_style("whitegrid")
fig, ax = plt.subplots(figsize=(8, 6))
sns.countplot(data=df, x="label", palette="viridis", ax=ax)

ax.set_title("Distribution Types", fontsize=14, fontweight="bold")
ax.set_xlabel("Tumor Type", fontsize=12)
ax.set_ylabel("Count", fontsize=12)

for p in ax.patches:
    ax.annotate(f'{int(p.get_height())}', (p.get_x() + p.get_width()/2, p.get_height()), ha='center', va='bottom', fontsize=11, c
plt.show();
```



```
In [ ]: import cv2
import warnings
warnings.filterwarnings("ignore")

num_images = 5

plt.figure(figsize=(15,12))

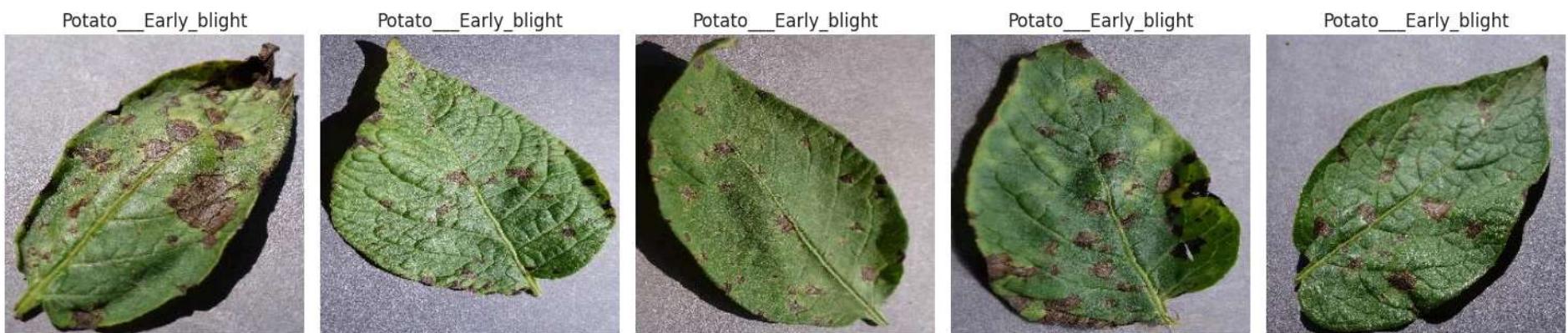
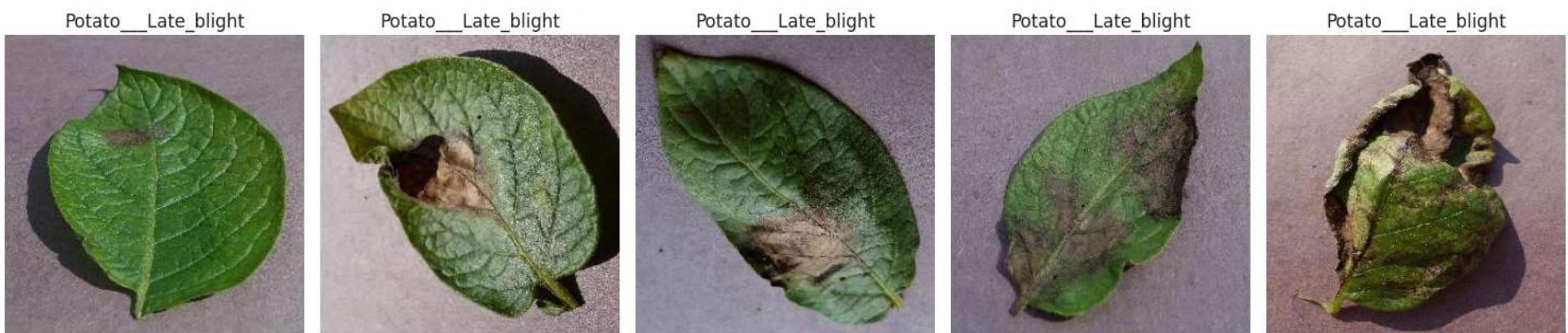
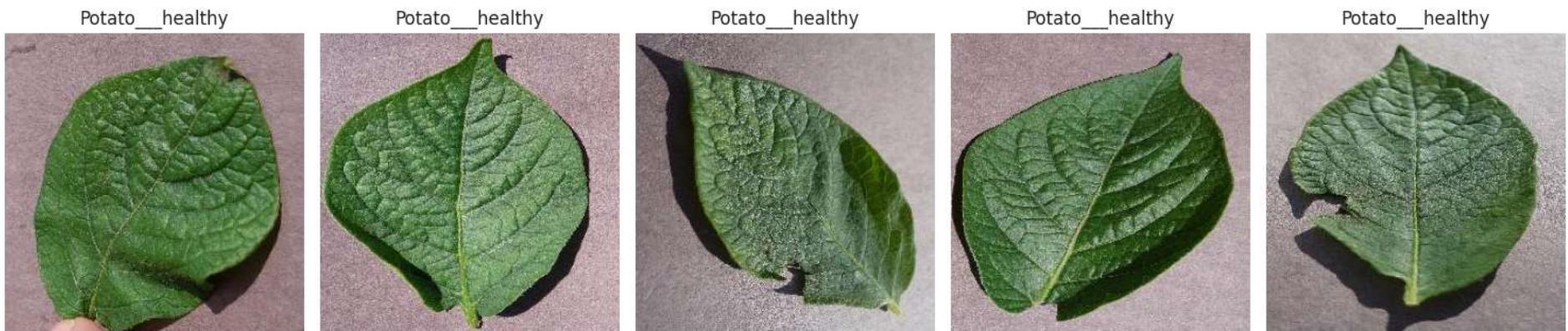
for i, category in enumerate(categories):
    category_images = df[df['label'] == category]['image_path'].iloc[:num_images]

    for j, img_path in enumerate(category_images):
        img = cv2.imread(img_path)
```

```
img = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)

plt.subplot(len(categories), num_images, i * num_images + j + 1)
plt.imshow(img)
plt.axis('off')
plt.title(category)

plt.tight_layout()
plt.show();
```



```
In [ ]: from sklearn.preprocessing import LabelEncoder  
label_encoder = LabelEncoder()  
  
df['category_encoded'] = label_encoder.fit_transform(df['label'])  
  
label_mapping = dict(zip(label_encoder.transform(label_encoder.classes_),label_encoder.classes_))
```

```

print("Label mapping:", label_mapping)

df = df[['image_path', 'category_encoded']]

from sklearn.utils import resample
max_count = df['category_encoded'].value_counts().max()

dfs = []
for category in df['category_encoded'].unique():
    class_subset = df[df['category_encoded'] == category]
    class_unsampled = resample(class_subset, replace=True, n_samples = max_count, random_state = 42)
    dfs.append(class_unsampled)

df_balanced = pd.concat(dfs).sample(frac = 1, random_state = 42).reset_index(drop = True)
df_balanced['category_encoded'].value_counts()

df_resampled = df_balanced
df_resampled['category_encoded'] = df_resampled['category_encoded'].astype(str)

```

Label mapping: {np.int64(0): 'Potato__Early_blight', np.int64(1): 'Potato__Late_blight', np.int64(2): 'Potato__healthy'}

In []: df_resampled["category_encoded"].value_counts()

Out[]:

category_encoded	count
1	1000
2	1000
0	1000

category_encoded	count
1	1000
2	1000
0	1000

dtype: int64

In []: from sklearn.model_selection import train_test_split
from tensorflow.keras.preprocessing.image import ImageDataGenerator

```

train_df_new, temp_df_new = train_test_split(
    df_resampled,
    train_size = 0.8,
    shuffle = True,
    random_state = 42,
    stratify = df_resampled['category_encoded']
)

```

```
valid_df_new, test_df_new = train_test_split(  
    temp_df_new,  
    test_size = 0.5,  
    shuffle = True,  
    random_state = 42,  
    stratify = temp_df_new['category_encoded'])  
)  
  
batch_size = 16  
img_size = (224, 224)  
channels = 3  
img_shape = (img_size[0], img_size[1], channels)  
  
tr_gen = ImageDataGenerator(rescale = 1./255)  
  
ts_gen = ImageDataGenerator(rescale = 1./255)  
  
train_gen_new = tr_gen.flow_from_dataframe(  
    train_df_new,  
    x_col = 'image_path',  
    y_col = 'category_encoded',  
    target_size = img_size,  
    class_mode = 'sparse',  
    color_mode = 'rgb',  
    shuffle = True,  
    batch_size = batch_size  
)  
  
valid_gen_new = ts_gen.flow_from_dataframe(  
    valid_df_new,  
    x_col = 'image_path',  
    y_col = 'category_encoded',  
    target_size = img_size,  
    class_mode = 'sparse',  
    color_mode = 'rgb',  
    shuffle = True,  
    batch_size = batch_size  
)  
  
test_gen_new = ts_gen.flow_from_dataframe(  
    test_df_new,  
    x_col = 'image_path',  
    y_col = 'category_encoded',  
    target_size = img_size,  
    class_mode = 'sparse',  
    color_mode = 'rgb',  
    shuffle = False,
```

```
    batch_size = batch_size
)
```

```
Found 2400 validated image filenames belonging to 3 classes.
```

```
Found 300 validated image filenames belonging to 3 classes.
```

```
Found 300 validated image filenames belonging to 3 classes.
```

```
In [ ]: import tensorflow as tf
print("Number of GPUs Available:", len(tf.config.list_physical_devices('GPU')))

gpus = tf.config.list_physical_devices('GPU')
if gpus:
    try:
        for gpu in gpus:
            tf.config.experimental.set_memory_growth(gpu, True)
        print("GPU is set for TensorFlow")
    except RuntimeError as e:
        print(e)
```

```
Number of GPUs Available: 1
```

```
GPU is set for TensorFlow
```

```
In [ ]: import tensorflow as tf
from tensorflow.keras.layers import (Input, Lambda, Conv2D, MaxPooling2D,
                                      Flatten, Dense, Reshape, Concatenate,
                                      GlobalAveragePooling1D, Softmax, Multiply)
from tensorflow.keras.models import Model

num_classes = len(train_df_new['category_encoded'].unique())
```

```
In [ ]: def split_image(image):
    upper_half = image[:, :img_size[0]//2, :, :]
    lower_half = image[:, img_size[0]//2:, :, :]
    return upper_half, lower_half

def flip_lower_half(lower_half):
    return tf.image.flip_left_right(lower_half)
```

```
In [ ]: input_layer = Input(shape=img_shape)

upper_half, lower_half = Lambda(split_image)(input_layer)
lower_half_flipped = Lambda(flip_lower_half)(lower_half)
```

```
In [ ]: upper = Conv2D(32, (3, 3), activation='relu', padding='same')(upper_half)
upper = MaxPooling2D((2, 2))(upper)
upper = Conv2D(64, (3, 3), activation='relu', padding='same')(upper)
```

```
upper = MaxPooling2D((2, 2))(upper)
upper = Conv2D(128, (3, 3), activation='relu', padding='same')(upper)
upper = MaxPooling2D((2, 2))(upper)
upper = Flatten()(upper)
upper_dense = Dense(512, activation='relu')(upper)
upper_reshape = Reshape((1, 512))(upper_dense)
```

```
In [ ]: lower = Conv2D(32, (3, 3), activation='relu',
padding='same')(lower_half_flipped)
lower = MaxPooling2D((2, 2))(lower)
lower = Conv2D(64, (3, 3), activation='relu', padding='same')(lower)
lower = MaxPooling2D((2, 2))(lower)
lower = Conv2D(128, (3, 3), activation='relu', padding='same')(lower)
lower = MaxPooling2D((2, 2))(lower)
lower = Flatten()(lower)
lower_dense = Dense(512, activation='relu')(lower)
lower_reshape = Reshape((1, 512))(lower_dense)
```

```
In [ ]: concat_seq = Concatenate(axis=1)([upper_reshape, lower_reshape])

similarity_scores = tf.keras.layers.Dot(axes=-1, normalize=True)([upper_reshape, lower_reshape])

attention_weights = Softmax(axis=1)(similarity_scores)

attended = Multiply()([attention_weights, upper_reshape])

combined = Concatenate(axis=-1)([attended, lower_reshape])
combined = Reshape((1024,))(combined)
```

```
In [ ]: fc1 = Dense(256, activation='relu')(combined)
fc2 = Dense(128, activation='relu')(fc1)

output = Dense(num_classes, activation='softmax')(fc2)
```

```
In [ ]: model = Model(inputs=input_layer, outputs=output)
model.compile(
    optimizer = 'adam',
    loss = 'sparse_categorical_crossentropy',
    metrics = ['accuracy']
)
model.summary()
```

Model: "functional"

Layer (type)	Output Shape	Param #	Connected to
input_layer (InputLayer)	(None, 224, 224, 3)	0	-
lambda (Lambda)	[None, 112, 224, 3), None, 112, 224, 3)]	0	input_layer[0][0]
lambda_1 (Lambda)	(None, 112, 224, 3)	0	lambda[0][1]
conv2d (Conv2D)	(None, 112, 224, 32)	896	lambda[0][0]
conv2d_3 (Conv2D)	(None, 112, 224, 32)	896	lambda_1[0][0]
max_pooling2d (MaxPooling2D)	(None, 56, 112, 32)	0	conv2d[0][0]
max_pooling2d_3 (MaxPooling2D)	(None, 56, 112, 32)	0	conv2d_3[0][0]
conv2d_1 (Conv2D)	(None, 56, 112, 64)	18,496	max_pooling2d[0]...
conv2d_4 (Conv2D)	(None, 56, 112, 64)	18,496	max_pooling2d_3[...]
max_pooling2d_1 (MaxPooling2D)	(None, 28, 56, 64)	0	conv2d_1[0][0]
max_pooling2d_4 (MaxPooling2D)	(None, 28, 56, 64)	0	conv2d_4[0][0]
conv2d_2 (Conv2D)	(None, 28, 56, 128)	73,856	max_pooling2d_1[...]
conv2d_5 (Conv2D)	(None, 28, 56, 128)	73,856	max_pooling2d_4[...]
max_pooling2d_2 (MaxPooling2D)	(None, 14, 28, 128)	0	conv2d_2[0][0]
max_pooling2d_5 (MaxPooling2D)	(None, 14, 28, 128)	0	conv2d_5[0][0]

flatten (Flatten)	(None, 50176)	0	max_pooling2d_2[...]
flatten_1 (Flatten)	(None, 50176)	0	max_pooling2d_5[...]
dense (Dense)	(None, 512)	25,690,624	flatten[0][0]
dense_1 (Dense)	(None, 512)	25,690,624	flatten_1[0][0]
reshape (Reshape)	(None, 1, 512)	0	dense[0][0]
reshape_1 (Reshape)	(None, 1, 512)	0	dense_1[0][0]
dot (Dot)	(None, 1, 1)	0	reshape[0][0], reshape_1[0][0]
softmax (Softmax)	(None, 1, 1)	0	dot[0][0]
multiply (Multiply)	(None, 1, 512)	0	softmax[0][0], reshape[0][0]
concatenate_1 (Concatenate)	(None, 1, 1024)	0	multiply[0][0], reshape_1[0][0]
reshape_2 (Reshape)	(None, 1024)	0	concatenate_1[0]...
dense_2 (Dense)	(None, 256)	262,400	reshape_2[0][0]
dense_3 (Dense)	(None, 128)	32,896	dense_2[0][0]
dense_4 (Dense)	(None, 3)	387	dense_3[0][0]

Total params: 51,863,427 (197.84 MB)

Trainable params: 51,863,427 (197.84 MB)

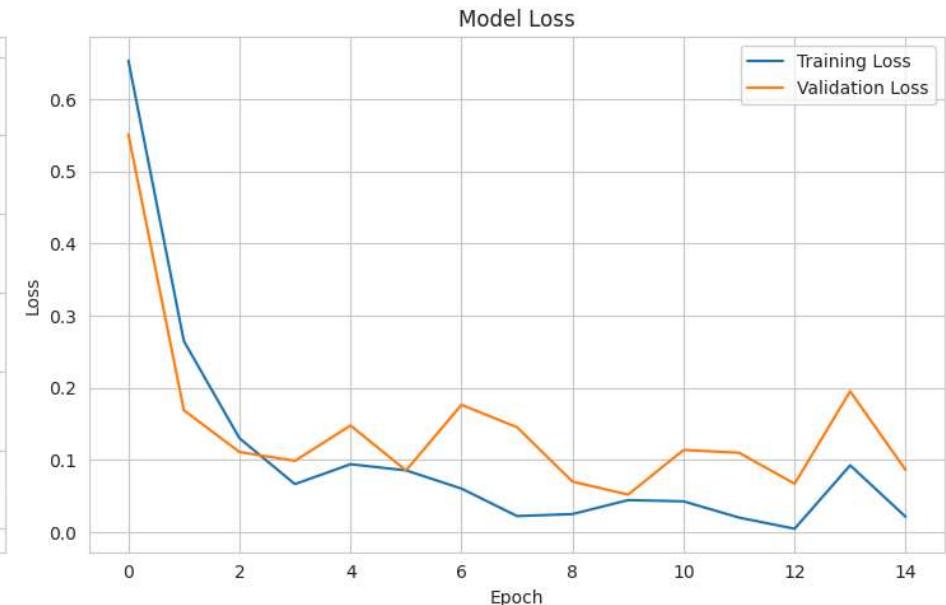
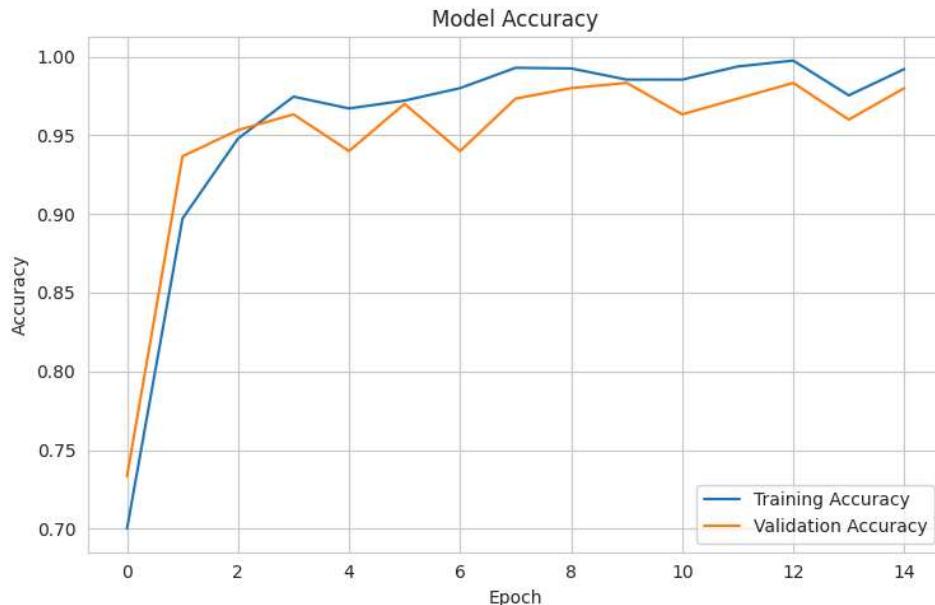
Non-trainable params: 0 (0.00 B)

```
In [ ]: history = model.fit(
    train_gen_new,
    validation_data=valid_gen_new,
    epochs=15,
    batch_size=batch_size
)
```

Epoch 1/15
150/150 18s 62ms/step - accuracy: 0.5478 - loss: 0.9494 - val_accuracy: 0.7333 - val_loss: 0.5517
Epoch 2/15
150/150 7s 49ms/step - accuracy: 0.8728 - loss: 0.3301 - val_accuracy: 0.9367 - val_loss: 0.1690
Epoch 3/15
150/150 7s 44ms/step - accuracy: 0.9558 - loss: 0.1156 - val_accuracy: 0.9533 - val_loss: 0.1111
Epoch 4/15
150/150 8s 55ms/step - accuracy: 0.9741 - loss: 0.0654 - val_accuracy: 0.9633 - val_loss: 0.0989
Epoch 5/15
150/150 7s 48ms/step - accuracy: 0.9819 - loss: 0.0508 - val_accuracy: 0.9400 - val_loss: 0.1479
Epoch 6/15
150/150 10s 45ms/step - accuracy: 0.9689 - loss: 0.0958 - val_accuracy: 0.9700 - val_loss: 0.0856
Epoch 7/15
150/150 8s 51ms/step - accuracy: 0.9862 - loss: 0.0459 - val_accuracy: 0.9400 - val_loss: 0.1765
Epoch 8/15
150/150 8s 51ms/step - accuracy: 0.9922 - loss: 0.0289 - val_accuracy: 0.9733 - val_loss: 0.1455
Epoch 9/15
150/150 7s 45ms/step - accuracy: 0.9829 - loss: 0.0509 - val_accuracy: 0.9800 - val_loss: 0.0700
Epoch 10/15
150/150 7s 48ms/step - accuracy: 0.9951 - loss: 0.0164 - val_accuracy: 0.9833 - val_loss: 0.0521
Epoch 11/15
150/150 7s 43ms/step - accuracy: 0.9868 - loss: 0.0452 - val_accuracy: 0.9633 - val_loss: 0.1140
Epoch 12/15
150/150 8s 52ms/step - accuracy: 0.9918 - loss: 0.0235 - val_accuracy: 0.9733 - val_loss: 0.1101
Epoch 13/15
150/150 10s 48ms/step - accuracy: 0.9975 - loss: 0.0057 - val_accuracy: 0.9833 - val_loss: 0.0671
Epoch 14/15
150/150 7s 46ms/step - accuracy: 0.9789 - loss: 0.0862 - val_accuracy: 0.9600 - val_loss: 0.1953
Epoch 15/15
150/150 7s 49ms/step - accuracy: 0.9951 - loss: 0.0124 - val_accuracy: 0.9800 - val_loss: 0.0861

```
In [ ]: def plot_training_history(history):
    fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(15, 5))
    ax1.plot(history.history['accuracy'], label='Training Accuracy')
    ax1.plot(history.history['val_accuracy'], label='Validation Accuracy')
    ax1.set_title('Model Accuracy')
    ax1.set_xlabel('Epoch')
    ax1.set_ylabel('Accuracy')
    ax1.legend()
    ax1.grid(True)
    ax2.plot(history.history['loss'], label='Training Loss')
    ax2.plot(history.history['val_loss'], label='Validation Loss')
    ax2.set_title('Model Loss')
    ax2.set_xlabel('Epoch')
    ax2.set_ylabel('Loss')
    ax2.legend()
    ax2.grid(True)
    plt.tight_layout()
```

```
plt.show()
plot_training_history(history)
```



```
In [ ]: print("Final Epoch Validation Accuracy: ", history.history['val_accuracy'][-1]*100)
print("Final Epoch Validation Loss: ", history.history['val_loss'][-1])
```

Final Epoch Validation Accuracy: 98.00000190734863
Final Epoch Validation Loss: 0.08609199523925781

```
In [ ]: test_loss, test_accuracy = model.evaluate(test_gen_new)
print(f"Test Accuracy: {test_accuracy:.4f}, Test Loss: {test_loss:.4f}")
```

19/19 ━━━━━━━━ 1s 38ms/step - accuracy: 0.9826 - loss: 0.0989
Test Accuracy: 0.9767, Test Loss: 0.1435

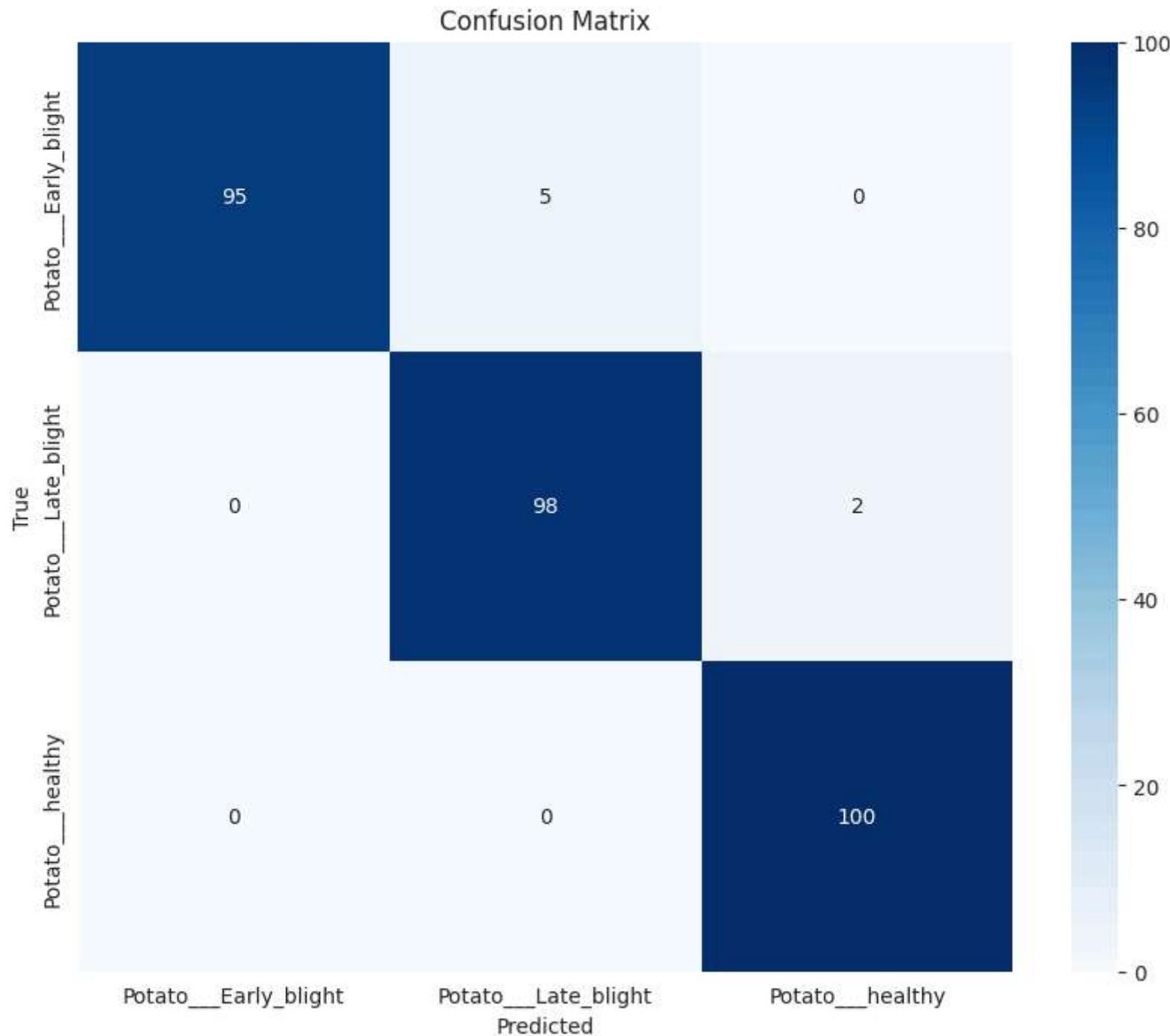
```
In [ ]: from sklearn.metrics import confusion_matrix, classification_report
import numpy as np
test_gen_new.reset()
y_pred = model.predict(test_gen_new)
y_pred_classes = np.argmax(y_pred, axis=1)
y_true = test_gen_new.classes
```

19/19 ━━━━━━━━ 1s 71ms/step

```
In [ ]: class_names = label_encoder.classes_

cm = confusion_matrix(y_true, y_pred_classes)
plt.figure(figsize=(10, 8))
sns.heatmap(cm, annot=True, fmt='d', cmap='Blues', xticklabels=class_names,
            yticklabels=class_names)
```

```
plt.title('Confusion Matrix')
plt.xlabel('Predicted')
plt.ylabel('True')
plt.show()
```



```
In [ ]: print("\nClassification Report:")
print(classification_report(y_true, y_pred_classes,
target_names=class_names))
```

Classification Report:

	precision	recall	f1-score	support
Potato__Early_blight	1.00	0.95	0.97	100
Potato__Late_blight	0.95	0.98	0.97	100
Potato__healthy	0.98	1.00	0.99	100
accuracy			0.98	300
macro avg	0.98	0.98	0.98	300
weighted avg	0.98	0.98	0.98	300

```
In [ ]:
```