HGRS

May 8, 2025

1 Milestone 1: Data Collection, Preprocessing, and Exploration

[1]:
```python
import os
import numpy as np
import matplotlib.pyplot as plt
import cv2
from sklearn.model_selection import train_test_split
from tensorflow.keras.utils import to_categorical
import pandas as pd
import seaborn as sns
```

[2]:
```python
# Define paths and parameters
DATA_PATH = r"C:\Users\shroo\Desktop\DEPI HGRS NEW2\Sign Language for Numbers"
IMG_SIZE = 64  # Resize images to 64x64
NUM_CLASSES = 11  # 0-9 + unknown
```

[3]:
```python
def load_dataset(data_path):
    """Load images and labels from the dataset directory"""
    images = []
    labels = []
    class_names = []

    # Iterate through class folders
    for class_id, class_name in enumerate(sorted(os.listdir(data_path))):
        class_dir = os.path.join(data_path, class_name)
        if os.path.isdir(class_dir):
            class_names.append(class_name)
            print(f"Loading class: {class_name} (ID: {class_id})")

            # Load all images for this class
            for img_name in os.listdir(class_dir):
                img_path = os.path.join(class_dir, img_name)
                try:
                    # Read and preprocess image
                    img = cv2.imread(img_path)
                    img = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)  # Convert BGR␣
 ↪to RGB
```

```
                    img = cv2.resize(img, (IMG_SIZE, IMG_SIZE))

                    images.append(img)
                    labels.append(class_id)
                except Exception as e:
                    print(f"Error loading image {img_path}: {e}")

    # Convert to numpy arrays
    X = np.array(images)
    y = np.array(labels)

    return X, y, class_names
```

[4]:
```
def visualize_samples(X, y, class_names, num_samples=10):
    """Visualize random samples from the dataset"""
    plt.figure(figsize=(15, 8))
    for i in range(num_samples):
        idx = np.random.randint(0, len(X))
        plt.subplot(2, 5, i+1)
        plt.imshow(X[idx])
        plt.title(f"Class: {class_names[y[idx]]}")
        plt.axis('off')
    plt.tight_layout()
    plt.show()
```

[5]:
```
def preprocess_data(X, y):
    """Preprocess the data for model training"""
    # Normalize pixel values to [0, 1]
    X_processed = X.astype('float32') / 255.0

    # Split into train, validation, and test sets
    X_train, X_temp, y_train, y_temp = train_test_split(X_processed, y,␣
 ↪test_size=0.3, random_state=42, stratify=y)
    X_val, X_test, y_val, y_test = train_test_split(X_temp, y_temp, test_size=0.
 ↪5, random_state=42, stratify=y_temp)

    # Convert labels to one-hot encoding
    y_train_cat = to_categorical(y_train, NUM_CLASSES)
    y_val_cat = to_categorical(y_val, NUM_CLASSES)
    y_test_cat = to_categorical(y_test, NUM_CLASSES)

    print(f"Train set: {X_train.shape}, {y_train.shape}")
    print(f"Validation set: {X_val.shape}, {y_val.shape}")
    print(f"Test set: {X_test.shape}, {y_test.shape}")

    return X_train, X_val, X_test, y_train_cat, y_val_cat, y_test_cat, y_train,␣
 ↪y_val, y_test
```

[6]:
```python
def explore_data_distribution(y, class_names):
    """Explore the class distribution in the dataset"""
    # Count samples per class
    unique, counts = np.unique(y, return_counts=True)
    class_dist = {class_names[c]: n for c, n in zip(unique, counts)}

    # Plot class distribution
    plt.figure(figsize=(12, 6))
    sns.barplot(x=list(class_dist.keys()), y=list(class_dist.values()))
    plt.title('Number of Images per Class')
    plt.xlabel('Class')
    plt.ylabel('Count')
    plt.xticks(rotation=45)
    plt.tight_layout()
    plt.show()

     # Print distribution details
    print("Class distribution:")
    for cls, count in class_dist.items():
        print(f"{cls}: {count} images ({count/len(y)*100:.2f}%)")
```

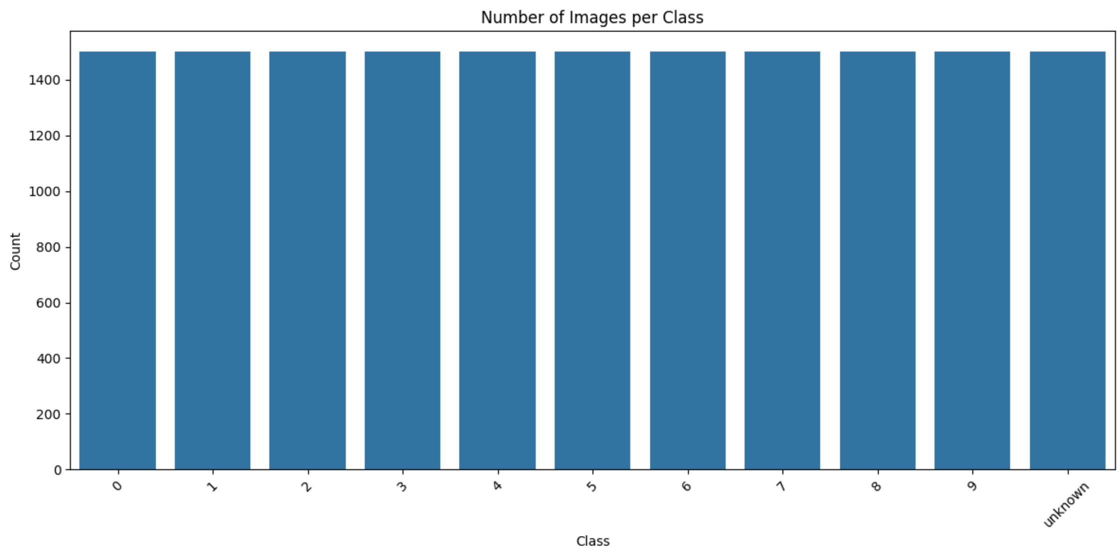
[7]:
```python
def data_augmentation_preview(X, y, class_names):
    """Preview data augmentation techniques on a sample image"""
    from tensorflow.keras.preprocessing.image import ImageDataGenerator

    # Sample image
    sample_idx = np.random.randint(0, len(X))
    sample_img = X[sample_idx]
    sample_class = class_names[y[sample_idx]]

    # Create augmentation generator
    datagen = ImageDataGenerator(
        rotation_range=20,
        width_shift_range=0.2,
        height_shift_range=0.2,
        shear_range=0.2,
        zoom_range=0.2,
        horizontal_flip=True,
        fill_mode='nearest'
    )

    # Generate augmented images
    aug_iter = datagen.flow(np.expand_dims(sample_img, axis=0), batch_size=1)

    # Display original and augmented images
    plt.figure(figsize=(12, 8))
    plt.subplot(3, 3, 1)
```

```
    plt.imshow(sample_img)
    plt.title(f"Original - Class: {sample_class}")
    plt.axis('off')

    for i in range(8):
        aug_img = next(aug_iter)[0].astype('uint8')
        plt.subplot(3, 3, i+2)
        plt.imshow(aug_img)
        plt.title(f"Augmented {i+1}")
        plt.axis('off')

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

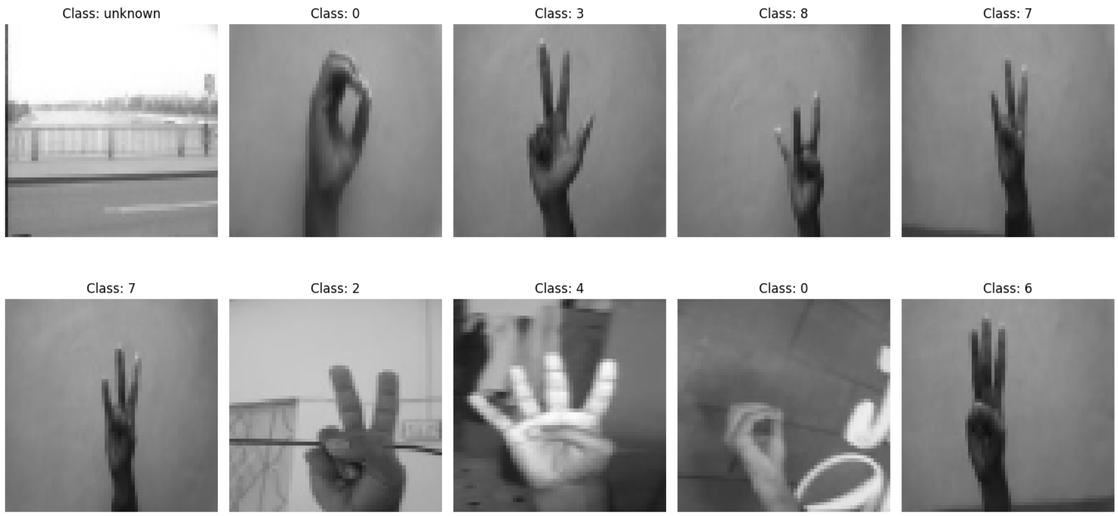
[9]:
```
# Main execution flow
if __name__ == "__main__":
    # Load the dataset
    X, y, class_names = load_dataset(DATA_PATH)
    print(f"Dataset loaded: {X.shape[0]} images, {len(class_names)} classes")

    # Explore data distribution
    explore_data_distribution(y, class_names)

    # Visualize random samples
    visualize_samples(X, y, class_names)

    # Preview data augmentation
    data_augmentation_preview(X, y, class_names)

    # Preprocess data for model training
    X_train, X_val, X_test, y_train_cat, y_val_cat, y_test_cat, y_train, y_val,␣
 ↪y_test = preprocess_data(X, y)

    # Create the 'data' directory if it doesn't exist
    os.makedirs('data', exist_ok=True)

    # Save processed data for model training
    np.save('data/X_train.npy', X_train)
    np.save('data/X_val.npy', X_val)
    np.save('data/X_test.npy', X_test)
    np.save('data/y_train_cat.npy', y_train_cat)
    np.save('data/y_val_cat.npy', y_val_cat)
    np.save('data/y_test_cat.npy', y_test_cat)

    print("Data preprocessing complete! Preprocessed data saved to 'data/'␣
 ↪directory.")
```

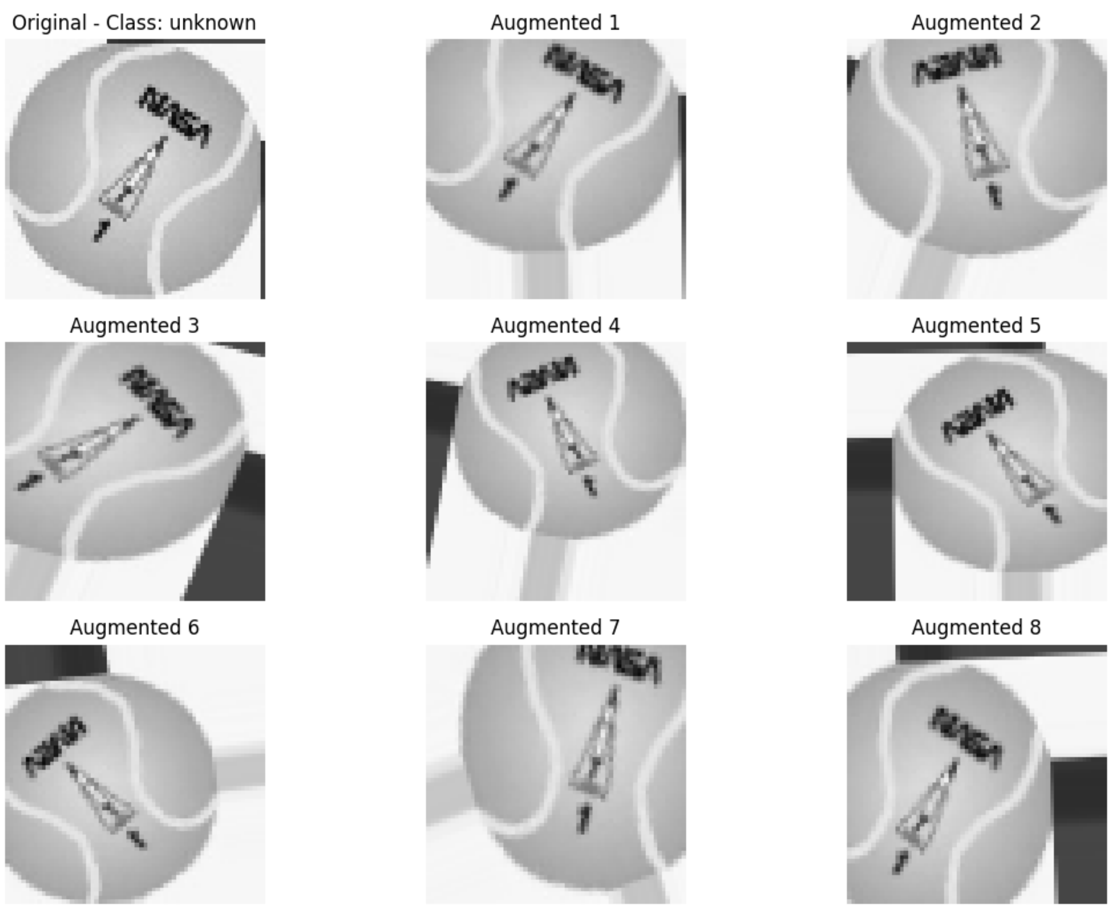
```
Loading class: 0 (ID: 0)
```

```
Loading class: 1 (ID: 1)
Loading class: 2 (ID: 2)
Loading class: 3 (ID: 3)
Loading class: 4 (ID: 4)
Loading class: 5 (ID: 5)
Loading class: 6 (ID: 6)
Loading class: 7 (ID: 7)
Loading class: 8 (ID: 8)
Loading class: 9 (ID: 9)
Loading class: unknown (ID: 10)
Dataset loaded: 16500 images, 11 classes
```




```
Class distribution:
0: 1500 images (9.09%)
1: 1500 images (9.09%)
2: 1500 images (9.09%)
3: 1500 images (9.09%)
4: 1500 images (9.09%)
5: 1500 images (9.09%)
6: 1500 images (9.09%)
7: 1500 images (9.09%)
8: 1500 images (9.09%)
9: 1500 images (9.09%)
unknown: 1500 images (9.09%)
```






```
Train set: (11550, 64, 64, 3), (11550,)
Validation set: (2475, 64, 64, 3), (2475,)
```

```
Test set: (2475, 64, 64, 3), (2475,)
Data preprocessing complete! Preprocessed data saved to 'data/' directory.
```

2 Milestone 2: Model Development and Training

[32]:
```python
import numpy as np
import matplotlib.pyplot as plt
import os
import tensorflow as tf
from tensorflow.keras.models import Sequential, Model
from tensorflow.keras.layers import Conv2D, MaxPooling2D, Flatten, Dense,␣
↪Dropout, BatchNormalization, Input
from tensorflow.keras.applications import MobileNetV2
from tensorflow.keras.callbacks import EarlyStopping, ModelCheckpoint,␣
↪ReduceLROnPlateau
from tensorflow.keras.preprocessing.image import ImageDataGenerator
from sklearn.metrics import classification_report, confusion_matrix
from tensorflow.keras.regularizers import l2
import seaborn as sns
```

[33]:
```python
# Set random seeds for reproducibility
np.random.seed(42)
tf.random.set_seed(42)

# Constants
IMG_SIZE = 64
NUM_CLASSES = 11
BATCH_SIZE = 32
EPOCHS = 25
```

[34]:
```python
def load_preprocessed_data():
    """Load preprocessed data from disk"""
    X_train = np.load('data/X_train.npy')
    X_val = np.load('data/X_val.npy')
    X_test = np.load('data/X_test.npy')
    y_train_cat = np.load('data/y_train_cat.npy')
    y_val_cat = np.load('data/y_val_cat.npy')
    y_test_cat = np.load('data/y_test_cat.npy')

    return X_train, X_val, X_test, y_train_cat, y_val_cat, y_test_cat
```

[36]:
```python
def create_data_generators(X_train, y_train_cat):
    """Create data generators with augmentation for training"""
    # Data augmentation for training
    train_datagen = ImageDataGenerator(
        rotation_range=20,
        width_shift_range=0.2,
```

```
        height_shift_range=0.2,
        shear_range=0.2,
        zoom_range=0.2,
        horizontal_flip=True,
        fill_mode='nearest'
    )

    # Create generator
    train_generator = train_datagen.flow(
        X_train, y_train_cat,
        batch_size=BATCH_SIZE
    )

    return train_generator
```

[37]:
```
def build_custom_cnn():
    """Build a custom CNN model with L2 regularization"""
    model = Sequential([
        # Input Layer
        Input(shape=(IMG_SIZE, IMG_SIZE, 3)),

        # First Convolutional Block
        Conv2D(32, (3, 3), activation='relu', padding='same',
               input_shape=(IMG_SIZE, IMG_SIZE, 3),
               kernel_regularizer=l2(0.001)),
        BatchNormalization(),
        Conv2D(32, (3, 3), activation='relu', padding='same',
               kernel_regularizer=l2(0.001)),
        BatchNormalization(),
        MaxPooling2D(pool_size=(2, 2)),
        Dropout(0.25),

        # Second Convolutional Block
        Conv2D(64, (3, 3), activation='relu', padding='same',
               kernel_regularizer=l2(0.001)),
        BatchNormalization(),
        Conv2D(64, (3, 3), activation='relu', padding='same',
               kernel_regularizer=l2(0.001)),
        BatchNormalization(),
        MaxPooling2D(pool_size=(2, 2)),
        Dropout(0.25),

        # Third Convolutional Block
        Conv2D(128, (3, 3), activation='relu', padding='same',
               kernel_regularizer=l2(0.001)),
        BatchNormalization(),
        Conv2D(128, (3, 3), activation='relu', padding='same',
```

```
                kernel_regularizer=l2(0.001)),
        BatchNormalization(),
        MaxPooling2D(pool_size=(2, 2)),
        Dropout(0.25),

        # Flatten and Dense Layers
        Flatten(),
        Dense(512, activation='relu', kernel_regularizer=l2(0.001)),
        BatchNormalization(),
        Dropout(0.5),
        Dense(NUM_CLASSES, activation='softmax')
    ])

    model.compile(
        optimizer='adam',
        loss='categorical_crossentropy',
        metrics=['accuracy']
    )

    return model
```

[38]:
```
def build_transfer_learning_model():
    """Build a transfer learning model using MobileNetV2"""
    # Load MobileNetV2 as base model (without top layers)
    base_model = MobileNetV2(
        weights='imagenet',
        include_top=False,
        input_shape=(IMG_SIZE, IMG_SIZE, 3)
    )

    # Freeze base model layers
    base_model.trainable = False

    # Create new model
    inputs = Input(shape=(IMG_SIZE, IMG_SIZE, 3))
    x = base_model(inputs, training=False)
    x = GlobalAveragePooling2D()(x)
    x = Dense(128, activation='relu')(x)
    x = BatchNormalization()(x)
    x = Dropout(0.5)(x)
    outputs = Dense(NUM_CLASSES, activation='softmax')(x)

    model = Model(inputs, outputs)

    # Compile model
    model.compile(
        optimizer='adam',
```

```
        loss='categorical_crossentropy',
        metrics=['accuracy']
    )

    return model
```

[39]:
```
def train_model(model, X_train, y_train_cat, X_val, y_val_cat,␣
↪use_augmentation=True):
    """Train the model with callbacks and optional data augmentation"""
    # Create output directory for model checkpoints
    os.makedirs('models', exist_ok=True)

    # Define callbacks
    callbacks = [
        EarlyStopping(monitor='val_loss', patience=3,␣
↪restore_best_weights=True),
        ReduceLROnPlateau(factor=0.5, patience=5, min_lr=1e-6),
        ModelCheckpoint('models/best_model.keras', save_best_only=True)
    ]

    if use_augmentation:
        # Train with data augmentation
        train_generator = create_data_generators(X_train, y_train_cat)

        history = model.fit(
            train_generator,
            #steps_per_epoch=len(X_train) // BATCH_SIZE,
            epochs=EPOCHS,
            validation_data=(X_val, y_val_cat),
            callbacks=callbacks
        )
    else:
        # Train without data augmentation
        history = model.fit(
            train_generator,
            epochs=EPOCHS,
            validation_data=(X_val, y_val_cat),
            callbacks=callbacks
        )

    return model, history
```

[40]:
```
def evaluate_model(model, X_test, y_test_cat, class_names, history):
    """Evaluate model performance and generate visualizations"""
    # Evaluate model
    test_loss, test_acc = model.evaluate(X_test, y_test_cat)
    print(f"Test accuracy: {test_acc:.4f}")
```

```python
    print(f"Test loss: {test_loss:.4f}")

    # Get predictions
    y_pred = model.predict(X_test)
    y_pred_classes = np.argmax(y_pred, axis=1)
    y_true_classes = np.argmax(y_test_cat, axis=1)

    # Calculate classification report
    report = classification_report(
        y_true_classes,
        y_pred_classes,
        target_names=class_names,
        output_dict=True
    )

    # Print classification report
    print("\nClassification Report:")
    for class_name in class_names:
        precision = report[class_name]['precision']
        recall = report[class_name]['recall']
        f1 = report[class_name]['f1-score']
        support = report[class_name]['support']
        print(f"{class_name}: Precision={precision:.4f}, Recall={recall:.4f},␣
↪F1-Score={f1:.4f}, Support={support}")

    # Plot confusion matrix
    plt.figure(figsize=(12, 10))
    cm = confusion_matrix(y_true_classes, y_pred_classes)
    sns.heatmap(cm, annot=True, fmt='d', cmap='Blues', xticklabels=class_names,␣
↪yticklabels=class_names)
    plt.xlabel('Predicted')
    plt.ylabel('True')
    plt.title('Confusion Matrix')
    plt.tight_layout()
    plt.savefig('confusion_matrix.png')
    plt.show()

    # Plot training history
    plt.figure(figsize=(12, 5))

    plt.subplot(1, 2, 1)
    plt.plot(history.history['accuracy'])
    plt.plot(history.history['val_accuracy'])
    plt.title('Model Accuracy')
    plt.xlabel('Epoch')
    plt.ylabel('Accuracy')
    plt.legend(['Train', 'Validation'], loc='lower right')
```

```
    plt.subplot(1, 2, 2)
    plt.plot(history.history['loss'])
    plt.plot(history.history['val_loss'])
    plt.title('Model Loss')
    plt.xlabel('Epoch')
    plt.ylabel('Loss')
    plt.legend(['Train', 'Validation'], loc='upper right')

    plt.tight_layout()
    plt.savefig('training_history.png')
    plt.show()

    # Visualize misclassified examples
    misclassified_indices = np.where(y_pred_classes != y_true_classes)[0]

    if len(misclassified_indices) > 0:
        plt.figure(figsize=(15, 10))
        for i, idx in enumerate(misclassified_indices[:min(10,␣
↪len(misclassified_indices))]):
            plt.subplot(2, 5, i+1)
            plt.imshow(X_test[idx] * 255.0)
            plt.title(f"True: {class_names[y_true_classes[idx]]}\nPred:␣
↪{class_names[y_pred_classes[idx]]}")
            plt.axis('off')
        plt.tight_layout()
        plt.savefig('misclassified_examples.png')
        plt.show()

    return y_pred, y_pred_classes, y_true_classes
```

[41]:
```
def save_model_summary(model):
    """Save model summary to a text file"""
    with open('model_summary.txt', 'w') as f:
        model.summary(print_fn=lambda x: f.write(x + '\n'))

    print("Model summary saved to 'model_summary.txt'")
```

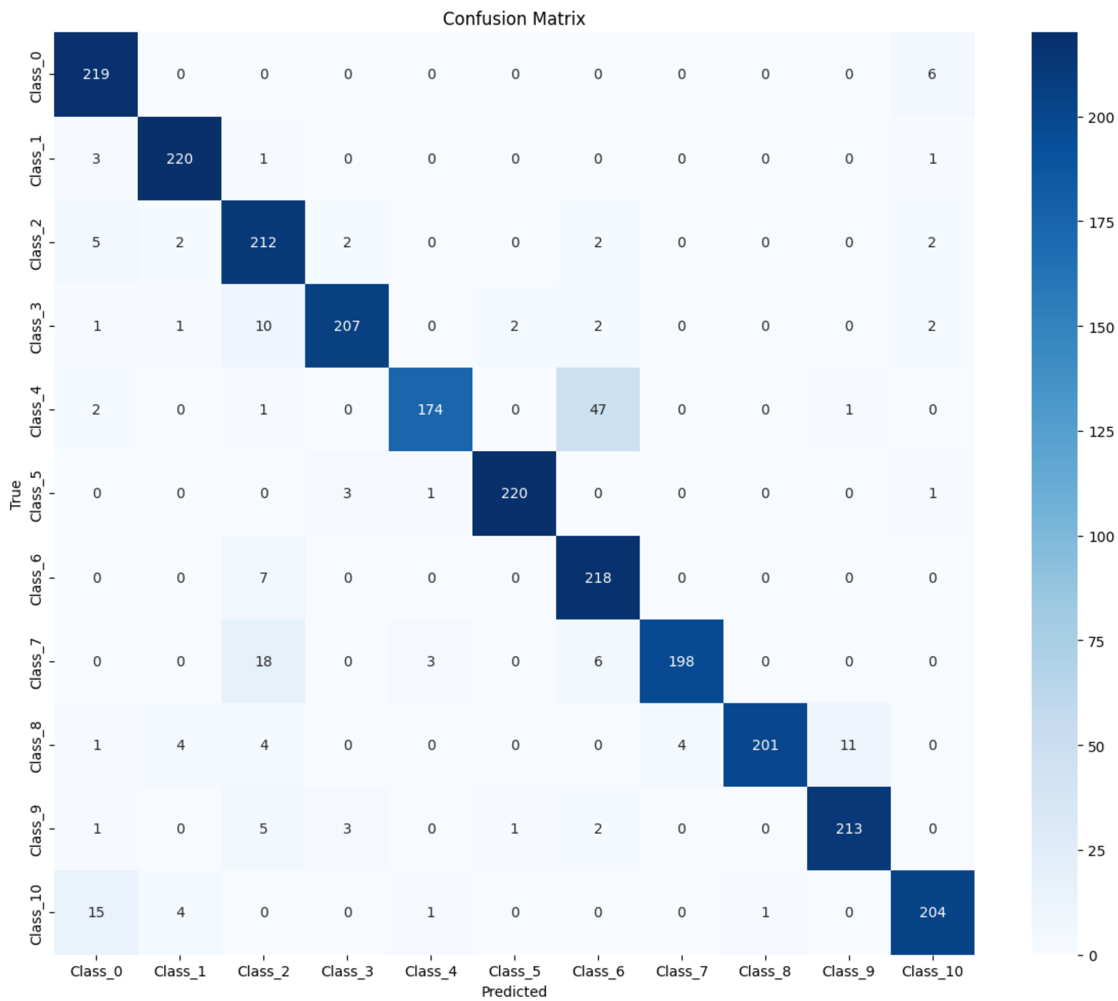
[42]:
```
# Main execution flow
if __name__ == "__main__":
    # Load preprocessed data
    X_train, X_val, X_test, y_train_cat, y_val_cat, y_test_cat =␣
↪load_preprocessed_data()

    # Load class names (you would need to save these during preprocessing)
    # For now, we'll just use generic names
    class_names = [f"Class_{i}" for i in range(NUM_CLASSES)]
```

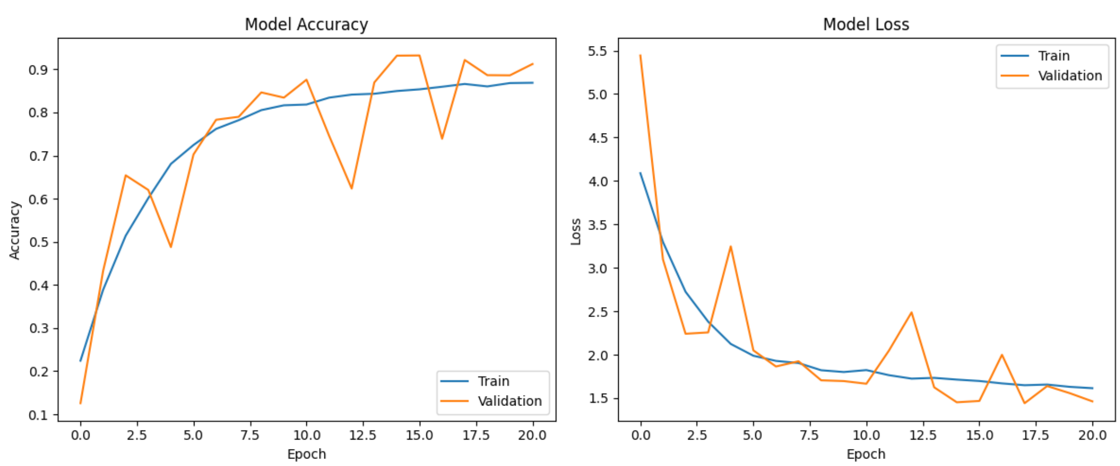
```python
    # Build model
    print("Building custom CNN model...")
    model = build_custom_cnn()

    # Save model architecture summary
    save_model_summary(model)

    # Train model
    print("Training model...")
    model, history = train_model(model, X_train, y_train_cat, X_val, y_val_cat)

    # Evaluate model
    print("Evaluating model...")
    y_pred, y_pred_classes, y_true_classes = evaluate_model(model, X_test,␣
↪y_test_cat, class_names, history)

    # Save the model
    model.save('models/hand_gesture_model.keras')
    print("Model saved to 'models/hand_gesture_model.keras'")
```

```
Building custom CNN model…


Model summary saved to 'model_summary.txt'
Training model…
Epoch 1/25
361/361              111s 295ms/step -
accuracy: 0.1776 - loss: 4.3606 - val_accuracy: 0.1257 - val_loss: 5.4439 -
learning_rate: 0.0010
Epoch 2/25
361/361              102s 282ms/step -
accuracy: 0.3562 - loss: 3.4430 - val_accuracy: 0.4323 - val_loss: 3.0964 -
learning_rate: 0.0010
Epoch 3/25
361/361              101s 279ms/step -
accuracy: 0.4815 - loss: 2.8553 - val_accuracy: 0.6541 - val_loss: 2.2407 -
learning_rate: 0.0010
Epoch 4/25
361/361              103s 286ms/step -
accuracy: 0.5798 - loss: 2.4574 - val_accuracy: 0.6202 - val_loss: 2.2562 -
learning_rate: 0.0010
Epoch 5/25
361/361              102s 282ms/step -
accuracy: 0.6728 - loss: 2.1448 - val_accuracy: 0.4877 - val_loss: 3.2468 -
learning_rate: 0.0010
Epoch 6/25
361/361              105s 291ms/step -
```

```
accuracy: 0.7219 - loss: 1.9922 - val_accuracy: 0.7026 - val_loss: 2.0496 -
learning_rate: 0.0010
Epoch 7/25
361/361            104s 289ms/step -
accuracy: 0.7526 - loss: 1.9449 - val_accuracy: 0.7830 - val_loss: 1.8640 -
learning_rate: 0.0010
Epoch 8/25
361/361            104s 287ms/step -
accuracy: 0.7800 - loss: 1.9035 - val_accuracy: 0.7899 - val_loss: 1.9240 -
learning_rate: 0.0010
Epoch 9/25
361/361            105s 290ms/step -
accuracy: 0.8085 - loss: 1.8041 - val_accuracy: 0.8465 - val_loss: 1.7050 -
learning_rate: 0.0010
Epoch 10/25
361/361            105s 292ms/step -
accuracy: 0.8123 - loss: 1.8115 - val_accuracy: 0.8343 - val_loss: 1.6963 -
learning_rate: 0.0010
Epoch 11/25
361/361            108s 299ms/step -
accuracy: 0.8176 - loss: 1.8261 - val_accuracy: 0.8760 - val_loss: 1.6654 -
learning_rate: 0.0010
Epoch 12/25
361/361            110s 305ms/step -
accuracy: 0.8281 - loss: 1.7846 - val_accuracy: 0.7459 - val_loss: 2.0476 -
learning_rate: 0.0010
Epoch 13/25
361/361            108s 300ms/step -
accuracy: 0.8382 - loss: 1.7267 - val_accuracy: 0.6234 - val_loss: 2.4871 -
learning_rate: 0.0010
Epoch 14/25
361/361            111s 307ms/step -
accuracy: 0.8378 - loss: 1.7380 - val_accuracy: 0.8695 - val_loss: 1.6243 -
learning_rate: 0.0010
Epoch 15/25
361/361            110s 303ms/step -
accuracy: 0.8471 - loss: 1.7084 - val_accuracy: 0.9317 - val_loss: 1.4519 -
learning_rate: 0.0010
Epoch 16/25
361/361            108s 299ms/step -
accuracy: 0.8521 - loss: 1.7008 - val_accuracy: 0.9321 - val_loss: 1.4674 -
learning_rate: 0.0010
Epoch 17/25
361/361            101s 280ms/step -
accuracy: 0.8615 - loss: 1.6692 - val_accuracy: 0.7390 - val_loss: 1.9986 -
learning_rate: 0.0010
Epoch 18/25
361/361            103s 286ms/step -
```

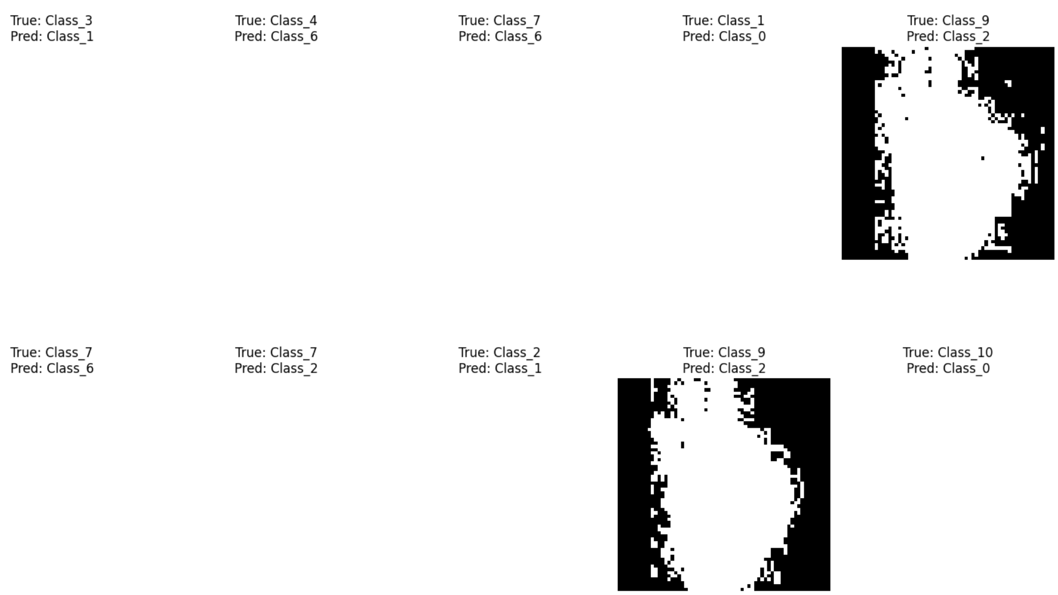
```
accuracy: 0.8665 - loss: 1.6411 - val_accuracy: 0.9216 - val_loss: 1.4413 -
learning_rate: 0.0010
Epoch 19/25
361/361            104s 289ms/step -
accuracy: 0.8679 - loss: 1.6105 - val_accuracy: 0.8865 - val_loss: 1.6390 -
learning_rate: 0.0010
Epoch 20/25
361/361            111s 307ms/step -
accuracy: 0.8627 - loss: 1.6633 - val_accuracy: 0.8861 - val_loss: 1.5567 -
learning_rate: 0.0010
Epoch 21/25
361/361            109s 301ms/step -
accuracy: 0.8667 - loss: 1.6202 - val_accuracy: 0.9123 - val_loss: 1.4627 -
learning_rate: 0.0010
Evaluating model…
78/78            4s 55ms/step -
accuracy: 0.9298 - loss: 1.4193
Test accuracy: 0.9236
Test loss: 1.4306
78/78            4s 49ms/step

Classification Report:
Class_0: Precision=0.8866, Recall=0.9733, F1-Score=0.9280, Support=225.0
Class_1: Precision=0.9524, Recall=0.9778, F1-Score=0.9649, Support=225.0
Class_2: Precision=0.8217, Recall=0.9422, F1-Score=0.8778, Support=225.0
Class_3: Precision=0.9628, Recall=0.9200, F1-Score=0.9409, Support=225.0
Class_4: Precision=0.9721, Recall=0.7733, F1-Score=0.8614, Support=225.0
Class_5: Precision=0.9865, Recall=0.9778, F1-Score=0.9821, Support=225.0
Class_6: Precision=0.7870, Recall=0.9689, F1-Score=0.8685, Support=225.0
Class_7: Precision=0.9802, Recall=0.8800, F1-Score=0.9274, Support=225.0
Class_8: Precision=0.9950, Recall=0.8933, F1-Score=0.9415, Support=225.0
Class_9: Precision=0.9467, Recall=0.9467, F1-Score=0.9467, Support=225.0
Class_10: Precision=0.9444, Recall=0.9067, F1-Score=0.9252, Support=225.0
```






```
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
```

```
RGB data ([0..1] for floats or [0..255] for integers). Got range [11.0..182.0].
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
RGB data ([0..1] for floats or [0..255] for integers). Got range [20.0..249.0].
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
RGB data ([0..1] for floats or [0..255] for integers). Got range [13.0..248.0].
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
RGB data ([0..1] for floats or [0..255] for integers). Got range [14.0..236.0].
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
RGB data ([0..1] for floats or [0..255] for integers). Got range [0.0..199.0].
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
RGB data ([0..1] for floats or [0..255] for integers). Got range [7.0..239.0].
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
RGB data ([0..1] for floats or [0..255] for integers). Got range [36.0..196.0].
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
RGB data ([0..1] for floats or [0..255] for integers). Got range [21.0..243.0].
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
RGB data ([0..1] for floats or [0..255] for integers). Got range [0.0..202.0].
WARNING:matplotlib.image:Clipping input data to the valid range for imshow with
RGB data ([0..1] for floats or [0..255] for integers). Got range [2.0..252.0].
```




```
Model saved to 'models/hand_gesture_model.keras'
```

3 Milestone 3: Real-Time Gesture Recognition and Deployment

[21]:
```python
import cv2
import numpy as np
import tensorflow as tf
```

```python
from tensorflow.keras.models import load_model
import time
import os
```

[22]:
```python
# Constants
IMG_SIZE = 64
NUM_CLASSES = 11
```

[23]:
```python
class HandGestureRecognizer:
    def __init__(self, model_path, class_names=None):
        """Initialize the hand gesture recognizer with a trained model"""
        # Load model
        self.model = load_model(model_path)
        print(f"Model loaded from {model_path}")

        # Set class names
        if class_names is None:
            # Default class names for numbers 0-9 and unknown
            self.class_names = ['0', '1', '2', '3', '4', '5', '6', '7', '8',␣
 ↪'9', 'unknown']
        else:
            self.class_names = class_names

        # Preprocessing parameters
        self.img_size = IMG_SIZE

    def preprocess_frame(self, frame):
        """Preprocess a video frame for prediction"""
        # Resize frame to expected input size
        resized = cv2.resize(frame, (self.img_size, self.img_size))

        # Convert to RGB if it's BGR
        if len(resized.shape) == 3 and resized.shape[2] == 3:
            resized = cv2.cvtColor(resized, cv2.COLOR_BGR2RGB)

        # Normalize pixel values
        normalized = resized.astype('float32') / 255.0

        # Expand dimensions to match model input shape
        expanded = np.expand_dims(normalized, axis=0)

        return expanded

    def predict(self, frame):
        """Make a prediction on a single frame"""
        # Preprocess the frame
        processed_frame = self.preprocess_frame(frame)
```

```
        # Make prediction
        prediction = self.model.predict(processed_frame, verbose=0)[0]

        # Get class index and confidence
        class_idx = np.argmax(prediction)
        confidence = prediction[class_idx]

        # Get class name
        class_name = self.class_names[class_idx]

        return class_name, confidence, prediction
```

[24]:
```
def run_real_time_recognition():
    """Run real-time hand gesture recognition using webcam"""
    # Check if model exists
    model_path = 'models/hand_gesture_model.keras'
    if not os.path.exists(model_path):
        print(f"Error: Model not found at {model_path}")
        print("Please train the model first or provide the correct path.")
        return

    # Initialize recognizer
    recognizer = HandGestureRecognizer(model_path)

    # Initialize webcam
    cap = cv2.VideoCapture(0)

    # Check if webcam opened successfully
    if not cap.isOpened():
        print("Error: Could not open webcam.")
        return

    # Set frame size
    cap.set(cv2.CAP_PROP_FRAME_WIDTH, 640)
    cap.set(cv2.CAP_PROP_FRAME_HEIGHT, 480)

    # Create window
    cv2.namedWindow('Hand Gesture Recognition', cv2.WINDOW_NORMAL)

    # ROI coordinates (default to center of frame)
    roi_size = 300
    roi_x, roi_y = None, None

    # Prediction variables
    last_prediction = None
    prediction_confidence = 0
```

```
    prediction_time = time.time()
    confidence_threshold = 0.7
    prediction_cooldown = 1.0  # seconds

    print("Press 'q' to quit, 'r' to reset ROI")

    while True:
        # Read frame
        ret, frame = cap.read()

        if not ret:
            print("Error: Failed to capture frame.")
            break

        # Flip frame horizontally for a more natural interaction
        frame = cv2.flip(frame, 1)

        # Set ROI position if not set
        if roi_x is None or roi_y is None:
            h, w = frame.shape[:2]
            roi_x = (w - roi_size) // 2
            roi_y = (h - roi_size) // 2

        # Draw ROI rectangle
        cv2.rectangle(frame, (roi_x, roi_y), (roi_x + roi_size, roi_y +␣
↪roi_size), (0, 255, 0), 2)

        # Extract ROI
        roi = frame[roi_y:roi_y + roi_size, roi_x:roi_x + roi_size]

        # Make prediction every 100ms
        current_time = time.time()
        if current_time - prediction_time > 0.1:
            try:
                # Get prediction
                class_name, confidence, _ = recognizer.predict(roi)

                # Update prediction if confidence is high enough
                if confidence > confidence_threshold and (last_prediction !=␣
↪class_name or current_time - prediction_time > prediction_cooldown):
                    last_prediction = class_name
                    prediction_confidence = confidence
                    prediction_time = current_time
            except Exception as e:
                print(f"Prediction error: {e}")

        # Display prediction
```

```
        if last_prediction is not None:
            # Display prediction text
            text = f"{last_prediction} ({prediction_confidence:.2f})"
            cv2.putText(frame, text, (roi_x, roi_y - 10), cv2.
↪FONT_HERSHEY_SIMPLEX, 1, (0, 255, 0), 2)

        # Show instruction text
        cv2.putText(frame, "Place hand gesture in green box", (10, 30), cv2.
↪FONT_HERSHEY_SIMPLEX, 0.7, (255, 255, 255), 2)

        # Display the frame
        cv2.imshow('Hand Gesture Recognition', frame)

        # Process key presses
        key = cv2.waitKey(1) & 0xFF

        if key == ord('q'):
            # Quit
            break
        elif key == ord('r'):
            # Reset ROI
            roi_x, roi_y = None, None

    # Release resources
    cap.release()
    cv2.destroyAllWindows()
```

[29]:

```
import mediapipe as mp

class MediapipeHandGestureRecognizer(HandGestureRecognizer):
            def __init__(self, model_path, class_names=None):
                """Initialize with mediapipe hand detection"""
                super().__init__(model_path, class_names)

                # Initialize mediapipe
                self.mp_hands = mp.solutions.hands
                self.mp_drawing = mp.solutions.drawing_utils
                self.hands = self.mp_hands.Hands(
                    static_image_mode=False,
                    max_num_hands=1,
                    min_detection_confidence=0.5,
                    min_tracking_confidence=0.5
                )

            def detect_and_preprocess_hand(self, frame):
                """Detect hand in the frame and crop it for prediction"""
                # Convert to RGB for mediapipe
```

```
            rgb_frame = cv2.cvtColor(frame, cv2.COLOR_BGR2RGB)

            # Process frame with mediapipe
            results = self.hands.process(rgb_frame)

            # Initialize variables
            hand_detected = False
            processed_hand = None
            hand_landmarks = None

            # Check if hand is detected
            if results.multi_hand_landmarks:
                # Get first hand landmarks
                hand_landmarks = results.multi_hand_landmarks[0]

                # Get bounding box
                h, w = frame.shape[:2]
                x_min, y_min = w, h
                x_max, y_max = 0, 0

                for landmark in hand_landmarks.landmark:
                    x, y = int(landmark.x * w), int(landmark.y * h)
                    x_min = min(x_min, x)
                    y_min = min(y_min, y)
                    x_max = max(x_max, x)
                    y_max = max(y_max, y)

                # Add padding
                padding = 20
                x_min = max(0, x_min - padding)
                y_min = max(0, y_min - padding)
                x_max = min(w, x_max + padding)
                y_max = min(h, y_max + padding)

                # Make square bounding box
                box_size = max(x_max - x_min, y_max - y_min)
                x_center = (x_min + x_max) // 2
                y_center = (y_min + y_max) // 2

                x_min = max(0, x_center - box_size // 2)
                y_min = max(0, y_center - box_size // 2)
                x_max = min(w, x_center + box_size // 2)
                y_max = min(h, y_center + box_size // 2)

                # Crop hand region
                if x_max > x_min and y_max > y_min:
                    hand_crop = frame[y_min:y_max, x_min:x_max]
```

```
                # Preprocess for prediction
                processed_hand = self.preprocess_frame(hand_crop)
                hand_detected = True

        return hand_detected, processed_hand, hand_landmarks, results

    def predict_with_detection(self, frame):
        """Detect hand and predict gesture"""
        hand_detected, processed_hand, landmarks, results = self.detect_and_preprocess_hand(frame)

        if hand_detected:
            # Make prediction
            prediction = self.model.predict(processed_hand, verbose=0)[0]

            # Get class index and confidence
            class_idx = np.argmax(prediction)
            confidence = prediction[class_idx]

            # Get class name
            class_name = self.class_names[class_idx]

            return True, class_name, confidence, landmarks, results

        return False, None, 0, None, results

    def draw_result(self, frame, detected, class_name, confidence, landmarks, results):
        """Draw detection and prediction results on frame"""
        # Draw hand landmarks if detected
        if results.multi_hand_landmarks:
            for hand_landmarks in results.multi_hand_landmarks:
                self.mp_drawing.draw_landmarks(
                    frame,
                    hand_landmarks,
                    self.mp_hands.HAND_CONNECTIONS
                )
    # Display prediction if hand detected
        if detected:
            # Display prediction text
            text = f"{class_name} ({confidence:.2f})"
            cv2.putText(frame, text, (10, 50), cv2.FONT_HERSHEY_SIMPLEX, 1, (0, 255, 0), 2)
        else:
            # Display "No hand detected" message
```

```
                    cv2.putText(frame, "No hand detected", (10, 50), cv2.
↪FONT_HERSHEY_SIMPLEX, 1, (0, 0, 255), 2)

                return frame
```

[30]:

```
def create_hand_detection_version():
    """Advanced version using hand detection"""
    try:

        def run_mediapipe_recognition():
            """Run real-time hand gesture recognition using mediapipe hand␣
↪detection"""
            # Check if model exists
            model_path = 'models/hand_gesture_model.keras'
            if not os.path.exists(model_path):
                print(f"Error: Model not found at {model_path}")
                print("Please train the model first or provide the correct path.
↪")
                return

            # Initialize recognizer
            recognizer = MediapipeHandGestureRecognizer(model_path)

            # Initialize webcam
            cap = cv2.VideoCapture(0)

            # Check if webcam opened successfully
            if not cap.isOpened():
                print("Error: Could not open webcam.")
                return

            # Set frame size
            cap.set(cv2.CAP_PROP_FRAME_WIDTH, 640)
            cap.set(cv2.CAP_PROP_FRAME_HEIGHT, 480)

            # Create window
            cv2.namedWindow('Hand Gesture Recognition', cv2.WINDOW_NORMAL)

            # Prediction variables
            last_prediction = None
            prediction_confidence = 0
            prediction_time = time.time()
            confidence_threshold = 0.7
            prediction_cooldown = 0.5  # seconds

            print("Press 'q' to quit")
```

```
        while True:
            # Read frame
            ret, frame = cap.read()

            if not ret:
                print("Error: Failed to capture frame.")
                break

            # Flip frame horizontally for a more natural interaction
            frame = cv2.flip(frame, 1)

            # Make prediction
            current_time = time.time()
            try:
                # Get prediction with hand detection
                detected, class_name, confidence, landmarks, results =␣
↪recognizer.predict_with_detection(frame)

                # Update prediction if hand detected and confidence is high
                if detected and confidence > confidence_threshold and␣
↪(last_prediction != class_name or current_time - prediction_time >␣
↪prediction_cooldown):
                    last_prediction = class_name
                    prediction_confidence = confidence
                    prediction_time = current_time

                # Draw result on frame
                frame = recognizer.draw_result(frame, detected,␣
↪last_prediction, prediction_confidence, landmarks, results)
            except Exception as e:
                print(f"Prediction error: {e}")

            # Display instruction text
            cv2.putText(frame, "Show hand gesture to camera", (10, 30), cv2.
↪FONT_HERSHEY_SIMPLEX, 0.7, (255, 255, 255), 2)

            # Display the frame
            cv2.imshow('Hand Gesture Recognition', frame)

            # Process key presses
            key = cv2.waitKey(1) & 0xFF

            if key == ord('q'):
                # Quit
                break

        # Release resources
```

```
            cap.release()
            cv2.destroyAllWindows()
            recognizer.hands.close()

        print("MediaPipe is available! You can use advanced hand detection.")
        return run_mediapipe_recognition
    except ImportError:
        print("MediaPipe not found. Using basic version without hand detection.
↪")
        return run_real_time_recognition
```

[31]:
```
def build_gui_app():
    """Create a simple GUI for the hand gesture recognition system"""
    try:
        import tkinter as tk
        from tkinter import ttk
        from PIL import Image, ImageTk

        class HandGestureRecognitionApp:
            def __init__(self, root):
                self.root = root
                self.root.title("Hand Gesture Recognition System")
                self.root.geometry("800x600")

                # Initialize variables
                self.is_running = False
                self.cap = None
                self.recognizer = None

                # Create main frames
                self.create_widgets()

                # Protocol to handle window close
                self.root.protocol("WM_DELETE_WINDOW", self.on_close)

            def create_widgets(self):
                # Create main frame
                main_frame = ttk.Frame(self.root, padding=10)
                main_frame.pack(fill=tk.BOTH, expand=True)

                # Title
                title_label = ttk.Label(
                    main_frame,
                    text="Hand Gesture Recognition System",
                    font=("Arial", 18)
                )
                title_label.pack(pady=10)
```

```
            # Video frame
            self.video_frame = ttk.Frame(main_frame, borderwidth=2,␣
↪relief=tk.GROOVE)
            self.video_frame.pack(fill=tk.BOTH, expand=True, pady=10)

            # Create canvas for video display
            self.canvas = tk.Canvas(self.video_frame, bg="black")
            self.canvas.pack(fill=tk.BOTH, expand=True)

            # Control frame
            control_frame = ttk.Frame(main_frame)
            control_frame.pack(fill=tk.X, pady=10)

            # Start/Stop button
            self.start_stop_btn = ttk.Button(
                control_frame,
                text="Start",
                command=self.toggle_recognition
            )
            self.start_stop_btn.pack(side=tk.LEFT, padx=5)

            # Mode selection
            ttk.Label(control_frame, text="Mode:").pack(side=tk.LEFT,␣
↪padx=5)
            self.mode_var = tk.StringVar(value="Basic")
            mode_combobox = ttk.Combobox(
                control_frame,
                textvariable=self.mode_var,
                values=["Basic", "MediaPipe (Advanced)"],
                state="readonly",
                width=20
            )
            mode_combobox.pack(side=tk.LEFT, padx=5)

            # Results frame
            results_frame = ttk.LabelFrame(main_frame, text="Recognition␣
↪Results", padding=10)
            results_frame.pack(fill=tk.X, pady=10)

            # Result label
            self.result_var = tk.StringVar(value="No gesture detected")
            result_label = ttk.Label(
                results_frame,
                textvariable=self.result_var,
                font=("Arial", 14)
            )
```

```
            result_label.pack(fill=tk.X)

            # Confidence bar
            ttk.Label(results_frame, text="Confidence:").pack(anchor=tk.W)
            self.confidence_bar = ttk.Progressbar(results_frame, orient=tk.HORIZONTAL, length=100, mode='determinate')
            self.confidence_bar.pack(fill=tk.X, pady=5)

            # Status bar
            self.status_var = tk.StringVar(value="Ready")
            status_bar = ttk.Label(self.root, textvariable=self.status_var, relief=tk.SUNKEN, anchor=tk.W)
            status_bar.pack(side=tk.BOTTOM, fill=tk.X)

        def toggle_recognition(self):
            if self.is_running:
                self.stop_recognition()
            else:
                self.start_recognition()

        def start_recognition(self):
            # Check if model exists
            model_path = 'models/hand_gesture_model.keras'
            if not os.path.exists(model_path):
                self.status_var.set("Error: Model not found! Please train the model first.")
                return

            # Initialize webcam
            self.cap = cv2.VideoCapture(0)

            # Check if webcam opened successfully
            if not self.cap.isOpened():
                self.status_var.set("Error: Could not open webcam.")
                return

            # Set frame size
            self.cap.set(cv2.CAP_PROP_FRAME_WIDTH, 640)
            self.cap.set(cv2.CAP_PROP_FRAME_HEIGHT, 480)

            # Initialize recognizer based on mode
            mode = self.mode_var.get()
            try:
                if mode == "MediaPipe (Advanced)":
                    import mediapipe as mp
                    self.recognizer = MediapipeHandGestureRecognizer(model_path)
```

```
                self.use_mediapipe = True
            else:
                self.recognizer = HandGestureRecognizer(model_path)
                self.use_mediapipe = False

            self.status_var.set(f"Started recognition in {mode} mode")
            self.is_running = True
            self.start_stop_btn.config(text="Stop")

            # Start video processing
            self.process_video()
        except Exception as e:
            self.status_var.set(f"Error: {str(e)}")

    def stop_recognition(self):
        # Stop recognition
        self.is_running = False
        self.start_stop_btn.config(text="Start")
        self.status_var.set("Recognition stopped")

        # Release resources
        if self.cap is not None:
            self.cap.release()
            self.cap = None

        # Close mediapipe resources if used
        if self.recognizer is not None and self.use_mediapipe:
            self.recognizer.hands.close()

        # Clear display
        self.canvas.delete("all")
        self.result_var.set("No gesture detected")
        self.confidence_bar['value'] = 0

    def process_video(self):
        if not self.is_running:
            return

        # Read frame
        ret, frame = self.cap.read()

        if ret:
            # Flip frame horizontally for more natural interaction
            frame = cv2.flip(frame, 1)

            # Process with appropriate method
            if self.use_mediapipe:
```

```
                        detected, class_name, confidence, landmarks, results =
self.recognizer.predict_with_detection(frame)
                        frame = self.recognizer.draw_result(frame, detected,
class_name, confidence, landmarks, results)

                        if detected and confidence > 0.7:
                            self.result_var.set(f"Detected: {class_name}")
                            self.confidence_bar['value'] = confidence * 100
                    else:
                        # Use basic method with ROI
                        h, w = frame.shape[:2]
                        roi_size = 300
                        roi_x = (w - roi_size) // 2
                        roi_y = (h - roi_size) // 2

                        # Draw ROI rectangle
                        cv2.rectangle(frame, (roi_x, roi_y), (roi_x + roi_size,
roi_y + roi_size), (0, 255, 0), 2)

                        # Extract ROI
                        roi = frame[roi_y:roi_y + roi_size, roi_x:roi_x +
roi_size]

                        # Get prediction
                        class_name, confidence, _ = self.recognizer.predict(roi)

                        # Display prediction if confidence is high enough
                        if confidence > 0.7:
                            text = f"{class_name} ({confidence:.2f})"
                            cv2.putText(frame, text, (roi_x, roi_y - 10), cv2.
FONT_HERSHEY_SIMPLEX, 1, (0, 255, 0), 2)

                            self.result_var.set(f"Detected: {class_name}")
                            self.confidence_bar['value'] = confidence * 100

                    # Convert frame to display on canvas
                    frame_rgb = cv2.cvtColor(frame, cv2.COLOR_BGR2RGB)
                    img = Image.fromarray(frame_rgb)
                    self.photo = ImageTk.PhotoImage(image=img)

                    # Update canvas
                    self.canvas.config(width=frame.shape[1], height=frame.
shape[0])
                    self.canvas.create_image(0, 0, image=self.photo, anchor=tk.
NW)
```

```
                # Schedule next frame processing
                self.root.after(33, self.process_video)  # ~30 FPS

            def on_close(self):
                # Stop recognition if running
                if self.is_running:
                    self.stop_recognition()

                # Close window
                self.root.destroy()

        def launch_gui():
            root = tk.Tk()
            app = HandGestureRecognitionApp(root)
            root.mainloop()

        print("Tkinter is available! You can use the GUI application.")
        return launch_gui
    except ImportError:
        print("Tkinter or PIL not found. Using command-line interface.")
        return create_hand_detection_version()
```

[33]:
```
if __name__ == "__main__":
    print("Hand Gesture Recognition System")
    print("===============================")
    print("1. Basic Recognition (with ROI)")
    print("2. Advanced Recognition (with hand detection, if available)")
    print("3. GUI Application (if available)")
    print("===============================")

    choice = input("Select mode (1-3): ")

    if choice == '1':
        run_real_time_recognition()
    elif choice == '2':
        detector_func = create_hand_detection_version()
        detector_func()
    elif choice == '3':
        gui_func = build_gui_app()
        gui_func()
    else:
        print("Invalid choice. Running basic recognition.")
        run_real_time_recognition()
```

```
Hand Gesture Recognition System
===============================
1. Basic Recognition (with ROI)
2. Advanced Recognition (with hand detection, if available)
```

```
3. GUI Application (if available)
===============================
Tkinter is available! You can use the GUI application.
Model loaded from models/hand_gesture_model.keras
```

4 Milestone 4: MLOps Implementation and Model Monitoring

[ ]:

```
```