

```
In [1]: # Step 1: Mount Google Drive
# This step connects Google Drive to access the ASL dataset and save the trained model.

from google.colab import drive
drive.mount('/content/drive')
```

Mounted at /content/drive

```
In [2]: # Step 2: Import required libraries
# This step imports all libraries needed for data cleaning, splitting, training, evaluation, and application.

import os
import shutil
import numpy as np
import matplotlib.pyplot as plt
import tensorflow as tf

from sklearn.model_selection import train_test_split
from sklearn.metrics import confusion_matrix, classification_report, accuracy_score

from tensorflow.keras.models import Model
from tensorflow.keras.layers import Dense, Dropout, GlobalAveragePooling2D
from tensorflow.keras.preprocessing.image import ImageDataGenerator
from tensorflow.keras.callbacks import EarlyStopping, ModelCheckpoint, ReduceLROnPlateau
from tensorflow.keras.optimizers import Adam

from tensorflow.keras.applications import MobileNetV2
from tensorflow.keras.applications.mobilenet_v2 import preprocess_input

print("TensorFlow Version:", tf.__version__)
```

TensorFlow Version: 2.20.0

```
In [4]: # Step 3: Define dataset path
# This step finds the correct ASL dataset folder inside Google Drive.

possible_paths = [
    "/content/drive/MyDrive/ASL_Project/ASL_Dataset/asl_dataset",
]

ORIGINAL_DATASET_DIR = None

for path in possible_paths:
    if os.path.isdir(path):
        ORIGINAL_DATASET_DIR = path
        break

if ORIGINAL_DATASET_DIR is None:
    print("Dataset folder not found.")
    print("Folders inside MyDrive:")
    print(os.listdir("/content/drive/MyDrive"))
    raise FileNotFoundError("Dataset path is not correct.")

print("Dataset Path:", ORIGINAL_DATASET_DIR)
print("Folders:", os.listdir(ORIGINAL_DATASET_DIR))

Dataset Path: /content/drive/MyDrive/ASL_Project/ASL_Dataset/asl_dataset
Folders: ['x', 'z', 'y', 't', 'v', 'q', 'm', 's', 'p', 'w', 'o', 'l', 'n', 'u', 'r', 'k', 'h', 'i', 'e', 'f', 'b', '7', 'd', 'g', 'c', 'a', '9', '8', '6', 'j', '5', '4', '0', '1', '2', '3']
```

```
In [5]: # Step 4: Define valid classes
# This step defines the 36 target classes: digits from 0 to 9 and letters from a to z.

VALID_CLASSES = [
    '0', '1', '2', '3', '4', '5', '6', '7', '8', '9',
    'a', 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i', 'j',
    'k', 'l', 'm', 'n', 'o', 'p', 'q', 'r', 's', 't',
    'u', 'v', 'w', 'x', 'y', 'z'
]

NUM_CLASSES = len(VALID_CLASSES)

print("Number of Classes:", NUM_CLASSES)
print("Classes:", VALID_CLASSES)

Number of Classes: 36
Classes: ['0', '1', '2', '3', '4', '5', '6', '7', '8', '9', 'a', 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i', 'j', 'k', 'l', 'm', 'n', 'o', 'p', 'q', 'r', 's', 't', 'u', 'v', 'w', 'x', 'y', 'z']
```

```
In [6]: # Step 5: Clean the dataset
# This step creates a clean dataset that contains only the required classes and image files.

CLEAN_DATASET_DIR = "/content/drive/MyDrive/ASL_Clean_Dataset_MobileNet"

if os.path.exists(CLEAN_DATASET_DIR):
    shutil.rmtree(CLEAN_DATASET_DIR)

os.makedirs(CLEAN_DATASET_DIR, exist_ok=True)

def find_class_folder(dataset_dir, class_name):
    possible_names = [class_name, class_name.upper(), class_name.lower()]

    for name in possible_names:
        path = os.path.join(dataset_dir, name)
        if os.path.isdir(path):
            return path

    return None

total_clean_images = 0

for class_name in VALID_CLASSES:
    source_class_dir = find_class_folder(ORIGINAL_DATASET_DIR, class_name)
    target_class_dir = os.path.join(CLEAN_DATASET_DIR, class_name)
    os.makedirs(target_class_dir, exist_ok=True)

    if source_class_dir is None:
        print("Missing class folder:", class_name)
        continue

    count = 0

    for root, dirs, files in os.walk(source_class_dir):
        for file in files:
            if file.lower().endswith((".jpg", ".jpeg", ".png", ".bmp", ".webp")):
                src_file = os.path.join(root, file)
                dst_file = os.path.join(target_class_dir, file)
                shutil.copy2(src_file, dst_file)
                count += 1

    total_clean_images += count
    print(f"{class_name}: {count} images copied")

print("\nClean Dataset Created Successfully")
print("Total Clean Images:", total_clean_images)
print("Clean Dataset Path:", CLEAN_DATASET_DIR)
```

```
0: 70 images copied
1: 70 images copied
2: 70 images copied
3: 70 images copied
4: 70 images copied
5: 70 images copied
6: 70 images copied
7: 70 images copied
8: 70 images copied
9: 70 images copied
a: 71 images copied
b: 70 images copied
c: 70 images copied
d: 70 images copied
e: 70 images copied
f: 70 images copied
g: 70 images copied
h: 70 images copied
i: 70 images copied
j: 70 images copied
k: 70 images copied
l: 70 images copied
m: 70 images copied
n: 70 images copied
o: 70 images copied
p: 70 images copied
q: 70 images copied
r: 70 images copied
s: 70 images copied
t: 65 images copied
u: 70 images copied
v: 70 images copied
w: 70 images copied
x: 70 images copied
y: 70 images copied
z: 70 images copied

Clean Dataset Created Successfully
Total Clean Images: 2516
Clean Dataset Path: /content/drive/MyDrive/ASL_Clean_Dataset_MobileNet
```

```
In [7]: # Step 6: Create split folders
# This step creates train, validation, and test folders for the dataset split.

SPLIT_DATASET_DIR = "/content/drive/MyDrive/ASL_Split_Dataset_MobileNet"

train_dir = os.path.join(SPLIT_DATASET_DIR, "train")
validation_dir = os.path.join(SPLIT_DATASET_DIR, "validation")
test_dir = os.path.join(SPLIT_DATASET_DIR, "test")

if os.path.exists(SPLIT_DATASET_DIR):
    shutil.rmtree(SPLIT_DATASET_DIR)

os.makedirs(train_dir, exist_ok=True)
os.makedirs(validation_dir, exist_ok=True)
os.makedirs(test_dir, exist_ok=True)

print("Split folders created successfully.")

Split folders created successfully.
```

```
In [8]: # Step 7: Split the dataset
# This step splits the clean dataset into 70% training, 10% validation, and 20% testing.

train_ratio = 0.70
validation_ratio = 0.10
test_ratio = 0.20

def split_and_copy_files(class_name):
    class_dir = os.path.join(CLEAN_DATASET_DIR, class_name)

    all_images = [
        os.path.join(class_dir, file)
        for file in os.listdir(class_dir)
        if file.lower().endswith((".jpg", ".jpeg", ".png", ".bmp", ".webp"))
    ]

    if len(all_images) < 3:
        print(f"Not enough images in class: {class_name}")
        return 0, 0, 0

    train_images, temp_images = train_test_split(
        all_images,
        test_size=0.30,
        random_state=42,
        shuffle=True
    )

    validation_images, test_images = train_test_split(
        temp_images,
        test_size=2/3,
        random_state=42,
        shuffle=True
    )

    split_data = {
        "train": train_images,
        "validation": validation_images,
        "test": test_images
    }

    for split_name, images in split_data.items():
        target_dir = os.path.join(SPLIT_DATASET_DIR, split_name, class_name)
        os.makedirs(target_dir, exist_ok=True)

        for image_path in images:
            shutil.copy2(image_path, target_dir)

    return len(train_images), len(validation_images), len(test_images)

total_train = 0
total_validation = 0
total_test = 0

for class_name in VALID_CLASSES:
    train_count, validation_count, test_count = split_and_copy_files(class_name)

    total_train += train_count
    total_validation += validation_count
    total_test += test_count

    print(f"{class_name}: Train={train_count}, Validation={validation_count}, Test={test_count}")

print("\nFinal Split:")
print("Training Images:", total_train)
print("Validation Images:", total_validation)
print("Testing Images:", total_test)
```

```
0: Train=49, Validation=7, Test=14
1: Train=49, Validation=7, Test=14
2: Train=49, Validation=7, Test=14
3: Train=49, Validation=7, Test=14
4: Train=49, Validation=7, Test=14
5: Train=49, Validation=7, Test=14
6: Train=49, Validation=7, Test=14
7: Train=49, Validation=7, Test=14
8: Train=49, Validation=7, Test=14
9: Train=49, Validation=7, Test=14
a: Train=49, Validation=7, Test=15
b: Train=49, Validation=7, Test=14
c: Train=49, Validation=7, Test=14
d: Train=49, Validation=7, Test=14
e: Train=49, Validation=7, Test=14
f: Train=49, Validation=7, Test=14
g: Train=49, Validation=7, Test=14
h: Train=49, Validation=7, Test=14
i: Train=49, Validation=7, Test=14
j: Train=49, Validation=7, Test=14
k: Train=49, Validation=7, Test=14
l: Train=49, Validation=7, Test=14
m: Train=49, Validation=7, Test=14
n: Train=49, Validation=7, Test=14
o: Train=49, Validation=7, Test=14
p: Train=49, Validation=7, Test=14
q: Train=49, Validation=7, Test=14
r: Train=49, Validation=7, Test=14
s: Train=49, Validation=7, Test=14
t: Train=45, Validation=6, Test=14
u: Train=49, Validation=7, Test=14
v: Train=49, Validation=7, Test=14
w: Train=49, Validation=7, Test=14
x: Train=49, Validation=7, Test=14
y: Train=49, Validation=7, Test=14
z: Train=49, Validation=7, Test=14
```

```
Final Split:
Training Images: 1760
Validation Images: 251
Testing Images: 505
```

```
In [10]: # Step 8: Define training parameters
# This step defines image size, batch size, epochs, and learning rate.
```

```
IMG_SIZE = 224
BATCH_SIZE = 16
EPOCHS = 30
LEARNING_RATE = 0.0001

print("Image Size:", IMG_SIZE)
print("Batch Size:", BATCH_SIZE)
print("Epochs:", EPOCHS)
print("Learning Rate:", LEARNING_RATE)
```

```
Image Size: 224
Batch Size: 16
Epochs: 30
Learning Rate: 0.0001
```

```
In [11]: # Step 9: Prepare data augmentation
# This step applies augmentation only to the training data to improve model generalization.
```

```
train_datagen = ImageDataGenerator(
    preprocessing_function=preprocess_input,
    rotation_range=20,
    width_shift_range=0.15,
    height_shift_range=0.15,
    zoom_range=0.15,
    shear_range=0.10,
    brightness_range=[0.7, 1.3],
    horizontal_flip=False,
    fill_mode="nearest"
)

val_test_datagen = ImageDataGenerator(
    preprocessing_function=preprocess_input
)
```

```
In [12]: # Step 10: Create training generator
# This step loads the training images from the train folder.
```

```
train_generator = train_datagen.flow_from_directory(
    train_dir,
    classes=VALID_CLASSES,
    target_size=(IMG_SIZE, IMG_SIZE),
    batch_size=BATCH_SIZE,
    class_mode="categorical",
    shuffle=True,
    seed=42
)

print("Training Images:", train_generator.n)
print("Training Classes:", train_generator.num_classes)
```

```
Found 1760 images belonging to 36 classes.
Training Images: 1760
Training Classes: 36
```

In [13]:

```
# Step 11: Create validation generator
# This step loads the validation images from the validation folder.

validation_generator = val_test_datagen.flow_from_directory(
    validation_dir,
    classes=VALID_CLASSES,
    target_size=(IMG_SIZE, IMG_SIZE),
    batch_size=BATCH_SIZE,
    class_mode="categorical",
    shuffle=False
)

print("Validation Images:", validation_generator.n)
print("Validation Classes:", validation_generator.num_classes)
```

Found 251 images belonging to 36 classes.
Validation Images: 251
Validation Classes: 36

In [14]:

```
# Step 12: Create test generator
# This step loads the test images from the test folder without shuffling.

test_generator = val_test_datagen.flow_from_directory(
    test_dir,
    classes=VALID_CLASSES,
    target_size=(IMG_SIZE, IMG_SIZE),
    batch_size=BATCH_SIZE,
    class_mode="categorical",
    shuffle=False
)

CLASS_NAMES = list(train_generator.class_indices.keys())
NUM_CLASSES = len(CLASS_NAMES)

print("Class Names:", CLASS_NAMES)
print("Number of Classes:", NUM_CLASSES)

print("Test Images:", test_generator.n)
print("Test Classes:", test_generator.num_classes)
```

Found 505 images belonging to 36 classes.
Class Names: ['0', '1', '2', '3', '4', '5', '6', '7', '8', '9', 'a', 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i', 'j', 'k', 'l', 'm', 'n', 'o', 'p', 'q', 'r', 's', 't', 'u', 'v', 'w', 'x', 'y', 'z']
Number of Classes: 36
Test Images: 505
Test Classes: 36

In [15]:

```
# Step 13: Build MobileNetV2 model
# This step uses MobileNetV2 as a pre-trained feature extractor.

base_model = MobileNetV2(
    weights="imagenet",
    include_top=False,
    input_shape=(IMG_SIZE, IMG_SIZE, 3)
)

base_model.trainable = False

print("MobileNetV2 base model loaded successfully.")

Downloading data from https://storage.googleapis.com/tensorflow/keras-applications/mobilenet_v2/mobilenet_v2_weights_tf_dim_ordering_tf_kernels_1.0_224_no_top.h5
[1m9406464/9406464][0m [32m-----[0m [0m[37m[0m [1m0s[0m 0us/step
MobileNetV2 base model loaded successfully.
```

```
In [16]: # Step 14: Add classification layers
# This step adds custom layers to classify ASL images into 36 classes.
```

```
x = base_model.output
x = GlobalAveragePooling2D()(x)
x = Dense(256, activation="relu")(x)
x = Dropout(0.5)(x)

output = Dense(NUM_CLASSES, activation="softmax")(x)

model = Model(
    inputs=base_model.input,
    outputs=output,
    name="MobileNetV2_ASL_Model"
)

model.summary()
```

Model: "MobileNetV2_ASL_Model"			
Layer (type)	Output Shape	Param #	Connected to
input_layer (InputLayer)	(None, 224, 224, 3)	0	-
Conv1 (Conv2D)	(None, 112, 112, 32)	864	input_layer[0][0]
bn_Conv1 (BatchNormalization)	(None, 112, 112, 32)	128	Conv1[0][0]
Conv1_relu (ReLU)	(None, 112, 112, 32)	0	bn_Conv1[0][0]
expanded_conv_dept... (DepthwiseConv2D)	(None, 112, 112, 32)	288	Conv1_relu[0][0]
expanded_conv_dept... (BatchNormalization)	(None, 112, 112, 32)	128	expanded_conv_de...
expanded_conv_dept... (ReLU)	(None, 112, 112, 32)	0	expanded_conv_de...
expanded_conv_proj... (Conv2D)	(None, 112, 112, 16)	512	expanded_conv_de...
expanded_conv_proj... (BatchNormalization)	(None, 112, 112, 16)	64	expanded_conv_pr...
block_1_expand (Conv2D)	(None, 112, 112, 96)	1,536	expanded_conv_pr...
block_1_expand_BN (BatchNormalization)	(None, 112, 112, 96)	384	block_1_expand[0...
block_1_expand_relu (ReLU)	(None, 112, 112, 96)	0	block_1_expand_B...
block_1_pad (ZeroPadding2D)	(None, 113, 113, 96)	0	block_1_expand_r...
block_1_depthwise (DepthwiseConv2D)	(None, 56, 56, 96)	864	block_1_pad[0][0]
block_1_depthwise... (BatchNormalization)	(None, 56, 56, 96)	384	block_1_depthwis...
block_1_depthwise... (ReLU)	(None, 56, 56, 96)	0	block_1_depthwis...
block_1_project (Conv2D)	(None, 56, 56, 24)	2,304	block_1_depthwis...
block_1_project_BN (BatchNormalization)	(None, 56, 56, 24)	96	block_1_project[...
block_2_expand (Conv2D)	(None, 56, 56, 144)	3,456	block_1_project_...
block_2_expand_BN (BatchNormalization)	(None, 56, 56, 144)	576	block_2_expand[0...
block_2_expand_relu (ReLU)	(None, 56, 56, 144)	0	block_2_expand_B...
block_2_depthwise (DepthwiseConv2D)	(None, 56, 56, 144)	1,296	block_2_expand_r...
block_2_depthwise... (BatchNormalization)	(None, 56, 56, 144)	576	block_2_depthwis...
block_2_depthwise... (ReLU)	(None, 56, 56, 144)	0	block_2_depthwis...
block_2_project (Conv2D)	(None, 56, 56, 24)	3,456	block_2_depthwis...
block_2_project_BN (BatchNormalization)	(None, 56, 56, 24)	96	block_2_project[...
block_2_add (Add)	(None, 56, 56, 24)	0	block_1_project_... block_2_project_...
block_3_expand (Conv2D)	(None, 56, 56, 144)	3,456	block_2_add[0][0]
block_3_expand_BN (BatchNormalization)	(None, 56, 56, 144)	576	block_3_expand[0...
block_3_expand_relu (ReLU)	(None, 56, 56, 144)	0	block_3_expand_B...
block_3_pad (ZeroPadding2D)	(None, 57, 57, 144)	0	block_3_expand_r...
block_3_depthwise (DepthwiseConv2D)	(None, 28, 28, 144)	1,296	block_3_pad[0][0]
block_3_depthwise... (BatchNormalization)	(None, 28, 28, 144)	576	block_3_depthwis...
block_3_depthwise... (ReLU)	(None, 28, 28, 144)	0	block_3_depthwis...
block_3_project (Conv2D)	(None, 28, 28, 32)	4,608	block_3_depthwis...
block_3_project_BN (BatchNormalization)	(None, 28, 28, 32)	128	block_3_project[...
block_4_expand (Conv2D)	(None, 28, 28, 192)	6,144	block_3_project_...
block_4_expand_BN (BatchNormalization)	(None, 28, 28, 192)	768	block_4_expand[0...
block_4_expand_relu (ReLU)	(None, 28, 28, 192)	0	block_4_expand_B...
block_4_depthwise (DepthwiseConv2D)	(None, 28, 28, 192)	1,728	block_4_expand_r...
block_4_depthwise... (BatchNormalization)	(None, 28, 28, 192)	768	block_4_depthwis...
block_4_depthwise... (ReLU)	(None, 28, 28, 192)	0	block_4_depthwis...
block_4_project (Conv2D)	(None, 28, 28, 32)	6,144	block_4_depthwis...
block_4_project_BN (BatchNormalization)	(None, 28, 28, 32)	128	block_4_project[...
block_4_add (Add)	(None, 28, 28, 32)	0	block_3_project_... block_4_project_...
block_5_expand (Conv2D)	(None, 28, 28, 192)	6,144	block_4_add[0][0]
block_5_expand_BN (BatchNormalization)	(None, 28, 28, 192)	768	block_5_expand[0...
block_5_expand_relu (ReLU)	(None, 28, 28, 192)	0	block_5_expand_B...
block_5_depthwise (DepthwiseConv2D)	(None, 28, 28, 192)	1,728	block_5_expand_r...
block_5_depthwise... (BatchNormalization)	(None, 28, 28, 192)	768	block_5_depthwis...
block_5_depthwise... (ReLU)	(None, 28, 28, 192)	0	block_5_depthwis...
block_5_project (Conv2D)	(None, 28, 28, 32)	6,144	block_5_depthwis...
block_5_project_BN (BatchNormalization)	(None, 28, 28, 32)	128	block_5_project[...
block_5_add (Add)	(None, 28, 28, 32)	0	block_4_add[0][0... block_5_project_...
block_6_expand (Conv2D)	(None, 28, 28, 192)	6,144	block_5_add[0][0]
block_6_expand_BN (BatchNormalization)	(None, 28, 28, 192)	768	block_6_expand[0...
block_6_expand_relu (ReLU)	(None, 28, 28, 192)	0	block_6_expand_B...
block_6_pad (ZeroPadding2D)	(None, 29, 29, 192)	0	block_6_expand_r...
block_6_depthwise (DepthwiseConv2D)	(None, 14, 14, 192)	1,728	block_6_pad[0][0]
block_6_depthwise...	(None, 14, 14, 192)	768	block_6_depthwis...

(BatchNormalizatio...	192)		
block_6_depthwise_... (ReLU)	(None, 14, 14, 192)	0	block_6_depthwis...
block_6_project (Conv2D)	(None, 14, 14, 64)	12,288	block_6_depthwis...
block_6_project_BN (BatchNormalizatio...	(None, 14, 14, 64)	256	block_6_project[...
block_7_expand (Conv2D)	(None, 14, 14, 384)	24,576	block_6_project_...
block_7_expand_BN (BatchNormalizatio...	(None, 14, 14, 384)	1,536	block_7_expand[0...
block_7_expand_relu (ReLU)	(None, 14, 14, 384)	0	block_7_expand_B...
block_7_depthwise (DepthwiseConv2D)	(None, 14, 14, 384)	3,456	block_7_expand_r...
block_7_depthwise_... (BatchNormalizatio...	(None, 14, 14, 384)	1,536	block_7_depthwis...
block_7_depthwise_... (ReLU)	(None, 14, 14, 384)	0	block_7_depthwis...
block_7_project (Conv2D)	(None, 14, 14, 64)	24,576	block_7_depthwis...
block_7_project_BN (BatchNormalizatio...	(None, 14, 14, 64)	256	block_7_project[...
block_7_add (Add)	(None, 14, 14, 64)	0	block_6_project_... block_7_project_...
block_8_expand (Conv2D)	(None, 14, 14, 384)	24,576	block_7_add[0][0]
block_8_expand_BN (BatchNormalizatio...	(None, 14, 14, 384)	1,536	block_8_expand[0...
block_8_expand_relu (ReLU)	(None, 14, 14, 384)	0	block_8_expand_B...
block_8_depthwise (DepthwiseConv2D)	(None, 14, 14, 384)	3,456	block_8_expand_r...
block_8_depthwise_... (BatchNormalizatio...	(None, 14, 14, 384)	1,536	block_8_depthwis...
block_8_depthwise_... (ReLU)	(None, 14, 14, 384)	0	block_8_depthwis...
block_8_project (Conv2D)	(None, 14, 14, 64)	24,576	block_8_depthwis...
block_8_project_BN (BatchNormalizatio...	(None, 14, 14, 64)	256	block_8_project[...
block_8_add (Add)	(None, 14, 14, 64)	0	block_7_add[0][0... block_8_project_...
block_9_expand (Conv2D)	(None, 14, 14, 384)	24,576	block_8_add[0][0]
block_9_expand_BN (BatchNormalizatio...	(None, 14, 14, 384)	1,536	block_9_expand[0...
block_9_expand_relu (ReLU)	(None, 14, 14, 384)	0	block_9_expand_B...
block_9_depthwise (DepthwiseConv2D)	(None, 14, 14, 384)	3,456	block_9_expand_r...
block_9_depthwise_... (BatchNormalizatio...	(None, 14, 14, 384)	1,536	block_9_depthwis...
block_9_depthwise_... (ReLU)	(None, 14, 14, 384)	0	block_9_depthwis...
block_9_project (Conv2D)	(None, 14, 14, 64)	24,576	block_9_depthwis...
block_9_project_BN (BatchNormalizatio...	(None, 14, 14, 64)	256	block_9_project[...
block_9_add (Add)	(None, 14, 14, 64)	0	block_8_add[0][0... block_9_project_...
block_10_expand (Conv2D)	(None, 14, 14, 384)	24,576	block_9_add[0][0]
block_10_expand_BN (BatchNormalizatio...	(None, 14, 14, 384)	1,536	block_10_expand[...
block_10_expand_re... (ReLU)	(None, 14, 14, 384)	0	block_10_expand_...
block_10_depthwise (DepthwiseConv2D)	(None, 14, 14, 384)	3,456	block_10_expand_...
block_10_depthwise... (BatchNormalizatio...	(None, 14, 14, 384)	1,536	block_10_depthwi...
block_10_depthwise... (ReLU)	(None, 14, 14, 384)	0	block_10_depthwi...
block_10_project (Conv2D)	(None, 14, 14, 96)	36,864	block_10_depthwi...
block_10_project_BN (BatchNormalizatio...	(None, 14, 14, 96)	384	block_10_project...
block_11_expand (Conv2D)	(None, 14, 14, 576)	55,296	block_10_project...
block_11_expand_BN (BatchNormalizatio...	(None, 14, 14, 576)	2,304	block_11_expand[...
block_11_expand_re... (ReLU)	(None, 14, 14, 576)	0	block_11_expand_...
block_11_depthwise (DepthwiseConv2D)	(None, 14, 14, 576)	5,184	block_11_expand_...
block_11_depthwise... (BatchNormalizatio...	(None, 14, 14, 576)	2,304	block_11_depthwi...
block_11_depthwise... (ReLU)	(None, 14, 14, 576)	0	block_11_depthwi...
block_11_project (Conv2D)	(None, 14, 14, 96)	55,296	block_11_depthwi...
block_11_project_BN (BatchNormalizatio...	(None, 14, 14, 96)	384	block_11_project...
block_11_add (Add)	(None, 14, 14, 96)	0	block_10_project... block_11_project...
block_12_expand (Conv2D)	(None, 14, 14, 576)	55,296	block_11_add[0][...
block_12_expand_BN (BatchNormalizatio...	(None, 14, 14, 576)	2,304	block_12_expand[...
block_12_expand_re... (ReLU)	(None, 14, 14, 576)	0	block_12_expand_...
block_12_depthwise (DepthwiseConv2D)	(None, 14, 14, 576)	5,184	block_12_expand_...
block_12_depthwise... (BatchNormalizatio...	(None, 14, 14, 576)	2,304	block_12_depthwi...
block_12_depthwise... (ReLU)	(None, 14, 14, 576)	0	block_12_depthwi...
block_12_project (Conv2D)	(None, 14, 14, 96)	55,296	block_12_depthwi...
block_12_project_BN (BatchNormalizatio...	(None, 14, 14, 96)	384	block_12_project...
block_12_add (Add)	(None, 14, 14, 96)	0	block_11_add[0][... block_12_project...
block_13_expand (Conv2D)	(None, 14, 14, 576)	55,296	block_12_add[0][...
block_13_expand_BN (BatchNormalizatio...	(None, 14, 14, 576)	2,304	block_13_expand[...
block_13_expand_re... (ReLU)	(None, 14, 14, 576)	0	block_13_expand_...
block_13_pad (ZeroPadding2D)	(None, 15, 15, 576)	0	block_13_expand_...
block_13_depthwise (DepthwiseConv2D)	(None, 7, 7, 576)	5,184	block_13_pad[0][...
block_13_depthwise... (BatchNormalizatio...	(None, 7, 7, 576)	2,304	block_13_depthwi...
block_13_depthwise... (ReLU)	(None, 7, 7, 576)	0	block_13_depthwi...
block_13_project (Conv2D)	(None, 7, 7, 160)	92,160	block_13_depthwi...
block_13_project_BN (BatchNormalizatio...	(None, 7, 7, 160)	640	block_13_project...
block_14_expand (Conv2D)	(None, 7, 7, 960)	153,600	block_13_project...
block_14_expand_BN (BatchNormalizatio...	(None, 7, 7, 960)	3,840	block_14_expand[...
block_14_expand_re... (ReLU)	(None, 7, 7, 960)	0	block_14_expand_...

block_14_depthwise (DepthwiseConv2D)	(None, 7, 7, 960)	8,640	block_14_expand_...
block_14_depthwise... (BatchNormalizatio...	(None, 7, 7, 960)	3,840	block_14_depthwi...
block_14_depthwise... (ReLU)	(None, 7, 7, 960)	0	block_14_depthwi...
block_14_project (Conv2D)	(None, 7, 7, 160)	153,600	block_14_depthwi...
block_14_project_BN (BatchNormalizatio...	(None, 7, 7, 160)	640	block_14_project...
block_14_add (Add)	(None, 7, 7, 160)	0	block_13_project.. block_14_project...
block_15_expand (Conv2D)	(None, 7, 7, 960)	153,600	block_14_add[0][...
block_15_expand_BN (BatchNormalizatio...	(None, 7, 7, 960)	3,840	block_15_expand[...
block_15_expand_re... (ReLU)	(None, 7, 7, 960)	0	block_15_expand_...
block_15_depthwise (DepthwiseConv2D)	(None, 7, 7, 960)	8,640	block_15_expand_...
block_15_depthwise... (BatchNormalizatio...	(None, 7, 7, 960)	3,840	block_15_depthwi...
block_15_depthwise... (ReLU)	(None, 7, 7, 960)	0	block_15_depthwi...
block_15_project (Conv2D)	(None, 7, 7, 160)	153,600	block_15_depthwi...
block_15_project_BN (BatchNormalizatio...	(None, 7, 7, 160)	640	block_15_project...
block_15_add (Add)	(None, 7, 7, 160)	0	block_14_add[0][... block_15_project...
block_16_expand (Conv2D)	(None, 7, 7, 960)	153,600	block_15_add[0][...
block_16_expand_BN (BatchNormalizatio...	(None, 7, 7, 960)	3,840	block_16_expand[...
block_16_expand_re... (ReLU)	(None, 7, 7, 960)	0	block_16_expand_...
block_16_depthwise (DepthwiseConv2D)	(None, 7, 7, 960)	8,640	block_16_expand_...
block_16_depthwise... (BatchNormalizatio...	(None, 7, 7, 960)	3,840	block_16_depthwi...
block_16_depthwise... (ReLU)	(None, 7, 7, 960)	0	block_16_depthwi...
block_16_project (Conv2D)	(None, 7, 7, 320)	307,200	block_16_depthwi...
block_16_project_BN (BatchNormalizatio...	(None, 7, 7, 320)	1,280	block_16_project...
Conv_1 (Conv2D)	(None, 7, 7, 1280)	409,600	block_16_project...
Conv_1_bn (BatchNormalizatio...	(None, 7, 7, 1280)	5,120	Conv_1[0][0]
out_relu (ReLU)	(None, 7, 7, 1280)	0	Conv_1_bn[0][0]
global_average_poo... (GlobalAveragePool...	(None, 1280)	0	out_relu[0][0]
dense (Dense)	(None, 256)	327,936	global_average_p...
dropout (Dropout)	(None, 256)	0	dense[0][0]
dense_1 (Dense)	(None, 36)	9,252	dropout[0][0]

Total params: 2,595,172 (9.90 MB)

Trainable params: 337,188 (1.29 MB)

Non-trainable params: 2,257,984 (8.61 MB)

In [17]: # Step 15: Compile the model
This step prepares the model for training using Adam optimizer and categorical_crossentropy.

```
model.compile(  
    optimizer=Adam(learning_rate=LEARNING_RATE),  
    loss="categorical_crossentropy",  
    metrics=["accuracy"]  
)
```

In [18]: # Step 16: Prepare callbacks
This step saves the best model and stops training when validation loss stops improving.

```
callbacks = [  
    EarlyStopping(  
        monitor="val_loss",  
        patience=7,  
        restore_best_weights=True,  
        verbose=1  
    ),  
  
    ReduceLROnPlateau(  
        monitor="val_loss",  
        factor=0.3,  
        patience=4,  
        min_lr=1e-6,  
        verbose=1  
    ),  
  
    ModelCheckpoint(  
        "best_mobilenetv2_as1_model.keras",  
        monitor="val_accuracy",  
        save_best_only=True,  
        verbose=1  
    )  
]
```

```
In [19]: # Step 17: Train the model
# This step trains MobileNetV2 using training data and validates it using validation data.

history = model.fit(
    train_generator,
    validation_data=validation_generator,
    epochs=EPOCHS,
    callbacks=callbacks
)
```

Epoch 1/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 939ms/step - accuracy: 0.0407 - loss: 3.9520
Epoch 1: val_accuracy improved from None to 0.20717, saving model to best_mobilenetv2_asl_model.keras

Epoch 1: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m126s][0m 1s/step - accuracy: 0.0636 - loss: 3.6473 - val_accuracy: 0.2072 - val_loss: 3.0609 - learning_rate: 1.0000e-04
Epoch 2/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 952ms/step - accuracy: 0.1444 - loss: 3.0957
Epoch 2: val_accuracy improved from 0.20717 to 0.37849, saving model to best_mobilenetv2_asl_model.keras

Epoch 2: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m116s][0m 1s/step - accuracy: 0.1733 - loss: 2.9944 - val_accuracy: 0.3785 - val_loss: 2.5608 - learning_rate: 1.0000e-04
Epoch 3/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 980ms/step - accuracy: 0.2541 - loss: 2.6570
Epoch 3: val_accuracy improved from 0.37849 to 0.48207, saving model to best_mobilenetv2_asl_model.keras

Epoch 3: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m149s][0m 1s/step - accuracy: 0.2693 - loss: 2.5811 - val_accuracy: 0.4821 - val_loss: 2.1596 - learning_rate: 1.0000e-04
Epoch 4/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 1s/step - accuracy: 0.3265 - loss: 2.3294
Epoch 4: val_accuracy improved from 0.48207 to 0.54582, saving model to best_mobilenetv2_asl_model.keras

Epoch 4: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m128s][0m 1s/step - accuracy: 0.3392 - loss: 2.2981 - val_accuracy: 0.5458 - val_loss: 1.8633 - learning_rate: 1.0000e-04
Epoch 5/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 960ms/step - accuracy: 0.3860 - loss: 2.1169
Epoch 5: val_accuracy improved from 0.54582 to 0.60159, saving model to best_mobilenetv2_asl_model.keras

Epoch 5: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m119s][0m 1s/step - accuracy: 0.4051 - loss: 2.0516 - val_accuracy: 0.6016 - val_loss: 1.6281 - learning_rate: 1.0000e-04
Epoch 6/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 955ms/step - accuracy: 0.4357 - loss: 1.8880
Epoch 6: val_accuracy improved from 0.60159 to 0.66534, saving model to best_mobilenetv2_asl_model.keras

Epoch 6: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m117s][0m 1s/step - accuracy: 0.4369 - loss: 1.8715 - val_accuracy: 0.6653 - val_loss: 1.4666 - learning_rate: 1.0000e-04
Epoch 7/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 950ms/step - accuracy: 0.5244 - loss: 1.7065
Epoch 7: val_accuracy improved from 0.66534 to 0.71713, saving model to best_mobilenetv2_asl_model.keras

Epoch 7: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m143s][0m 1s/step - accuracy: 0.5091 - loss: 1.7038 - val_accuracy: 0.7171 - val_loss: 1.3215 - learning_rate: 1.0000e-04
Epoch 8/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 934ms/step - accuracy: 0.5312 - loss: 1.6241
Epoch 8: val_accuracy improved from 0.71713 to 0.73705, saving model to best_mobilenetv2_asl_model.keras

Epoch 8: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m115s][0m 1s/step - accuracy: 0.5483 - loss: 1.5794 - val_accuracy: 0.7371 - val_loss: 1.2151 - learning_rate: 1.0000e-04
Epoch 9/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 944ms/step - accuracy: 0.5827 - loss: 1.4565
Epoch 9: val_accuracy improved from 0.73705 to 0.75697, saving model to best_mobilenetv2_asl_model.keras

Epoch 9: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m114s][0m 1s/step - accuracy: 0.5727 - loss: 1.4620 - val_accuracy: 0.7570 - val_loss: 1.1156 - learning_rate: 1.0000e-04
Epoch 10/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 946ms/step - accuracy: 0.5899 - loss: 1.4013
Epoch 10: val_accuracy did not improve from 0.75697
[1m10/110][0m @][32m-----][0m][37m][0m @][1m116s][0m 1s/step - accuracy: 0.6040 - loss: 1.3621 - val_accuracy: 0.7450 - val_loss: 1.0412 - learning_rate: 1.0000e-04
Epoch 11/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 930ms/step - accuracy: 0.6069 - loss: 1.3272
Epoch 11: val_accuracy did not improve from 0.75697
[1m10/110][0m @][32m-----][0m][37m][0m @][1m114s][0m 1s/step - accuracy: 0.6187 - loss: 1.2992 - val_accuracy: 0.7570 - val_loss: 0.9683 - learning_rate: 1.0000e-04
Epoch 12/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 907ms/step - accuracy: 0.6136 - loss: 1.2386
Epoch 12: val_accuracy improved from 0.75697 to 0.77291, saving model to best_mobilenetv2_asl_model.keras

Epoch 12: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m122s][0m 1s/step - accuracy: 0.6381 - loss: 1.2098 - val_accuracy: 0.7729 - val_loss: 0.8971 - learning_rate: 1.0000e-04
Epoch 13/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 968ms/step - accuracy: 0.6389 - loss: 1.1894
Epoch 13: val_accuracy did not improve from 0.77291
[1m10/110][0m @][32m-----][0m][37m][0m @][1m117s][0m 1s/step - accuracy: 0.6460 - loss: 1.1691 - val_accuracy: 0.7570 - val_loss: 0.8698 - learning_rate: 1.0000e-04
Epoch 14/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 934ms/step - accuracy: 0.6865 - loss: 1.0981
Epoch 14: val_accuracy improved from 0.77291 to 0.78088, saving model to best_mobilenetv2_asl_model.keras

Epoch 14: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m116s][0m 1s/step - accuracy: 0.6875 - loss: 1.0904 - val_accuracy: 0.7809 - val_loss: 0.8180 - learning_rate: 1.0000e-04
Epoch 15/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 939ms/step - accuracy: 0.7194 - loss: 1.0138
Epoch 15: val_accuracy improved from 0.78088 to 0.80478, saving model to best_mobilenetv2_asl_model.keras

Epoch 15: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m116s][0m 1s/step - accuracy: 0.7000 - loss: 1.0317 - val_accuracy: 0.8048 - val_loss: 0.7604 - learning_rate: 1.0000e-04
Epoch 16/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 924ms/step - accuracy: 0.6999 - loss: 0.9903
Epoch 16: val_accuracy did not improve from 0.80478
[1m10/110][0m @][32m-----][0m][37m][0m @][1m112s][0m 1s/step - accuracy: 0.7011 - loss: 0.9990 - val_accuracy: 0.8048 - val_loss: 0.7404 - learning_rate: 1.0000e-04
Epoch 17/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 967ms/step - accuracy: 0.7054 - loss: 0.9272
Epoch 17: val_accuracy did not improve from 0.80478
[1m10/110][0m @][32m-----][0m][37m][0m @][1m119s][0m 1s/step - accuracy: 0.7119 - loss: 0.9260 - val_accuracy: 0.7968 - val_loss: 0.7040 - learning_rate: 1.0000e-04
Epoch 18/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 946ms/step - accuracy: 0.7057 - loss: 0.9434
Epoch 18: val_accuracy did not improve from 0.80478
[1m10/110][0m @][32m-----][0m][37m][0m @][1m116s][0m 1s/step - accuracy: 0.7210 - loss: 0.9209 - val_accuracy: 0.8048 - val_loss: 0.6886 - learning_rate: 1.0000e-04
Epoch 19/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 940ms/step - accuracy: 0.7255 - loss: 0.9256
Epoch 19: val_accuracy improved from 0.80478 to 0.80876, saving model to best_mobilenetv2_asl_model.keras

Epoch 19: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m114s][0m 1s/step - accuracy: 0.7261 - loss: 0.9168 - val_accuracy: 0.8088 - val_loss: 0.6543 - learning_rate: 1.0000e-04
Epoch 20/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 928ms/step - accuracy: 0.7479 - loss: 0.8781
Epoch 20: val_accuracy improved from 0.80876 to 0.82072, saving model to best_mobilenetv2_asl_model.keras

Epoch 20: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m112s][0m 1s/step - accuracy: 0.7506 - loss: 0.8615 - val_accuracy: 0.8207 - val_loss: 0.6280 - learning_rate: 1.0000e-04
Epoch 21/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 953ms/step - accuracy: 0.7561 - loss: 0.8330
Epoch 21: val_accuracy did not improve from 0.82072
[1m10/110][0m @][32m-----][0m][37m][0m @][1m118s][0m 1s/step - accuracy: 0.7420 - loss: 0.8560 - val_accuracy: 0.8167 - val_loss: 0.6172 - learning_rate: 1.0000e-04
Epoch 22/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 923ms/step - accuracy: 0.7674 - loss: 0.7964
Epoch 22: val_accuracy did not improve from 0.82072
[1m10/110][0m @][32m-----][0m][37m][0m @][1m138s][0m 1s/step - accuracy: 0.7631 - loss: 0.8027 - val_accuracy: 0.8088 - val_loss: 0.6114 - learning_rate: 1.0000e-04
Epoch 23/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 951ms/step - accuracy: 0.7484 - loss: 0.7967
Epoch 23: val_accuracy did not improve from 0.82072
[1m10/110][0m @][32m-----][0m][37m][0m @][1m115s][0m 1s/step - accuracy: 0.7574 - loss: 0.7955 - val_accuracy: 0.8207 - val_loss: 0.5867 - learning_rate: 1.0000e-04
Epoch 24/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 946ms/step - accuracy: 0.7785 - loss: 0.7790
Epoch 24: val_accuracy did not improve from 0.82072
[1m10/110][0m @][32m-----][0m][37m][0m @][1m114s][0m 1s/step - accuracy: 0.7716 - loss: 0.7573 - val_accuracy: 0.8127 - val_loss: 0.5787 - learning_rate: 1.0000e-04
Epoch 25/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 954ms/step - accuracy: 0.7674 - loss: 0.7685
Epoch 25: val_accuracy improved from 0.82072 to 0.83665, saving model to best_mobilenetv2_asl_model.keras

Epoch 25: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m118s][0m 1s/step - accuracy: 0.7847 - loss: 0.7372 - val_accuracy: 0.8367 - val_loss: 0.5538 - learning_rate: 1.0000e-04
Epoch 26/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 934ms/step - accuracy: 0.8098 - loss: 0.6843
Epoch 26: val_accuracy did not improve from 0.83665
[1m10/110][0m @][32m-----][0m][37m][0m @][1m123s][0m 1s/step - accuracy: 0.8051 - loss: 0.6901 - val_accuracy: 0.8207 - val_loss: 0.5327 - learning_rate: 1.0000e-04
Epoch 27/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 901ms/step - accuracy: 0.8139 - loss: 0.6277
Epoch 27: val_accuracy did not improve from 0.83665
[1m10/110][0m @][32m-----][0m][37m][0m @][1m111s][0m 1s/step - accuracy: 0.7920 - loss: 0.6683 - val_accuracy: 0.8287 - val_loss: 0.5201 - learning_rate: 1.0000e-04
Epoch 28/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 901ms/step - accuracy: 0.7821 - loss: 0.7233
Epoch 28: val_accuracy did not improve from 0.83665
[1m10/110][0m @][32m-----][0m][37m][0m @][1m111s][0m 1s/step - accuracy: 0.7943 - loss: 0.6944 - val_accuracy: 0.8207 - val_loss: 0.5200 - learning_rate: 1.0000e-04
Epoch 29/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 911ms/step - accuracy: 0.7987 - loss: 0.6432
Epoch 29: val_accuracy did not improve from 0.83665
[1m10/110][0m @][32m-----][0m][37m][0m @][1m112s][0m 1s/step - accuracy: 0.7994 - loss: 0.6460 - val_accuracy: 0.8367 - val_loss: 0.5153 - learning_rate: 1.0000e-04
Epoch 30/30
[1m10/110][0m @][32m-----][0m][37m][0m @][1m0s][0m 904ms/step - accuracy: 0.8137 - loss: 0.6333
Epoch 30: val_accuracy improved from 0.83665 to 0.85259, saving model to best_mobilenetv2_asl_model.keras

Epoch 30: finished saving model to best_mobilenetv2_asl_model.keras
[1m10/110][0m @][32m-----][0m][37m][0m @][1m111s][0m 1s/step - accuracy: 0.8040 - loss: 0.6428 - val_accuracy: 0.8526 - val_loss: 0.4784 - learning_rate: 1.0000e-04
Restoring model weights from the end of the best epoch: 30.

```
In [20]: # Step 18: Evaluate the model on validation and test data
# This step calculates final validation and test accuracy.

val_loss, val_accuracy = model.evaluate(validation_generator, verbose=0)
test_loss, test_accuracy = model.evaluate(test_generator, verbose=0)

print(f"Validation Accuracy: {val_accuracy * 100:.2f}%")
print(f"Validation Loss: {val_loss:.4f}")

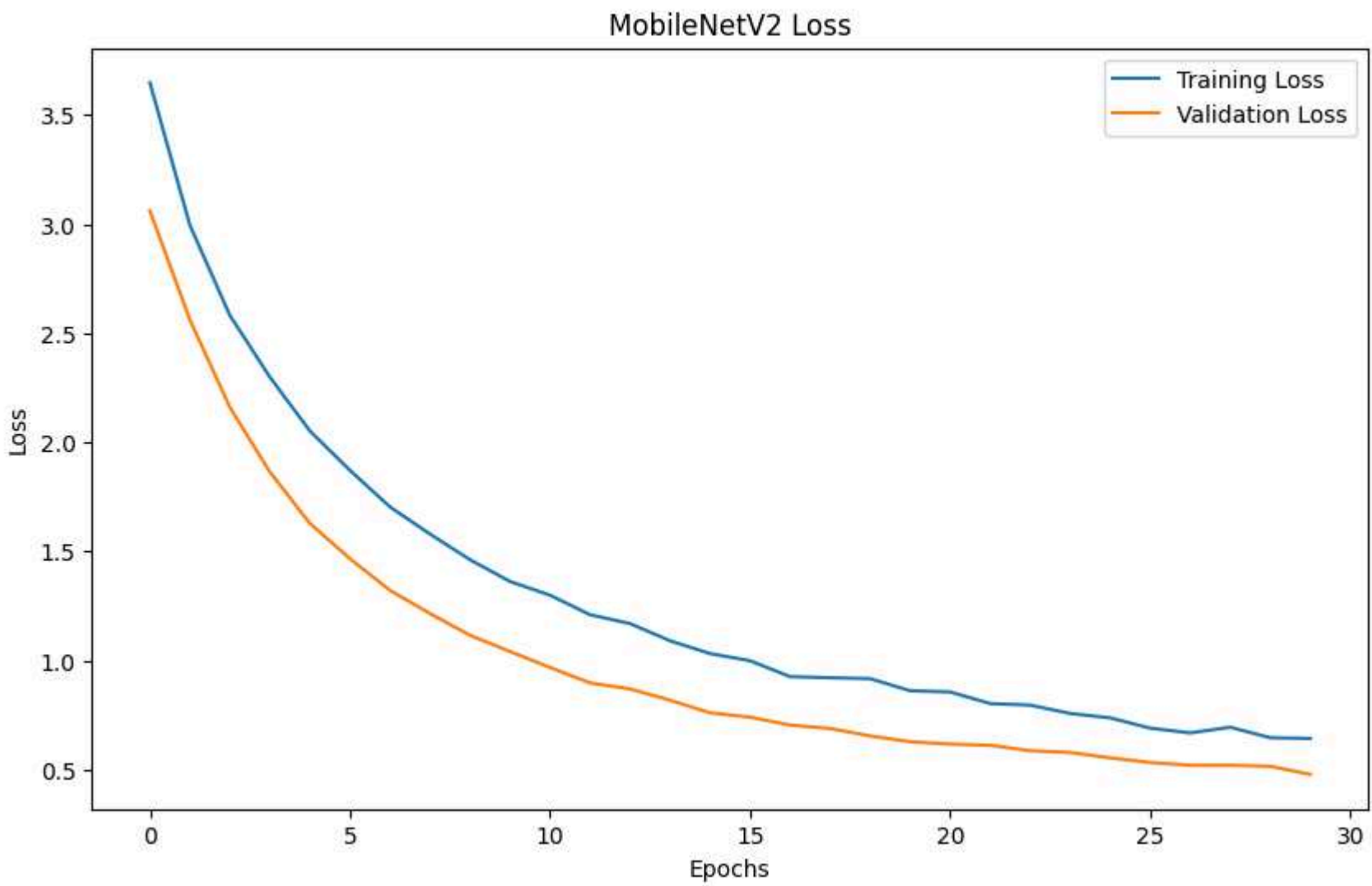
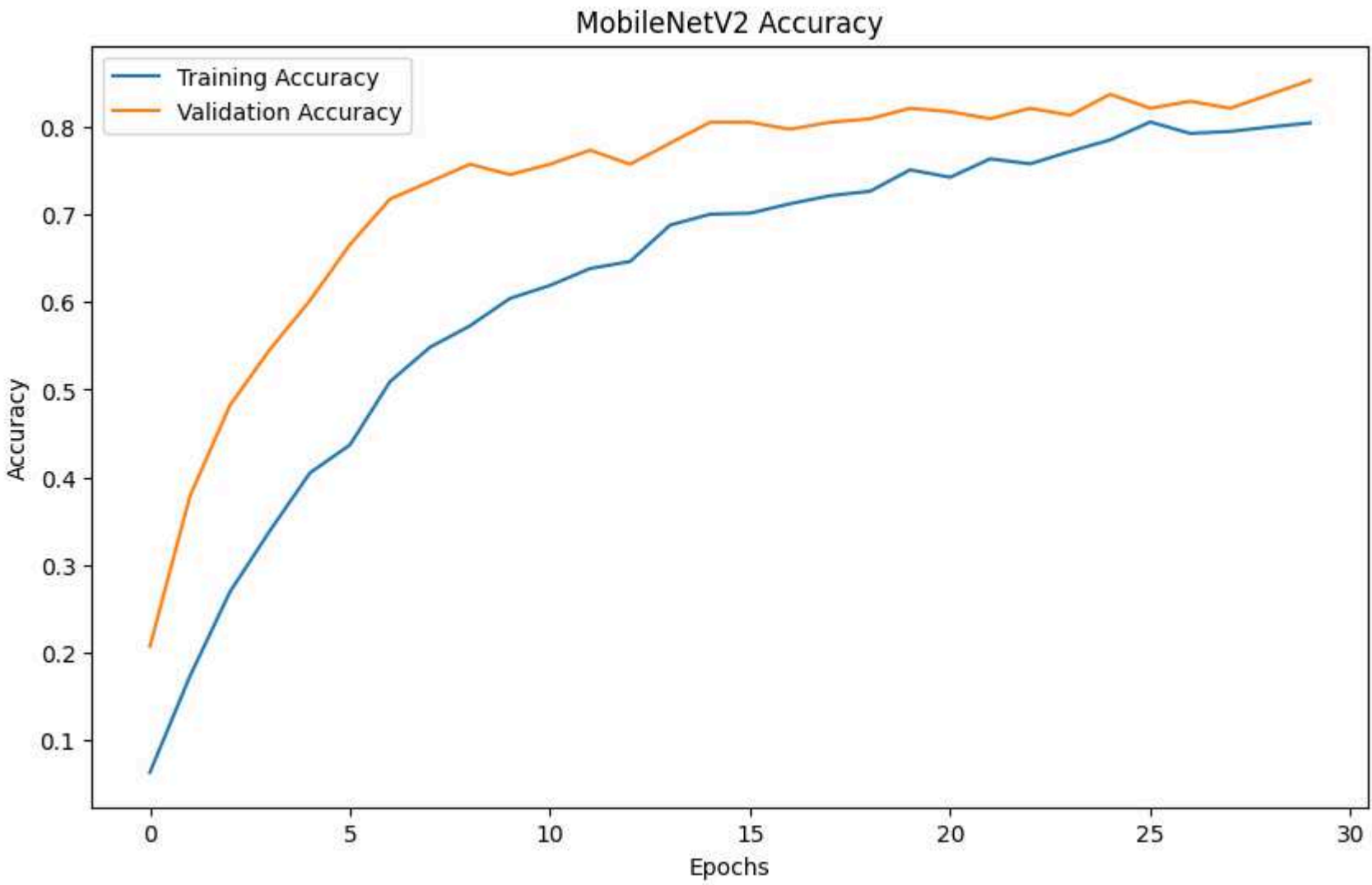
print(f"Test Accuracy: {test_accuracy * 100:.2f}%")
print(f"Test Loss: {test_loss:.4f}")

Validation Accuracy: 85.26%
Validation Loss: 0.4784
Test Accuracy: 87.92%
Test Loss: 0.4512
```

```
In [21]: # Step 19: Plot training curves
# This step shows training and validation accuracy and loss across epochs.

plt.figure(figsize=(10, 6))
plt.plot(history.history["accuracy"], label="Training Accuracy")
plt.plot(history.history["val_accuracy"], label="Validation Accuracy")
plt.title("MobileNetV2 Accuracy")
plt.xlabel("Epochs")
plt.ylabel("Accuracy")
plt.legend()
plt.show()

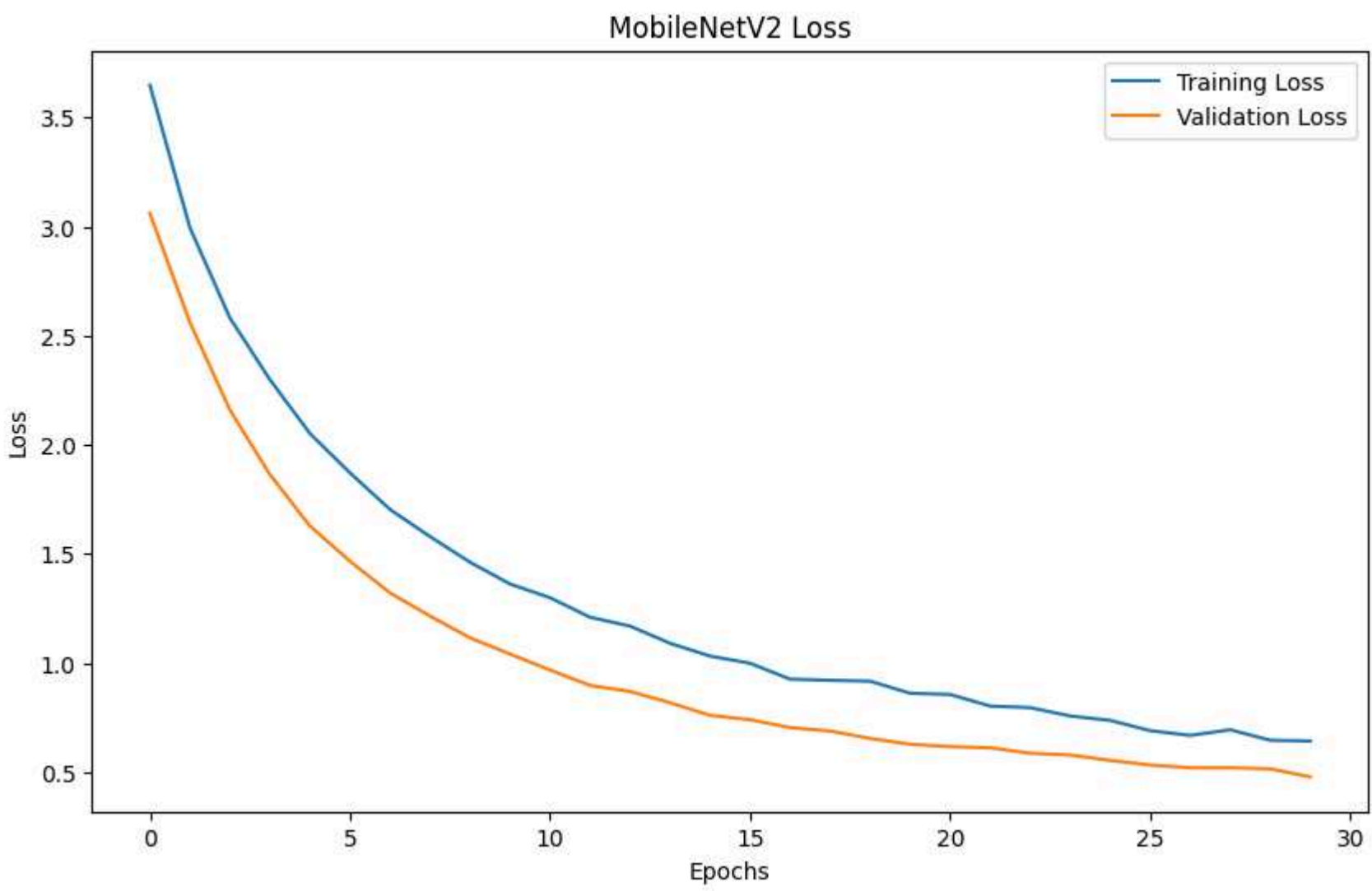
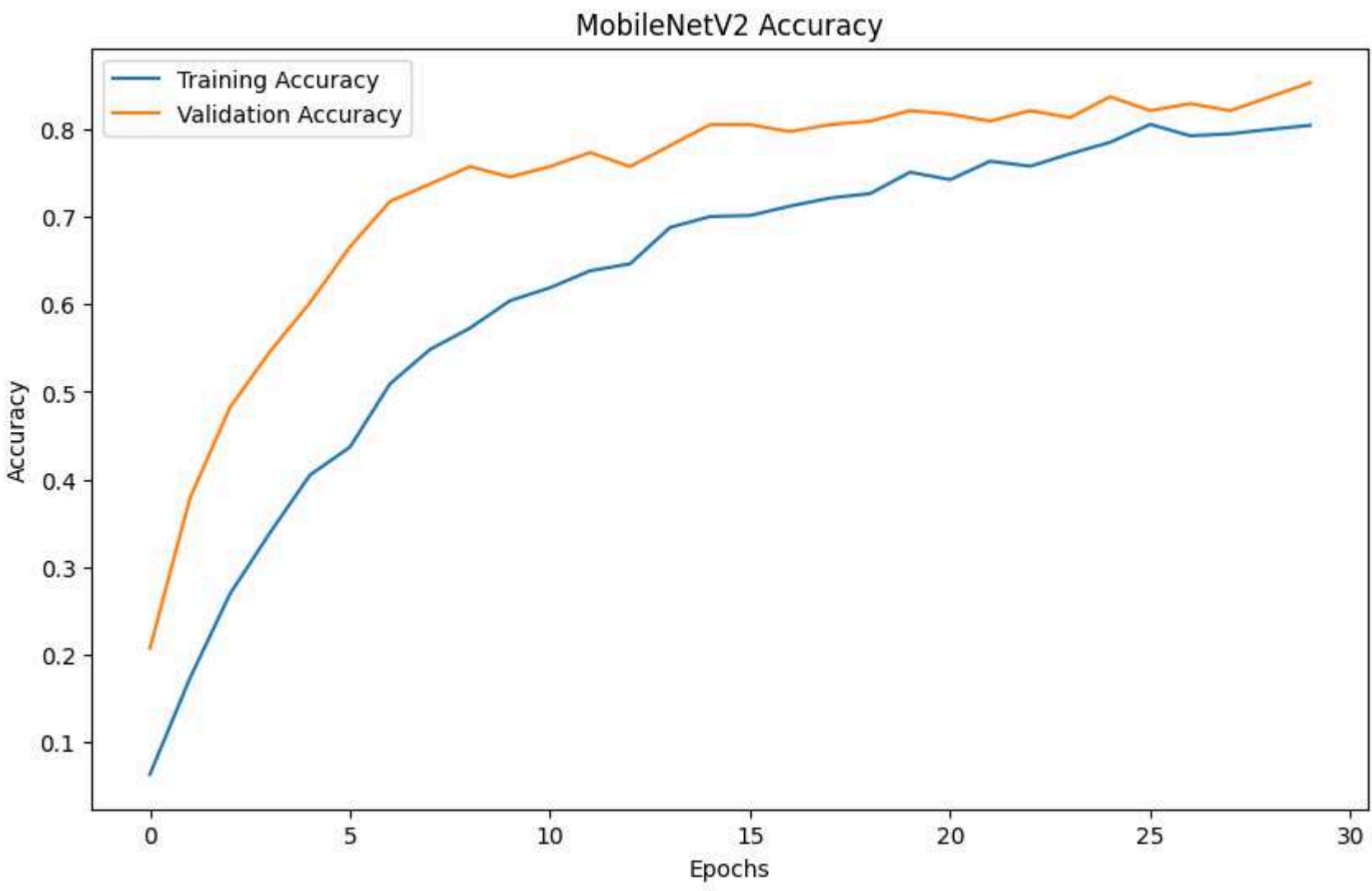
plt.figure(figsize=(10, 6))
plt.plot(history.history["loss"], label="Training Loss")
plt.plot(history.history["val_loss"], label="Validation Loss")
plt.title("MobileNetV2 Loss")
plt.xlabel("Epochs")
plt.ylabel("Loss")
plt.legend()
plt.show()
```



```
In [22]: # Step 19: Plot training curves
# This step shows training and validation accuracy and loss across epochs.
```

```
plt.figure(figsize=(10, 6))
plt.plot(history.history["accuracy"], label="Training Accuracy")
plt.plot(history.history["val_accuracy"], label="Validation Accuracy")
plt.title("MobileNetV2 Accuracy")
plt.xlabel("Epochs")
plt.ylabel("Accuracy")
plt.legend()
plt.show()

plt.figure(figsize=(10, 6))
plt.plot(history.history["loss"], label="Training Loss")
plt.plot(history.history["val_loss"], label="Validation Loss")
plt.title("MobileNetV2 Loss")
plt.xlabel("Epochs")
plt.ylabel("Loss")
plt.legend()
plt.show()
```



In [23]: # Step 20: Create Confusion Matrix
This step predicts test images and displays the confusion matrix.

```
test_generator.reset()

predictions = model.predict(test_generator)

y_pred = np.argmax(predictions, axis=1)
y_true = test_generator.classes

cm = confusion_matrix(y_true, y_pred)

plt.figure(figsize=(18, 16))
plt.imshow(cm)

plt.title("MobileNetV2 Confusion Matrix")
plt.xlabel("Predicted Label")
plt.ylabel("True Label")

plt.xticks(
    ticks=np.arange(len(CLASS_NAMES)),
    labels=CLASS_NAMES,
    rotation=90
)

plt.yticks(
    ticks=np.arange(len(CLASS_NAMES)),
    labels=CLASS_NAMES
)

plt.colorbar()

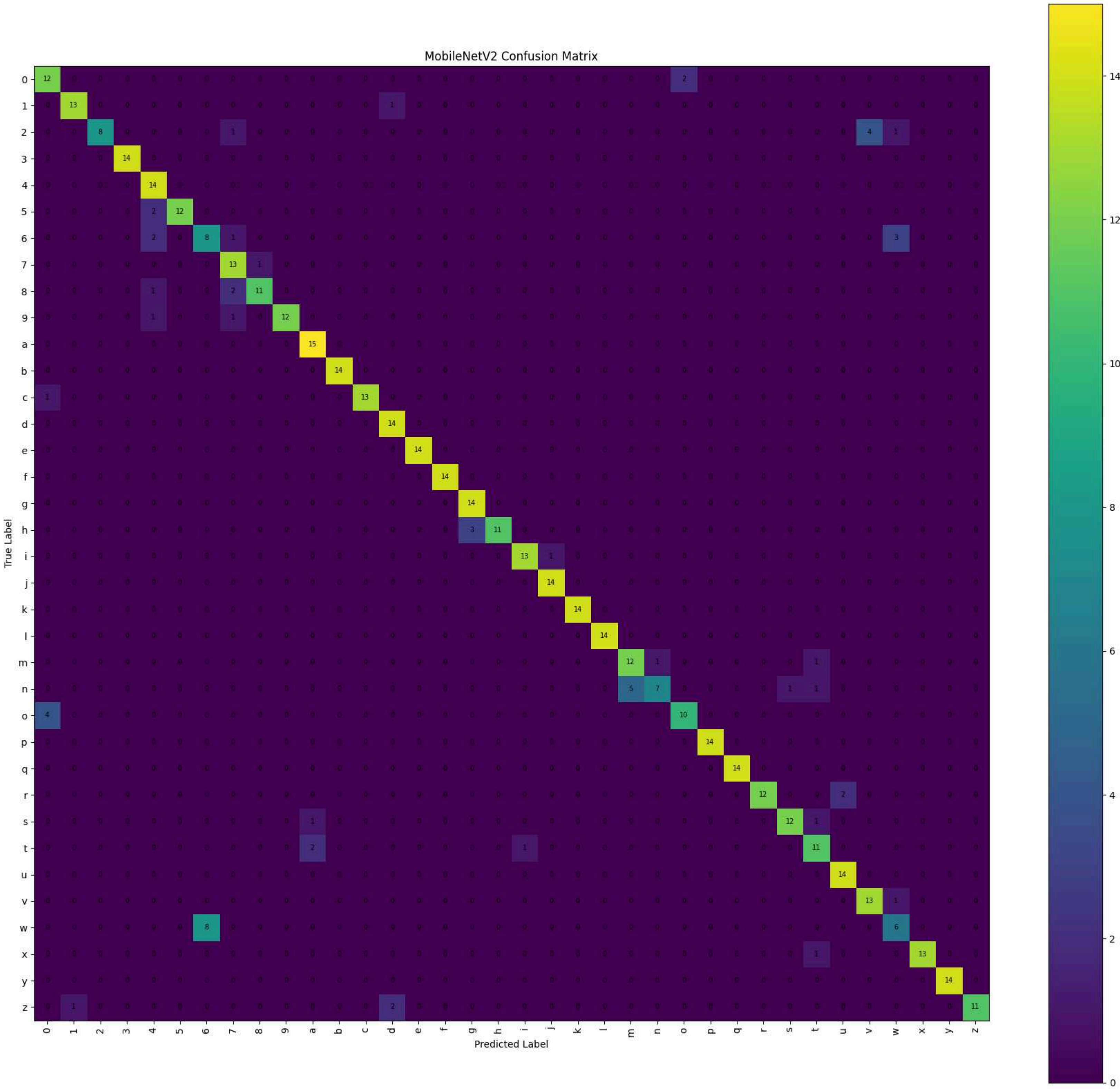
for i in range(len(CLASS_NAMES)):
    for j in range(len(CLASS_NAMES)):
        plt.text(
            j,
            i,
            cm[i, j],
            ha="center",
            va="center",
            fontsize=7
        )

plt.tight_layout()
plt.show()

print("Test Accuracy:", accuracy_score(y_true, y_pred))

print("MobileNetV2 Classification Report")
print(classification_report(
    y_true,
    y_pred,
    target_names=CLASS_NAMES,
    zero_division=0
))
```

1m32/3200m 32m 0m 37m0m 1m26s0m 782ms/step



Test Accuracy: 0.8792079207920792				
MobileNetV2 Classification Report				
	precision	recall	f1-score	support
0	0.71	0.86	0.77	14
1	0.93	0.93	0.93	14
2	1.00	0.57	0.73	14
3	1.00	1.00	1.00	14
4	0.70	1.00	0.82	14
5	1.00	0.86	0.92	14
6	0.50	0.57	0.53	14
7	0.72	0.93	0.81	14
8	0.92	0.79	0.85	14
9	1.00	0.86	0.92	14
a	0.83	1.00	0.91	15
b	1.00	1.00	1.00	14
c	1.00	0.93	0.96	14
d	0.82	1.00	0.90	14
e	1.00	1.00	1.00	14
f	1.00	1.00	1.00	14
g	0.82	1.00	0.90	14
h	1.00	0.79	0.88	14
i	0.93	0.93	0.93	14

j	0.93	1.00	0.97	14
k	1.00	1.00	1.00	14
l	1.00	1.00	1.00	14
m	0.71	0.86	0.77	14
n	0.88	0.50	0.64	14
o	0.83	0.71	0.77	14
p	1.00	1.00	1.00	14
q	1.00	1.00	1.00	14
r	1.00	0.86	0.92	14
s	0.92	0.86	0.89	14
t	0.73	0.79	0.76	14
u	0.88	1.00	0.93	14
v	0.76	0.93	0.84	14
w	0.55	0.43	0.48	14
x	1.00	0.93	0.96	14
y	1.00	1.00	1.00	14
z	1.00	0.79	0.88	14
accuracy			0.88	505
macro avg	0.89	0.88	0.88	505
weighted avg	0.89	0.88	0.88	505

```
In [24]: # Step 21: Save the confusion matrix image
# This step saves the confusion matrix as a PNG file.

plt.figure(figsize=(18, 16))
plt.imshow(cm)

plt.title("MobileNetV2 Confusion Matrix")
plt.xlabel("Predicted Label")
plt.ylabel("True Label")

plt.xticks(
    ticks=np.arange(len(CLASS_NAMES)),
    labels=CLASS_NAMES,
    rotation=90
)

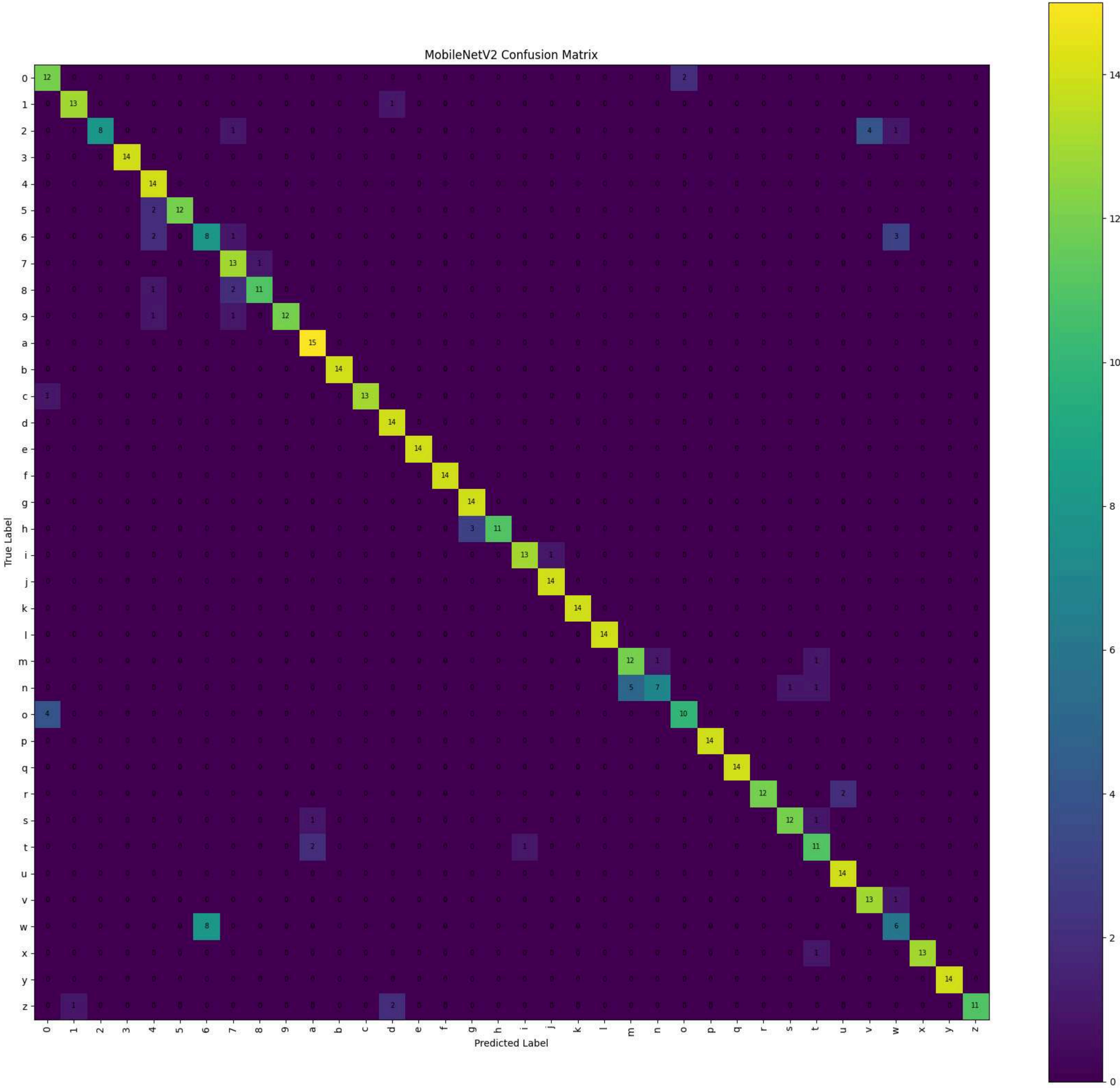
plt.yticks(
    ticks=np.arange(len(CLASS_NAMES)),
    labels=CLASS_NAMES
)

plt.colorbar()

for i in range(len(CLASS_NAMES)):
    for j in range(len(CLASS_NAMES)):
        plt.text(
            j,
            i,
            cm[i, j],
            ha="center",
            va="center",
            fontsize=7
        )

plt.tight_layout()
plt.savefig("mobilenetv2_confusion_matrix.png", dpi=300, bbox_inches="tight")
plt.show()

print("Confusion Matrix saved as: mobilenetv2_confusion_matrix.png")
```



Confusion Matrix saved as: mobilenetv2_confusion_matrix.png

```
In [25]: # Step 22: Save the trained model and class names
# This step saves the final MobileNetV2 model and class labels for later use.

model.save("final_mobilenetv2_asl_model.keras")

with open("asl_class_names.txt", "w") as file:
    for class_name in CLASS_NAMES:
        file.write(class_name + "\n")

print("Model saved as: final_mobilenetv2_asl_model.keras")
print("Class names saved as: asl_class_names.txt")
```

Model saved as: final_mobilenetv2_asl_model.keras
Class names saved as: asl_class_names.txt

Colab notebook detected. To show errors in colab notebook, set debug=True in launch()
 * Running on public URL: <https://a22fad475a779f588a.gradio.live>

This share link expires in 1 week. For free permanent hosting and GPU upgrades, run 'gradio deploy' from the terminal in the working directory to deploy to Hugging Face Spaces (<https://huggingface.co/spaces>)

Upload an ASL hand sign image and the MobileNetV2 model will predict the class.

Submit