part1

December 5, 2022

1 Part 1: Stand/Sit Detector

1.0.1 This part creates a stand/sit detector based on images of sheep and uses accelerometer data as ground truth

```python
# imports
import pandas as pd
import numpy as np
import cv2
from sklearn.model_selection import train_test_split

import os
os.environ['TF_CPP_MIN_LOG_LEVEL'] = '3'

from tensorflow.keras import layers, models
import tensorflow as tf
tf.config.set_visible_devices([], 'GPU')
pre_loaded = True
```

```python
if not pre_loaded:
    # read in the data first
    files = ['W.csv', 'B.csv', 'M.csv', 'P.csv', 'O_0.csv', 'N.csv', 'K.csv',
 ↪'Q.csv']
    sheep_raw = []
    data_dir = 'data/'
    for file in files:
        path = data_dir + file
        df = pd.read_csv(path)
        # drop unnecessary columns
        df = df.drop(columns=df.columns[3:])
        df = df.drop(columns=df.columns[0:1])

        # rename columns
        df.columns = ['File', 'Standing']

        # change accelerometer value to 1 if standing, 0 if sitting
        df['Standing'] = np.where(df['Standing'] < -0.4, 1, 0)
```

```
        # change the timestamp to the filename for the image
        time_stamps = df['File'].to_list()
        file_names = []
        for ts in time_stamps:
            filename = ts
            filename = filename.replace(' ', '_')
            filename = filename.replace(':', ',')
            filename = filename.replace('/', '-')
            filename = filename + '.png'

            # UNCOMMENT THIS LINE WHEN YOU KNOW PATH TO IMAGE FOLDER
            filename = '/mnt/d/WhitlockSheepStudy/output' + '/' + file[0] + '/'␣
 ↪+ filename

            file_names.append(filename)

        df = df.assign(File=file_names)
        sheep_raw.append(df)
```

```
print(os.listdir('/mnt/d/WhitlockSheepStudy/output'))
```

```
if not pre_loaded:
    # Grab images from files on the hard drive
    X = []
    y = []

    bad_reads = 0
    for sheep in sheep_raw:
        files = sheep['File'].to_list()
        labels = sheep['Standing'].to_list()
        for file, label in zip(files, labels):
            try:
                img = cv2.imread(file, cv2.IMREAD_GRAYSCALE)
                # downscale image
                img = cv2.resize(img, (108,243))

                # normalize image
                img = img/255
                # img = cv2.normalize(img, None, alpha=0, beta=1, norm_type=cv2.
 ↪NORM_MINMAX, dtype=cv2.CV_32F)

                # store image
                X.append(img)
                y.append(label)

                # save every 100 images
                if len(X) % 100 == 0:
```

```python
                    np.save('X.npy', np.asarray(X))
                    np.save('y.npy', np.asarray(y))
                    print('Saving...')

                if len(X) % 1000 == 0:
                    break
            except:
                bad_reads += 1
                continue

    print(f'Bad or missing images: {bad_reads}')
    print(f'Good images:          {len(X)}')
```

```python
if pre_loaded:
    X = np.load('X.npy')
    y = np.load('y.npy')
```

```python
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2,
 ↪stratify=y, random_state=42)
```

```python
def create_model(num_filters: list, kernel_sizes: list, input_shape: tuple,
 ↪optimizer: str):
    model = models.Sequential()

    model.add(layers.Conv2D(num_filters[0], (kernel_sizes[0],kernel_sizes[0]),
 ↪activation='relu', input_shape=input_shape))
    model.add(layers.MaxPooling2D((2,2)))

    for i in range(1, len(kernel_sizes)):
        model.add(layers.Conv2D(num_filters[i],
 ↪(kernel_sizes[i],kernel_sizes[i]), activation='relu'))
        model.add(layers.MaxPooling2D((2,2)))

    model.add(layers.Flatten())
    model.add(layers.Dense(64, activation='relu'))
    model.add(layers.Dense(1, activation='sigmoid'))

    model.compile(optimizer=optimizer, loss = 'binary_crossentropy',
 ↪metrics=['accuracy'])
    # print(model.summary())

    return model
```

```python
params = {
    'num_filters': [64, 32, 16],
    'kernel_sizes': [3, 3, 3]
}
```

```
X_train_np = np.array(X_train)
X_train_np = X_train_np.reshape(X_train_np.shape[0], X_train_np.shape[1],␣
 ↪X_train_np.shape[2], 1)
X_test_np = np.array(X_test)
X_test_np = X_test_np.reshape(X_test_np.shape[0], X_test_np.shape[1], X_test_np.
 ↪shape[2], 1)

y_train_np = np.array(y_train)
y_test_np = np.array(y_test)

model = create_model(params['num_filters'], params['kernel_sizes'],␣
 ↪X_train_np[0].shape, 'sgd')
```

```
[ ]: del X_train
     del X_test
     del y_train
     del y_test
```

```
[ ]: print(type(X_train_np[0][0][0][0]))
```

```
<class 'numpy.float64'>
```

```
[ ]: # # create tf dataset to save space
     # train_dataset = tf.data.Dataset.from_tensor_slices((X_train_np, y_train_np))
     # test_dataset = tf.data.Dataset.from_tensor_slices((X_test_np, y_test_np))
```

```
[ ]: # train the model
     es = tf.keras.callbacks.EarlyStopping(monitor='loss', patience=3)

     history = model.fit(X_train_np, y_train_np, epochs=50,␣
      ↪validation_data=(X_test_np, y_test_np), batch_size=16, callbacks=[es])
```

```
Epoch 1/10
400/400 [==============================] - 20s 24ms/step - loss: 0.6778 -
accuracy: 0.5911 - val_loss: 0.6478 - val_accuracy: 0.7013
Epoch 2/10
400/400 [==============================] - 9s 23ms/step - loss: 0.6157 -
accuracy: 0.6755 - val_loss: 0.5861 - val_accuracy: 0.7206
Epoch 3/10
400/400 [==============================] - 9s 24ms/step - loss: 0.5680 -
accuracy: 0.7077 - val_loss: 0.5354 - val_accuracy: 0.7419
Epoch 4/10
400/400 [==============================] - 10s 24ms/step - loss: 0.5264 -
accuracy: 0.7398 - val_loss: 0.5035 - val_accuracy: 0.7556
Epoch 5/10
400/400 [==============================] - 10s 25ms/step - loss: 0.4822 -
```

```
accuracy: 0.7722 - val_loss: 0.4750 - val_accuracy: 0.7856
Epoch 6/10
400/400 [==============================] - 18s 45ms/step - loss: 0.4448 -
accuracy: 0.8036 - val_loss: 0.4134 - val_accuracy: 0.8225
Epoch 7/10
400/400 [==============================] - 40s 99ms/step - loss: 0.4055 -
accuracy: 0.8242 - val_loss: 0.3965 - val_accuracy: 0.8269
Epoch 8/10
400/400 [==============================] - 15s 38ms/step - loss: 0.3662 -
accuracy: 0.8509 - val_loss: 0.3517 - val_accuracy: 0.8525
Epoch 9/10
400/400 [==============================] - 17s 43ms/step - loss: 0.3185 -
accuracy: 0.8717 - val_loss: 0.3151 - val_accuracy: 0.8900
Epoch 10/10
400/400 [==============================] - 38s 94ms/step - loss: 0.2820 -
accuracy: 0.8916 - val_loss: 0.2563 - val_accuracy: 0.9181
```

```python
# save the model
model.save('models/ten_epoch_SGD')
```

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op,
_jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing
3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/ten_epoch_SGD/assets

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```python
# Time to do a grid search
#num_filters: list, kernel_sizes: list, input_shape: tuple, optimizer: str

num_filters = [
    [32, 16, 8],
    [64, 32, 16],
]
kernel_sizes = [
    [3, 3, 3],
    [2, 2, 2]
]
optimizers = ['sgd', 'adam', 'rmsprop']

es = tf.keras.callbacks.EarlyStopping(monitor='val_loss', patience=3)

for i, filters in enumerate(num_filters):
    for j, kernels in enumerate(kernel_sizes):
        for k, opt in enumerate(optimizers):
            if (i == 0 and j == 0 and k == 0) or (i == 0 and j == 0 and k == 1):
                continue
```

```
model = create_model(filters, kernels, X_train_np[0].shape, opt)

log_dir = f'logs/model_{i}_{j}_{k}'
tb = tf.keras.callbacks.TensorBoard(log_dir=log_dir,
↪histogram_freq=1)

model.fit(X_train_np, y_train_np, epochs=50,
↪validation_data=(X_test_np, y_test_np), batch_size=16, callbacks=[tb, es])
model.save(f'models/model_{i}_{j}_{k}')
```

```
Epoch 1/50
400/400 [==============================] - 21s 50ms/step - loss: 0.5462 -
accuracy: 0.7195 - val_loss: 0.3831 - val_accuracy: 0.8525
Epoch 2/50
400/400 [==============================] - 21s 53ms/step - loss: 0.2996 -
accuracy: 0.8788 - val_loss: 0.2286 - val_accuracy: 0.9181
Epoch 3/50
400/400 [==============================] - 18s 45ms/step - loss: 0.1896 -
accuracy: 0.9311 - val_loss: 0.1678 - val_accuracy: 0.9525
Epoch 4/50
400/400 [==============================] - 18s 45ms/step - loss: 0.1455 -
accuracy: 0.9495 - val_loss: 0.1501 - val_accuracy: 0.9544
Epoch 5/50
400/400 [==============================] - 19s 47ms/step - loss: 0.1163 -
accuracy: 0.9605 - val_loss: 0.1518 - val_accuracy: 0.9619
Epoch 6/50
400/400 [==============================] - 18s 44ms/step - loss: 0.0947 -
accuracy: 0.9709 - val_loss: 0.1990 - val_accuracy: 0.9425
Epoch 7/50
400/400 [==============================] - 17s 43ms/step - loss: 0.0853 -
accuracy: 0.9708 - val_loss: 0.1184 - val_accuracy: 0.9669
Epoch 8/50
400/400 [==============================] - 18s 44ms/step - loss: 0.0729 -
accuracy: 0.9762 - val_loss: 0.1262 - val_accuracy: 0.9613
Epoch 9/50
400/400 [==============================] - 17s 43ms/step - loss: 0.0694 -
accuracy: 0.9758 - val_loss: 0.1366 - val_accuracy: 0.9631
Epoch 10/50
400/400 [==============================] - 17s 43ms/step - loss: 0.0567 -
accuracy: 0.9794 - val_loss: 0.1165 - val_accuracy: 0.9675
Epoch 11/50
400/400 [==============================] - 17s 43ms/step - loss: 0.0527 -
accuracy: 0.9816 - val_loss: 0.1428 - val_accuracy: 0.9675
Epoch 12/50
400/400 [==============================] - 17s 43ms/step - loss: 0.0515 -
accuracy: 0.9825 - val_loss: 0.1301 - val_accuracy: 0.9669
```

```
Epoch 13/50
400/400 [==============================] - 17s 44ms/step - loss: 0.0461 -
accuracy: 0.9837 - val_loss: 0.1426 - val_accuracy: 0.9600

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op,
_jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing
3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/model_0_0_2/assets

INFO:tensorflow:Assets written to: models/model_0_0_2/assets

Epoch 1/50
400/400 [==============================] - 19s 46ms/step - loss: 0.6855 -
accuracy: 0.5616 - val_loss: 0.6778 - val_accuracy: 0.6488
Epoch 2/50
400/400 [==============================] - 17s 41ms/step - loss: 0.6573 -
accuracy: 0.6577 - val_loss: 0.6253 - val_accuracy: 0.6944
Epoch 3/50
400/400 [==============================] - 15s 38ms/step - loss: 0.6045 -
accuracy: 0.6958 - val_loss: 0.5747 - val_accuracy: 0.7038
Epoch 4/50
400/400 [==============================] - 16s 40ms/step - loss: 0.5626 -
accuracy: 0.7125 - val_loss: 0.5399 - val_accuracy: 0.7350
Epoch 5/50
400/400 [==============================] - 16s 39ms/step - loss: 0.5255 -
accuracy: 0.7336 - val_loss: 0.5093 - val_accuracy: 0.7444
Epoch 6/50
400/400 [==============================] - 16s 39ms/step - loss: 0.4884 -
accuracy: 0.7702 - val_loss: 0.4628 - val_accuracy: 0.8181
Epoch 7/50
400/400 [==============================] - 15s 39ms/step - loss: 0.4460 -
accuracy: 0.8034 - val_loss: 0.4490 - val_accuracy: 0.7688
Epoch 8/50
400/400 [==============================] - 16s 39ms/step - loss: 0.4125 -
accuracy: 0.8272 - val_loss: 0.3810 - val_accuracy: 0.8700
Epoch 9/50
400/400 [==============================] - 16s 39ms/step - loss: 0.3691 -
accuracy: 0.8506 - val_loss: 0.4091 - val_accuracy: 0.8094
Epoch 10/50
400/400 [==============================] - 15s 38ms/step - loss: 0.3382 -
accuracy: 0.8658 - val_loss: 0.3666 - val_accuracy: 0.8406
Epoch 11/50
400/400 [==============================] - 16s 39ms/step - loss: 0.2920 -
accuracy: 0.8925 - val_loss: 0.2897 - val_accuracy: 0.9119
Epoch 12/50
400/400 [==============================] - 16s 39ms/step - loss: 0.2691 -
accuracy: 0.9006 - val_loss: 0.2516 - val_accuracy: 0.9187
Epoch 13/50
400/400 [==============================] - 15s 39ms/step - loss: 0.2376 -
```

```
accuracy: 0.9148 - val_loss: 0.3131 - val_accuracy: 0.8694
Epoch 14/50
400/400 [==============================] - 16s 40ms/step - loss: 0.2111 -
accuracy: 0.9291 - val_loss: 0.2264 - val_accuracy: 0.9300
Epoch 15/50
400/400 [==============================] - 16s 39ms/step - loss: 0.1922 -
accuracy: 0.9323 - val_loss: 0.2055 - val_accuracy: 0.9525
Epoch 16/50
400/400 [==============================] - 15s 39ms/step - loss: 0.1651 -
accuracy: 0.9439 - val_loss: 0.1893 - val_accuracy: 0.9538
Epoch 17/50
400/400 [==============================] - 16s 39ms/step - loss: 0.1523 -
accuracy: 0.9453 - val_loss: 0.2723 - val_accuracy: 0.9331
Epoch 18/50
400/400 [==============================] - 16s 39ms/step - loss: 0.1428 -
accuracy: 0.9509 - val_loss: 0.1935 - val_accuracy: 0.9519
Epoch 19/50
400/400 [==============================] - 15s 39ms/step - loss: 0.1300 -
accuracy: 0.9564 - val_loss: 0.2126 - val_accuracy: 0.9281

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op,
_jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing
3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/model_0_1_0/assets

INFO:tensorflow:Assets written to: models/model_0_1_0/assets

Epoch 1/50
400/400 [==============================] - 19s 45ms/step - loss: 0.5230 -
accuracy: 0.7377 - val_loss: 0.3698 - val_accuracy: 0.8731
Epoch 2/50
400/400 [==============================] - 16s 41ms/step - loss: 0.2936 -
accuracy: 0.8928 - val_loss: 0.2344 - val_accuracy: 0.9169
Epoch 3/50
400/400 [==============================] - 15s 39ms/step - loss: 0.2017 -
accuracy: 0.9287 - val_loss: 0.1842 - val_accuracy: 0.9438
Epoch 4/50
400/400 [==============================] - 16s 40ms/step - loss: 0.1462 -
accuracy: 0.9536 - val_loss: 0.1598 - val_accuracy: 0.9519
Epoch 5/50
400/400 [==============================] - 16s 39ms/step - loss: 0.1223 -
accuracy: 0.9569 - val_loss: 0.1765 - val_accuracy: 0.9494
Epoch 6/50
400/400 [==============================] - 15s 39ms/step - loss: 0.1092 -
accuracy: 0.9644 - val_loss: 0.1420 - val_accuracy: 0.9606
Epoch 7/50
400/400 [==============================] - 16s 39ms/step - loss: 0.0938 -
accuracy: 0.9686 - val_loss: 0.1481 - val_accuracy: 0.9631
Epoch 8/50
```

```
400/400 [==============================] - 16s 39ms/step - loss: 0.0772 -
accuracy: 0.9737 - val_loss: 0.1641 - val_accuracy: 0.9638
Epoch 9/50
400/400 [==============================] - 15s 39ms/step - loss: 0.0737 -
accuracy: 0.9747 - val_loss: 0.2545 - val_accuracy: 0.9181

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_jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing
3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/model_0_1_1/assets

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Epoch 1/50
400/400 [==============================] - 19s 45ms/step - loss: 0.5354 -
accuracy: 0.7311 - val_loss: 0.4249 - val_accuracy: 0.8444
Epoch 2/50
400/400 [==============================] - 16s 41ms/step - loss: 0.3313 -
accuracy: 0.8730 - val_loss: 0.2381 - val_accuracy: 0.9256
Epoch 3/50
400/400 [==============================] - 15s 39ms/step - loss: 0.2224 -
accuracy: 0.9156 - val_loss: 0.1917 - val_accuracy: 0.9356
Epoch 4/50
400/400 [==============================] - 16s 39ms/step - loss: 0.1685 -
accuracy: 0.9428 - val_loss: 0.1544 - val_accuracy: 0.9550
Epoch 5/50
400/400 [==============================] - 16s 40ms/step - loss: 0.1337 -
accuracy: 0.9561 - val_loss: 0.1501 - val_accuracy: 0.9544
Epoch 6/50
400/400 [==============================] - 16s 39ms/step - loss: 0.1120 -
accuracy: 0.9625 - val_loss: 0.1402 - val_accuracy: 0.9588
Epoch 7/50
400/400 [==============================] - 15s 38ms/step - loss: 0.0917 -
accuracy: 0.9697 - val_loss: 0.1254 - val_accuracy: 0.9600
Epoch 8/50
400/400 [==============================] - 16s 39ms/step - loss: 0.0793 -
accuracy: 0.9748 - val_loss: 0.1282 - val_accuracy: 0.9638
Epoch 9/50
400/400 [==============================] - 16s 39ms/step - loss: 0.0691 -
accuracy: 0.9756 - val_loss: 0.1298 - val_accuracy: 0.9706
Epoch 10/50
400/400 [==============================] - 16s 39ms/step - loss: 0.0619 -
accuracy: 0.9805 - val_loss: 0.1380 - val_accuracy: 0.9644

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op,
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INFO:tensorflow:Assets written to: models/model_0_1_2/assets
```

```
INFO:tensorflow:Assets written to: models/model_0_1_2/assets

Epoch 1/50
400/400 [==============================] - 42s 101ms/step - loss: 0.6715 -
accuracy: 0.6044 - val_loss: 0.6618 - val_accuracy: 0.5437
Epoch 2/50
400/400 [==============================] - 38s 96ms/step - loss: 0.6019 -
accuracy: 0.6864 - val_loss: 0.5672 - val_accuracy: 0.7225
Epoch 3/50
400/400 [==============================] - 39s 96ms/step - loss: 0.5511 -
accuracy: 0.7178 - val_loss: 0.5199 - val_accuracy: 0.7613
Epoch 4/50
400/400 [==============================] - 38s 95ms/step - loss: 0.5059 -
accuracy: 0.7539 - val_loss: 0.4742 - val_accuracy: 0.8081
Epoch 5/50
400/400 [==============================] - 38s 96ms/step - loss: 0.4604 -
accuracy: 0.7945 - val_loss: 0.4365 - val_accuracy: 0.8238
Epoch 6/50
400/400 [==============================] - 38s 95ms/step - loss: 0.4190 -
accuracy: 0.8152 - val_loss: 0.3903 - val_accuracy: 0.8494
Epoch 7/50
400/400 [==============================] - 38s 96ms/step - loss: 0.3671 -
accuracy: 0.8531 - val_loss: 0.3754 - val_accuracy: 0.8544
Epoch 8/50
400/400 [==============================] - 38s 95ms/step - loss: 0.3177 -
accuracy: 0.8805 - val_loss: 0.3131 - val_accuracy: 0.9038
Epoch 9/50
400/400 [==============================] - 38s 96ms/step - loss: 0.2704 -
accuracy: 0.8958 - val_loss: 0.3477 - val_accuracy: 0.8481
Epoch 10/50
400/400 [==============================] - 38s 96ms/step - loss: 0.2253 -
accuracy: 0.9194 - val_loss: 0.2096 - val_accuracy: 0.9250
Epoch 11/50
400/400 [==============================] - 38s 96ms/step - loss: 0.1915 -
accuracy: 0.9302 - val_loss: 0.2394 - val_accuracy: 0.9069
Epoch 12/50
400/400 [==============================] - 38s 95ms/step - loss: 0.1668 -
accuracy: 0.9417 - val_loss: 0.1684 - val_accuracy: 0.9431
Epoch 13/50
400/400 [==============================] - 39s 97ms/step - loss: 0.1434 -
accuracy: 0.9509 - val_loss: 0.1538 - val_accuracy: 0.9544
Epoch 14/50
400/400 [==============================] - 39s 97ms/step - loss: 0.1220 -
accuracy: 0.9589 - val_loss: 0.1764 - val_accuracy: 0.9531
Epoch 15/50
400/400 [==============================] - 39s 98ms/step - loss: 0.1144 -
accuracy: 0.9605 - val_loss: 0.1823 - val_accuracy: 0.9356
Epoch 16/50
```

```
400/400 [==============================] - 39s 97ms/step - loss: 0.1046 -
accuracy: 0.9636 - val_loss: 0.1540 - val_accuracy: 0.9538

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op,
_jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing
3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/model_1_0_0/assets

INFO:tensorflow:Assets written to: models/model_1_0_0/assets

Epoch 1/50
400/400 [==============================] - 43s 104ms/step - loss: 0.5616 -
accuracy: 0.7084 - val_loss: 0.4169 - val_accuracy: 0.8344
Epoch 2/50
400/400 [==============================] - 39s 97ms/step - loss: 0.3659 -
accuracy: 0.8462 - val_loss: 0.2608 - val_accuracy: 0.8938
Epoch 3/50
400/400 [==============================] - 39s 97ms/step - loss: 0.2168 -
accuracy: 0.9183 - val_loss: 0.1794 - val_accuracy: 0.9494
Epoch 4/50
400/400 [==============================] - 38s 96ms/step - loss: 0.1452 -
accuracy: 0.9492 - val_loss: 0.1649 - val_accuracy: 0.9463
Epoch 5/50
400/400 [==============================] - 38s 96ms/step - loss: 0.1186 -
accuracy: 0.9589 - val_loss: 0.1408 - val_accuracy: 0.9638
Epoch 6/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0984 -
accuracy: 0.9670 - val_loss: 0.1462 - val_accuracy: 0.9494
Epoch 7/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0813 -
accuracy: 0.9734 - val_loss: 0.1305 - val_accuracy: 0.9681
Epoch 8/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0753 -
accuracy: 0.9736 - val_loss: 0.1359 - val_accuracy: 0.9663
Epoch 9/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0672 -
accuracy: 0.9759 - val_loss: 0.1917 - val_accuracy: 0.9494
Epoch 10/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0581 -
accuracy: 0.9791 - val_loss: 0.1296 - val_accuracy: 0.9625
Epoch 11/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0564 -
accuracy: 0.9809 - val_loss: 0.1220 - val_accuracy: 0.9712
Epoch 12/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0411 -
accuracy: 0.9864 - val_loss: 0.1564 - val_accuracy: 0.9694
Epoch 13/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0429 -
accuracy: 0.9831 - val_loss: 0.1775 - val_accuracy: 0.9581
```

```
Epoch 14/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0379 -
accuracy: 0.9870 - val_loss: 0.1382 - val_accuracy: 0.9700

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op,
_jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing
3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/model_1_0_1/assets

INFO:tensorflow:Assets written to: models/model_1_0_1/assets

Epoch 1/50
400/400 [==============================] - 42s 103ms/step - loss: 0.5842 -
accuracy: 0.6797 - val_loss: 0.7682 - val_accuracy: 0.6100
Epoch 2/50
400/400 [==============================] - 39s 97ms/step - loss: 0.3257 -
accuracy: 0.8705 - val_loss: 0.3643 - val_accuracy: 0.8706
Epoch 3/50
400/400 [==============================] - 39s 97ms/step - loss: 0.1780 -
accuracy: 0.9347 - val_loss: 0.1731 - val_accuracy: 0.9456
Epoch 4/50
400/400 [==============================] - 38s 96ms/step - loss: 0.1303 -
accuracy: 0.9539 - val_loss: 0.1666 - val_accuracy: 0.9425
Epoch 5/50
400/400 [==============================] - 38s 96ms/step - loss: 0.1059 -
accuracy: 0.9645 - val_loss: 0.1290 - val_accuracy: 0.9619
Epoch 6/50
400/400 [==============================] - 38s 95ms/step - loss: 0.0930 -
accuracy: 0.9694 - val_loss: 0.1403 - val_accuracy: 0.9550
Epoch 7/50
400/400 [==============================] - 39s 97ms/step - loss: 0.0779 -
accuracy: 0.9742 - val_loss: 0.1144 - val_accuracy: 0.9694
Epoch 8/50
400/400 [==============================] - 38s 95ms/step - loss: 0.0672 -
accuracy: 0.9772 - val_loss: 0.1643 - val_accuracy: 0.9606
Epoch 9/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0593 -
accuracy: 0.9805 - val_loss: 0.1383 - val_accuracy: 0.9675
Epoch 10/50
400/400 [==============================] - 38s 96ms/step - loss: 0.0513 -
accuracy: 0.9833 - val_loss: 0.1439 - val_accuracy: 0.9712

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op,
_jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing
3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/model_1_0_2/assets

INFO:tensorflow:Assets written to: models/model_1_0_2/assets
```

```
Epoch 1/50
400/400 [==============================] - 36s 87ms/step - loss: 0.6629 -
accuracy: 0.6187 - val_loss: 0.6205 - val_accuracy: 0.6981
Epoch 2/50
400/400 [==============================] - 33s 82ms/step - loss: 0.5920 -
accuracy: 0.6992 - val_loss: 0.5602 - val_accuracy: 0.7125
Epoch 3/50
400/400 [==============================] - 32s 80ms/step - loss: 0.5486 -
accuracy: 0.7209 - val_loss: 0.5458 - val_accuracy: 0.7506
Epoch 4/50
400/400 [==============================] - 32s 80ms/step - loss: 0.5054 -
accuracy: 0.7517 - val_loss: 0.4881 - val_accuracy: 0.7606
Epoch 5/50
400/400 [==============================] - 32s 80ms/step - loss: 0.4758 -
accuracy: 0.7850 - val_loss: 0.4498 - val_accuracy: 0.7919
Epoch 6/50
400/400 [==============================] - 32s 80ms/step - loss: 0.4434 -
accuracy: 0.8097 - val_loss: 0.4848 - val_accuracy: 0.7575
Epoch 7/50
400/400 [==============================] - 32s 80ms/step - loss: 0.4085 -
accuracy: 0.8298 - val_loss: 0.4512 - val_accuracy: 0.8031
Epoch 8/50
400/400 [==============================] - 32s 80ms/step - loss: 0.3814 -
accuracy: 0.8464 - val_loss: 0.3635 - val_accuracy: 0.8462
Epoch 9/50
400/400 [==============================] - 32s 81ms/step - loss: 0.3436 -
accuracy: 0.8591 - val_loss: 0.3763 - val_accuracy: 0.8675
Epoch 10/50
400/400 [==============================] - 32s 80ms/step - loss: 0.3103 -
accuracy: 0.8797 - val_loss: 0.3424 - val_accuracy: 0.8475
Epoch 11/50
400/400 [==============================] - 31s 78ms/step - loss: 0.2888 -
accuracy: 0.8913 - val_loss: 0.3339 - val_accuracy: 0.8550
Epoch 12/50
400/400 [==============================] - 31s 78ms/step - loss: 0.2500 -
accuracy: 0.9067 - val_loss: 0.2661 - val_accuracy: 0.8963
Epoch 13/50
400/400 [==============================] - 31s 78ms/step - loss: 0.2160 -
accuracy: 0.9222 - val_loss: 0.2157 - val_accuracy: 0.9281
Epoch 14/50
400/400 [==============================] - 31s 79ms/step - loss: 0.1952 -
accuracy: 0.9339 - val_loss: 0.2085 - val_accuracy: 0.9388
Epoch 15/50
400/400 [==============================] - 31s 78ms/step - loss: 0.1712 -
accuracy: 0.9416 - val_loss: 0.1957 - val_accuracy: 0.9337
Epoch 16/50
400/400 [==============================] - 32s 79ms/step - loss: 0.1538 -
accuracy: 0.9459 - val_loss: 0.1904 - val_accuracy: 0.9456
```

```
Epoch 17/50
400/400 [==============================] - 32s 79ms/step - loss: 0.1426 -
accuracy: 0.9494 - val_loss: 0.1697 - val_accuracy: 0.9513
Epoch 18/50
400/400 [==============================] - 32s 79ms/step - loss: 0.1238 -
accuracy: 0.9578 - val_loss: 0.1691 - val_accuracy: 0.9613
Epoch 19/50
400/400 [==============================] - 32s 80ms/step - loss: 0.1161 -
accuracy: 0.9592 - val_loss: 0.1406 - val_accuracy: 0.9606
Epoch 20/50
400/400 [==============================] - 32s 79ms/step - loss: 0.1066 -
accuracy: 0.9638 - val_loss: 0.1386 - val_accuracy: 0.9619
Epoch 21/50
400/400 [==============================] - 32s 80ms/step - loss: 0.1000 -
accuracy: 0.9678 - val_loss: 0.1379 - val_accuracy: 0.9638
Epoch 22/50
400/400 [==============================] - 32s 79ms/step - loss: 0.0960 -
accuracy: 0.9644 - val_loss: 0.1425 - val_accuracy: 0.9644
Epoch 23/50
400/400 [==============================] - 32s 80ms/step - loss: 0.0837 -
accuracy: 0.9722 - val_loss: 0.1470 - val_accuracy: 0.9650
Epoch 24/50
400/400 [==============================] - 33s 82ms/step - loss: 0.0823 -
accuracy: 0.9725 - val_loss: 0.1538 - val_accuracy: 0.9600

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op,
_jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing
3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/model_1_1_0/assets

INFO:tensorflow:Assets written to: models/model_1_1_0/assets

Epoch 1/50
400/400 [==============================] - 36s 87ms/step - loss: 0.5155 -
accuracy: 0.7359 - val_loss: 0.3327 - val_accuracy: 0.8763
Epoch 2/50
400/400 [==============================] - 33s 82ms/step - loss: 0.2804 -
accuracy: 0.8917 - val_loss: 0.2372 - val_accuracy: 0.9219
Epoch 3/50
400/400 [==============================] - 32s 81ms/step - loss: 0.1872 -
accuracy: 0.9292 - val_loss: 0.1565 - val_accuracy: 0.9556
Epoch 4/50
400/400 [==============================] - 32s 81ms/step - loss: 0.1413 -
accuracy: 0.9520 - val_loss: 0.1832 - val_accuracy: 0.9350
Epoch 5/50
400/400 [==============================] - 32s 81ms/step - loss: 0.1177 -
accuracy: 0.9580 - val_loss: 0.1784 - val_accuracy: 0.9319
Epoch 6/50
400/400 [==============================] - 32s 80ms/step - loss: 0.1011 -
```

```
accuracy: 0.9667 - val_loss: 0.1401 - val_accuracy: 0.9500
Epoch 7/50
400/400 [==============================] - 32s 81ms/step - loss: 0.0810 -
accuracy: 0.9720 - val_loss: 0.1322 - val_accuracy: 0.9600
Epoch 8/50
400/400 [==============================] - 32s 81ms/step - loss: 0.0648 -
accuracy: 0.9786 - val_loss: 0.1407 - val_accuracy: 0.9625
Epoch 9/50
400/400 [==============================] - 32s 81ms/step - loss: 0.0707 -
accuracy: 0.9764 - val_loss: 0.1381 - val_accuracy: 0.9694
Epoch 10/50
400/400 [==============================] - 33s 81ms/step - loss: 0.0573 -
accuracy: 0.9787 - val_loss: 0.1881 - val_accuracy: 0.9556

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op,
_jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing
3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/model_1_1_1/assets

INFO:tensorflow:Assets written to: models/model_1_1_1/assets

Epoch 1/50
400/400 [==============================] - 36s 89ms/step - loss: 0.5654 -
accuracy: 0.6956 - val_loss: 0.4455 - val_accuracy: 0.8169
Epoch 2/50
400/400 [==============================] - 33s 83ms/step - loss: 0.3332 -
accuracy: 0.8672 - val_loss: 0.2606 - val_accuracy: 0.8981
Epoch 3/50
400/400 [==============================] - 32s 81ms/step - loss: 0.2015 -
accuracy: 0.9291 - val_loss: 0.2449 - val_accuracy: 0.9100
Epoch 4/50
400/400 [==============================] - 32s 81ms/step - loss: 0.1414 -
accuracy: 0.9539 - val_loss: 0.3080 - val_accuracy: 0.8888
Epoch 5/50
400/400 [==============================] - 33s 81ms/step - loss: 0.1159 -
accuracy: 0.9647 - val_loss: 0.1496 - val_accuracy: 0.9513
Epoch 6/50
400/400 [==============================] - 33s 82ms/step - loss: 0.0942 -
accuracy: 0.9689 - val_loss: 0.1451 - val_accuracy: 0.9631
Epoch 7/50
400/400 [==============================] - 32s 81ms/step - loss: 0.0828 -
accuracy: 0.9731 - val_loss: 0.1203 - val_accuracy: 0.9650
Epoch 8/50
400/400 [==============================] - 33s 82ms/step - loss: 0.0677 -
accuracy: 0.9786 - val_loss: 0.1209 - val_accuracy: 0.9625
Epoch 9/50
400/400 [==============================] - 32s 81ms/step - loss: 0.0628 -
accuracy: 0.9789 - val_loss: 0.1233 - val_accuracy: 0.9669
Epoch 10/50
```

```
400/400 [==============================] - 32s 81ms/step - loss: 0.0570 -
accuracy: 0.9830 - val_loss: 0.1662 - val_accuracy: 0.9619
```

WARNING:absl:Found untraced functions such as _jit_compiled_convolution_op, _jit_compiled_convolution_op, _jit_compiled_convolution_op while saving (showing 3 of 3). These functions will not be directly callable after loading.

INFO:tensorflow:Assets written to: models/model_1_1_2/assets

INFO:tensorflow:Assets written to: models/model_1_1_2/assets