In [ ]:
```
import os
import numpy as np
import pandas as pd
from PIL import Image
import matplotlib.pyplot as plt
from tensorflow import keras
from keras import layers
import sklearn
from sklearn.model_selection import train_test_split
from sklearn.metrics import accuracy_score, f1_score, precision_score, recall_score,
```

Preprocess data and load data

Firstly I need to retrieve the labels from the jsonl file, then load the images into a numpy array. Then we connect the labels with the images and preprocess the data.

In [ ]:
```
#read jsonl file
df = pd.read_json('./data/metadata.jsonl', lines=True)
df.head()
```

Out[ ]:

	file_name	text_prompt
0	train/sample_0.png	Low masking level
1	train/sample_1.png	Low masking level
2	train/sample_2.png	Low masking level
3	train/sample_3.png	Low masking level
4	train/sample_4.png	Low masking level

In [ ]:
```
#convert text prompt to 0,1,2 instead of Low, Medium, High respectively
df['text_prompt'] = df['text_prompt'].map({'Low masking level': 0, 'Medium masking le

df.head()
```

Out[ ]:

	file_name	text_prompt
0	train/sample_0.png	0
1	train/sample_1.png	0
2	train/sample_2.png	0
3	train/sample_3.png	0
4	train/sample_4.png	0

In [ ]:
```
#what is the distribution of the data
df['text_prompt'].value_counts()
```

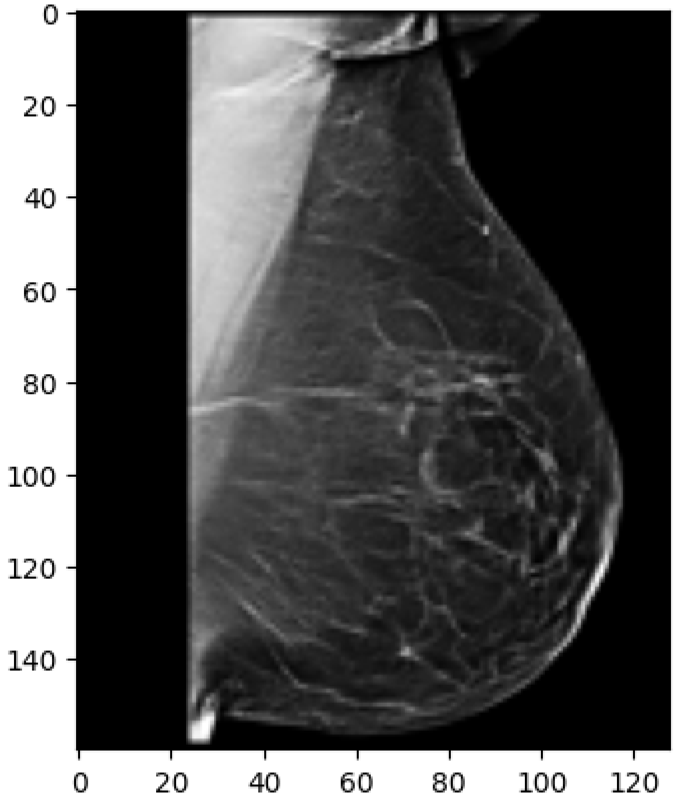
Out[ ]:
```
text_prompt
0    33333
1    33333
2    33333
Name: count, dtype: int64
```

```
In [ ]: labels = []
        #read labels from jsonl file
        for i in range(99999):
            labels.append(df['text_prompt'][i])

        print(labels)
```

Here we do the preprocessing of the images reducing the size to 128x160 and also making sure the image is in grayscale. All the processed images are saved into a folder for future use, so we don't need to preprocess the images again.

```
In [ ]: #load png files

        processed_folder = './data/processed/'
        num_required_images = 99999

        #check if the processed folder exists and has enough images
        if os.path.exists(processed_folder) and len(os.listdir(processed_folder)) >= num_requ
            print('Processed folder exists and has enough images')
            images = []
            for i in range(num_required_images):
                print("Loading image", i)
                img = Image.open(os.path.join(processed_folder, 'sample_' + str(i) + '.png'))
                img = img.convert('L')
                img_array = np.array(img)
                images.append(img_array)
        else:
            #process and save images
            print('Processing and saving images')
            images = []
            original_folder = './data/train/'
            for i in range(num_required_images):
                print("Processing image", i)
                filename = 'sample_' + str(i) + '.png'

                #create the processed folder if it doesn't exist
                if not os.path.exists(processed_folder):
                    os.makedirs(processed_folder)

                #process the image
                img = Image.open(os.path.join(original_folder, filename))
                img = img.resize((128, 160))
                img = img.convert('L')
                img_array = np.array(img)

                #save the processed image
                img.save(os.path.join(processed_folder, filename))

                images.append(img_array)
```

```
In [ ]: print(images[0].shape)
        #are the images loaded correctly?
        plt.imshow(images[0], cmap='gray')

(160, 128)

Out[ ]: <matplotlib.image.AxesImage at 0x294ff4970>
```



Now a very important part is splitting the data into training, validation and test sets. We will use 60% of the data for training, 20% for validation and 20% for testing. To save memory we also delete the unused variables.

In [ ]:
```
#initial split of the data 80% train, 20% test
X_train_temp, X_test, y_train_temp, y_test = train_test_split(images, labels, test_si

#further split the training data into 75% train, 25% validation
X_train, X_val, y_train, y_val = train_test_split(X_train_temp, y_train_temp, test_si

#clear unused variables for memory
del X_train_temp
del y_train_temp
del images
```

Building the base deep learning model

In the case that we have already built the model we will load it from the file, otherwise we will build the model and save it to a file.

In [ ]:
```
#if modelV1.h5 exists, load it
try:
    modelV1 = keras.models.load_model('./models/modelV1.h5')
    print('Model loaded')
    print(modelV1.summary())
    print(modelV1.history)
    V1Created = True
except:
    V1Created = False
    print('Model not found')
```

```
2024-03-03 18:09:22.577014: I metal_plugin/src/device/metal_device.cc:1154] Metal device set to: Apple M1
2024-03-03 18:09:22.577336: I metal_plugin/src/device/metal_device.cc:296] systemMemory: 8.00 GB
2024-03-03 18:09:22.577713: I metal_plugin/src/device/metal_device.cc:313] maxCacheSize: 2.67 GB
2024-03-03 18:09:22.578160: I tensorflow/core/common_runtime/pluggable_device/pluggable_device_factory.cc:303] Could not identify NUMA node of platform GPU ID 0, defaulting to 0. Your kernel may not have been built with NUMA support.
2024-03-03 18:09:22.579061: I tensorflow/core/common_runtime/pluggable_device/pluggable_device_factory.cc:269] Created TensorFlow device (/job:localhost/replica:0/task:0/device:GPU:0 with 0 MB memory) -> physical PluggableDevice (device: 0, name: METAL, pci bus id: <undefined>)
Model loaded
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_1 (InputLayer)        [(None, 160, 128, 1)]     0

 conv2d (Conv2D)             (None, 158, 126, 16)      160

 max_pooling2d (MaxPooling2  (None, 79, 63, 16)        0
 D)

 flatten (Flatten)           (None, 79632)             0

 dense (Dense)               (None, 3)                 238899

=================================================================
Total params: 239059 (933.82 KB)
Trainable params: 239059 (933.82 KB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
None
None
```

If we haven't built the model yet, we will build a simple deep learning model with 1 convolutional layer, a 2d max pooling layer,a flatten layer and 1 dense layer that is the classifier output using softmax. We will use the Adam optimizer and the categorical crossentropy loss function.

In [ ]:

```
if not V1Created:
    inputs = keras.Input(shape=(160,128,1)) #resolution of images
    x = layers.Conv2D(16, 3, activation="relu")(inputs)
    x = layers.MaxPooling2D(pool_size=2)(x)
    x = layers.Flatten()(x)
    outputs = layers.Dense(3, activation="softmax")(x) #3 classes
    modelV1 = keras.Model(inputs=inputs, outputs=outputs)
```

In [ ]:

```
modelV1.summary()
print(modelV1.history)
```

```
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 input_1 (InputLayer)        [(None, 160, 128, 1)]     0         
                                                                 
 conv2d (Conv2D)             (None, 158, 126, 16)      160       
                                                                 
 max_pooling2d (MaxPooling2  (None, 79, 63, 16)        0         
 D)                                                              
                                                                 
 flatten (Flatten)           (None, 79632)             0         
                                                                 
 dense (Dense)               (None, 3)                 238899    
                                                                 
=================================================================
Total params: 239059 (933.82 KB)
Trainable params: 239059 (933.82 KB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
None
```

In [ ]:
```
#compile model if not loaded
if not V1Created:
    #legacy is faster on mac m1 chip
    modelV1.compile(optimizer=keras.optimizers.legacy.Adam(learning_rate=0.001),
                loss='sparse_categorical_crossentropy',
                metrics=['accuracy'])
```

Now we will train the model using the training set and validate it using the validation set. We will also save the model to a file.

In [ ]:
```
#train model if not loaded
if not V1Created:

    modelV1.fit(np.array(X_train), np.array(y_train), epochs=1, batch_size=16, valida
```

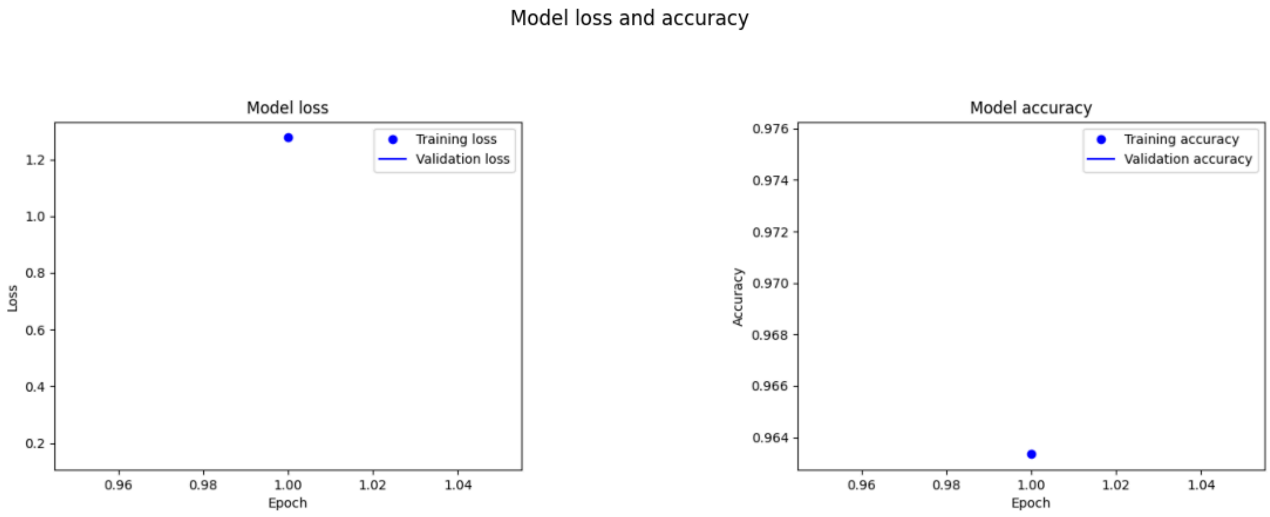
In [ ]:
```
#save model if not loaded
if not V1Created:
    modelV1.save('./models/modelV1.h5')
```

Below we define a few functions to plot the training history and to evaluate the model using the test set.

In [ ]:
```
#show graph of training loss and validation loss

def plot_loss_accuracy(modelCreated, model, modelName):
    if not modelCreated:
        history_dict = model.history.history
        loss_values = history_dict["loss"]
        val_loss_values = history_dict["val_loss"]
        epochs = range(1, len(loss_values) + 1)
        plt.plot(epochs, loss_values, "bo", label="Training loss")
        plt.plot(epochs, val_loss_values, "b", label="Validation loss")
        plt.title('Model loss')
        plt.ylabel('Loss')
        plt.xlabel('Epoch')
        plt.legend()
        plt.savefig('./models/' + modelName + '_loss.png')
        plt.show()
```

```
        plt.clf()
        plt.plot(epochs, history_dict['accuracy'], 'bo', label='Training accuracy')
        plt.plot(epochs, history_dict['val_accuracy'], 'b', label='Validation accurac
        plt.title('Model accuracy')
        plt.ylabel('Accuracy')
        plt.xlabel('Epoch')
        plt.legend()
        plt.savefig('./models/' + modelName + '_accuracy.png')
        plt.show()

    else:
        img1 = Image.open('./models/' + modelName + '_loss.png')
        img2= Image.open('./models/' + modelName + '_accuracy.png')
        fig, ax = plt.subplots(1, 2, figsize=(15, 5))
        fig.suptitle('Model loss and accuracy')
        ax[0].imshow(img1)
        ax[0].axis('off')

        ax[1].imshow(img2)
        ax[1].axis('off')
```

In [ ]:
```
plot_loss_accuracy(V1Created, modelV1, 'modelV1')
```



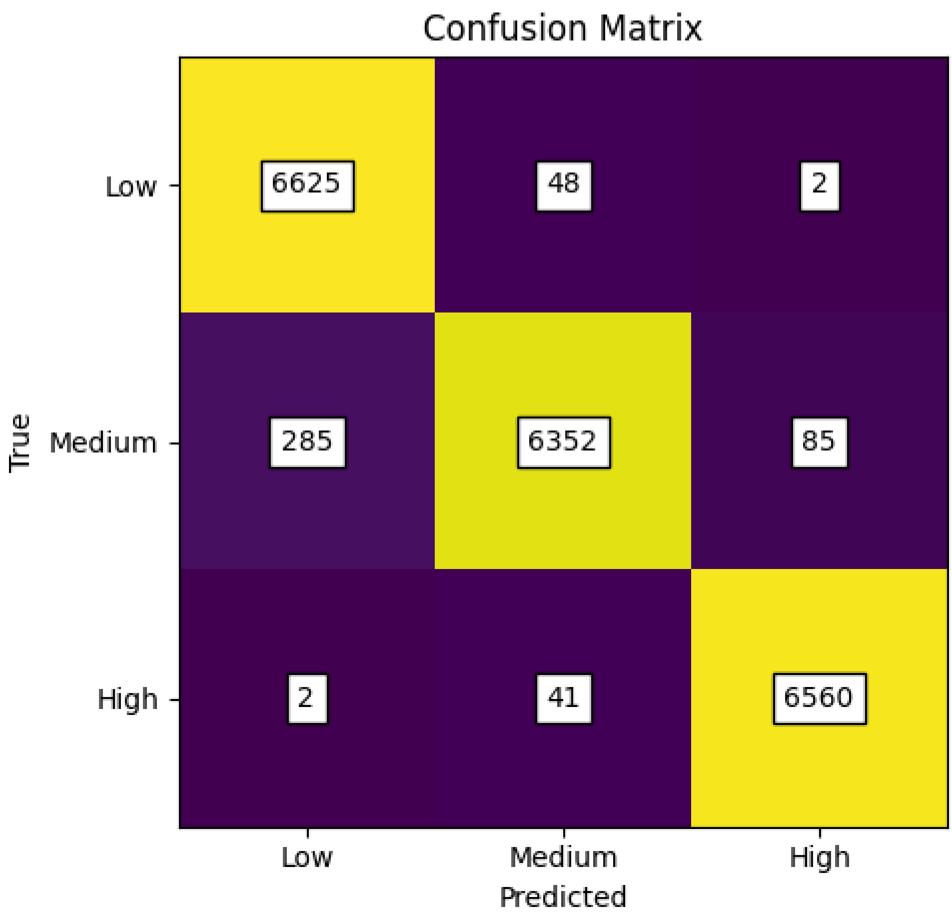
In [ ]:
```
#evaluate model
def evaluate_model(model, X_test, y_test, modelName):
    results = model.evaluate(np.array(X_test), np.array(y_test))

    #get predictions
    y_pred = model.predict(np.array(X_test))

    #convert probabilities to class labels
    y_pred = np.argmax(y_pred, axis=1)

    accuracy = accuracy_score(y_test, y_pred)
    f1 = f1_score(y_test, y_pred, average='weighted')
    precision = precision_score(y_test, y_pred, average='weighted')
    recall = recall_score(y_test, y_pred, average='weighted')
    conf_matrix = confusion_matrix(y_test, y_pred)

    print("Results:", results)
    print("Accuracy:", accuracy)
    print("F1 Score:", f1)
    print("Precision:", precision)
    print("Recall:", recall)
    print("Confusion Matrix:\n", conf_matrix)

    #plot confusion matrix with numbers and labels
```

```python
    fig, ax = plt.subplots()
    im = ax.imshow(conf_matrix)

    ax.set_xticks(np.arange(3))
    ax.set_yticks(np.arange(3))
    ax.set_xticklabels(['Low', 'Medium', 'High'])
    ax.set_yticklabels(['Low', 'Medium', 'High'])
    ax.set_xlabel('Predicted')
    ax.set_ylabel('True')

    for i in range(3):
        for j in range(3):
            text = ax.text(j, i, conf_matrix[i, j], ha="center", va="center", color="


    ax.set_title("Confusion Matrix")
    fig.tight_layout()

    plt.show()

    #create a pandas series with the results
    results = pd.Series([modelName ,accuracy, f1, precision, recall], index=['Model',
    return results
```

In [ ]:

```python
modeV1_results = evaluate_model(modelV1, X_test, y_test, 'modelV1')
modeV1_results
```

```
2024-03-03 18:09:25.144292: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step - loss: 0.1388 - accuracy: 0.9
768
 12/625 [..............................] - ETA: 6s
2024-03-03 18:09:33.599095: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 5s 8ms/step
Results: [0.13882388174533844, 0.9768499732017517]
Accuracy: 0.97685
F1 Score: 0.9767627858890039
Precision: 0.9771766914265317
Recall: 0.97685
Confusion Matrix:
 [[6625   48    2]
 [ 285 6352   85]
 [   2   41 6560]]
```



Out[ ]:
```
Model          modelV1
Accuracy       0.97685
F1 Score      0.976763
Precision     0.977177
Recall         0.97685
dtype: object
```

The first base model has already done an exceptional job, however there is still room for improvement. Which leads us to the next step.

Improving the model

We will attempt to find the best parameters for the model by adjusting the parameters values creating a model for each different value and testing the model. The results for each model will be saved and we I shall compare the results to find the best model.

Values to tune:

- learning rate
- optimizer
- batch size
- epochs
- layers

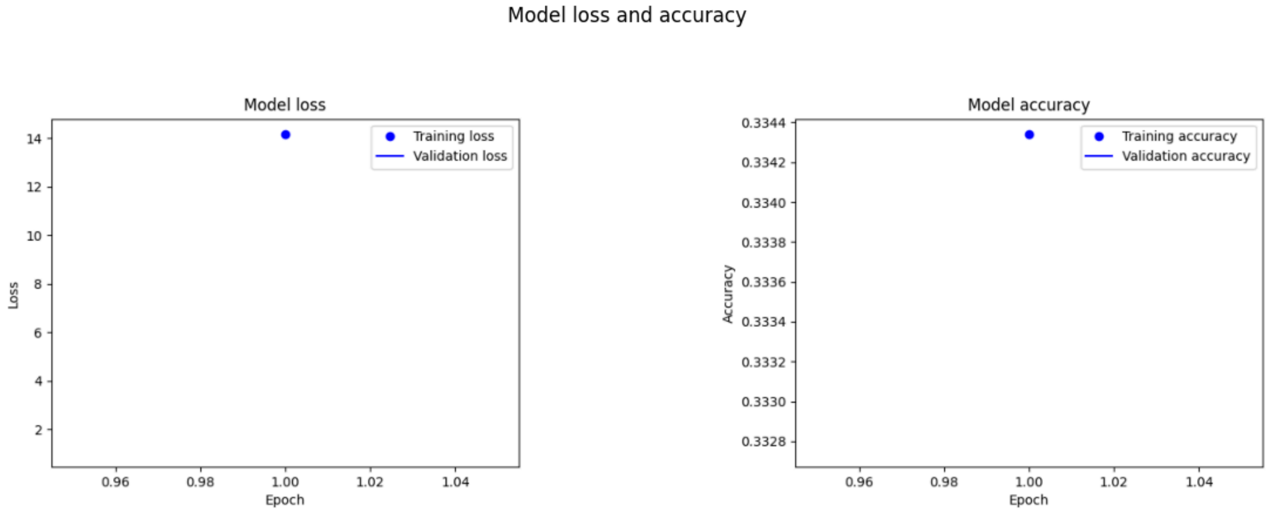
Learning rate

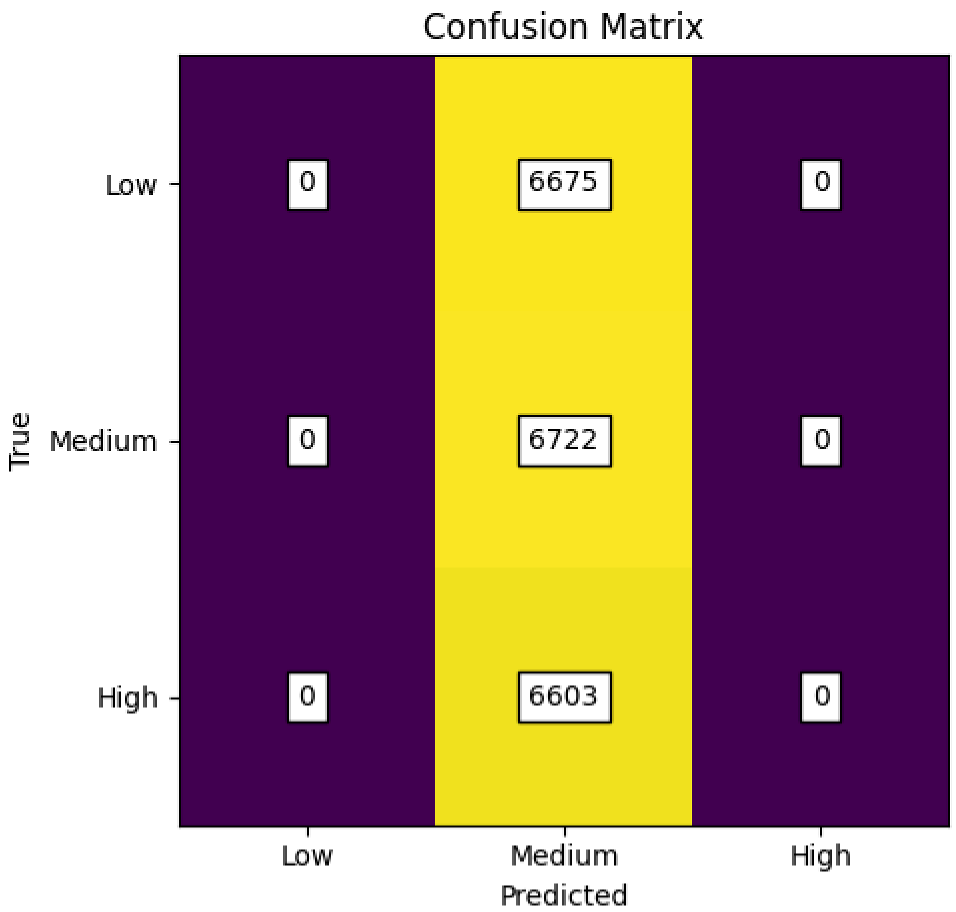
In [ ]:
```
#tuning different learning rates
#modelv1 uses adam optimizer, so it had a default learning rate of 0.001
#we will try learning rates of 0.1, 0.01, 0.0001
```

```python
lr_df = pd.DataFrame(columns=['Learning Rate', 'Accuracy', 'F1 Score', 'Precision', '
learning_rates = [0.1, 0.01, 0.001, 0.0001, 0.00001]

for rate in learning_rates:

    #try load already built model
    try:
        model_name = 'modelV1_lr_'+ str(rate)
        model = keras.models.load_model('./models/'+model_name+'.h5')
        print('Model loaded')
        modelCreated = True
    except:
        modelCreated = False
        print('Model not found')

    print("Learning Rate:", rate)

    if not modelCreated:
        #same model as modelV1, but with different learning rates
        inputs = keras.Input(shape=(160,128,1)) #resolution of images
        x = layers.Conv2D(16, 3, activation="relu")(inputs)
        x = layers.MaxPooling2D(pool_size=2)(x)
        x = layers.Flatten()(x)
        outputs = layers.Dense(3, activation="softmax")(x) #3 classes
        model = keras.Model(inputs=inputs, outputs=outputs)

        model.compile(optimizer=keras.optimizers.legacy.Adam(learning_rate=rate),
                loss='sparse_categorical_crossentropy',
                metrics=['accuracy'])
        model.fit(np.array(X_train), np.array(y_train), epochs=1, batch_size=16, vali

        model.save('./models/'+ model_name + '.h5')

    plot_loss_accuracy(modelCreated, model, model_name)
    results = evaluate_model(model, X_test, y_test, model_name)
    results['Learning Rate'] = rate
    lr_df.loc[len(lr_df.index)] = results
```

```
Model loaded
Learning Rate: 0.1
  1/625 [..............................] - ETA: 2:39 - loss: 1.1016 - accuracy: 0.3125
2024-03-03 18:09:40.617964: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step - loss: 1.0990 - accuracy: 0.3
361
  9/625 [..............................] - ETA: 9s
2024-03-03 18:09:48.726153: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 6s 9ms/step
Results: [1.0989689826965332, 0.3361000120639801]
Accuracy: 0.3361
F1 Score: 0.16909394506399222
Precision: 0.11296321000000001
Recall: 0.3361
Confusion Matrix:
 [[   0 6675    0]
 [   0 6722    0]
 [   0 6603    0]]
```

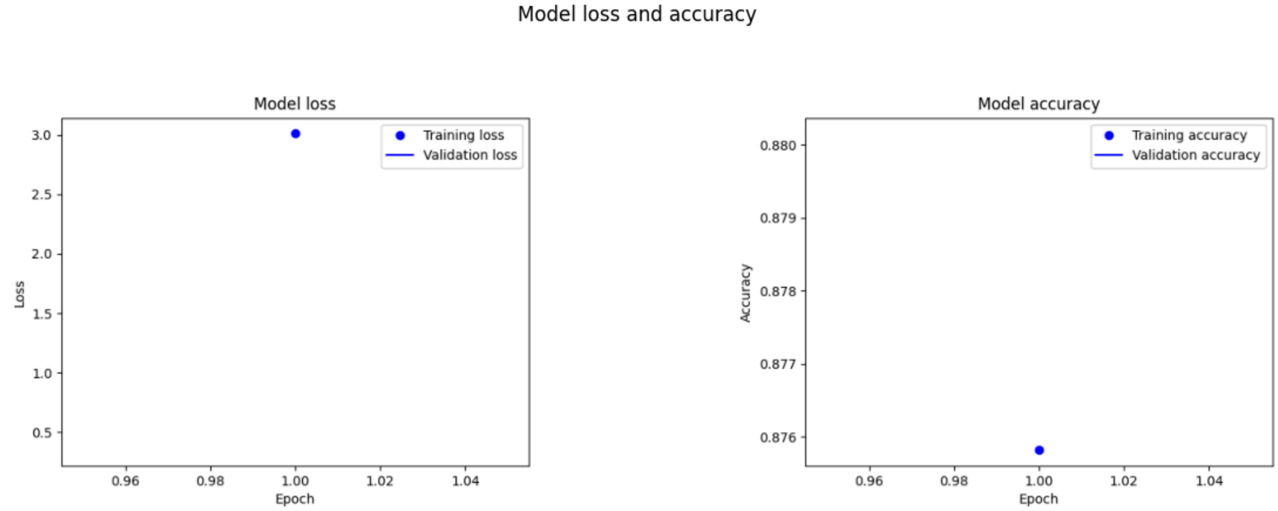
```
/Library/Frameworks/Python.framework/Versions/3.10/lib/python3.10/site-packages/sklear
n/metrics/_classification.py:1497: UndefinedMetricWarning: Precision is ill-defined an
d being set to 0.0 in labels with no predicted samples. Use `zero_division` parameter
to control this behavior.
  _warn_prf(average, modifier, f"{metric.capitalize()} is", len(result))
```

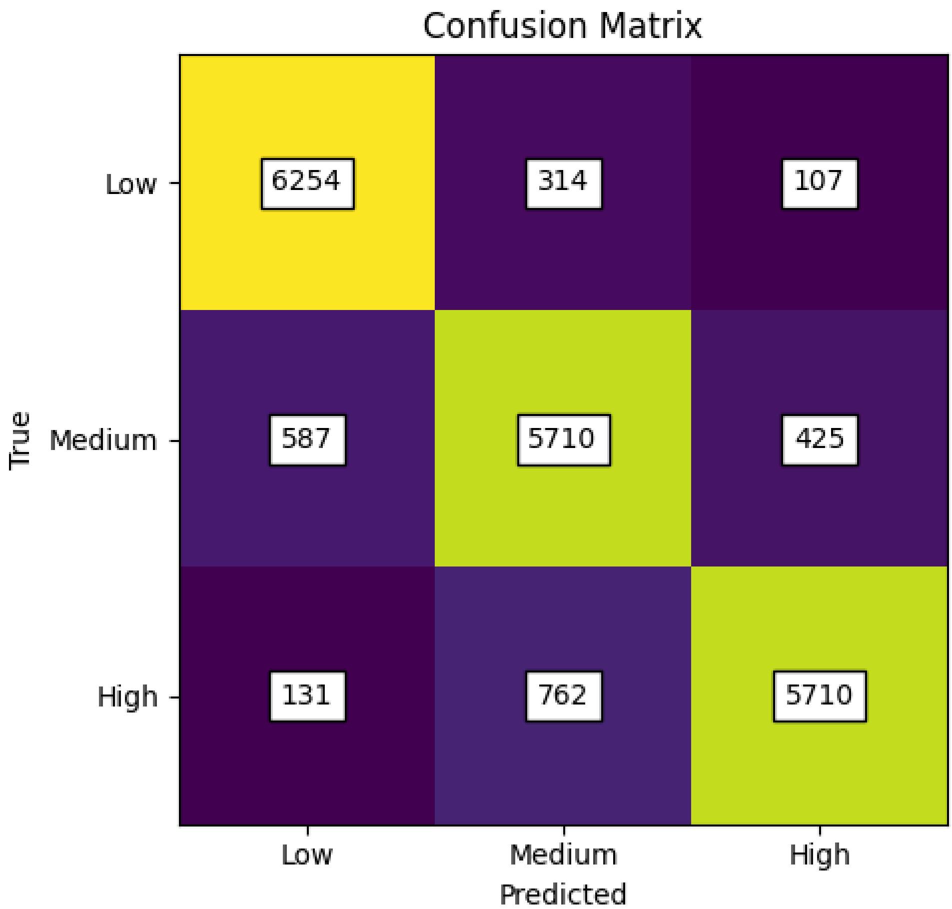





```
Model loaded
Learning Rate: 0.01
  4/625 [..............................] - ETA: 11s - loss: 0.3479 - accuracy: 0.8594
2024-03-03 18:09:55.861604: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step - loss: 0.3327 - accuracy: 0.8
837
  1/625 [..............................] - ETA: 2:12
2024-03-03 18:10:03.845696: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
```

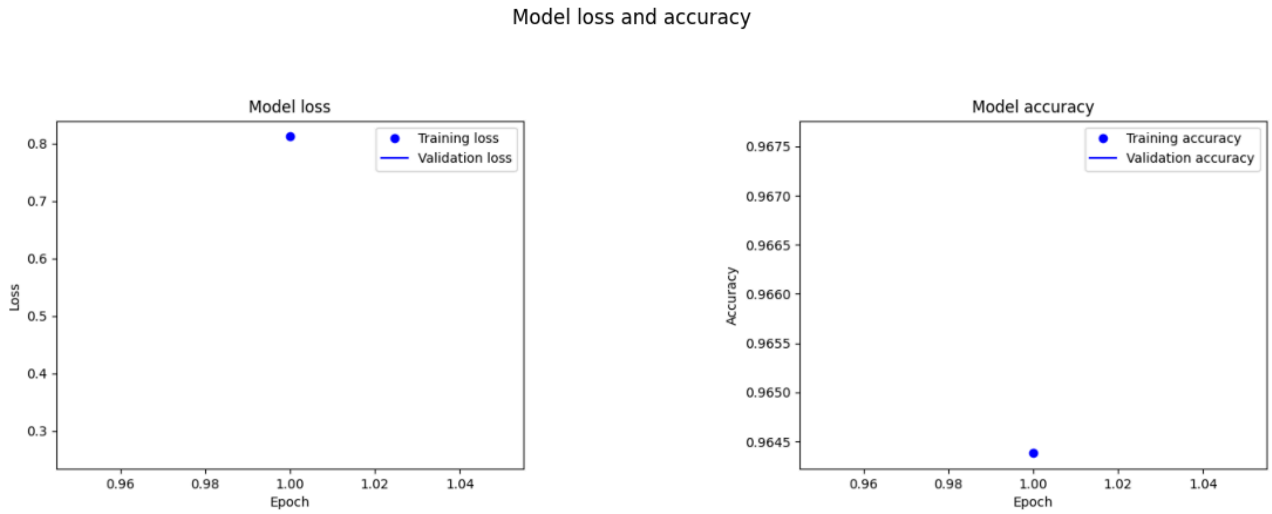
```
625/625 [==============================] - 5s 8ms/step
Results: [0.3326594829559326, 0.8837000131607056]
Accuracy: 0.8837
F1 Score: 0.883565805812315
Precision: 0.8841983153762792
Recall: 0.8837
Confusion Matrix:
 [[6254  314  107]
 [ 587 5710  425]
 [ 131  762 5710]]
```

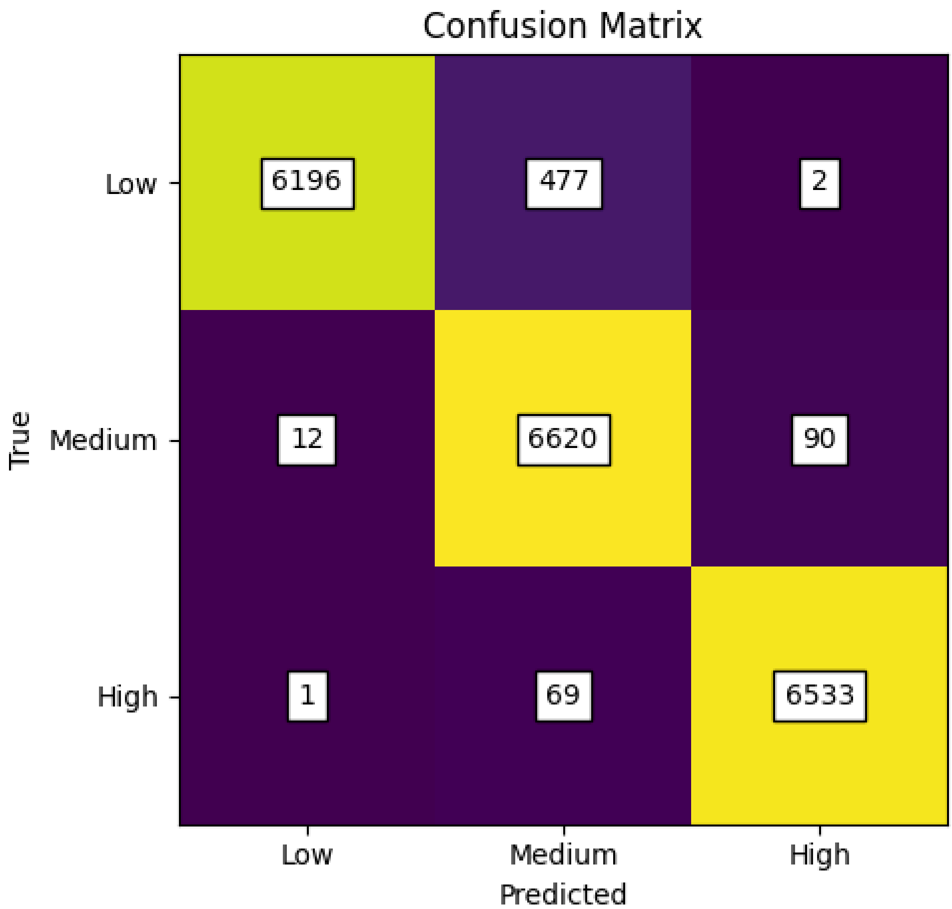





```
Model loaded
Learning Rate: 0.001
  5/625 [..............................] - ETA: 9s - loss: 0.4963 - accuracy: 0.9563
2024-03-03 18:10:10.858600: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 9s 14ms/step - loss: 0.2774 - accuracy: 0.9
675
  9/625 [..............................] - ETA: 9s
```

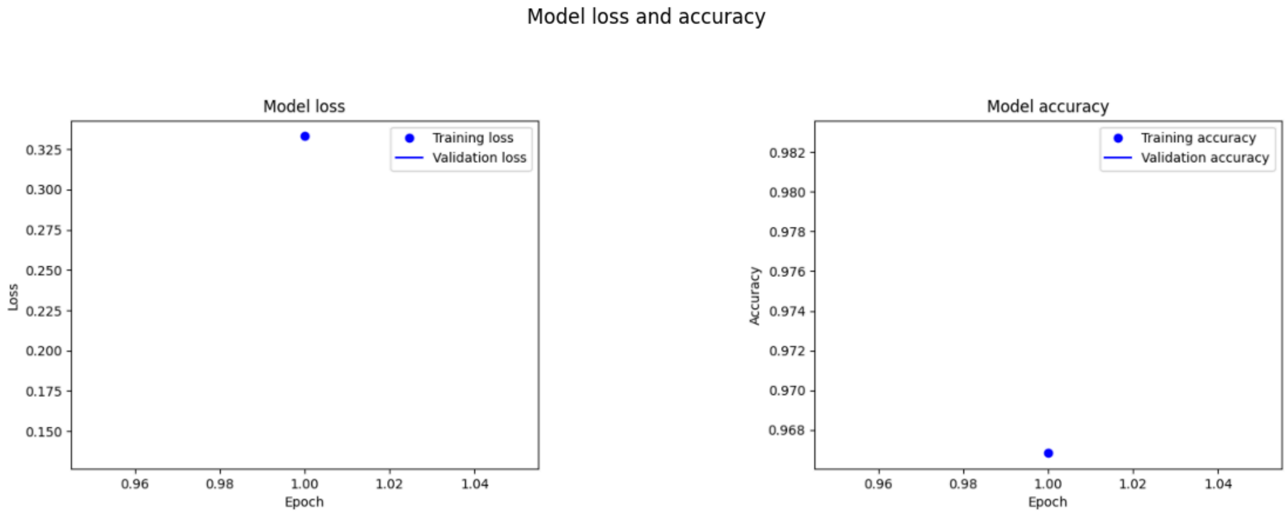
```
2024-03-03 18:10:20.649848: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step
Results: [0.27738699316978455, 0.9674500226974487]
Accuracy: 0.96745
F1 Score: 0.9675297730913924
Precision: 0.969107979028746
Recall: 0.96745
Confusion Matrix:
 [[6196  477    2]
 [  12 6620   90]
 [   1   69 6533]]
```

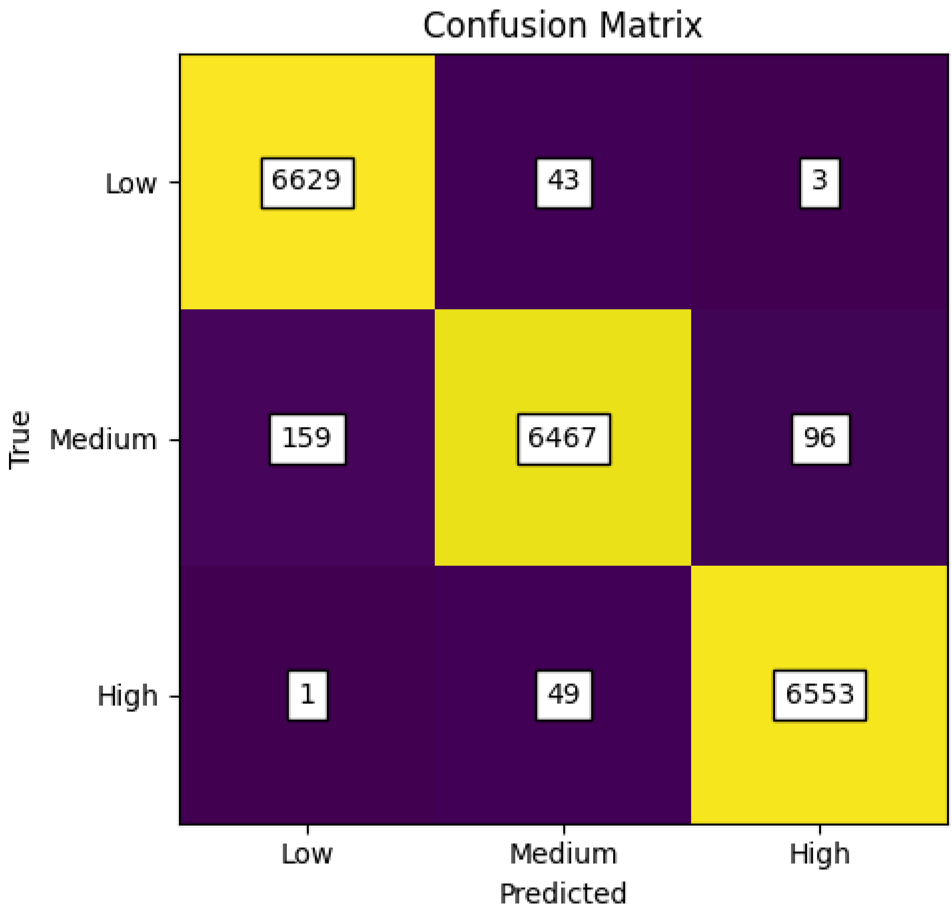





```
Model loaded
Learning Rate: 0.0001
  1/625 [..............................] - ETA: 2:26 - loss: 0.1616 - accuracy: 0.9688
2024-03-03 18:10:29.106757: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
```

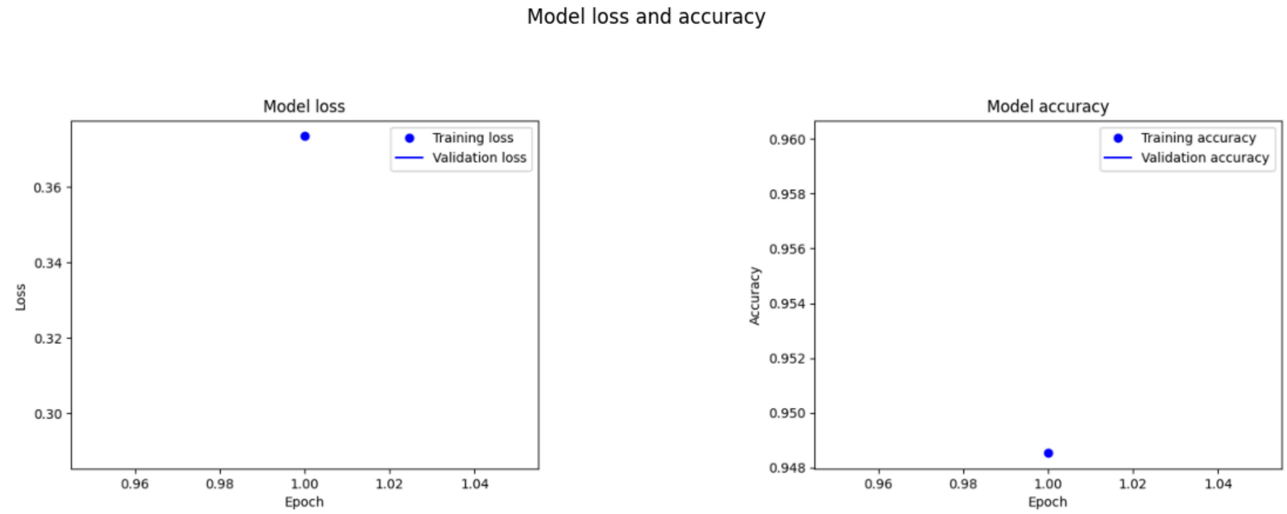
```
625/625 [==============================] - 9s 14ms/step - loss: 0.1435 - accuracy: 0.9
825
  8/625 [..............................] - ETA: 11s
2024-03-03 18:10:39.064325: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step
Results: [0.14349274337291718, 0.982450008392334]
Accuracy: 0.98245
F1 Score: 0.9824009056758656
Precision: 0.9825064814648422
Recall: 0.98245
Confusion Matrix:
 [[6629   43    3]
 [ 159 6467   96]
 [   1   49 6553]]
```

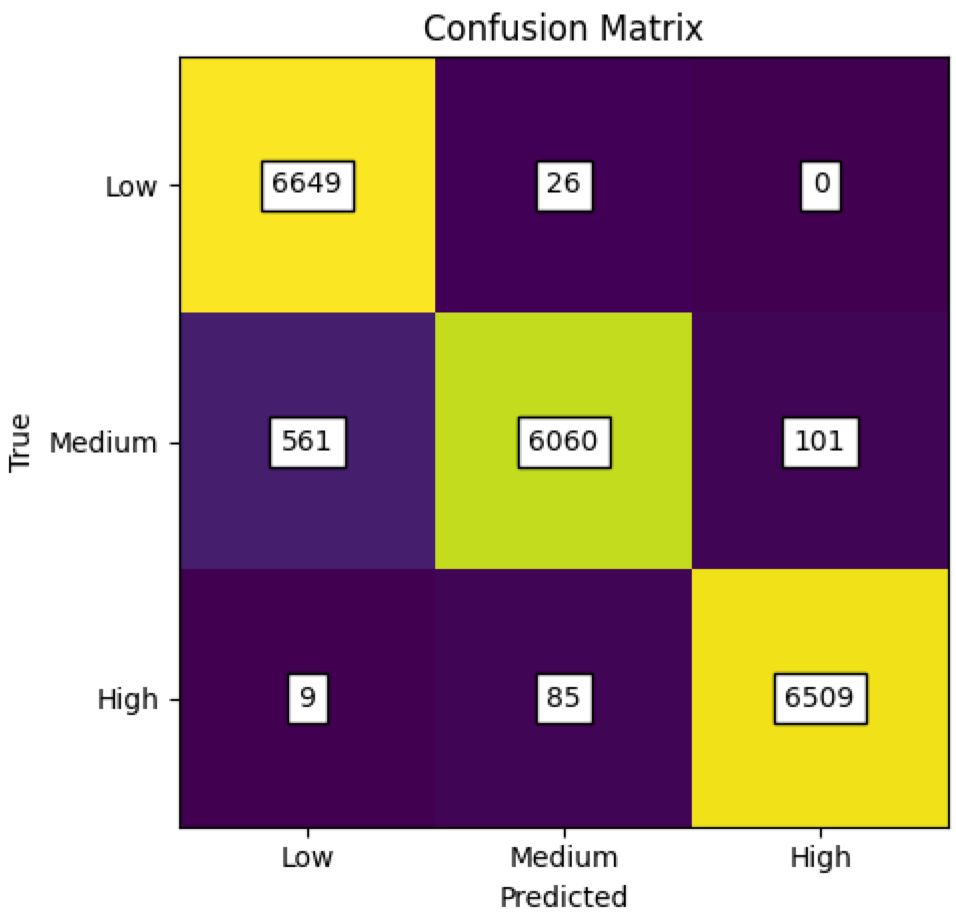





```
Model loaded
Learning Rate: 1e-05
  4/625 [..............................] - ETA: 14s - loss: 0.0381 - accuracy: 0.9844
```

```
2024-03-03 18:10:47.405423: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 9s 14ms/step - loss: 0.2740 - accuracy: 0.9609
  8/625 [..............................] - ETA: 10s
2024-03-03 18:10:57.690376: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step
Results: [0.2740277349948883, 0.9609000086784363]
Accuracy: 0.9609
F1 Score: 0.960660090874092
Precision: 0.9625574620649122
Recall: 0.9609
Confusion Matrix:
 [[6649   26    0]
 [ 561 6060  101]
 [   9   85 6509]]
```



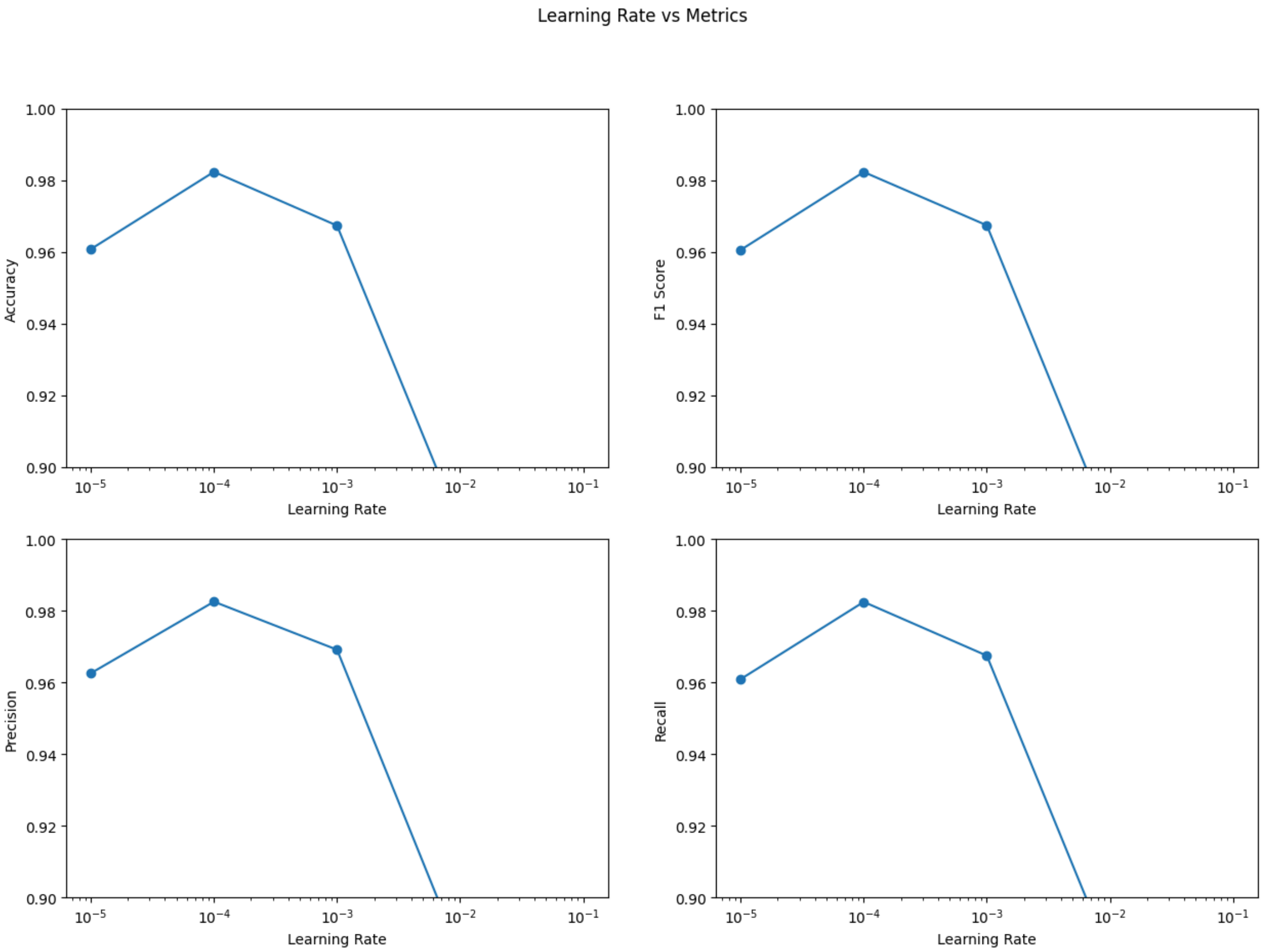


In [ ]:
```
#show the table results for each learning rate
lr_df
```

Out[ ]:

	Learning Rate	Accuracy	F1 Score	Precision	Recall
0	0.1	0.3361	0.169094	0.112963	0.3361
1	0.01	0.8837	0.883566	0.884198	0.8837
2	0.001	0.96745	0.96753	0.969108	0.96745
3	0.0001	0.98245	0.982401	0.982506	0.98245
4	0.00001	0.9609	0.96066	0.962557	0.9609

In [ ]:
```
#draw line graphs for learning rate vs acc, f1, prec, recall
fig, axs = plt.subplots(2, 2, figsize=(15, 10))
fig.suptitle('Learning Rate vs Metrics')

axs[0,0].plot(lr_df['Learning Rate'], lr_df['Accuracy'], label='Accuracy', marker='o'
axs[0,0].set_xscale('log')
axs[0,0].set_xlabel('Learning Rate')
axs[0,0].set_ylabel('Accuracy')
axs[0,0].set_ylim(0.9, 1)


axs[0,1].plot(lr_df['Learning Rate'], lr_df['F1 Score'], label='F1 Score', marker='o'
axs[0,1].set_xscale('log')
axs[0,1].set_xlabel('Learning Rate')
axs[0,1].set_ylabel('F1 Score')
axs[0,1].set_ylim(0.9, 1)


axs[1,0].plot(lr_df['Learning Rate'], lr_df['Precision'], label='Precision', marker='
axs[1,0].set_xscale('log')
axs[1,0].set_xlabel('Learning Rate')
axs[1,0].set_ylabel('Precision')
axs[1,0].set_ylim(0.9, 1)


axs[1,1].plot(lr_df['Learning Rate'], lr_df['Recall'], label='Recall', marker='o')
axs[1,1].set_xscale('log')
axs[1,1].set_xlabel('Learning Rate')
axs[1,1].set_ylabel('Recall')
axs[1,1].set_ylim(0.9, 1)


plt.show()
```



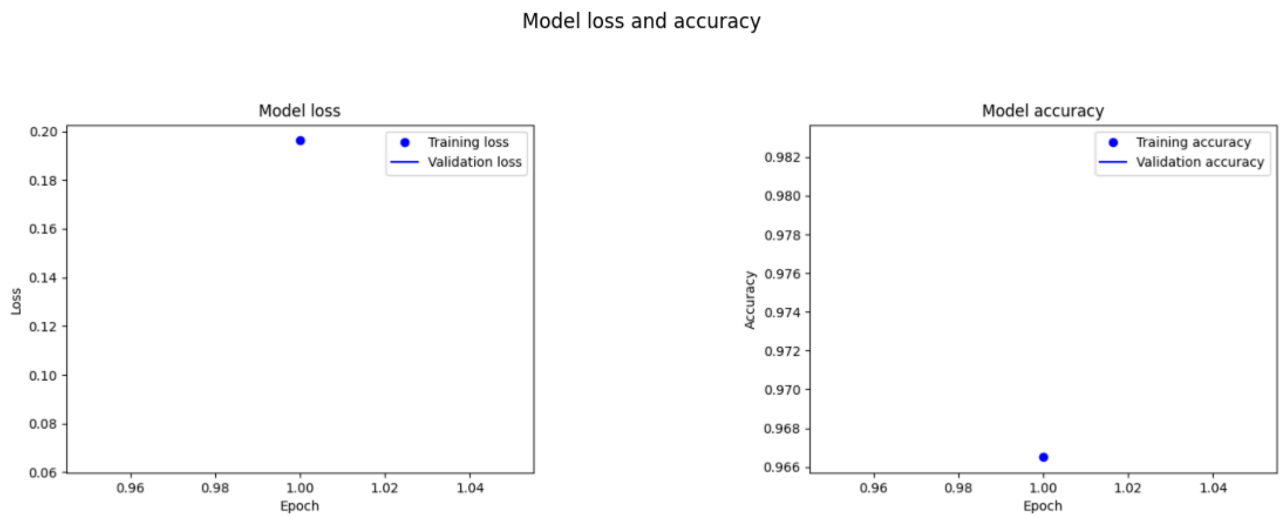
From these results it seems quiet clear that 0.0001 is the best learning rate for the model and I shall move on using this rate.

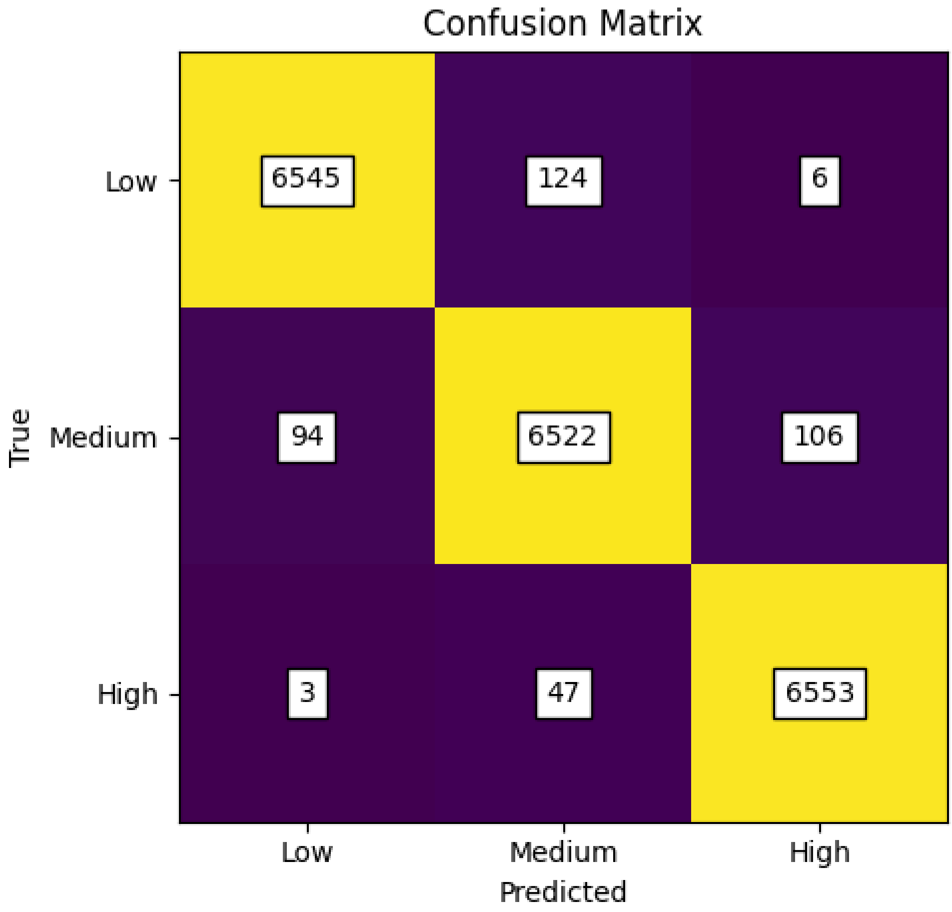
Optimizer

In [ ]:
```
#tuning different optimizers

opt_df = pd.DataFrame(columns=['Optimizers', 'Accuracy', 'F1 Score', 'Precision', 'Re
optimizers = {
    'sgd': keras.optimizers.legacy.SGD(learning_rate=0.0001),
    'rmsprop': keras.optimizers.legacy.RMSprop(learning_rate=0.0001),
    'adagrad': keras.optimizers.legacy.Adagrad(learning_rate=0.0001),
    'adam': keras.optimizers.legacy.Adam(learning_rate=0.0001),
}

for name, optimizer in optimizers.items():

    #try load already built model
    try:
        model_name = 'modelV1_opt_'+ str(name)
        model = keras.models.load_model('./models/'+model_name+'.h5')
        print('Model loaded')
        modelCreated = True
    except:
        modelCreated = False
        print('Model not found')

    print("OPTIMIZER:", name)

    if not modelCreated:
```

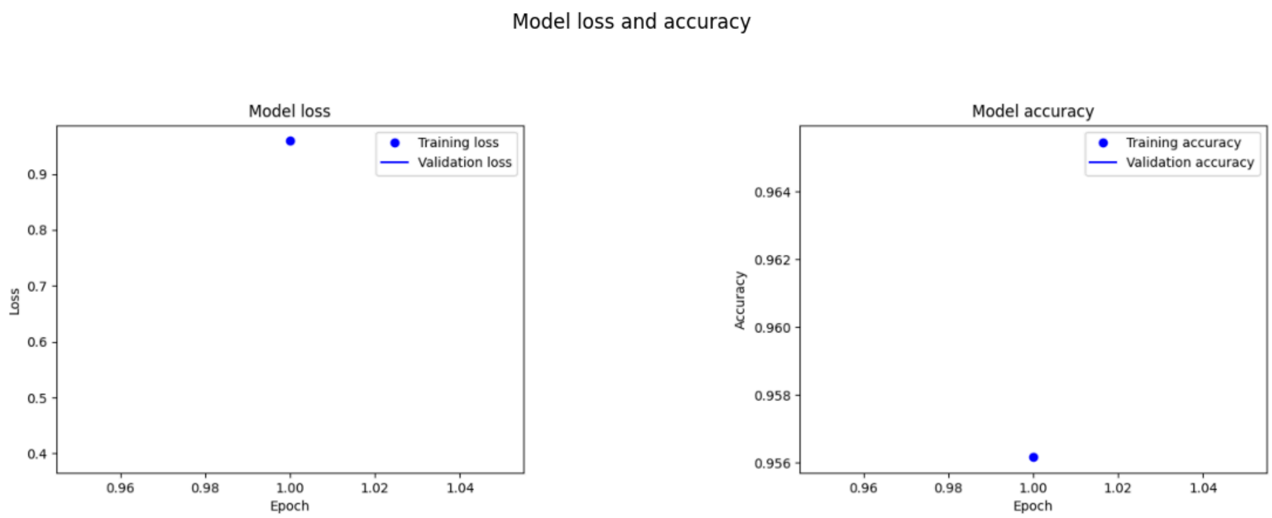
```
        inputs = keras.Input(shape=(160,128,1)) #resolution of images
        x = layers.Conv2D(16, 3, activation="relu")(inputs)
        x = layers.MaxPooling2D(pool_size=2)(x)
        x = layers.Flatten()(x)
        outputs = layers.Dense(3, activation="softmax")(x) #3 classes
        model = keras.Model(inputs=inputs, outputs=outputs)

        model.compile(optimizer=optimizer,
                loss='sparse_categorical_crossentropy',
                metrics=['accuracy'])
        model.fit(np.array(X_train), np.array(y_train), epochs=1, batch_size=16, vali

        model.save('./models/'+ model_name + '.h5')


    plot_loss_accuracy(modelCreated, model, model_name)
    results = evaluate_model(model, X_test, y_test, model_name)
    results['Optimizers'] = name
    opt_df.loc[len(opt_df.index)] = results
```

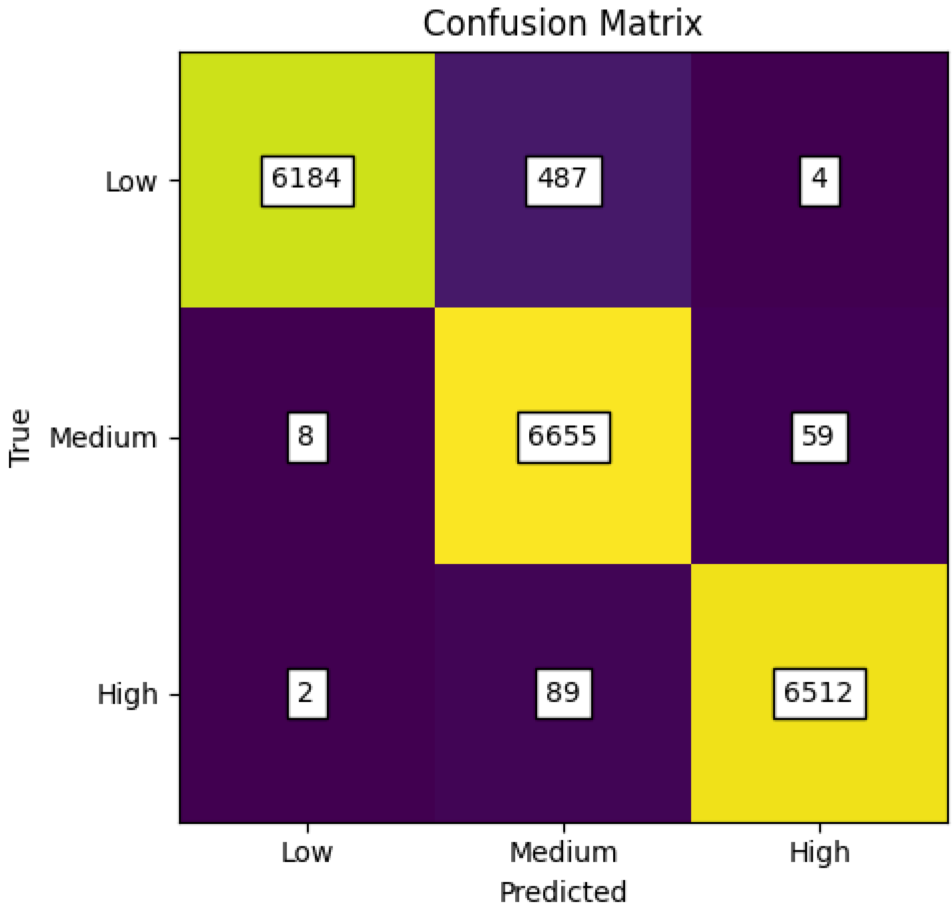
```
Model loaded
OPTIMIZER: sgd
  6/625 [..............................] - ETA: 6s - loss: 0.0768 - accuracy: 0.9740
2024-03-03 18:11:07.676993: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 10ms/step - loss: 0.0702 - accuracy: 0.9
810
 23/625 [>.............................] - ETA: 4s
2024-03-03 18:11:14.766806: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 5s 8ms/step
Results: [0.07020875811576843, 0.9810000061988831]
Accuracy: 0.981
F1 Score: 0.9809848120648418
Precision: 0.9809909501979848
Recall: 0.981
Confusion Matrix:
 [[6545  124    6]
 [  94 6522  106]
 [   3   47 6553]]
```



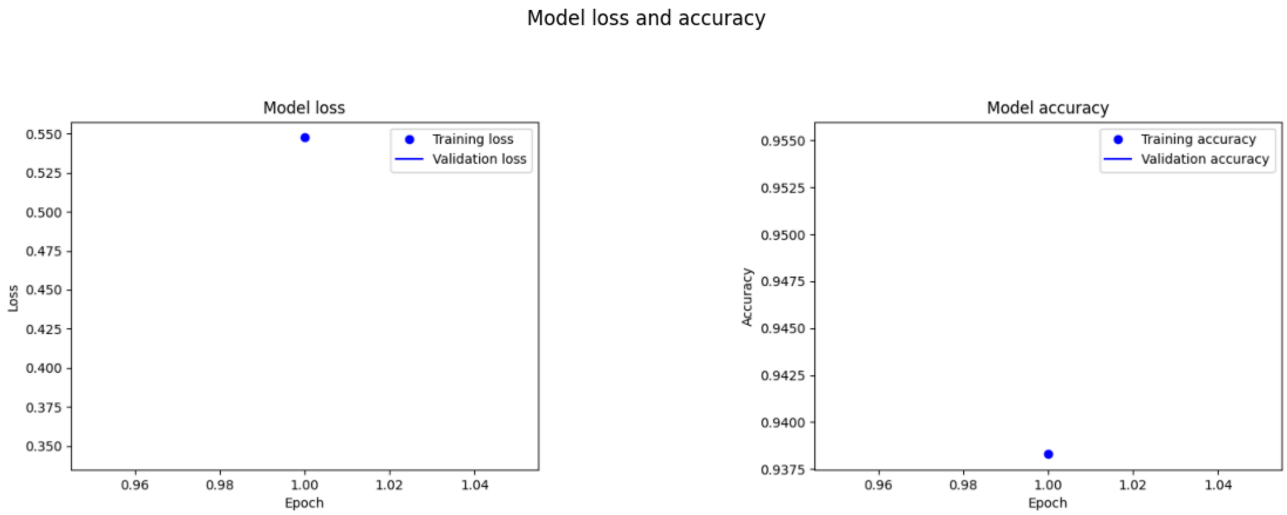


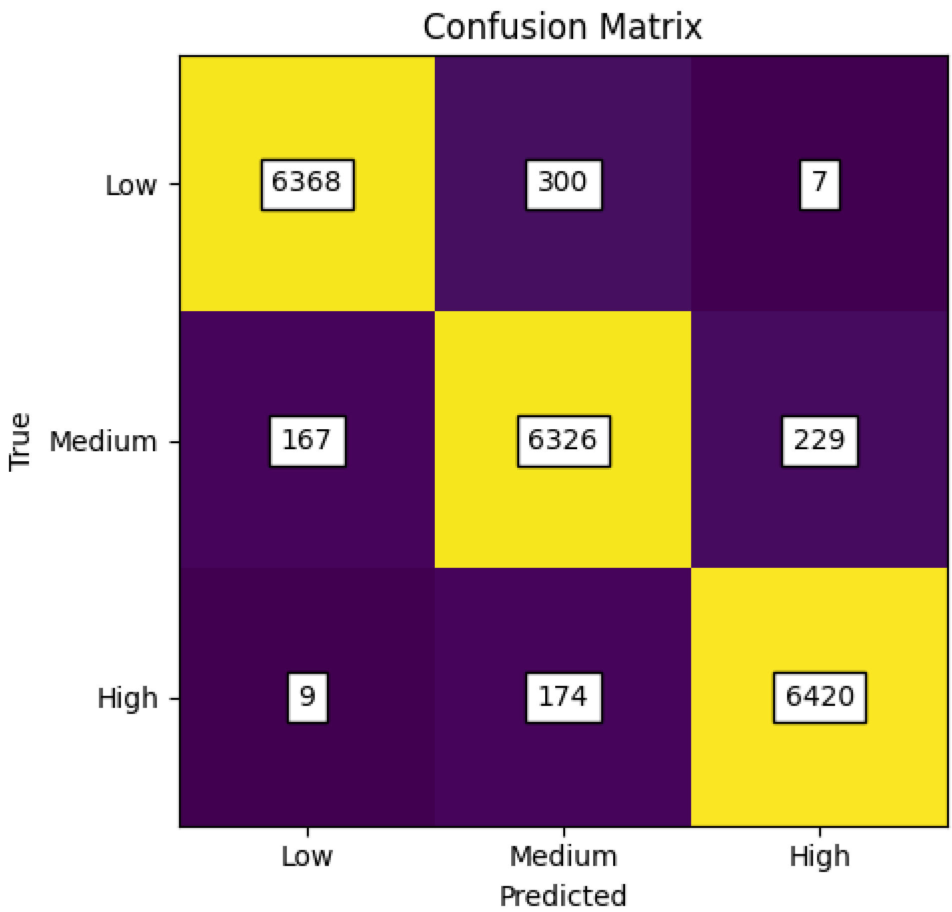

```
Model loaded
OPTIMIZER: rmsprop
2024-03-03 18:11:21.830581: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 10ms/step - loss: 0.3749 - accuracy: 0.9
675
  9/625 [..............................] - ETA: 10s
2024-03-03 18:11:29.802985: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 5s 8ms/step
Results: [0.37493258714675903, 0.9675499796867371]
Accuracy: 0.96755
F1 Score: 0.9676600869968636
Precision: 0.9695250291234244
Recall: 0.96755
Confusion Matrix:
 [[6184  487    4]
 [   8 6655   59]
 [   2   89 6512]]
```



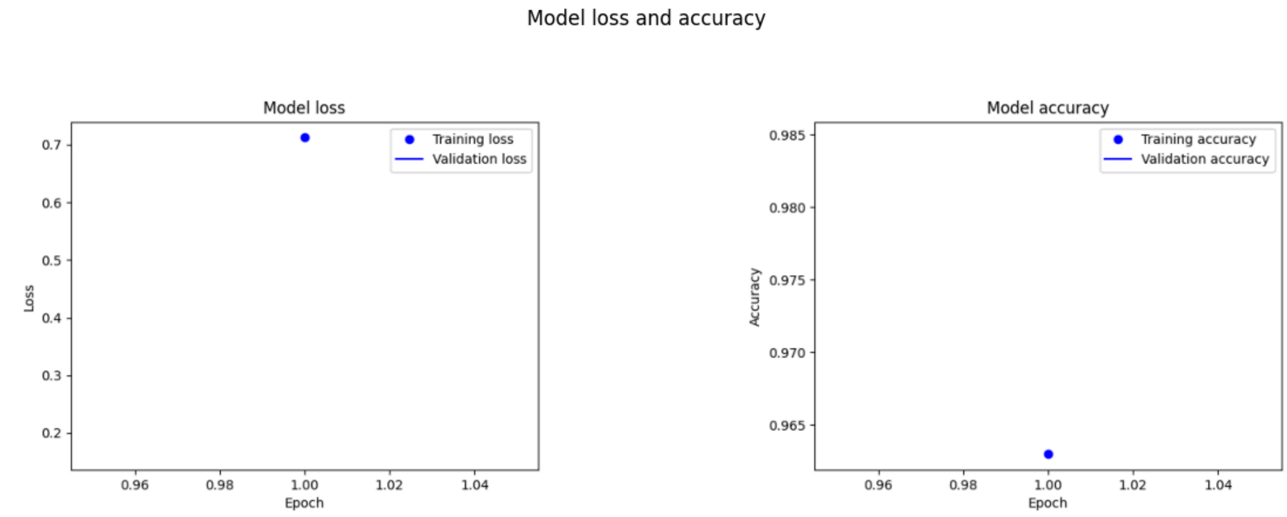


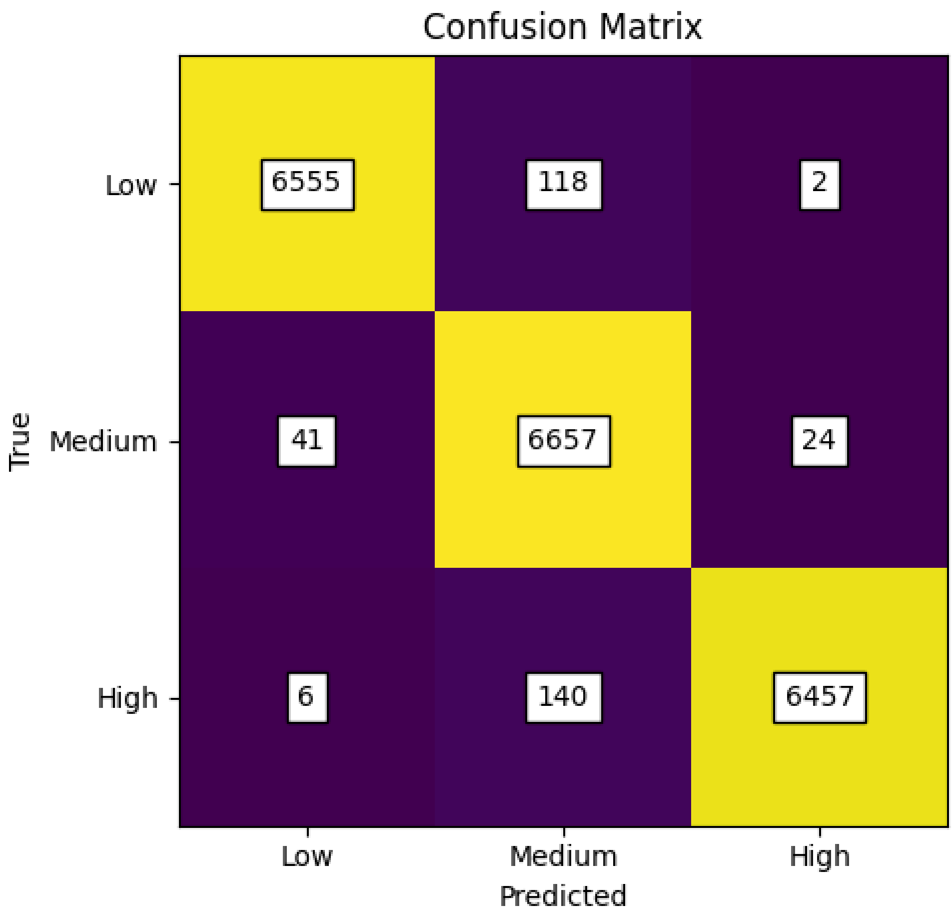

```
Model loaded
OPTIMIZER: adagrad
  5/625 [..............................] - ETA: 8s - loss: 0.4961 - accuracy: 0.9500
2024-03-03 18:11:37.745855: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 10ms/step - loss: 0.3245 - accuracy: 0.9
557
 14/625 [..............................] - ETA: 5s
2024-03-03 18:11:46.115668: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 6s 9ms/step
Results: [0.3244965970516205, 0.9556999802589417]
Accuracy: 0.9557
F1 Score: 0.9557476707835761
Precision: 0.9558896519085218
Recall: 0.9557
Confusion Matrix:
 [[6368  300    7]
 [ 167 6326  229]
 [   9  174 6420]]
```






```
Model loaded
OPTIMIZER: adam
2024-03-03 18:11:53.730862: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 10ms/step - loss: 0.1794 - accuracy: 0.9
834
  6/625 [..............................] - ETA: 14s
2024-03-03 18:12:01.791543: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step
Results: [0.17939729988574982, 0.9834499955177307]
Accuracy: 0.98345
F1 Score: 0.9835018962696649
Precision: 0.9837599958999846
Recall: 0.98345
Confusion Matrix:
 [[6555  118    2]
 [  41 6657   24]
 [   6  140 6457]]
```





In [ ]:
```
opt_df
```

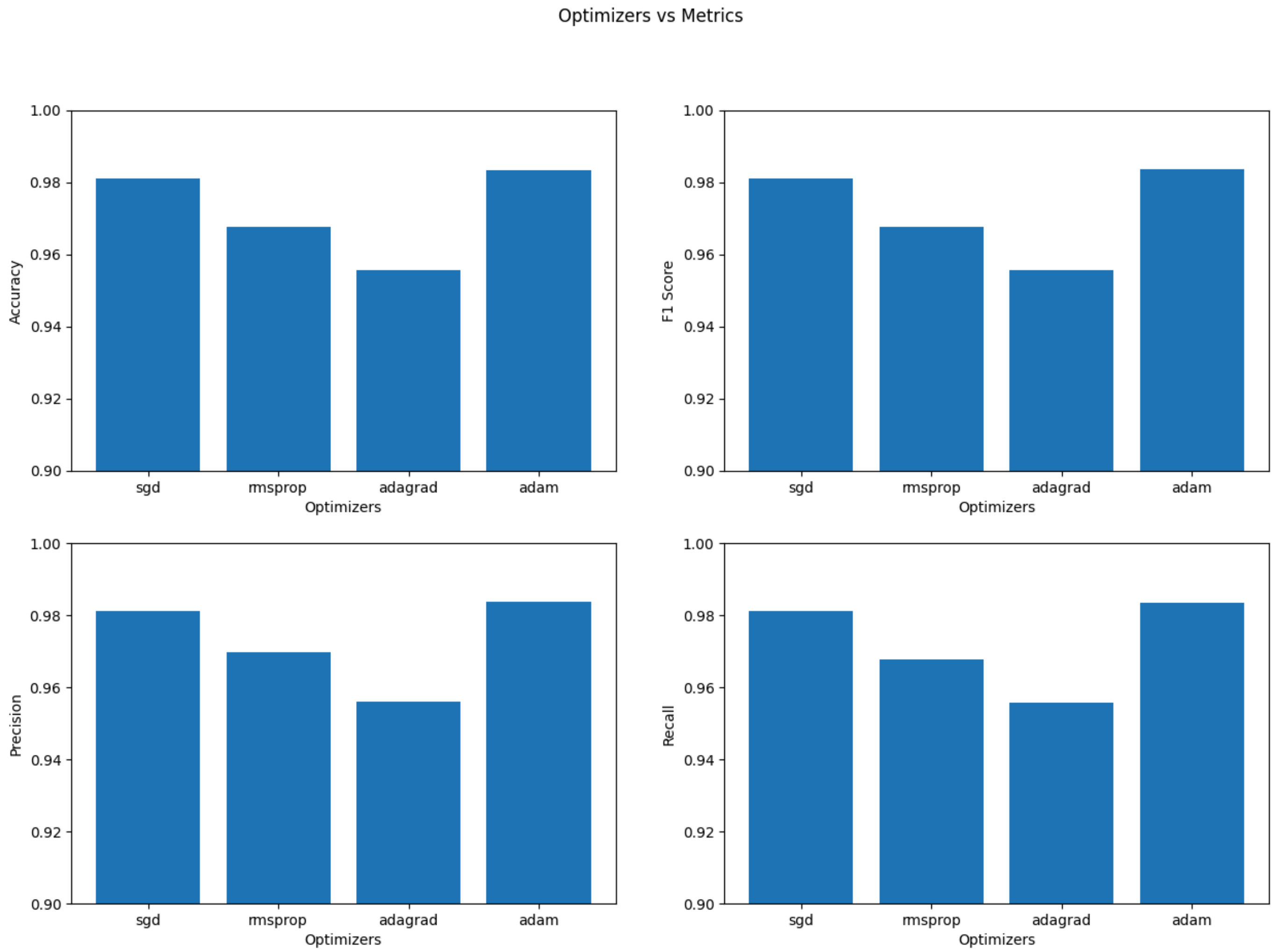
Out[ ]:

	Optimizers	Accuracy	F1 Score	Precision	Recall
0	sgd	0.981	0.980985	0.980991	0.981
1	rmsprop	0.96755	0.96766	0.969525	0.96755
2	adagrad	0.9557	0.955748	0.95589	0.9557
3	adam	0.98345	0.983502	0.98376	0.98345

In [ ]:
```
fig, axs = plt.subplots(2, 2, figsize=(15, 10))
fig.suptitle('Optimizers vs Metrics')

axs[0,0].bar(opt_df['Optimizers'], opt_df['Accuracy'], label='Accuracy')
axs[0,0].set_xlabel('Optimizers')
axs[0,0].set_ylabel('Accuracy')
axs[0,0].set_ylim(0.9, 1.0)
```

```
axs[0,1].bar(opt_df['Optimizers'], opt_df['F1 Score'], label='F1 Score')
axs[0,1].set_xlabel('Optimizers')
axs[0,1].set_ylabel('F1 Score')
axs[0,1].set_ylim(0.9, 1.0)


axs[1,0].bar(opt_df['Optimizers'], opt_df['Precision'], label='Precision')
axs[1,0].set_xlabel('Optimizers')
axs[1,0].set_ylabel('Precision')
axs[1,0].set_ylim(0.9, 1.0)


axs[1,1].bar(opt_df['Optimizers'], opt_df['Recall'], label='Recall')
axs[1,1].set_xlabel('Optimizers')
axs[1,1].set_ylabel('Recall')
axs[1,1].set_ylim(0.9, 1.0)
```

Out[ ]: (0.9, 1.0)



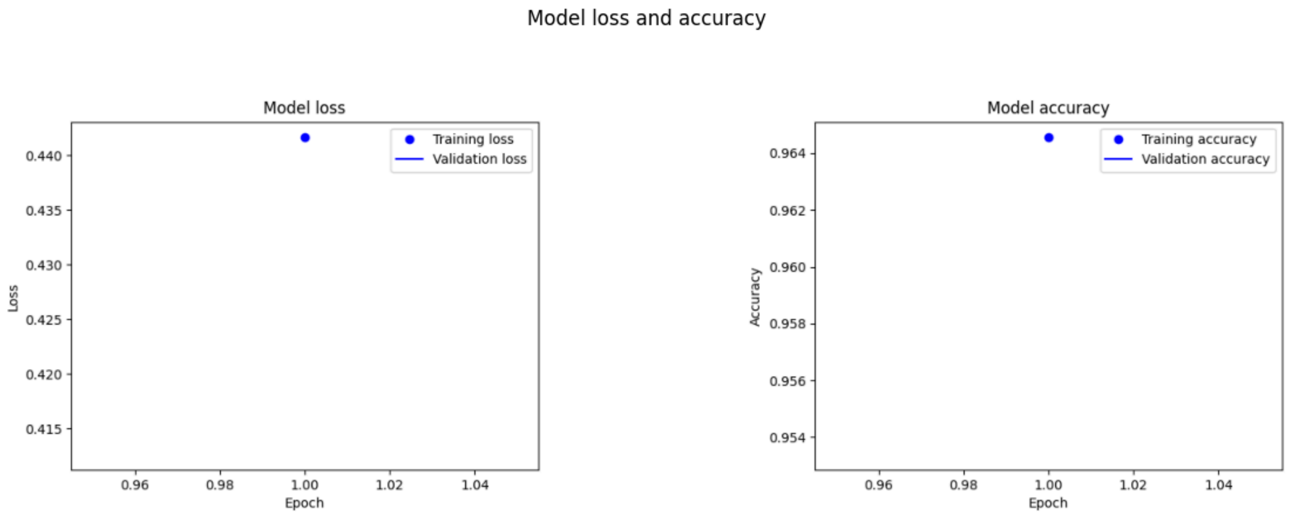
After testing all the optimiser both sgd and adam seem to be the best optimisers for the model. Although adam seems to be slightly better than sgd, I shall move on using adam.

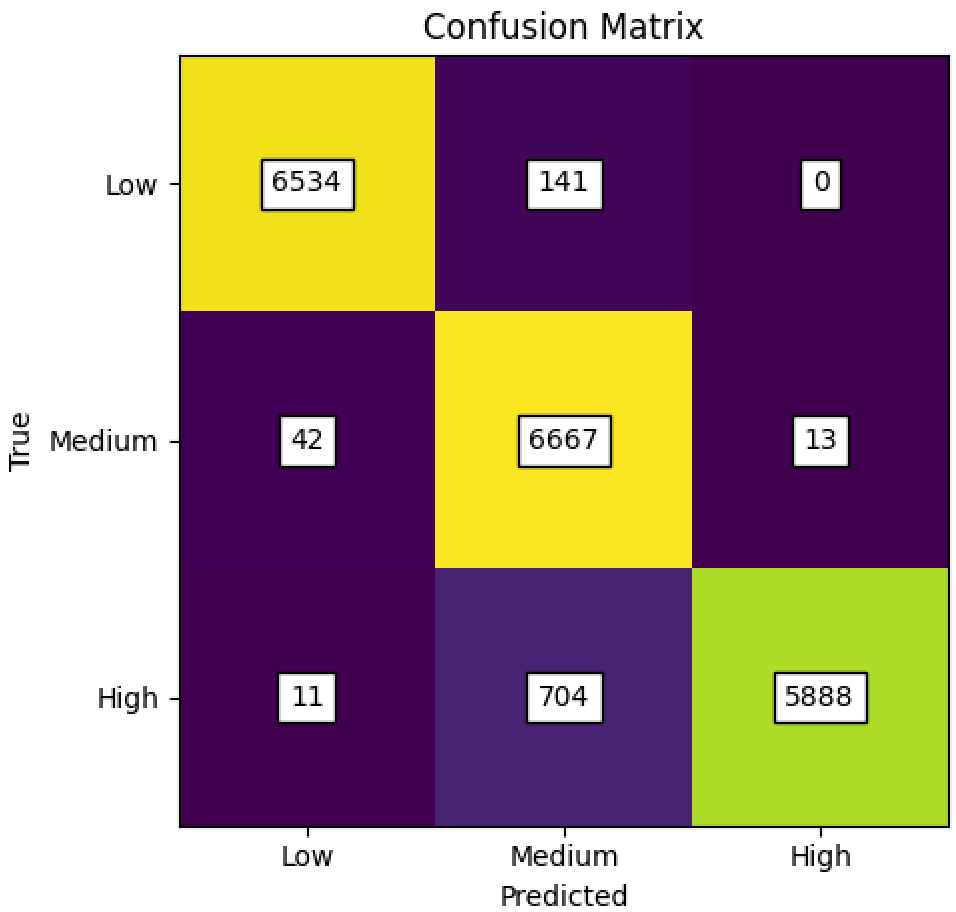
Batch size

In [ ]:
```
#tuning different batch sizes

batch_df = pd.DataFrame(columns=['Batch Size', 'Accuracy', 'F1 Score', 'Precision', '
batch_sizes = [8, 16, 32, 64]
```

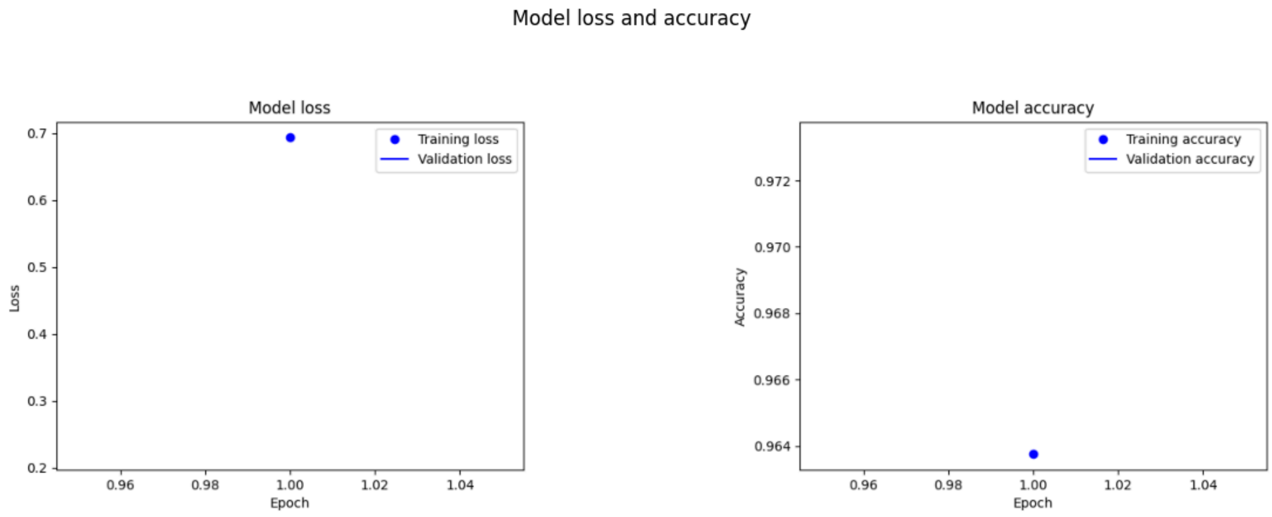
```python
for batch_size in batch_sizes:

    #try load already built model
    try:
        model_name = 'modelV1_batch_'+ str(batch_size)
        model = keras.models.load_model('./models/'+model_name+'.h5')
        print('Model loaded')
        modelCreated = True
    except:
        modelCreated = False
        print('Model not found')

    print("Batch Size:", batch_size)

    if not modelCreated:
        inputs = keras.Input(shape=(160,128,1)) #resolution of images
        x = layers.Conv2D(16, 3, activation="relu")(inputs)
        x = layers.MaxPooling2D(pool_size=2)(x)
        x = layers.Flatten()(x)
        outputs = layers.Dense(3, activation="softmax")(x) #3 classes
        model = keras.Model(inputs=inputs, outputs=outputs)

        model.compile(optimizer=keras.optimizers.legacy.Adam(learning_rate=0.0001),
                loss='sparse_categorical_crossentropy',
                metrics=['accuracy'])
        model.fit(np.array(X_train), np.array(y_train), epochs=1, batch_size=batch_si

        model.save('./models/'+ model_name + '.h5')


    plot_loss_accuracy(modelCreated, model, model_name)
    results = evaluate_model(model, X_test, y_test, model_name)
    results['Batch Size'] = batch_size
    batch_df.loc[len(batch_df.index)] = results
```

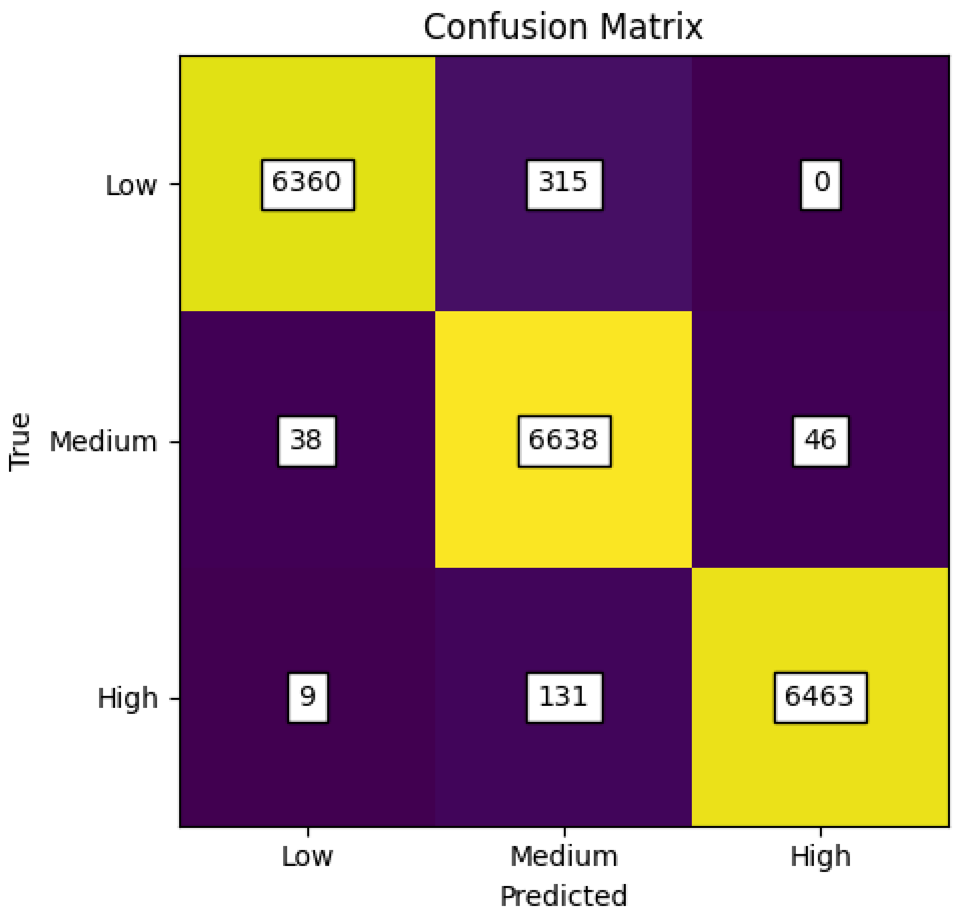
```
Model loaded
Batch Size: 8
  3/625 [..............................] - ETA: 16s - loss: 0.9733 - accuracy: 0.9271
2024-03-03 18:12:10.640954: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 9s 14ms/step - loss: 0.4173 - accuracy: 0.9
545
  3/625 [..............................] - ETA: 28s
2024-03-03 18:12:20.743437: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step
Results: [0.4173380732536316, 0.9544500112533569]
Accuracy: 0.95445
F1 Score: 0.9546448033459637
Precision: 0.9587804952310373
Recall: 0.95445
Confusion Matrix:
 [[6534  141    0]
 [  42 6667   13]
 [  11  704 5888]]
```



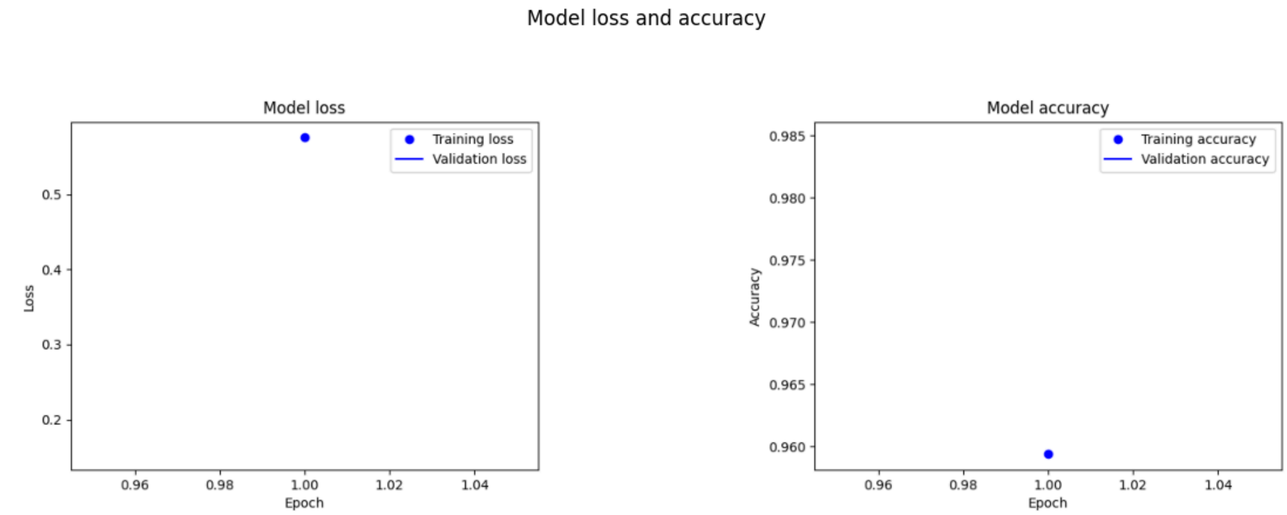


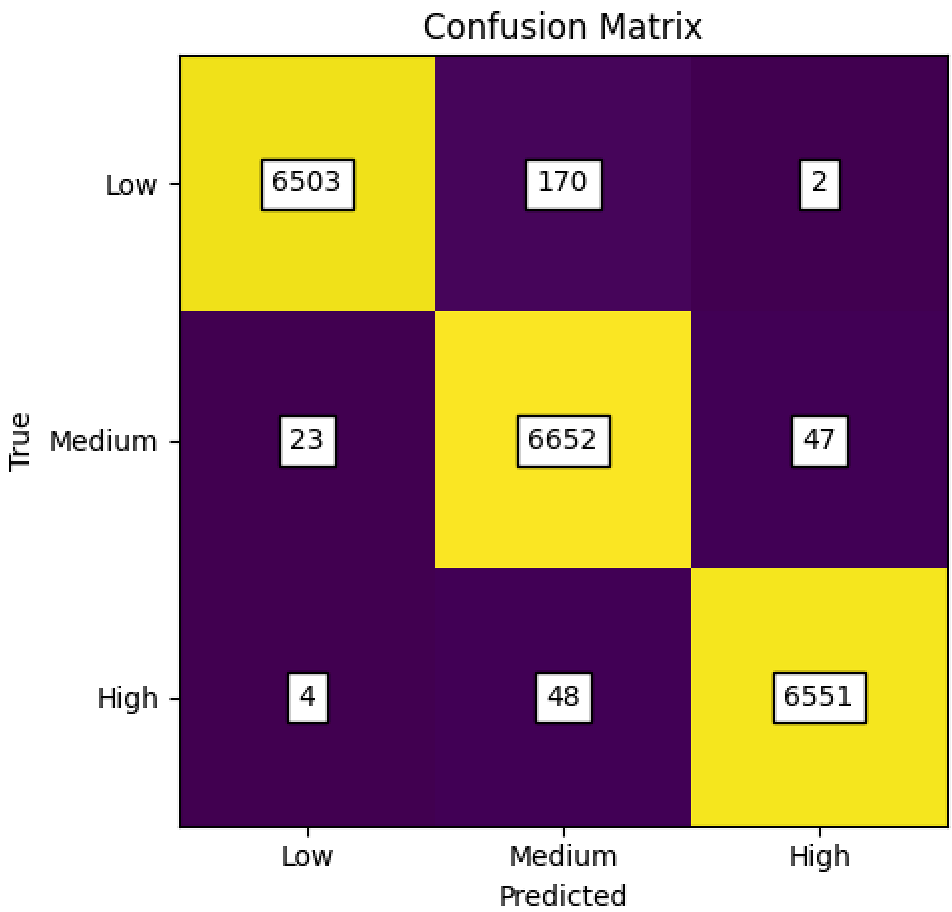

```
Model loaded
Batch Size: 16
2024-03-03 18:12:30.311034: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 15s 23ms/step - loss: 0.2471 - accuracy: 0.
9730
  6/625 [..............................] - ETA: 7s
2024-03-03 18:12:46.746385: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 8s 13ms/step
Results: [0.24707791209220886, 0.9730499982833862]
Accuracy: 0.97305
F1 Score: 0.9731786857494813
Precision: 0.9740580396408756
Recall: 0.97305
Confusion Matrix:
 [[6360  315    0]
 [  38 6638   46]
 [   9  131 6463]]
```



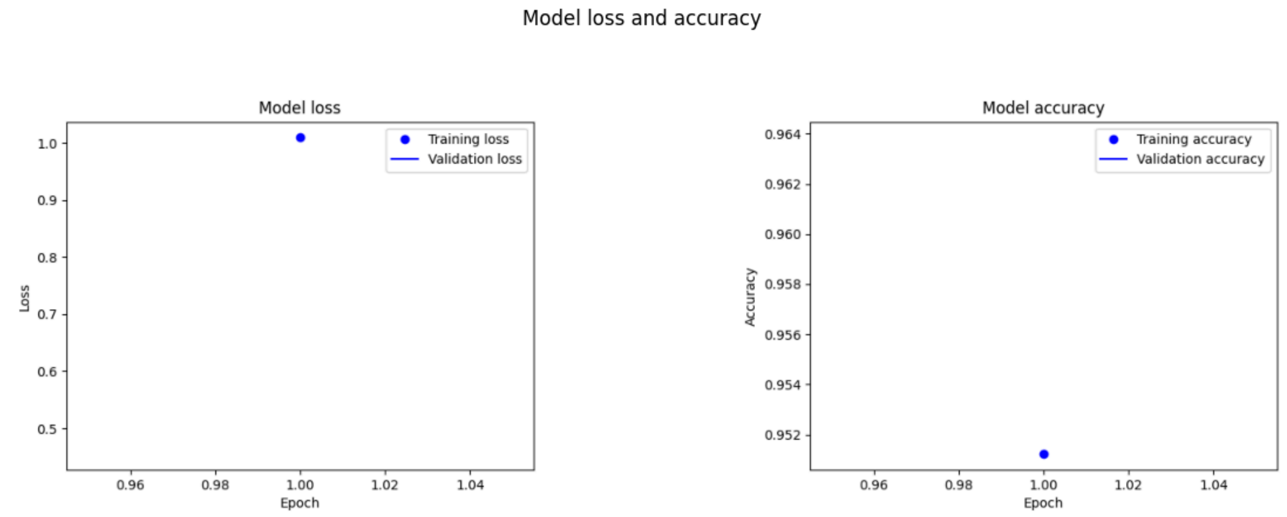


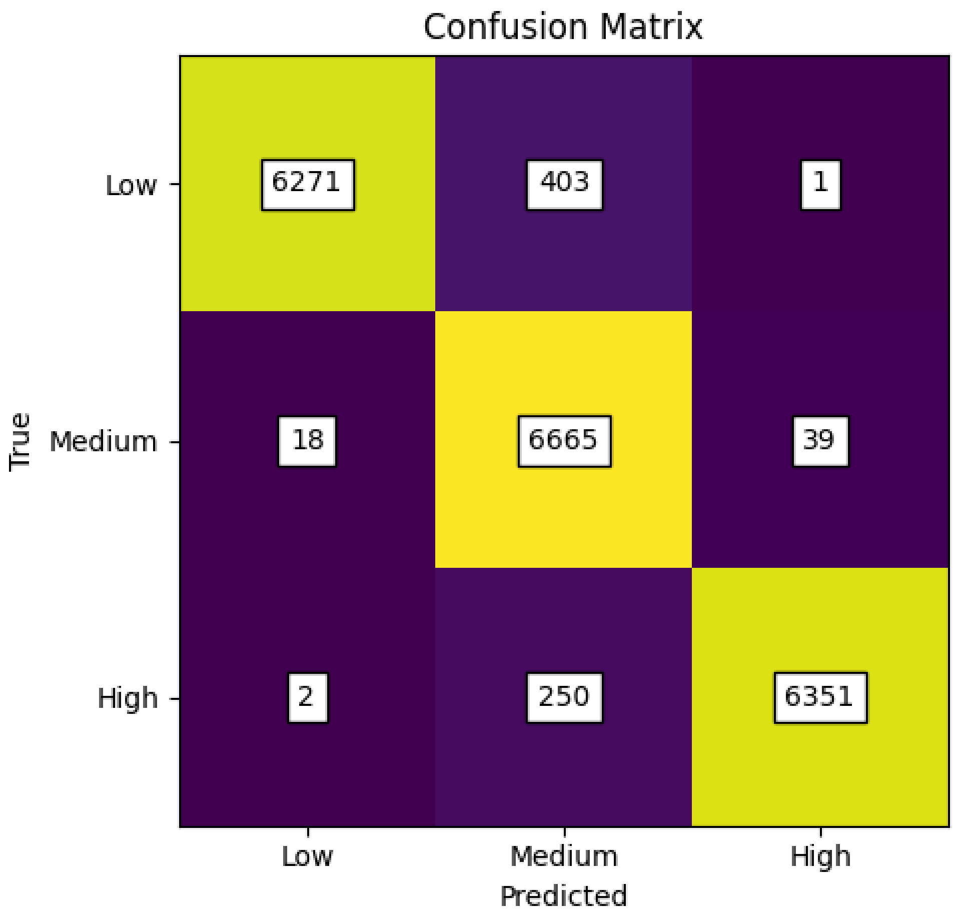

```
Model loaded
Batch Size: 32
2024-03-03 18:12:56.609466: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 10s 15ms/step - loss: 0.1468 - accuracy: 0.
9853
 15/625 [..............................] - ETA: 4s
2024-03-03 18:13:06.890360: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 5s 9ms/step
Results: [0.14678354561328888, 0.9853000044822693]
Accuracy: 0.9853
F1 Score: 0.985323196396591
Precision: 0.9855037273840304
Recall: 0.9853
Confusion Matrix:
 [[6503  170    2]
 [  23 6652   47]
 [   4   48 6551]]
```






```
Model loaded
Batch Size: 64
2024-03-03 18:13:14.785529: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 10ms/step - loss: 0.4720 - accuracy: 0.9643
 21/625 [>.............................] - ETA: 4s
2024-03-03 18:13:23.458896: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 5s 7ms/step
Results: [0.47198939323425293, 0.9643499851226807]
Accuracy: 0.96435
F1 Score: 0.9646704601681986
Precision: 0.9668817316365499
Recall: 0.96435
Confusion Matrix:
 [[6271  403    1]
 [  18 6665   39]
 [   2  250 6351]]
```



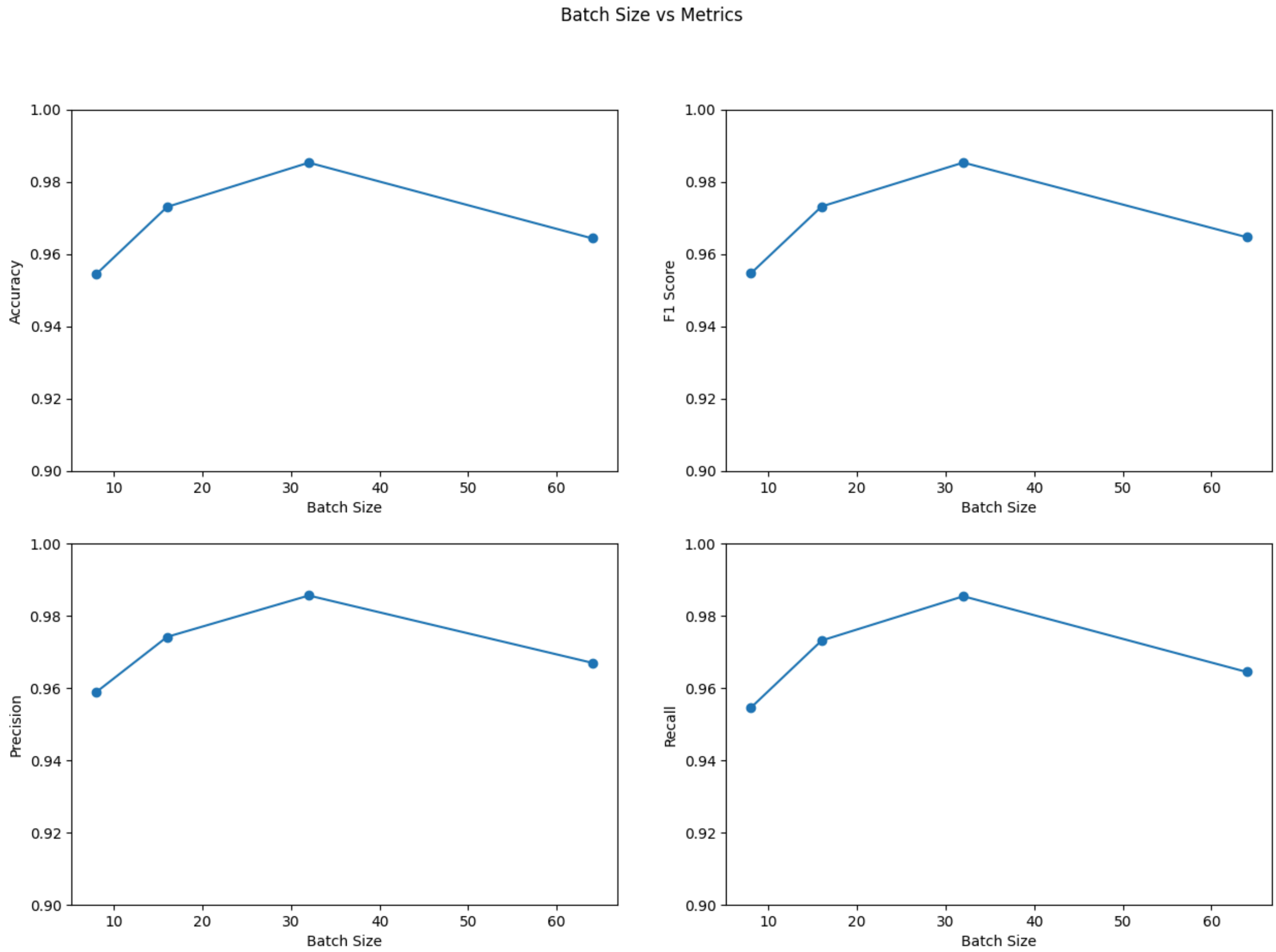


In [ ]:

```
fig, axs = plt.subplots(2, 2, figsize=(15, 10))
fig.suptitle('Batch Size vs Metrics')

axs[0,0].plot(batch_df['Batch Size'], batch_df['Accuracy'], label='Accuracy', marker=
axs[0,0].set_xlabel('Batch Size')
axs[0,0].set_ylabel('Accuracy')
axs[0,0].set_ylim(0.9, 1.0)

axs[0,1].plot(batch_df['Batch Size'], batch_df['F1 Score'], label='F1 Score', marker=
axs[0,1].set_xlabel('Batch Size')
axs[0,1].set_ylabel('F1 Score')
axs[0,1].set_ylim(0.9, 1.0)

axs[1,0].plot(batch_df['Batch Size'], batch_df['Precision'], label='Precision', marke
axs[1,0].set_xlabel('Batch Size')
axs[1,0].set_ylabel('Precision')
axs[1,0].set_ylim(0.9, 1.0)

axs[1,1].plot(batch_df['Batch Size'], batch_df['Recall'], label='Recall', marker='o')
```

```
axs[1,1].set_xlabel('Batch Size')
axs[1,1].set_ylabel('Recall')
axs[1,1].set_ylim(0.9, 1.0)
```

Out[ ]: (0.9, 1.0)



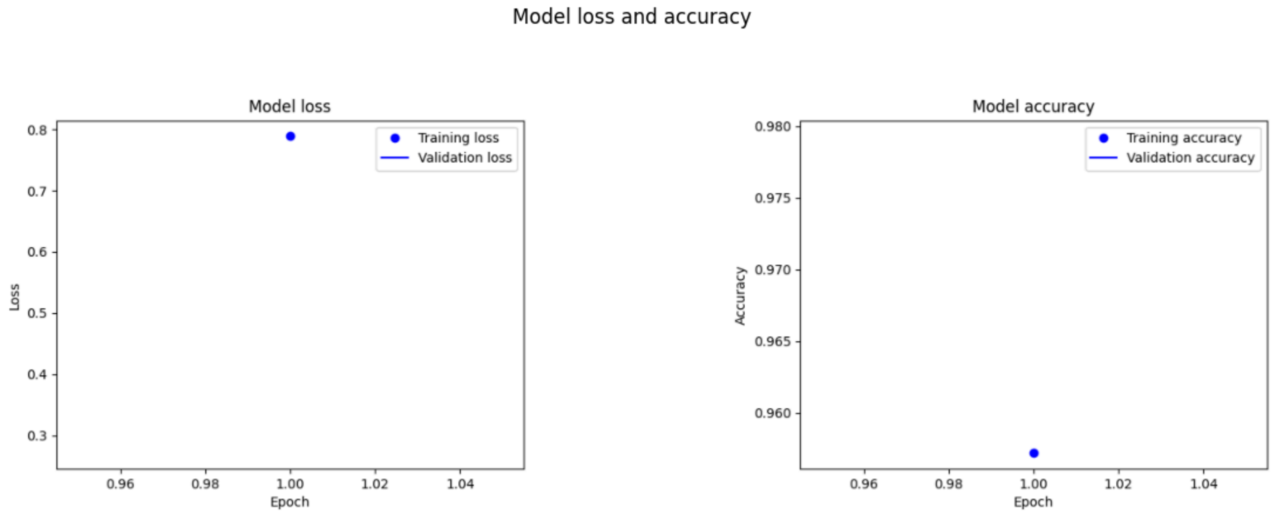
These results show a lovely graph showing that the optimal batch size for this model and the data is 32 and anything above or below this value will result in a decrease in the model's performance.

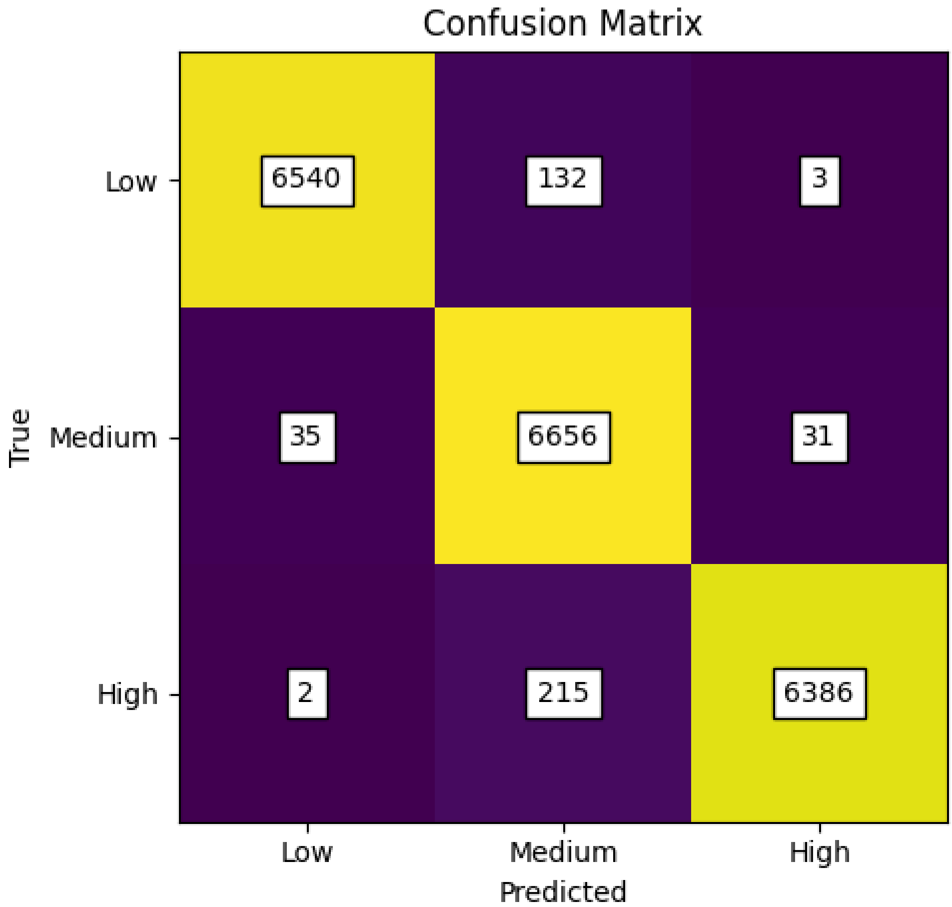
Epochs

In [ ]:
```
epoch_df = pd.DataFrame(columns=['Epochs', 'Accuracy', 'F1 Score', 'Precision', 'Reca
epochs = [1, 5, 10, 20]

for epoch in epochs:

    #try load already built model
    try:
        model_name = 'modelV1_epoch_'+ str(epoch)
        model = keras.models.load_model('./models/'+model_name+'.h5')
        print('Model loaded')
        modelCreated = True
    except:
        modelCreated = False
        print('Model not found')

    print("Epochs:", epoch)

    if not modelCreated:
        inputs = keras.Input(shape=(160,128,1)) #resolution of images
        x = layers.Conv2D(16, 3, activation="relu")(inputs)
```

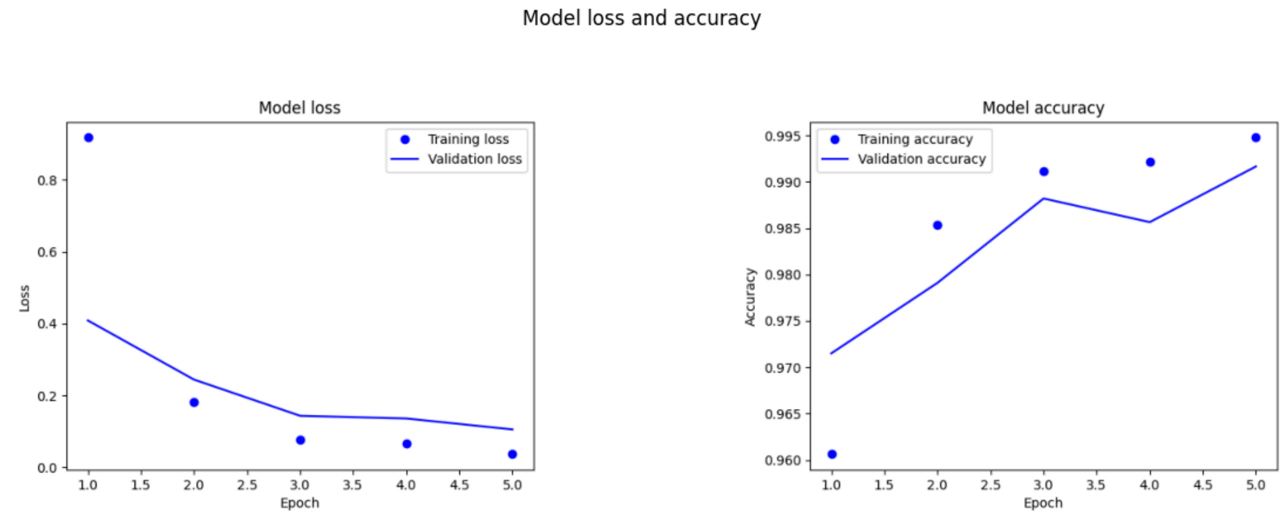
```
        x = layers.MaxPooling2D(pool_size=2)(x)
        x = layers.Flatten()(x)
        outputs = layers.Dense(3, activation="softmax")(x) #3 classes
        model = keras.Model(inputs=inputs, outputs=outputs)

        model.compile(optimizer=keras.optimizers.legacy.Adam(learning_rate=0.0001),
                loss='sparse_categorical_crossentropy',
                metrics=['accuracy'])
        model.fit(np.array(X_train), np.array(y_train), epochs=epoch, batch_size=32,

        model.save('./models/'+ model_name + '.h5')


    plot_loss_accuracy(modelCreated, model, model_name)
    results = evaluate_model(model, X_test, y_test, model_name)
    results['Epochs'] = epoch
    epoch_df.loc[len(epoch_df.index)] = results
```

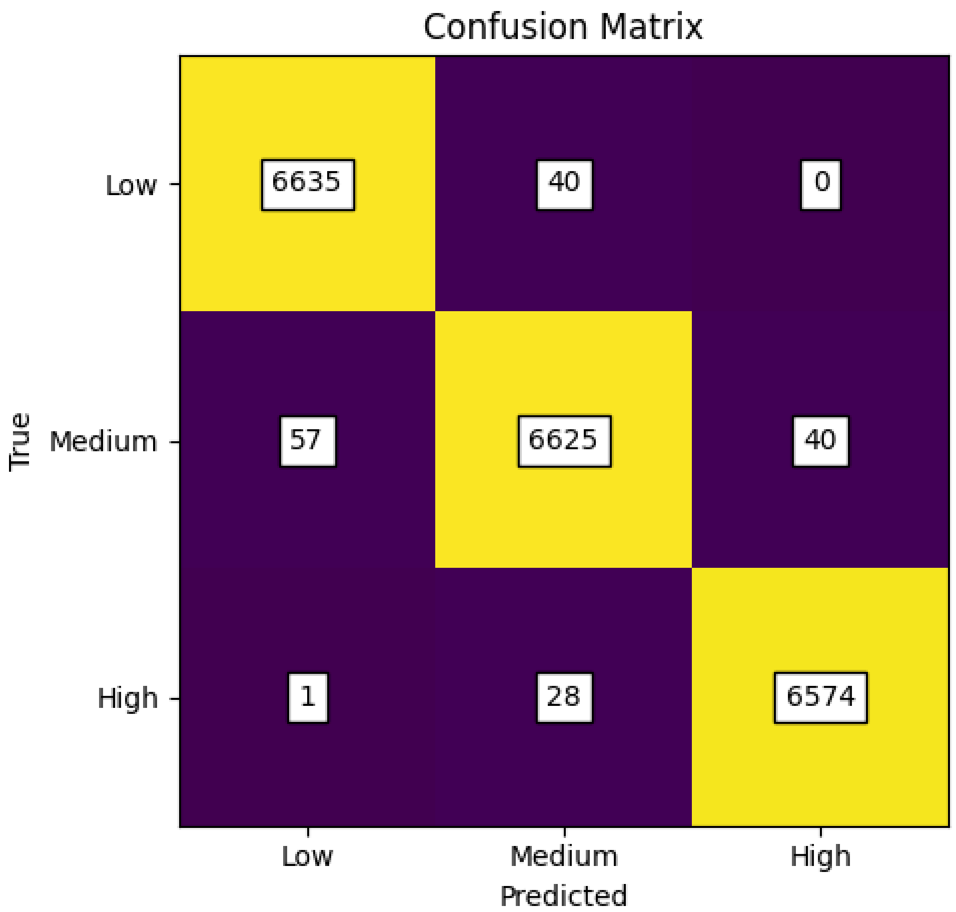
```
Model loaded
Epochs: 1
  6/625 [..............................] - ETA: 6s - loss: 0.3647 - accuracy: 0.9844
2024-03-03 18:13:30.886547: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step - loss: 0.2899 - accuracy: 0.9
791
 23/625 [>.............................] - ETA: 4s
2024-03-03 18:13:39.790837: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 5s 7ms/step
Results: [0.2898976802825928, 0.9790999889373779]
Accuracy: 0.9791
F1 Score: 0.9791914141384966
Precision: 0.979720156505092
Recall: 0.9791
Confusion Matrix:
 [[6540  132    3]
 [  35 6656   31]
 [   2  215 6386]]
```






```
Model loaded
Epochs: 5
  6/625 [..............................] - ETA: 7s - loss: 0.3617 - accuracy: 0.9740
2024-03-03 18:13:46.140667: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 7s 11ms/step - loss: 0.1070 - accuracy: 0.9
917
  9/625 [..............................] - ETA: 10s
2024-03-03 18:13:54.265499: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 6s 10ms/step
Results: [0.10703562200069427, 0.9916999936103821]
Accuracy: 0.9917
F1 Score: 0.991695817317054
Precision: 0.9916963936614269
Recall: 0.9917
Confusion Matrix:
 [[6635   40    0]
 [  57 6625   40]
 [   1   28 6574]]
```

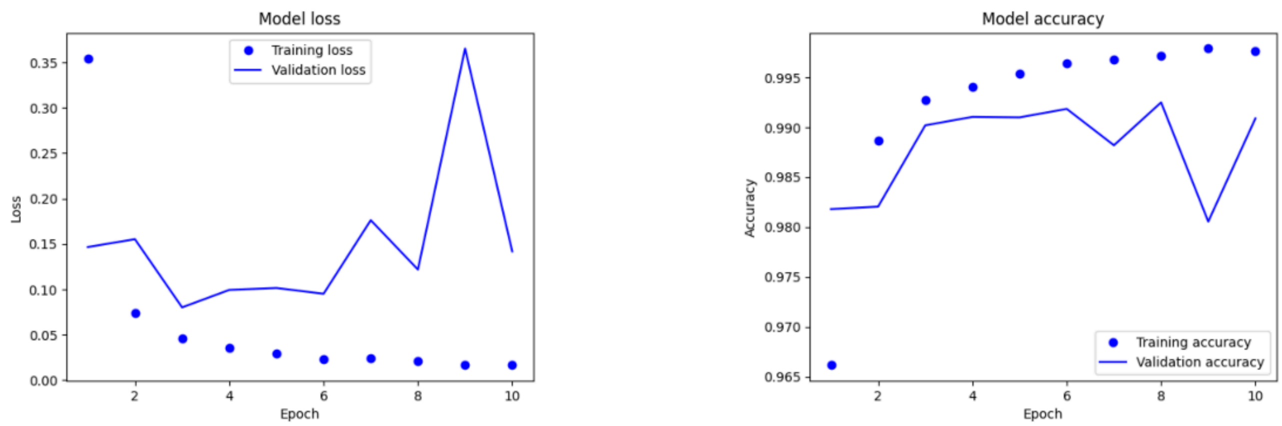


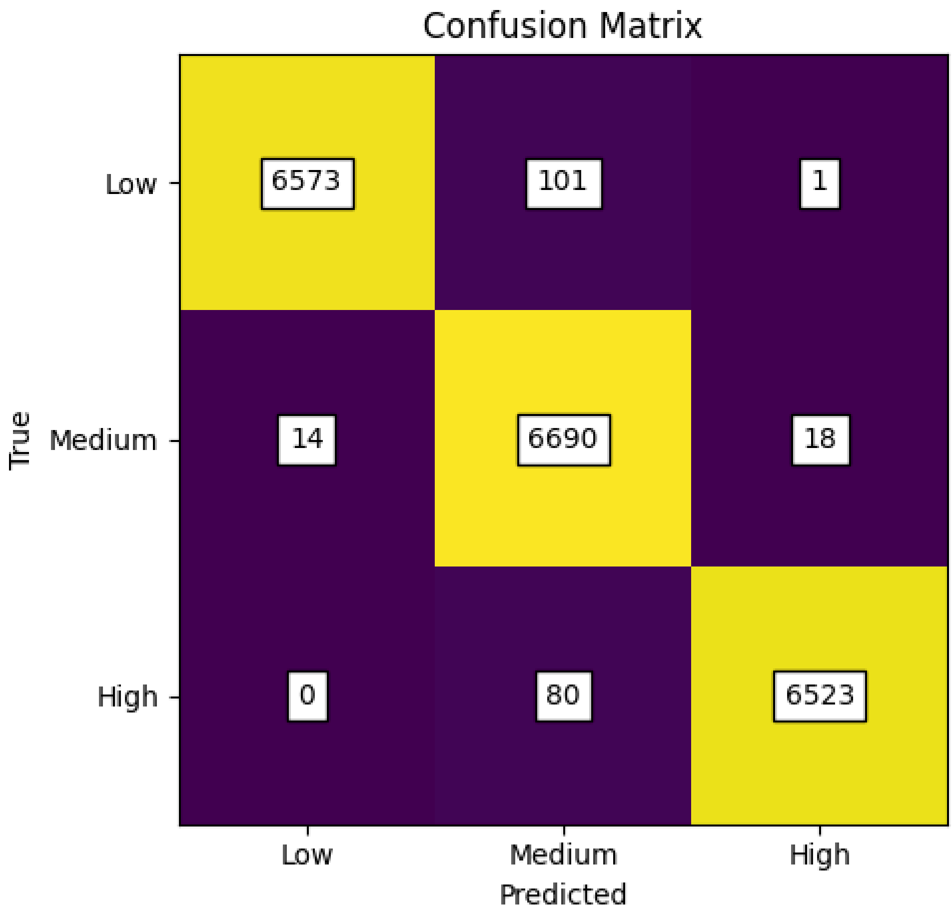



```
Model loaded
Epochs: 10
  4/625 [..............................] - ETA: 10s - loss: 0.7481 - accuracy: 0.9688
2024-03-03 18:14:01.915800: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 9s 14ms/step - loss: 0.1525 - accuracy: 0.9
893
  1/625 [..............................] - ETA: 2:38
2024-03-03 18:14:12.144460: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
```

```
625/625 [==============================] - 8s 12ms/step
Results: [0.15249274671077728, 0.989300012588501]
Accuracy: 0.9893
F1 Score: 0.989327641811542
Precision: 0.9894780424642031
Recall: 0.9893
Confusion Matrix:
 [[6573  101    1]
 [  14 6690   18]
 [   0   80 6523]]
```

Model loss and accuracy

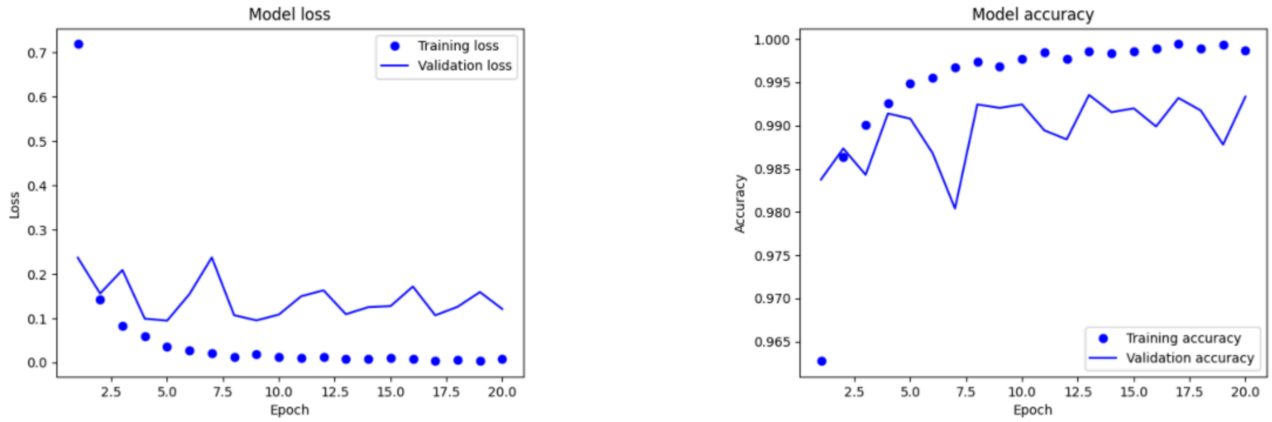


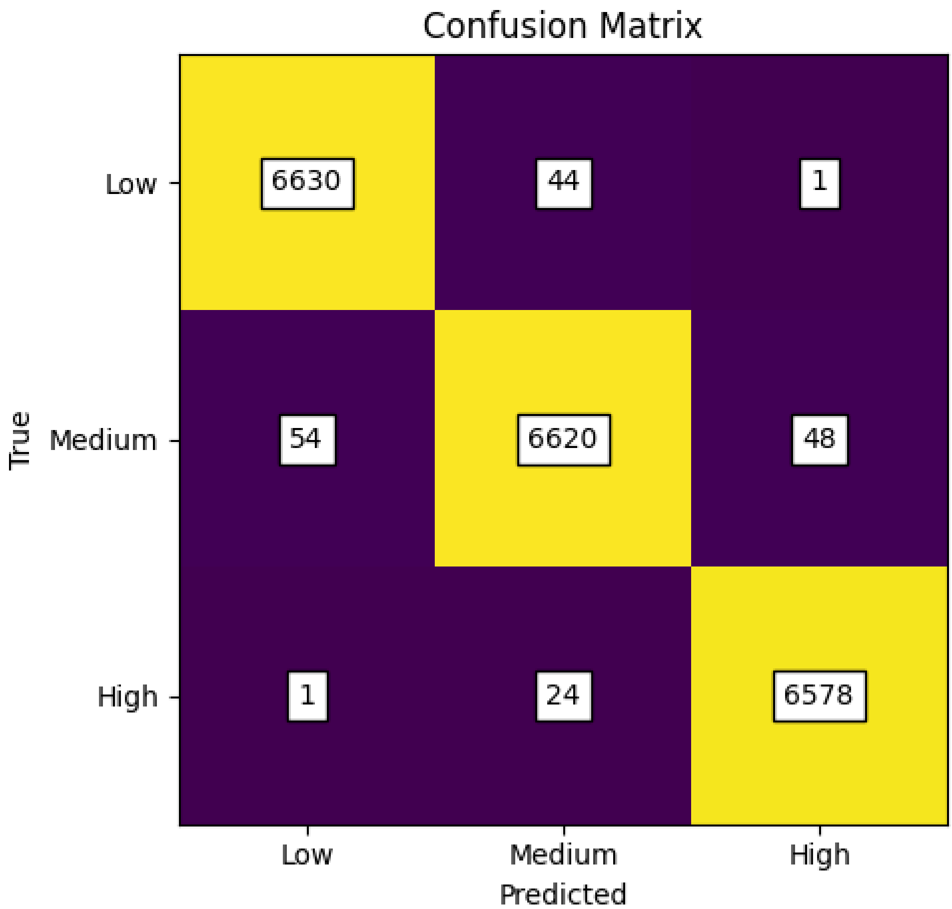



```
Model loaded
Epochs: 20
2024-03-03 18:14:21.969614: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 10s 15ms/step - loss: 0.1365 - accuracy: 0.9914
  4/625 [..............................] - ETA: 11s
2024-03-03 18:14:32.462518: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
```

```
625/625 [==============================] - 7s 11ms/step
Results: [0.13652931153774261, 0.9914000034332275]
Accuracy: 0.9914
F1 Score: 0.991394451725914
Precision: 0.9913957017914836
Recall: 0.9914
Confusion Matrix:
 [[6630   44    1]
 [  54 6620   48]
 [   1   24 6578]]
```

Model loss and accuracy

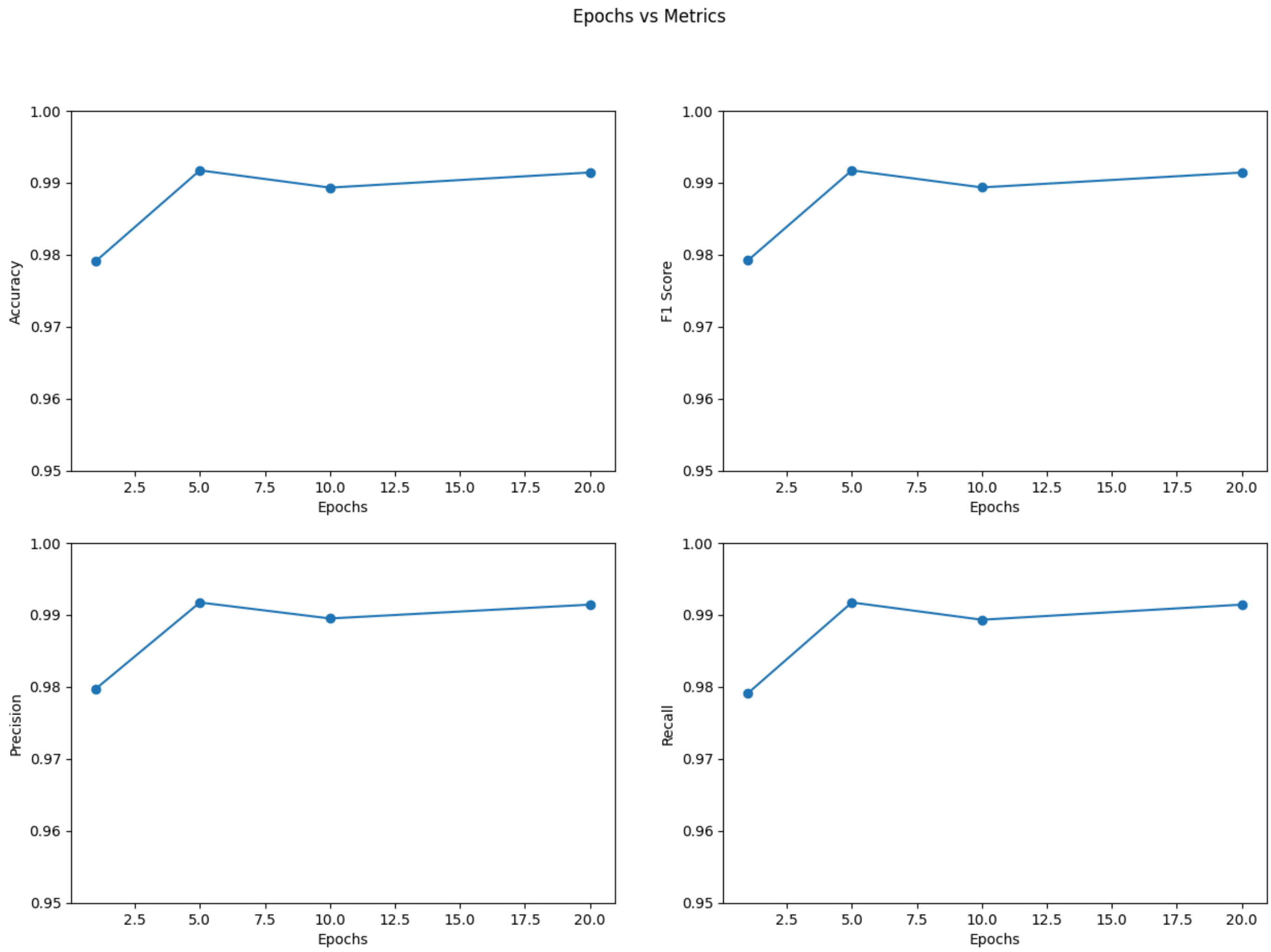




In [ ]:
```python
#plot line graphs for epochs vs acc, f1, prec, recall
fig, axs = plt.subplots(2, 2, figsize=(15, 10))
fig.suptitle('Epochs vs Metrics')

axs[0,0].plot(epoch_df['Epochs'], epoch_df['Accuracy'], label='Accuracy', marker='o')
axs[0,0].set_xlabel('Epochs')
axs[0,0].set_ylabel('Accuracy')
axs[0,0].set_ylim(0.95, 1.0)
```

```
axs[0,1].plot(epoch_df['Epochs'], epoch_df['F1 Score'], label='F1 Score', marker='o')
axs[0,1].set_xlabel('Epochs')
axs[0,1].set_ylabel('F1 Score')
axs[0,1].set_ylim(0.95, 1.0)

axs[1,0].plot(epoch_df['Epochs'], epoch_df['Precision'], label='Precision', marker='o
axs[1,0].set_xlabel('Epochs')
axs[1,0].set_ylabel('Precision')
axs[1,0].set_ylim(0.95, 1.0)

axs[1,1].plot(epoch_df['Epochs'], epoch_df['Recall'], label='Recall', marker='o')
axs[1,1].set_xlabel('Epochs')
axs[1,1].set_ylabel('Recall')
axs[1,1].set_ylim(0.95, 1.0)
```

Out[ ]: (0.95, 1.0)



These results are not as clear as the previous ones, since from 5 epochs and above the model's performance is very similar. However, upon looking at the training history of the model, it seems that the model is overfitting after 5 epochs, since after 5 epochs the validation accuracy begins plateauing and not improving. Therefore, I shall move on using 5 epochs to avoid overfitting.

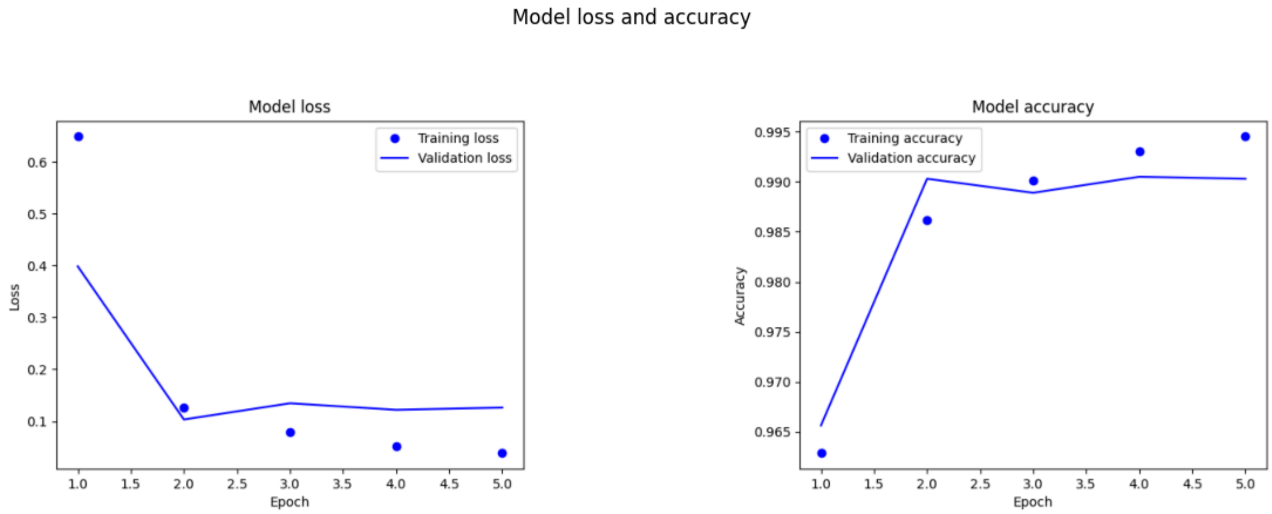
Layers

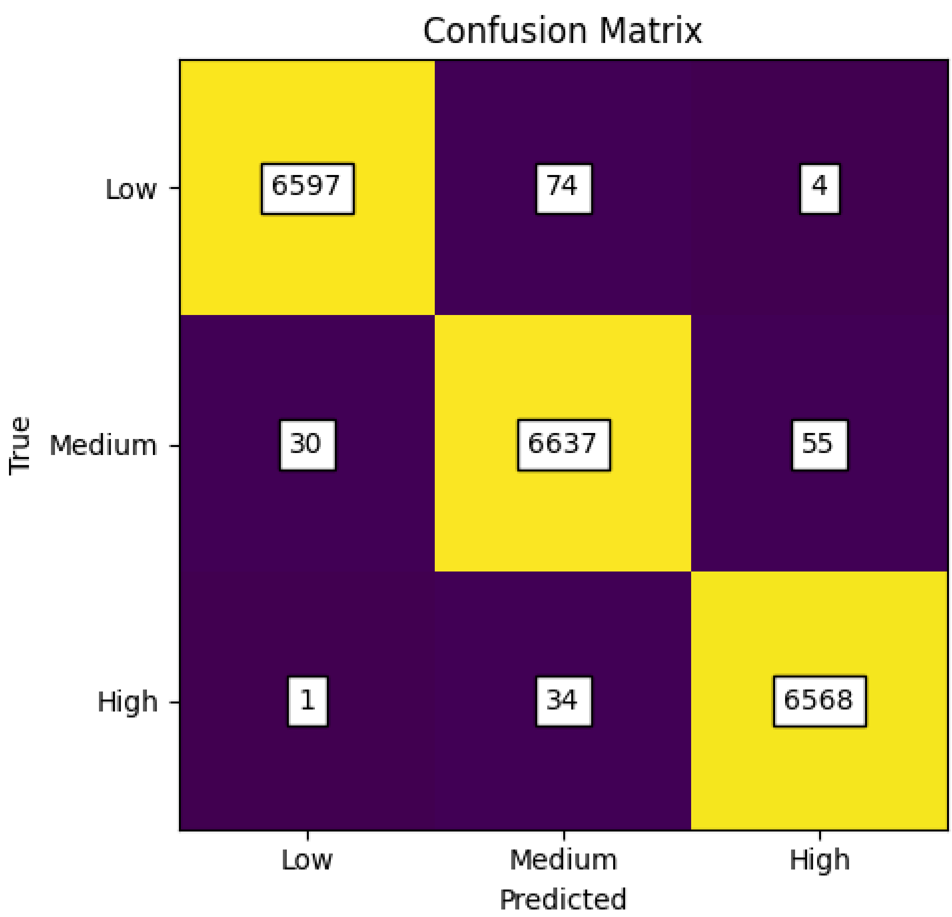
In [ ]:
```
#tuning for best amount of layers
layers_df = pd.DataFrame(columns=['Layer Config', 'Accuracy', 'F1 Score', 'Precision'
layers_to_test = [
    {'conv_layers': 1, 'dense_layers': 1},
    {'conv_layers': 2, 'dense_layers': 1},
    {'conv_layers': 1, 'dense_layers': 2},
```

```python
    {'conv_layers': 2, 'dense_layers': 2},
]

for layer_config in layers_to_test:
    num_conv_layers = layer_config['conv_layers']
    num_dense_layers = layer_config['dense_layers']

    layer_config_name = str(num_conv_layers) + ' Conv Layers, ' + str(num_dense_layer
    #try load already built model
    try:
        model_name = 'modelV1_'+str(num_conv_layers)+'conv_'+ str(num_dense_layers)+'
        model = keras.models.load_model('./models/'+model_name+'.h5')
        print('Model loaded')
        modelCreated = True
    except:
        modelCreated = False
        print('Model not found')

    print("Layer Config:", layer_config_name)

    if not modelCreated:
        #same model as modelV1, but with different learning rates
        inputs = keras.Input(shape=(160,128,1)) #resolution of images
        x = inputs

        #add the convolutional layers
        for _ in range(num_conv_layers):
            x = layers.Conv2D(16, 3, activation="relu")(x)
            x = layers.MaxPooling2D(pool_size=2)(x)

        x = layers.Flatten()(x)

        #add the dense layers
        for _ in range(num_dense_layers - 1):  #subtract 1 since we already have a de
            x = layers.Dense(32, activation="relu")(x)

        outputs = layers.Dense(3, activation="softmax")(x) #3 classes
        model = keras.Model(inputs=inputs, outputs=outputs)

        model.compile(optimizer=keras.optimizers.legacy.Adam(learning_rate=0.0001),
                loss='sparse_categorical_crossentropy',
                metrics=['accuracy'])
        model.fit(np.array(X_train), np.array(y_train), epochs=5, batch_size=32, vali

        model.save('./models/'+ model_name + '.h5')


    plot_loss_accuracy(modelCreated, model, model_name)
    results = evaluate_model(model, X_test, y_test, model_name)
    layer_config_name = str(num_conv_layers) + 'CL ' + str(num_dense_layers) + 'DL'
    results['Layer Config'] = layer_config_name
    layers_df.loc[len(layers_df.index)] = results
```

```
Model loaded
Layer Config: 1 Conv Layers, 1 Dense Layers
  4/625 [..............................] - ETA: 11s - loss: 0.2836 - accuracy: 0.9844
2024-03-03 18:14:41.543000: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 9s 14ms/step - loss: 0.1337 - accuracy: 0.9
901
  1/625 [..............................] - ETA: 2:33
2024-03-03 18:14:51.817286: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
```

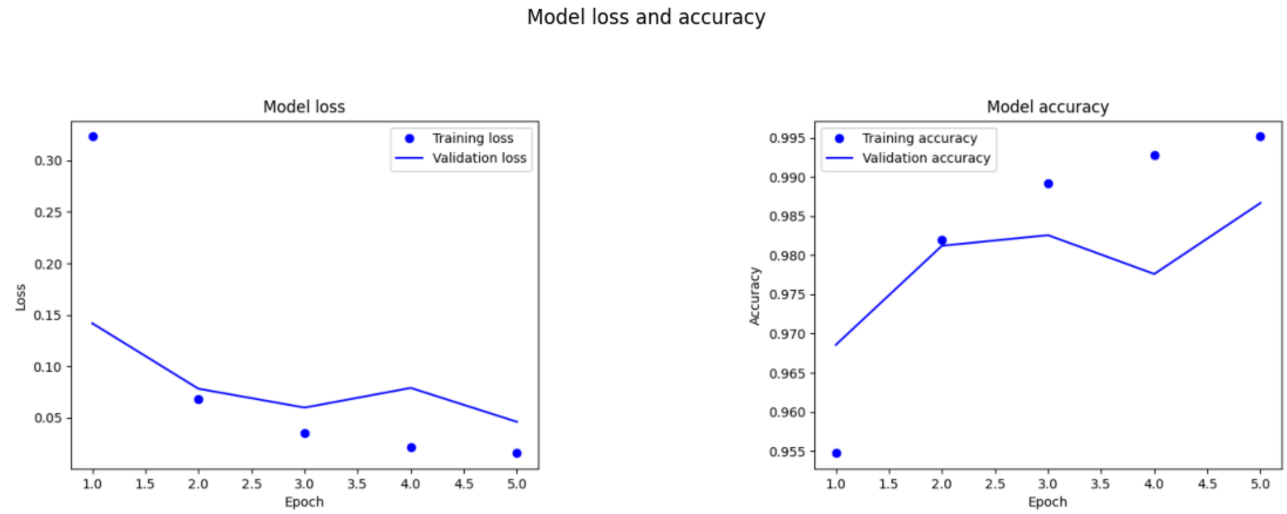
```
625/625 [==============================] - 7s 11ms/step
Results: [0.13368579745292664, 0.9901000261306763]
Accuracy: 0.9901
F1 Score: 0.990102876024772
Precision: 0.9901181059577124
Recall: 0.9901
Confusion Matrix:
 [[6597   74    4]
 [  30 6637   55]
 [   1   34 6568]]
```

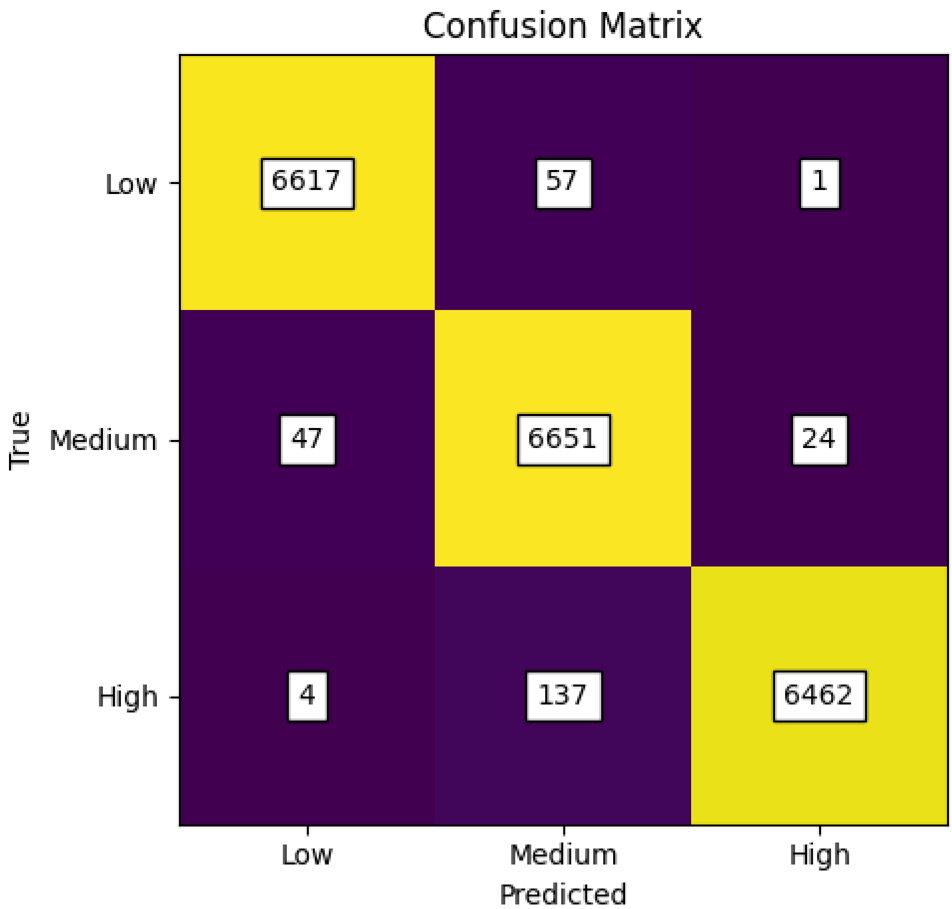





```
Model loaded
Layer Config: 2 Conv Layers, 1 Dense Layers
2024-03-03 18:15:00.716793: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 11s 16ms/step - loss: 0.0454 - accuracy: 0.9865
  6/625 [..............................] - ETA: 16s
2024-03-03 18:15:12.337887: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
```

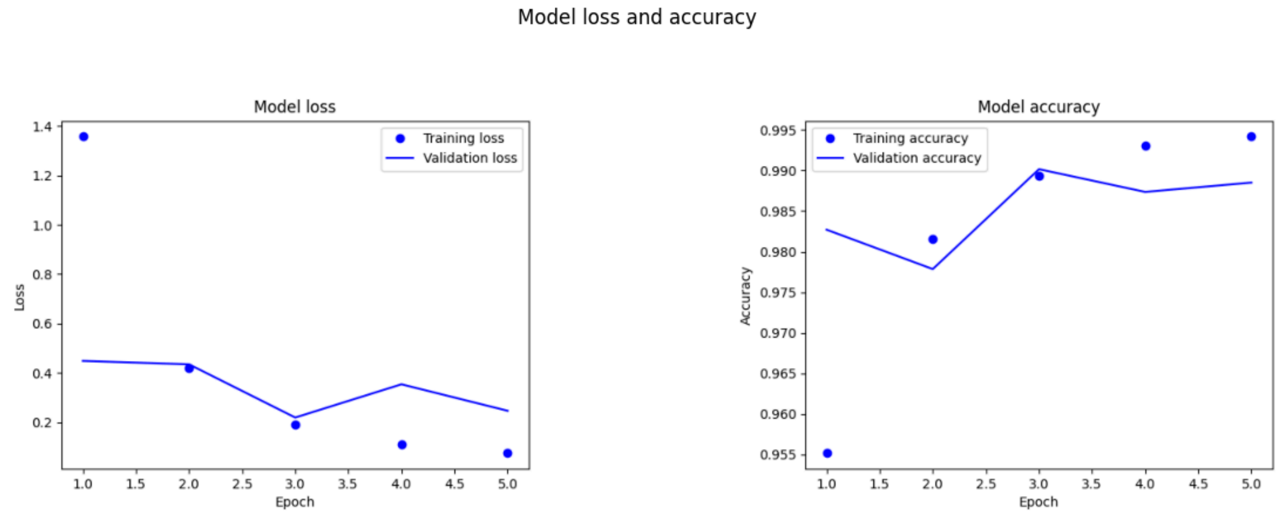
```
625/625 [==============================] - 9s 14ms/step
Results: [0.04540864750742912, 0.9865000247955322]
Accuracy: 0.9865
F1 Score: 0.9865218572670048
Precision: 0.9866492730488097
Recall: 0.9865
Confusion Matrix:
 [[6617   57    1]
 [  47 6651   24]
 [   4  137 6462]]
```

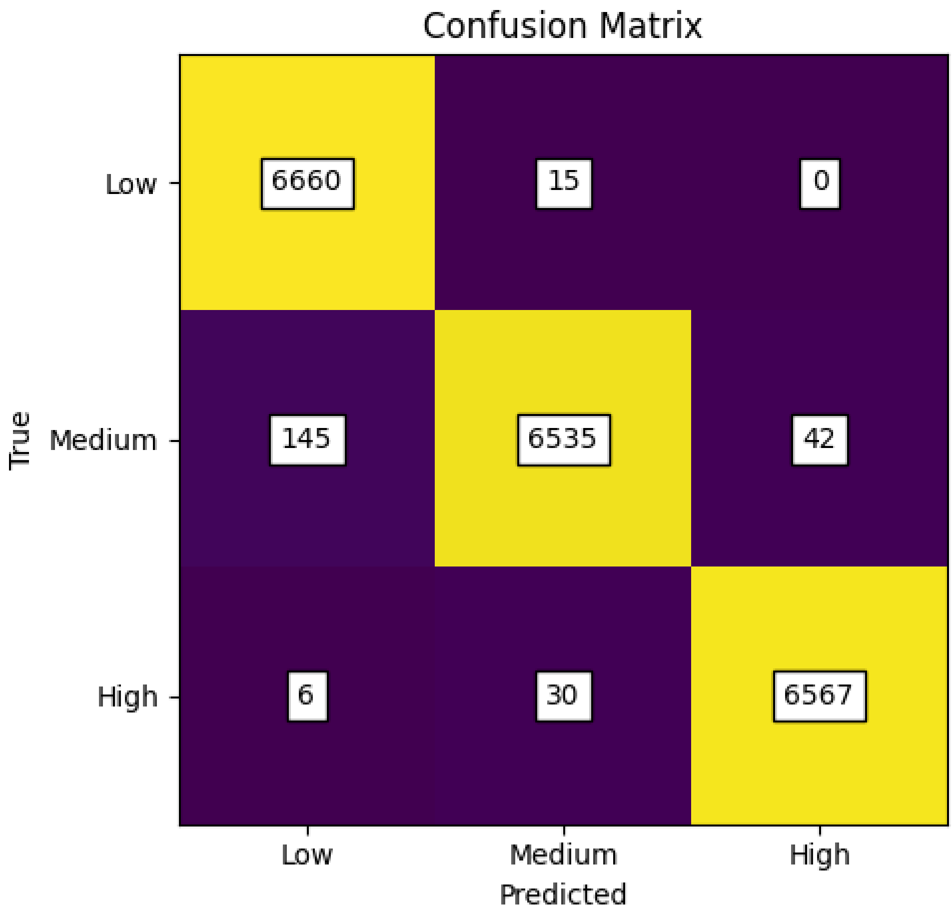





```
Model loaded
Layer Config: 1 Conv Layers, 2 Dense Layers
2024-03-03 18:15:22.896378: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 11s 17ms/step - loss: 0.2577 - accuracy: 0.
9881
  5/625 [..............................] - ETA: 21s
2024-03-03 18:15:35.152461: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
```

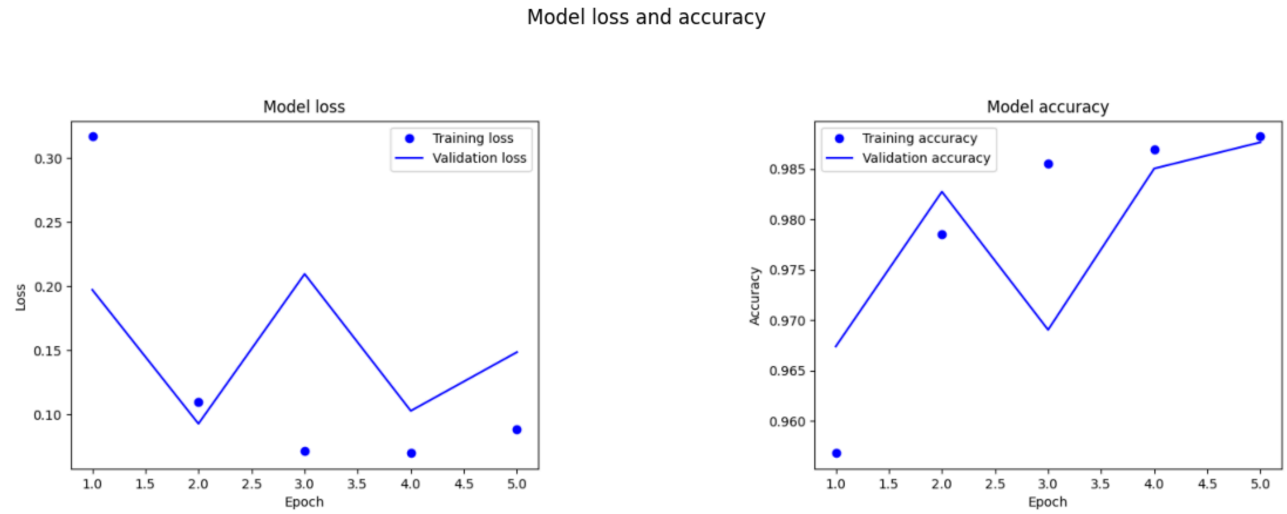
```
625/625 [==============================] - 9s 15ms/step
Results: [0.2576688230037689, 0.988099992275238]
Accuracy: 0.9881
F1 Score: 0.9880808208654004
Precision: 0.9882041063899354
Recall: 0.9881
Confusion Matrix:
 [[6660   15    0]
 [ 145 6535   42]
 [   6   30 6567]]
```

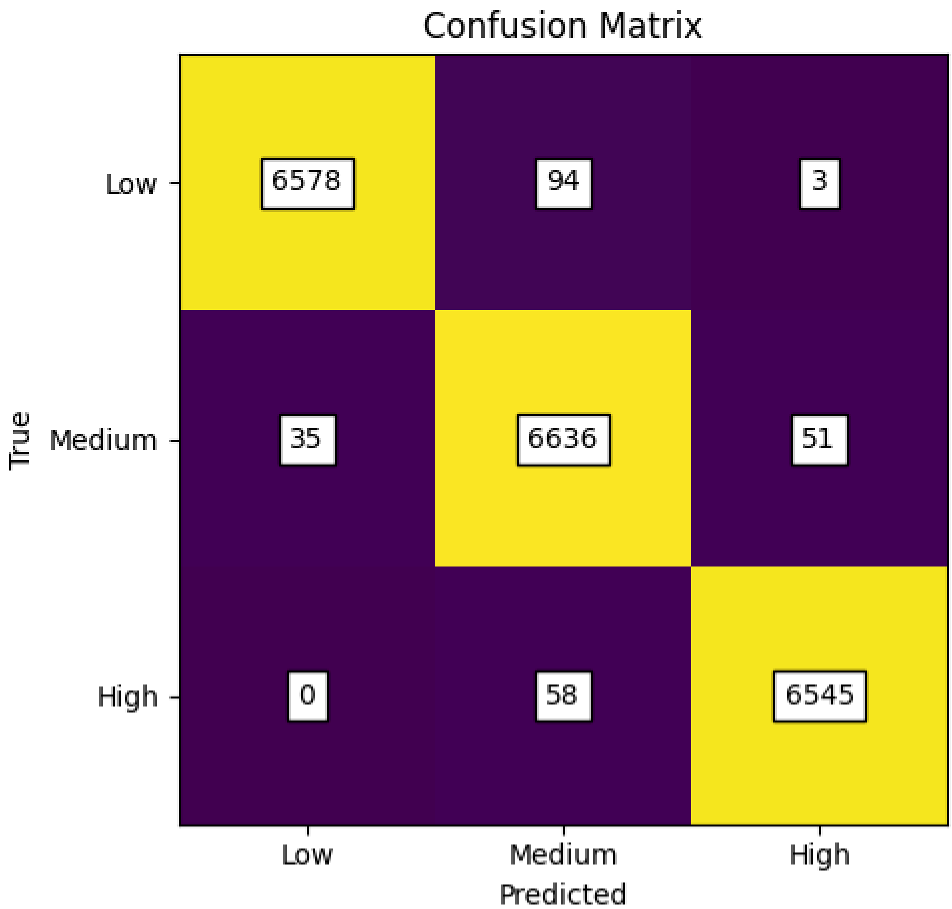





```
Model loaded
Layer Config: 2 Conv Layers, 2 Dense Layers
  5/625 [..............................] - ETA: 8s - loss: 0.1588 - accuracy: 0.9750
2024-03-03 18:15:47.081388: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 8s 13ms/step - loss: 0.1443 - accuracy: 0.9
880
  6/625 [..............................] - ETA: 15s
```

```
2024-03-03 18:15:56.653524: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 6s 10ms/step
Results: [0.1443140059709549, 0.9879500269889832]
Accuracy: 0.98795
F1 Score: 0.9879628216502099
Precision: 0.9880058514204385
Recall: 0.98795
Confusion Matrix:
 [[6578   94    3]
 [  35 6636   51]
 [   0   58 6545]]
```



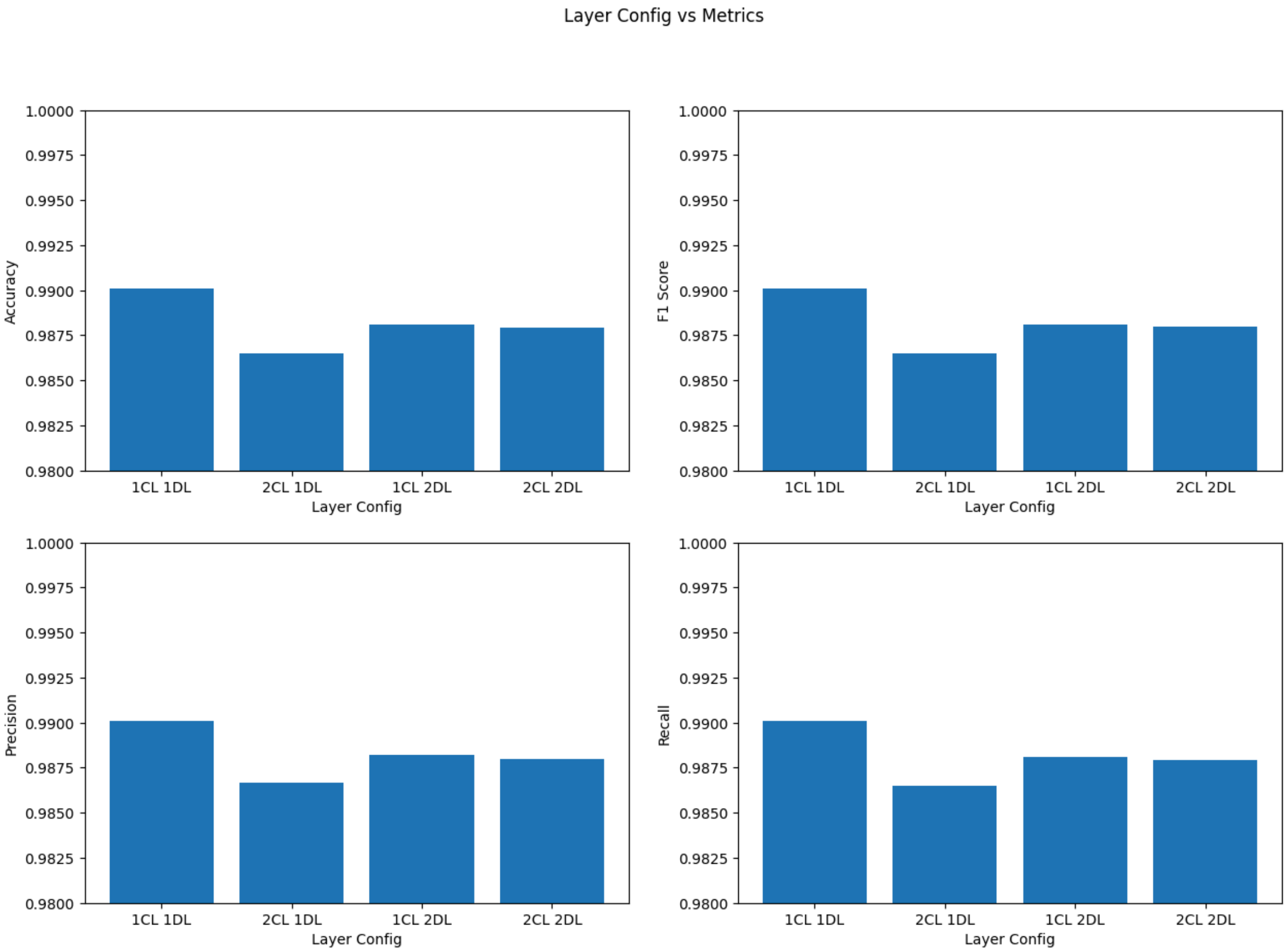


In [ ]:

```python
#plot bar graphs for layer config vs acc, f1, prec, recall
fig, axs = plt.subplots(2, 2, figsize=(15, 10))
fig.suptitle('Layer Config vs Metrics')

axs[0,0].bar(layers_df['Layer Config'], layers_df['Accuracy'], label='Accuracy')
axs[0,0].set_xlabel('Layer Config')
```

```
axs[0,0].set_ylabel('Accuracy')
axs[0,0].set_ylim(0.98, 1.0)

axs[0,1].bar(layers_df['Layer Config'], layers_df['F1 Score'], label='F1 Score')
axs[0,1].set_xlabel('Layer Config')
axs[0,1].set_ylabel('F1 Score')
axs[0,1].set_ylim(0.98, 1.0)

axs[1,0].bar(layers_df['Layer Config'], layers_df['Precision'], label='Precision')
axs[1,0].set_xlabel('Layer Config')
axs[1,0].set_ylabel('Precision')
axs[1,0].set_ylim(0.98, 1.0)

axs[1,1].bar(layers_df['Layer Config'], layers_df['Recall'], label='Recall')
axs[1,1].set_xlabel('Layer Config')
axs[1,1].set_ylabel('Recall')
axs[1,1].set_ylim(0.98, 1.0)
```

Out[ ]: (0.98, 1.0)



From these results it definitely seems quite clear that the best out of the tested layer configurations is 1 Convolutional Layer and 1 Dense Layer.This seems to be the best model.

Final Model

After all the testing and tuning, the best model seems to be the one with the following parameters:

- Learning rate: 0.0001
- Optimizer: Adam
- Batch size: 32

- Epochs: 5
- Layers: 1 Convolutional Layer and 1 Dense Layer

We shall save this model and use it to evaluate the test set.

In [ ]:
```
#save the 1c1d as the best model if it doesn't exist
if not os.path.exists('./models/best_model.h5'):
    best_model = keras.models.load_model('./models/modelV1_1conv_1dense.h5')
    best_model.save('./models/best_model.h5')
else:
    best_model = keras.models.load_model('./models/best_model.h5')
```

Evaluating the model against a pretrained VGG16 model

As a final evaluation, I will compare the model I have built with a pretrained VGG16 model. I will load the VGG16 model and train it using the training set and validate it using the validation set. I will also save the model to a file.

However the VGG16 model does not take the same input shape as the model I have built, so I will need to preprocess the data again where we include the RGB values and resize the images to 224x224. Due to memory limitations on my machine, I will only use 6000 images for the training set, 2000 images for the validation set and 2000 images for the test set.

In [ ]:
```
#VGG Only takes rgb images and images of size 224x224, so we need to load the images
images_rgb = []
num_required_images = 99999
processed_folder = './data/processed/'
for i in range(num_required_images):
    print("Loading image", i)
    img = Image.open(os.path.join(processed_folder, 'sample_' + str(i) + '.png'))
    img = img.convert('RGB')
    #resize the image to 224x224 because VGG16 only takes that size
    img = img.resize((224, 224))
    img_array = np.array(img)
    images_rgb.append(img_array)
```

In [ ]:
```
#only use 10000 images for VGG16 due to memory issues so split the data again
throw_away_x, X_reduced, throw_away_y, y_reduced = train_test_split(images_rgb, label

del throw_away_x
del throw_away_y
del images_rgb
#now split the data into 80% train, 20% test
X_train_temp_vgg, X_test_vgg, y_train_temp_vgg, y_test_vgg = train_test_split(X_reduc

#further split the training data into 75% train, 25% validation
X_train_vgg, X_val_vgg, y_train_vgg, y_val_vgg = train_test_split(X_train_temp_vgg, y

del X_train_temp_vgg
del y_train_temp_vgg
```

In [ ]:
```
#first check if the model exists
try:
    modelVGG = keras.models.load_model('./models/modelVGG16.h5')
    print('Model loaded')
    modelVGGCreated = True
```

```python
except:
    modelVGGCreated = False
    print('Model not found')
```

```
Model loaded
```

Now we can compile the VGG16 model and train it using the training set and validate it using the validation set. We will also save the model to a file.

Finally we will evaluate the model using the test sets and compare the results with the model I have built.

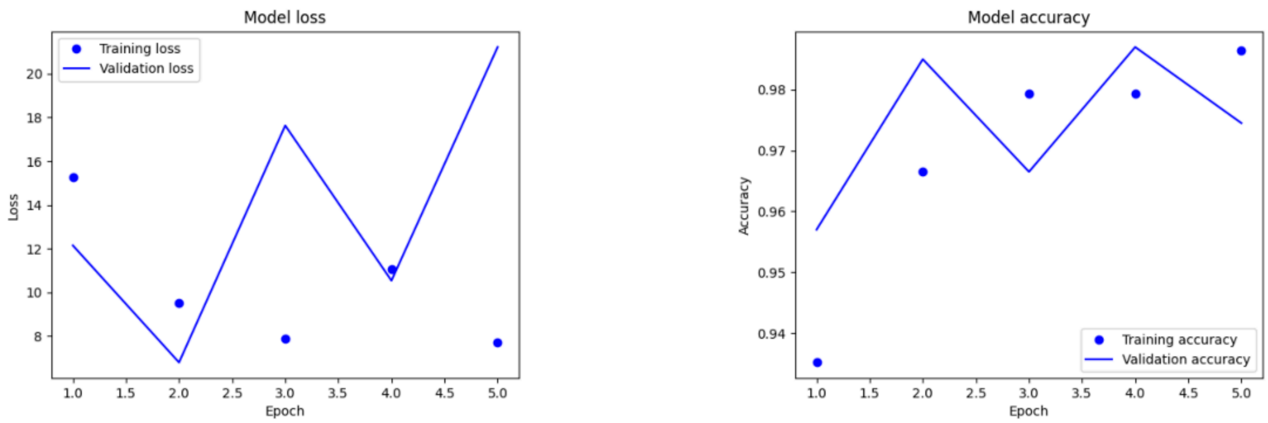
In [ ]:
```python
if not modelVGGCreated:
    from keras.applications import VGG16

    #load pre-trained VGG16 model
    vgg16 = VGG16(weights='imagenet', include_top=False, input_shape=(224, 224, 3))

    for layer in vgg16.layers:
        layer.trainable = False

    #add custom layers
    x = layers.Flatten()(vgg16.output)
    x = layers.Dense(1024, activation='relu')(x)
    x = layers.Dropout(0.2)(x)
    predictions = layers.Dense(3, activation='softmax')(x)

    modelVGG = keras.Model(vgg16.input, predictions)
```

In [ ]:
```python
if not modelVGGCreated:
    #compile the model
    modelVGG.compile(optimizer='adam',
                loss='sparse_categorical_crossentropy',
                metrics=['accuracy'])
```

In [ ]:
```python
if not modelVGGCreated:
    #train the model
    modelVGG.fit(np.array(X_train_vgg), np.array(y_train_vgg), epochs=5, batch_size=4

    #save the model
    modelVGG.save('./models/modelVGG16.h5')
```

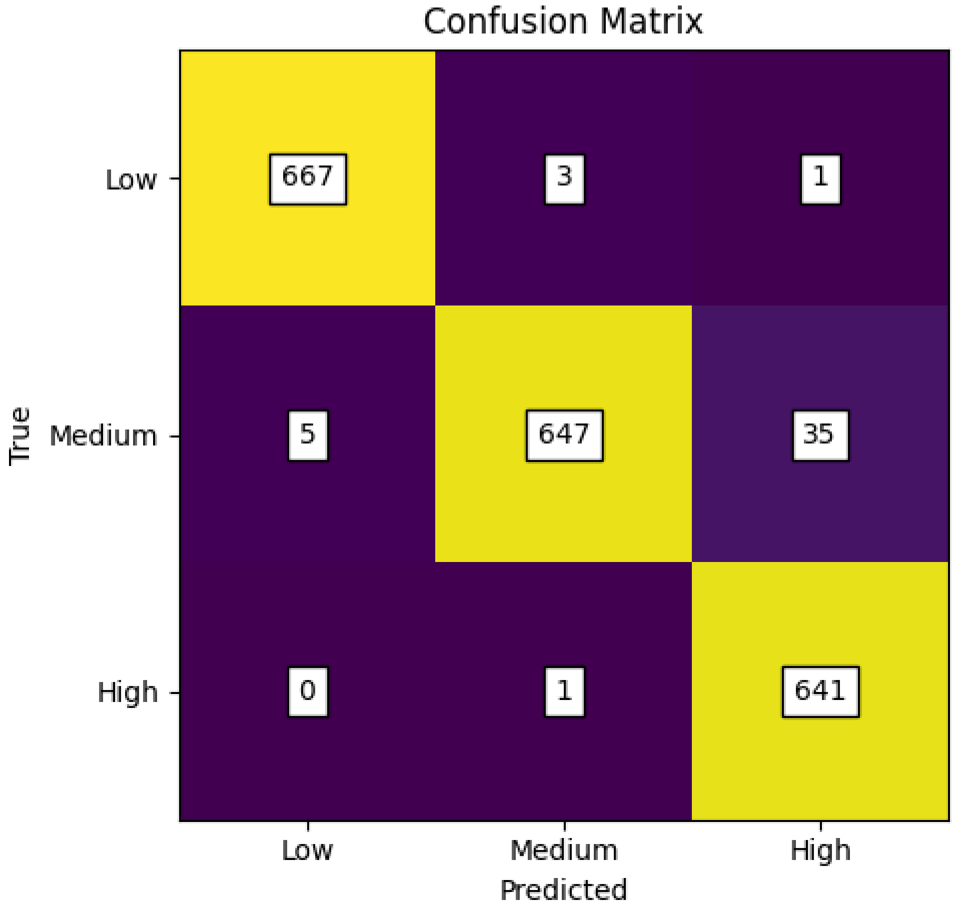
In [ ]:
```python
#plot the loss and accuracy graphs
plot_loss_accuracy(modelVGGCreated, modelVGG, 'modelVGG16')
```

Model loss and accuracy



In [ ]:
```
#evaluate the model
vgg_results = evaluate_model(modelVGG, X_test_vgg, y_test_vgg, 'modelVGG16')
vgg_results
```

```
2024-03-03 18:18:41.316180: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
63/63 [==============================] - 81s 1s/step - loss: 14.5549 - accuracy: 0.977
5
2024-03-03 18:20:03.036861: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
63/63 [==============================] - 69s 1s/step
Results: [14.55486011505127, 0.9775000214576721]
Accuracy: 0.9775
F1 Score: 0.9774511623274429
Precision: 0.9783236972306552
Recall: 0.9775
Confusion Matrix:
 [[667   3   1]
 [  5 647  35]
 [  0   1 641]]
```

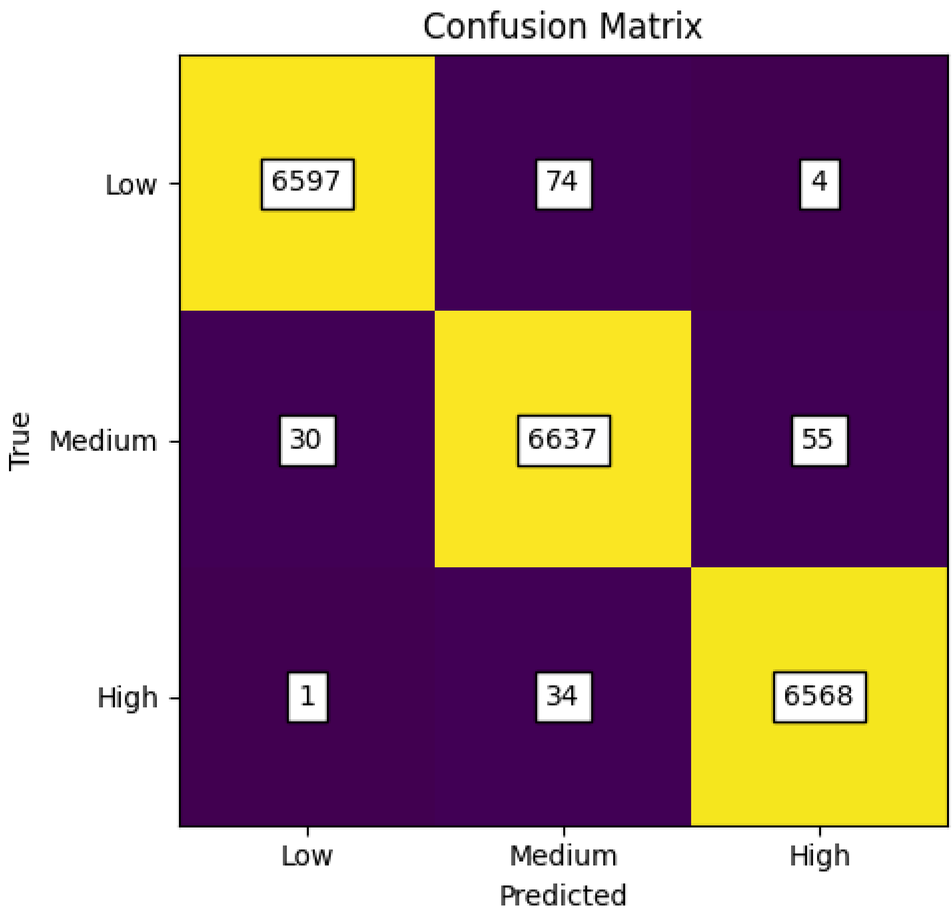


Out[ ]:
```
Model        modelVGG16
Accuracy         0.9775
F1 Score       0.977451
Precision      0.978324
Recall           0.9775
dtype: object
```

In [ ]:
```
#evaluate the best model
best_model_results = evaluate_model(best_model, X_test, y_test, 'best_model')
```

```
  4/625 [..............................] - ETA: 10s - loss: 0.2836 - accuracy: 0.9844
2024-03-03 18:21:15.567914: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
```

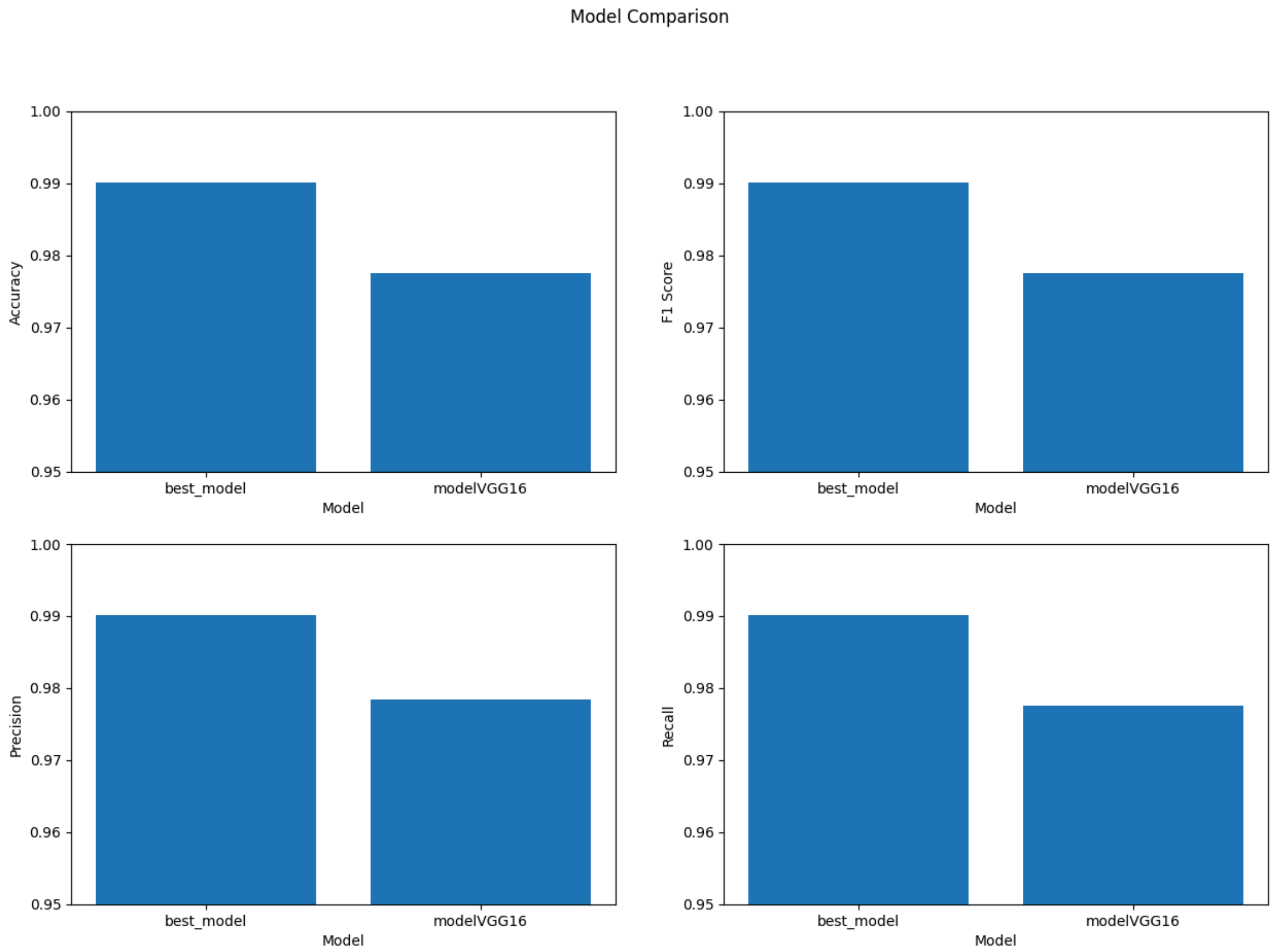
```
625/625 [==============================] - 7s 11ms/step - loss: 0.1337 - accuracy: 0.9
901
 12/625 [..............................] - ETA: 6s
2024-03-03 18:21:23.633450: I tensorflow/core/grappler/optimizers/custom_graph_optimiz
er_registry.cc:114] Plugin optimizer for device_type GPU is enabled.
625/625 [==============================] - 6s 9ms/step
Results: [0.13368579745292664, 0.9901000261306763]
Accuracy: 0.9901
F1 Score: 0.990102876024772
Precision: 0.9901181059577124
Recall: 0.9901
Confusion Matrix:
 [[6597   74    4]
 [  30 6637   55]
 [   1   34 6568]]
```



In [ ]:
```
#plot the best models evaluation results against the vgg16 model
results_df = pd.DataFrame(columns=['Model', 'Accuracy', 'F1 Score', 'Precision', 'Rec
results_df.loc[len(results_df.index)] = best_model_results
results_df.loc[len(results_df.index)] = vgg_results

fig, axs = plt.subplots(2, 2, figsize=(15, 10))
fig.suptitle('Model Comparison')

axs[0,0].bar(results_df['Model'], results_df['Accuracy'], label='Accuracy')
axs[0,0].set_xlabel('Model')
axs[0,0].set_ylabel('Accuracy')
axs[0,0].set_ylim(0.95, 1.0)

axs[0,1].bar(results_df['Model'], results_df['F1 Score'], label='F1 Score')
axs[0,1].set_xlabel('Model')
axs[0,1].set_ylabel('F1 Score')
axs[0,1].set_ylim(0.95, 1.0)

axs[1,0].bar(results_df['Model'], results_df['Precision'], label='Precision')
```

```
axs[1,0].set_xlabel('Model')
axs[1,0].set_ylabel('Precision')
axs[1,0].set_ylim(0.95, 1.0)

axs[1,1].bar(results_df['Model'], results_df['Recall'], label='Recall')
axs[1,1].set_xlabel('Model')
axs[1,1].set_ylabel('Recall')
axs[1,1].set_ylim(0.95, 1.0)
```

Out[ ]: (0.95, 1.0)



The custom built model has done exceptionally well in beating out the VGG16 model, where the custom built model has an accuracy, f1 score, precision and recall all at about 0.99 and the VGG16 model shortly behind with all around 0.97. This is a great result and shows that the custom built model is a great model for this dataset.

Conclusion

In conclusion, the project has successfully developed and evaluated a deep learning model for classifying masking levels in mammograms, contributing to the field of medical image analysis. The implementation of a convolutional neural network (CNN) allowed for accurate and efficient classification of breast tissue density, aiding in the early detection of breast cancer.