Feed_Forward_Network_using_Pytorch_with_MNIST

April 18, 2022

1 Implementing DNN and CNN on MNIST dataset

Implemented 2 and 3 hidden layer DNN and a single convolutional layer CNN for classification of digits on MNIST dataset

Libraries used:
1) PyTorch - for implementing DNN and CNN
2) Matplotlib - to plot the graph

[1]:
```
import torch
import torch.nn as nn
import torchvision
import torchvision.transforms as transforms
import matplotlib.pyplot as plt
```

[2]:
```
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
```

Setting the hyper-parameters

[3]:
```
input_size = 784 # 28x28
hidden_size = 512
num_classes = 10
num_epochs = 5
batch_size = 100
learning_rate = 0.001
```

Importing the MNIST dataset

[4]:
```
train_dataset = torchvision.datasets.MNIST(root='./data',
                                           train=True,
                                           transform=transforms.ToTensor(),
                                           download=True)

test_dataset = torchvision.datasets.MNIST(root='./data',
                                          train=False,
                                          transform=transforms.ToTensor())
```

[5]:
```
print(train_dataset)
print(test_dataset)
```

```
Dataset MNIST
    Number of datapoints: 60000
    Root location: ./data
    Split: Train
    StandardTransform
Transform: ToTensor()
Dataset MNIST
    Number of datapoints: 10000
    Root location: ./data
    Split: Test
    StandardTransform
Transform: ToTensor()
```

Loading the datasets into mini-batches of size 100 samples

[6]:
```
train_loader = torch.utils.data.DataLoader(dataset=train_dataset,
                                           batch_size=batch_size,
                                           shuffle=True)

test_loader = torch.utils.data.DataLoader(dataset=test_dataset,
                                          batch_size=batch_size,
                                          shuffle=False)
```

1.0.1 Question 2) a) Class DeepNeuralNet

Implements the DNN with 2 hidden layers and
ReLU hidden activation on both the hidden layers
with hidden neuron size = 512

[7]:
```
class DeepNeuralNet(nn.Module):
    def __init__(self, input_size, hidden_size, num_classes):
        super(DeepNeuralNet, self).__init__()
        self.input_size = input_size
        self.l1 = nn.Linear(input_size, hidden_size)
        self.relu = nn.ReLU()
        self.l2 = nn.Linear(hidden_size, hidden_size)
        self.l3 = nn.Linear(hidden_size, num_classes)

    def forward(self, x):
        out = self.l1(x)
        out = self.relu(out)
        out = self.l2(out)
        out = self.relu(out)
        out = self.l3(out)
        return out

model = DeepNeuralNet(input_size, hidden_size, num_classes).to(device)
```

Using Cross-Entropy Loss and Adam Optimizer

[8]:
```
criterion = nn.CrossEntropyLoss()
optimizer = torch.optim.Adam(model.parameters(), lr=learning_rate)
```

1.0.2 Function train(model, optimizer, type)

Trains the given model using the MNIST dataset in mini-batches and
Plots the Loss curve for each step of SGD.

[9]:
```
def train(model, optimizer, type = "DNN"):
    n_total_steps = len(train_loader)

    loss_plot = []
    for epoch in range(num_epochs):
        for i, (images, labels) in enumerate(train_loader):
            # origin shape: [100, 1, 28, 28]
              # resized: [100, 784]

            if type == "DNN":
                images = images.reshape(-1, 28*28).to(device)
            else:
                images = images.to(device)
            labels = labels.to(device)

            # Forward pass
            outputs = model(images)
            loss = criterion(outputs, labels)

            # Backward and optimize
            optimizer.zero_grad()
            loss.backward()
            optimizer.step()

            if (i+1) % 100 == 0:
                print (f'Epoch [{epoch+1}/{num_epochs}], Step [{i+1}/
↪{n_total_steps}], Loss: {loss.item():.4f}')
                loss_plot.append(loss.item())

    plt.plot([i for i in range(num_epochs * 6)], loss_plot, marker="o",␣
↪color='b')
    plt.xlabel('Epoch - Mini Batch')
    plt.ylabel('Loss')
    plt.title('Loss curve')
    plt.show()
```

1.0.3 Function predict(model, type)

Predicts the output of the data point using the trained model and calculates the test accuracy of the model.

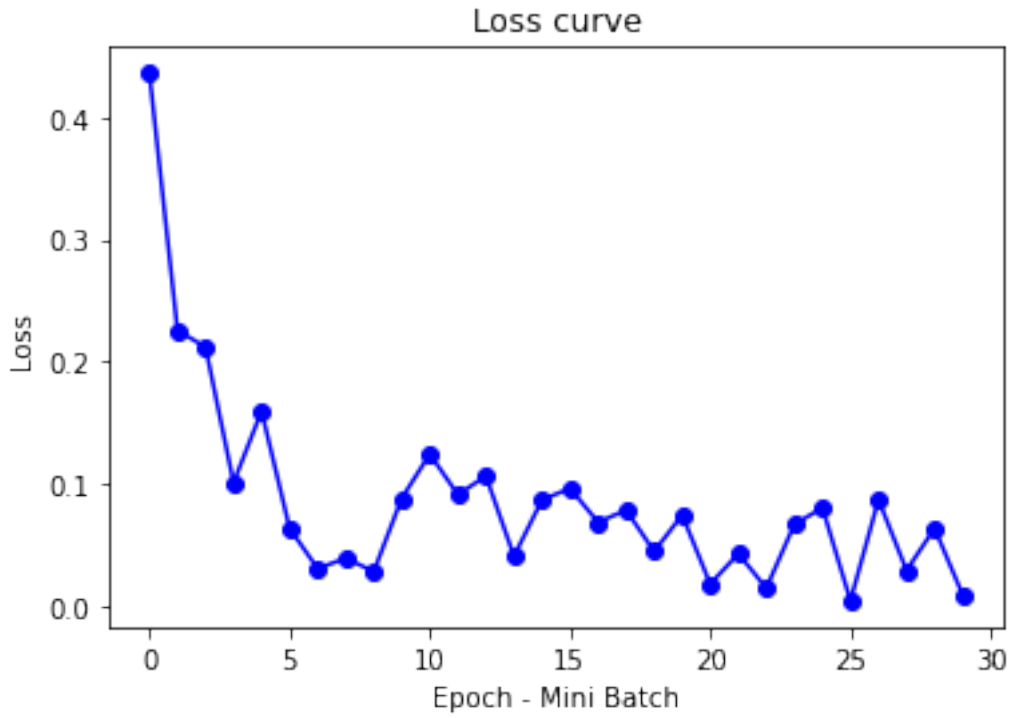
[10]:
```
def predict(model, type = "DNN"):
    with torch.no_grad():
        n_correct = 0
        n_samples = 0
        for images, labels in test_loader:
            if type == "DNN":
                images = images.reshape(-1, 28*28).to(device)
            else:
                images = images.to(device)

            labels = labels.to(device)

            outputs = model(images)

            # max returns (value ,index)
            _, predicted = torch.max(outputs.data, 1)
            n_samples += labels.size(0)
            n_correct += (predicted == labels).sum().item()

        acc = 100.0 * n_correct / n_samples
        print(f'#### Test Accuracy of the network on 10000 test images: {acc} %␣
 ↪####')
```

Training the DNN with 2 hidden layer

[11]:
```
train(model, optimizer)
```

```
Epoch [1/5], Step [100/600], Loss: 0.4363
Epoch [1/5], Step [200/600], Loss: 0.2255
Epoch [1/5], Step [300/600], Loss: 0.2119
Epoch [1/5], Step [400/600], Loss: 0.1008
Epoch [1/5], Step [500/600], Loss: 0.1594
Epoch [1/5], Step [600/600], Loss: 0.0634
Epoch [2/5], Step [100/600], Loss: 0.0304
Epoch [2/5], Step [200/600], Loss: 0.0390
Epoch [2/5], Step [300/600], Loss: 0.0280
Epoch [2/5], Step [400/600], Loss: 0.0881
Epoch [2/5], Step [500/600], Loss: 0.1242
Epoch [2/5], Step [600/600], Loss: 0.0910
Epoch [3/5], Step [100/600], Loss: 0.1062
Epoch [3/5], Step [200/600], Loss: 0.0406
Epoch [3/5], Step [300/600], Loss: 0.0866
Epoch [3/5], Step [400/600], Loss: 0.0962
Epoch [3/5], Step [500/600], Loss: 0.0684
```

```
Epoch [3/5], Step [600/600], Loss: 0.0783
Epoch [4/5], Step [100/600], Loss: 0.0445
Epoch [4/5], Step [200/600], Loss: 0.0743
Epoch [4/5], Step [300/600], Loss: 0.0177
Epoch [4/5], Step [400/600], Loss: 0.0426
Epoch [4/5], Step [500/600], Loss: 0.0144
Epoch [4/5], Step [600/600], Loss: 0.0666
Epoch [5/5], Step [100/600], Loss: 0.0802
Epoch [5/5], Step [200/600], Loss: 0.0042
Epoch [5/5], Step [300/600], Loss: 0.0869
Epoch [5/5], Step [400/600], Loss: 0.0289
Epoch [5/5], Step [500/600], Loss: 0.0634
Epoch [5/5], Step [600/600], Loss: 0.0090
```



Calculating the Test Accuracy of the trained DNN with 2 hidden layer Test Accuracy = 97.89%

[12]:
```
predict(model)
```

```
#### Test Accuracy of the network on 10000 test images: 97.89 % ####
```

1.0.4 Class DeepNeuralNet_Three

Implements the DNN with 3 hidden layers and
ReLU hidden activation on all the hidden layers
with hidden neuron size = 512

[13]:
```
class DeepNeuralNet_Three(nn.Module):
    def __init__(self, input_size, hidden_size, num_classes):
        super(DeepNeuralNet_Three, self).__init__()
        self.input_size = input_size
        self.l1 = nn.Linear(input_size, hidden_size)
        self.relu = nn.ReLU()
        self.l2 = nn.Linear(hidden_size, hidden_size)
        self.l3 = nn.Linear(hidden_size, hidden_size)
        self.l4 = nn.Linear(hidden_size, num_classes)

    def forward(self, x):
        out = self.l1(x)
        out = self.relu(out)
        out = self.l2(out)
        out = self.relu(out)
        out = self.l3(out)
        out = self.relu(out)
        out = self.l4(out)
        return out

model = DeepNeuralNet_Three(input_size, hidden_size, num_classes).to(device)
```

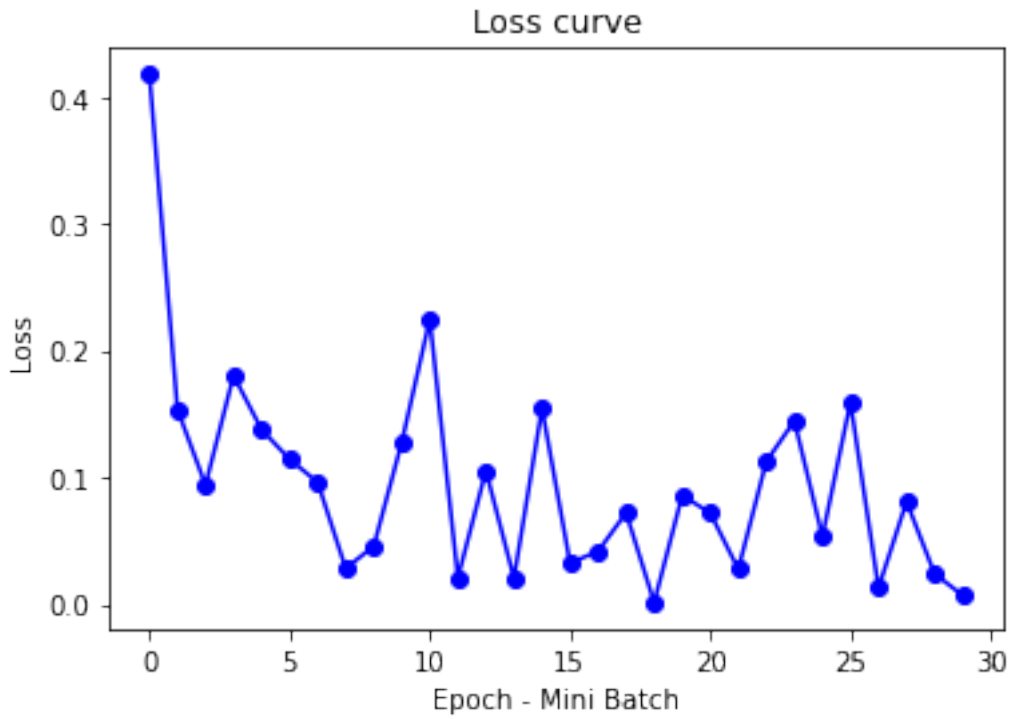
[14]:
```
optimizer = torch.optim.Adam(model.parameters(), lr=learning_rate)
```

Training the DNN with 3 hidden layer

[15]:
```
train(model, optimizer)
```

```
Epoch [1/5], Step [100/600], Loss: 0.4178
Epoch [1/5], Step [200/600], Loss: 0.1536
Epoch [1/5], Step [300/600], Loss: 0.0940
Epoch [1/5], Step [400/600], Loss: 0.1802
Epoch [1/5], Step [500/600], Loss: 0.1378
Epoch [1/5], Step [600/600], Loss: 0.1143
Epoch [2/5], Step [100/600], Loss: 0.0962
Epoch [2/5], Step [200/600], Loss: 0.0283
Epoch [2/5], Step [300/600], Loss: 0.0458
Epoch [2/5], Step [400/600], Loss: 0.1278
Epoch [2/5], Step [500/600], Loss: 0.2246
Epoch [2/5], Step [600/600], Loss: 0.0209
Epoch [3/5], Step [100/600], Loss: 0.1053
Epoch [3/5], Step [200/600], Loss: 0.0206
Epoch [3/5], Step [300/600], Loss: 0.1545
```

```
Epoch [3/5], Step [400/600], Loss: 0.0325
Epoch [3/5], Step [500/600], Loss: 0.0418
Epoch [3/5], Step [600/600], Loss: 0.0721
Epoch [4/5], Step [100/600], Loss: 0.0014
Epoch [4/5], Step [200/600], Loss: 0.0858
Epoch [4/5], Step [300/600], Loss: 0.0720
Epoch [4/5], Step [400/600], Loss: 0.0277
Epoch [4/5], Step [500/600], Loss: 0.1126
Epoch [4/5], Step [600/600], Loss: 0.1445
Epoch [5/5], Step [100/600], Loss: 0.0535
Epoch [5/5], Step [200/600], Loss: 0.1593
Epoch [5/5], Step [300/600], Loss: 0.0129
Epoch [5/5], Step [400/600], Loss: 0.0810
Epoch [5/5], Step [500/600], Loss: 0.0241
Epoch [5/5], Step [600/600], Loss: 0.0071
```



Calculating the Test Accuracy of the trained DNN with 3 hidden layer Test Accuracy = 97.84%

[16]:
```
predict(model)
```

```
#### Test Accuracy of the network on 10000 test images: 97.84 % ####
```

1.0.5 Question 2) b) Class CNN

Implements CNN with single 2D-convolutional layer
with kernel size = 3 and 128 filters followed by
two Dense layers of 256 neurons

[17]:
```
class CNN(nn.Module):
    def __init__(self, filter, kernel_size, hidden_size):
        super(CNN, self).__init__()
        self.conv1 = nn.Sequential(
            nn.Conv2d(
                in_channels = 1,
                out_channels = filter,
                kernel_size = kernel_size,
                stride=1,
            ),
            nn.ReLU(),
        )
        self.l2 = nn.Linear(filter * 26 * 26, hidden_size)
        self.relu = nn.ReLU()
        self.l3 = nn.Linear(hidden_size, 10)


    def forward(self, x):
        x = self.conv1(x)
        # flatten the output of conv1 to (batch_size, filter * 26 * 26)
        x = x.view(x.size(0), -1)
        x = self.l2(x)
        x = self.relu(x)
        out = self.l3(x)
        return out

model = CNN(128, 3, 256).to(device)
```

Using Cross-Entropy Loss and Adam Optimizer

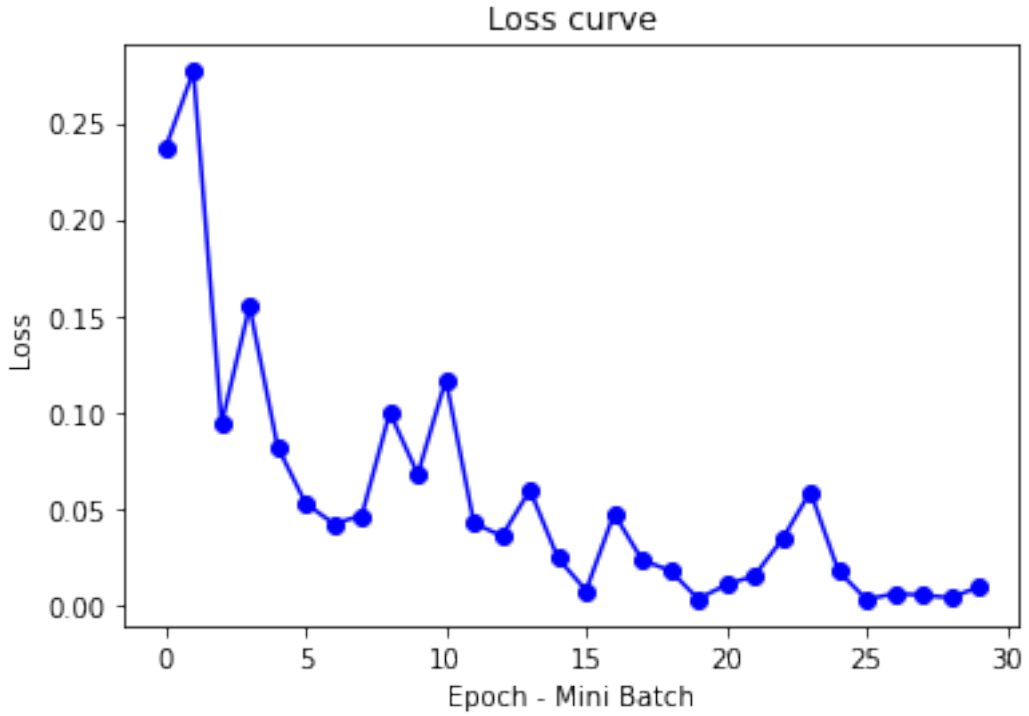
[18]:
```
criterion = nn.CrossEntropyLoss()
optimizer = torch.optim.Adam(model.parameters(), lr=learning_rate)
```

Training the CNN

[19]:
```
train(model, optimizer, "CNN")
```

```
Epoch [1/5], Step [100/600], Loss: 0.2368
Epoch [1/5], Step [200/600], Loss: 0.2767
Epoch [1/5], Step [300/600], Loss: 0.0940
Epoch [1/5], Step [400/600], Loss: 0.1550
Epoch [1/5], Step [500/600], Loss: 0.0822
Epoch [1/5], Step [600/600], Loss: 0.0529
```

```
Epoch [2/5], Step [100/600], Loss: 0.0424
Epoch [2/5], Step [200/600], Loss: 0.0466
Epoch [2/5], Step [300/600], Loss: 0.1000
Epoch [2/5], Step [400/600], Loss: 0.0680
Epoch [2/5], Step [500/600], Loss: 0.1171
Epoch [2/5], Step [600/600], Loss: 0.0427
Epoch [3/5], Step [100/600], Loss: 0.0361
Epoch [3/5], Step [200/600], Loss: 0.0598
Epoch [3/5], Step [300/600], Loss: 0.0245
Epoch [3/5], Step [400/600], Loss: 0.0079
Epoch [3/5], Step [500/600], Loss: 0.0476
Epoch [3/5], Step [600/600], Loss: 0.0236
Epoch [4/5], Step [100/600], Loss: 0.0181
Epoch [4/5], Step [200/600], Loss: 0.0035
Epoch [4/5], Step [300/600], Loss: 0.0108
Epoch [4/5], Step [400/600], Loss: 0.0155
Epoch [4/5], Step [500/600], Loss: 0.0344
Epoch [4/5], Step [600/600], Loss: 0.0590
Epoch [5/5], Step [100/600], Loss: 0.0179
Epoch [5/5], Step [200/600], Loss: 0.0032
Epoch [5/5], Step [300/600], Loss: 0.0062
Epoch [5/5], Step [400/600], Loss: 0.0055
Epoch [5/5], Step [500/600], Loss: 0.0041
Epoch [5/5], Step [600/600], Loss: 0.0096
```



Calculating the test accuracy of CNN Test accuracy = 98.25%

[20]:
```
predict(model, type = "CNN")
```

```
#### Test Accuracy of the network on 10000 test images: 98.25 % ####
```

1.1 Comparing DNN and CNN

CNN got a better test accuracy of 98.25% than both the DNN with 2 and 3 hidden layers with test accuracy of 97.89% and 97.84% respectively.

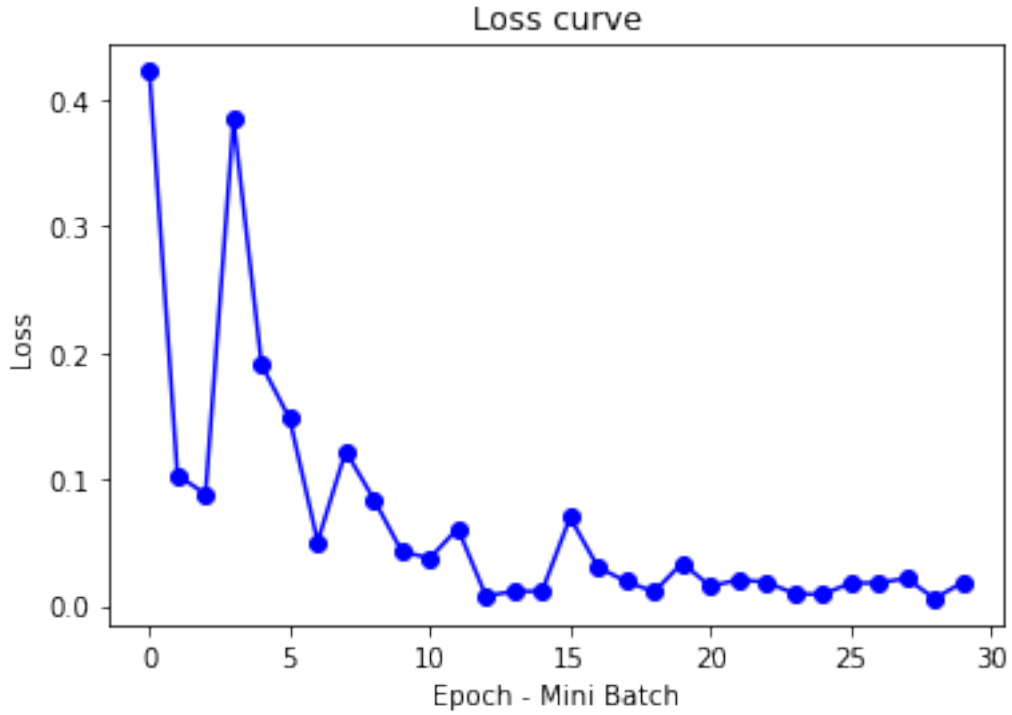
1.1.1 Question 2) c) Analysis of CNN on Different filter size and Hidden layer dimensions

For Filter sizes = [32, 64, 128, 256] and
For Hidden Layer dimension = [128, 256, 512]

[21]:
```
filter = [32, 64, 128, 256]

for j in filter:
    print("\n\n############ CNN with Filters = ", j, " and Hidden layer␣
 ↪dimension = 128 ############")
    model = CNN(j, 3, 128).to(device)
    optimizer = torch.optim.Adam(model.parameters(), lr=learning_rate)
    train(model, optimizer, "CNN")
    predict(model, type = "CNN")
```

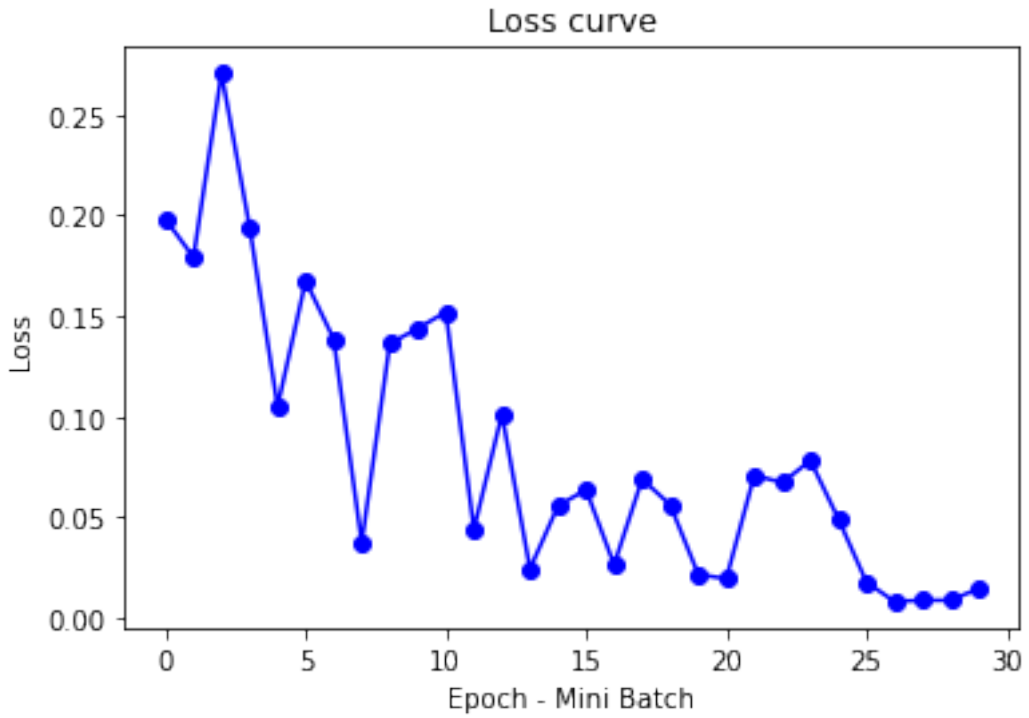
```
############ CNN with Filters =  32  and Hidden layer dimension = 128 ############
Epoch [1/5], Step [100/600], Loss: 0.4227
Epoch [1/5], Step [200/600], Loss: 0.1033
Epoch [1/5], Step [300/600], Loss: 0.0883
Epoch [1/5], Step [400/600], Loss: 0.3845
Epoch [1/5], Step [500/600], Loss: 0.1905
Epoch [1/5], Step [600/600], Loss: 0.1480
Epoch [2/5], Step [100/600], Loss: 0.0507
Epoch [2/5], Step [200/600], Loss: 0.1223
Epoch [2/5], Step [300/600], Loss: 0.0844
Epoch [2/5], Step [400/600], Loss: 0.0430
Epoch [2/5], Step [500/600], Loss: 0.0376
Epoch [2/5], Step [600/600], Loss: 0.0612
Epoch [3/5], Step [100/600], Loss: 0.0078
Epoch [3/5], Step [200/600], Loss: 0.0115
Epoch [3/5], Step [300/600], Loss: 0.0114
Epoch [3/5], Step [400/600], Loss: 0.0699
Epoch [3/5], Step [500/600], Loss: 0.0305
Epoch [3/5], Step [600/600], Loss: 0.0193
Epoch [4/5], Step [100/600], Loss: 0.0111
```

```
Epoch [4/5], Step [200/600], Loss: 0.0339
Epoch [4/5], Step [300/600], Loss: 0.0154
Epoch [4/5], Step [400/600], Loss: 0.0206
Epoch [4/5], Step [500/600], Loss: 0.0188
Epoch [4/5], Step [600/600], Loss: 0.0096
Epoch [5/5], Step [100/600], Loss: 0.0089
Epoch [5/5], Step [200/600], Loss: 0.0180
Epoch [5/5], Step [300/600], Loss: 0.0181
Epoch [5/5], Step [400/600], Loss: 0.0218
Epoch [5/5], Step [500/600], Loss: 0.0057
Epoch [5/5], Step [600/600], Loss: 0.0186
```



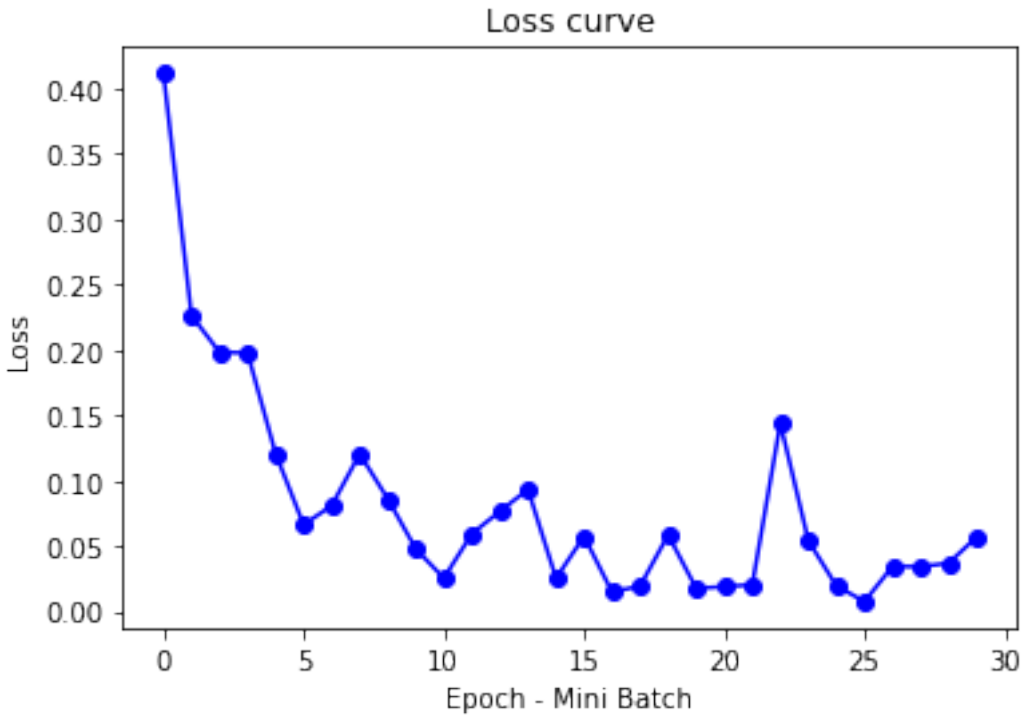

```
#### Test Accuracy of the network on 10000 test images: 98.29 % ####


############ CNN with Filters =  64  and Hidden layer dimension = 128 ############
Epoch [1/5], Step [100/600], Loss: 0.1981
Epoch [1/5], Step [200/600], Loss: 0.1792
Epoch [1/5], Step [300/600], Loss: 0.2707
Epoch [1/5], Step [400/600], Loss: 0.1944
Epoch [1/5], Step [500/600], Loss: 0.1051
Epoch [1/5], Step [600/600], Loss: 0.1675
Epoch [2/5], Step [100/600], Loss: 0.1385
Epoch [2/5], Step [200/600], Loss: 0.0372
```

```
Epoch [2/5], Step [300/600], Loss: 0.1363
Epoch [2/5], Step [400/600], Loss: 0.1438
Epoch [2/5], Step [500/600], Loss: 0.1520
Epoch [2/5], Step [600/600], Loss: 0.0439
Epoch [3/5], Step [100/600], Loss: 0.1012
Epoch [3/5], Step [200/600], Loss: 0.0243
Epoch [3/5], Step [300/600], Loss: 0.0556
Epoch [3/5], Step [400/600], Loss: 0.0636
Epoch [3/5], Step [500/600], Loss: 0.0264
Epoch [3/5], Step [600/600], Loss: 0.0689
Epoch [4/5], Step [100/600], Loss: 0.0561
Epoch [4/5], Step [200/600], Loss: 0.0216
Epoch [4/5], Step [300/600], Loss: 0.0193
Epoch [4/5], Step [400/600], Loss: 0.0708
Epoch [4/5], Step [500/600], Loss: 0.0672
Epoch [4/5], Step [600/600], Loss: 0.0781
Epoch [5/5], Step [100/600], Loss: 0.0491
Epoch [5/5], Step [200/600], Loss: 0.0177
Epoch [5/5], Step [300/600], Loss: 0.0081
Epoch [5/5], Step [400/600], Loss: 0.0087
Epoch [5/5], Step [500/600], Loss: 0.0087
Epoch [5/5], Step [600/600], Loss: 0.0145
```



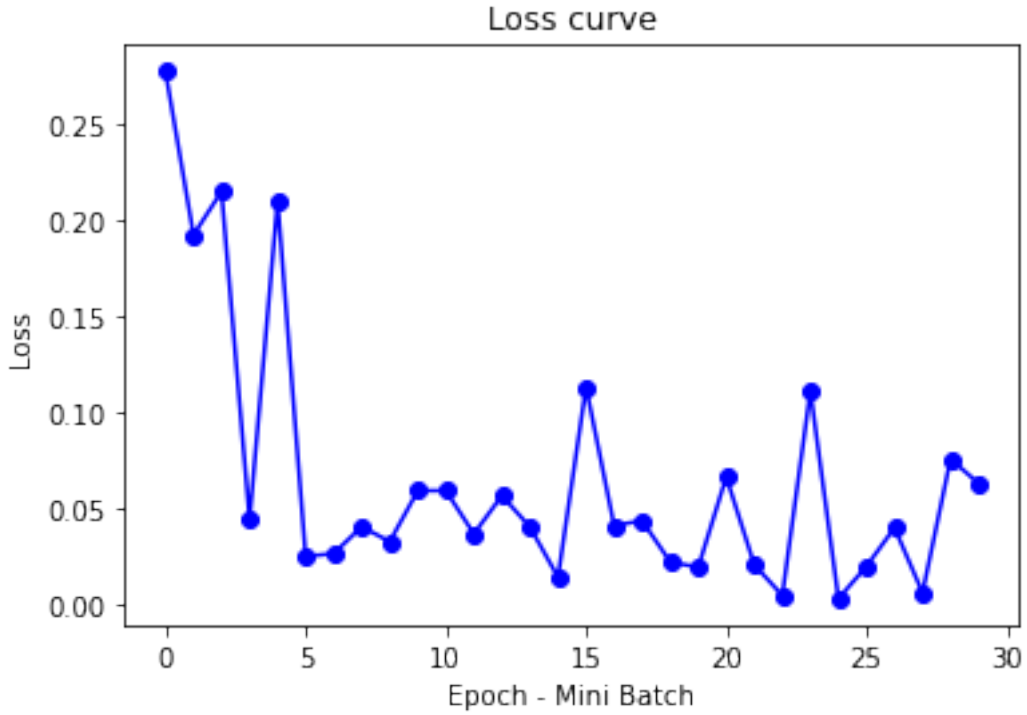

```
#### Test Accuracy of the network on 10000 test images: 98.15 % ####
```

```
########### CNN with Filters =  128  and Hidden layer dimension = 128
###########
Epoch [1/5], Step [100/600], Loss: 0.4118
Epoch [1/5], Step [200/600], Loss: 0.2263
Epoch [1/5], Step [300/600], Loss: 0.1983
Epoch [1/5], Step [400/600], Loss: 0.1977
Epoch [1/5], Step [500/600], Loss: 0.1207
Epoch [1/5], Step [600/600], Loss: 0.0662
Epoch [2/5], Step [100/600], Loss: 0.0809
Epoch [2/5], Step [200/600], Loss: 0.1204
Epoch [2/5], Step [300/600], Loss: 0.0860
Epoch [2/5], Step [400/600], Loss: 0.0477
Epoch [2/5], Step [500/600], Loss: 0.0253
Epoch [2/5], Step [600/600], Loss: 0.0593
Epoch [3/5], Step [100/600], Loss: 0.0765
Epoch [3/5], Step [200/600], Loss: 0.0933
Epoch [3/5], Step [300/600], Loss: 0.0252
Epoch [3/5], Step [400/600], Loss: 0.0573
Epoch [3/5], Step [500/600], Loss: 0.0146
Epoch [3/5], Step [600/600], Loss: 0.0193
Epoch [4/5], Step [100/600], Loss: 0.0584
Epoch [4/5], Step [200/600], Loss: 0.0175
Epoch [4/5], Step [300/600], Loss: 0.0188
Epoch [4/5], Step [400/600], Loss: 0.0202
Epoch [4/5], Step [500/600], Loss: 0.1439
Epoch [4/5], Step [600/600], Loss: 0.0539
Epoch [5/5], Step [100/600], Loss: 0.0193
Epoch [5/5], Step [200/600], Loss: 0.0074
Epoch [5/5], Step [300/600], Loss: 0.0343
Epoch [5/5], Step [400/600], Loss: 0.0341
Epoch [5/5], Step [500/600], Loss: 0.0368
Epoch [5/5], Step [600/600], Loss: 0.0567
```




```
#### Test Accuracy of the network on 10000 test images: 98.08 % ####


############ CNN with Filters =  256  and Hidden layer dimension = 128
############
Epoch [1/5], Step [100/600], Loss: 0.2774
Epoch [1/5], Step [200/600], Loss: 0.1920
Epoch [1/5], Step [300/600], Loss: 0.2147
Epoch [1/5], Step [400/600], Loss: 0.0438
Epoch [1/5], Step [500/600], Loss: 0.2096
Epoch [1/5], Step [600/600], Loss: 0.0244
Epoch [2/5], Step [100/600], Loss: 0.0260
Epoch [2/5], Step [200/600], Loss: 0.0400
Epoch [2/5], Step [300/600], Loss: 0.0322
Epoch [2/5], Step [400/600], Loss: 0.0587
Epoch [2/5], Step [500/600], Loss: 0.0587
Epoch [2/5], Step [600/600], Loss: 0.0362
Epoch [3/5], Step [100/600], Loss: 0.0562
Epoch [3/5], Step [200/600], Loss: 0.0398
Epoch [3/5], Step [300/600], Loss: 0.0137
Epoch [3/5], Step [400/600], Loss: 0.1128
Epoch [3/5], Step [500/600], Loss: 0.0406
Epoch [3/5], Step [600/600], Loss: 0.0431
Epoch [4/5], Step [100/600], Loss: 0.0217
```

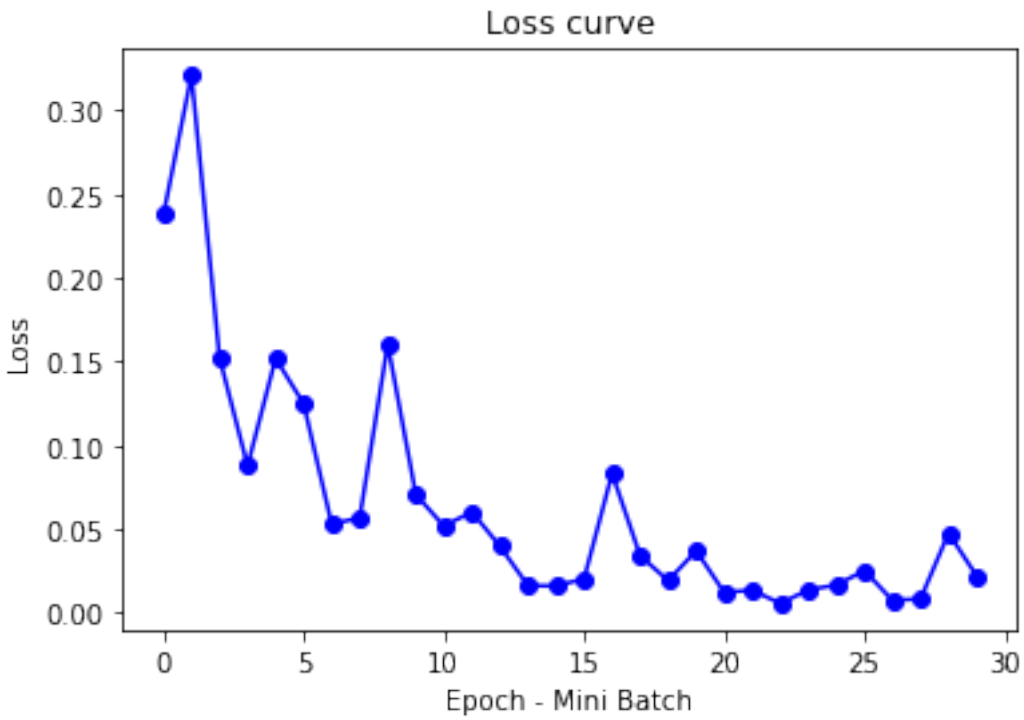
```
Epoch [4/5], Step [200/600], Loss: 0.0188
Epoch [4/5], Step [300/600], Loss: 0.0659
Epoch [4/5], Step [400/600], Loss: 0.0201
Epoch [4/5], Step [500/600], Loss: 0.0041
Epoch [4/5], Step [600/600], Loss: 0.1107
Epoch [5/5], Step [100/600], Loss: 0.0025
Epoch [5/5], Step [200/600], Loss: 0.0193
Epoch [5/5], Step [300/600], Loss: 0.0394
Epoch [5/5], Step [400/600], Loss: 0.0056
Epoch [5/5], Step [500/600], Loss: 0.0753
Epoch [5/5], Step [600/600], Loss: 0.0625
```




```
#### Test Accuracy of the network on 10000 test images: 97.68 % ####
```

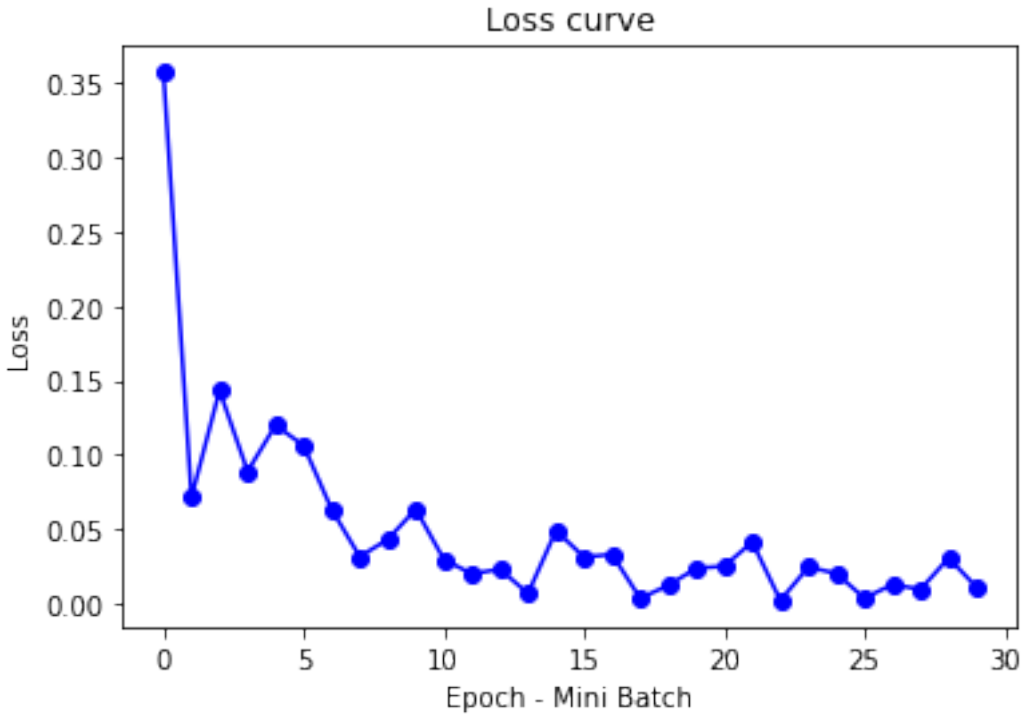
[22]:
```
for j in filter:
    print("\n\n############ CNN with Filters = ", j, " and Hidden layer␣
 ↪dimension = 256 ############")
    model = CNN(j, 3, 256).to(device)
    optimizer = torch.optim.Adam(model.parameters(), lr=learning_rate)
    train(model, optimizer, "CNN")
    predict(model, type = "CNN")
```

```
############ CNN with Filters =  32  and Hidden layer dimension = 256 ############
Epoch [1/5], Step [100/600], Loss: 0.2377
Epoch [1/5], Step [200/600], Loss: 0.3210
Epoch [1/5], Step [300/600], Loss: 0.1523
Epoch [1/5], Step [400/600], Loss: 0.0878
Epoch [1/5], Step [500/600], Loss: 0.1520
Epoch [1/5], Step [600/600], Loss: 0.1249
Epoch [2/5], Step [100/600], Loss: 0.0530
Epoch [2/5], Step [200/600], Loss: 0.0568
Epoch [2/5], Step [300/600], Loss: 0.1605
Epoch [2/5], Step [400/600], Loss: 0.0707
Epoch [2/5], Step [500/600], Loss: 0.0518
Epoch [2/5], Step [600/600], Loss: 0.0603
Epoch [3/5], Step [100/600], Loss: 0.0398
Epoch [3/5], Step [200/600], Loss: 0.0163
Epoch [3/5], Step [300/600], Loss: 0.0161
Epoch [3/5], Step [400/600], Loss: 0.0204
Epoch [3/5], Step [500/600], Loss: 0.0832
Epoch [3/5], Step [600/600], Loss: 0.0342
Epoch [4/5], Step [100/600], Loss: 0.0193
Epoch [4/5], Step [200/600], Loss: 0.0371
Epoch [4/5], Step [300/600], Loss: 0.0122
Epoch [4/5], Step [400/600], Loss: 0.0136
Epoch [4/5], Step [500/600], Loss: 0.0056
Epoch [4/5], Step [600/600], Loss: 0.0138
Epoch [5/5], Step [100/600], Loss: 0.0167
Epoch [5/5], Step [200/600], Loss: 0.0253
Epoch [5/5], Step [300/600], Loss: 0.0074
Epoch [5/5], Step [400/600], Loss: 0.0084
Epoch [5/5], Step [500/600], Loss: 0.0476
Epoch [5/5], Step [600/600], Loss: 0.0221
```



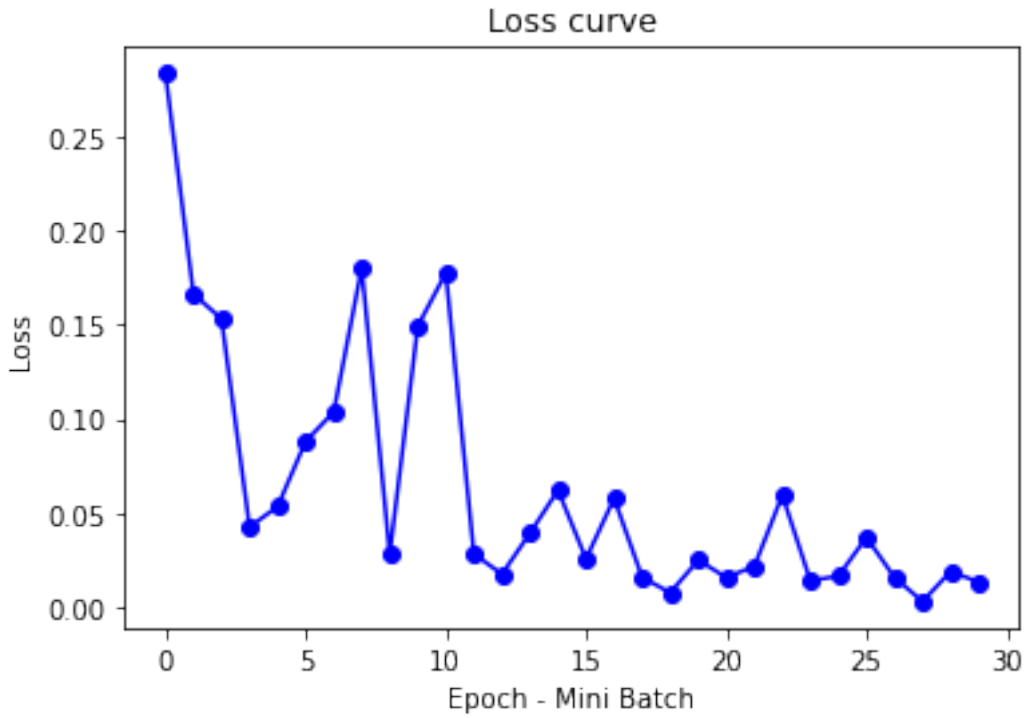

```
#### Test Accuracy of the network on 10000 test images: 98.55 % ####


############ CNN with Filters =  64  and Hidden layer dimension = 256 ############
Epoch [1/5], Step [100/600], Loss: 0.3570
Epoch [1/5], Step [200/600], Loss: 0.0715
Epoch [1/5], Step [300/600], Loss: 0.1434
Epoch [1/5], Step [400/600], Loss: 0.0890
Epoch [1/5], Step [500/600], Loss: 0.1200
Epoch [1/5], Step [600/600], Loss: 0.1063
Epoch [2/5], Step [100/600], Loss: 0.0634
Epoch [2/5], Step [200/600], Loss: 0.0317
Epoch [2/5], Step [300/600], Loss: 0.0433
Epoch [2/5], Step [400/600], Loss: 0.0637
Epoch [2/5], Step [500/600], Loss: 0.0299
Epoch [2/5], Step [600/600], Loss: 0.0201
Epoch [3/5], Step [100/600], Loss: 0.0234
Epoch [3/5], Step [200/600], Loss: 0.0070
Epoch [3/5], Step [300/600], Loss: 0.0492
Epoch [3/5], Step [400/600], Loss: 0.0315
Epoch [3/5], Step [500/600], Loss: 0.0333
Epoch [3/5], Step [600/600], Loss: 0.0038
Epoch [4/5], Step [100/600], Loss: 0.0124
Epoch [4/5], Step [200/600], Loss: 0.0239
```

```
Epoch [4/5], Step [300/600], Loss: 0.0254
Epoch [4/5], Step [400/600], Loss: 0.0416
Epoch [4/5], Step [500/600], Loss: 0.0023
Epoch [4/5], Step [600/600], Loss: 0.0248
Epoch [5/5], Step [100/600], Loss: 0.0204
Epoch [5/5], Step [200/600], Loss: 0.0039
Epoch [5/5], Step [300/600], Loss: 0.0131
Epoch [5/5], Step [400/600], Loss: 0.0098
Epoch [5/5], Step [500/600], Loss: 0.0308
Epoch [5/5], Step [600/600], Loss: 0.0112
```



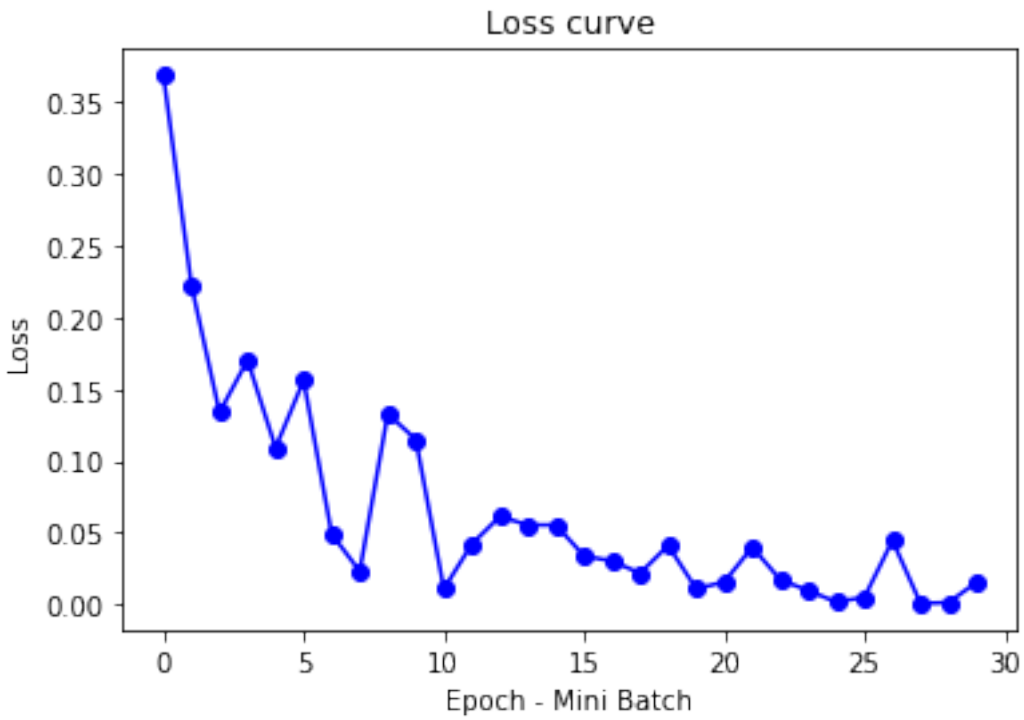

```
#### Test Accuracy of the network on 10000 test images: 98.36 % ####


########### CNN with Filters =  128  and Hidden layer dimension = 256
###########
Epoch [1/5], Step [100/600], Loss: 0.2840
Epoch [1/5], Step [200/600], Loss: 0.1665
Epoch [1/5], Step [300/600], Loss: 0.1532
Epoch [1/5], Step [400/600], Loss: 0.0424
Epoch [1/5], Step [500/600], Loss: 0.0532
Epoch [1/5], Step [600/600], Loss: 0.0879
Epoch [2/5], Step [100/600], Loss: 0.1035
Epoch [2/5], Step [200/600], Loss: 0.1803
```

```
Epoch [2/5], Step [300/600], Loss: 0.0280
Epoch [2/5], Step [400/600], Loss: 0.1494
Epoch [2/5], Step [500/600], Loss: 0.1776
Epoch [2/5], Step [600/600], Loss: 0.0280
Epoch [3/5], Step [100/600], Loss: 0.0173
Epoch [3/5], Step [200/600], Loss: 0.0391
Epoch [3/5], Step [300/600], Loss: 0.0619
Epoch [3/5], Step [400/600], Loss: 0.0254
Epoch [3/5], Step [500/600], Loss: 0.0576
Epoch [3/5], Step [600/600], Loss: 0.0156
Epoch [4/5], Step [100/600], Loss: 0.0073
Epoch [4/5], Step [200/600], Loss: 0.0247
Epoch [4/5], Step [300/600], Loss: 0.0155
Epoch [4/5], Step [400/600], Loss: 0.0214
Epoch [4/5], Step [500/600], Loss: 0.0593
Epoch [4/5], Step [600/600], Loss: 0.0137
Epoch [5/5], Step [100/600], Loss: 0.0162
Epoch [5/5], Step [200/600], Loss: 0.0368
Epoch [5/5], Step [300/600], Loss: 0.0155
Epoch [5/5], Step [400/600], Loss: 0.0027
Epoch [5/5], Step [500/600], Loss: 0.0187
Epoch [5/5], Step [600/600], Loss: 0.0130
```




```
#### Test Accuracy of the network on 10000 test images: 98.53 % ####
```

```
########### CNN with Filters =  256  and Hidden layer dimension = 256
###########
Epoch [1/5], Step [100/600], Loss: 0.3685
Epoch [1/5], Step [200/600], Loss: 0.2221
Epoch [1/5], Step [300/600], Loss: 0.1338
Epoch [1/5], Step [400/600], Loss: 0.1702
Epoch [1/5], Step [500/600], Loss: 0.1092
Epoch [1/5], Step [600/600], Loss: 0.1561
Epoch [2/5], Step [100/600], Loss: 0.0492
Epoch [2/5], Step [200/600], Loss: 0.0232
Epoch [2/5], Step [300/600], Loss: 0.1327
Epoch [2/5], Step [400/600], Loss: 0.1150
Epoch [2/5], Step [500/600], Loss: 0.0110
Epoch [2/5], Step [600/600], Loss: 0.0422
Epoch [3/5], Step [100/600], Loss: 0.0614
Epoch [3/5], Step [200/600], Loss: 0.0554
Epoch [3/5], Step [300/600], Loss: 0.0554
Epoch [3/5], Step [400/600], Loss: 0.0339
Epoch [3/5], Step [500/600], Loss: 0.0303
Epoch [3/5], Step [600/600], Loss: 0.0219
Epoch [4/5], Step [100/600], Loss: 0.0412
Epoch [4/5], Step [200/600], Loss: 0.0110
Epoch [4/5], Step [300/600], Loss: 0.0158
Epoch [4/5], Step [400/600], Loss: 0.0400
Epoch [4/5], Step [500/600], Loss: 0.0173
Epoch [4/5], Step [600/600], Loss: 0.0098
Epoch [5/5], Step [100/600], Loss: 0.0018
Epoch [5/5], Step [200/600], Loss: 0.0052
Epoch [5/5], Step [300/600], Loss: 0.0447
Epoch [5/5], Step [400/600], Loss: 0.0008
Epoch [5/5], Step [500/600], Loss: 0.0014
Epoch [5/5], Step [600/600], Loss: 0.0156
```

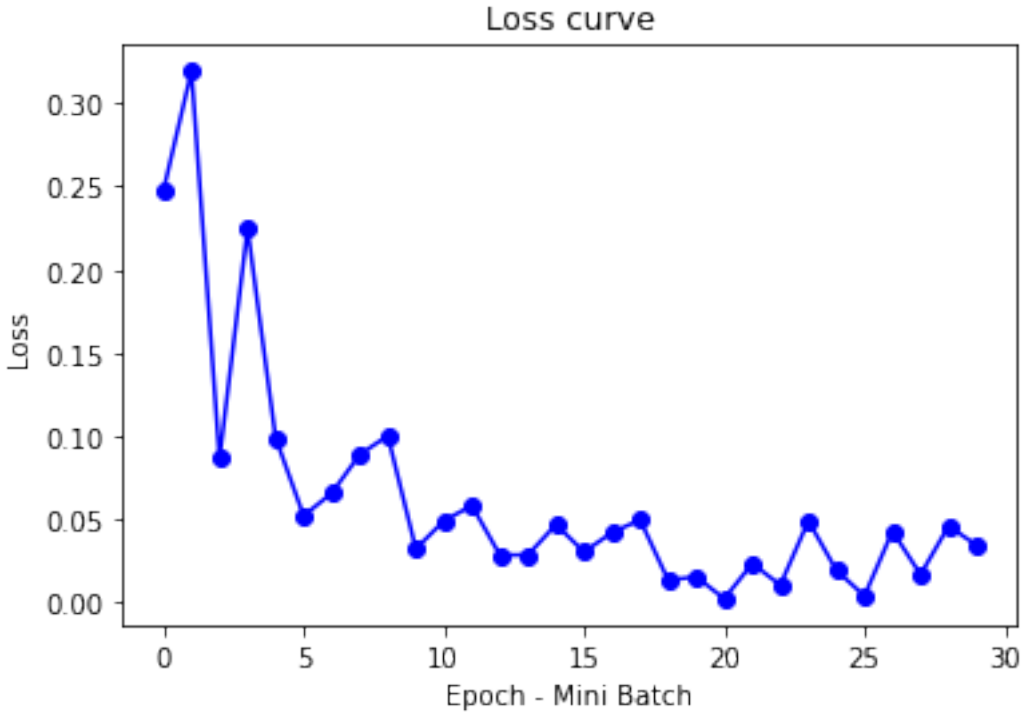



```
#### Test Accuracy of the network on 10000 test images: 98.34 % ####
```

[23]:
```
for j in filter:
    print("\n\n############ CNN with Filters = ", j, " and Hidden layer␣
 ↪dimension = 512 ############")
    model = CNN(j, 3, 512).to(device)
    optimizer = torch.optim.Adam(model.parameters(), lr=learning_rate)
    train(model, optimizer, "CNN")
    predict(model, type = "CNN")
```

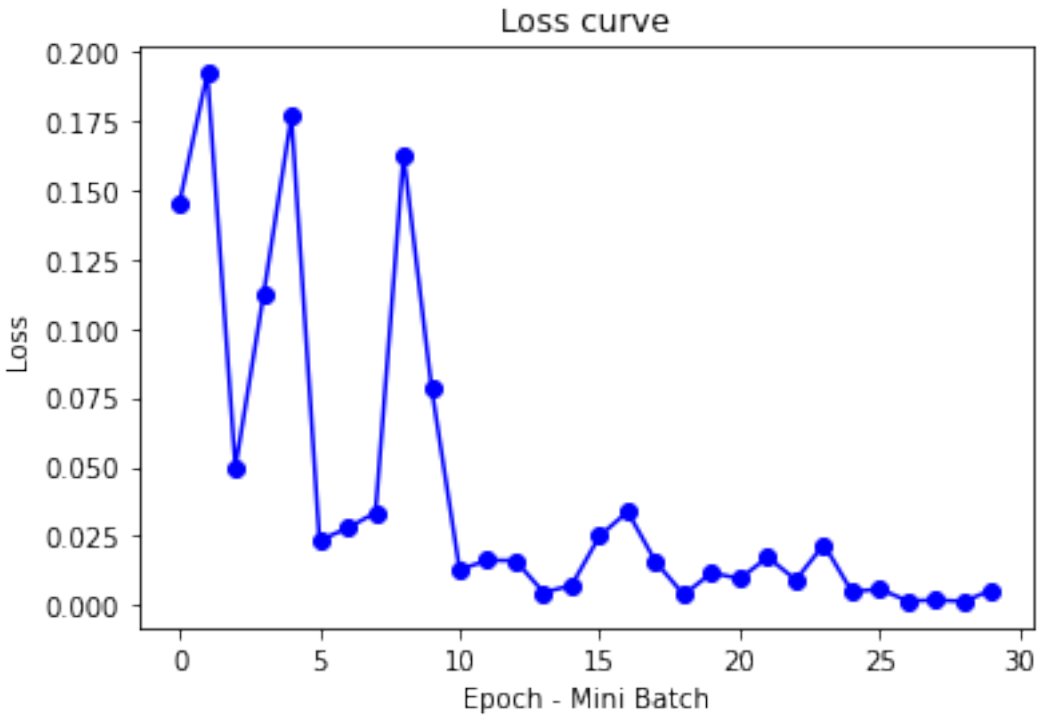
```
############ CNN with Filters =  32  and Hidden layer dimension = 512 ############
Epoch [1/5], Step [100/600], Loss: 0.2476
Epoch [1/5], Step [200/600], Loss: 0.3193
Epoch [1/5], Step [300/600], Loss: 0.0867
Epoch [1/5], Step [400/600], Loss: 0.2249
Epoch [1/5], Step [500/600], Loss: 0.0991
Epoch [1/5], Step [600/600], Loss: 0.0523
Epoch [2/5], Step [100/600], Loss: 0.0659
Epoch [2/5], Step [200/600], Loss: 0.0890
Epoch [2/5], Step [300/600], Loss: 0.1004
Epoch [2/5], Step [400/600], Loss: 0.0325
Epoch [2/5], Step [500/600], Loss: 0.0492
```

```
Epoch [2/5], Step [600/600], Loss: 0.0584
Epoch [3/5], Step [100/600], Loss: 0.0286
Epoch [3/5], Step [200/600], Loss: 0.0288
Epoch [3/5], Step [300/600], Loss: 0.0470
Epoch [3/5], Step [400/600], Loss: 0.0306
Epoch [3/5], Step [500/600], Loss: 0.0423
Epoch [3/5], Step [600/600], Loss: 0.0498
Epoch [4/5], Step [100/600], Loss: 0.0136
Epoch [4/5], Step [200/600], Loss: 0.0157
Epoch [4/5], Step [300/600], Loss: 0.0025
Epoch [4/5], Step [400/600], Loss: 0.0236
Epoch [4/5], Step [500/600], Loss: 0.0107
Epoch [4/5], Step [600/600], Loss: 0.0493
Epoch [5/5], Step [100/600], Loss: 0.0195
Epoch [5/5], Step [200/600], Loss: 0.0042
Epoch [5/5], Step [300/600], Loss: 0.0431
Epoch [5/5], Step [400/600], Loss: 0.0170
Epoch [5/5], Step [500/600], Loss: 0.0461
Epoch [5/5], Step [600/600], Loss: 0.0346
```



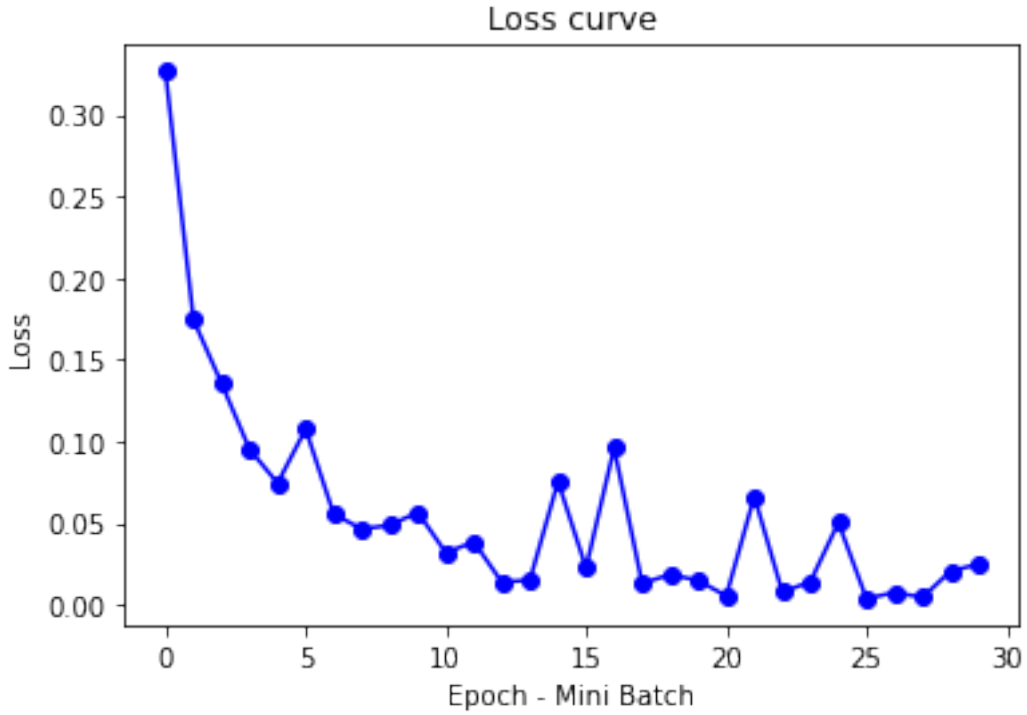

```
#### Test Accuracy of the network on 10000 test images: 98.55 % ####

############ CNN with Filters =  64  and Hidden layer dimension = 512 ############
```

```
Epoch [1/5], Step [100/600], Loss: 0.1452
Epoch [1/5], Step [200/600], Loss: 0.1923
Epoch [1/5], Step [300/600], Loss: 0.0498
Epoch [1/5], Step [400/600], Loss: 0.1119
Epoch [1/5], Step [500/600], Loss: 0.1767
Epoch [1/5], Step [600/600], Loss: 0.0234
Epoch [2/5], Step [100/600], Loss: 0.0279
Epoch [2/5], Step [200/600], Loss: 0.0334
Epoch [2/5], Step [300/600], Loss: 0.1628
Epoch [2/5], Step [400/600], Loss: 0.0786
Epoch [2/5], Step [500/600], Loss: 0.0128
Epoch [2/5], Step [600/600], Loss: 0.0163
Epoch [3/5], Step [100/600], Loss: 0.0161
Epoch [3/5], Step [200/600], Loss: 0.0046
Epoch [3/5], Step [300/600], Loss: 0.0072
Epoch [3/5], Step [400/600], Loss: 0.0251
Epoch [3/5], Step [500/600], Loss: 0.0338
Epoch [3/5], Step [600/600], Loss: 0.0156
Epoch [4/5], Step [100/600], Loss: 0.0038
Epoch [4/5], Step [200/600], Loss: 0.0117
Epoch [4/5], Step [300/600], Loss: 0.0096
Epoch [4/5], Step [400/600], Loss: 0.0173
Epoch [4/5], Step [500/600], Loss: 0.0091
Epoch [4/5], Step [600/600], Loss: 0.0220
Epoch [5/5], Step [100/600], Loss: 0.0049
Epoch [5/5], Step [200/600], Loss: 0.0058
Epoch [5/5], Step [300/600], Loss: 0.0015
Epoch [5/5], Step [400/600], Loss: 0.0019
Epoch [5/5], Step [500/600], Loss: 0.0013
Epoch [5/5], Step [600/600], Loss: 0.0056
```



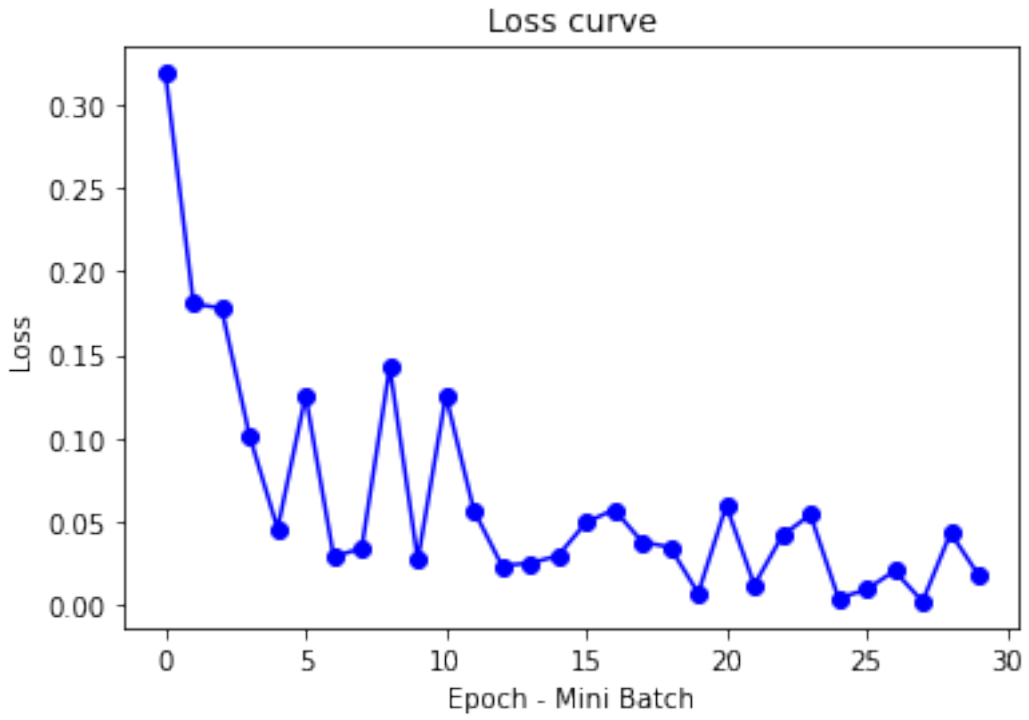

```
#### Test Accuracy of the network on 10000 test images: 98.24 % ####


############ CNN with Filters =  128  and Hidden layer dimension = 512
############
Epoch [1/5], Step [100/600], Loss: 0.3267
Epoch [1/5], Step [200/600], Loss: 0.1744
Epoch [1/5], Step [300/600], Loss: 0.1354
Epoch [1/5], Step [400/600], Loss: 0.0951
Epoch [1/5], Step [500/600], Loss: 0.0744
Epoch [1/5], Step [600/600], Loss: 0.1074
Epoch [2/5], Step [100/600], Loss: 0.0554
Epoch [2/5], Step [200/600], Loss: 0.0463
Epoch [2/5], Step [300/600], Loss: 0.0485
Epoch [2/5], Step [400/600], Loss: 0.0565
Epoch [2/5], Step [500/600], Loss: 0.0318
Epoch [2/5], Step [600/600], Loss: 0.0384
Epoch [3/5], Step [100/600], Loss: 0.0136
Epoch [3/5], Step [200/600], Loss: 0.0151
Epoch [3/5], Step [300/600], Loss: 0.0754
Epoch [3/5], Step [400/600], Loss: 0.0225
Epoch [3/5], Step [500/600], Loss: 0.0959
Epoch [3/5], Step [600/600], Loss: 0.0129
Epoch [4/5], Step [100/600], Loss: 0.0185
```

```
Epoch [4/5], Step [200/600], Loss: 0.0147
Epoch [4/5], Step [300/600], Loss: 0.0053
Epoch [4/5], Step [400/600], Loss: 0.0662
Epoch [4/5], Step [500/600], Loss: 0.0077
Epoch [4/5], Step [600/600], Loss: 0.0140
Epoch [5/5], Step [100/600], Loss: 0.0502
Epoch [5/5], Step [200/600], Loss: 0.0036
Epoch [5/5], Step [300/600], Loss: 0.0074
Epoch [5/5], Step [400/600], Loss: 0.0044
Epoch [5/5], Step [500/600], Loss: 0.0205
Epoch [5/5], Step [600/600], Loss: 0.0248
```




```
#### Test Accuracy of the network on 10000 test images: 98.3 % ####


########### CNN with Filters =  256  and Hidden layer dimension = 512
###########
Epoch [1/5], Step [100/600], Loss: 0.3187
Epoch [1/5], Step [200/600], Loss: 0.1807
Epoch [1/5], Step [300/600], Loss: 0.1779
Epoch [1/5], Step [400/600], Loss: 0.1014
Epoch [1/5], Step [500/600], Loss: 0.0459
Epoch [1/5], Step [600/600], Loss: 0.1256
Epoch [2/5], Step [100/600], Loss: 0.0289
```

```
Epoch [2/5], Step [200/600], Loss: 0.0342
Epoch [2/5], Step [300/600], Loss: 0.1428
Epoch [2/5], Step [400/600], Loss: 0.0270
Epoch [2/5], Step [500/600], Loss: 0.1256
Epoch [2/5], Step [600/600], Loss: 0.0568
Epoch [3/5], Step [100/600], Loss: 0.0237
Epoch [3/5], Step [200/600], Loss: 0.0252
Epoch [3/5], Step [300/600], Loss: 0.0295
Epoch [3/5], Step [400/600], Loss: 0.0496
Epoch [3/5], Step [500/600], Loss: 0.0573
Epoch [3/5], Step [600/600], Loss: 0.0380
Epoch [4/5], Step [100/600], Loss: 0.0347
Epoch [4/5], Step [200/600], Loss: 0.0072
Epoch [4/5], Step [300/600], Loss: 0.0597
Epoch [4/5], Step [400/600], Loss: 0.0122
Epoch [4/5], Step [500/600], Loss: 0.0417
Epoch [4/5], Step [600/600], Loss: 0.0542
Epoch [5/5], Step [100/600], Loss: 0.0043
Epoch [5/5], Step [200/600], Loss: 0.0093
Epoch [5/5], Step [300/600], Loss: 0.0206
Epoch [5/5], Step [400/600], Loss: 0.0022
Epoch [5/5], Step [500/600], Loss: 0.0433
Epoch [5/5], Step [600/600], Loss: 0.0179
```



```
#### Test Accuracy of the network on 10000 test images: 98.16 % ####
```

1.1.2 In general, from the plots above, it is noted that, the Test accuracy decreases (in most cases) with increase in filter sizes (from 32 to 256)

1.1.3 In this case, the hidden layer dimensions = 256 performed better in all choices of filter sizes than the models with hidden layer dimension = 128 and 512. And the model with 512 hidden layer dimension performed better than the model with 128 hidden layer dimension.