assignment_06

October 10, 2021

1 Multi-class classification based on Softmax and Cross-Entropy using pytorch

1.1 import libraries

[ ]:
```
import torch
import torch.nn as nn
import torch.nn.functional as F
import torchvision
from torch.utils.data import Dataset
from torchvision import datasets, transforms
import torchvision.transforms.functional as F
import numpy as np
import matplotlib.pyplot as plt
import math
from tqdm import tqdm
import random
import os
```

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

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call
drive.mount("/content/drive", force_remount=True).
```

1.2 load data

[ ]:
```
directory_data  = 'drive/MyDrive/'
filename_data   = 'assignment_06_data.npz'
data            = np.load(os.path.join(directory_data, filename_data))

x_train = data['x_train']
y_train = data['y_train']

x_test  = data['x_test']
y_test  = data['y_test']

num_data_train  = x_train.shape[0]
```

```
num_data_test   = x_test.shape[0]

print('*************************************************')
print('size of x_train :', x_train.shape)
print('size of y_train :', y_train.shape)
print('*************************************************')
print('size of x_test :', x_test.shape)
print('size of y_test :', y_test.shape)
print('*************************************************')
print('number of training image :', x_train.shape[0])
print('height of training image :', x_train.shape[1])
print('width of training image :', x_train.shape[2])
print('*************************************************')
print('number of testing image :', x_test.shape[0])
print('height of testing image :', x_test.shape[1])
print('width of testing image :', x_test.shape[2])
print('*************************************************')
```

```
*************************************************
size of x_train : (20000, 32, 32)
size of y_train : (20000,)
*************************************************
size of x_test : (8000, 32, 32)
size of y_test : (8000,)
*************************************************
number of training image : 20000
height of training image : 32
width of training image : 32
*************************************************
number of testing image : 8000
height of testing image : 32
width of testing image : 32
*************************************************
```

1.3 number of classes

[ ]:
```
print('*************************************************')
print('number of classes :', len(set(y_train)))
print('*************************************************')
```

```
*************************************************
number of classes : 10
*************************************************
```

1.4 hyper-parameters

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

     number_epoch    = 100
     size_minibatch  = 20
     learning_rate   = 0.01
     weight_decay    = 1e-3
```

1.5 custom data loader for the PyTorch framework

```
[ ]: class dataset(Dataset):

         def __init__(self, image, label):

             self.image  = image
             self.label  = label.astype(np.long)

         def __getitem__(self, index):

             image   = self.image[index, :, :]
             label   = self.label[index, ]

             image   = torch.FloatTensor(image).unsqueeze(dim=0)
             label   = torch.LongTensor([label])

             return image, label

         def __len__(self):

             return self.image.shape[0]

         def collate_fn(self, batch):
             images  = list()
             labels  = list()

             for b in batch:
                 images.append(b[0])
                 labels.append(b[1])

             images  = torch.stack(images, dim=0)
             labels  = torch.stack(labels, dim=0).squeeze()

             return images, labels
```

1.6 construct datasets and dataloaders for training and testing

[ ]:
```
dataset_train   = dataset(x_train, y_train)
dataset_test    = dataset(x_test, y_test)

dataloader_train    = torch.utils.data.DataLoader(dataset_train,␣
↪batch_size=size_minibatch, shuffle=True, drop_last=True,␣
↪collate_fn=dataset_train.collate_fn)
dataloader_test     = torch.utils.data.DataLoader(dataset_test,␣
↪batch_size=size_minibatch, shuffle=True, drop_last=True,␣
↪collate_fn=dataset_test.collate_fn)
```

1.7 shape of the data when using the data loader

[ ]:
```
image, label    = next(iter(dataloader_train))
print('************************************************************')
print('size of mini-batch of the image:', image.shape)
print('************************************************************')
print('size of mini-batch of the label:', label.shape)
print('************************************************************')
```

```
************************************************************
size of mini-batch of the image: torch.Size([20, 1, 32, 32])
************************************************************
size of mini-batch of the label: torch.Size([20])
************************************************************
```

1.8 class for the neural network

[ ]:
```
class Classifier(nn.Module):
    def __init__(self):
        super(Classifier, self).__init__()

        self.feature    = nn.Sequential(

            nn.Conv2d(1, 16, 3, padding=1),
            nn.BatchNorm2d(16),
            nn.ReLU(),
            nn.Conv2d(16, 32, 3,padding=1),
            nn.BatchNorm2d(32),
            nn.ReLU(),
            nn.MaxPool2d(2, 2),
            nn.Conv2d(32, 64, 3,padding=1),
            nn.BatchNorm2d(64),
            nn.ReLU(),
            nn.MaxPool2d(2, 2),
```

```python
        )

        self.classifier = nn.Sequential(
            nn.Linear(64*8*8,128),
            nn.BatchNorm1d(128),
            nn.ReLU(),
            nn.Linear(128,64),
            nn.BatchNorm1d(64),
            nn.ReLU(),
            nn.Linear(64,32),
            nn.BatchNorm1d(32),
            nn.ReLU(),
            nn.Linear(32,10),
        )

        self.network    = nn.Sequential(
            self.feature,
            nn.Flatten(),
            self.classifier,
        )

        self.initialize()


    def initialize(self):

        for m in self.network.modules():

            if isinstance(m, nn.Conv2d):

                #nn.init.constant_(m.weight, 0.01)
                torch.nn.init.xavier_uniform_(m.weight)
                nn.init.constant_(m.bias, 1)

            elif isinstance(m, nn.Linear):

                torch.nn.init.xavier_uniform_(m.weight)
                nn.init.constant_(m.bias, 1)


    def forward(self, input):

        output = self.network(input)

        return output
```

1.9 build network

```
[ ]: classifier  = Classifier().to(device)
     optimizer   = torch.optim.SGD(classifier.parameters(), lr=learning_rate,␣
      ↪weight_decay=weight_decay)
```

1.10 print the defined neural network

```
[ ]: print(classifier)
```

```
Classifier(
  (feature): Sequential(
    (0): Conv2d(1, 16, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU()
    (3): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (4): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU()
    (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    (7): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (8): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (9): ReLU()
    (10): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Linear(in_features=4096, out_features=128, bias=True)
    (1): BatchNorm1d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (2): ReLU()
    (3): Linear(in_features=128, out_features=64, bias=True)
    (4): BatchNorm1d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (5): ReLU()
    (6): Linear(in_features=64, out_features=32, bias=True)
    (7): BatchNorm1d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
    (8): ReLU()
    (9): Linear(in_features=32, out_features=10, bias=True)
  )
  (network): Sequential(
    (0): Sequential(
      (0): Conv2d(1, 16, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(16, eps=1e-05, momentum=0.1, affine=True,
```

```
track_running_stats=True)
      (2): ReLU()
      (3): Conv2d(16, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (4): BatchNorm2d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (5): ReLU()
      (6): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
      (7): Conv2d(32, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (8): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (9): ReLU()
      (10): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
    )
    (1): Flatten(start_dim=1, end_dim=-1)
    (2): Sequential(
      (0): Linear(in_features=4096, out_features=128, bias=True)
      (1): BatchNorm1d(128, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (2): ReLU()
      (3): Linear(in_features=128, out_features=64, bias=True)
      (4): BatchNorm1d(64, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (5): ReLU()
      (6): Linear(in_features=64, out_features=32, bias=True)
      (7): BatchNorm1d(32, eps=1e-05, momentum=0.1, affine=True,
track_running_stats=True)
      (8): ReLU()
      (9): Linear(in_features=32, out_features=10, bias=True)
    )
  )
)
```

1.11 compute the prediction

[ ]:
```
def compute_prediction(model, input):

    prediction = model(input)

    return prediction
```

1.12 compute the loss

```
[ ]: def compute_loss(prediction, label):

         criterion   = nn.CrossEntropyLoss()
         loss        = criterion(prediction, label)
         loss_value  = loss.item()

         return loss, loss_value
```

```
[ ]: dataiter = iter(dataloader_train)
     image,label = dataiter.next()

     image_ = image.to(device)
     label_ = label.to(device)

     print(label_)
     print(len(label_))
     pred = compute_prediction(classifier,image_)
     agmax = torch.argmax(pred,dim=1)
     print(sum(torch.eq(label_,agmax).tolist()))
```

```
tensor([3, 1, 6, 0, 9, 0, 5, 4, 7, 2, 8, 1, 5, 1, 1, 6, 9, 4, 7, 8],
       device='cuda:0')
20
1
```

1.13 compute the accuracy

```
[ ]: def compute_accuracy(prediction, label):
         #
      ↪================================================================================
      ↪

         # complete the function body
         argmax_   = torch.argmax(prediction,dim=1)
         compare   = torch.eq(label,argmax_).tolist()
         accuracy = sum(compare)/len(label)
         #
      ↪================================================================================
      ↪

         return accuracy
```

1.14 variables for the learning curve

[ ]:
```
loss_mean_train     = np.zeros(number_epoch)
loss_std_train      = np.zeros(number_epoch)
accuracy_mean_train = np.zeros(number_epoch)
accuracy_std_train  = np.zeros(number_epoch)

loss_mean_test      = np.zeros(number_epoch)
loss_std_test       = np.zeros(number_epoch)
accuracy_mean_test  = np.zeros(number_epoch)
accuracy_std_test   = np.zeros(number_epoch)
```

1.15 train and test

[ ]:
```
#␣
 ↪===============================================================================
#
# iterations for epochs
#
#␣
 ↪===============================================================================
for i in tqdm(range(number_epoch)):

    #␣
 ↪===============================================================================
    #
    # training
    #
    #␣
 ↪===============================================================================
    loss_train_epoch        = []
    accuracy_train_epoch    = []

    classifier.train()

    for index_batch, (image_train, label_train) in enumerate(dataloader_train):

        image_train = image_train.to(device)
        label_train = label_train.to(device)

        prediction_train                = compute_prediction(classifier,␣
 ↪image_train)
        loss_train, loss_value_train    = compute_loss(prediction_train,␣
 ↪label_train)
        accuracy_train                  = compute_accuracy(prediction_train,␣
 ↪label_train)
```

```
        optimizer.zero_grad()
        loss_train.backward()
        optimizer.step()

        loss_train_epoch.append(loss_value_train)
        accuracy_train_epoch.append(accuracy_train)

    loss_mean_train[i]       = np.mean(loss_train_epoch)
    loss_std_train[i]        = np.std(loss_train_epoch)

    accuracy_mean_train[i]   = np.mean(accuracy_train_epoch)
    accuracy_std_train[i]    = np.std(accuracy_train_epoch)

    # 
↪===============================================================================
    #
    # testing
    #
    # 
↪===============================================================================
    loss_test_epoch         = []
    accuracy_test_epoch     = []

    classifier.train()

    for index_batch, (image_test, label_test) in enumerate(dataloader_test):

        image_test = image_test.to(device)
        label_test = label_test.to(device)

        prediction_test             = compute_prediction(classifier, image_test)
        loss_test, loss_value_test  = compute_loss(prediction_test, label_test)
        accuracy_test               = compute_accuracy(prediction_test, 
↪label_test)

        loss_test_epoch.append(loss_value_test)
        accuracy_test_epoch.append(accuracy_test)

    loss_mean_test[i]       = np.mean(loss_test_epoch)
    loss_std_test[i]        = np.std(loss_test_epoch)

    accuracy_mean_test[i]   = np.mean(accuracy_test)
    accuracy_std_test[i]    = np.std(accuracy_test)
```

```
100%|     | 100/100 [07:32<00:00,  4.52s/it]
```

1.16 plot curve

```
[ ]: def plot_curve_error(data_mean, data_std, x_label, y_label, title):

         plt.figure(figsize=(8, 6))
         plt.title(title)

         alpha = 0.3

         plt.plot(range(len(data_mean)), data_mean, '-', color = 'red')
         plt.fill_between(range(len(data_mean)), data_mean - data_std, data_mean +␣
      ↪data_std, facecolor = 'blue', alpha = alpha)

         plt.xlabel(x_label)
         plt.ylabel(y_label)

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

```
[ ]: def print_curve(data, index):

         for i in range(len(index)):

             idx = index[i]
             val = data[idx]

             print('index = %2d, value = %12.10f' % (idx, val))
```

```
[ ]: def get_data_last(data, index_start):

         data_last = data[index_start:]

         return data_last
```

```
[ ]: def get_max_last_range(data, index_start):

         data_range = get_data_last(data, index_start)
         value = data_range.max()

         return value
```

```
[ ]: def get_min_last_range(data, index_start):

         data_range = get_data_last(data, index_start)
         value = data_range.min()

         return value
```

2 functions for presenting the results

```
[ ]: def function_result_01():

        plot_curve_error(loss_mean_train, loss_std_train, 'epoch', 'loss', 'loss␣
     ↪(training)')
```

```
[ ]: def function_result_02():

        plot_curve_error(accuracy_mean_train, accuracy_std_train, 'epoch',␣
     ↪'accuracy', 'accuracy (training)')
```

```
[ ]: def function_result_03():

        plot_curve_error(loss_mean_test, loss_std_test, 'epoch', 'loss', 'loss␣
     ↪(testing)')
```

```
[ ]: def function_result_04():

        plot_curve_error(accuracy_mean_test, accuracy_std_test, 'epoch',␣
     ↪'accuracy', 'accuracy (testing)')
```

```
[ ]: def function_result_05():

        data_last = get_data_last(loss_mean_train, -10)
        index = np.arange(0, 10)
        print_curve(data_last, index)
```

```
[ ]: def function_result_06():

        data_last = get_data_last(accuracy_mean_train, -10)
        index = np.arange(0, 10)
        print_curve(data_last, index)
```

```
[ ]: def function_result_07():

        data_last = get_data_last(loss_mean_test, -10)
        index = np.arange(0, 10)
        print_curve(data_last, index)
```

```
[ ]: def function_result_08():

        data_last = get_data_last(accuracy_mean_test, -10)
```

```
    index = np.arange(0, 10)
    print_curve(data_last, index)
```

[ ]:
```
def function_result_09():

    value = get_max_last_range(accuracy_mean_train, -10)
    print('best training accuracy = %12.10f' % (value))
```

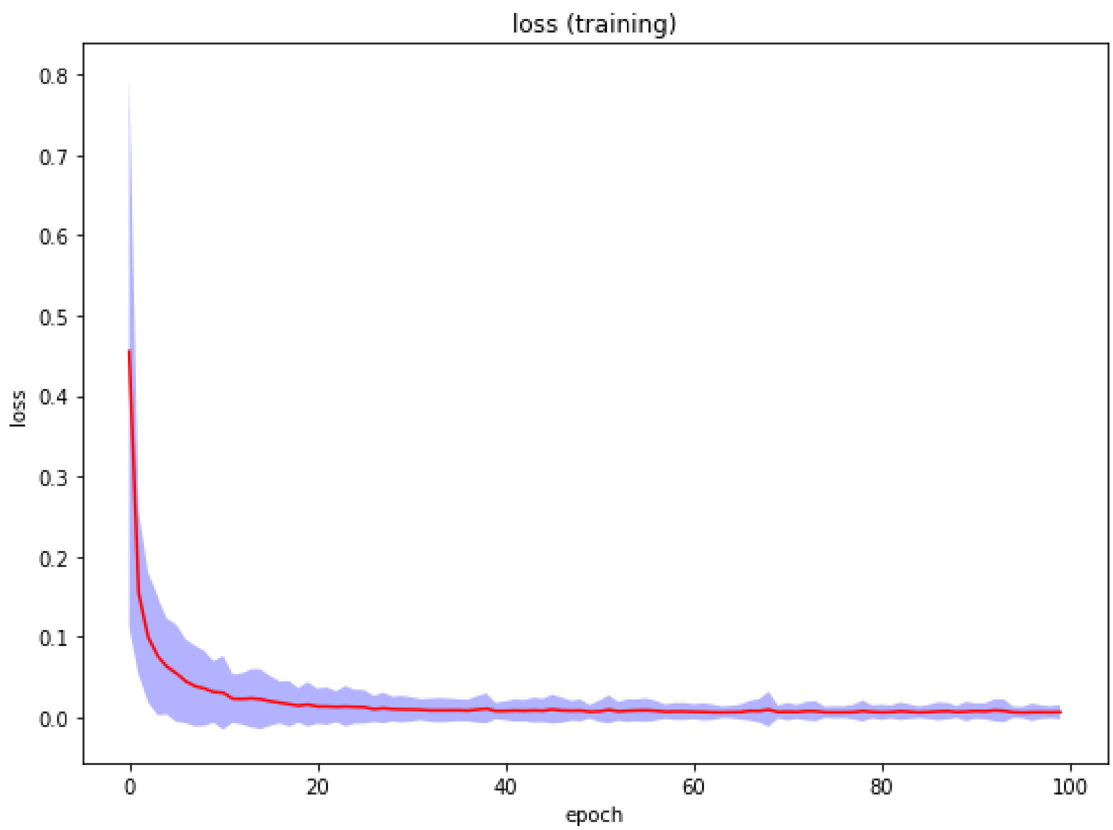
[ ]:
```
def function_result_10():

    value = get_max_last_range(accuracy_mean_test, -10)
    print('best testing accuracy = %12.10f' % (value))
```

---

3 RESULTS

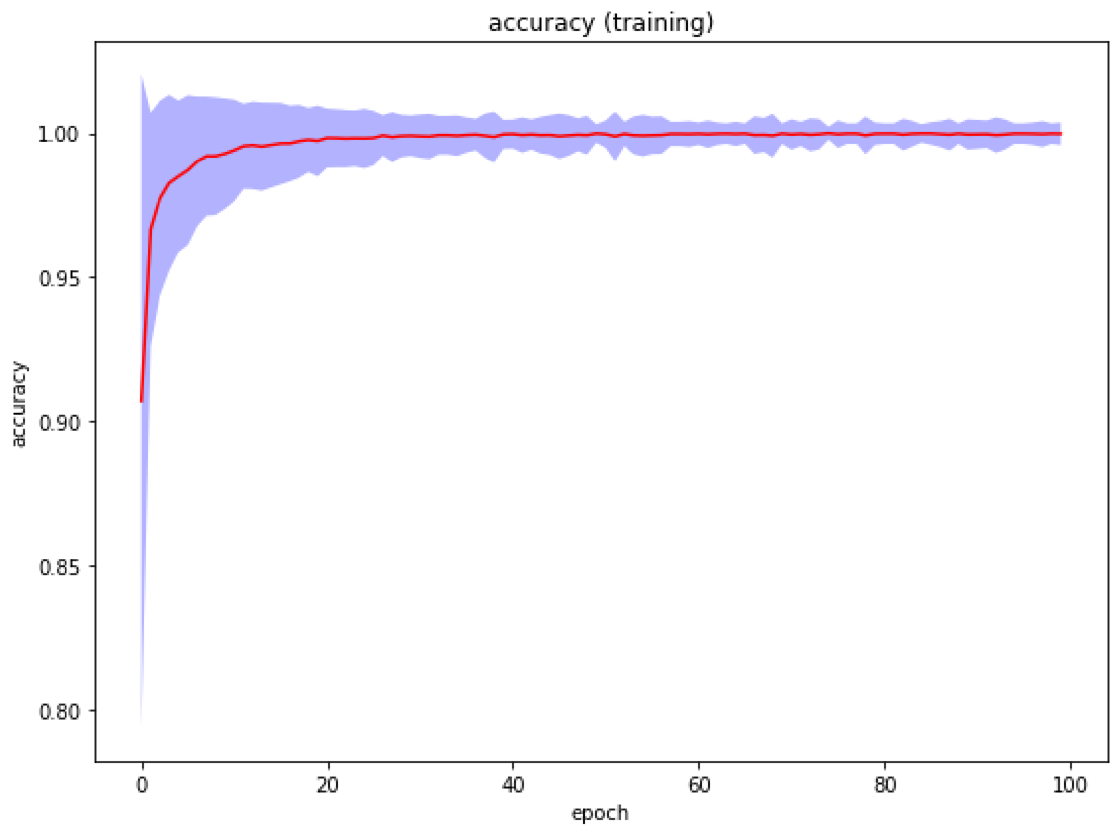
3.1 # 01. plot the training loss curve (mean, std)

[ ]:
```
function_result_01()
```



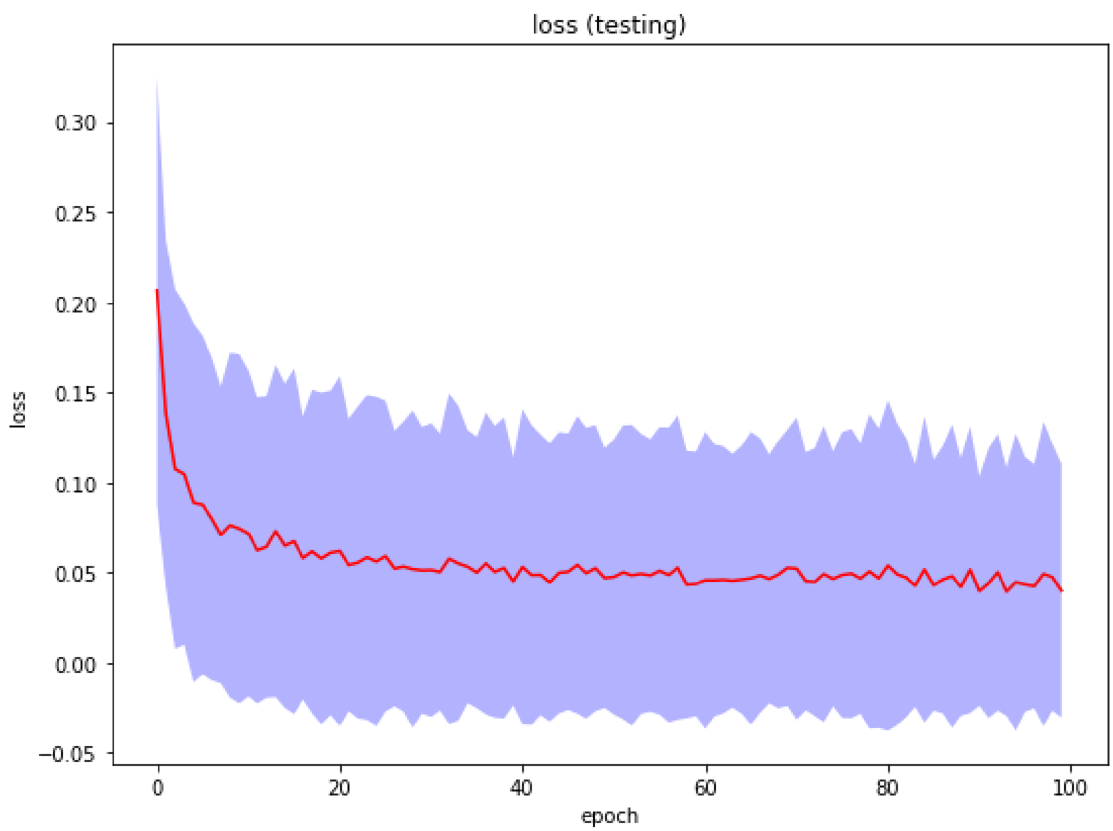
3.2 # 02. plot the training accuracy curve (mean, std)

[ ]:
```
function_result_02()
```



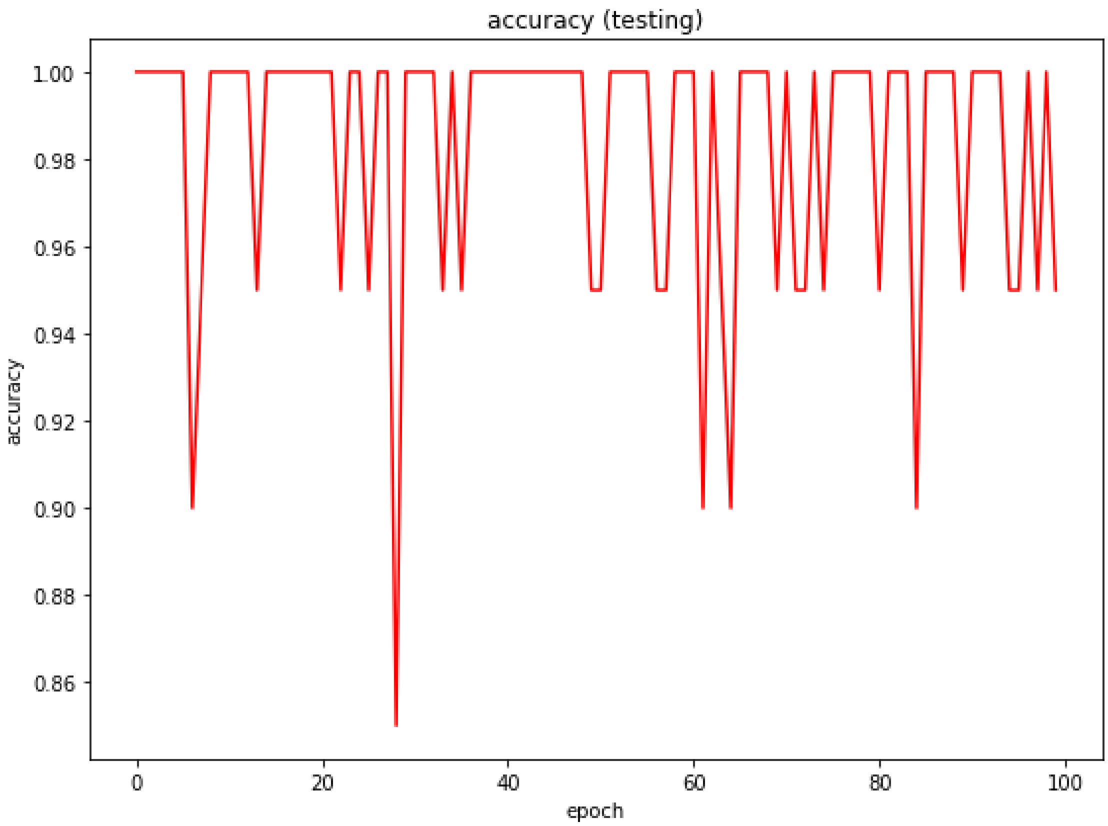
3.3 # 03. plot the testing loss curve (mean, std)

[ ]:
```
function_result_03()
```



3.4 # 04. plot the testing accuracy curve (mean, std)

[ ]:
```
function_result_04()
```



3.5 # 05. print the training (mean) loss over batches at last 10 epochs

[ ]:
```
function_result_05()
```

```
index =  0, value = 0.0076850174
index =  1, value = 0.0072676652
index =  2, value = 0.0085482572
index =  3, value = 0.0078744456
index =  4, value = 0.0061955091
index =  5, value = 0.0057137411
index =  6, value = 0.0060999207
index =  7, value = 0.0062038752
index =  8, value = 0.0059937446
index =  9, value = 0.0063737490
```

3.6 # 06. print the training (mean) accuracy over batches at last 10 epochs

[ ]:
```
function_result_06()
```

```
index =  0, value = 0.9995000000
index =  1, value = 0.9995500000
```

```
index =  2, value = 0.9992500000
index =  3, value = 0.9994500000
index =  4, value = 0.9997500000
index =  5, value = 0.9997500000
index =  6, value = 0.9997000000
index =  7, value = 0.9996000000
index =  8, value = 0.9997500000
index =  9, value = 0.9997000000
```

3.7 # 07. print the testing (mean) loss over batches at last 10 epochs

[ ]:
```
function_result_07()
```

```
index =  0, value = 0.0396715618
index =  1, value = 0.0440520212
index =  2, value = 0.0501337058
index =  3, value = 0.0394022307
index =  4, value = 0.0446191651
index =  5, value = 0.0433655200
index =  6, value = 0.0423881852
index =  7, value = 0.0491576031
index =  8, value = 0.0474655072
index =  9, value = 0.0399477717
```

3.8 # 08. print the testing (mean) accuracy over batches at last 10 epochs

[ ]:
```
function_result_08()
```

```
index =  0, value = 1.0000000000
index =  1, value = 1.0000000000
index =  2, value = 1.0000000000
index =  3, value = 1.0000000000
index =  4, value = 0.9500000000
index =  5, value = 0.9500000000
index =  6, value = 1.0000000000
index =  7, value = 0.9500000000
index =  8, value = 1.0000000000
index =  9, value = 0.9500000000
```

3.9 # 09. print the best training (mean) accuracy within the last 10 epochs

[ ]:
```
function_result_09()
```

```
best training accuracy = 0.9997500000
```

3.10 # 10. print the best testing (mean) accuracy within the last 10 epochs

[ ]:
```
function_result_10()
```

```
best testing accuracy = 1.0000000000
```

[ ]:
```

```