Double Pendulum Trajectory Forecasting using RNN

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In [11]:
```
#What are we working with?
import sys
sys.version
```

Out[11]: '3.6.3 |Anaconda custom (64-bit)| (default, Oct 6 2017, 12:04:38) \n[GCC 4.2.1 Compatible Clang 4.0.1 (tags/RELEASE_401/final)]'

In [12]:
```
#Import Libraries
import tensorflow as tf
import pandas as pd
import numpy as np
import os
import matplotlib
import matplotlib.pyplot as plt
import random
%matplotlib inline
import tensorflow as tf
import shutil
import tensorflow.contrib.learn as tflearn
import tensorflow.contrib.layers as tflayers
from tensorflow.contrib.learn.python.learn import learn_runner
import tensorflow.contrib.metrics as metrics
import tensorflow.contrib.rnn as rnn

from numpy import sin, cos
import numpy as np
import matplotlib.pyplot as plt
import scipy.integrate as integrate
import matplotlib.animation as animation
import random

```

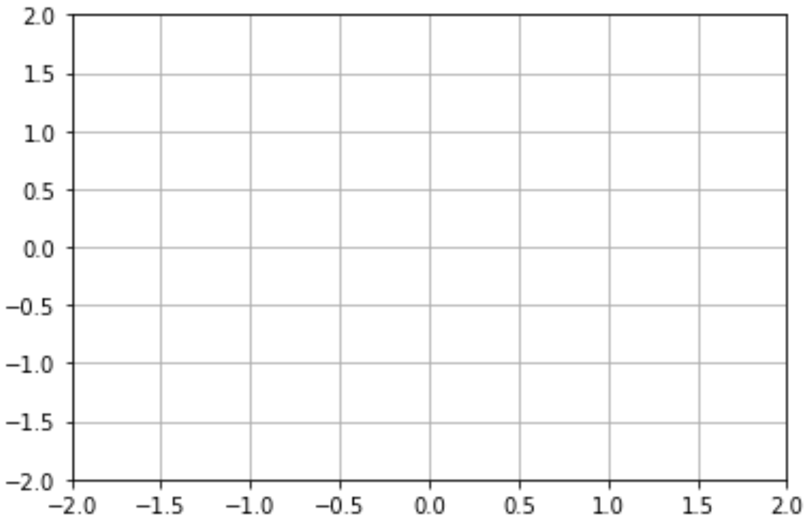
In [13]:
```
#TF Version
tf.__version__


```

Out[13]: '1.4.1'

In [14]:
```

# for each experiment value of l1,l2,m1,m2 and th1,th2,w1,w2 are s

G = 9.8  # acceleration due to gravity, in m/s^2
L1 = 1.0  # length of pendulum 1 in m
```

```
L2 = 1.0  # length of pendulum 2 in m
M1 = 1.0  # mass of pendulum 1 in kg
M2 = 1.0  # mass of pendulum 2 in kg


def derivs(state, t):

    dydx = np.zeros_like(state)
    dydx[0] = state[1]

    del_ = state[2] - state[0]
    den1 = (M1 + M2)*L1 - M2*L1*cos(del_)*cos(del_)
    dydx[1] = (M2*L1*state[1]*state[1]*sin(del_)*cos(del_) +
               M2*G*sin(state[2])*cos(del_) +
               M2*L2*state[3]*state[3]*sin(del_) -
               (M1 + M2)*G*sin(state[0]))/den1

    dydx[2] = state[3]

    den2 = (L2/L1)*den1
    dydx[3] = (-M2*L2*state[3]*state[3]*sin(del_)*cos(del_) +
               (M1 + M2)*G*sin(state[0])*cos(del_) -
               (M1 + M2)*L1*state[1]*state[1]*sin(del_) -
               (M1 + M2)*G*sin(state[2]))/den2

    return dydx

# create a time array from 0..100 sampled at 0.05 second steps
dt = 0.1
t = np.arange(0.0, 100, dt)

# th1 and th2 are the initial angles (degrees)
# w10 and w20 are the initial angular velocities (degrees per seco

th1 = 120.0
w1 = 0.0
th2 = 0.0
w2 = 0.0

# initial state
state = np.radians([th1, w1, th2, w2])

# integrate your ODE using scipy.integrate.
y = integrate.odeint(derivs, state, t)

x1 = L1*sin(y[:, 0])
y1 = -L1*cos(y[:, 0])

#print("x1 : ",x1)
#print("y1 : ",y1)

x2 = L2*sin(y[:, 2]) + x1
y2 = -L2*cos(y[:, 2]) + y1

```

```
#print("x2 : ",x2)
#print("y2 : ",y2)

fig = plt.figure()
ax = fig.add_subplot(111, autoscale_on=False, xlim=(-2, 2), ylim=(
ax.grid()

line, = ax.plot([], [], 'o-', lw=2)
time_template = 'time = %.1fs'
time_text = ax.text(0.05, 0.9, '', transform=ax.transAxes)


def init():
    line.set_data([], [])
    time_text.set_text('')
    return line, time_text


def animate(i):
    thisx = [0, x1[i], x2[i]]
    thisy = [0, y1[i], y2[i]]

    line.set_data(thisx, thisy)
    time_text.set_text(time_template % (i*dt))
    return line, time_text

ani = animation.FuncAnimation(fig, animate, np.arange(1, len(y)),i
```



Generate some data

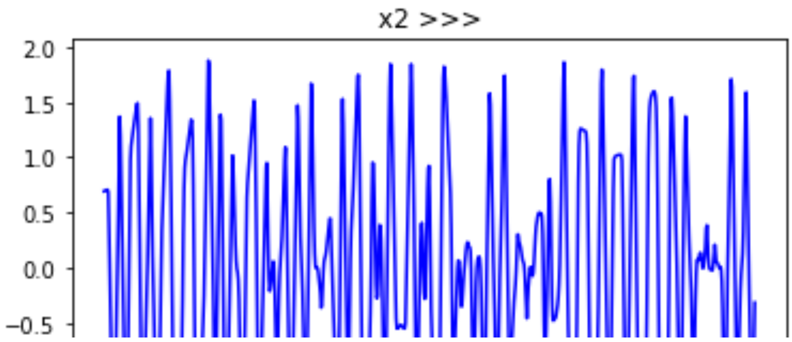
In [15]:

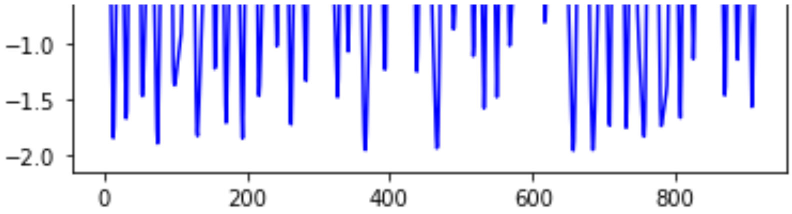
```
random.seed(111)
#ts.head(10)

f = open("data/x2.txt" , "r")
t = open("data/time_slots.txt" , "r")
```

```
t = open('data/time_slots.txt' , 'r')
array1 = []
array2 = []

for line in f.read().split('\n') :
  array1.append(line )
for line in t.read().split('\n') :
  array2.append(line )
f.close()
t.close()
array1.pop()
array2.pop()
data = []

for i in range(len(array1)):
    data.append([array1[i]])
test = np.array(data)
mylist = test.astype(np.float)

print("length of test data : ",len(mylist))
print(mylist.shape)
mylist.reshape(1,-1)
#print(mylist)

ts = np.delete(mylist,[i for i in range(912,1001)],0)

print("length of test data : ",len(ts))
print(ts.shape)
ts.reshape(1,-1)
#print(ts)

plt.plot(ts,c='b')
plt.title('x2 >>>')
plt.show()

```

```
length of test data :  1000
(1000, 1)
length of test data :  912
(912, 1)
```

```
/Users/omkarchakradharthawakar/anaconda3/lib/python3.6/site-packages
/ipykernel_launcher.py:29: DeprecationWarning: in the future out of
bounds indices will raise an error instead of being ignored by `nump
y.delete`.
```





Convert data into array that can be broken up into training "batches" that we will feed into our RNN model. Note the shape of the arrays.

In [16]:

```
TS = np.array(ts)
num_periods = 100
f_horizon = 1  #forecast horizon, one period into the future

x_data = TS[:(len(TS)-(len(TS) % num_periods))]
#print(len(x_data))
#print("x_data : ",x_data)
x_batches = x_data.reshape(-1, 100, 1)

#print (len(x_batches))
print ("x_batches shape : ",x_batches.shape)
#print (x_batches[0:1])

y_data = TS[1:(len(TS)-(len(TS) % num_periods))+f_horizon]
#print(y_data.shape)
y_batches = y_data.reshape(-1, 100, 1)


#print ("y_batches : ",y_batches[0:1])
print ("y_batches shape : ",y_batches.shape)
```

```
x_batches shape :  (9, 100, 1)
y_batches shape :  (9, 100, 1)
```

Pull out our test data

In [17]:
```
def test_data(series,forecast,num_periods):
    test_x_setup = TS[-(num_periods + forecast):]
    testX = test_x_setup[:num_periods].reshape(-1, 100, 1)
    testY = TS[-(num_periods):].reshape(-1, 100, 1)
    return testX,testY

X_test, Y_test = test_data(TS,f_horizon,num_periods )
print (X_test.shape)
print(len(X_test))
#print (X_test)

print (Y_test.shape)
print(len(Y_test))
#print (Y_test)
```

```
(1, 100, 1)
1
(1, 100, 1)
1
```

In [18]:
```
tf.reset_default_graph()   #We didn't have any previous graph obje
 
num_periods = 100      #number of periods per vector we are using
inputs = 1            #number of vectors submitted
hidden = 100          #number of neurons we will recursively work
output = 1            #number of output vectors

X = tf.placeholder(tf.float32, [None, num_periods, inputs])   #cre
y = tf.placeholder(tf.float32, [None, num_periods, output])

print(X)


basic_cell = tf.contrib.rnn.BasicRNNCell(num_units=hidden, activat
rnn_output, states = tf.nn.dynamic_rnn(basic_cell, X, dtype=tf.flo

learning_rate = 0.001   #small learning rate so we don't overshoot

stacked_rnn_output = tf.reshape(rnn_output, [-1, hidden])
stacked_outputs = tf.layers.dense(stacked_rnn_output, output)
outputs = tf.reshape(stacked_outputs, [-1, num_periods, output])

loss = tf.reduce_sum(tf.square(outputs - y))    #define the cost f
optimizer = tf.train.AdamOptimizer(learning_rate=learning_rate)
training_op = optimizer.minimize(loss)          #train the result
 
init = tf.global_variables_initializer()           #initialize all
```

```
Tensor("Placeholder:0", shape=(?, 100, 1), dtype=float32)
```

In [19]:
```
with tf.Session() as sess:
    writer = tf.summary.FileWriter("outputs_x", sess.graph)
    print(sess.run(init))
    writer.close()
```

```
None
```

In [20]:
```
epochs = 5000     #number of iterations or training cycles, includ
errors = []
iterations = []
with tf.Session() as sess:
    init.run()
    for ep in range(epochs):
        sess.run(training_op, feed_dict={X: x_batches, y: y_batche
        errors.append(loss.eval(feed_dict={X: x_batches, y: y_batc
        iterations.append(ep)
        if ep % 100 == 0:
            mse = loss.eval(feed_dict={X: x_batches, y: y_batches}
            print(ep, "\tMSE:", mse)
    y_pred = sess.run(outputs, feed_dict={X: X_test})
    print(y_pred)

```

```
0       MSE: 581.299
100     MSE: 21.9139
200     MSE: 12.3388
300     MSE: 8.77889
400     MSE: 6.77277
500     MSE: 5.22588
600     MSE: 4.9033
700     MSE: 6.821
800     MSE: 3.76563
900     MSE: 2.98707
1000    MSE: 2.75795
1100    MSE: 2.17701
1200    MSE: 2.0295
1300    MSE: 2.43033
1400    MSE: 1.79029
1500    MSE: 1.72781
1600    MSE: 5.30996
1700    MSE: 1.79617
1800    MSE: 1.8805
1900    MSE: 1.38517
```

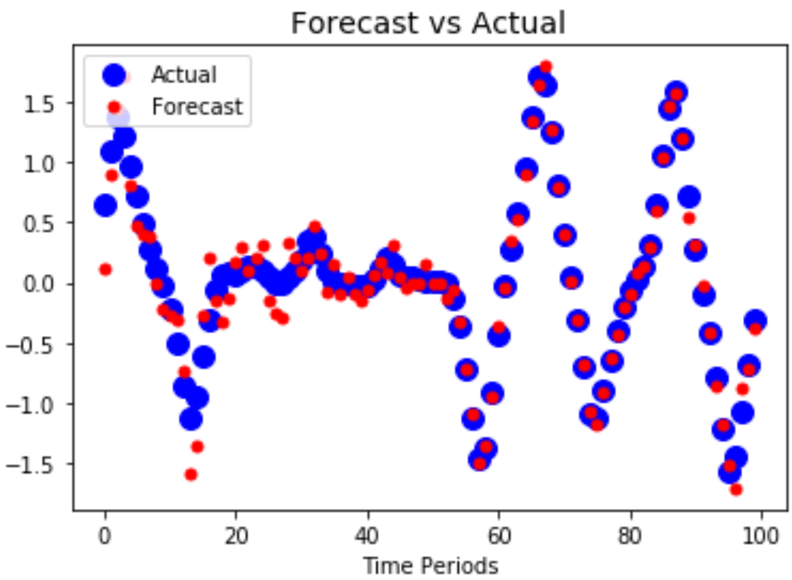
In [21]:
```
for i in range(len(y_pred[0])):
    print(Y_test[0][i] , y_pred[0][i])
```

```
[ 0.65130467] [ 0.11410932]
[ 1.09132992] [ 0.89627552]
[ 1.37144135] [ 1.44897664]
[ 1.21651892] [ 1.71158433]
[ 0.97162507] [ 0.8172189]
[ 0.72589668] [ 0.46351272]
[ 0.48853033] [ 0.40691406]
```

```
[ 0.27832533] [ 0.38316971]
[ 0.11489424] [-0.00178191]
[-0.02420258] [-0.22794408]
[-0.21427559] [-0.26626092]
[-0.50669374] [-0.30810457]
[-0.85925168] [-0.73403341]
[-1.13167657] [-1.59167254]
[-0.95782469] [-1.36332059]
[-0.61549438] [-0.28320479]
[-0.30240578] [ 0.21157284]
[-0.05761067] [-0.14463066]
[ 0.06338403] [-0.32162577]
[ 0.07530041] [-0.12596682]
[ 0.06631454] [ 0.16767716]
[ 0.0894524] [ 0.29701078]
[ 0.12633476] [ 0.0917605]
[ 0.13430522] [ 0.20406596]
[ 0.09856873] [ 0.30929607]
[ 0.03986353] [-0.15431131]
[-0.00484348] [-0.25821829]
[-0.00530485] [-0.296938]
[ 0.03851473] [ 0.32963818]
[ 0.10526395] [ 0.20661542]
[ 0.19581869] [ 0.08956158]
[ 0.35444059] [ 0.19669402]
[ 0.38391367] [ 0.4662289]
[ 0.24240832] [ 0.24906678]
[ 0.09770974] [-0.07866869]
[ 0.01087227] [ 0.147808]
[-0.01532095] [-0.09739791]
[-0.01517639] [ 0.04980822]
[-0.01779135] [-0.09956768]
[-0.02711376] [-0.15162851]
[-0.02167907] [-0.05864833]
[ 0.02783662] [ 0.06854813]
[ 0.12130583] [ 0.17318968]
[ 0.20708524] [ 0.08733192]
[ 0.14766094] [ 0.30945748]
[ 0.05862946] [ 0.03614395]
[ 0.04653323] [-0.05074906]
[ 0.03991749] [-0.01027462]
[ 0.0202778] [-0.00997065]
[ 0.00221897] [ 0.14318383]
[ 0.00124234] [-0.01404033]
[ 0.0074545] [-0.01189621]
[-0.01629526] [-0.13261202]
[-0.12572245] [-0.06816506]
[-0.36588313] [-0.33585334]
[-0.72359457] [-0.72709185]
[-1.12660005] [-1.09314263]
[-1.4615919] [-1.50020337]
[-1.38285285] [-1.36206031]
[-0.91067614] [-0.95579511]
```

```
[-0.43405067] [-0.36643404]
[-0.03064884] [-0.03553419]
[ 0.27709761] [ 0.35466939]
[ 0.58015971] [ 0.53275359]
[ 0.95527806] [ 0.90614963]
[ 1.3693463] [ 1.34341359]
[ 1.70937176] [ 1.64881873]
[ 1.64389586] [ 1.80004609]
[ 1.25006619] [ 1.26295519]
[ 0.81802814] [ 0.79744136]
[ 0.40409593] [ 0.40137595]
[ 0.03812776] [ 0.01298887]
[-0.31645917] [-0.31637269]
[-0.71024779] [-0.68096083]
[-1.08525045] [-1.07467639]
[-1.13675535] [-1.18827653]
[-0.89340507] [-0.91509259]
[-0.64483472] [-0.62212855]
[-0.40788684] [-0.43438023]
[-0.20193168] [-0.20286737]
[-0.05761479] [-0.09417319]
[ 0.02882913] [ 0.07786477]
[ 0.12503108] [ 0.13308384]
[ 0.31956288] [ 0.29332834]
[ 0.64465777] [ 0.59997213]
[ 1.04973698] [ 1.03490579]
[ 1.44037188] [ 1.46780825]
[ 1.5906479] [ 1.56928825]
[ 1.20738599] [ 1.20467997]
[ 0.72600604] [ 0.53968328]
[ 0.27699223] [ 0.30956614]
[-0.09186728] [-0.01996212]
[-0.42028866] [-0.41483206]
[-0.79916594] [-0.86987001]
[-1.2227152] [-1.18975425]
[-1.56572053] [-1.5258019]
[-1.45399075] [-1.71298969]
[-1.07415974] [-0.88234341]
[-0.68102279] [-0.71233374]
[-0.31814455] [-0.3750999]
```

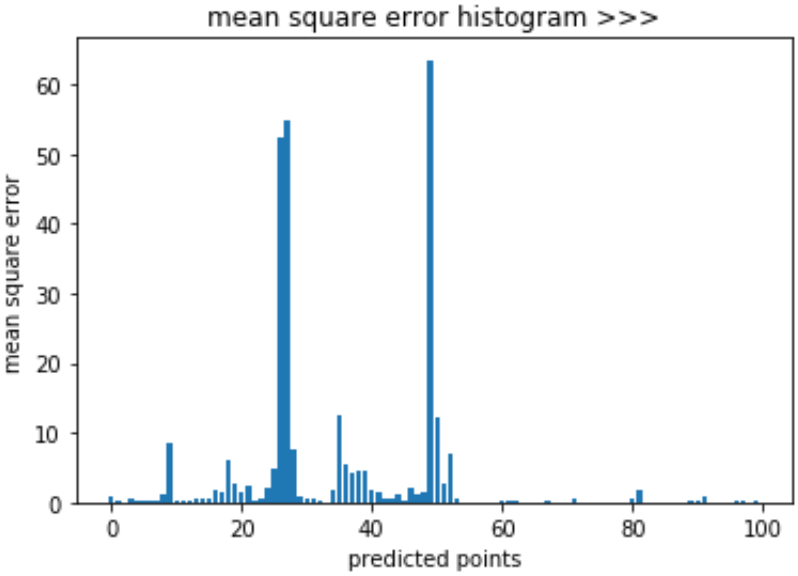
In [22]:
```
plt.title("Forecast vs Actual", fontsize=14)
plt.plot(pd.Series(np.ravel(Y_test)), "bo", markersize=10, label="
#plt.plot(pd.Series(np.ravel(Y_test)), "w*", markersize=10)
plt.plot(pd.Series(np.ravel(y_pred)), "r.", markersize=10, label="

plt.legend(loc="upper left")
plt.xlabel("Time Periods")

plt.show()


```



In [23]:
```
error = []
print(y_pred[0][1][0])
print(abs(y_pred[0][0][0]-Y_test[0][0][0]))
print(len(y_pred[0]))
for i in range(len(y_pred[0])):
    err = abs((y_pred[0][i][0]-Y_test[0][i][0])/Y_test[0][i][0])
    error.append(err)
x = np.arange(len(error))
print(error)
plt.bar(x,error,align='center')
plt.xlabel('predicted points')
plt.ylabel('mean square error')
plt.title('mean square error histogram >>>')
plt.show()
```

```
0.896276
0.537195347766
100
[0.82479885735421021, 0.17873091660864704, 0.056535617569429084, 0.4
0695249758644347, 0.15891538085358409, 0.36146185976063561, 0.167064
90159623735, 0.37669723502933816, 1.0155091389574211, 8.418172122594
4077, 0.24260970361966022, 0.39193135693594194, 0.1457294509909573,
0.40647299499562695, 0.42335084896025166, 0.53987427925879139, 1.699
6322698932671, 1.5104837776229436, 6.0742396569336385, 2.67285691210
```

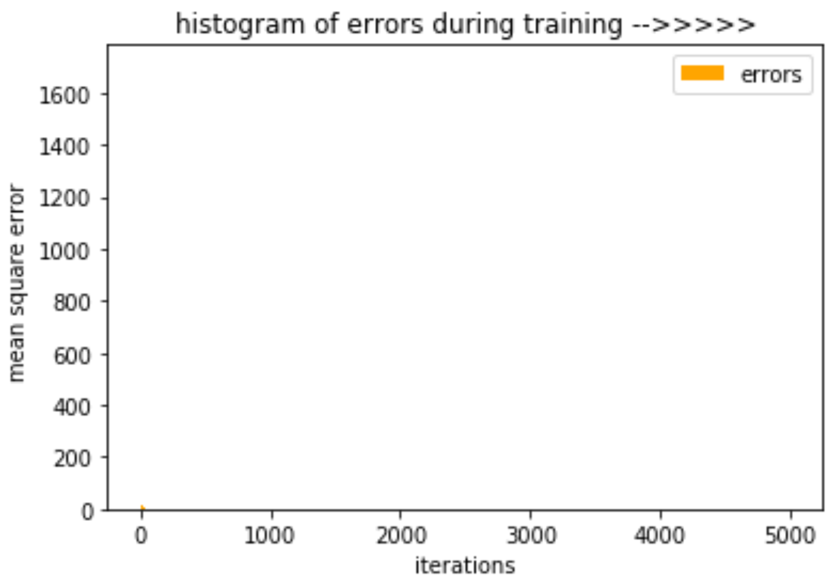
```
7068, 1.5285130009544887, 2.3203219634295973, 0.27367180022630683, 0
.51941940363727945, 2.1378719806526667, 4.870990104676693, 52.312515
634560341, 54.974767971748527, 7.5587561854505019, 0.962831735611528
57, 0.54263007557194132, 0.445057866894704, 0.21441077185500015, 0.0
27467981031326232, 1.8051264163052774, 12.594957531741299, 5.3571735
449221132, 4.2819539565130231, 4.5964089273276816, 4.592308004455262
, 1.7052968854886312, 1.4625166417764086, 0.42771118969625821, 0.578
28031735837893, 1.0957301414730016, 0.38351893693781069, 2.090598234
4459582, 1.2573964121394885, 1.4917026438121852, 63.527121249045472,
12.301524049537251, 2.5958423440047595, 7.1380747640804119, 0.457813
12562855658, 0.082074809021109002, 0.0048331963505130159, 0.02969769
3394686933, 0.026417409213273839, 0.015035978506083444, 0.0495444706
34499793, 0.15578050559248882, 0.15939762014323597, 0.27994388693558
858, 0.081712195277340499, 0.051428416898243491, 0.018938021417176785
5, 0.035424139704469705, 0.094987903422785569, 0.010310650719808804,
0.025166343796214376, 0.0067310288749893674, 0.65933311660153127, 0.
00027327175091571595, 0.041234843646573052, 0.0097434240177029473, 0
.045323013706180304, 0.024275118232454599, 0.035212397183297640, 0.06
4952794242754588, 0.0046337023317053515, 0.63453146201285737, 1.7009
061365881817, 0.064406023696921569, 0.082095062491180440, 0.069316847
122788933, 0.014128482133283772, 0.019048110675930204, 0.01342827050
5682459, 0.0022412213081291939, 0.25664078444630256, 0.1175986470904
7234, 0.7827070006285276, 0.012982994293059137, 0.088472320062014567
, 0.026957180517797014, 0.025495377064424764, 0.17812970002776218, 0
.1785733701256626, 0.045976355127444427, 0.17902349326050634]
```



In [24]:

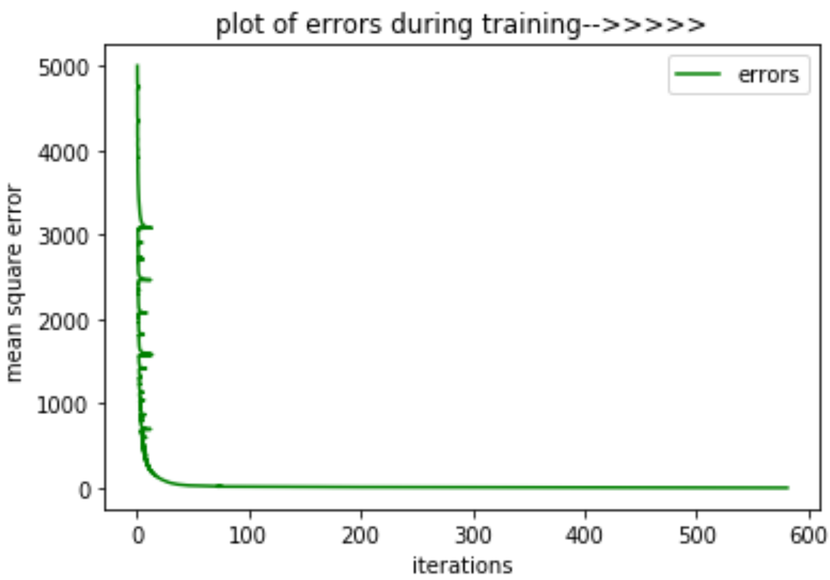
```python
#!/usr/bin/env python
import numpy as np
import matplotlib.mlab as mlab
import matplotlib.pyplot as plt

errors=np.array(errors)
iterations=np.array(iterations)
print(errors.shape)
#print(errors)

plt.hist(errors,iterations,label='errors', facecolor='orange')

plt.xlabel('iterations')
plt.ylabel('mean square error ')
plt.title('histogram of errors during training -->>>>>')
plt.legend()
plt.show()
```

```
(5000,)
```



In [25]:
```
#!/usr/bin/env python
import numpy as np
import matplotlib.mlab as mlab
import matplotlib.pyplot as plt

errors=np.array(errors)
iterations=np.array(iterations)
print(errors.shape)
#print(errors)

plt.plot(errors,iterations,label='errors',color='green')

plt.xlabel('iterations')
plt.ylabel('mean square error ')
plt.title('plot of errors during training-->>>>>')
plt.legend()
plt.show()
```

(5000,)



In [ ]:
```

```