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#
#The files contain code and data associated with the paper titled
#"A Deep Learning Approach to Estimate Stress Distribution: A Fast and
#Accurate Surrogate of Finite Element Analysis".
#
#The paper is authored by Liang Liang, Minliang Liu, Caitlin Martin,
#and Wei Sun, and published at Journal of The Royal Society Interface, 2018.
#
#The file list: ShapeData.mat, StressData.mat, DLStress.py, im2patch.m,
#UnsupervisedLearning.m, ReadMeshFromVTKFile.m, ReadPolygonMeshFromVTKFile.m,
#WritePolygonMeshAsVTKFile.m, Visualization.m, TemplateMesh3D.vtk, TemplateMesh2D.vtk.
#Note: *.m and *.py files were converted to pdf files for documentation purpose.
#
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#INCLUDING, WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS
#FOR A PARTICULAR PURPOSE.
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#%%
# go to cmd and follow the instructions to setup matlab python engine
#https://www.mathworks.com/help/matlab/matlab\_external/install-the-matlab-engine-for-python.html
#%%

from keras.models import Sequential
from keras.layers import Dense, Conv2DTranspose
import numpy
from numpy.random import RandomState
import scipy.io as sio
import time
import matlab.engine

#%% Unsupervised Learning is done in Matlab
def UnsupervisedLearning(DataFile, ShapeDataFile, StressDataFile, IdxList_train, IdxList_test):
    idx_train_mat=matlab.double(list(IdxList_train+1)) #+1 to matlab index
    idx_test_mat=matlab.double(list(IdxList_test+1)) #+1 to matlab index
    DataFlag = eng.UnsupervisedLearning(DataFile, ShapeDataFile, StressDataFile, idx_train_mat,
    idx_test_mat)
    MatData=sio.loadmat(DataFile)
    X=MatData['ShapeCode_train']
    X=numpy.asmatrix(X)
    X=X.transpose()
    S=MatData['Stress_train']
    S=numpy.asmatrix(S)
    Y_ = MatData['Y2n_train']
    Y = numpy.array([])
    Y.resize((len(IdxList_train),64))
    for k in range(0, len(IdxList_train)):
        Y[k,:]=Y_[:, :, :, k]
    #end
    Y=numpy.asmatrix(Y)
    #
    X_t=MatData['ShapeCode_test']

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X_t=numpy.asmatrix(X_t)
X_t=X_t.transpose()
S_t=MatData['Stress_test']
S_t=numpy.asmatrix(S_t)
Y_t_ = MatData['Y2n_test']
Y_t_ = numpy.array([])
Y_t.resize((len(IdxList_test),64))
for k in range(0, len(IdxList_test)):
    Y_t[k,:]=Y_t_[:, :, :, k]
#end
Y_t=numpy.asmatrix(Y_t)
#
L=MatData['L2']
W1=MatData['W1']
W2=MatData['W2']
#
Proj=MatData['Proj']
MeanShape=MatData['MeanShape']
#
return X, X_t, Y, Y_t, S, S_t, L, W1, W2, Proj, MeanShape
#end
#-----
#% S11/S22/S12: 5000xN, S_all=[S11; S22; S12]
def ComputeVonMisesStress_all(S_all):
    N=S_all.shape[1]
    VM_all=numpy.array([])
    VM_all.resize(5000, N)
    S11_all=S_all[0:5000,:]
    S22_all=S_all[5000:10000,:]
    S12_all=S_all[10000:15000,:]
    for n in range(0,N):
        for k in range(0, 5000):
            S11=S11_all[k,n]
            S22=S22_all[k,n]
            S12=S12_all[k,n]
            VM=S11*S11+S22*S22-S11*S22+3*S12*S12
            VM=numpy.sqrt(VM)
            VM_all[k,n]=VM
        #end
    #end
    return VM_all;
#end
#----- A is ground truth, A[:,n] is vector of stress values; B is the reconstructed
version of A
def ComputeError(A, B):
    MAE=numpy.zeros(A.shape[1])
    NMAE=numpy.zeros(A.shape[1])
    for n in range(0, A.shape[1]):
        a=A[:,n]
        b=B[:,n]
        c=numpy.absolute(a-b)
        a_abs=numpy.absolute(a)
        a_max=numpy.max(a_abs[301:4700])

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    .....MAE[n]=numpy.mean(c) .....
    .....NMAE[n]=MAE[n]/a_max
    .....#end
    .....return MAE, NMAE
#end
#-----
def ComputeError_peak(A, B):
    .....AE=numpy.zeros(A.shape[1])
    .....APE=numpy.zeros(A.shape[1])
    .....for n in range(0, A.shape[1]): .....
    .....a=A[:,n]
    .....b=B[:,n]
    .....a_abs=numpy.absolute(a)
    .....b_abs=numpy.absolute(b)
    .....a_max=numpy.max(a_abs[301:4700]) .....
    .....b_max=numpy.max(b_abs[301:4700]) .....
    .....AE[n]=numpy.absolute(a_max-b_max)
    .....APE[n]=AE[n]/a_max
    .....#end
    .....return AE, APE
#end
### Define the Deep Learning Model: shape_encoding, nonlinear mapping, stress_decoding
def CreateModel_ShapeEncoding(NodeCount, Proj):
    .....model = Sequential()
    .....model.add(Dense(3, input_dim=NodeCount*3, kernel_initializer='normal', activation='linear'))
    .....W0=model.layers[0].get_weights()
    .....W0[0]=Proj
    .....model.layers[0].set_weights(W0)
    .....model.compile(loss='mean_squared_error', optimizer='adamax')
    .....return model
#end
#-----
def CreateModel_NonlinearMapping(Xshape, Yshape):
    .....model = Sequential()
    .....model.add(Dense(128, input_dim=Xshape[1], kernel_initializer='normal', activation='softplus'
    .....))
    .....model.add(Dense(128, kernel_initializer='normal', activation='softplus')) .....
    .....model.add(Dense(Yshape[1], kernel_initializer='normal', activation='linear')) .....
    .....model.compile(loss='mean_squared_error', optimizer='adamax')
    .....return model
#end
#-----
def CreateModel_StressDecoding(W1_in, W2_in):
    .....model = Sequential()
    .....model.add(Conv2DTranspose(filters=256, kernel_size=[5,5], strides=(1,1), input_shape=(1,1,64
    .....), data_format='channels_last'))
    .....model.add(Conv2DTranspose(filters=3, kernel_size=[10,20], strides=(10,20)))
    .....model.compile(loss='mean_squared_error', optimizer='adamax')
    .....W0=model.layers[0].get_weights()
    .....W1=model.layers[1].get_weights() .....
    .....W0[0]=W2_in
    .....W1[0]=W1_in .....
    .....model.layers[0].set_weights(W0)

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model.layers[1].set_weights(W1)
return model
#end
#-----
###
ShapeDataFile='ShapeData.mat'
StressDataFile='StressData.mat'
TempDataFile='TempData.mat'
ResultFile='DL_Stress_result.mat'
#
MatData_shape=sio.loadmat(ShapeDataFile)
ShapeData=MatData_shape['ShapeData']
###
#make sure you can see DLStress.py in the current directory of spyder
eng=matlab.engine.start_matlab()
rng=RandomState(0)
IndexList=numpy.arange(0,729,1)
S11MAE=[]; S11NMAE=[];
S22MAE=[]; S22NMAE=[];
S12MAE=[]; S12NMAE=[];
VMMAE=[]; VMNMAE=[];
S11AE=[]; S11APE=[];
S22AE=[]; S22APE=[];
S12AE=[]; S12APE=[];
VMAE=[]; VMAPE=[];
IndexList_test=[];
IndexList_train=[];
for k in range(0,100):
    #specify training set and testing set
    rng.shuffle(IndexList)
    idx_train=IndexList[0:656]
    idx_test=IndexList[656:729]
    IndexList_train.append(idx_train)
    IndexList_test.append(idx_test)
    ShapeData_train=ShapeData[:,idx_train]
    ShapeData_test=ShapeData[:,idx_test]
    #unsupervised learning in Matlab
    t1=time.clock()
    [X,X_t,Y,Y_t,S,S_t,L,W1,W2,Proj,MeanShape]=UnsupervisedLearning(TempDataFile,
        ShapeDataFile,StressDataFile,idx_train,idx_test)
    t2=time.clock()
    print(k,'Unsupervised Learning',t2-t1)
    #subtract mean shape
    for n in range(0,656):
        ShapeData_train[:,n]-=MeanShape[:,0]
    #end
    for n in range(0,73):
        ShapeData_test[:,n]-=MeanShape[:,0]
    #end
    #althouth encoding has been done in Matlab, redo it here

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ShapeEncoder = CreateModel_ShapeEncoding (5000, Proj)
X=ShapeEncoder.predict (ShapeData_train.transpose(), batch_size=100, verbose=0)
X_t=ShapeEncoder.predict (ShapeData_test.transpose(), batch_size=100, verbose=0)
t3=time.clock()
print(k, 'Shape Encoding', t3-t2)

NMapper=CreateModel_NonlinearMapping (X.shape, Y.shape)
NMapper.fit (X, Y, epochs=5000, batch_size=100, verbose=0)
#test
Yp=NMapper.predict (X_t, batch_size=idx_test.size, verbose=0)
for n in range(0, 64):
    Yp[:,n]=Yp[:,n]*L[n]
#end
Ypp = numpy.array([])
Ypp.resize((idx_test.size,1,1,64))
for n in range(0, idx_test.size):
    Ypp[n,0,0,:]=Yp[n,:]
#end
t4=time.clock()
print(k, 'Nonlinear Mapping', t4-t3)

StressDecoder=CreateModel_StressDecoding (W1, W2);
Spp=StressDecoder.predict (Ypp);
Sp = numpy.array([])
Sp.resize((15000, idx_test.size))
for n in range(0, idx_test.size):
    tempS11=Spp[n,:,:,0];
    tempS11=tempS11.reshape((5000), order='F')
    Sp[0:5000,n]=tempS11
    tempS22=Spp[n,:,:,1];
    tempS22=tempS22.reshape((5000), order='F')
    Sp[5000:10000,n]=tempS22
    tempS12=Spp[n,:,:,2];
    tempS12=tempS12.reshape((5000), order='F')
    Sp[10000:15000,n]=tempS12
#end
Sp=numpy.asmatrix(Sp)
t5=time.clock()
print(k, 'Stress Decoding', t5-t4)

#compare ground-truth S and predicted Sp
[S11MAE_k, S11NMAE_k]=ComputeError(S_t[0:5000,:], Sp[0:5000,:])
S11MAE.append(S11MAE_k)
S11NMAE.append(S11NMAE_k)
[S22MAE_k, S22NMAE_k]=ComputeError(S_t[5000:10000,:], Sp[5000:10000,:])
S22MAE.append(S22MAE_k)
S22NMAE.append(S22NMAE_k)
[S12MAE_k, S12NMAE_k]=ComputeError(S_t[10000:15000,:], Sp[10000:15000,:])
S12MAE.append(S12MAE_k)
S12NMAE.append(S12NMAE_k)
#peak stress error
[S11AE_k, S11APE_k]=ComputeError_peak(S_t[0:5000,:], Sp[0:5000,:])
S11AE.append(S11AE_k)

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    S11APE.append(S11APE_k)
    [S22AE_k, S22APE_k]=ComputeError_peak(S_t[5000:10000,:], Sp[5000:10000,:])
    S22AE.append(S22AE_k)
    S22APE.append(S22APE_k)
    [S12AE_k, S12APE_k]=ComputeError_peak(S_t[10000:15000,:], Sp[10000:15000,:])
    S12AE.append(S12AE_k)
    S12APE.append(S12APE_k)
    #compare Von Mises Stress
    VM_t=ComputeVonMisesStress_all(S_t)
    VMp=ComputeVonMisesStress_all(Sp)
    [VMMAE_k, VMNMAE_k]=ComputeError(VM_t, VMp)
    VMMAE.append(VMMAE_k)
    VMNMAE.append(VMNMAE_k)
    #peak stress error
    [VMAE_k, VMAPE_k]=ComputeError_peak(VM_t, VMp)
    VMAE.append(VMAE_k)
    VMAPE.append(VMAPE_k)
    #####
    #report
    t6=time.clock()
    print(k, 'ComputeError', t6-t5)
    print('VM', numpy.mean(VMMAE), numpy.std(VMMAE), numpy.mean(VMNMAE), numpy.std(VMNMAE))
    print('S11', numpy.mean(S11MAE), numpy.std(S11MAE), numpy.mean(S11NMAE), numpy.std(S11NMAE))
    #####
    print('S22', numpy.mean(S22MAE), numpy.std(S22MAE), numpy.mean(S22NMAE), numpy.std(S22NMAE))
    print('S12', numpy.mean(S12MAE), numpy.std(S12MAE), numpy.mean(S12NMAE), numpy.std(S12NMAE))
    print('VMpeak', numpy.mean(VMAE), numpy.std(VMAE), numpy.mean(VMAPE), numpy.std(VMAPE))
    print('S11peak', numpy.mean(S11AE), numpy.std(S11AE), numpy.mean(S11APE), numpy.std(S11APE))
    print('S22peak', numpy.mean(S22AE), numpy.std(S22AE), numpy.mean(S22APE), numpy.std(S22APE))
    print('S12peak', numpy.mean(S12AE), numpy.std(S12AE), numpy.mean(S12APE), numpy.std(S12APE))
#end#####
###
sio.savemat(ResultFile,
            {'DataFile':DataFile,
            'IndexList_test':IndexList_test, 'IndexList_train':IndexList_train,
            'VMMAE':VMMAE, 'VMNMAE':VMNMAE,
            'S11MAE':S11MAE, 'S11NMAE':S11NMAE,
            'S22MAE':S22MAE, 'S22NMAE':S22NMAE,
            'S12MAE':S12MAE, 'S12NMAE':S12NMAE,
            'VMAE':VMAE, 'APE':VMAPE,
            'S11AE':S11AE, 'S11APE':S11APE,
            'S22AE':S22AE, 'S22APE':S22APE,
            'S12AE':S12AE, 'S12APE':S12APE})
###
# to save the predicted stress distribution during cross validation
# insert the function below to the code block of the cross validation
# sio.savemat('StressData_pred.mat', {'Sp':Sp, 'idx_test':idx_test})
### show the time cost on the testing set: input shape, output stress
t_start=time.clock()
X_t=ShapeEncoder.predict(ShapeData_test.transpose(), batch_size=100, verbose=0)
Yp=NMapper.predict(X_t, batch_size=idx_test.size, verbose=0)
for n in range(0, 64):
    Yp[:,n]=Yp[:,n]*L[n]

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#end
Ypp = numpy.array([])
Ypp.resize((idx_test.size,1,1,64))
for n in range(0,idx_test.size):
    Ypp[n,0,0,:]=Yp[n,:]
#end
Spp=StressDecoder.predict(Ypp);
Sp = numpy.array([])
Sp.resize((15000,idx_test.size))
for n in range(0,idx_test.size):
    tempS11=Spp[n,:,:,:0];
    tempS11=tempS11.reshape((5000),order='F')
    Sp[0:5000,n]=tempS11
    tempS22=Spp[n,:,:,:1];
    tempS22=tempS22.reshape((5000),order='F')
    Sp[5000:10000,n]=tempS22
    tempS12=Spp[n,:,:,:2];
    tempS12=tempS12.reshape((5000),order='F')
    Sp[10000:15000,n]=tempS12
#end
Sp=numpy.asmatrix(Sp)
t_end=time.clock()
print('Time Cost Per Testing Sample ',(t_end-t_start)/73)

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