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Analysis of Methods used to Investigate Engineering Measured Experimental Data

Mohamad Tariq Mohamad Barakat
Albalqa Applied University
Faculty of Engineering Technology
Jordan Amman

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Abstract: The results of many measured engineering experiments require an analysis and study process in order to determine the relationships between the independent variables and the dependent variables, and accordingly, the accuracy of the values of the adopted variables becomes an urgent necessity.
In this research paper we will take a sample of laboratory data and find the necessary relationships between the different variables, and then we will present some models of artificial neural networks to find solutions to these relationships in order to make the necessary comparisons to reach some of the necessary recommendations regarding the handling of measured data.
Keywords: Experimental data, regression, ANN, CFANN, FFANN, EANN, MSE.

1- Introduction

Many experiments and studies are carried out in many laboratories and engineering workshops, the results of which are a set of measurements, which constitute values for a set of values of independent variables and values of a set of approved variables.
The values obtained in the laboratory as a result of the measurement process may be large, which creates difficulties in linking these values with each other to find the necessary relationships that can be used with high accuracy to find the values of the variables adopted by knowing the values of the independent variables.

To obtain the relationship between the independent and dependent variables in the measured data we can use regression model [1], [2], this model can be easily solved using matlab, figure 1 shows an obtained experimentally results with 4 independent variables (x1, x2, x3, and x4 and dependent variable y), the regressed out can be obtained applying the following code:


```
>> X = [ones(size(x1)) x1 x2 x3 x4];
b = regress(y,X)

b =

   -5.0003
    2.0000
    2.0000
   -1.6000
    2.7000

>> y1=b(1)+b(2)*x1+b(3)*x2+b(4)*x3+b(5)*x4;
```

The mean square error between the measured output and the calculated one can calculate using equation1:

$$MSE = average((target - calculated)^2) \quad (1)$$

X1	X2	X3	X4	Y	Reg-out
9.5013	1.0420	20.9530	7.4483	2.6723	2.6722
2.3114	6.3516	0.4910	13.4965	47.9811	47.9810
6.0684	14.6370	17.0319	12.3244	42.4357	42.4357
4.8598	0.1775	9.4870	9.6737	16.0143	16.0144
8.9130	2.5000	20.7949	12.2696	17.6822	17.6822
7.6210	3.6498	12.5703	9.9034	24.1682	24.1683
4.5647	3.5770	17.7368	5.1296	-3.2457	-3.2456
0.1850	10.8683	10.7223	4.3459	11.6848	11.6847
8.2141	4.8994	7.6154	5.1179	22.8606	22.8606
4.4470	3.5787	4.7413	8.0112	25.0954	25.0955
6.1543	0.2749	4.8358	10.9067	29.5693	29.5692
7.9194	13.4421	17.0556	4.6394	22.9603	22.9603
9.2181	8.0117	7.5691	12.5774	51.3082	51.3081
7.3821	16.7727	13.5418	8.5211	44.6495	44.6496
1.7627	8.3879	3.7718	5.5562	24.2679	24.2679
4.0571	7.5357	17.4475	10.5411	18.7305	18.7306
9.3547	15.2320	9.4593	8.1986	51.1746	51.1747
9.1690	9.4527	21.5003	6.6732	15.8608	15.8605
4.1027	3.6477	21.3414	10.4185	4.4845	4.4846
8.9365	12.0985	14.8391	9.3197	38.4905	38.4906

MSE = 1.0900e-08

Figure 1: Results of measurements and the regressed output

From figure 1 we can see that solving the regression model for the experimental data provide a very small error which can be accepted, in the following parts we will check whether artificial neural networks [19], [20], [21] gives better results.

2- Artificial Neural Networks

Artificial neural network (ANN) [8], [9] is a powerful mathematical model which can be used to solve various problems such as digital images [3], [4], [5] classification, speech recognition [6], [7], function approximation and many other problems.

ANN is asset of fully connected neurons [10], [11] which are arranged in one or more layers [12], each neuron is a computational cell which as shown in figure 2 performs summation of the products of the weights and inputs [13], then according to the selected activation function calculates the cell output[14].

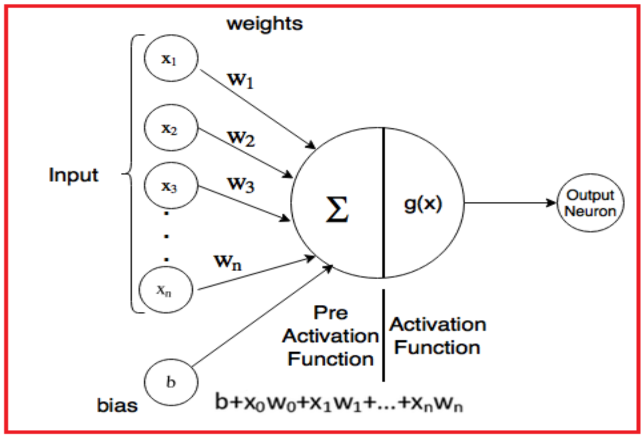

Figure 2: Neuron operations

In order to get ANN desired output it must be trained [15], [16], each training cycle is done in two ways as shown in figure 3: the feedforward phase in which the neurons outputs are calculated, starting from the input layer, and a backward phase to find the error, and according to obtained error adjust the weights [17], [18]. Figures 4 and 5 show an example of one training cycle calculation.

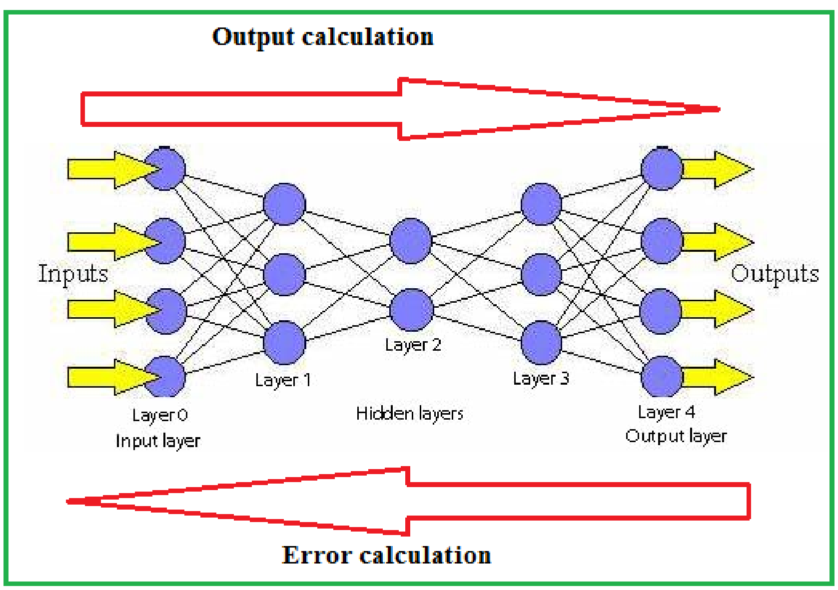

Figure 3: Training cycle

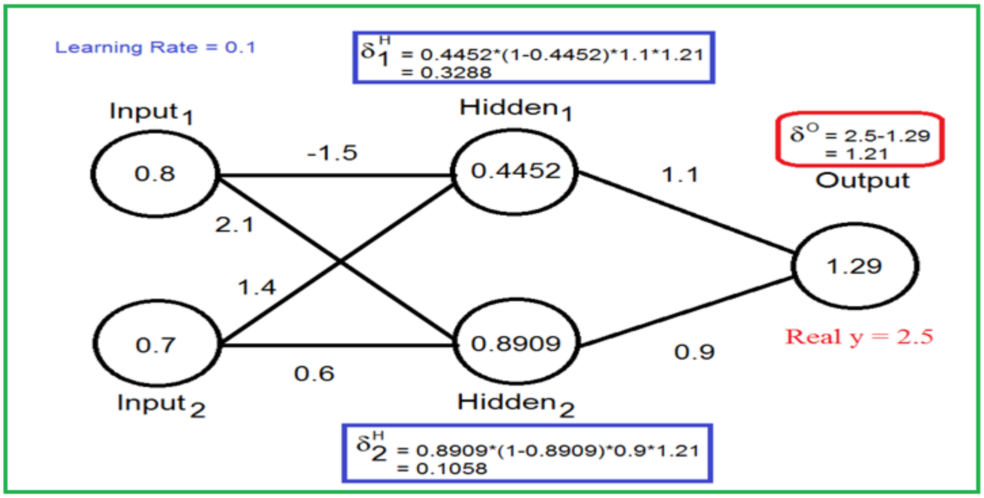

Figure 4: Training cycle calculations

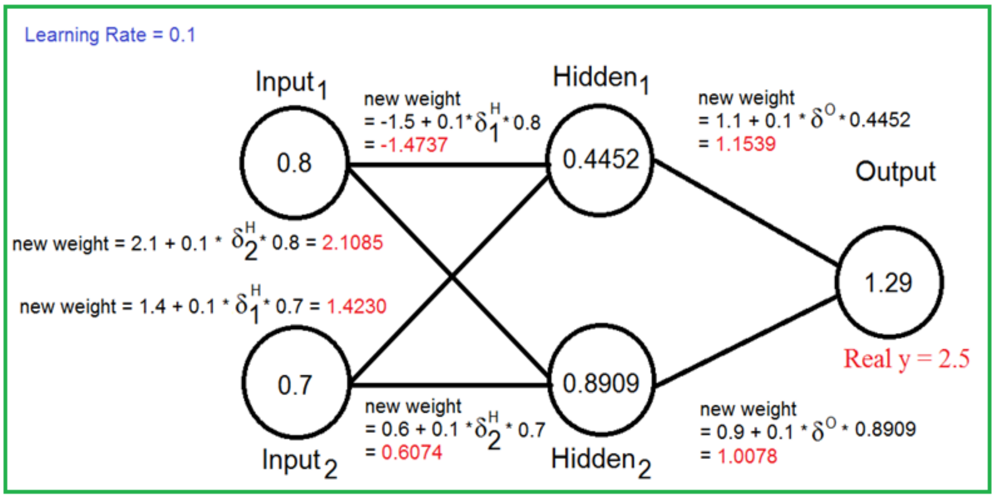

Figure 5: Training cycle calculations (continued)

ANN can be used in different variations, mostly and widely used are feedforward (FFANN), cascade-forward (CANN and Elman (EANN) neural networks [10], [11]. In FFANN (see figure 6) the neurons are organized in layer and each neuron is fully connected to neurons in the previous layer.

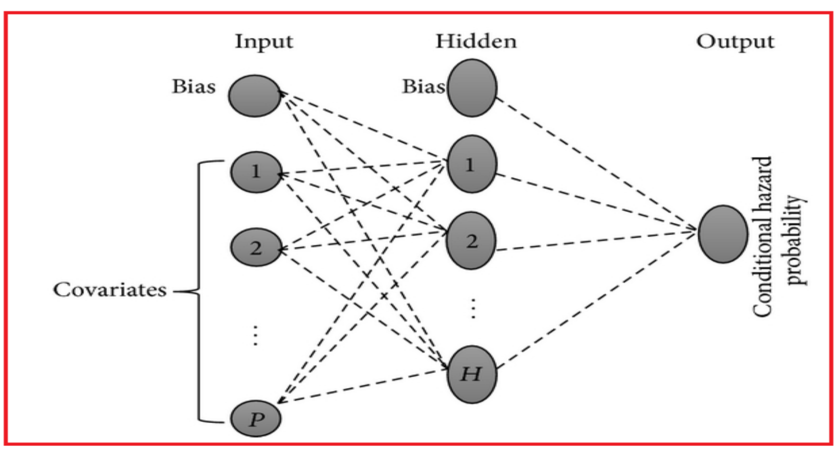

Figure 6: FFANN

In CFANN the inputs weights are connected to the other layers as shown in figure 7.

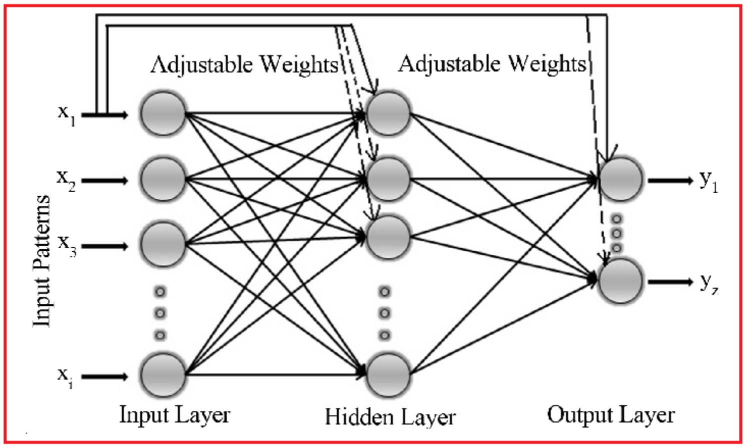

Figure 7: CFANN

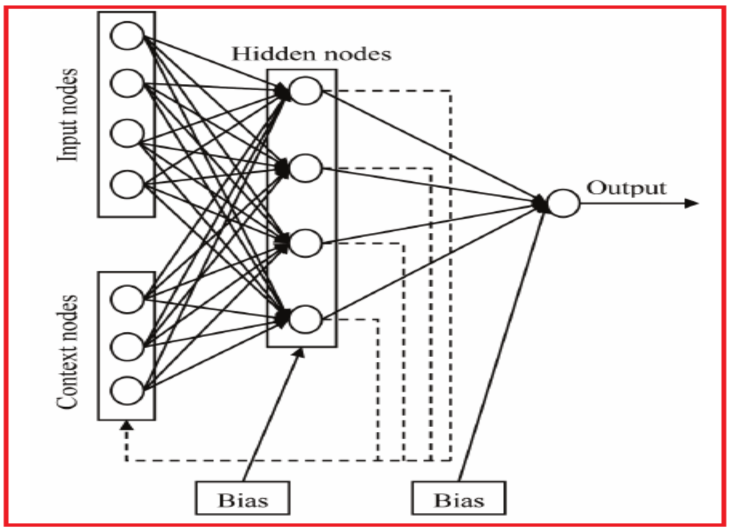

Figure 8: EANN

In EANN the outputs of the hidden layer feed the input layer and form a context delay nodes.

3- Implementation and Experimental Results

To use ANN as a computation tool we have to follow the following steps [8], [9]:

- Select the input dataset.
- Normalize the dataset if needed.
- Select the target output (outputs).
- Create and build ANN architecture by defining the number of layers, defining the number of neurons in each layer, defining the activation function for each layer [10], [11], selecting ANN type.
- Setting all the weights to zeros by initializing the net.
- Setting the number of training cycles.
- Setting the error to zero.
- Training the net.
- Run the net.
- Checking the error and the calculated outputs, if acceptable save ANN to be used later as a computational tool, else modify the architecture OF ANN by adding extra hidden layer, or changing the activation function, or by increasing the number of training cycles and train ANN again.

The following matlab code was written and it will be used for results analysis:

```
data1=[9.5013    1.0420   20.9530    7.4483    2.6723
    2.3114    6.3516    0.4910   13.4965   47.9811
    6.0684   14.6370   17.0319   12.3244   42.4357
    4.8598    0.1775    9.4870    9.6737   16.0143
    8.9130    2.5000   20.7949   12.2696   17.6822
    7.6210    3.6498   12.5703    9.9034   24.1682
    4.5647    3.5770   17.7368    5.1296   -3.2457
    0.1850   10.8683   10.7223    4.3459   11.6848
    8.2141    4.8994    7.6154    5.1179   22.8606
    4.4470    3.5787    4.7413    8.0112   25.0954
    6.1543    0.2749    4.8358   10.9067   29.5693
    7.9194   13.4421   17.0556    4.6394   22.9603
    9.2181    8.0117    7.5691   12.5774   51.3082
    7.3821   16.7727   13.5418    8.5211   44.6495
    1.7627    8.3879    3.7718    5.5562   24.2679
    4.0571    7.5357   17.4475   10.5411   18.7305
    9.3547   15.2320    9.4593    8.1986   51.1746
    9.1690    9.4527   21.5003    6.6732   15.8608
    4.1027    3.6477   21.3414   10.4185    4.4845
    8.9365   12.0985   14.8391    9.3197   38.4905]';
data=data1/20;
```

```
target=[ 2.6723
   47.9811
   42.4357
   16.0143
   17.6822
   24.1682
   -3.2457
   11.6848
   22.8606
   25.0954
   29.5693
   22.9603
   51.3082
   44.6495
   24.2679
   18.7305
   51.1746
   15.8608
    4.4845
   38.4905]';
```

```
imagerec=newcf(minmax(data),[4 1],{'logsig','purelin'});

imagerec=init(imagerec);
imagerec.trainParam.goal=0;
imagerec.trainParam.epochs=800;
imagerec.trainParam.lr=0.001;
imagerec=train(imagerec,data,target);
a=sim(imagerec,data);
MSE = mean((target - a).^2)
```

The above code was implemented varying ANN type, by replacing newcf to newff to use FFANN and to newelm to use EANN. Figure 9 shows the obtained results using CFANN; figure 10 shows the obtained results using CFANN, while figure 11 shows the obtained results using EANN.

X1	X2	X3	X4	Target	ANN output
9.5013	1.0420	20.9530	7.4483	2.6723	2.6723
2.3114	6.3516	0.4910	13.4965	47.9811	47.9811
6.0684	14.6370	17.0319	12.3244	42.4357	42.4357
4.8598	0.1775	9.4870	9.6737	16.0143	16.0143
8.9130	2.5000	20.7949	12.2696	17.6822	17.6822
7.6210	3.6498	12.5703	9.9034	24.1682	24.1682
4.5647	3.5770	17.7368	5.1296	-3.2457	-3.2457
0.1850	10.8683	10.7223	4.3459	11.6848	11.6848
8.2141	4.8994	7.6154	5.1179	22.8606	22.8606
4.4470	3.5787	4.7413	8.0112	25.0954	25.0954
6.1543	0.2749	4.8358	10.9067	29.5693	29.5693
7.9194	13.4421	17.0556	4.6394	22.9603	22.9603
9.2181	8.0117	7.5691	12.5774	51.3082	51.3082
7.3821	16.7727	13.5418	8.5211	44.6495	44.6495
1.7627	8.3879	3.7718	5.5562	24.2679	24.2679
4.0571	7.5357	17.4475	10.5411	18.7305	18.7305
9.3547	15.2320	9.4593	8.1986	51.1746	51.1746
9.1690	9.4527	21.5003	6.6732	15.8608	15.8608
4.1027	3.6477	21.3414	10.4185	4.4845	4.4845
8.9365	12.0985	14.8391	9.3197	38.4905	38.4905

MSE = 2.7103e-18

Figure 9: Obtained results using CFANN

X1	X2	X3	X4	Y	out
9.5013	1.0420	20.9530	7.4483	2.6723	2.6725
2.3114	6.3516	0.4910	13.4965	47.9811	47.9819
6.0684	14.6370	17.0319	12.3244	42.4357	42.4383
4.8598	0.1775	9.4870	9.6737	16.0143	16.0121
8.9130	2.5000	20.7949	12.2696	17.6822	17.6812
7.6210	3.6498	12.5703	9.9034	24.1682	24.1681
4.5647	3.5770	17.7368	5.1296	-3.2457	-3.2424
0.1850	10.8683	10.7223	4.3459	11.6848	11.6830
8.2141	4.8994	7.6154	5.1179	22.8606	22.8607
4.4470	3.5787	4.7413	8.0112	25.0954	25.0955
6.1543	0.2749	4.8358	10.9067	29.5693	29.5719
7.9194	13.4421	17.0556	4.6394	22.9603	22.9602
9.2181	8.0117	7.5691	12.5774	51.3082	51.3063
7.3821	16.7727	13.5418	8.5211	44.6495	44.6502
1.7627	8.3879	3.7718	5.5562	24.2679	24.2681
4.0571	7.5357	17.4475	10.5411	18.7305	18.7289
9.3547	15.2320	9.4593	8.1986	51.1746	51.1713
9.1690	9.4527	21.5003	6.6732	15.8608	15.8609
4.1027	3.6477	21.3414	10.4185	4.4845	4.4831
8.9365	12.0985	14.8391	9.3197	38.4905	38.4929

MSE = 2.9531e-06

Figure 10: Obtained results using FFANN

X1	X2	X3	X4	Y	out
9.5013	1.0420	20.9530	7.4483	2.6723	2.2015
2.3114	6.3516	0.4910	13.4965	47.9811	48.0051
6.0684	14.6370	17.0319	12.3244	42.4357	42.3378
4.8598	0.1775	9.4870	9.6737	16.0143	16.3302
8.9130	2.5000	20.7949	12.2696	17.6822	17.7860
7.6210	3.6498	12.5703	9.9034	24.1682	23.7562
4.5647	3.5770	17.7368	5.1296	-3.2457	-2.5896
0.1850	10.8683	10.7223	4.3459	11.6848	11.4730
8.2141	4.8994	7.6154	5.1179	22.8606	22.7684
4.4470	3.5787	4.7413	8.0112	25.0954	24.9651
6.1543	0.2749	4.8358	10.9067	29.5693	30.0648
7.9194	13.4421	17.0556	4.6394	22.9603	23.2030
9.2181	8.0117	7.5691	12.5774	51.3082	51.2130
7.3821	16.7727	13.5418	8.5211	44.6495	44.9428
1.7627	8.3879	3.7718	5.5562	24.2679	24.2211
4.0571	7.5357	17.4475	10.5411	18.7305	18.3630
9.3547	15.2320	9.4593	8.1986	51.1746	50.8868
9.1690	9.4527	21.5003	6.6732	15.8608	16.2745
4.1027	3.6477	21.3414	10.4185	4.4845	4.5971
8.9365	12.0985	14.8391	9.3197	38.4905	38.4015

MSE = 0.0912

Figure 11: Figure 10: Obtained results using EANN

From the obtained results we can see that using CFANN gave the best results by minimizing the value of MSE, and the tools sorted according to the accuracy will be as follows:

- CFANN
- Regression method
- FFANN
- EANN

And here we can highly recommend CFANN to be used as a computational tool to find the relationship between any measured experimental data.

Conclusion

A measured experimental data was collected and the relationship between the independent variables and the dependent ones was obtained using regression model. The results of the regression model were good and the can be acceptable.

An experiments were done to see whether we can enhance the accuracy of the regression model. Different computational tools using ANN were built and tested. It was shown that using cascade-forward ANN as a computational tool gave an excellent enhancement, thus it can be highly recommended.

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