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Vehicles Classification Using the HRBF Neural Network

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The paper presents the problem of using a neural network for military vehicle classification on the basis of ground vibration. One of the main elements of the system is a unit called the geophone. This unit allows to measure the amplitude of ground vibration in each direction for a certain period of time. The value of the amplitude is used to fix the characteristic frequencies of each vehicle. If we want to fix the main frequency it is necessary to use the Fourier transform. In this case the fast Fourier transform FFT was used. Since the neural network (Hyper Radial Basis Function network) was used, a learning set has to be prepared.
Please find the attached results of using the HRBF neural network, which include: examples of learning, validation and test sets, the structure of the networks and the learning algorithm, learning and testing results.

Keywords: neural networks, classification, learning set.

1. Introduction

The main area of the interest of scientists is the decision system automation. The results are usually used in industry or military systems.

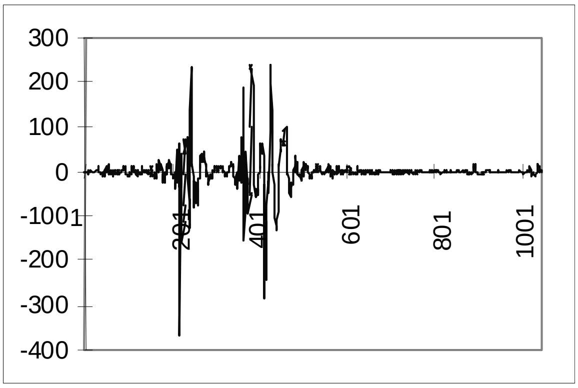
In this case the neural network was used as an element of the decision subsystem. The inputs of the network are calculated as characteristic values of the object. These values are the base of the classification. The output values are the answer of the network. Because of the local representation (of the output values) each of the outputs is connected to one type of the object (one vehicle).

The main problem was to choose the correct characteristics values on the base of ground vibration. The values of the ground vibration amplitude were obtained by using a geophone. Figure 1 shows the example of the measurements.

2. The Ground Vibration Analysis Caused by Vehicles

It is possible to measure the amplitude of ground vibration for each vehicle. In this case 6 vehicles were chosen: Kraz, Jelcz, Skot, Tatra, Volvo, Land Rover. The measurements were performed at different vehicle speeds, different types of ground and obstacles.

There were two possible ways of signal analysis. The first case − analysis of the signal amplitude (for a certain period of time), the second case − analysis of an amplitude signal transformation. In this paper the Fast Fourier Transform was used (using the Cooley-Tukey algorithm).



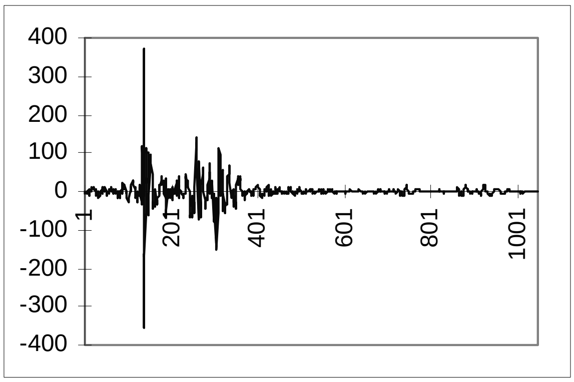


Fig. 1. Examples of measurements for Kraz (speed 25km/h and 35km/h)

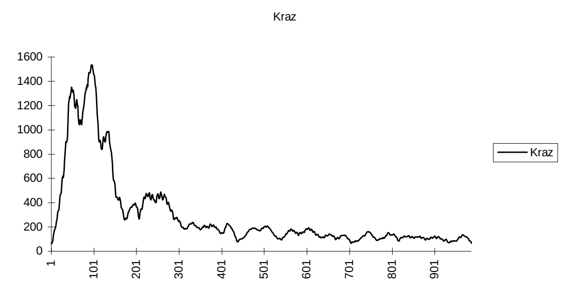


Fig. 2. Example of measurements for Kraz – FFT transform

Each vehicle has its characteristic frequencies, because of the front and rare axle vibration and car body vibration.

The whole FFT is too big to be ”included” into the learning process and validation set. As a result of the analysis three parameters were fixed. The first parameter was the value of the frequency of the biggest FFT amplitude, the second was the value of the biggest FFT amplitude and the last one was the number of the vehicle axle. The vehicle axle number is evaluated on the basis of the value of the ground vibration amplitude.

3. The Radial Base Function Neural Network for Objects Classification

The neuron with the radial base transfer function is the main element of the RBF (Radial Base Function) neural network.

$$\varphi(r) = e^{-\frac{r^2}{2\sigma^2}} \quad (1)$$

where: σ – parameter of transfer function (σ>0).

The next equation shows the example of *r* parameter:

$$r = \| x - t \| \quad (2)$$

where: *x* – input signals, *t* – centres of transfer function.

As we can see, the value on the output of the radial neuron depends directly on its value on the inputs as well as the value of the centres t_i. For each input of the neuron the differences between the input values and centres are calculated. These differences are the argument of the transfer function (radial function). According to the above equation the radial neuron ”is activated“ only for a limited range of value (x_i-t_i). The specific functioning of the whole Radial Base Function network is the result of the features.

There are also similar transfer functions used in RBF neurons:

$$\varphi(x) = \frac{1}{\sqrt{(x-t)^2 + \sigma^2}} \quad (3)$$

$$\varphi(x) = \sqrt{(x-t)^2 + \sigma^2} \quad (4)$$

$$\varphi(x) = r^{2n+1} n = 0,1,2,\ldots. \quad (5)$$

The radial neurons are located in the hidden layer of the network. The output values of the hidden layer are put (in the simplest case) into the inputs of the single output.

The radial function depends on the value $r = \|x - t\|$. The value of *r* is usually calculated using the Euclidean norm. In more complex models of RBF neural networks (HRBF neural network) the weighted norm is applied. It means that value r_i (see fig. 3) is multiplied (for each direction) by the value Q_i:

$$r_i^Q = Q_i (x - t_i) \quad (6)$$

The values of Q_i are evaluated during the learning process of the neural network.

$$Q = [Q_1, Q_2, \ldots, Q_i, \ldots, Q_n] \quad (7)$$

Figure 3 shows the model of the HRBF neural network.

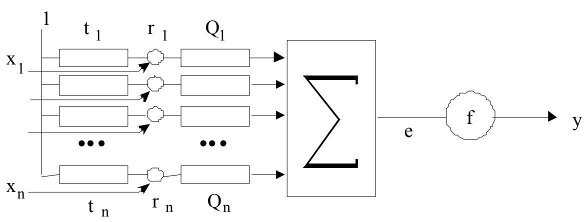


Fig. 3. Model of the neuron of the HRBF neural network

The structure of the HRBF neural network consists of neurons as above (see fig. 4.).

The output layer consists of neurons with a sigmoid transfer function. It means that the values on the outputs of the network belong to the range (0,1). The number of neural network inputs (n) depends on the size of the analyzed space (Rn). The number of radial neurons in the hidden layer is evaluated during the learning process of the network. The number of output neurons is connected to the number of different classes (number of object types).

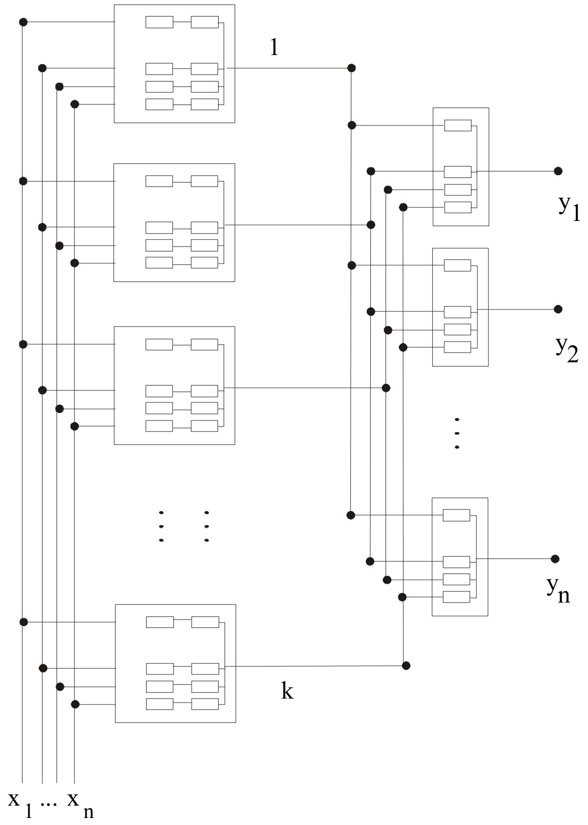


Fig. 4. Model of the HRBF neural network

The Learning Algorithm

During the experiments the supervised type of learning algorithm was applied (with gradient method). The main element of the algorithm – the criterion function is fixed on the basis of the RBF neural network structure. The criterion function is directly connected to the optimization method, as shown (for the network with one output neuron):

$$E = \frac{1}{2}\sum_{i=0}^{K}[W_i \varphi_i(x) - d]^2 \qquad (8)$$

where:

W_i – values of output neuron weights,

d – required value on the output of the neural network,

K – number of radial neurons in hidden layer,

x – values of network inputs.

The form of the transfer function in the hidden layer is as follows:

$$\varphi_i(x) = e^{-\frac{1}{2}[Q_i(x-t_i)]^T[Q_i(x-t_i)]} \qquad (9)$$

In each step of the learning algorithm the new values of the output neuron weights and values of t and Q are calculated.

4. The Experiments and Results

The Structure of Learning, Testing and Validation Sets

Because of the learning process difficulties the values of characteristics parameters were changed in the learning, testing and validation sets. The values of the biggest amplitude (1st parameter) were divided 100 times and the number of axles were multiplied 10 times.

The part of the learning set[1] presented in the paper is shown below as an example. The three (left) columns are the values of the characteristic parameter. The next 6 columns describe the required values on the HRBF network outputs.

```
; RWR-RBF.EXE
; Learning data
; DATASTRUCTURE=<Column
description>
PAIRS=(224)
DATACOLUMN[ 1]=INPUT
DATACOLUMN[ 2]=INPUT
DATACOLUMN[ 3]=INPUT
DATACOLUMN[ 4]=INPUT
DATACOLUMN[ 5]=INPUT

           . . .
DATACOLUMN[ 9]=OUTPUT

LEARN DATA
8.05  16.77 30  1  0  0  0  0  0
9.22  19.03 30  1  0  0  0  0  0
6.83  18.76 30  1  0  0  0  0  0
6.83  21.01 30  1  0  0  0  0  0
8.54  19.17 30  1  0  0  0  0  0
```

The whole learning set consists of 224 elements with 6 types of wheeled vehicles.

The structure of the testing and validation set is similar to the learning set. The testing set consists example of considered six types of vehicle. The testing set consists of all elements from the learning set and additional examples for each kind of vehicle.

Structure of the HRBF Neural Network

The structure of the network is the result of the task presented in this paper. The number of hidden neurons was evaluated during the learning of the network. The description of the HRBF is presented below[2]:

```
;RBF Network struc. RWR-RBF.EXE
;(C)Roman WANTOCH-REKOWSKI, 2010
```

[1] It is the *vehicle.lrn* file contents.

[2] It is the *vehicle.str* file contents.

```
LAYER INPUT NODES=<3>

LAYER HIDDEN NODES=< 16>
FUNCTION=GAUSS(1.00)

LAYER OUTPUT NODES=< 6>
FUNCTION=SIGMOID(0.90)
```

RBF Neural Network Learning

The presented learning algorithm (gradient method) was used to learn the neural network. The value of the learning coefficient was calculated during the learning process. The initial value of the learning coefficient was the biggest while the final value the lowest. Parameters of the RBF network are included in the *vehicle.net* file.

```
Network parameters RWR-RBF.EXE
;RBF neural network parameters
;The name of the file with the
neural network structure
(*.STRucture)

STRUCTURESET=pojazdy.str

; The name of the file with
learn data (*.LeaRN)
LEARNINGSET=pojazdy.lrn

; The name of the file with
validat data  (*.VALidation)
VALIDATIONSET=pojazdy.val

; The name of the file with test
data (*.TeST)
TESTINGSET=pojazdy.tst

; The name of the file with
learning results (*.Learn
REsults)
LEARNINGRESULTSET=pojazdy.lre

; The name of the file with the
testing results (*.Test REsults)
TESTINGRESULTSET=pojazdy.tre

; The name of the file with
network weights (*.WEIghts)
WEIGHTSET=pojazdy.wei

; Type of gradient method
WEIGHTCHANGEMETHOD=NAJWIEKSZYSPA
DEK | MOMENTUM |
WEIGHTCHANGEMETHOD=NAJWIEKSZYSPA
DK
;MOMENTUM(0.3)

; Kind of learning coefficient
LEARNINGMETHOD=STALY[nCoefficien
t] | ZMIENNY [nCoefficient]|
MINIMALIZACJAKIERUNKOWA |
;
ZLOTYPODZIAL[nWspUczenia]
LEARNINGMETHOD=STALY(0.2)

;Type of weights method
initializing
WEIGHTINIT=ZPRZEDZIALU[nWspInicj
alizacji]|
BOTTOU[nWspInicjalizacji] |
SMIEJA | NGUYENWIDROW
WEIGHTINIT=ZPRZEDZIALU(0.9)

;Type of method of radial
function centres initializing
;ZPRZEDZIALU(10)
;<YES> or <NO> change the number
of radial neurons during the
learning process

RBFINIT=DOBIERZ(20,-0.1)
RBFNEURONSCHANGE=(5,50) <NO>

;Type of Q matrix coefficient
method initializing
;DIAGONALSTALA(3)
;DIAGONALLOSOWA(5)

COEFMATRIXQ=DIAGONALSTALA(0.5,-
0.01)

;The number of learning elements
added into a learning set
ADDPERCENTOFNOISEELEMENTS=nEleme
ntowDoZaszumienia,nProcentZaszum
ieni

ADDPERCENTOFNOISEELEMENTS=(0,0)

; Stop condition - network error

ERRCONDITIONSTOP=(0.00001)

; Stop condition - max number of
learning epoch

EPOKCONDITIONSTOP=(500)

; Stop condition -  percent of
recognized elements of the
learning set

LEARNSETCONDITIONSTOP=(100)
```

```
;Stop condition -  percent of
recognized elements of the
validation set

VALIDSETCONDITIONSTOP=(100)

;Coefficient of recognition

RECOGNITIONPRECITION=(0.3)

JOGOFWEIGHTS=nLiczbaJOGOFWEIGHTS
,nProcentJOGOFWEIGHTS

JOGOFWEIGHTS=(0,0)

; Mix the learning set
MIXLEARNSET=YES
```

The file presented below (it is the *vehicle.lre* file contents) shows an example of learning process for the RBF neural network using the learning set from the file *vehicle.lrn*.

```
; Result data RWR-RBF.EXE
;(C)Roman WANTOCH-REKOWSKI, 2010

 Epoka  %CU   %CW   Net Err Lrn-cof.  Max-gr. Ukr.

 1    0.0    0 0.14 0.92 |0.01| 16
 2    7.6   16 0.05 0.95 |0.01| 16
 3   53.6   50 0.03 0.98 |0.01| 16
 4   82.1   66 0.02 1.01 |0.06| 16
 5   96.9 100 0.00 1.04 |0.01| 16
 6   99.1 100 0.00 1.07 |0.00| 16
 7   99.6 100 0.00 1.17 |0.01| 16
 8  100.0 100 0.00 1.20 |0.00| 16
```

where:

EPOKA – the number of learning epoch
% CU – the percent of correctly recognized elements of the learning set (*.lrn)
% CW – the percent of correctly recognized elements of the validation set (*.val)
Net Err. – the network error value
Lrn-cof. – the value of the learning coefficient
Max-gr. – the largest value of the network gradient
Ukr – number of hidden (radial) neurons.

The description of the RBF neural network structure is included in the *vehicle.str* file.

```
;Network structure RWR-RBF.EXE
;(C)Roman WANTOCH-REKOWSKI, 2010

LAYER INPUT  NODES=<128>

LAYER HIDDEN NODES=<10>
FUNCTION=GAUSS(1.00)

LAYER OUTPUT NODES=<14>
FUNCTION=SIGMOID(0.90)
```

The file consists of a layer description: input layer, hidden layer and output layer. The number of nodes in the input layer means the number of inputs of the network. The number of nodes in the output layer means the number of outputs of the network.

5. Conclusions

The experiments show that the RBF neural network can be used for vehicles classification based on ground vibration. The main problem was to fix the correct characteristic parameter of the FFT.

6. Bibliography

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Klasyfikacja pojazdów z wykorzystaniem sieci neuronowej HRBF

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W opracowaniu przedstawiono zagadnienie wykorzystania sieci neuronowej do klasyfikacji określonych typów pojazdów na podstawie analizy amplitudy drgań gruntu. Jednym z elementów systemu do pomiaru amplitudy drgań gruntu jest geofon. Umożliwia on pomiar amplitudy drgań gruntu w wybranym kierunku dla określonego przedziału czasu. Wartość wyznaczonej amplitudy wykorzystywana jest do wyznaczenia charakterystycznych częstotliwości drgań dla poszczególnych pojazdów. Do wyznaczenia charakterystycznych częstotliwości wykorzystywana jest transformata Fouriera FFT. Do klasyfikacji wykorzystana została sieć neuronowa z radialną funkcją aktywacji, dlatego też wymagane jest przygotowanie odpowiedniego zbioru uczącego. W opracowaniu przedstawiono wyniki użycia sieci HRBF. Przedstawiono strukturę oraz zawartość zbioru uczącego.

Słowa kluczowe: sieci neuronowe, klasyfikacja, zbiór uczący.