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Connectionist Expert System to Diagnose Neck and Arm Pain

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ABSTRACT

A connectionist expert system (CES) called BIONET aimed at assisting physicians in the diagnosis of diseases, such as neck and arm pain has been proposed. BIONET is an artificial network or connectionist network model capable of classifying diseases. Need for the development of CES for defence personnel has been discussed. BIONET is a feedforward three layer neural network with one hidden layer. The input layer has been designated as stimulus layer, the hidden layer as receptor layer and output layer as cortical layer. The sequential connections with spatial orientation have been maintained between stimulus layer and receptor layer for each specific factor. Parallel connections are established only at the cortical layer. Direct firing and facilitatory and inhibitory mechanisms are adhered to the neurophysiology of human nervous system. An algorithm for training on BIONET is also given. BIONET is simulated on a digital computer with training samples of patients collected from various hospitals in Tamil Nadu to diagnose neck and arm pain diseases for testing purpose.

1. INTRODUCTION

Computers excel human beings in numerical computation. Human beings perform recognition of patterns effortlessly under a wide range of conditions and even in the presence of noise or distortion. Neural network applications reflect a non-algorithmic black-box strategy, which is trainable. It is possible to train a neural network in such a way that it learns the correct response of output for each training sample[1]. This is particularly useful in pattern recognition. Diagnosis of the diseases may be viewed as a pattern recognition problem which performs the pattern classification task.

Computer technology has its impact on the practice of medicine in dramatic ways. On analysing recent developments in medical computer science, sophisticated equipment have been used to develop new methods for computer-aided diagnosis in clinical practice[2].

2. BIONET FOR DEFENCE PERSONNEL

BIONET, a connectionist expert system (CES), is an artificial neural network model designed for diagnosing diseases. For defence personnel, it is necessary to maintain periodic records of physiological parameters to ascertain their physical fitness, apart from diagnosing the disease whenever they are ill. BIONET can be used for the defence personnel by having it in the Biomedical Engineering Department. Even though a number of expert systems[3] are available for periodic check-up for neurologic fitness, soundness of mind and eyesight, this CES will be quite useful, where experts are not available for neck and arm pain. Due to ageing factor, almost everybody suffers from neck and arm pain. Because of the increased use of automobiles, even the youngsters are suffering from this disease.

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3. DIAGNOSIS OF NECK & ARM PAIN

The neck and arm pain infers a wide spectrum of illness which could result from simple pain to disability paralysis of both arms and legs[4-6]. As such, no work on neck and arm pain has been reported in the literature so far[2,7]. Most of the patients who suffer from neck and arm pain have an uncomplicated cause for their pain which may result due to diseases like cervical spondylosis or collagen disorder. A small number of patients have infections of cervical spine (caries spine) or have life-threatening diseases like tumors of cervical spine (malignancy) which are uncommon sources of neck and arm pain. But they require timely recognition and immediate treatment. Hence, the common diseases like cervical spondylosis, collagen disorder and rare diseases like caries spine and malignancy are included in the diagnosis of diseases causing neck and arm pain. This project has been taken up to diagnose neck and arm pain with four diseases, viz., cervical spondylosis, collagen disorder, caries spine (tuberculosis of the cervical spine) and malignancy.

The diagnoses of neck and arm pain diseases are made by conducting the following examinations of the patients:

- General examination
- Regional examination
- Neurological examination
- Vascular examination
- Examination of cardiovascular system
- Examination of respiratory system
- Abdomen examination
- Haematological examination
- Radiological examination/computerised tomography (CT) scan
- Mantoux test (Mx-test).

General examination include testing for anemia, jaundice, cyanosis, blood pressure, lymphadenopathy, oedema of legs, etc. Regional examination include neck examination, palpation of the spinous process and movement of joints. In neurological examination, myotome, sensation, reflex, bladder and bowel tests are carried out. In vascular examination, tests for rombergism, tandem walking, etc. are made. Cardiovascular system is examined by pulse rate and blood pressure. Respiratory rate is examined in the respiratory system examination. Abdomen is tested in abdominal examination. Haematological examination include erythrocyte sedimentation rate (ESR), blood sugar level and rheumatoid arthritis test (RAT). In radiological examination, the X-ray of cervical spine, bone density, disc space narrowing and erosion, intervertical foramen, etc. are examined. CT scans are useful in getting a clear picture about the radiological examination. Mx-test is helpful in finding the infection of spine. In addition, psychogenic pain disorders are tested and psychological factors are considered. These examinations are carried out systematically to diagnose the disease. The signs and symptoms involved in these examinations are enormous. There is a chance of missing some signs and symptoms which may lead to wrong diagnosis, or missing a disease when a patient suffers from more than one disease. Hence, all the signs and symptoms are evaluated carefully from the patients' history. In consultation with the medical experts, the signs and symptoms for the diseases resulting in neck and arm pain have been derived[8] conclusively by radiology, pathology and serology, based on clinical records of 521 patients who have complaint of neck and arm pain (Table 1).

Artificial neural network has been more powerful than a traditional expert system in the diagnosis of diseases[9-11]. Multilayer feedforward neural network is useful for pattern classification problems[12]. For the diagnosis of cervical spondylosis with the combination of four diseases, viz., radiculopathy, myelopathy, dysphagia, and vertebro basilar insufficiency (VBI) using multilayer feedforward network with back propagation learning law, the convergence is very slow[13]. Because of the slower convergence of result and the difficulty in fixing hidden units, a new neural network model BIONET is proposed to overcome these difficulties. BIONET is developed based on the neurophysiology of human nervous system.

4. HUMAN NERVOUS SYSTEM

Human brain has more than 100 billion neurons with its precise interconnection and neurotransmission occurs by marvelous biochemical factory[14]. Each specific nerve fibre transmits only one modality of sensation[15]. An important feature of human nervous system is its spatial orientation with equal number of receptors in the peripheral areas and corresponding areas in the brain. After receiving impulses from respective receptors, the information is processed by

Table 1. Signs and symptoms of neck and arm pain

Factors	Cervical spondylosis	Collagen disorder	Caries spine	Malignancy
Neck pain on activity	0.5 F	0.25 F	0.5 F	0.5 F
Neck pain on automobile travel	0.5 F	—	0.5 F	0.5 F
Neck pain on lifting strain	0.5 F	0.25 F	0.5 F	0.5 F
Resting pain/discomfort	0.25 F	0.25 F	0.5 F	1.0 F
Neck pain in early morning	-0.5 I	2.0 F	-0.5 I	-0.5 I
Worsening of pain during night	-0.5 I	-0.5 I	2.0 F	2.0 F
Stiffness after early morning and rest exceeding 30 min.	-0.5 I	2.0 F	-0.5 I	-0.5 I
Persistent stiffness	0.25 F	1.0 F	1.0 F	1.0 F
Slow onset	0.5 F	0.5 F	1.0 F	1.0 F
No progression	1.0 F	—	-0.5 I	-0.5 I
Slow progression	0.5 F	0.5 F	1.0 F	1.0 F
Relapse and remission	-0.5 I	2.0 F	-0.5 I	-0.5 I
No constitutional symptoms	2.0 F	—	—	—
Constitutional symptoms present	-0.5 I	0.5 F	2.0 F	0.5 F
Well-nourished	1.0 F	0.5 F	0.25 F	-0.5 I
Ill-nourished	-0.5 I	-0.5 I	1.0 F	1.0 F
Cachexia	-0.5 I	-0.5 I	—	2.0 F
Spinal tenderness	0.5 F	0.5 F	1.0 F	1.0 F
No spinal tenderness	0.25 F	—	-0.5 I	-0.5 I
No restriction of range of movement (ROM)	0.25 F	-0.5 I	-0.5 I	-0.5 I
Partial restriction of ROM	0.25 F	-0.5 F	-0.5 F	-0.5 F
Total restriction of ROM	0.25 I	-1.0 F	-1.0 F	-1.0 F
Trapezius tenderness present	1.0 F	0.5 F	0.25 F	0.25 F
Trapezius tenderness absent	-0.5 I	—	—	—
Associated pain and swelling of smaller joints	-0.5 I	2.0 F	-0.5 I	0.5 I
Bambooing	2.0 F	—	—	—
ESR normal	1.0 F	—	—	—
ESR high	-0.5 I	1.0 F	1.0 F	1.0 F
RA positive (+)	-0.5 I	1.0 F	-0.5 I	-0.5 I
Mantoux test positive (+)	-0.5 I	-0.5 I	2.0 F	-0.5 I
Alkaline phosphatase high	-0.5 I	-0.5 I	-0.5 I	1.0 F
Bence Jone's test postive (+)	-0.5 I	-0.5 I	-0.5 I	D
EPP abnormal	-0.5 I	-0.5 I	-0.5 I	D
Disc narrowing	1.0 F	-0.5 I	1.0 F	-0.5 I
Osteophyte positive (+)	1.0 F	—	—	—
No osteophyte	-0.5 I	—	—	—
IVF narrow	1.0 F	—	—	—
IVF widening	-0.5 I	-0.5 I	-0.5 I	2.0 F
Osteolytic lesion	-0.5 I	-0.5 I	1.0 F	1.0 F
Prevertebral shadow positive (+)	-0.5 I	-0.5 I	2.0 F	—
Atlanto subluxation positive (+)	-0.5 I	2.0 F	—	—
Ankylosis of spine	-0.5 I	2.0 F	-0.5 I	-0.5 I
Osteolytic lesion with disc narrowing	—	—	D	—
Osteolytic lesion with cold abcess	—	—	D	—
Sparing of disc with osteolytic lesion	—	—	—	D

F - Facilitation I - Inhibition D - Direct firing
Numeric values represent weight values.

the association areas of the brain in addition to the primary areas of the brain. Only extensive parallel connections are used in human brain.

Another unique feature of human nervous system is functioning by the mechanism of direct firing, facilitatory firing and inhibitory firing of neurons. When the impulse firing reaches the threshold value, it directly excites the corresponding neuron but when it is inadequate, it needs to be facilitated by the adjoining neurons[15].

Conceiving the above facts, a CES with the following features has been designed:

- The sequential connections with spatial orientation have been maintained for each specific factor.
- Parallelism is established only at the output layer.
- Direct firing, facilitatory and inhibitory mechanisms are incorporated based on the neurophysiology of human nervous system.

5. MULTILAYER FEEDFORWARD NETWORK

The basic building block of neural network may be one of the following models:

(a) McCulloch-Pitts model
(b) Perceptron
(c) Adaline (adaptive linear element)

Artificial neural networks (ANN) accomplish pattern recognition task only when the processing units are organised in a proper way. Normally, ANNs are arranged in layers of processing units. There are four types of ANNs[16]:

(a) Feedforward
(b) Feedback or recurrent
(c) Combination of (a) and (b)
(d) Lattice structures.

The simplest feedforward network is a two-layer network with N input units in input layer and M output units in output layer. Each input unit is connected to each of the output units. Each connection is associated with a weight representing the synaptic strength. A multilayer feedforward neural network consists of multiple layers of units, each layer feeding input to the subsequent layer in a feedforward manner through a set of connection weights. The layers between the input and output layers are called hidden layers. Feedforward networks are used for pattern classification.

Feedback network neurons have feedback connections with other neurons or with itself. These networks are used for pattern storage. The combination of the first two types of networks are used for pattern clustering. A lattice structure consists of one-dimensional or multidimensional array of neurons. A lattice network is really a feedforward network with the output neurons arranged in rows or columns.

Multilayer feedforward neural networks are normally used for implementing pattern classification function. According to Kolmogorov's theorem, any continuous function can be implemented exactly by a three-layer feedforward neural network having n neurons in the input layer, $(2n+1)$ neurons in the middle layer and m neurons in the output layer[17].

More complex neural networks generally offer greater computational capabilities. Arranging neurons in layers duplicate the layered structure of certain portions of the brain. These multilayer networks have capabilities beyond those of a single layer[18]. Any continuous mapping can be approximately realised by multilayer neural networks with at least one hidden layer whose output functions are sigmoid functions[19,20]. Also, multilayer feedforward networks are a class of universal approximators[21,22] but the theorems of universal approximators do not suggest any method to determine the number of hidden units and weights to achieve a given accuracy for approximation of the function. These are the difficulties with multilayer feedforward network, and to overcome these difficulties, BIONET has been designed with known number of hidden units and prior knowledge of weight fixed by the medical expert.

6. BIONET

BIONET is a multilayer feedforward neural network model based on the following neurophysiological features of human nervous system:

6.1 Frequency Coding

On receipt of the input stimuli, the receptors generate receptor potential which is converted to action potential or nerve impulse. All nerve impulses have equal amplitudes. The information they carry is represented by the number of impulses generated per unit time. This is known as frequency coding[23]. This is one of the neural codings which codes the sensory events into impulse patterns[24]. The hidden layer gives the frequency code as the output in BIONET.

6.2 Spatial Orientation

Individual modality of sensation is transmitted along the specific tract. This is called spatial orientation. Each modality of sensation is received by a specific receptor, transmitted along a specific nerve

and reaches its destination. Initial connections are made between the input layer and the subsequent layer following spatial orientation in BIONET.

6.3 Connectivity

Between the receptor and the brain, the neurons are sequentially connected by synapses to transmit impulses to the corresponding areas of the brain. Parallel connections are made in the cortical layer. In BIONET, parallel connections are made between the hidden layer and the output layer.

The architecture of BIONET has been presented in Fig. 1. It is a feedforward three-layer network with one hidden layer. The input layer has been designated as stimulus layer, the hidden layer as receptor layer and the output layer as cortical layer. The stimulus layer is presented with the inputs. The hidden layer consists of four groups of neurons for classifying four patterns. Each group consists of neurons equal to the number of contributing factors fixed by the medical expert for that particular pattern. The synaptic strengths of links or weights connecting receptor layer are fixed by the medical expert based on the objective criteria given in Appendix A. The output of each neuron in receptor layer is calculated by multiplying input X from stimulus layer with the respective weight, W in that link.

From the receptor layer all the neurons in each group are connected to the respective neuron in the cortical layer for classification. The links from the contributing factors for a disease are considered as facilitatory links. In addition, each neuron in cortical layer receives inhibitory inputs from the other groups of neurons. The presence of certain factors which are available in other groups reduce the possibility of a disease. Such factors are considered as inhibitory factors. These inhibitory type of neurons have been decided based on the existing literature by the medical experts. Hence, each neuron in cortical layer receives both facilitatory and inhibitory inputs. The weights for all the facilitatory neurons have been fixed as 0.5 and –0.5 for all the inhibitory neurons. This architecture of BIONET represents the patterns for classification.

7. TRAINING ALGORITHM FOR BIONET

Step 1 Give the input vector, X to the stimulus layer. The weight vector, W is fixed by the expert

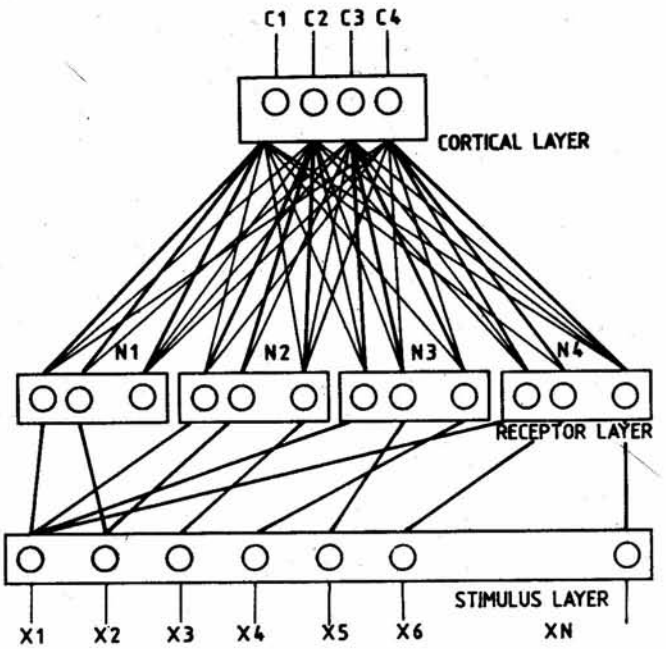

Figure 1. Architecture of BIONET to classify four patterns. X1, X2, X3... XN represent inputs to stimulus layer. N is the number of neurons in the stimulus layer. Ni is the number of neurons facilitating pattern i in the receptor layer for i = 1 to 4 Ci is the output from cortical neuron i for i = 1 to 4. Thick lines represent facilitatory connections and thin lines represent inhibitory connections.

and the weights are assigned to the links connecting receptor layer. Initially, the weights of the facilitatory links connecting cortical layer are uniformly fixed as 0.5 and inhibitory links as – 0.5.

Step 2 Find the output of each neuron in receptor layer

$$u_i = f(x_i * w_i) = 1/(1 + e^{-(x_i * w_i)})$$

where x_i is the input from the ith neuron of stimulus layer and w_i is the fixed weight of the link connecting stimulus layer and receptor layer.

Step 3 Find the sum of weighted inputs in the cortical layer for ith neuron to obtain the output in cortical layer for each training sample of the pattern j.

$$y_i = f(\Sigma_{i = 1 \text{ to } n} u_i v_{ij})$$

where n is the number of neurons contributing to pattern j.

$$= 1/(1 + e^{-(\Sigma u_i v_{ij})})$$

where u_i is the output of ith neuron from receptor layer V_{ij} is the weight linking receptor neuron i and cortical neuron j.

Step 4 Calculate error value and δ value similar to back propagation law[25].

$$\text{Error} = E = \text{Desired output} - \text{actual output}$$

$$= d_i - y_i$$

$$\delta = y_i (1 - y_i) E$$

$$\Delta W_{ij} = \eta \delta_j y_i$$

where η is the training rate coefficient.

The weight at step $(t + 1)$ is given by

change in weight $W_{ij} (t + 1) = W_{ij} (t) + \Delta W_{ij}$

Adjust the weights for the cortical layer using the above formula to minimise the error. No weight adjustment is made in the receptor layer.

Step 5 Repeat steps 2 through 4 for each vector in the training set until the error for the entire set is minimised to the acceptable level.

8. SIMULATION OF BIONET

Methodology of BIONET consists of two phases, viz., training phase and diagnosing phase. BIONET is trained with the training samples and the trained BIONET is used for diagnosis in the diagnosing phase. Training samples are the clinical records of patients suffering from neck and arm pain for which the doctor has already diagnosed the diseases. The disease diagnosed is confirmed by observing the recovery of patients from the disease after undergoing the treatment. Thus, the training samples collected for each disease are already diagnosed and confirmed for that disease. Training samples are the inputs to BIONET during training phase. BIONET is trained using these training samples applying the training algorithm given in Section 7. The trained BIONET is used to diagnose diseases of the patients having complaint of neck and arm pain.

The doctor first listens to the complaints of the patients and then examines them. The necessary haematological/radiological examinations are done as per the doctor's advice. This information is input for BIONET. The input is denoted by 1 for the presence of a sign or symptom and denoted by 0 in the absence of it. The signs and symptoms of patients listed in Table 1 are given as inputs to BIONET to be used to diagnose the nature of disease. The validation samples are collected in the same way as training samples and are used to test the BIONET.

9. TEST RESULTS & INFERENCES

For training the BIONET, 100 samples for each disease were collected from the Govt. General Hospital; Chennai Medical College; Institute of Thoracic Medicine; Govt. Hospital, Chetput, Chennai; and Tirunelveli Medical College Hospital, Tirunelveli. Another 50 samples were collected and used as a source of validation. This BIONET has been tested in the Department of Physical Medicine and Rehabilitation, Tirunelveli Medical College Hospital, Tirunelveli.

To compare the results of BIONET, three medical experts did the blind-folded study. In this study, the experts were given the validation samples collected from the hospitals. By seeing the clinical records (samples), the experts diagnosed the diseases. The percentage of correct diagnoses is listed in Table 2.

Only the contributing signs and symptoms yield output in the receptor layer for the respective disease. The cortical layer receives facilitatory inputs from the respective group of neurons in the receptor layer and

Table 2. Diagnosis of diseases

Pattern	Disease	No. of patients	Percentage of correct diagnosis			
			Expert 1	Expert 2	Expert 3	BIONET
Disease 1	Cervical spondylosis	50	98	96	94	94
Disease 2	Collagen disorder	50	100	96	96	96
Disease 3	Caries spine	50	100	96	96	9
Disease 4	Malignancy	50	100	94	92	96
	Overall percentage		99.5	99.5	94.5	96

inhibitory inputs from some of the neurons of other groups in the receptor layer. The number of neurons in the stimulus layer and the cortical layer are 45 and 4, respectively. The proposed BIONET has been implemented using the training algorithm described above. Using this model, the diseases, viz., cervical spondylosis, collagen disorder, caries spine, and malignancy have been classified[26]. A graphical representation of the comparison of diagnosis of BIONET with three medical experts is shown in Fig. 2.

- It can be used as a tutor for the medical students.
- It assists the experts in the diagnosis.
- It increases the productivity of the system because of its fast diagnosis.
- It can be used for defence personnel.

However, BIONET has the following limitations:

- Doctors only can use BIONET because others may not know the signs and symptoms of the disease.

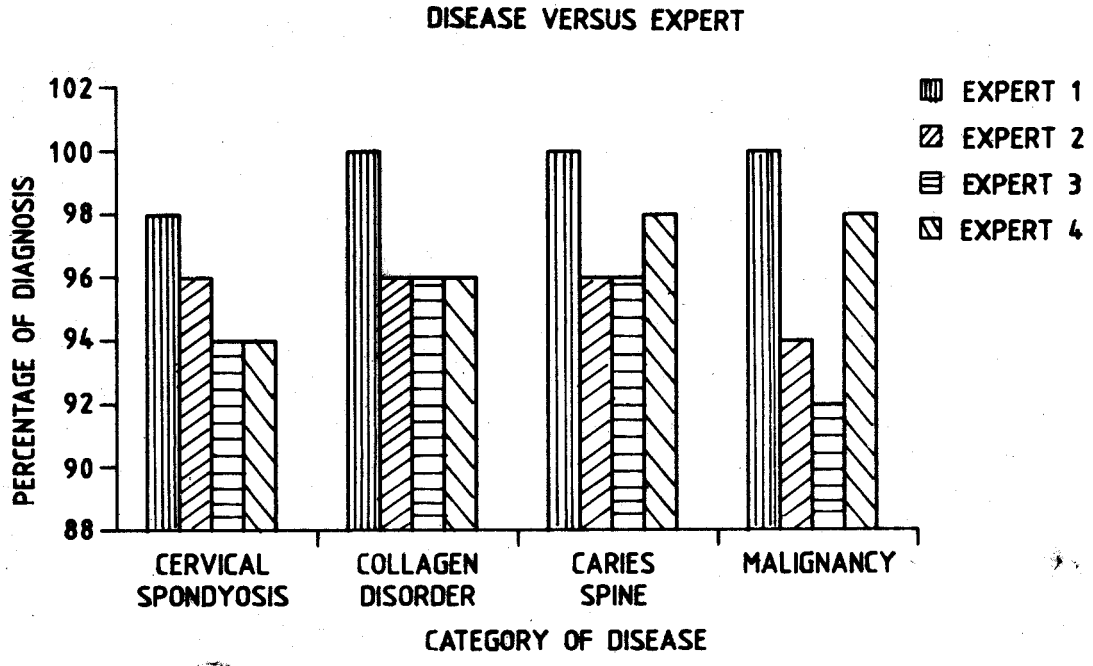

Figure 2. Diagnosis by BIONET in comparison to clinical diagnosis by experts

This project work has been tested in the Department of Physical Medicine and Rehabilitation, Tirunelveli Medical College Hospital, Tirunelveli by implementing the algorithm in C language. The problem discussed above has also been implemented using the existing multilayer feedforward network[27,28]. The result obtained in BIONET is as good as the result obtained using conventional neural networks.

10. FEATURES OF BIONET

The main features of BIONET are:

- Training is very fast compared to conventional neural networks.
- It can be used in Rural Health Care Centres where experts are not available.
- Doctors must be trained to make use of this connectionist expert system.
- Sign or symptom not covered in Table 1 cannot be considered for diagnosis.

11. CONCLUSION

BIONET does not require much time for training like other neural networks. It has been proved to be a successful neural network for the diagnosis of neck and arm pain diseases. The experts feel that the input data covers the necessary details required for diagnosis. They are convinced with BIONET to use it as an assisting tool for diagnosis.

This BIONET has extensibility, which means that more number of diseases can also be diagnosed if the

contributing factors are properly identified and fed into BIONET. It does not impose any restriction on the number of signs and symptoms, whereas in other conventional neural networks the time complexity involved in getting convergence of result is quite high. It may not converge also. Further, BIONET not only assists the medical expert but also helps to educate the medical students about the concept of the systematic approach for diagnosis of diseases. It can be quite useful in remote places where experts are not available. In this way, it can be helpful for defence personnel.

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REFERENCES

1. Wasserman, Philip D. Neural computing: Theory and practice. Van Nostrand Reinhold, New York. 1989. p. 47.
2. Bronzino, Joseph D. The biomedical engineering handbook. CRC Press Inc, USA, 1995. p. 1.
3. Kandasamy, A. & Sukesh Kumar, A. Role of medical expert systems in health care in the Indian context. *Def. Sci. J.*, 1997, **47**(4), 499-503.
4. Ingalhalikar, V.T. Neck pain and related problems. Merck E. Ltd. India. 1994, pp. 11-14.
5. Nakano, Kenneth K. Neck pain. *In* Text book of rheumatology, Ed. 2. Saunders Publications, 1985. pp. 416-35.
6. Ramamurthy, Somayaji. Cervical pain. *In* Practical management of pain year book, edited by Prithivi Raj P. Medical Publishers Inc., 1986. pp. 418-42.
7. Rogers, W. *et al.* Computer-aided medical diagnosis: Literature review. *Int. J. Biomedi. Comput.*, 1979, **10**, 267-89.
8. Thamarai Selvi, S. & Ramar, S. Study of signs and symptoms for neck and arm pain and input design for neural network. UGC Minor Research Project, New Delhi, September 1997. 56 p. Report No. UGC-4 AG-96-15.
9. Kennedy, R.L.; Harrison, R.F. & Burton A.M. An artificial neural network system for diagnosis of acute myocardial infarction in the accident and emergency departments: Evaluation and comparison with serum myoglobin measurements. *Comput. Methods Prog. Biomed.*, 1997, **52**(2), 93-103.
10. Rudzki, K.; Hartleb, M.; Sadowski, T. & Rudzka, J. Focal liver disease: Neural network-aided diagnosis based on clinical and laboratory data. *Gastroenterolclinical Biology*, 1997, **21**(2), 98-102.
11. Zou, Y.; Shen, Y.; Shu, L. & Wang, Y. Artificial neural network to assist psychiatric diagnosis. *Psychiatry*, 1996, **169**(1), 64-67.
12. Richard, Lippmann P. An introduction to computing with neural nets. *IEEE ASSP Mag.*, 1987, **3**(4), 4-22.
13. Thamarai Selvi, S.; Ramar, S. & Arumugam, S. Diagnosis of cervical spondylosis using neural networks. *In* Proceedings of the National Conference on Microcomputer Systems, 18-19 February 1995, Trivandrum Chapter of Computer Society of India, Trivandrum, 1995. pp.1-4.
14. Dalal, P.M. Decade of brain: 2000 AD. *In* Medicine update gold apicon-95, Vol. V, edited by P.S. Shankar. The Association of Physicians of India, 1995. pp. 347-52.
15. Arthur, Guyton C. Text book of medical physiology, Ed. 8. Prism Books (Pvt.) Ltd., Bangalore, 1991. p. 495.
16. Simon, Haykin. Neural networks: A comprehensive foundation. *IEEE Press*, 1992. p. 22.

17. Robert, Hecht-Nielsen. Neurocomputing. Addison-Wesley Publishing Comp., NewYork, 1991. p. 122.

18. Bernard, Widrow & Michael, A. Lehr. 30 Years of adaptive neural networks: Perceptron, madaline and back propagation. *Proceedings IEEE*, September 1990, **78**(9), 1415-42.

19. Funahashi, K. On the approximate realisation of continuous mappings by neural networks. *Neural Networks,* 1989, **2**(3), 183-92.

20. Cybenko, G. Approximation by superpositions of a sigmoidal function. *Math. Control Signals Syst.*,1989, **2**, 303-14.

21. Hornik, K.; Stinchcombe, M. & White, H. Multilayer feedforward networks are universal approximators. *Neural Networks*, 1989, **2**, 359-66.

22. Neil, E. Cotter. The Stone-Weierstrass theorem and its application to neural networks. *IEEE Trans. Neural Netw.,* 1990, **1**, 290-95.

23. Charles, F. Stevens. The neuron. *In* Neuro control systems theory and applications, edited by M.M. Gupta, and D.H. Rao. 1995, pp. 101-11.

24. Mountcastle, Vernon, B. (Ed). Sensory receptors and neural encoding: Introduction to sensory process. *In* Medical physiology, Vol. 1. 1980. pp. 327-47.

25. Rumelheart, D.E.; Hinton, G.E. & Williams, R.J. Learning internal representations by error propagation. *In* Parallel distributed processing: Explorations in the microstructure of cognition, Vol.1, edited by D.E. Rumelhart and J.L. McClelland. MIT Press, Cambridge, 1986. pp. 318-62.

26. Thamarai Selvi, S.; Ramar, S. & Arumugam, S. BIONET. *In* Robotics, vision and parallel processing for industrial automation, edited by P.A. Venkatachalam. Proceedings of the International Conference, 28-30 November 1996, Universiti Sains Malaysia, Perak, Malaysia, 1996. pp. 394-99.

27. Thamarai Selvi, S.; Ramar, S. & Arumugam, S. Connectionist expert system for neck and arm pain diagnosis. *In* Automation, edited by Pradeep K. Chande, A.K. Ramani.; Shubhalaxmi Kher and Nirmal Dagdee. Proceedings of the International Conference, 12-14 December 1995, Shri G. S. Institute of Technology and Science, Indore. Allied Publishers, 1995. pp. 5-7.

28. Thamarai Selvi, S.; Ramar, S. & Arumugam, S. Neck and arm pain evaluation using neural network. *In* Recent trends in applied systems reaserch, edited by P. Radhakrishnan, G. Gurusamy, Proceedings of the Nineteenth National Systems Conference, 14-16 December 1995, PSG College of Technology, Coimbatore, Allied Publishers, 1995. pp. 532-36.

APPENDIX 1

Criteria for Weight Assignment

The weight of each factor has been assigned according to the relative importance of that factor decided by the expert based on the literature. The facilitatory weight values are assumed from 0.25 to 2.0 and the inhibitory weight values are assumed to be – 0.5. These weights can be scaled up or scaled down. Whatever the above said weight values assumed, the output obtained from BIONET is less than or equal to 1 because of the sigmoidal function used in the training algorithm. Direct firing factor fires the neuron in the cortical layer, and hence, presence of such a factor always gets more weight value which is more than or equal to the threshold value of that neuron.

1. Neck Pain on Activity

Pain in the neck is produced by inflammatory changes in the pain-sensitive tissues, viz., capsule, synovium and ligaments of the joint and nerve roots. The inflammation is triggered by activity, especially in cervical spondylosis.

OR

The pain may be triggered by the compression or irritation of the nerve root or irritation of the pain-sensitive tissues during movements incurred by the activity in case of cervical spondylosis, caries spine and malignancy. Hence, equal weight of 0.5 has been assigned for the above diseases. However, in the case of collagen disorder, the inflammatory changes are not provoked by activity. The inflammation is produced by an autoimmune mechanism. Except in atlanto axial sub-luxation, there was no neural compression. In an uncomplicated collagen disorder, pain is not triggered by the mechanisms explained for the remaining diseases. Hence, a lower weight of 0.25 has been assigned for collagen disorder.

2. Neck Pain on Automobile Travel

During automobile travel, there is a transient or sustained nerve force. Hence, the pain is provoked or increased by automobile travel. This mechanism holds good for all the diseases except collagen disorder. Hence, equal weight of 0.5 has been given.

3. Neck Pain on Lifting Strain

Because of lifting strain, there is a sustained nerve force and hence for cervical spondylosis, caries spine and malignancy, equal weight of 0.5 has been assigned, whereas in the case of collagen disorder the inflamed tissues are stretched by lifting strain and there is no compression of nerve. Hence, an increase of pain is relatively less than in the remaining diseases. Hence, a lower weight of 0.25 has been fixed for collagen disorder.

4. Pain on Resting

It is produced by

(a) Relative ischemia of the tissues
(b) Hyperemia of the tissues
(c) Sustained compression or irritation of the neural element
(d) Cumulation of hyaluranic acid during resting period

In cervical spondylosis, sustained compression or irritation of the neural element may induce pain (c). In collagen disorder, pain is produced by cumulation of hyaluranic acid (d). In caries spine factors (c) and rarely (a) may induce pain. In malignancy, factor (b) and (c) are working. Hence, a value of 0.25, 0.25, 0.5 and 1.0 is assigned, respectively.

5. Neck Pain on Early Morning

It is pathognimonic factor for the diagnosis of collagen disorder. Hence, facilitatory value of 2 has been assigned for collagen disorder and inhibition value of – 0.5 has been assigned for other diseases.

6. Worsening of Pain during Night/Recumbency

During night, there is venous (impure blood) stasis resulting in worsening of pain in malignancy. In TB of the spine, there is muscle relaxation during night (sleep) resulting in chances of rubbing of the eroded adjacent vertebrae during change of posture. This will produce pain. This is called nocturnal cry. Facilitatory value of 2 has been assigned for tuberculosis and malignancy. An inhibitory value of – 0.5 has been assigned for the remaining conditions.

7. Stiffness after Rest

A joint stiffness is possible after a period of rest both in degenerative joint disease and collagen disorder due to accumulation of hyaluranic acid. However, the joint stiffness is more common in collagen disorder especially after a night sleep, i.e., in early morning in case of collagn disorder. To differentiate the stiffness of collagen disorder from that of degenerative joint

disease, time factor has been considered. If the stiffness is more in the early morning and if it exceeds 30 min., it is mostly due to collagen disorder. Hence, a value of 2 has been assigned for early morning stiffness as well as stiffness after rest exceeding 30 min., and inhibitory value of – 0.5 has been assigned for the remaining diseases.

8. Presistent Stiffness

There is fusion of joint in collagen disorder in later stages, destruction of the joint in caries spine and destruction of the body and/or appendicular processes of the spine in case of malignancy resulting in persistent stiffness of spine. Hence, a value of 1 has been assigned for malignancy, caries spine and collagen disorder. However, in cervical spondylosis, the stiffiness vanishes after subsidence of pain. Very rarely residual stiffness with lesser magnitude prevails. Hence, a facilitatory value of 0.25 has been assigned.

9. Slow Onset of Disease

The onset of disease is slow in all the four conditions. However, an actue exacerbation is possible in cervical spondylosis and collagen disorder. Hence, a lesser value of 0.5 has been assigned for cervical spondylosis and collagen disorder, and a value of 1 has been assigned for malignancy and caries spine.

10. No Progression of Disease

In cervical spondylosis, the disease may not show any progression. Hence, a facilitatory value of 1 has been assigned for this disease. In malignancy and caries spine, there is no chance of absence of progression. Hence, an inhibitory value of – 0.5 has been assigned for these two diseases. In collagen disorder, as the disease shows relapse and remission, no value has been assigned for this parameter. However relapse and remission gains its value.

11. Slow Progression of Disease

In cervical spondylosis and collagen disorder the disease exhibits slow progression but at times the disease may exacerbate. Hence a lesser value of 0.5 has been assigned for both conditions. In tuberculosis and malignancy, a value of 1 has been assigned as it is not deviating from its course of progression.

12. Relapse and Remission

This specific mode of presentation is seen only in collagen disorder. Hence, a facilitatory value of 2 has been assigned to this disease and the inhibitory value of – 0.5 has been assigned for the remaining diseases.

13. No Constitutional Symptom

Cervical spondylosis does not exhibit any constitutional symptom whereas it is one of the manifestations of remaining diseases. Hence, the absence of constitutional symptom gains facilitatory value of 2 in case of cervical spondylosis. Invariably collagen disorder, caries spine and malignancy present the constitutional symptoms. Hence no value is assigned for these diseases.

14. Presence of Constitutional Symptoms

Antagonise is the diagnosis of cervical spondylosis. Hence, an inhibitory value of – 0.5 has been assigned. It is the key manifestation in caries spine. Hence a facilitatory value of 2 has been assigned, whereas consitutional symptom is of lesser magnitude in collagen disorder and malignancy. Hence, a lesser value of 0.5 has been assigned.

15. Nutritional Status in Cervical Spondylosis

In cervical spondylosis, nutritional status per se is not modified or affected. Hence, the value of 1 is assigned for well-nourished and inhibitory value of – 0.5 is assigned for ill-nourished or cachexia. Similarly in collagen disorder also nutritional status is not affected. However, persistent pain and drug therapy can induce loss of appetite and minimal ill-nourishment. Hence, the value of 0.5 is assigned for well-nourished.

16. Nutritional Status in Tuberculosis of Spine

In tuberculosis of the spine, nutritional status was considered primarily affected by loss of appetite and weight due to the disease per se. However, the present generation of tuberculosis cases does not exhibit loss of appetite and loss of weight. However, some cases may show the older profile of loss of appetite and weight. Hence, a low value of 0.25 has been assigned in well-nourished in case of tuberculosis. If the patient exhibits symptoms of ill-nourishment, a facilitatory value of 1 has been assigned for caries spine and malignancy for the factor of ill-nourishment. However, cachexia is not seen in tuberculosis of recent generation. Hence, this factor has been ignored in case of caries spine.

17. Nutritional Status of Malignancy

In case of malignancy, an inhibitory value of – 0.5 has been assigned for well-nourished. It may be dubious during the initial phases of the disease. However, when they report pain in neck, it has already crossed the early stage. Hence, an inhibitory value of – 0.5 has been assigned for the factor of well-nourished.

18. Spinal Tenderness

Tenderness is conspicuous in caries spine and malignancy as the destructional and inflammatory changes of the corresponding vertebrae are much more than in cervical spondylosis and collagen disorder. Hence, a facilitatory value of 1 is assigned for caries spine and malignancy and lesser value of 0.5 is assigned for cervical spondylosis and collagen disorder.

19. No Spinal Tenderness

Due to degenerative changes associated with minimal or no inflammatory changes, most of the cases of cervical spondylosis do not exhibit spinal tenderness. However the tenderness is very much conspicuous in caries spine and malignancy. Hence, a facilitatory value of 0.25 is assigned for cervical spondylosis and inhibitory value of – 0.5 is assigned for caries spine and malignancy.

20. No Restriction of Movement

In early stages of cervical spondylosis, the range of movement (ROM) of cervical spine is not affected and the movements are free, whereas in collagen disorder, caries spine and malignancy, there is definite restriction of movement. Hence, a facilitatory value of 0.25 is assigned for cervical spondylosis and inhibitory value of – 0.5 is assigned for remaining diseases.

21. Partial Restriction of Movement

Partial restriction of movement is present in all the diseases, including cervical spondylosis which has crossed the early stage, and hence facilitatory value 0.25 for cervical spondylosis and equal facilitatory value of 0.5 is assigned for all other diseases.

22. Total Restriction of Movement

It is present in late stages of collagen disorder, caries spine and malignancy, and hence a facilitatory value of 1 is assigned to these diseases, whereas total restriction of movement is an unusual feature of cervical spondylosis. It may be rarely present due to acute nerve compression. Hence, an inhibitory value of – 0.5 is assigned for cervical spondylosis.

23. Trapezius Tenderness

It is a common feature in cervical spondylosis. It may be present in collagen disorder. It may not be present in caries spine and malignancy. Hence, relative facilitatory values of 1, 0.5, 0.25, 0.25 were assigned for cervical spondylosis, collagen disorder, caries spine and malignancy, respectively.

24. Trapezius Tenderness Absent

Absence of trapezius tenderness elicits an inhibitory value of – 0.5 for cervical spondylosis and collagen disorder.

25. Associated Pain and Swelling of Smaller Joints

Associated pain and swelling of smaller joints elicit a facilitatory value of 2 for collagen disorder and inhibitory value of – 0.5 for other diseases.

26. Bambooing

It may be present in cervical spondylosis only and hence it elicits a facilitatory value of 2 for cervical spondylosis, whereas the remaining diseases do not have this effect and hence no value is assigned.

27. ESR Normal

ESR is normal in cervical spondylosis and hence a facilitatory value of 1 is assigned for it. The remaining diseases do not have the significance by normal ESR.

28. ESR High

High ESR elicits an inhibitory value of – 0.5 for cervical spondylosis and facilitatory value of 1 of remaining diseases because these diseases may result in high ESR.

29. Rheumatoid Arthrites (RA) Positive

Rheumatoid arthrites (RA) may be positive in case of collagen disorder and its presence does not confirm it. Hence, positive RA elicits a facilitatory value of 1 for collagen disorder and inhibitory value of – 0.5 for the remaining diseases.

30. Mantoux Test Positive

Mantoux test (MX-test) positive helps in identifying caries spine and hence it elicits a facilitatory value 2 of caries spine and inhibitory value – 0.5 for the remaining diseases.

31. High Alkaline Phosphatase

It may be present only in malignancy and hence it elicits a facilitatory value of 1 for malignancy and inhibitory value of – 0.5 for the remaining diseases.

32. Positive Bence Jone's Protein

Positive Bence Jone's protein confirms malignancy and hence it elicits a direct firing for malignancy and inhibitory value of – 0.5 for the remaining diseases.

33. Abnormal EPP

Myelomo protein resulting in abnormal EPP confirms malignancy and hence it elicits a direct firing for malignancy and inhibitory value of – 0.5 for the remaining diseases

34. Disc Narrowing

It may be present in cervical spondylosis and caries spine and hence it elicits facilitatory value of 1 for cervical spondylosis and carries spine and inhibitory value of – 0.5 for collagen disorder and malignancy.

35. Osteophytes Positive

It elicits a facilitatory value of 1 for cervical spondylosis only.

36. No Osteophytes

It elicits an inhibitory value of – 0.5 for cervical spondylosis only.

37. IVF Narrowing

It elicits a facilitatory value of 1 for cervical spondylosis only.

38. IVF Widening

It is present only in case of malignancy and hence it elicits a facilitatory value of 2 for malignancy and inhibitory value of – 0.5 for other diseases.

39. Osteolytic Lesion

It may be present only in caries spine and malignancy and hence it elicits a facilitatory value of 1 for caries spine and malignancy and inhibitory value of – 0.5 for the remaining diseases.

40. Prevertebral Shadow

It is present in caries spine only and hence it elicits a facilitatory value of 2 for caries spine and inhibitory value of – 0.5 for cervical spondylosis and collagen disorder. It has no effect on malignancy.

41. Positive Atlanto Sub-luxation

It is present only in collagen disorder and inhibits cervical spondylosis. Hence, it elicits a facilitatory value of 2 for collagen disorder and inhibitory value of – 0.5 for cervical spondylosis. It has no effect on caries spine and malignancy.

42. Ankylosis of Spine

It is present only in collagen disorder and hence it elicits a facilitatory value of 2 for collagen disorder and inhibitory value of – 0.5 for other diseases.

43. Osteolytic Lesion with Disc Narrowing

This confirms the disease caries spine and hence elicits a direct firing for caries spine and no effect on other diseases.

44. Osteolytic Lesion with Cold Abcess

This confirms the disease caries spine and hence elicits a direct firing for caries spine and no effect on other diseases.

45. Sparing of Disc with Osteolytic Lesion

This confirms malignancy and elicits a direct firing for malignancy and has no effect on other diseases.

Contributor

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