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Application of Neural and Artificial Networks in Biomedical Engineering

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ABSTRACT

Equipping medical science with intelligent tools for diagnosing and treating diseases can reduce medical errors and human and financial losses. In this article, we have evaluated the typical applications of neural networks in medicine. We tried to make this article usable for both artificial intelligence researchers and medicine. The evaluation of practical examples was able to generate suitable ideas for further research.

Keywords: neural networks, disease diagnosis, disease prognosis, medical engineering

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Introduction

Neural networks have been used in medicine since the late 1980s. Both types of networks, namely supervised and unsupervised learning networks, have been used as successful solutions in medicine. In many medical researches where it is not possible to draw conclusions from large data related to a specific disease manually, neural networks have been able to help doctors in diagnosing the disease [1]. Neural networks are also used in many medical problems such as predicting the life expectancy of specific patients or making medical devices. The accuracy and precision of the final results obtained from neural networks does not only depend on the structure of the network but also on the data used to train the network. If correct information is available from a larger number of patients, then the performance of the network will improve significantly. An important point is that for extracting disease information or any other medical application, an attempt has been made to explain these methods in an understandable way in each case to give the necessary attitude to interested experts [2]. We have presented the applications of neural networks in medicine in three sections: 1- Disease diagnosis 2- Prediction and forecasting 3- Medical engineer. Neural networks can improve the process of diagnosing diseases in the medical field. The minimum information that can be obtained with the help of these neural networks is what is wrong with the patient's body. Then with the help of these networks, the complex treatment process can be easily planned for that patient. So far, several scientific articles have been published, based on which artificial neural networks can greatly increase the speed of diagnosis [3]. At this stage, it seems that most authors of reputable sources believe that this is simply due to the high accuracy of artificial neural networks in diagnosing certain diseases. In a scientific article, it was claimed that neural networks can diagnose five specific diseases such as Chickenpox, with an accuracy of 90 to 97 percent. Also another study showed that when this diagnostic ability is combined with the knowledge of a doctor, the ability to diagnose diseases will reach a very desirable accuracy (accuracy of 99.5 percent). So more than the need for doctors who are experts in the field of artificial intelligence, we will probably need an artificial intelligence assistant who is aware of aspects of the medical field [1-3].

Disease diagnosis

Disease diagnosis is the most important step in treatment because in many cases, it is not possible for doctors to process large amounts of data related to a specific disease manually or it is very complex and time-consuming. The use of neural networks which are very fast and reasonably reliable, has been able to solve many of these problems. The way in which information related to each disease is extracted is very important and the more patients are used, the better the network performance will be. Below, we evaluate some examples of relevant research.

Image analysis system in tuberculosis diagnosis

In recent years, neural networks have been widely used to analyze medical images, such as tumor detection and X-ray image classification. In the following, we briefly describe one of the applications of neural networks, namely the diagnosis of pulmonary tuberculosis.

Tuberculosis and feature extraction

Pulmonary tuberculosis is a type of infectious bacterial infection caused by Mycobacterium tuberculosis. In this disease, the lungs are first infected and then the infection gradually spreads to other organs. The symptoms of the disease are not obvious at the beginning. Some of the symptoms of this disease include cough, mild fever and in the final stages, weight loss, sweating, feeling tired and hearing loss. If we listen to the patient's lungs with a stethoscope, abnormal sounds can be heard. For the final diagnosis, chest X-ray images, lung biopsy tests and Bronchoscopy are used. Chest X-ray images taken using Mass Miniature Radiographs (MMR) have been used to extract features. In MMR related to healthy people, bones are seen in white, air sacs in black and the heart in gray. But in the case of infected people, the air sac area is seen in gray. Therefore, the areas with tuberculosis lesions will have a different gray color than other areas which can be separated from the rest by considering a threshold level. In this system, digital images obtained from the scanner are sent to an image processor. The image processor also filters out noise and enhances the image quality and then extracts the necessary features from different MMR regions.

Neural Network Model and Its Training

Here sMLP network with sHidden layer is used for training. The typical size of digital images is 512×512 pixels which is converted into a 10×10 pixel file by a compression algorithm by the image processor so the input layer of the network is reduced to 100 cells. This network is trained with different values of learning rate α and momentum constant, η and the error rate at different epochs is measured. The best responses are obtained for α=0.5 and η=0.1.

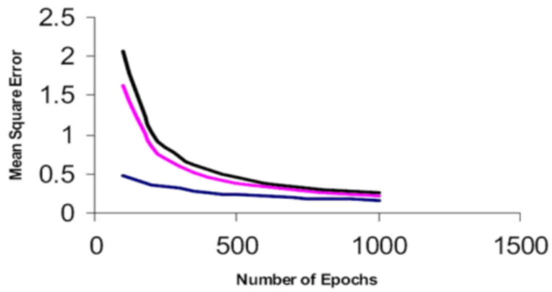

Fig 1- learning curves based on different values of α and η

Based on the aforementioned value, the network error in detecting tuberculosis lesions is reduced to 20 percent.

Application of neural networks in breast cancer diagnosis

The measures in this field can be classified into three groups:

1- Predicting the presence of malignant breast lesions using mammography data

2- Classifying malignant lesions as advanced cancer (Situ vs. Invasive)

3- Preventing the malignant status of breast tissue masses using ultrasound data

In all these studies, a single-layer perceptron network and the BP error backpropagation learning algorithm were used. By guiding information such as the benign or malignant status of tumors as well as the detection of advanced cancer types (previously only accessible through live tissue biopsy surgeries), neural networks have great potential to improve the management methods of patients with breast lesions. By using these networks, the number of unnecessary surgeries on patients and the associated costs can be reduced. Mammography and ultrasound are still the main imaging tests for early detection of breast cancer. Although mammography has good sensitivity, meaning that it can detect healthy, non-cancerous lesions with a reasonable degree of confidence, it is not reliable in detecting cancerous lesions. Therefore 60 percent of cases referred for biopsy are benign lesions that do not actually require biopsy. Network Inputs The inputs to the neural network are encoded medical information that is extracted by medical laboratory tools such as mammography, ultrasound or from patient records and the final outputs that are applied to the network as desired results are also the results of biopsy. They are divided into three categories: benign, malignant and advanced cancer. The images are interpreted by radiologists in the BI-RADS system. BI-RADS is a standard dictionary provided by the American College of Radiology and aims to increase the necessary harmonization for the interpretations provided by mammographic images. Some of the inputs are ultrasound findings interpreted by the Stavros system. This is an informal standard system that is widely used.

Prediction of malignant cancer using mammography

The neural network uses mammography findings (BI-RADS) and patient records. The goal is to determine whether the lesions are benign or malignant. If the network correctly determines that the lesions are benign, then patients can undergo a short course of treatment and follow-up with mammography at a lower cost than biopsy. Among the 500 suspicious cases on mammography that underwent surgery, 174 malignant and 326 benign cancers were identified and in each case, 10 BI-RADS parameters were extracted along with the patients' ages and applied as inputs to train the network. The output data are values in the range [4], where 1 means malignant cancer and 0 means benign cancer. Here to separate these two groups, we consider a value as a threshold level in the output, higher values than which indicate malignant cancer and lower values indicate benign cancer status. The lower the threshold value, then the cases below it are more likely to be benign and the sensitivity increases. In fact sensitivity refers to the probability that the patient is placed in the benign patient group by the network when there is actually benign cancer and the same is true for malignant cancer. To obtain the highest sensitivity, the threshold is considered as small as possible (equal to 0.13). At this value, the sensitivity reaches the 98 percent limit which means that 171 out of 174 patients with malignant cancer were above the threshold and correctly placed in the True-Positive class. At this threshold, 42 percent of benign cases were below this value so they were correctly classified as True-Negative, so sampling could easily be avoided for 136 of 326 patients with benign cancer.

Predicting advanced cancer using mammography

Following the aforementioned study and in another experiment, the neural network, in addition to diagnosing benign or malignant status, also determines the rate of progression of malignant cancer. Here only mammography data was used to train the network. This may seem unreasonable to doctors because the rate of progression of cancer is determined based on microscopic information and cannot be directly observed from mammography (which is a macroscopic method). This was based on the hypothesis that in many patients, there is a sufficient connection between microscopic and macroscopic facts and the results of this study clearly demonstrated the correctness of this hypothesis. Also the inputs included all cases that were

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above the threshold of the previous stage. At a threshold of 0.6, the network was able to correctly identify 65 of 120 cases of progressive cancer above this level (54 percent sensitivity) and correctly identify 218 of 243 negative cases below the threshold (90 percent).

Diagnosis of malignant cancer using ultrasounds

Ultrasound in breast images is used only to differentiate simple cysts from solid masses. In one project [5], 175 patients had breast abnormalities in the US test of which 65 had breast tissue samples taken. Using the Stavors ultrasound image interpretation system, seven data points were extracted from these images and used as input to a neural network. At a threshold of 0.24 in the network output, 30 of 31 cancers were diagnosed as malignant (sensitivity 97 percent) and 27 of 34 benign cancers were above this level (79 percent). These results are very promising considering the small number of samples and confirm that US can be used more in the diagnosis of benign and malignant cancers.

Prediction and prognosis

Input data and network training

An experiment was conducted with 1693 patients with NPC in Kuala Lumpur between 1969 and 1999. The input variables of this experiment are: age, gender, race, dialect, time of first symptom appearance, type of symptom, tissue sampling tests, tumor size and nerve compressions. The Pre-Processed method was used for this data. In this method, all variables are coded into different binary values. In this regard, two neural network models were designed and trained. One is an MLP network and the other is an Elman type Recurrent Network. The outputs were in the format of

Artificial neural networks are a good alternative to conventional statistical methods aimed at estimating life expectancy. Estimating life expectancy is essentially predicting the course and outcome of the disease and the general signs of improvement. Providing prognosis about the disease at the individual level can help the patient to make an informed decision about his treatment. The definite advantage of neural networks in this field over statistical methods such as Life-Table or Kaplan-Meier method and other conventional methods is that here it is no longer possible to manually censor the data. Statistical methods are also used to estimate the life expectancy of a group of patients. In other words, neural networks can estimate the life expectancy exclusively for each patient while statistical methods estimate the chance of recovery for each disease by studying a group of patients. Below we have presented an example of predictions based on neural networks[6].

Determining life expectancy for patients

NPC or Nasopharyx, is a common head and neck cancer among residents of Southeast Asia, China, Taiwan, Hong Kong, Malaysia and Singapore.

0 and 1 and 50 patients were present in the testing phase. To determine the life expectancy of these patients, the ROC (Receiver Operating Characteristic) factor is usually used. ROC is the sensitivity curve. Sensitivity refers to the proportion of all cases for which the network correctly predicted death (value 1) (+true) and this is the proportion of all cases in the input that actually died. Specificity refers to the proportion of people who were correctly identified as alive in the output (value 0) and this is the proportion of all cases in the input that actually survived.

Table 1 . True Negative/Positive Definitions

	Dead(+)	Alive(-)
Result Positive	A=True Positive	B=False Positive
Result Negative	C=False negative	D=True Negative

Application in Medical Engineering

Medical engineering is the science of designing and manufacturing equipment used in medicine. In recent years, neural networks have been used in the manufacture of medical equipment. What is mentioned as a practical example is useful and important for cancer treatment.

Design of a temperature sensor probe using optical fiber

Cancer cells are less resistant to heat compared to normal cells. When the temperature reaches 42 degrees Celsius, cancer cells are quickly damaged and inactivated while healthy cells are less damaged. Based on this fact, heat-therapy is possible. Using microwaves to treat cancer with heat-therapy is one of the

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appropriate solutions. Therefore, conventional temperature sensors used in the microwave cancer treatment process cannot have the necessary efficiency due to the presence of electromagnetic waves in the environment. These waves cause interference and noise. Therefore, the construction of a temperature sensor with an optical fiber that is not interfered with in magnetic fields and is also very small and precise [7] is one of the most practical medical devices that is built with the help of neural networks.

How the sensor works

In this sensor, some materials react to changes in the refractive index (n) of light in response to heat. You can see the structure of the probe in Figure 2. When the probe is in the radiation mode, here the amount of its radiant energy is affected by the value of n. When the temperature rises, the value of n must decrease so the radiant energy also decreases. But when the temperature decreases, the value of n increases and as a result the radiant energy increases. This relationship between temperature and radiant energy has been used to design a heat sensor. The amount of radiant energy is measured based on the amount of energy returned at the end of the probe. Here the important issue is to choose the value of n which should be selected in the best working conditions and the material used should also show the highest amount of changes in radiant energy against constant temperature changes. To prepare the desired material, two materials with a certain refractive index were used. A neural network was used to obtain the ratio of the combination of these two materials.

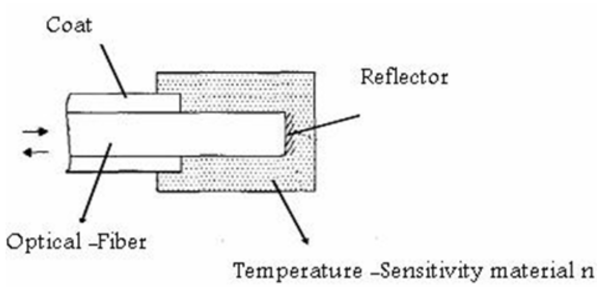

Fig 2 - fiber optic probe structure

GANs and 3D printing

GANs are a specific framework in artificial neural networks that are used in various industries. Because of the careful look that a GAN has at the input data, it can continuously improve its outputs. This structure is used in all fields such as blockchain, cybersecurity, the 3D printing industry and the pharmaceutical industry. Now we can say why GAN or other neural network frameworks are divided into two parts. The first part is called the generator and is used to automatically produce the desired outputs. The second part is called the dispeler which constantly challenges the generator's outputs. These outputs can be used in almost any field, depending on the industry. Now let's take the field of 3D printing as an example. One of the latest trends in 3D printing is "metal printing" or the use of 3D printers to produce metal-based products. The use of artificial neural networks in this area has been initiated by companies such as Sculpteo and AI-Build. These companies have talked about the possibility of artificial intelligence being a game changer for a new era in this industry, as well as in the 3D printing industry. For this to happen, networks such as GANs will have to achieve 3D printing and, as a result, automation of production. Now imagine a world where factories can do everything without any human intervention. Of course, we are still a long way from that point, but a great start to this dream future is for 3D printing companies to use GANs and integrate them into all their machines, gradually training the machines to gradually approach full automation.

Artificial networks and self-driving cars

Neural networks are essential for the continued production, development and maintenance of any type of autonomous vehicle. The easiest way to understand this is to think about how self-driving cars will arrive and improve data analysis. In simple terms, building an AI system based on a reinforcement learning framework means ensuring that data is learned in the same way that humans are trained. Artificial neural networks repeat an action until it reaches a desired value. The desired value is not like a reward or a limit that the system wants to achieve, but rather the value required for the system to function optimally. This desired number indicates how perfectly the AI has performed an action. If we apply all these requirements to the context of neural networks and self-driving cars, then we can say that every action that the vehicle chooses will be processed as an input and then given to other hidden layers of the artificial neural network and the output will be weighted with an appropriate q value. A specific example is if the car learns to turn right at a speed of 300 km/h and also knows how to do it correctly when it is traveling at a speed of 350 km/h. Then eventually the car learns how to achieve the desired result. With this example, you will understand that artificial neural networks are an integral part of autonomous vehicles. Of course, this is still in the early stages of development and progress.

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Conclusion

Neural networks, with their unique capabilities, help medical science and, in cases where this science has not yet been able to overcome its shortcomings on its own, are an effective help in overcoming its inadequacies. Reducing costs, increasing the confidence and accuracy of doctors in their decision-making and creating more efficient medical devices are some of the services that neural networks have provided for doctors. We hope that with more interaction between engineers and doctors, more effective steps will be taken to improve human life.

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