Quantitative Analysis of Cardiac Q Wave Modeling Using Adaptive Neuro Fuzzy Inference System

S.Ananthi, V.Vignesh and K.Padmanabhan

***Abstract*— The significance of diagnostic Q-waves for myocardial ischemia and infraction have been well studied over several decades [1]. Myocardial infarction (MI), is commonly known as a heart attack, occurs when the blood supply to the portion of the heart is blocked causing some heart cells to die. This information is depicted in the elevated ST wave, increased Q wave amplitude and inverted T wave of the electrocardiogram (ECG) signal. However, the presence or absence of a Q wave does correlate with some aspects of the clinical course of patients after myocardial infarction, and is therefore of prognostic value. It is stated that a sheer presence or absence of a Q wave greater than 0.03 sec in duration may lead to "correct" diagnosis of infarction or not in 79% of trials. After all, the ECG waveform obtained from the limb and pericardial leads are the only data for such diagnosis. Diagnosis of site of myocardium from such Q waves is one aspect while the extant of pathology present therein is another. For instance, the lateral infarction is related to q waves in lead 1 and V5, V6 leads. There are also estimates of recent or old infarctions which are related to the elevation of the S-T segment along with the q wave. Recoverable ischemia is also likely to show up as Q waves along with ST elevation or depression. To develop an ANFIS trained network for clearly modeling the Q wave and providing a crisp output in the form a Q-wave index value which should be able to provide a comparable estimate of cardiac pathological diagnosis.**

***Index Terms*—ECG, Q wave, Echocardiography, Fuzzy Model, ANFIS.**

Dr. S. Ananthi, Head, *Dept. of Network Systems & Information Technology, University of Madras, AC Tech Campus, Guindy, Chennai-25, India.*

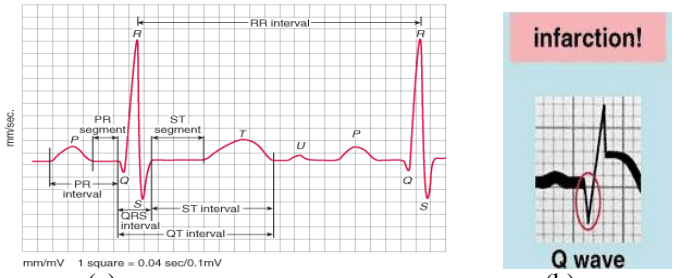
V.Vignesh, *Research Scholar, Dept. Network Systems & Information Technology, University of Madras, AC Tech i Campus, Guindy, Chennai-25, India.*

Prof. K.Padmanabhan, Emeritus Professor, *Dept. of Chemical Engineering, Anna University, Alagappa Chettiar College of Technolgy, Chennai, India.*

I. CARDIAC PATHOLOGY DIAGNOSIS BY Q WAVES IN ELECTROCARDIOGRAM (ECG)

The significance of diagnostic Q-waves for myocardial ischemia and infraction have been well studied over several decades [1]. The Q wave is the initial downward slope and negative going peak in the ECG as shown in fig.1. It is stated that a mere presence or absence of a Q wave greater than 0.03 sec in duration may lead to "correct" diagnosis of infarction or not in 79% of trials. After all, the ECG waveform obtained from the limb and pericardial leads are the only data for such diagnosis. Diagnosis of site of myocardium from such Q waves is one aspect while the extent of pathology present therein is another. For instance, the lateral infarction is related to q waves in lead 1 and V5, V6 leads. There are also estimates of recent or old infarctions which are related to the elevation of the S-T segment along with the q wave. Recoverable ischemia is also likely to show up as Q waves along with ST elevation or depression.

The usually observed electrocardiograms are based on the same time scale graph pattern originally used by Einthoven. Today, with more powerful analog signal acquisition methods and display of waveforms to a better scale and resolution, there is a lot which can be contributed to the inference of the cardiologist.



(a) (b)

Fig. 1 a) A typical ECG waveform showing names of peaks and timings.
b) A pathological Q wave.

II. Q WAVES FROM DIFFERENT ELECTRODE CONFIGURATIONS

Presently, diagnosis is inferred using ECG waves in the standard pattern with chart movement of 0.2 inch per second and 1 mV per inch of vertical axis from the limb and pericardial leads. After all, the ECG itself is a small wave segment comprising of the various complexes, such as the Q, R, S, T and P waves. The P wave relates to atrial activity, the Q, R, S relates to ventricular compression and the T wave to ventricular relaxation. The signal is obtained from leads after amplification and filtering to a bandwidth of 100 Hz. The nature of the filter also contributes to the Q and ST segment shapes. The total QRS time is about 60-100 ms and within this, there is a time segment in the initial part of it with the

negative going Q wave for about 10-30ms. Small 'septal' Q waves are typically seen in the left-sided leads (I, aVL, V5 and V6). Small Q waves are normal in most leads Deeper Q waves (>2 mm) may be seen in leads III and aVR as a normal variant.

Under normal circumstances, Q waves are not seen in the right-sided leads (V1 to V3). The main diagnostic requirements are Myocardial infarction and Cardiomyopathies — Hypertrophic (HOCM) and infiltrative myocardial disease conditions. The first refers to tissue scar or dead tissue while the second refers to muscular insufficiency and cardiac muscle related pathologic conditions. An example showing predominant Q waves of significance is given in fig.2. This shows fairly peaky (more than 3mm) q waves in the leads II, III and aVF.

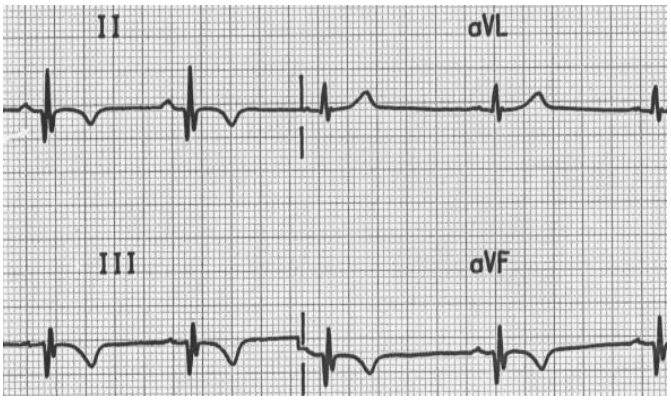


Fig.2. Q waves of significance noted in a heart with previously damaged infarction of certain tissue areas.

The pericardial leads are more decisive in determining the regions of damaged tissue. For example, in fig.3 [2], Anterior Q waves (V1-4) with ST elevation due to acute MI is seen in this figure. But leads V4 –V6 are not showing Q waves though, but they show improper depolarization due to elevated S-T segments. In fig.4, for instance, in these same leads, we note Q waves predominant.

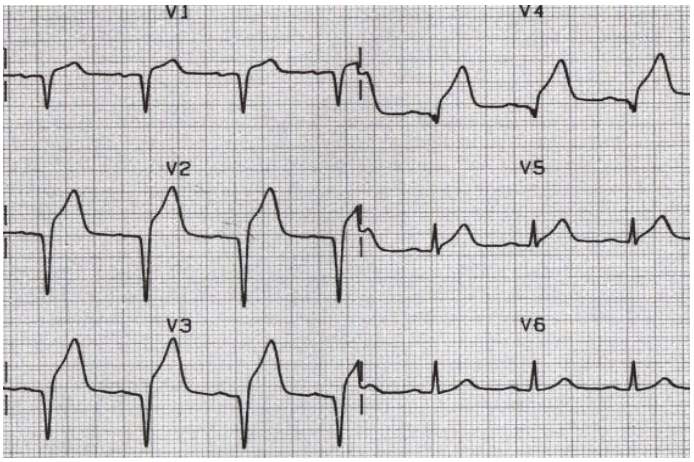


Fig.3 Pericardial leads showing Q waves in the anterior leads (acute infarction).

The present diagnosis merely estimates the height or amplitude of the Q wave and the width in time. A 0.5 mm ECG Q wave depth with a time of about 20-30ms is considered as abnormal, by the long standing experience in ECG observation. The information about adjoining ST segment elevation, its slope and extant are deciding the conditions causing the onset of a recent infarction. At present, the methodology is not sufficient to predict the possibility of an infarction from the ECG pattern.

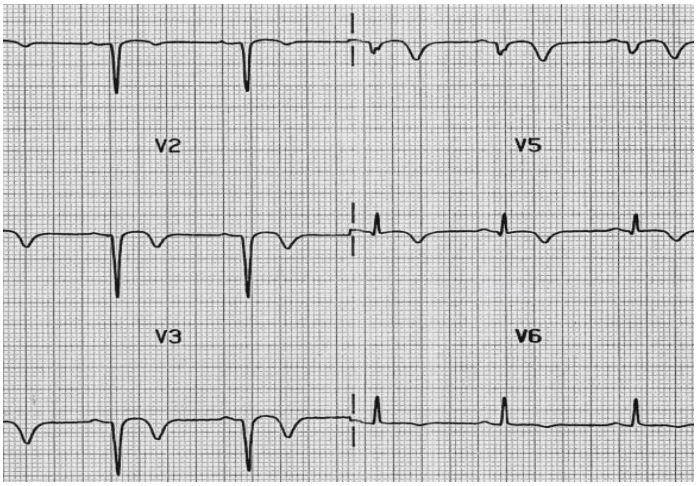


Fig.4. Showing Q waves with no ST elevation but inverted T waves due to supposedly recently infracted tissue in the anterior ventricular region.

III. EXPANDED Q WAVES AND PARAMETER RECOGNITION

While it is possible to expand the time scale of the Q wave segment as also the ST elevations and also to provide a more precise estimate of the slope of the leading and trailing edges of the Q waves, amplitude and width in time, the data needs to be analysed by an expert system. Present visual estimate based on just measurements of height and widths at half height are not sufficient to characterize the Q wave pathology. At present, the available ECG machines do not portray the signal of the QRS or the Q wave in expanded format. With such an expanded waveform for the Q, the following are the possible parameters.

1. Slope of First negative going droop in mV/ms (Leading slope)
2. Peak of the negative Q wave
3. Width at half height of Q wave (important parameter)
4. Second rising slope of the Q wave (Trailing Slope)
5. Slope of S_T segment in mV/ms
6. Point of inflection of the Q wave to R wave
7. Height of S-T segment following Q wave.
8. Information as to whether contiguous leads show Q waves; for example, if V1 shows, does V2 and V3 or only V2 shows it.

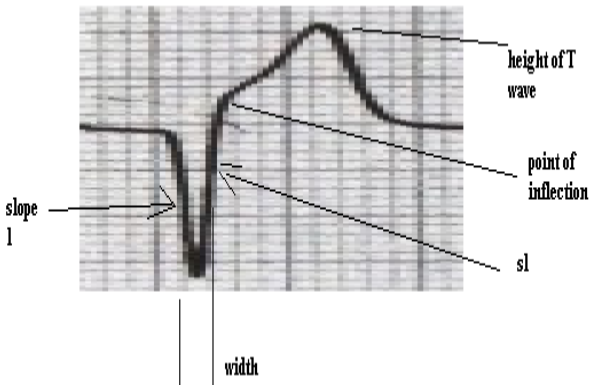


Fig. 5 Expanded Q wave and salient noteworthy quantitative features.

It is not yet known as to how the various parameters of such Q waves vary as per the pathological conditions in the ventricular fibres. The slopes of leading and trailing edges of the negative Q wave dip are based on the ionic conductance prevailing in the area as per the lead positions. The conduction contraction couplings in the myocardial fibers have been extensively experimented [3].

Different stages of of cardiac pathology is shown in figure 5b.

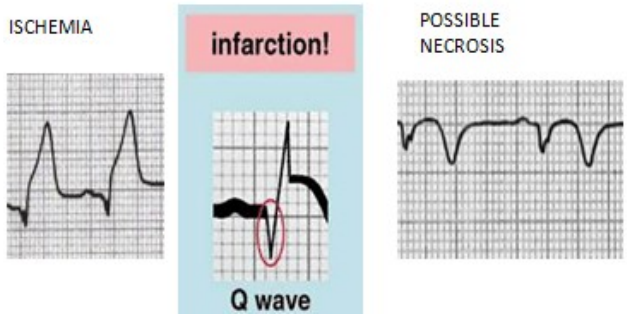


Fig.5b shows the Different Stage of cardiac pathology

The basic cardiac fibre action potential of mammals (fig.6) has been recognized to be different from the nerve action potentials because of the prolonged plateau period of the former.

The electrodes of the ECG system get their signals via capacitive conductive coupling through the flesh and skin in between the electrode and the myocardium. If we consider the action potential as a wave propagating fast (within a fraction of a second <100ms) via the nervous system comprising of nodes and fibres, the signal picked up between two electrodes will reflect the changes in the action potential only. Since the rise portion of the AP and its fall are alone coupled capacitively to the electrodes, the waveform of the ECG is just as if it is the differentiated waveform of the AP (Fig. 6b).

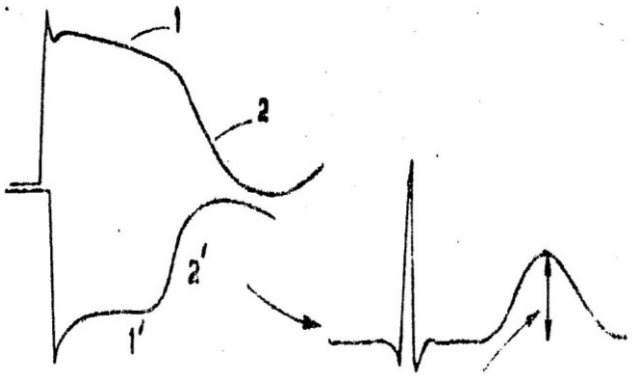


Fig. 6 The basic Cardiac Action potential (AP) waveform and its differentiated waveform which is like the ECG.

If the AP is same all through its movement as it excites all the fibres in its path of the ventricle (fig. 7), then the ECG will show only the effect of the rises and falls. If some fibres en-route the propagation through the ventricular septum is mal-functioning, differences arising in the peaks, their slopes and timing changes will cause abnormal wave patterns in the externally observed ECG signals. This is the cause of the Q wave as well. Thus, the Q wave properties mentioned above are attributable to the ionic disturbances in certain local positions in the propagating path. Such a study is well worth its pursuit. While such results are not directly available, the present cardiologic technology is based on observations and empirical learning.

IV. Data collection from Q waves of PATIENTS for an Expert Fuzzy inference system

The modeling of such data with more inputs and values of the above wave parameters could be done with a Fuzzy model [4.]

There are two Fuzzy models in a Fuzzy logic based Inference System (FIS). The first method is called the Mamdani method and the second one as the Takagi-Sugeno Model.

It is possible to delineate the parameters of slopes, amplitudes, bandwidth and time width values in a fuzzy inference system (FIS).

Therefore we have about eight antecedent parameters of the Fuzzy model and in each of the parameters; we have to define clinically significant linguistic variables.

The output decision parameter is similar to current diagnostic inference which would mean one of the following:

1. Acute recent myocardial infarction
2. Moderate but recent myocardial infarction
3. Recent mild myocardial infarction
4. Mild long standing infarction
5. Moderate long standing infarction
6. Acute long standing infarction

Hence, it was found advisable to classify the output in two functions:

1. Acuteness of infarction
2. Whether it is recent (and hence recoverable) or old.

There are eight premise parameters each of which can be divided into three fuzzy membership functions, for three levels of classification – mild, moderate and large.

For the present, the mainly used parameters 1 to 3. Q waves are supposed to be pathological if one or more of the following are noted from the ECG records.

1. 40 ms (1 mm) wide
2. 2 mm deep
3. 25% of depth of QRS complex

So, if the width of the Q wave is less than 20 ms it is low and 20-40 as moderate risk and over 30 up to 100 is considered as high risk.

Likewise if the peak of the Q wave is 1 mm to 1.5 mm, it is considered as low risk; if 1.5 – 2.5 mm, it is moderate and more than 2 mm it is high risk.

If the ratio of the Q peak to R wave is less than 20%, it is low risk; if between 15 to 40%, it is moderate and if more than that it is high risk.

The membership functions as per the above are shown in fig. 6. The choice of the shape of the function is left to choice, but fig.6 shows trapezium type shapes.

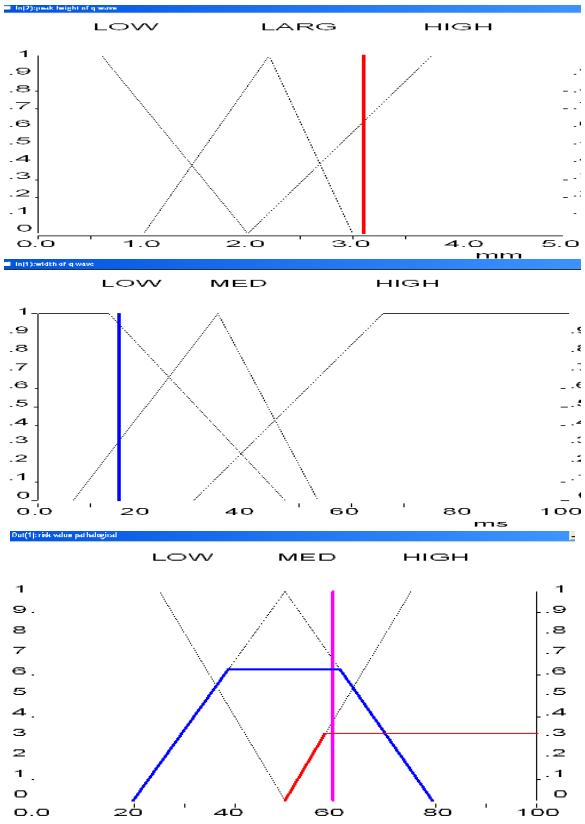


Fig. 6 Membership functions of Q wave Fuzzy inference method for width and peak only. The risk value is 59%. Given peak is 3 mm and width is 15 ms.

Coming to the output decision which is named as Risk value, we can divide into three categories initially as LOW, MODERATE and HIGH, though the remaining three pertaining to long standing can be considered as a separate output function which can be linguistically termed as not recent, fairly long standing and old.

For this second output, since it is necessary to consider the relations of ST segment height, duration, ratio to Q wave etc., it is left out presently in this illustration and to be taken up later.

In an example calculation, it is seen from the model Mamdani system, that if the width of Q wave was 15 ms and the peak height was 3 mm, the risk of pathology is 59%. This corresponds to an ejection fraction of

(100- Risk %) × (Maximum value of Ejection fraction of 70%) = 28%.

From Ultrasound imaging for this patient. Since the Risk is the complement of the actual function of the heart leading to ejection, we subtract the value from 100. We multiply by the actual highest possible EF value of 0.7 since 100% EF is unfeasible.

Thus, this case corresponds to critical condition inasmuch as its EF value is less than 30.

A. Mamdani Model:

The above Membership functions are related by the Mamdani FIS. To start with, such a model gives some solution even with limited knowledge. This knowledge can be built up using Fuzzy knowledge builder [5].

Thus far, in cardiac diagnosis, no quantitative index of Q wave pathology is used. Let us know arrive at the method based on this model for giving a quantitative estimate of the same.

Then, what quantitative information is presently available to assess ventricular pathology? Though not from the ECG, the Ultrasound echo cardiogram calculates a value called "Ejection Fraction" (EF), which is obtained from the ultrasound display of chamber volumes [6]. This EF value varies between 45-60% for normal heart functioning and will drop down with patients having Q waves. Q waves indicate damaged cardiac fibers and therefore reduce the compression action in those areas. Using M-mode echo image, it is evident that certain areas of the ventricle are 'akinetic' (not moving sufficiently). The Ejection Fraction gets reduced on account of insufficient contraction of the ventricle. Fig.7 illustrates this EF.

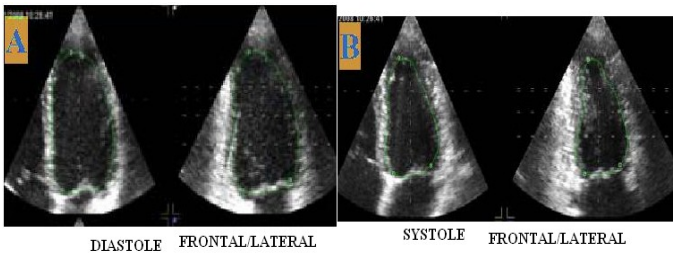


Fig.7 Illustration of Ejection Fraction relating to ventricular pathology.

Now, the FIS result for a patient with Q waves can be compared to the EF value. Since this is presently the only quantitative index of ventricular contraction, this will be the starting point for building up our needed expert system model for Q wave assessment.

We need a rule base for the FIS to work. This is really the expert's opinion in words. In the case of the simple FIS Q wave model with three inputs, for each input variable there are 3 choices so that there are 3x3x3 =27combinations possible for the input choices.

Taking one set of the 27 for example:

RULE 1

If the width of the Q-wave is LOW and if the peak is LOW and if the Ratio to R wave is LOW, Then the RESULT Risk is LOW

This rule is simple commonsense. But for other rules, we need the overall opinion of several cardiologists to arrive at a total rule base. For example again, if we take the following RULE:

RULE n:

If the width of the Q wave is moderate and if the peak is high and if the ratio to R wave is moderate, the RISK value is……..

The risk value for this rule cannot be stated by ordinary common sense. It can be either moderate or high risk. This is possible to decide by an expert cardiologist.

With Mamdani model, we get a crisp output in percentage of risk for any input variable set. If there were only two inputs and one output, we can plot the surface plot of risk with respect to peak height and width (fig.8).

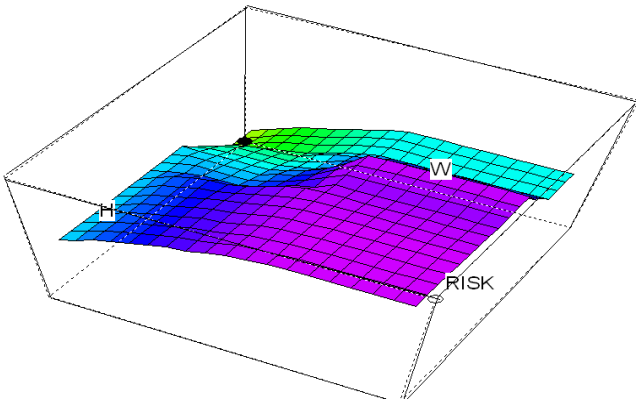


Fig. 8 The surface plot for Risk value with respect to Width and height of Q waves.

But with three inputs, there will be a hyper surface and hence only a three dimensioned matrix will result from the calculations.

This matrix

RISK (width, peak, Q_R ratio)

will be a 10x10x10 matrix if each of the above inputs are normalized and divided into ten parts each.

If we took only one input, say, the width of the Q wave, we would get a simple curve in a two dimensional plot. That curve spans the values of low, medium and high risk. This curve may be split to three parts and approximated by straight line relations.

Thus,

If RISK is LOW, its equation would be: r1 w + C1

If RISK is moderate, its equation is: r2w + C2

If RISK is High, its equation is: r3w +C3

B. From Mamdani to Sugeno Model and ANFIS

The Takagi Sugeno model [4] is more useful for building up a progressively expanding expert inference system for the Q wave pathology. In this model, there are equations describing the output variable "RISK" in terms of the membership values of the inputs WIDTH (w) , Height of PEAK (h)etc. Thus, these equations for Risk R, one for each rule, will be of the form

$$Rn = pn\ w + qn\ h + sn$$

There could be less than 27 rules also, but to that extent the result will be of less accuracy.

The Sugeno model is feasible for adaptive adjustment of the input member functions and the equation coefficients p,q,s.

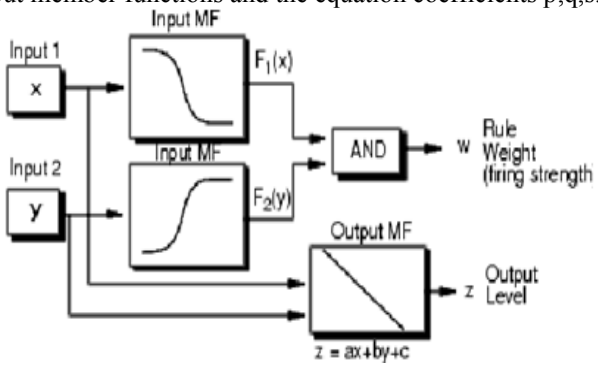


Fig.9a Sugeno model.

Such a method is known as the Adaptive Network or Adaptive Neural Fuzzy Inference System (ANFIS) [7]. The Sugeno model is shown in figure 9a and the model of the network is shown in fig.9b.

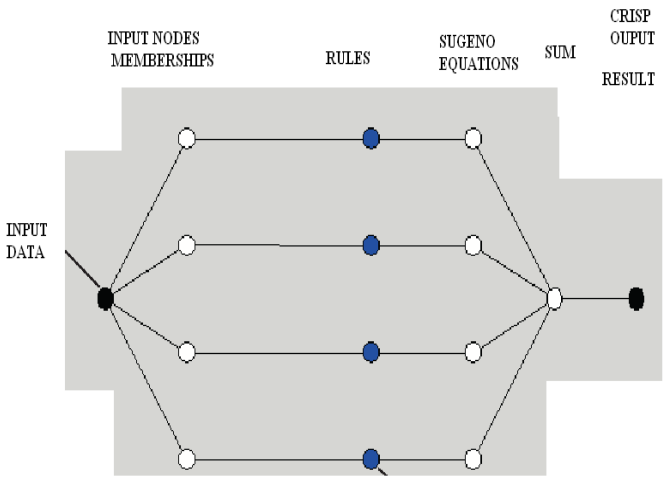


Fig. 9b. An ANFIS network uses input data and output result and finds the Fuzzy Inference System model for such data pair. One single input and one output model shown.

V. CONCLUSION

Like a neural network, the method trains the output data with respect to input data, given a sufficient set of data points. The Rule base given by the expert system is used. The training requires several iterations involving adjustment of the consequent parameters of pn,qn and sn as well as the premise parameters of choice of Membership functions – their span. If Gaussian curve type of Membership functions are chosen, it adjust the parameter σ of the curve. The training uses a hybrid algorithm of least squares and gradient descent methods. Matlab uses such an algorithm.

With more and more data on Q waves and EF getting included, the better will be adapted network and the FIS for the benefit of the cardiology diagnosis.

Collecting such data from records, it is feasible to develop an ANFIS trained network for clearly modeling the Q wave and providing a crisp output in the form a Q-wave index value which should be able to provide a comparable estimate of cardiac pathological diagnosis.

REFERENCES

[1] L. LEO G. HORAN, M.D., NANCY C. FLOWERS, M.D.,AND JENNIFER C. JOHNSON, M.D.,Circulation, Amer. Heart Assoc. , 1971
[2] ECG waveforms from http:\\lifeinthelastlane/ECG.library.Basics/Qwaves…
[3] "Contractile Behavior of the Heart muscle.,Proc.Symp. in Belgium ,1970,CardioVascularResarch Supplement I, 1971.
[4] Fuzzy models in T. J. Ross, Fuzzy Logic with Engineering Applications, McGraw- Hill, Inc, 1995.
[5] Fuzzy knowledge builder in "Fuzzy Logic – A Practical Approach" by .Martin McNeill and E. Ellen Throw, Academic Press, 1994.
[6] Ejection fraction from Ultrasound images in Nanda N.S. 1989, "Doppler Ecocaridography",2 Ed., Lea and Febiger, Phil.
[7] J.-S. Roger Jang and C.-T. Sun, `` Neuro-Fuzzy Modeling and Control", The Proceedings of the IEEE, Vol. 83, No. 3, pp 378-406, March 1995.
[8] K.Padmanabhan and S.Ananthi Analysis of Fibrillation and defibrillation with a View to Develop a minimal energy Defibrillation Technique, , Journal of I.E.(India), Vol. 89, May 2008 p.3-10.

Dr.S.Ananthi got her B.E. in Electronics and Communication from the Anna University. She did M.Tech. at the Indian Institute of Science (IISc) Bangalore and later did Doctorate from the Instrumentation Centre of Madras University. She is presently working as a Professor and Head in charge of the Department of Network Systems and Information Technology, AC Tech Campus of University of Madras. Her areas of specialization are in Electrical and Electronics Instrumentation Engg., Network Security and Information Technology, Advanced Microprocessor/controllers, Digital Communications and Biomedical telemetry. She is a Member of I.E.T.E., I.E.E.E., I.E(I). She was awarded the Environmental Tamil Nadu national award for the year 2004.

Mr. V.Vignesh is a M.Sc.(Physics), Thiruvalluvar University and M.Phil. in Scientific Instrumentation from the University of Madras. Presently he is doing Ph.D. in the Department of Network Systems and Information Technology, University of Madras. He has presented several papers in several National and International conferences. He has also published his research findings in reputed Journals. His areas interests includes Digital Signal Processing, Communication Theory, Embedded hardware and software and Bio –medical Instrumentation.

Dr.K.Padmanabhan, did his Grad.Brit.IRE, B.E. from Guindy Engineering College and Doctorate from the Madras University and has served as Professor and Head of the Instrumentation Centre, University of Madras. After retirement, he is A.I.C.T.E. Emeritus Professor in the Anna University. He is a Fellow of IETE, Senior Member IEEE and Fellow IEE. His areas of specialization range from Applied Electronics, Microprocessors, Instrumentation, Telecommunications and Digital Signal processing. His current interest is on the development of novel DSP based Telecom applications.

