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ŽABLJAK

XIX

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INFORMACIONE TEHNOLOGIJE

SADAŠNJOST I BUDUĆNOST

Urednik
Božo Krstajić

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Zbornik radova sa XIX naučno - stručnog skupa
INFORMACIONE TEHNOLOGIJE - sadašnjost i budućnost
održanog na Žabljaku od 24. do 28. februara 2014. godine

Zbornik radova
INFORMACIONE TEHNOLOGIJE - sadašnjost i budućnost 2014

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Univerziteta Crne Gore

Tiraž
150

Podgorica 2014.

Organizator

Elektrotehnički fakultet Univerziteta Crne Gore

Skup su podržali:

* Ministarstvo za informaciono društvo i telekomunikacije
* Pošta Crne Gore
* Agencija za elektronske komunikacije i poštansku djelatnost
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SADRŽAJ

KONCEPT ZA EKSPERTNI SISTEM ZA AUTOMATIZOVANU EKG DIJAGNOSTIKU
A CONCEPT OF EXPERT SYSTEM FOR AUTOMATED ECG DIAGNOSIS

Roman Golubovski, *Faculty of Electrical Engineering, University "Goce Delčev" - Štip, Republic of Macedonia*

Sadržaj: *Ekspertni Sistem (ES) je softver koji koristi bazu znanja ljudske ekspertize za rešavanje problema, ili rasćiščavanje nejasnoča gde se uobičajeno konsultuju eksperti. Ekspertni sistemi se uobičajeno koriste za specifične uske domene veštačke inteligencije (AI) gde je problematika sveobuhvatno pokrivena "znanjem". Ekspertni sistemi mogu implementirati i učenje. Jedna od fundamentalnih implementacionih područja je medicinska dijagnostika. Medžu najprominentnijim njenim apliakcijama je automatizovana EKG dijagnostika, jer EKG morfologija je potpuno determinirana. Predloženi ES se oslanja na standardni 12-kanalni EKG set - relevantni naponski parametri i vremenski segmenti i itnervali. Preliminarno testiranje na EKG snimke idu u prilog visokoj tačnosti dijagnostike konzistentno sa ekspertizom iskusnih kardiologa.*

Abstract: *An expert system (ES) is software that uses a knowledge base of human expertise for problem solving, or clarify uncertainties where normally one or more human experts would need to be consulted. Expert systems are most common in a specific problem domain, and are a traditional application and/or subfield of artificial intelligence (AI). Expert systems may or may not have learning components. One of the fundamental implementation areas is the medical diagnostics, most prominent being the automated ECG diagnostics since the ECG morphology is completely determined. The proposed ES relies on the standard 12-lead ECG set of relevant voltage deflections (amplitudes) and time segments and intervals (durations). Preliminary testing against ECG records promise high accuracy consistent with diagnostic opinions of expert cardiologists.*

1. INTRODUCTION TO EXPERT SYSTEMS

A common and acceptable definition of the Expert System (ES) is that it is a special type of system built upon detailed experience and knowledge acquired by human's brain, and formatted in such a way that allows a computer to solve problems from within a specific domain, that normally need human expertise. In the context of this paper the "problem" is the ECG diagnosis and the "expert" is a skilful cardiologist.

The fundamental concept behind the ES is trying to mimic the human reasoning which is still impossible to achieve in full. The human mental process is internal, and it is too complex to be represented as an algorithm. However, most experts are capable of expressing their knowledge in the form of rules for problem solving. The term rule in AI, which is the most commonly used type of knowledge representation, can be defined as an IF-THEN structure that relates given information or facts in the IF part (the condition) to some action in the THEN part (the action). A rule provides some description of how to solve a problem. Rules are relatively easy to create and understand. Rules can represent relations, recommendations, directives, strategies and heuristics. In the context of this paper rules test ECG parameters with threshold values in their conditional part and draw partial diagnostic conclusions.

The foundation of the modern ES is the ***production*** rule system model proposed by Newell & Simon (figure 1).

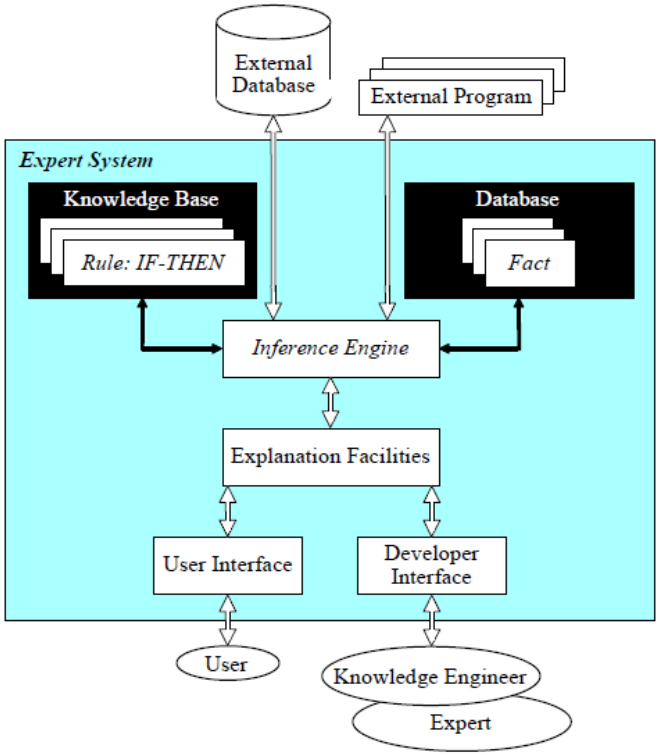

Figure 1. Complete structure of a rule-based ES

The production model is based on the idea that humans solve problems by applying their knowledge (expressed as production rules) to a given problem represented by problem-

specific information. The ***knowledge base*** contains the domain knowledge useful for problem solving. When the condition part of a rule is satisfied, the rule is said to ***fire*** and the action part is executed. The ***database*** (*working memory*) includes a set of facts used to match against the IF (condition) parts of rules stored in the knowledge base. The ***inference engine*** carries out the reasoning whereby the expert system reaches a solution. It links the rules given in the knowledge base with the facts provided in the database. The ***explanation facilities*** enable the user to ask the expert system ***how*** a particular conclusion is reached and ***why*** a specific fact is needed. An expert system must be able to explain its reasoning and justify its advice, analysis or conclusion. The ***user interface*** is the means of communication between a user seeking a solution to the problem and an expert system.

ES is widely implemented in modern ECG devices, but it is still just a helping tool to assist physicians in interpreting ECG (it must not be used as unverified diagnostic source). So being able to explain the deductive reasoning (forward or data-driven inference chaining) helps the physician to validate the conclusions.

2. IMPLEMENTATION OF THE ECG DATA

The standard 12-lead ECG is consisted of the six limb leads in the vertical plane - aVR, aVL, aVF, DI, DII and DIII (figure 2), and the six precordial leads in the horizontal plane - V1, V2, V3, V4, V5 and V6 (figure 3).

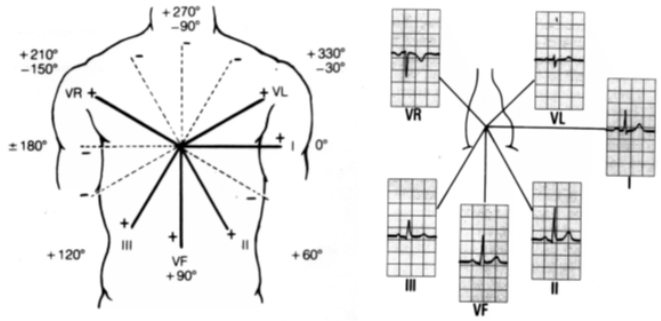

Figure 2. The limb leads

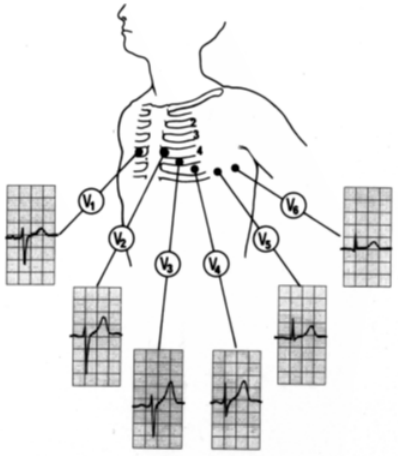

Figure 3. The precordial leads

An ECG record is a non-invasive diagnostic tool used for the assessment of a patient's heart condition. The features of the ECG, when recognized by simple observations, and combined with heart rate, can lead to a fairly accurate and fast diagnosis.

So far there have been a number of successful developments in the automated diagnosis domain. Like the ES for ECG analysis [1] that works by hierarchically organizing the knowledge in a context tree, where diseases are recognized by traversing the tree having symptoms as nodes and diseases as leafs. Others [2] have used time and frequency domain parameters and correlation constants derived from ECG signals as inputs for their expert system. A software for ECG beat detection and classification [3] had been developed and made available as an open source system for use by researchers. A technique for analyzing ECG signals using hidden Markov models for beat segmentation and classification [4] had also been proposed. The use of neural networks for automatic ECG analysis for the classification of different cardiac abnormalities [5] had also been explored.

Typical ECG morphology is presented on figure 4:

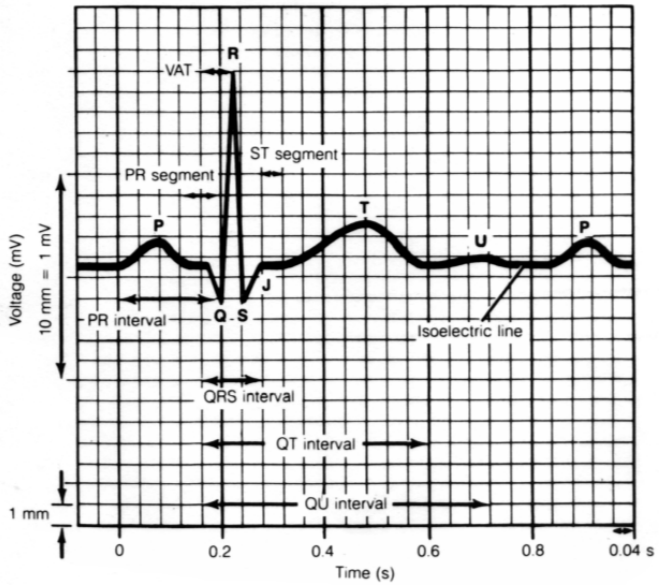

Figure 4. Typical ECG morphology

The proposed expert system concept/algorithm is a rule-based decision support system to aid physicians in the diagnosis of heart diseases. The set of ECG parameters of all 12 leads is related to voltage deflections and time segments/intervals (figure 4) of the:

- P wave
- QRS complex (Q, R and S strokes)
- ST segment
- T wave
- PR interval
- QRS duration
- QT interval
- RR interval
- PP interval

3. THE EXPERT SYSTEM CONCEPT

The concept of the proposed ES is shown in figure 1. The framework of the rule based expert system consists of:

- Facts - input obtained from derived parameters of the 12-lead ECG
- Knowledge Base - a set of rules developed in consultation with experts based on heart rate and ECG wave characteristics (parameters)
- Inference Engine - matches the input (facts) with a rule in the rule-base to identify the abnormality
- Database - stores the patient's personal details, inputs, diagnosed results and user's comments (suggestions)
- Explanation Facilities - provides the forward inference chaining in support of the proposed diagnosis

After thorough analysis of the available relations between the diagnostic conclusions and the corresponding sets of input values, all ECG diagnoses are divided in the following list of groups, which are chained for the process of determining diagnosis, whereas each of the group is consisted of *familiar* diagnostic statements:

- Preliminaries
- Conduction Abnormalities
- Hypertrophy
- Myocardial Infarct
- ST Elevation
- ST Depression
- T Wave Abnormalities
- Rhythm Statements

The algorithm passes through the chain of groups performing lists of tests within them and passing results to their next group of tests. Before evaluating the group list of tests it first performs the group's ***skip tests*** (figure 5). Skip tests decide weather group's evaluation is feasible or available data is insufficient resulting in skipping the current group tests.

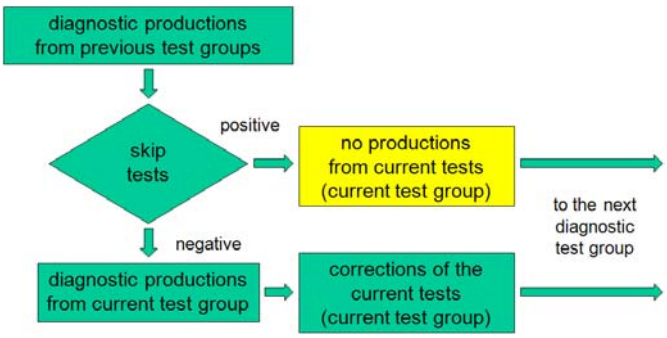

Figure 5. Algorithm of diagnostic chain evaluation

A condition statement follows each interpretive statement. Conditions and their meanings are listed in the table on figure 6.

The ***Preliminaries*** group identifies following conditions: Arm Lead Reversal and Dextrocardia; Wolff-Parkinson-White (WPW); Atrial Enlargement; Axis Deviation; Low Voltage; S1-S2-S3 Pattern; Pulmonary Disease.

The ***Conduction Abnormalities*** are: Right Bundle Conduction; Left Bundle Conduction; Non Specific Conduction Abnormality.

The ***Hypertrophies*** are: Right Ventricular Hypertrophy; Left Ventricular Hypertrophy.

The ***Myocardial Infarctions*** are: Anterior Infarct; Septal Infarct; Anteroseptal Infarct; Lateral Infarct; Anterolateral Infarct; Inferior Infarct; Inferior Infarct with Posterior Extension; Infarct Suppressions.

The ***ST Elevation*** diagnoses are: ST Segment Elevation; Early Repolarization; Pericarditis; Anterior and Septal Epicardial Injury; Lateral Epicardial Injury; Inferior Epicardial Injury.

The ***ST Depression*** diagnoses are: ST Depression; T Wave Abnormality and Ischemia.

The ***T Wave Abnormalities*** are: T Wave Abnormality, Nonspecific.

Condition	Meaning
Normal ECG	Normal
Atypical ECG	An unusual pattern has been observed but has no specific significance.
Borderline ECG	Criteria have limited specificity or prognostic significance or where only minimal criteria are met.
Abnormal ECG	Abnormal
Abnormal Rhythm ECG	Abnormal Rhythm
No Further Interpretation Possible	Upon detecting the phenomenon in question, no further useful interpretation of the record is possible.
No Condition Associated	Used with statement prefixes and suffixes.

Figure 6. General condition statements and explanation

Rhythm Statements: Sinus-, Atrial-, Junctional-, Supraventricular- (Tachycardia / Rhythm / Bradycardia); Undetermined (regular) rhythm; Atrial fibrillation; Atrial flutter; Electronic ventricular pacemaker. Known modifiers are also used for recognized specific condition details.

4. ES PRODUTION EXAMPLES

First Preliminaries test checks for possible lead reversal:

IF	THEN
No Q in lead I and R amplitude < 150uV in lead I **or** Q amplitude > 0 in lead I and P axis > 90 and PR duration >= 110 ms and QRS axis > 90	PRINT "Arm leads reversed" **REASON**: *Inverted P & QRS in lead I*
If above criteria are met and R amplitude < 500 uV in lead V6 and Maximum S amplitude > Maximum R amplitude in lead V6 and P amplitude < 20 uV in lead V6 and P' amplitude < -20 uV in lead V6	PRINT "Dextrocardia" **REASON**: *Inverted P & QRS in V6*

Figure 7. Test for Arm Lead Reversal and Dextrocardia

IF	THEN
R amplitude > 100 uV in V1 & V2 and R duration > 20 ms in V1 and V2 and no S in V1 or V2 **or** R'amplitude > 100 uV in V1 & V2 and R' duration > 20 ms in V1 & V2 and no S' in V1 or V2	PRINT "RsR' (QR) in V1/V2 consistent with right ventricular conduction delay"
Either of the above is true and QRS duration > 90 ms and QRS duration < 120 ms and S duration >= 40 ms in any 2 leads of I/aVL/V4/V5/V6	PRINT "Incomplete right bundle branch block" **REASON**: *90+ ms QRS duration, terminal R in V1/V2, 40+ ms S in I/aVL/V4/V5/V6*
QRS duration >= 120 ms and S duration >= 40 ms in any 2 leads of I/aVL/V4/V5/V6 and R duration < 100 ms in any 4 leads of I/aVL/V4/V5/V6 and QRS area > 0 in V1 and V1 does not terminate in S or S' **or** QRS duration > 105 ms and S duration >= 60 ms in any 3 leads of I/aVL/V4/V5/V6 and R duration > 60 ms in V1 and QRS area > 0 in V1	PRINT "Right bundle branch block" **REASON**: *120+ ms QRS duration, upright V1, 40+ ms S in I/aVL/V4/V5/V6*
The test for right bundle branch block is positive and R amplitude > 1500 uV in V1 and QRS axis > 110	PRINT "Right bundle branch block plus possible Right Ventricular Hypertrophy" **REASON**: *RBBB, 1.5 mV R in V1, RAD*

Figure 8. Right Bundle Conduction test

Figure 8 shows the amount of processing needed for RBBB determination. Figure 9 shows the ***skip*** tests for the Right Ventricular Hypertrophy:

SKIP TEST IF
The test for Right Bundle Branch Block is positive
or the test for Left Bundle Branch Block is positive
or age < 16
or S amplitude < 250 uV in I
or S amplitude > 1000 uV in V1
or QRS axis < 60
or QRS duration > 140 ms and net QRS amplitude < 0 in V1
or Q amplitude > S amplitude and R exists in I

Figure 9. Skip test for Right Ventricular Hypertrophy

Test for Inferior Infarct with Posterior Extension:

SKIP TEST IF
The test for an inferior infarct is negative
The test for Right Bundle Branch Block is positive

IF	THEN
Q amplitude > 0 in V1 or V2 and R duration >= 40 ms in V1 & V2 **or** R duration >= 35 ms and QRS net amplitude > 0 in V1 or V2 **or** R duration >= 30 ms and QRS net amplitude > 0 in V1 and V2	Append "with posterior extension" "prominent R Wave in V1/V2" to the inferior infarct statement

Figure 10. Testing for Inferior Inf. with Posterior Ext.

5. CONCLUSION

The proposed ES conceptualizes the standard cardiologists' reasoning, following a cardiology expertise supported by the vast clinical ECG experience. The data-chaining of the parameters tests follow the well established ECG diagnostic procedures, therefore high accuracy and reliability is expected upon thorough clinical performance investigation.

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CIP - Каталогизација у публикацији
Национална библиотека Црне Горе, Цетиње

ISBN 978-86-85775-15-4
COBISS.CG-ID 24749840

ISBN 978-86-85775-15-4