Increasing the Efficiency of the "Excluding Rules" of the Minnesota Coding System using the Fuzzy Logic

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Abstract. *A modified Minnesota Coding system was developed, which was 9,3% more efficient when coding the 3-1, 3-2, 6-4-1, 7-1-1, 7-2-1, 7-3, 7-4 rules. The beat-to-beat alteration of the QRS and QT parameters was analysed to examine the utility of fuzzy modification. Beat-to-beat variability showed 4,0 ms average standard deviation for the QRS and 7,9 ms for the QT.*

Keywords: Minnesota Coding system, fuzzy logic, wave parameters, beat-to-beat alteration

1. Introduction

This paper presents a beat-to-beat variability analysis of QRS and QT ECG parameters. The fuzzy based Minnesota Coding (MC) system can consider this type of variability and can increase the efficiency of the original Minnesota Coding system [1]. For the beat-to-beat analysis 20 patients (60 sec., 1 kHz, 12-lead) were examined. To test the modified MC system, an ECG dataset including 181 ECGs (120 sec., 1 kHz, 12-lead) was used. A total of 49 male (12 with definite coronary heart disease) and 47 female (7 with definite coronary heart disease) patients aged between 23 and 69 were enrolled.

2. Subject and Methods

Wave parameter detection

First the cycle-segmentation was done, this procedure was based on the R-waves and fidutial-points, subsequently the cycles were classified according to their waveform similarity [2]. A level of 0.98 was applied as a correlation threshold [3].

After the segmentation step the cycles not included in the dominant class were classified and sorted into several subclasses. Finally all the cycles had their own classes.

The average-cycles of each class and subclass were calculated, and the wave limits were detected automatically class by class using Eq. (1):

$$F(t) = \frac{dS(t)}{dt} \tag{1}$$

where $S(t_i) = \sigma\lfloor x_{j=1\ldots n}(t_i)\rfloor$ at a given t_i moment, n is the number of the channels and x_j is the j^{th} lead of the ECG record.

The crossing of a predefined threshold (by the standard deviation of an iso-potential period of the $F(t)$ function) shows one of the wave limits. Based on this results there is a manual opportunity to adjust the calculated wave limits (see Fig. 1).

All elements of the classes inherit the wave limits of the average cycle of their class. Then the Q_{onset}, S_{offset} and T_{offset} markers - showing the integration limits for QRS- and QRST- time integrals - can be modified interactively on one of the thorax leads of the 12-lead system arrangement (V1-V6) by the program. This option is suitable for the most accurate lead selection.

In this manner this study shows the "best-case" results. It means that our throughputs will provide the lower-bounds.

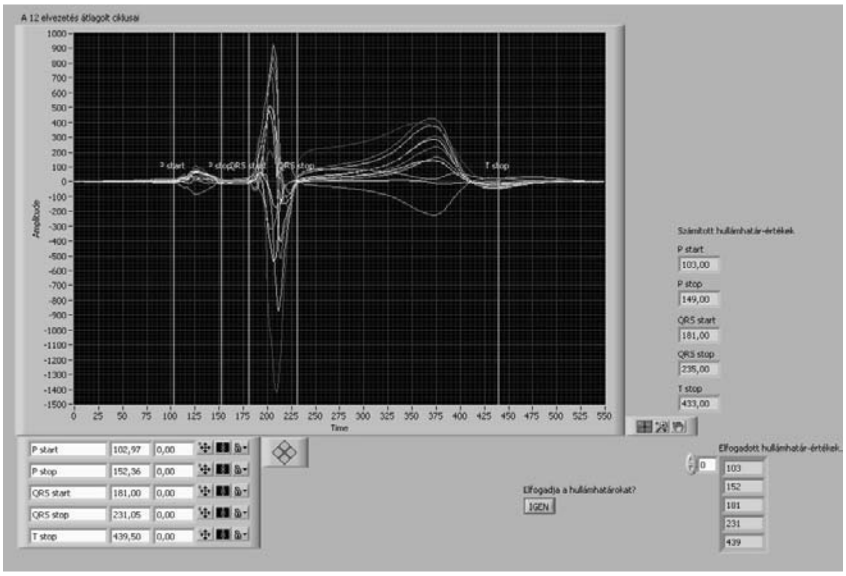

Fig. 1. Interactive marker-adjustment software

Minnesota Coding system

To evaluate the 12-lead ECG measurements the MC system [4, 5] was used. A minor amplitude or duration change can sometimes produce a significant MC change because ECGs are continuous whereas MC items are categorical [6]. The differences between the original and the fuzzy membership function of the 7-4 rule are shown in the Fig. 2-3.

This problem is especially crucial when coding the excluding rules that can suppress other Minnesota codes. To reduce the false diagnoses of the MC, some of the excluding rules (3-1, 3-2, 6-4-1, 7-1-1, 7-2-1, 7-3, 7-4) were modified using fuzzy logic. Ranges were created instead of well defined limits and the risk of accepting a rule was determined. The risk of accepting a rule can be low or high. If the risk is too high, the algorithm does not accept the rule.

First the ECGs coded with the 3-1, 3-2, 6-4-1, 7-1-1, 7-2-1, 7-3, 7-4 MC rules were selected. Subsequently the results of the original and modified MC system were compared. If there was a difference between the results, a technician coder and a senior supervisor examined the results.

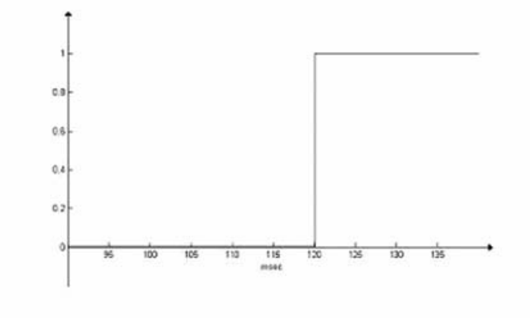

Fig. 2. The original membership function of the 7-4 rule

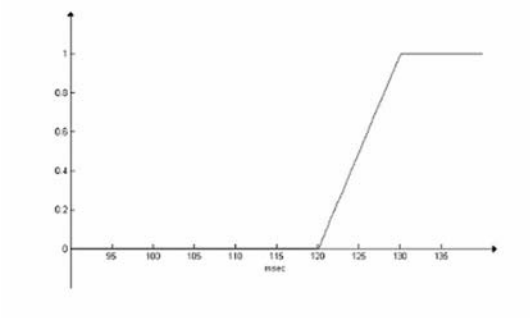

Fig. 3. The fuzzy membership function of the 7-4 rule

3. Results

The auto-correlation functions showed that the examined wave-parameters are independent variates in beat-to-beat monitoring. Table 1 shows the results of the beat-to-beat variations.

Table 1. QRS and QT beat-to-beat variability in 20 pateint's ECGs. (min.=minimum value, max.=maximum value, std=standard deviation)

	min. QRS [ms]	**max. QRS [ms]**	**std QRS [ms]**	**min. QT [ms]**	**max. QT [ms]**	**std QT [ms]**
1	87,4	112,8	3,9	411,8	459,7	10,4
2	93,1	110,0	3,0	454,1	479,5	5,9
3	88,9	95,9	2,5	382,8	411,8	9,7
4	102,6	119,7	4,1	370,5	396,1	5,3
5	93,1	104,4	3,1	341,3	361,0	4,0
6	81,8	98,7	2,9	363,8	406,2	8,1
7	79,0	95,9	3,9	400,5	445,8	9,3
8	84,6	95,9	2,6	377,9	414,6	6,4
9	98,7	124,1	6,2	349,7	392,1	8,6
10	81,8	98,7	3,6	349,7	372,3	4,7
11	70,5	81,8	2,6	394,9	420,3	6,1
12	76,2	90,3	3,0	425,9	456,9	8,1
13	76,2	93,1	3,5	400,5	434,4	7,7
14	125,4	148,2	3,7	418,9	467,4	9,6
15	79,8	122,5	8,3	336,3	390,4	9,6
16	93,1	110,0	3,9	414,6	445,6	7,5
17	64,9	81,8	4,4	406,2	456,9	13,0
18	168,1	185,2	4,2	421,8	461,7	8,5
19	79,0	98,9	5,0	403,3	434,4	6,5
20	87,4	107,2	4,7	361,0	409,0	9,4
Average	NA	NA	**4,0**	NA	NA	**7,9**

Testing the modified MC system out of the 181 ECGs, 28 ones were coded with excluding rules that were modified with fuzzy logic. In 6 of the cases the modified MC system did not accept some of the excluding rules and in these cases other non-excluding rules were coded (in agreement with the two human coders). For example, there was a man aged 45 who had 120 ms QRS duration, so the 7-4 Minnesota rule was coded and all 2-, 3-, 4- and 5-codes, 9-2, 9-4, 9-5 were excluded. The fuzzy based MC system determined that the risk of accepting the

7-4 rule is high, so the rules above were taken into consideration and 4-1 MC was coded, which agreed with the two human coders. In 11 of the cases the modified MC system did not accept some of the excluding rules and other non-excluding rules were not coded (in agreement with the two human coders).

4. Discussion

Having analysed the QRS- and QT-intervals, it was pointed out that both ECG parameters had significant deviation during one patient's 60 sec long record. It suggests applying the fuzzy logic to increase the utility of the MC. For a selected parameter the recommended deviation can be estimated, while the standard deviation of this averaged parameter is a function of the number of the cycles involved in the averaging . Taking advantage of this fact, the ranges of the fuzzy logic can be constructed. The original and the modified MC system were compared. The 3-1, 3-2, 6-4-1, 7-1-1, 7-2-1, 7-3, 7-4 excluding rules were modified using fuzzy logic. We had 17 cases when the modified MC system did not accept some of these rules. In 6 cases without these rules other non-excluding rules were coded and in 11 cases non excluding rules were not coded. This comparison showed that the efficiency of the original MC [4, 5] can be improved. Other rules of the MC can be also modified using the fuzzy logic, but it has to be noted that the complexity will increase substantially with the number of the conditions of a rule.

Acknowledgements

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