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Diagnosing Dangerous Arrhythmia of Patients by Automatic Detecting of QRS Complexes in ECG

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***Abstract*—**In this paper, an automatic detecting algorithm for QRS complex detecting was applied for analyzing ECG recordings and five criteria for dangerous arrhythmia diagnosing are applied for a protocol type of automatic arrhythmia diagnosing system. The automatic detecting algorithm applied in this paper detected the distribution of QRS complexes in ECG recordings and related information, such as heart rate and RR interval. In this investigation, twenty sampled ECG recordings of patients with different pathologic conditions were collected for off-line analysis. A combinative application of four digital filters for bettering ECG signals and promoting detecting rate for QRS complex was proposed as pre-processing. Both of hardware filters and digital filters were applied to eliminate different types of noises mixed with ECG recordings. Then, an automatic detecting algorithm of QRS complex was applied for verifying the distribution of QRS complex. Finally, the quantitative clinic criteria for diagnosing arrhythmia were programmed in a practical application for automatic arrhythmia diagnosing as a post-processor. The results of diagnoses by automatic dangerous arrhythmia diagnosing were compared with the results of off-line diagnoses by experienced clinic physicians. The results of comparison showed the application of automatic dangerous arrhythmia diagnosis performed a matching rate of 95% compared with an experienced physician's diagnoses.

***Keywords*—** Signal processing, electrocardiography (ECG), QRS complex, arrhythmia.

I. Introduction

CARDIOPATHY is one of the top three causes of death in recent years. The survey of causes of death for the population aged over 65 years old in Taiwan shows that the number of the people who died of heart diseases has increased 23.78 people per one hundred thousand populations from 2004 to 2005. Because the population is aging gradually in Taiwan, the issue about preventing, diagnosing, and therapy of cardiopathy for elder civilians is becoming a serious problem.

Cardiopathy always attacks patients unpredictably and let patients fall into an immediate fatal situation. Without emergent treatment, patients could die or be cured with permanent injures. Recently, medical technicians monitor the ECG signals of arrhythmia patients by a mobile nursing system [1]. In this wireless nursing system, a wireless ECG detector keeps recording and transferring patient's ECG signals to monitoring server in hospital twenty four hours a day no matter where he is. Medical technicians keep watching the ECG signals transferred from patients and make decisions for whether to take advanced diagnosis by a clinic physician or not. In practical operation, a medical technician must monitor several ECG signal sources from different patients simultaneously, and it is possible for a medical technician to make wrong decisions for patients or ignore emergent situations. Any tiny mistake or ignorance will result unpredictable damages for patients. As a solution of this problem, automatic QRS complex detecting techniques applied for pre-diagnosing patients' conditions are being developed in recent years [2]. To clarify the process for automatic arrhythmia diagnosing, the whole process was divided to three parts. They are:

1) Noise elimination - Real ECG recording are mixtures of QRS complexes, P-wave, T-wave, natural noises, interference of power sources, interferences from other bio-signals, unidentified noises, etc. Hardware filters, digital filters and signal smoothing techniques [2,3] are common techniques applied for purifying ECG recordings. In this study, the original ECG recordings detected directly from patients were treated by hardware filters and digital filters. Those digital filters are supported in toolbox of Matlab.
2) QRS complex detecting – Many QRS detection algorithms [4,5,6,7] were proposed in succession. In this paper, several QRS complex detecting algorithms were applied to detect the QRS complex of ECG. Base on the comparison of results for different QRS detecting algorithms, the algorithm with the highest detecting rate was applied for automatic QRS complex detecting algorithm.
3) Arrhythmia diagnosing – The arrhythmia diagnosing algorithm based on the clinic quantitative criteria for

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diagnosing arrhythmia was implemented in Matlab and used to estimate the ill-conditions of arrhythmia for patients.

Hence, we tried to combine with noise eliminating techniques, automatic QRS complex detecting algorithm, and modeling of quantitative criteria for arrhythmia diagnosing to an protocol type of automatic dangerous arrhythmia diagnosing system. Furthermore, results of automatic diagnosing were checked with physician's diagnoses for evaluating the performance of automatic arrhythmia diagnosing system.

II. Material and Methods

In this investigation, twenty samples of ECG recordings of different patients were used for study cases. These ECG recordings were collected and recorded by CARD GUARD in digital format. It is easy to redraw and analysis those digital ECG recordings in Matlab. The number of samples is not enough for a complete research concerning the effects of age, gender, weight, etc. Because the purpose of this study focuses on automatic QRS complex detecting and arrhythmia diagnosing, these factors, such as age, gender, and weight, etc. are not concern factors for sampling. Hence, twenty study cases from different patients with different statuses of arrhythmia were tested the performance of automatic diagnosing system for five common ill-conditions of arrhythmia.

Guard card – a mobile device for recording and transferring ECG signal

For practical application, Guard card shown in Fig.1, product of CARD GUARD Inc. Switzerland, is used to monitor patients' ECG in Taiwan. This device can keep tracing patients' ECG no matter what time it is and where patients are. The ECG signals are transferred to the monitoring center in hospital via telephone immediately. For the concern of real-time monitoring, the period of ECG signal transferring is as small as possible. In monitoring center of hospital, medical technicians keep watching patients' ECG signals all over the time. They make immediate responses for patient's ill-conditions. Guard card transfer ECG signals with public mobile communication system. Because public mobile communication system is becoming unbounded, this distant monitoring device can help patients of cardiopathy leave hospital and have normal lives.

Fig. 1 Guard card implemented by the Far Eastern Memorial hospital

Electrocardiogram (ECG) signal

ECG signal is a time-series changing of voltage in a cardio-system. Because ionic currents are the source of an ECG signal, it can reflect and record the activity of heart. The complete waveform in Fig. 2 is called an ECG signal, with labels P, Q, R, S, and T indicating its distinctive features [9]. The P-wave arises from depolarization of the atrium. The QRS complex arises from depolarization of the ventricles. The magnitude of the R-wave within this complex is approximately 1 mV. The T-wave arises from repolarization of the ventricle muscle. QRS complex is the most significant wave of an ECG signal and R-R interval can be used for obtaining the heart rate.

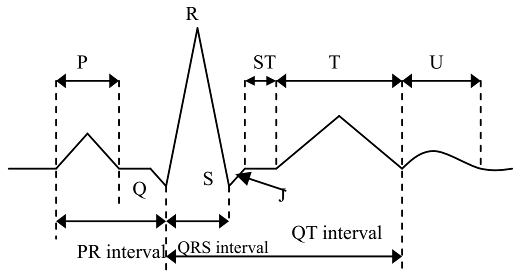

Fig. 2 Schematic of an ECG signal

Traditional ECG recorder draws ECG signals on grid paper [Fig.3] with grid size of 1mm. The longitude direction represents time axis and the lateral direction represents the voltage. The scales of grid paper are 0.4 sec/cm for time and 1 mV/cm for voltage. When recording ECG, recorder scrolls grid paper in a constant speed of 25 mm/sec. In the other words, each grid width represents 0.04 sec.

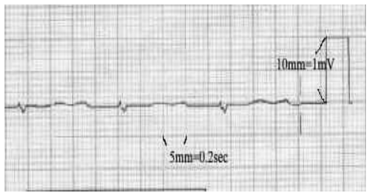

Fig. 3 ECG Recording on grid paper

QRS complex detecting algorithm

In recent years more and more QRS complex detecting algorithms were proposed in succession. In 1990, Friesen et al. compared the noise sensitivity of nine QRS detection algorithms [7]. The Digital Filter 1 has better performance for detecting QRS complexes of ECG signals mixed with different combinations of noises. In this paper, the algorithm of Digital Filter 1 was applied for QRS complex detecting algorithm. The algorithm of Digital Filter 1 is an adaptation of the developed by Engelese and Zeelenberg [7]. The ECG is passed through a differentiator with a 62.5 Hz notch filter and a digital low pass filter. Two thresholds, equal in magnitude but opposite in polarity, are used for scanning and classifying a base-line shift, a QRS candidate, or as noise.

Five Criteria for diagnosing arrhythmia ill-conditions

Referring a textbook of ECG recording and arrhythmia diagnosis [8], there are over three hundred types of ill-conditions of arrhythmia which can be identified by ECG. One hundred and eighteen out of the three hundred types of ill-conditions commonly checked in regular examinations for diagnosing heart diseases in the Far Eastern Memorial hospital. However, the QRS complex detecting algorithm applied in this paper can extract R-R interval and QRS complex interval of

ECG signal but not P-R interval, S-T interval, and Q-T interval. Most of ill-conditions of arrhythmia are complicated and unclear. They cannot be expressed with inequalities of R-R interval and QRS interval. And these ill-conditions are not emergent conditions and need to be diagnosed by experienced physicians. Here, functions of an automatic diagnosing should be limited for diagnosing dangerous and common ill-conditions of arrhythmia. Therefore, five common and dangerous ill-conditions of arrhythmia were applied as a set of clinic quantitative criteria. These clinic criteria for detecting arrhythmia ill-conditions are:

(a) Heart beat pauses (HBP)
(b) Extreme bradycardia (EB)
(c) Narrow QRS tachycardia (NT)
(d) Wide QRS tachycardia (WT)
(e) Mobitz type II (MT II)

In this paper, these criteria were redefined in inequalities of R-R interval and QRS complex interval. Here, these inequalities are called as quantitative criteria. Quantitative criteria are convenient for modeling. For instance, it is difficult to define the regularity of heart beat in text description. A quantitative criterion can define the regularity of heart beat as an inequality of R-R interval, the distance between two contiguous QRS complexes. For example, when all the R-R intervals of ECG locate in the range between average R-R interval plus ten percents and minus ten percents, the regularity of heart beat can be diagnosed as good [8]. Otherwise, the heart beat has bad regularity. Each parameter extracted from ECG signals can show particular characteristic of heart beats. For example, P-R interval is the key factor of regularity of atrium beat. In the other words, the regularity of atrium beat can be defined as the stability of P-R intervals. When the atrium beats regularly, the P-R intervals are similar to a constant [8].

Implementation

In this investigation, the original recordings of ECG were recorded in digital format. For the purposes for evaluating the performances of automatic QRS complex detecting and arrhythmia diagnosing, digital ECG recordings should be redrawn on grid paper for convenience that analyst and physician can read and diagnose original ECG plots easily. Here, automatic QRS complex detecting algorithm and automatic diagnosing criteria were implemented in Matlab. The results of automatic arrhythmia diagnosing were compared with those by man-made diagnosing with ECG plots on grid paper for confirming the performances of automatic algorithms. As mentioned above, ECG in digital format cannot be read and diagnosed by technicians or physicians without ECG plots. To redraw the waveforms of ECG make analysts and physicians easy to study the features of ECG recordings. Furthermore, the scales of waveforms of ECG should be similar to scale of traditional ECG plots on grid paper. It makes an experienced clinic physician to read those ECG plots easily. An ECG plot in proper scale is shown in Fig. 4.

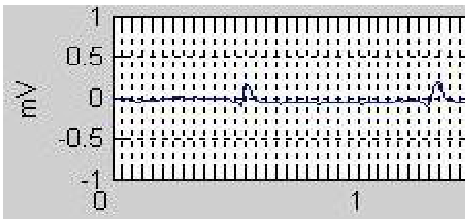

Fig. 4 An ECG plot in proper scale

1) Toolbox of digital filters in Matlab

There are many functions of digital filters in the toolbox of MATLAB. In this study, referring the characteristics of ECG data and noises, infinite impulse register (IIR) was applied as digital filter for filtering ECG recordings. This digital filter can support all the functions of low pass filter, high pass filter, band pass filter, and band stop filter. It is easy to modify the function of filter by setting characteristic parameters of digital filter.

For the purposes to eliminate the noises and to better ECG signals, some parameters should be set with proper values. The order of filtering is one of those parameters. A higher order of filtering could make filter to cut off more signals, not just the noises. Here, the second order of filtering was suggested by experiences. Another critical parameter of digital filter is the type of filter. There are four basic types of digital filters in the toolbox of Matlab. The four basic filters and their parameters applied in this study were described as following:

(a) Low-pass filter

For a commercial ECG recorder, there are three options, 15Hz, 25Hz, and 40Hz, for cutoff frequency of low pass filter. When signals pass through a low pass filter, the part of signals with frequencies higher than cutoff frequency will be filtered. Here, the three options of cutoff frequencies were considered to be different types of low pass filters. The results with different low pass filter were also compared for verifying the effect of cutoff frequency for a low-pass filter.

(b) High-pass filter

The cutoff frequency for high-pass filter was fixed at 0.01Hz. Any noise with frequency lower than 0.01Hz will be eliminated by a high-pass filter.

(c) Band-stop filter

The frequency of band-pass filter is not a single value but a span. In general, the band of filtering in this study was set on the span between 55Hz and 65Hz. As a digital filter in toolbox of Matlab, band-stop filter is a sub-type of band pass filter with an action code of ‘STOP’. The function of this digital filter is focus on the purpose of eliminating power-line interference.

(d) Median filter

Purpose of digital median filter is smoothing signals by taking the median of odd number of continuous sampling points [10]. The median filter thus uses both past and future values for predicting the current point. It can also be used to eliminate the singular points. Fig.5. shows a simulating for an median filter. Solid line represents the original signals and dot line represents the filtered signals.

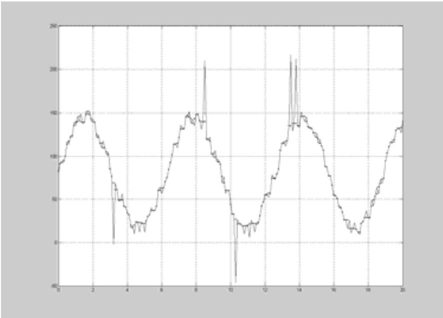

Fig. 5 A simulation of median filter. There are five stand-out points of original signals eliminated by median filter. The filtered signals have similar waveform to original signals without stand-out points.

2) Detecting and marking QRS complexes

The algorithm of Digital Filter 1 for automatic QRS complex detecting was implemented in Matlab. By this detecting algorithm, Q-wave can be detected first. Because Q-wave is the start-point of QRS complex, it is easy to trace the significant peak of R-wave closely next to Q-wave and the next reversing point for S-wave. Here, the Q-wave and R-wave of QRS complex were marked by lines (shown in Fig. 6 and Fig. 7).

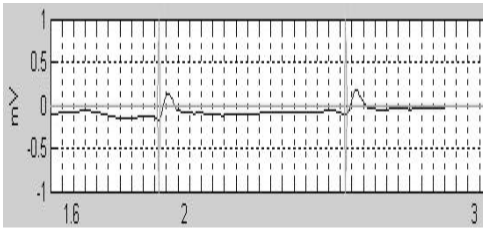

Fig. 6 Marks of Q-waves in ECG

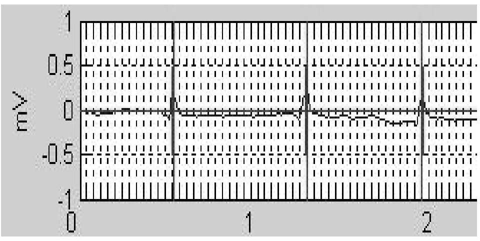

Fig. 7 Marks of R-waves in ECG

3) The quantitative criteria for arrhythmia diagnosing

In this study, five quantitative criteria for common ill-conditions of heart were implemented as following:

(a) Pause of heart beat

In this study, ECG was recorded with the sampling rate of 225 Hz. The time-interval of three seconds has 675 sampling points. When a R-R interval covered over 675 sampling points, a serious ill-condition for pause of heart beat will alarm immediately. Because it is a fatal ill-condition, automatic diagnosing system should deliver an emergent message for rescue.

(b) Extreme bradycardia

The ill-condition of extreme bradycardia means that heart beats too slowly. As a quantitative criterion, the inequality can be expressed as:

Heart rate < 40 beats/min or R-R interval > 1.5 sec

This ill-condition must be a contiguous ill-condition because heart rate is a dynamic variable. It can be derived as a temporal value with a single R-R interval. In previous criterion for diagnosing the ill-condition for pause of heart beat, it should be diagnosed immediately when a new R-wave cannot be identified for over 675 sampling points following the last R-wave. But the ill-condition of extreme bradycardia cannot be diagnosed when a single R-R interval was over 1.5 seconds. That six continuous R-R intervals are over 1.5 seconds in an adequate period is a clear sign for diagnosing the ill-condition of extreme bradycadia.

(c) Narrow QRS tachycardia

The ill-condition of narrow QRS tachycardia can be identified by two conditions. One is narrow time span of QRS complex, and the other one is narrow R-R interval. For a quantitative criterion of diagnosing ill-condition of narrow QRS complex, time span of QRS complex should be smaller than 0.1 second. Condition of narrow R-R interval is detected when R-R interval is smaller than 0.4 second. When both conditions were satisfied, the ill-condition of narrow QRS tachycardia can be detected.

(d) Wide QRS tachycardia (persistent or short-run/3-6 continuous VPC)

The quantitative criterion for diagnosing ill-condition of wide QRS tachycardia is an inequality of the time span between two continuous QRS complexes and R-R interval. When the time span between two continuous QRS complexes was bigger than or equal to 0.12 sec and R-R interval was smaller than 0.6 sec, the single sign of wide QRS tachycardia was detected. But, just one sign is not sufficient for diagnosing ill-condition of wide QRS tachycardia. Six or more signs of wide QRS tachycardia are required for confirming it. While the number of signs of wide QRS tachycardia was bigger than three but smaller than six, another ill-condition for short-run/3-6 continuous VPC was diagnosed.

(e) Mobitz type II

P-R interval is also an important parameter for diagnosing arrhythmia. As a normal situation, P-R intervals should be similar to each other. In this ill-condition, two conditions should be satisfied simultaneously. One is the similarity between two continuous P-R intervals and the other is QRS complex interval. Ill-condition of second degree AVB was detected when the similarity between two continuous P-R intervals was bad and QRS complex interval was smaller than 0.1 second. Because R-waves were not always clear, P-R intervals could not be figured out certainly. So the quantitative criterion for diagnosing the ill-condition of Mobitz type II was simplified to inequality of QRS complex interval here.

Evaluating the performance of automatic diagnosing

The sampled ECG recordings were plotted on grid papers for man-made diagnoses. On the other hand, digital ECG recordings were convenient for automatic diagnosing. The coherence between results of automatic diagnosing and diagnoses by experienced physicians was calculated as an indicator of performance of automatic diagnosing. In this study, each ECG recording was treated by the criteria for diagnosing these five ill-conditions mentioned previously. Physician also diagnosed the five ill-conditions to every ECG recording. The results were tabulated by IDs of samples, ill-conditions, and diagnosing mechanisms, automatic algorithm or man-made diagnoses. Furthermore, for the purpose of estimating the effect of cutoff frequency of low-pass filter, ECG recordings were filtered by low-pass filters with different cutoff frequencies. And each option of cutoff frequency was tabulated for an independent study case. So, there are sixty study cases, five ill-conditions, and two diagnosing mechanisms in this study. The results of diagnoses of the same study case and same ill-condition but different diagnosing mechanisms were put together for comparison.

III. Results

Twenty sampled recordings of ECG from different patients were used for study cases in this study. The original ECG recordings of study cases were filtered by four filters with different functions. They were low pass filter, high pass filter, band stop filter, and median filter. In this study, only the cutoff frequency of low pass filter was set up with three options, 15Hz, 25Hz, and 40Hz. The frequencies of the other filters were set up with fixed parameters.

The diagnoses will be marked with symbols. When a diagnosis is positive, it was marked with '+'. Otherwise, it was marked with '-'. Here, a positive diagnosis means that the inequality of quantitative criterion of single ill-condition is satisfied. Table 1 showed the comparison results of both diagnosing mechanisms, automatic diagnosing and physician's diagnosis, for all the different cutoff frequencies of low pass filter, cases, and ill-conditions. To verify the results of different diagnosing mechanisms, 'auto' was used for diagnosis by automatic diagnosing algorithm and 'phys' for diagnosis by physician. Checking the diagnoses of the same study case but different diagnosing mechanisms, it was noted as 'match' when diagnoses of both diagnosing mechanisms are similar to each other. The ratio of numbers of matches and study cases was defined as matching rate. To discuss the effect of cutoff frequency of low pass filter, the matching rate of different cutoff frequencies of low pass filter were calculated with twenty ECG recordings and five ill-conditions. They are 93.57% for 15Hz, 95.00% for 25Hz, and 96.42% for 40Hz. The average matching rate for three different low pass filters is 95.00%. It is seem to be a higher cutoff frequency of low pass filter can result a better matching rate when the cutoff frequency of low pass filter is limited in a reasonable range.

IV. Conclusions

In this study, an automatic arrhythmia diagnosing application was built up and evaluated by comparison with man-made diagnoses. A fundamental architecture of automatic arrhythmia diagnosing consists of signal filtering, automatic ECG signal detecting, and criteria modeling for arrhythmia diagnosing. Here, four basic types of digital filters in Matlab toolbox were applied for bettering the sampled ECG recordings. For an advanced application to eliminate more noises in ECG recordings, more knowledge of sorts of noises is required. There are still many unpredictable noises in ECG recordings when the wireless ECG recording devices are applied for patients who stay in different surroundings. The best way for reducing the noises in ECG recordings is to figure out the sorts of noises and filter them as possible as we can. The QRS complex detecting algorithm applied in this paper performed a good performance with high detecting rate of QRS complex. But for an advanced application, more information hidden in ECG signals should also be detected. The further information includes P-R interval, S-T interval, Q-T interval, and distribution of P-waves and T-waves. In this study, the goal was narrowed down for detecting five common ill-conditions of arrhythmia. The automatic diagnosing model with quantitative diagnosing criteria performed an matching rate of 95 percents. As mentioned before, more than three hundred types of ill-conditions of arrhythmia can be figured out in ECG recordings. For commercial application, more quantitative criteria for diagnosing ill-conditions of arrhythmia should be built in automatic diagnosing model. There are still a lot of works to do in future.

Table I
The comparison results of both diagnosing mechanisms, automatic diagnosing and physician's diagnosis, for all the different cutoff frequencies of low pass filter, cases, and ill-conditions. To verify the results of different diagnosing mechanisms, 'auto' was used for diagnosis by automatic diagnosing algorithm and 'phys' for diagnosis by physician

Patient ID	Cutoff frequency of low pass filter	ill condition									
		HBP		EB		NT		WT		MT II	
		Diagnosing mechanism									
		auto	Phys	auto	phys	auto	phys	auto	phys	auto	Phys
1	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
2	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
3	15Hz	-	-	-	-	-	-	+	+	-	-
	25Hz	-	-	-	-	-	-	+	+	-	-

	40Hz	-	-	-	-	-	-	+	+	-	-
4	15Hz	-	-	-	-	+	+	-	-	-	-
	25Hz	-	-	-	-	+	+	-	-	-	-
	40Hz	-	-	-	-	+	+	-	-	-	-
5	15Hz	-	-	-	-	-	-	-	-	-	+
	25Hz	-	-	-	-	-	-	-	-	+	+
	40Hz	-	-	-	-	-	-	-	-	+	+
6	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
7	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
8	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
9	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
10	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
11	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
12	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
13	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	+	-
	40Hz	-	-	-	-	-	-	-	-	-	-
14	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-
15	15Hz	-	-	-	-	+	+	-	-	-	-
	25Hz	-	-	-	-	+	+	-	-	-	-
	40Hz	-	-	-	-	+	+	-	-	-	-
16	15Hz	-	-	-	-	-	-	-	-	+	+
	25Hz	-	-	-	-	-	-	-	-	+	+
	40Hz	-	-	-	-	-	-	-	-	+	+
17	15Hz	-	-	-	-	-	-	-	+	-	-
	25Hz	-	-	-	-	-	-	-	+	-	-
	40Hz	-	-	-	-	-	-	-	+	-	-
18	15Hz	-	-	-	-	-	-	-	+	+	-
	25Hz	-	-	-	-	-	-	-	+	-	-
	40Hz	-	-	-	-	-	-	-	+	-	-
19	15Hz	-	-	-	-	-	-	-	-	+	-
	25Hz	-	-	-	-	-	-	-	-	+	-
	40Hz	-	-	-	-	-	-	-	-	-	-
20	15Hz	-	-	-	-	-	-	-	-	-	-
	25Hz	-	-	-	-	-	-	-	-	-	-
	40Hz	-	-	-	-	-	-	-	-	-	-

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