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Development of Arrhythmia Diagnosis Algorithm for Effective Control of Antitachycardia Pacing and High Energy Shock of ICD

Hangsik Shin, Chungkeun Lee, Jinkwon Kim , Myoungho Lee

Abstract*— *In this paper, we propose a modified arrhythmia diagnosis and therapy control algorithm based on VENTAK PRIZM 2TM algorithm of the Guidant corp. Existing arrhythmia detection and therapy control algorithms control arrhythmia through two steps. First step is event detection using peak-to-peak interval detection, and the second step is duration detection. We modify these stages to improve diagnosis time delay and treatment efficiency.

I. INTRODUCTION

Implantable cardiac supporting device algorithms adopted to ICDs(Implantable Cardioverter defibrillators) or pacemakers are to diagnose the heart condition and to treat cardiac arrhythmia such as bradycardia, tachycardia, and fibrillation. Nowadays, many ICD and pacemaker vendors have their own diagnosis and control algorithm for effective treatment [1][2][3].

The most important factor of these algorithms are diagnosis accuracy and effectiveness of the treatment on arrhythmia. However, the latest algorithms of implantable cardiac devices have very high diagnosis accuracy. Therefore, power saving methods through effective control [4], rate adoptive methods through activity monitoring [5], and improving technique for arrhythmia detection and treatment using morphological analysis are considered as more important factors for evaluating algorithms of cardiac supporting devices [6].

Operating procedure of implantable cardiac support system consists mainly of acquisition of electrogram, peak detection of obtained signals, real-time arrhythmia diagnosis, and stimulator or defibrillator control for treatment. Most implantable cardiac supporting devices adopt the AGC (Auto Gain Control) method for peak-detection of electrogram [1][2][3][7]. However, algorithms of each vender have somewhat different characteristics. These differences provide important viewpoints in evaluating algorithm performance. We propose a more efficient diagnosis algorithm based on VENTAK PRIZM 2™ of Guidant corp.

H. Shin is with Department of Electrical and Electronic Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea (e-mail: glority@yonsei.ac.kr)
C. Lee is with Department of Electrical and Electronic Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea (e-mail: micon78@yonsei.ac.kr)
J. Kim is with Department of Electrical and Electronic Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea (e-mail: jinkwon-mailbox@yonsei.ac.kr)
M. Lee is with Department of Electrical and Electronic Engineering, Yonsei University, 134 Sinchon-dong, Seodaemun-gu, Seoul, Korea (corresponding author to provide phone: +82-2-2123-4946; fax: +82-2-312-2770; e-mail: mhlee@yonsei.ac.kr).
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II. VENTAK PRIZM 2™ ALGORITHM

VENTAK PRIZM2™ algorithm consists of sensing, detection and duration, detection enhancement, and therapy stages [7]. Sensing means signal acquisition and peak-detection, detection and duration means arrhythmia event generation and diagnosis, detection enhancement means rate-adaptive methods for more accurate diagnosis, and therapy means ATP (Anti-Tachycardia Pacing) or HES (High Energy Shock)..

A. Sensing

Sensing means beat-detection procedure. For example, in sensing procedure P-wave is detected from the atrium and R-wave is detected from the ventricle. Fig. 1 shows peak-detection procedure of VENTAK PRIZM 2™. In sensing, the threshold is automatically set at 75% of the maximum peak amplitude when the sensed signal is larger than the maximum threshold. Once the threshold is setup, the threshold decreases exponentially until it meets the next peak signal. The system recognizes the peak and adjusts the threshold level accordingly.

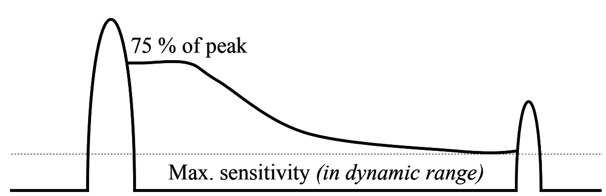

Fig. 1 Basic sensing algorithm of VENTAK PRIZM 2™ using AGC method.

B. Detection and duration

In general, implantable cardioverter defibrillator compares peak-to-peak duration to diagnose arrhythmia. Fig. 2 is a example of arrhythmia diagnosis criteria. From the RRI(R to R Interval) of ventricle signal we could diagnose the arrhythmia condition.

Fig. 3 shows the diagnosis procedure using the above criteria. First of all, in the detection zone, we collect the latest 10 peak to peak durations. Then, we count the number of available peak durations based on Fig. 3. Arrhythmia event is diagnosed if the number of available peak-duration exceeds the threshold that

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was already set by the programmer. After the event occurrence, in the duration zone, we perform the same procedure as in the detection zone. If the signal exceeds the threshold that had been set, the defibrillator recognizes the situation as an arrhythmia.

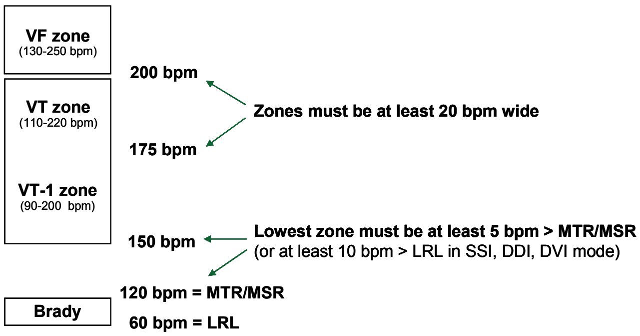

Fig. 2. An example of the criteria for ventricle arrhythmia diagnosis. i) Calculate RR interval, ii) Calculate bpm (beats per minute), iii) When bpm>200, it is considered ventricular fibrillation. When 200>bpm>175, it is considered fast ventricular tachycardia. When 175>bpm>150, it is considered slow ventricular tachycardia. When 60>bpm, it is considered ventricular bradycardia. (MTR: Maximum Tracking Rate, MSR: Maximum Sensor Rate, LRL: Lower Rate Limit)

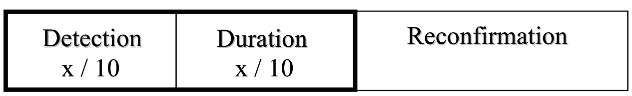

Fig. 3. The procedure of arrhythmia diagnosis. x means the predetermined threshold.

C. Detection Enhancement

In some cases such as exercise, implantable cardiac devices are capable of misdiagnosing arrhythmia. Therefore, ICD algorithms have to consider these special cases, VENTAK PRIZM 2™ algorithm provides a detection enhancement zone to discriminate between real arrhythmia conditions and wrong diagnosed arrhythmia. For activity measurement, accelerometer or rate-adaptive algorithms are generally used. In VENTAK PRIZM 2™, onset/offset methods and stability algorithm are used as a detection enhancement procedure.

D. Therapy

Implantable defibrillator uses two kinds of electrical stimulus to treat cardiac arrhythmia. One is ATP, which exerts electrical stimulation at 70~80 % duration of tachycardia beat-to-beat interval. ATP is mainly used to remove slow-tachycardia, however depending on circumstances it could be used as an effective treatment method in removing fast-tachycardia.

Another therapy method is HES, which recovers normal state from arrhythmia by stimulating with 5 ~ 31 Js of high energy shock [8]. HES is generally used for the recovery of fast tachycardia which has failed to recover with ATP and fibrillation.

VENTAK PRIZM 2™'s therapy methods could be set for user convenience. Both the number of stimulus and stimulus interval could be controlled. Moreover, the power of HES is could also be controlled. Generally, ICDs give ATP in slow tachycardia cases, ATP or HES in fast-tachycardia cases, and HES in fibrillation cases. When repetition therapy is needed, we could increase the number of ATP or increase the output power of HES. Moreover, we could change the therapy mode to HES, if ATP does not work properly.

III. Modified Detection and Duration Zone Control

A. Delayed Therapy Problem

Existing algorithms have a detection zone and a duration zone to diagnose arrhythmia. In this algorithm, arrhythmia is detected in the duration zone finally after an event is established in the detection zone. From this characteristic, therapy delay could occur when diagnosis results do not match between the detection zone and the duration zone.

In table 1, we can find that improper therapy is possible in the following case, diagnosis results are not match between detection zone and duration zone. Surely, recovering is possible by changing the therapy type after failed therapy, but improvement is needed in time delay and power consumption viewpoint.

Table 1
Diagnosis and Therapy by Comparing Diagnosis Results between Detection and Duration Zone.

Detection zone	Duration zone	Diagnosis	Therapy
Slow-VT	Normal	Re-detection	-
Slow-VT	Slow-VT	Slow-VT	ATP
Slow-VT	Fast-VT	Slow-VT	ATP(E)
Slow-VT	Fibrillation	Slow-VT	ATP(E)
Fast-VT	Normal	Re-detection	-
Fast-VT	Slow-VT	Re-detection	-
Fast-VT	Fast-VT	Fast-VT	ATP/HES
Fast-VT	Fibrillation	Fast-VT	ATP/HES(E)
Fibrillation	Normal	Re-detection	-
Fibrillation	Slow-VT	Re-detection	-
Fibrillation	Fast-VT	Re-detection	-
Fibrillation	Fibrillation	Fibrillation	HES

B. Modified Event Methods

The algorithm mentioned above makes arrhythmia event in the detection zone and diagnoses arrhythmia in the duration zone. Using this algorithm, if results between the detection zone and the duration zone are different, it is possible to diagnose again from the detection zone or to perform improper therapy. Moreover, this causes an effective power management and delayed diagnosis problem. Table 1 shows these contents, we find type of therapy in each detection zone and duration zone cases.

To compensate for these problems, in this paper, we propose a modified detection and duration zone diagnosis methods.

1) Modified-event detection zone method (MEDZM)

In the detection zone, existing methods make an event by calculating the peak-to-peak interval. Arrhythmia events are classified into VT, VT-1, and VF by existing algorithm. VT means Fast Ventricular Tachycardia (FVT), VT-1 means Ventricular Tachycardia (VT), and VF means Ventricular Fibrillation (VF).

The MEDZM events are not classified into VT, VT-1, and VF events, but just into arrhythmia event or not. Therefore, in fig. 4, we show event detection methods using proposed MEDZM.

(a)

Normal	VT-1 event (slow VT)	VT event (fast VT)	VF event

(b)

Normal	Arrhythmia Event

Fig. 4 Event occurrence criteria in detection zone. (a) Existing event detection zone method, (b) Modified Event Detection Zone Method (MEDZM).

2) Modified Duration Zone Method (MDZM)

The MDZM modifies the stage of deciding which arrhythmia type. When an arrhythmia event has occurred in the detection zone, then the arrhythmia type is decided in the duration zone. However, when normal condition is also detected in the detection zone, re-detection is needed for arrhythmia detection.

From these procedures, the arrhythmia diagnosis procedure follows state machine illustrated in Fig. 5.

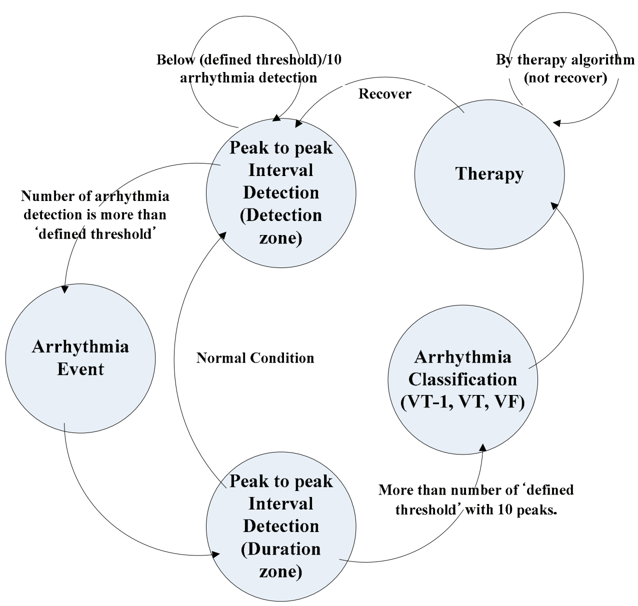

Fig. 5 State machine of proposed algorithm using MEDZM and MDZM.

3) Descending Level Therapy (DLT) / Ascending Level Therapy (ALT)

Existing therapy algorithms control arrhythmia using ATP or HES. In VT-1 condition, ATP is used for recovering, and in VT or VF conditions ATP/HES or HES are used for arrhythmia treatment.

Before an algorithm secures reliability, it must decide on the diagnosis from the detection and the duration zone results. However, in this case, repetitive detection is needed before reaching the final diagnosis result. This algorithm does not have to reach an agreement between event occurrence and diagnostic results. Therefore it could cause some trouble related with efficiency and safety if existing therapy methods are used as it is.

In this paper, we consider a modified therapy method using DLT and ALT technique. DLT means that the duration zone has lower arrhythmia level than the results of the detection zone. In this case, the state of arrhythmia is getting better during diagnosis, such as non Sustained Ventricle Tachycardia (NSVT).

ALT means the results of the duration zone has higher arrhythmia level than the result of the detection zone. In this case, arrhythmia level is getting worse during diagnosis. In the proposed algorithm, results from the duration zone drive a therapy. By the way, we need to consider whether level ascending or level descending is caused from peak-detection process error.

Table 2 shows the modified therapy method considering the level changing problem mentioned above. In an ALT case, therapy is performed based on results from the duration zone. In a DLT case, we consider the results from the detection and duration zones. HES is activated if symptoms change from VF to VT, and ATP/HES is activated when VF changes into VT-1.

TABLE 2
DLT, ALT ALGORITHM TABLE

Detection zone	Duration zone	Diagnosis	Therapy
Slow-VT	Normal	Re-detection	-
	Slow-VT	Slow-VT	ATP
	Fast-VT	Fast-VT	ATP/HES
	Fibrillation	Fibrillation	HES
Fast-VT	Normal	Re-detection	-
	Slow-VT	Slow-VT	-ATP
	Fast-VT	Fast-VT	ATP/HES
	Fibrillation	Fibrillation	HES
Fibrillation	Normal	Re-detection	-
	Slow-VT	Slow-VT	ATP/HES
	Fast-VT	Fast-VT	-HES
	Fibrillation	Fibrillation	HES

4) Arrhythmia Diagnosis Using Proposed Algorithm

We estimate arrhythmia diagnosis result accuracy for evaluation by comparing results from the original algorithm and the modified algorithm. For estimation, we consider state transition based on the logic of table 3.1 and table 3.2.

Table 3.3 shows the arrhythmia diagnosis results using the proposed algorithm. We assume that all the parameters for diagnosis have the same value. In the proposed algorithm, the type of therapy depends on the arrhythmia type in the duration zone. This characteristic has an advantage of decreasing time delay to treatment, but it has the disadvantage of prudent diagnosis. In power consumption point of view, the modified algorithm consumes less power than the original algorithm, because the modified algorithm could decrease the number of therapy repetitions when former therapies have failed. However, we need to consider the fact that the modified algorithm uses higher stage therapy than the original algorithm, therefore it could be ineffective when arrhythmia could be removed with lower level of therapy.

TABLE 3
ARRHYTHMIA DIAGNOSIS RESULTS USING PROPOSED ALGORITHM
(VT-1: Slow Ventricular Tachycardia, VT: Ventricular Tachycardia, VF: Ventricular Fibrillation)

Detection zone		Duration	Diagnosis result		Therapy	
Original	Proposed		Original	Proposed	Original	Proposed
VT-1	Arrhythmia	Normal	Re	Re	-	-
VT-1		VT-1	VT-1	VT-1	ATP	ATP
VT-1		VT	VT-1	VT	ATP(E)	ATP /HES
VT-1		VF	VT-1	VF	ATP(E)	HES
VT		Normal	Re	Re	-	-
VT		VT-1	Re	VT-1	-	ATP
VT		VT	VT	VT	ATP /HES	ATP /HES
VT		VF	VT	VF	ATP /HES(E)	HES
VF		Normal	Re	Re	-	-
VF		VT-1	Re	VT-1	-	ATP /HES
VF		VT	Re	VT	-	HES
VF		VF	VF	VF	HES	HES

IV. CONCLUSION

Applied to implantable cardiac supporting devices such as ICDs and pacemakers, algorithms need to satisfy safety and effectiveness simultaneously. The proposed algorithm has high priority in decreasing the time required from arrhythmia occurrence to therapy, because this characteristic has a trade off relationship with timing delay and power consumption. Safety is also considered as important a factor for practical use.

To overcome these problems, optimized ATP or HES research have to be performed. Moreover, considering the algorithm's characteristics, the proposed algorithm is more vulnerable to short term noise since it performs diagnoses right after an event unlike other algorithms that performed diagnosis after multiple event detections. Therefore, additional research in finding the optimal parameter, such as number of peaks, and peak intervals, is needed.

REFERENCES

[1] T. Kenny, The nuts and bolts of ICD therapy, Blackwell Futura, USA, 2006.

[2] Medtronic, Kappa™ 900/800 Series Pacemaker Reference Guide, USA, 1999.

[3] Guidant, Pacemaker system guide PULSAR MAX™ II, USA, 1999.

[4] Heinz et al. "Energy Saving Cardiac Pacemaker", US patent number : 4,979,507, Dec. 25, 1990

[5] L. Ferasin, M. Faena, S. M. Henderson, K. Langford, P. G. G. Darke, "Use of a multi-stage exercise test to assess the responsiveness of rate-adaptive pacemakers in dogs", Journal of Small Animal Practice, Volume 46, Issue 3, Page 115-120, Mar 2005

[6] Lin, D., Jenkins, J.M., DiCarlo, L.A., MacDonald, R.S., "Arrhythmia diagnosis using morphology and timing from atrial and ventricular leads", Proc., Computers in Cardiology 1988., Page(s):159 - 162, 25-28 Sept. 1988

[7] Guidant corporation USA, "VENTAK PRIZM / HE / 2 Automatic Implantable Cardioverter Defibrillator Models 1860/1861", USA, 2000

[8] Irnich, W., "Optimal programming of defibrillation pulses", Proc. of the 18th Conf. IEEE, Volume 3, 31 Oct.-3 Nov. 1996 Page(s):1300 - 1301