

The implementation of a rapid ECG signal compression algorithm and its application in BSN

Hao Sun and Wei Chen¹

Abstract. The applications of BSN (Body Sensor Network) require the wearable computing system's power consumption as low as possible. Compared to other components, the wireless communication link is the most power demanding part of the BSN. While effective compression algorithm can sharply cut the data volume down and then reduce the wireless transmitting consumption. Based on this consideration, we studied the improved rapid LADT (Linear Approximation Distance Threshold) algorithm and develop a BSN platform based on FPGA (Field-Programmable Gate Array) to detect process, compress, record and transmit the ECG (Electrocardiograph) signals. Experiments showed that the improved rapid LADT algorithm can reduce the total number of occupied slices in FPGA system and efficiently compress signal data without change the feature of the ECG signals.

Keywords: BSN; FPGA; LADT; ECG.

1 Introduction

In recent years, with the rapid progressing of the healthcare technology and the increasing of public demand for personal health management, there's a great evolution of the IOT (Internet of Things) in the world [1]. As a special branch of the IOT and the wireless sensor network [2], BSN has been widely employed in the

H. Sun
City College, Kunming University of Science & Technology, Kunming, 650051, China
e-mail: 6176867@qq.com

¹W. Chen (✉)
National Key Laboratory of Biomedical sensor, Zhejiang University, Hang Zhou, 310027, China
e-mail: williechen@zju.edu.cn

areas such as healthcare, telecare, disability aid and so on. Though BSN has been developed quickly in the following years since the concept and the model of BSN first proposed by Professor Thomas of MIT in 1996, but there existing many challenges, such as reducing the data volume of BSN node, realizing low-power dissipation.

The application of FPGA in the ASIC design can shorten the design cycle, sharply reduce the design cost and has the advantage of high reliability, flexibility and convenience to verify the various modules and algorithms. Nowadays, FPGA are powerful enough with some kind of suitable soft-core processor and a perfect set of peripheral interfaces, many BSN platform based on FPGA have been developed like Nokia's NWSP (Nokia Wrist-Attached Sensor Platform)[18], SHIMMER™ (Sensing Health with Intelligence, Modularity, Mobility and Experimental Reusability)[19].

The method of LADT [7-9] provides a way to reaching the maximum compression ratio in time domain by applying polygonal line to fit a given curve. LADT algorithm compresses the data by the approach of keeping the distance between each point on the curve and the polygonal line under a limit value. So the LADT makes it possible to get a higher compression ratio and keep the original curve shape.

This paper proposed a novel rapid signal compression algorithm for BSN application and realization of FPGA system. This algorithm is suitable for compress the data from an ECG data acquisition node in BSN system based on FPGA platform. We designed a FPGA signal processing system and added the LADT signal compression algorithm to this system, achieved highly data compression rate of ECG data from the ECG signal node, simplified the FPGA hardware configuration and the reduced the slice occupation and the wireless data transmission volume, finally, accomplished the aim of low power consumption of BSN system.

2 BSN and its applications

BSN is a special branch of wireless sensor networks; aim to transmit various physiological parameters by the implanted sensors in the human body. The biomedical signal consist physiological signal (e.g. heart rate, oxygen saturation, pulse wave, blood pressure and heart sounds, body temperature), daily activity information and environmental parameters. These signals detected by the wearable sensors will be transmitted to the remote medical cloud server through the wearable internet node after the processing like filtering, compressing, or encoding.

The technology of BSN is a fusion of software, hardware and wireless communication, including the physiological signal acquisition, processing technology and wireless communication technology. Particularly, the physiological signal acquisition and processing node usually contains signal processing, physical sensory data feature extraction and lightweight data fusion algorithm. Obviously, the

lightweight data fusion algorithm can reduce amount of the calculation more or less, and then reduce the whole system energy-consumption, and match the requirement of low power consumption which almost the biggest bottleneck of BSN applications [6, 11].

With the rapid progress of healthcare, especially for the continuous monitoring and health defense, many constructive BSN applications had been studied [11-13]. Pattichis C.S. has studied wireless transmission technology and success applied it to the Telemedicine System (e.g. electronic medical record, emergency remote expert consultation, tele-radiology and home monitoring) [4]. Chris Otto designed a wireless sensor network monitoring the body activity and the heart activity [14]. Hong J.H. developed a three channel ECG transmission system, which can monitor the physical condition of old people, patients and disabled through the PDA mobile phone [15].

3 The basic principle of improved LADT algorithm

Decreasing BSN node data volume and reducing the power dissipation are the two challenges for the BSN data fusion technology. To resolve the two problems above, this paper propose an improved rapid LADT data compression algorithm, which can compress the node data volume and lower the wireless network power by reducing the transmit data volume.

The method of LADT can get a very highly compression ratio in time domain by using a serial of polygonal lines to fit the original curve. The basic principle of LADT shows in Fig 1.

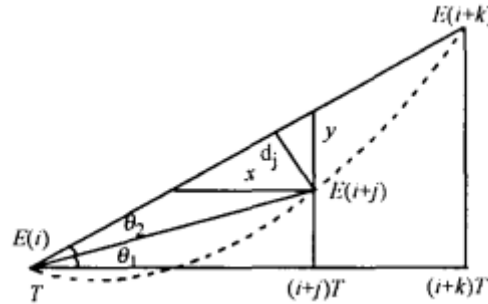


Fig.1 The basic principle of LADT algorithm

The approximation procedure can be described as follows:

Here, Let parameter $E(i)$ as the begin point of polygonal line, and search the end point $E(i+k)$ by repeat compute the distance between fitting curve and original curve fitting method and keep the $d_{j\max} < \varepsilon$, where d_j defined by Formula (1) below [9]:

$$\begin{aligned}
d_j^2 &= \left(\frac{|jT \sin(\theta_2 - \theta_{1j})|}{|\cos \theta_{1j}|} \right)^2 \\
&= \frac{\{j[E(i+k) - E(j)] - k[E(i+j) - E(i)]\} T^2}{[E(i+k) - E(i)]^2 + k^2 T^2}
\end{aligned} \tag{1}$$

And ε means the admissible distance error, the maximum distance $d_{j\max} = \max\{d_j\}, j = 1, 2, \dots, k$, and T represents the sampling time interval and usually is 0.001s.

LADT algorithm obtains good compressing results and decreases the distortion rate remarkably, but the calculation is very large. The similarity principle of triangle makes it possible to deduce the rapid LADT algorithm[7], and the distance computational formula is:

$$\begin{aligned}
d_j^2 &= \frac{(j\Delta_k/k - \Delta_j)^2 (j - k\Delta_j/\Delta_k)^2 T^2}{(j\Delta_k/k - \Delta_j)^2 + (j - k\Delta_j/\Delta_k)^2 T^2} \\
&= \frac{(j\Delta_k - k\Delta_j)^2 T^2}{\Delta_k^2 + k^2 T^2}
\end{aligned} \tag{2}$$

Here, $\Delta_k = E(i+k) - E(i)$, $\Delta_j = E(i+j) - E(i)$

Due to the Formula (2) still exists square calculation, we simplify the Formula (2) according to the features of ECG data. In Formula (2), the parameter k stands for the detection step length and usually ranges between 0 and 10(include 10). Therefore, we can use the formulas $0 < k^2 T^2 < 10^{-4}$ and $\Delta_k^2 > 1$ to obtain the formula $\Delta_k^2 \gg k^2 T^2$. Thus the simplifying distance formula is:

$$d_j^2 \approx \frac{(j\Delta_k - k\Delta_j)^2 T^2}{\Delta_k^2},$$

That is,

$$d_j \approx \left| \frac{(j\Delta_k - k\Delta_j)T}{\Delta_k} \right| \tag{3}$$

Comparing the Formula (1), Formula (2) and Formula (3), it can be conclude that the calculation of LADT algorithm can be greatly reduced and then save the FPGA's hardware resource.

4 The FPGA implementation of improved LADT Algorithm

We choose the cheap and low power dissipation XC2S200 chip as BSN design and simulation platform, which consists of a ECG signal extraction module, a Zigbee wireless module, and a AVR software MCU core, show in Fig. 2.

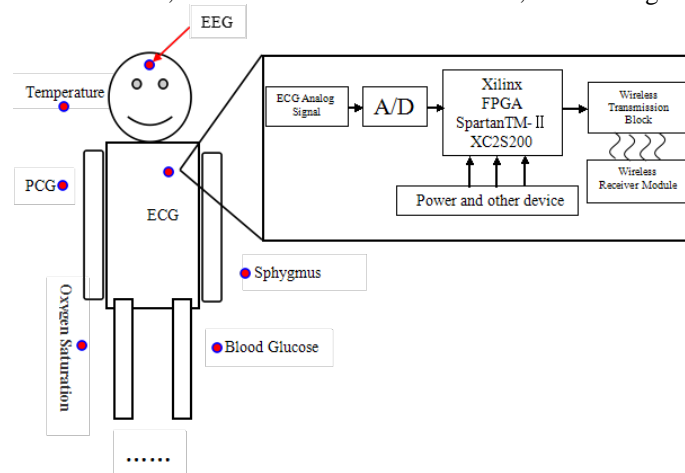


Fig. 2 The architecture of BSN system based on FPGA platform

For saving the computing resource of FPGA and accelerating the computing speed, we optimize the program as follows:

(1) While calculating the absolute value, we should compare the value of the two numbers before calculation.

(2) Using the integrated IP in the FPGA's ISE development tools to design the bits multiplier, we select the Multiplier Generator's IP core which is convenient and efficient.

(3) Calculating the maximum by applying the bubble sort method (Attention: the algorithm must be realized in one procedure statement in the FPGA.)

(4) Quantifying the coefficients. As the coefficients ε and T in this algorithm are float, and each ECG data is demanded multiply with parameter T , so the calculation is very large. Therefore, we can transform the two parameters to integer (e.g. amplify the two coefficients N times) and use the quantified coefficients to calculate. Because the two sides of the discriminant $d_{j\max} < \varepsilon$ are all multiplied by N , the result is not being affected.

4 Experiment and discussion

According the Fig. 3, it can be concluded that both of these two algorithms can keep the features of ECG very well. Though the two algorithms are capable of compressing data, the time they spend are very different, just as Table.1 has showed.

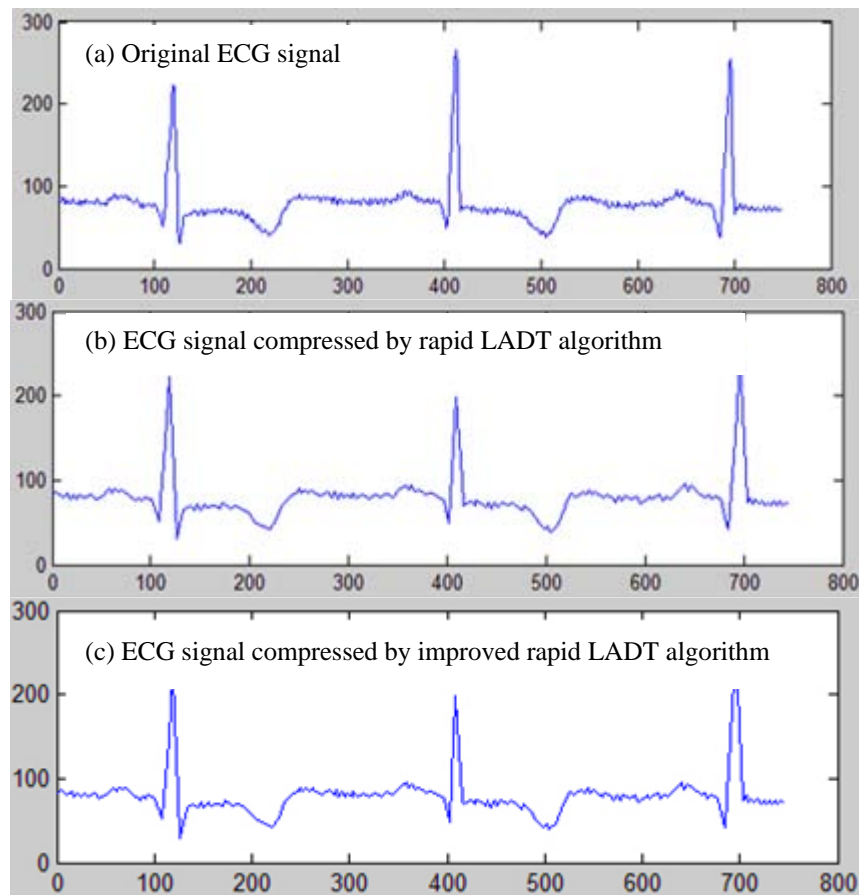


Fig. 3 The comparison of the rapid LADT algorithm and improved rapid LADT algorithm to the ECG signal

Comparing the Fig. 3 and Table 1, it can be conclude that the two algorithms are suitable for the ECG signal compression and modified rapid LADT algorithm costs less time and make the low-power dissipation more efficiently.

Table 1 The comparison of the time cost and compression ratio of the rapid LADT algorithm and modified rapid LADT algorithms

| Algorithm Feature | Data Volume | | Compression Ratio | Time Cost/(s) |
|---|-------------|------------|-------------------|---------------|
| | Original | Compressed | | |
| Rapid LADT compression algorithm | 750 | 161 | 4.7:1 | 0.7174 |
| Improved rapid LADT compression algorithm | 750 | 161 | 4.7:1 | 0.2663 |

5 Conclusions

This paper explores the application of developed rapid compression LADT algorithm in ECG signal in the BSN and realizes the utilization of the rapid LADT algorithm and improved rapid LADT algorithm for FPGA system. The experiment confirms the improved rapid LADT algorithm could facilitate the FPGA hardware configuration, consolidate the algorithm's real-time performance, and increase the ECG signal data volume in the BSN. Thus the algorithm can achieve the aim reducing the BSN node volume and save the BSN's power to some extent finally.

Acknowledgments This study is supported by the National Science Foundation of Yunnan Province, China (No. 2009ZC051M).

References

- [1]. Atzori L, Iera A, Morabito G. The internet of things: A survey [J]. Computer Networks, 2010, 54(15): 2787-2805.
- [2]. Akyildiz, I. F., Su, W., Sankarasubramanian, Y., & Cayirci, E. (2002). Wireless sensor networks: a survey. Computer networks, 38(4), 393-422.
- [3]. Lo, B., Thienjarus, S., King, R., & Yang, G. Z. (2005, May). Body sensor network-a wireless sensor platform for pervasive healthcare monitoring. In The 3rd International Conference on Pervasive Computing (Vol. 13, pp. 77-80).
- [4]. Pattichis, C. S., Kyriacou, E., Voskarides, S., Pattichis, M. S., Istepanian, R., & Schizas, C. N. (2002). Wireless telemedicine systems: an overview. Antennas and Propagation Magazine, IEEE, 44(2), 143-153.
- [5]. Baldus, H., Klabunde, K., & Muesch, G. (2004). Reliable set-up of medical body-sensor networks. In Wireless Sensor Networks (pp. 353-363). Springer Berlin Heidelberg.
- [6]. Bachmann, C., Ashouei, M., Pop, V., Vidojkovic, M., Groot, H. D., & Gyselinckx, B. (2012). Low-power wireless sensor nodes for ubiquitous long-term biomedical signal monitoring. Communications Magazine, IEEE, 50(1), 20-27.

- [7]. Yongming, Y., Jungang, L., & Jianmin, W. (2007, May). LADT Arithmetic Improved and Hardware Implemented for FPGA-Based ECG Data Compression. In *Industrial Electronics and Applications, 2007. ICIEA 2007. 2nd IEEE Conference on* (pp. 2230-2234). IEEE.
- [8]. Zhiwen, M., Li, T., Xiao, T., & Shu, L. (2006). The Algorithm of the Quick Fitting LADT. *IJCSNS*, 6(6), 52.
- [9]. Chatterjee H K, Gupta R, Mitra M. Real time P and T wave detection from ECG using FPGA [J]. *Procedia Technology*, 2012, 4: 840-844.
- [10]. Nemati E, Deen M J, Mondal T. A wireless wearable ECG sensor for long-term applications [J]. *Communications Magazine, IEEE*, 2012, 50(1): 36-43.
- [11]. Lo B, Thiemjarus S, Panousopoulou A, et al. Bioinspired Design for Body Sensor Networks [Life Sciences][J]. *Signal Processing Magazine, IEEE*, 2013, 30(1): 165-170.
- [12]. Hao Y, Foster R. Wireless body sensor networks for health-monitoring applications[J]. *Physiological measurement*, 2008, 29(11): R27.
- [13]. Shudi B, C.Y. P C, Lianfeng S, et al. Authenticated symmetric-key establishment for medical body sensor networks [J]. *Journal of electronics*, 2007, 24(3): 421-427.
- [14]. Otto C, Milenkovic A, Sanders C, et al. System architecture of a wireless body area sensor network for ubiquitous health monitoring[J]. *Journal of Mobile Multimedia*, 2006, 1(4): 307-326.
- [15]. Hong J H, Kim J M, Cha E J, et al. A wireless 3-channel ECG transmission system using PDA phone[C]//*Convergence Information Technology, 2007. International Conference on. IEEE*, 2007: 462-465.
- [16]. Seyedi A, Sikdar B. Modeling and analysis of energy harvesting nodes in body sensor networks[C]//*Medical Devices and Biosensors, 2008. ISSS-MDBS 2008. 5th International Summer School and Symposium on. IEEE*, 2008: 175-178.
- [17]. Lo B, Yang G Z. Key technical challenges and current implementations of body sensor networks[C]//*Proc. 2nd International Workshop on Body Sensor Networks (BSN 2005)*. 2005.
- [18]. Ahola, T., Korpinen, P., Rakkola, J., Ramo, T., Salminen, J., & Savolainen, J. (2007, August). Wearable FPGA based wireless sensor platform. In *Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE* (pp. 2288-2291). IEEE.
- [19]. Burns, A.; Greene, B.R.; McGrath, M.J.; O'Shea, T.J.; Kuris, B.; Ayer, S.M.; Stroiescu, F.; Cionca, V.. (2010). SHIMMER™—A wireless sensor platform for noninvasive biomedical research. *Sensors Journal, IEEE*, 10(9), 1527-1534.