Journal of information and communication convergence engineering
http://jicce.org

J. Inf. Commun. Converg. Eng. 16(2): 130-134, Jun. 2018

Regular paper

Reducing Power Consumption of Wireless Capsule Endoscopy Utilizing Compressive Sensing Under Channel Constraint

Oka Danil Saputra[1], Fahri Wisnu Murti[2], Mohammad Irfan[3], Nadea Nabilla Putri[4] and Soo Young Shin[2]*, ***Member*, *KIICE***

[1]Neural Technologies, Jakarta 12930, Indonesia
[2]Department of IT Convergence Engineering, Kumoh National Institute of Technology, Gumi 39177, Korea
[3]Institut national de la recherche scientifique (INRS), Montreal, Canada
[4]Ikonsultan Inovatama, Jakarta 12550, Indonesia

Abstract

Wireless capsule endoscopy (WCE) is considered as recent technology for the detection cancer cells in the human digestive system. WCE sends the captured information from inside the body to a sensor on the skin surface through a wireless medium. In WCE, the design of low-power consumption devices is a challenging topic. In the Shannon-Nyquist sampling theorem, the number of samples should be at least twice the highest transmission frequency to reconstruct precise signals. The number of samples is proportional to the power consumption in wireless communication. This paper proposes compressive sensing as a method to reduce power consumption in WCE, by means of a trade-off between samples and reconstruction accuracy. The proposed scheme is validated under channel constraints, expressed as the realistic human body path loss. The results show that the proposed scheme achieves a significant reduction in WCE power consumption and achieves a faster computation time with low signal error reconstruction.

Index Terms: Compressive sensing, Path loss, Power consumption, Wireless capsule endoscopy

I. INTRODUCTION

Cancer is a dangerous human diseases faced in the current world. In the biomedical field, wireless capsule endoscopy (WCE) is a significant breakthrough in the discovery of cancer cells located in the esophagus, stomach, small intestine, and colon. It was invented to provide diagnosis of abnormal cells and the cancer location via image or video, transmitted by the capsule. Based on complementary metal oxide semiconductor technology, the WCE capsule can be swallowed by the patient. It is also highly mobile compared with conventional endoscopy. However, there are several challenges that should be overcome to enhance the WCE performance, including localization of the capsule, antenna design, and power efficiency [1]. Instead of solving these problems simultaneously, in this study, we focus on reducing the power consumption of WCE, by considering realistic human body path-loss under channel constraints.

The system operation design of WCE has been successfully applied for autofluorescence intensity detection in biological tissues [2]. Intestinal tissue that emits photons in responses to LED illumination, namely the single-photon

---

Received 11 May 2018, **Revised** 11 June 2018, **Accepted** 12 June 2018
***Corresponding Author** Soo Young Shin (E-mail: wdragon@kumoh.ac.kr, Tel: +82-54-478-7473)
Department of IT Convergence Engineering, Kumoh National Institute of Technology, 61, Daehak-ro, Gumi 39177, Korea.

Open Access https://doi.org/10.6109/jicce.2018.16.2.130 print ISSN: 2234-8255 online ISSN: 2234-8883

avalanche diode (SPAD), generates a train of pulses in proportion to the light intensity. The pulses within a fixed period are also counted and then transmitted via ultra-high frequency (UHF) radio to the external receiver, to build a miniaturized low power sensor prototype. However, further studies are required regarding power reduction techniques to gain further advantages of WCE.

Compressive sensing (CS) is an innovative technique in information theory, which has the capability to reconstruct the signal using a sampling rate far less than the Nyquist rate. Unlike the Shannon-Nyquist principle, in which most of the sampling data remain unused, the CS method only samples valuable data from the signal. Additionally, CS guarantees a highly accurate reconstruction of the original signal, with the conditions that the signals must be incoherent and sparse in a certain domain [3]. In [4], the authors proposed the combination of CS with shearlet transform for medical image purpose. However, the authors did not consider the analysis of its power consumption and its implementation in the WCE. Based on the huge benefits of CS in signal processing, this paper proposes the WCE application of reducing power consumption.

To the best of our knowledge, this is the first work that has evaluated the power consumption of WCE with CS. Firstly, we propose CS implementation for WCE to reduce power consumption. Then, the relation between the data transmission and power consumption of WCE is derived, and the proposed scheme is validated through simulation. Further, the signal-to-noise ratio (SNR), additive white Gaussian noise (AWGN), and path loss based on 3D human body models are considered to provide a more realistic scenario. Finally, the proposed scheme is evaluated in terms of power consumption, computational time, and error performance.

The rest of the paper is organized as follows: Section II presents the system model and our proposed scheme. In this section, the relation of the proposed scheme and 3D human body channel model are derived and explained. Then, Section III provides the results and discussion, including performance evaluation in terms of power consumption, computational time, and error performance. Finally, Section IV concludes this paper.

II. SYSTEM AND PROPOSED MODEL

The overall block diagram of the proposed scheme is presented in Fig. 1. Suppose $x = (x_1, x_2, ..., x_N)$ represents the generated signal of WCE, with a maximum signal length of N. Then, we assume that x is k-sparse in a particular domain; thus, the measurement matrix can be represented as Φ, consisting $M \times N$ matrix, where the random measurement M value is normally smaller than N. In short, the signal $y = y_1, y_2, ..., y_M$ is the measurement vector from x, which is calculated from $y = \Phi x$. Then, the WCE sends the signal y from inside to an on-body sensor. Eq. (1) gives the proposed signal reception r, which include the path loss effect α, and AWGN noise n, as follows:

$$r = y\alpha + n \tag{1}$$

$$\alpha = \tau\beta, \; \tau = PL_0 + 10\delta\log\frac{d}{d_0} + S, \; \beta = e^{-j2\pi f_c}$$

where PL_0 is the path loss at reference distance, d_0 is the distance between the WCE and sensor, δ is the path loss exponent, β is the phase shift, and f_c is the carrier frequency [5]. One of the latest WCE devices is considered as the model. This WCE device has technical features including an application-specific integrated circuit (ASIC) and SPAD, which improve the accuracy of cancer cell detection compared to prior WCE devices [2]. Then, following the proposed model in Fig. 1, the total power consumption of WCE can be calculated as follows:

$$P_c = P_L + P_A + P_S + P_{CR} + P_t. \tag{2}$$

In (2), P_c is used to compute the total power consumption of WCE, P_L is the LED power consumption, P_A is the ASIC power consumption, P_S is the SPAD power consumption, and P_{CR} is the controller and radio link power consumption. Fig. 2 shows the WCE located in the colon at (a; b); it is to be noted that the WCE location can be modelled as a uniform distribution $1/W^2$, and an on-body sensor located in the center of the small intestine at ($W/2$, $W/2$). The relation between the power transmission P_t, the data transmission power D, and the expected value of distance $E[d^2]$ are derived as follows:

$$\begin{aligned} E[d^2] &= \int_0^W \int_0^W \left[\left(a - \frac{W}{2}\right)^2 + \left(b - \frac{W}{2}\right)^2\right] \frac{1}{W^2} dxdy \\ &= \frac{W^2}{6} \pm 0.5 \text{ mm} \end{aligned} \tag{3}$$

Then, the value of P_t can be obtained by utilizing $E[d^2]$ as follows:

$$\begin{aligned} P_t &= D\,E[d^2] \\ &= \frac{DW^2}{6}. \end{aligned} \tag{4}$$

The performance of the proposed scheme is measured using the average iteration of mean absolute error (MAE) as the performance matrix because it has been widely used to measure the information loss. The average MAE can be calculated as follows:

$$MAE_{avg} = \frac{1}{I}\sum_{i=1}^{I}\left(\frac{1}{N}\sum_{j=1}^{N}\left|x_i[j] - \hat{x}_i[j]\right|\right) \tag{5}$$

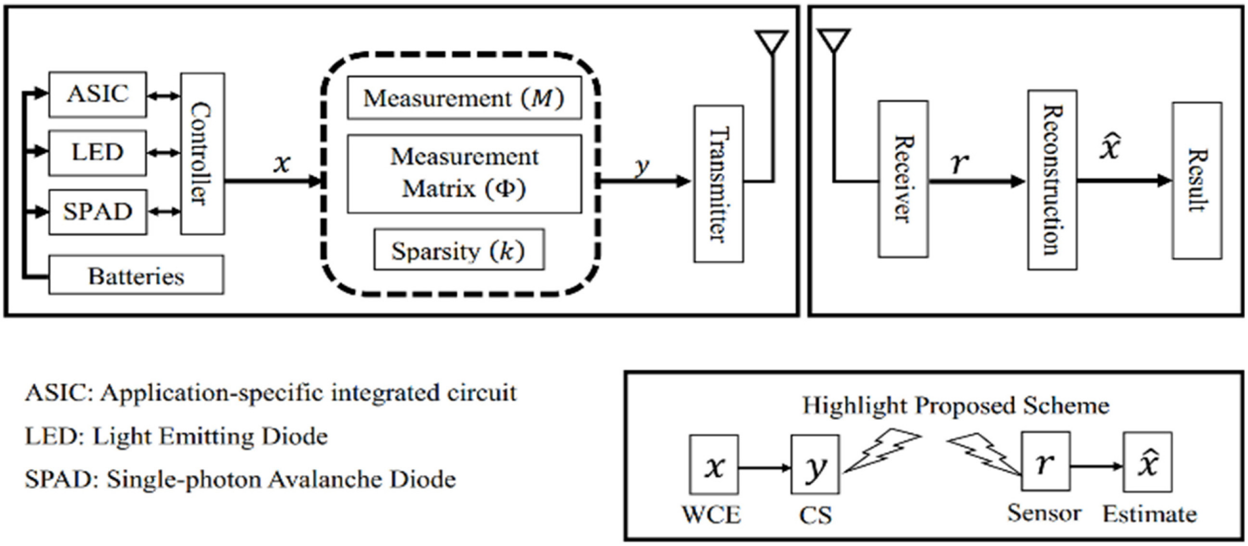

Fig. 1. Block diagram of the proposed scheme.

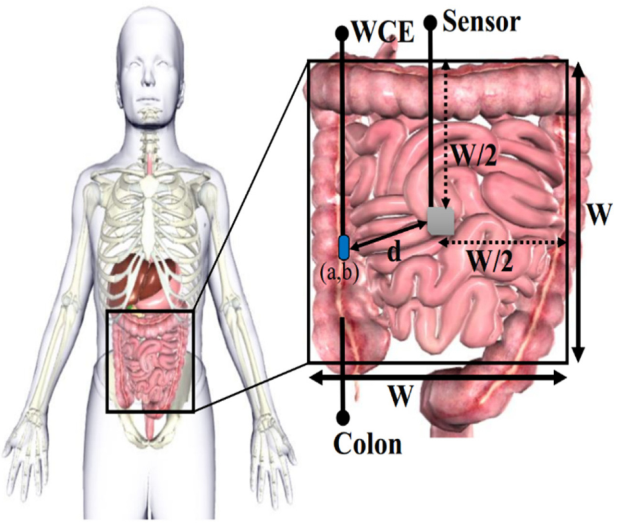

Fig. 2. Proposed scheme environment for in-body communication.

where I denotes the number of iterations, N represents the total number samples, $x_i[j]$ is the generated signal, and $\hat{x}_i[j]$ is the estimated signal in the receiver.

III. RESULTS AND DISCUSSION

To validate the proposed scheme, a simulation was performed under the same design assumptions as a real WCE environment and parameters. Fig. 2 shows the WCE device located in the colon, where the distance to the on-body sensor d is 100 mm. The path loss exponent δ is 4.26, the shadowing effect σ_S is 7.85 dB, the path loss at a reference distance PL_0 is 47.14 dB, the reference distance d_0 is 50 mm, and the carrier frequency f_c is 402 MHz [5]. The total power consumption of WCE is calculated based on the assumption that the ASIC consumes 1.76 mW, LED consumes 19.8 mW, SPAD consumes 255 µW, controller and radio link require 150 µW [2], and the transmission of 100 bits of data requires a power of approximately 100 µW/cm^2. The WCE signal length, N, is 1,000 samples with 10-pulse signals; the length of the WCE discover area, W, is 200 mm; and the number of iteration, I, is 100. The standard basis pursuit problem is utilized to estimate the signal, $\hat{x}$, from the original signal, x [6].

In this section, we calculate the simulation result into two evaluations. First, the power consumption and computational time comparison between the full sampling and proposed scheme are derived. Then, we also provide analysis of the peak signal-to-noise ratio (PSNR) and an image reconstruction of our proposed scheme.

Fig. 3 shows the comparison of the original and estimated WCE signals which is investigated under the channel constraints, and Table 1 show the performance comparison of the proposed CS with full samples, including power consumption, computational time, and error rate. In the simulation, the number of measurement M is 100 samples, and an SNR of 5 dB is considered. The SNR value of 5 dB is used to indicate that the environment is appropriate for communication. For power consumption performance, the percentage of reduced power consumption for WCE (P_{CS}) using the proposed power transmission with signals (P_{CM}) compared to that without using the CS scheme with N signals (P_{CN}) can be calculated as

$$P_{CS} = \left(\frac{P_{CN}-P_{CM}}{P_{CN}}\right)100\% \tag{6}$$

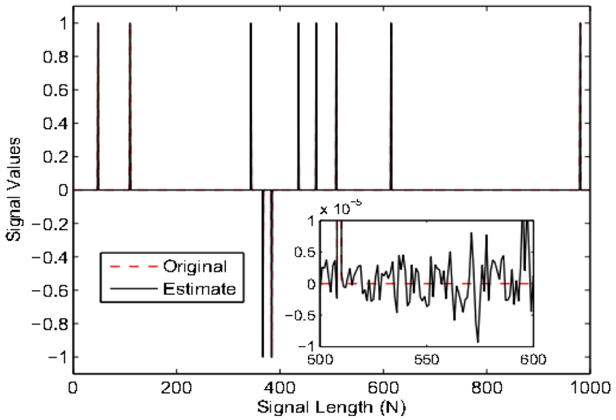

Fig. 3. WCE original signal with 10-pulse and estimate signal result.

Table 1. The WCE power consumption comparison result

Scheme	Number of samples	P_C (mW)	P_{CS} (%)	MAE_{avg}	T_S (s)
Full sampled	1,000	88 ± 0.5	0	1.1×10^{-6}	259.9
Proposed	100	28 ± 0.5	68 ± 0.1	2.2×10^{-6}	14.5

In summary, by using (2) and the simulation parameters, the WCE power consumption P_C, power saving P_{CS}, MAE_{avg}, and computation time T_s are calculated and listed in Table 1.

The results show that the proposed scheme can save up to 68% of the WCE's power consumption, compared to the full sample. Furthermore, the proposed scheme also is approximately 17 times faster than the full sampled scheme, where the number of samples equals to the numbers of data. In terms of error performance, the proposed scheme produces a highly accuracy of signal reconstruction with a very small MAE_{avg} of 2.2×10^{-6}. As presented in Table. 1, the MAE_{avg} result is closely enough compared to full sampled scheme, while the proposed scheme has better performance in terms of complexity and power consumption.

IV. CONCLUSION

This paper presented the viability of using the CS algorithm to reduce the power consumption of WCE. In our algorithm, the wireless channel is considered for the signal transmission between the WCE and an on-body sensor. The performance of the proposed scheme was investigated under channel constraints by considering the path loss from human tissue. The results showed that the proposed scheme realized far less computation time, very low power consumption and highly accurate signal reconstruction compared to the full sampled scheme. For future works, the real images will be considered as the signal information from WCE and the environment of the scheme will be investigated under the wireless body area network with multiple sensors to capture the WCE signal.

ACKNOWLEDGMENTS

This research was supported by the MSIT (Ministry of Science and ICT), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2017-2014-0-00639) supervised by the IITP (Institute for Information and communications Technology Promotion).

REFERENCES

[1] G. Ciuti, A. Menciassi, and P. Dario, “Capsule endoscopy: from current achievements to open challenges,” *IEEE Reviews in Biomedical Engineering*, vol. 4, pp. 59-72, 2011. DOI: 10.1109/RBME.2011.2171182.

[2] M. A. Al-Rawhani, D. Chitnis, J. Beeley, S. Collins, and D. R. Cumming, “Design and implementation of a wireless capsule suitable for autofluorescence intensity detection in biological tissues,” *IEEE Transactions on Biomedical Engineering*, vol. 60, no. 1, pp. 55-62, 2013. DOI: 10.1109/TBME.2012.2222641.

[3] D. L. Donoho, “Compressed sensing,” *IEEE Transactions on Information Theory*, vol. 52, no. 4, pp. 1289-1306, 2006. DOI: 10.1109/TIT.2006.871582.

[4] L. Niu and M. X. Duan, “Fusion for medical images based on shearlet transform and compressive sensing model,” *International Journal of Signal Processing, Image Processing and Pattern Recognition*, vol. 9, no. 4, pp. 1-10, 2016. DOI: 10.14257/ijsip.2016.9.4.01.

[5] K.Y. Yazdandoost and K. Sayrafian-Pour, “Channel model for body area network (BAN),” 2009 [Internet], Available: https://mentor.ieee.org/802.15/dcn/08/15-08-0780-09-0006-tg6-channel-model.pdf.

[6] E. J. Candes and J. Romberg, “l1-magic: recovery of sparse signals via convex programming,” 2005 [Internet], Available: http://www.cs.bham.ac.uk/~axk/Sakinah/inspiring_readings/l1magic.pdf.

Oka Danil Saputra
received the B.S. degrees in electrical engineering from Diponegoro University, Semarang, Indonesia, in 2012. He received the M.S degrees in Department of IT Convergence Engineering, Kumoh National Institute of Technology (KIT), Gumi, Korea in 2015. Currently, he is application engineer in Neural Technologies, Jakarta, Indonesia.

Fahri Wisnu Murti
was born in 1992. He received the B.S. degrees in telecommunication engineering from Telkom University, Bandung, Indonesia, in 2014. Currently, he is pursuing his M.S. degree at Wireless and Emerging Network System (WENS) Lab, Department of IT Convergence Engineering, Kumoh National Institute of Technology (KIT), Gumi, Korea. He was student internship at Huawei Technologies, Shenzhen & Beijing, China, in November 2013. From 2014 to 2016, he was Core & IP Transport engineer at Nokia Networks, Jakarta, Indonesia. His major research interests include future wireless communication and networks such as non-orthogonal multiple access (NOMA), cooperative NOMA, MIMO, secure communication, vehicular communication, heterogeneous networks (HetNet), and ultra-dense network.

Mohammad Irfan
received his B.S. degree in electrical and electronics engineering from Islamic University of Technology, Dhaka, Bangladesh, in 2011. He received the M.S. degree in Department of IT Convergence Engineering, Kumoh National Institute of Technology (KIT), Gumi, Korea in 2015. Currently, he is with INRS Montreal, Canada. His main research area includes orthogonal/non-orthogonal multiple access, MIMO, and new information carrying domains for wireless communications.

Nadea Nabilla Putri
received the B.S. degrees from School of Electrical Engineering and Informatics, Bandung, Indonesia, in 2014. She received the M.S degrees in Department of IT Convergence Engineering, Kumoh National Institute of Technology (KIT), Gumi, Korea in 2017. Currently, she is working as analyst for consultant company in Indonesia.

Soo Young Shin
received his B.S., M.S., and Ph.D. degrees in Electrical Engineering and Computer Science from Seoul National University, Korea. He was a post doc in FUNLab at University of Washington, USA. After working in WiMAX design laboratory of Samsung Electronics, he joined as a full-time professor in School of Electronics in Kumoh National Institute of Technology. He was a visiting scholar in WiNMoS Lab. at The University of British Columbia, Canada. His research interests include wireless networks and communications, 5G and beyond, Internet of Things, VR/AR/MR, and drone applications