Biosignal Monitoring Platform Using Wearable IoT

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Abstract—**Thanks to the IoT technology advancement and wearable devices, the healthcare industry is shifting ahead to a brighter future. In this paper, we present a Wi-Fi and battery powered wearable IoT system to monitor patient's Biosignal from anywhere at any time through an IP based network. The system is unique as it is composed of a 2 or/and 8 channel electrodes to measure ECG and EMG signals with a sampling frequency fixed at 1 KHz, an analog front-end (AFE) compliant with the IEEE 802.11 standard, a microcontroller for data processing and transmission, and a power management unit. The prototype operates at 2.4 GHz, 3.3v. The transceiver consumes very low power in arrange of 9mW, has a communication range between 20m and 100m, a data-rate of 128 kB/s, a latency of 1.2ms, equipped with Advanced Encryption Standard (AES) for real-time data encryption and has a high common-mode rejection ratio (CMRR). Experimental test result demonstrates that our developed prototype has a better performance than state of the art systems.**

I. Introduction

The legacy healthcare system is facing problems in meeting the demands for better and affordable health care services. A home monitoring system using wearable devices can reduce the cost of the healthcare systems. For instance, it has been tested and proved with evidence that a continuous monitoring of the ECG signal might prevent strokes for vulnerable people [1].

The healthcare needs a major shift and embraces a new system where patients are continuously monitored in their daily life. Wireless sensor networks based wearable devices for patient monitoring have been proposed as an attractive technology solution for monitoring and prognosis [2].

Internet of Things (IoT), is a new paradigm that aims to connect sensors, actuators, machines, and humans to the internet. In healthcare, IoT has enabled the establishment of new sets of wearable devices and pervasive health care services [3].

Bioelectronics systems together with wireless sensor network (WSN) and smartphone span are the widely used technologies for IoT enabled healthcare systems. Nowadays, data generated from sensors attached to patients are available to doctors, caregivers, family or any other stakeholders.

Fig. 1, shows a common IoT based patient monitoring healthcare system with smart gateway operation.

The IoT based sensor needs to be tiny as shown in Fig. 2. That is the energy storage units, communication, and the signal acquisition part should be integrated into one package [4]. These sensors developed using hardware and software platform, designed to be wearable and have wireless connectivity.

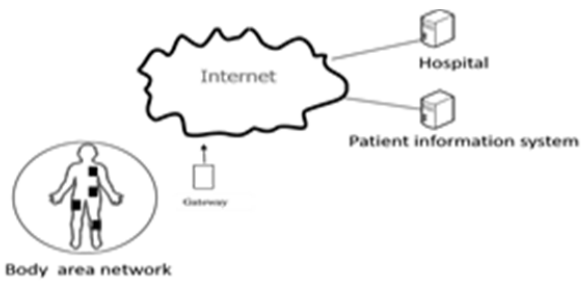

Fig. 1. IoT based Healthcare monitoring

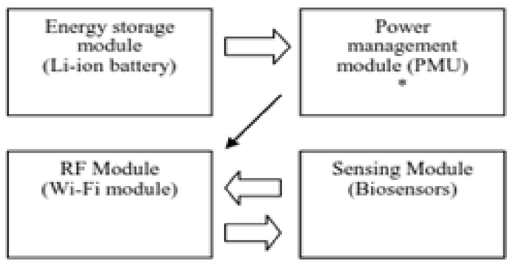

Fig. 2 Block diagram of the IoT based sensor node in one package

Wi-Fi enabled devices have the capacity of collecting a large amount of data with a higher bandwidth. It has been reported that the wearable market will grow by millions of units by the end of 2020 [5]. However, it is important to design eHealth systems that offer best QoS, enable for continuous monitoring of the patient’s Biosignal, and have a longer battery life.

In this paper, we present an e-health platform using Wi-Fi technology. The system that is designed to acquire, transmit and monitor ECG and EMG signals through an IP based network. The system is designed for Biosignal wireless sensor which has multi-functionalities; transmitting data, signal processing, and real-time monitoring system. The platform enables the data stored on a local server or on a cloud that can be accessed through web application or internet with a mobile phone or smartphone to support patients with caregivers. The main contribution of this work lies in the design of Wi-Fi-based 2 or/ and 8 channel electrodes Biosignal measuring unit. The device is capable of processing, collecting and transmitting in real time through IP protocol device based on IoT application. In addition, we show the module has a reliable capability and, is lightweight, low cost, low-power that has the lowest latency, has reliable security encryptions mechanism and more features as compared to the previous other existing platforms. The significant contribution of the paper is to discuss; the wearable Biosignal monitoring Wi-Fi based low power multi-channel module and the implementation of IoT based high data rate transmitting device. The device's application is tested with the sEMG signal measurement of the facial muscle for possible pain monitoring and assessment application.

The rest of the paper is organized as follows. First, in section II, we discuss related work with an indication of the motivation for this work. Then in section III, we describe the system architecture of the proposed prototype design. Subsequently, in section IV we describe the implementation and results. Finally, in section V we conclude the paper

II. MOTIVATION AND RELATED WORK

In recent years, a number of wearable IoT for healthcare applications have been proposed and investigated. A survey work that covers the recent progress in this area is reported on [3]. It states how IoT based health care system facilitates economies and societies for the sustainable development. In [6], the authors proposed an IoT wearable platform and an algorithm for ECG real-time processing. The authors of [7] proposed an ECG monitoring system using ZigBee technology. Some other published work considered alternative communication protocols such as Bluetooth low-energy [8], SimplicTI [9], Bluetooth [10], nRF [11]. Eventually, in today's advancements in semiconductor design, Wi-Fi sensors play an important role to enable the biosensing and monitoring systems. These extend to new bioinspired areas that can keep people safe and empower them. Similar technology used for ECG monitors will use for EMG signal through the measurement of the electrical activity of soft tissue [6].

In this paper, we present an e-health platform using Wi-Fi technology. The system that is designed to acquire, transmit and monitor ECG and EMG signals through an IP based network. The system is designed for Biosignal wireless sensor which has multi-functionalities; transmitting data, signal processing, and real-time monitoring system. The platform enables the data stored on a local server or on a cloud that can be accessed through web application or internet with mobile

III. SYSTEM ARCHITECTURE

The design is based on IoT, in order to get benefit from remote health monitoring system. Patents can be able to monitor on their premises rather than in hospital. It will allow elderly people to live their own home longer and reduces the costs of the hospitals. IoT health care system is beneficial by using a device which is be able to measure and to monitor the patient's conditions regularly and accurately using wearable sensors.

In order to have an optimal design consideration, we compare different WSN standard and come up with affordable and relevant architecture. The table below summarizes different wireless network technology standard including their battery life, frequency band, and range and power conceptions. A system capable of working with a higher data rate that is needed for monitoring and assessing the health conditions using Biosignal.

TABLE I. COMPARISONS OF WSN SOME OF THE STANDARDS PARAMETER

Standard	IEEE 802.11ah	Bluetooth	6LowPAN	ZigBee
Frequency Band	24.5 GHZ	Yes2.4 GHZ	900/2400MHZ	13.5 MHZ
Range (m)	100	10	16	100
Power	High	Medium	High	High
Battery life	Low	Medium	High	High

Wi-Fi would be a better selection for high data rate applications such as for medical and audio or video multimedia appliance. The power consumption is an important design consideration as most WSN devices are battery-operated. Wi-Fi has longer power consumption compared with the other standard. However, since biosensors are used for monitoring and assessing health condition we need to implement hardware with a high data rate.

The prototype is tiny, has promising low power consumption and easy to use. It is composed of a low power microcontroller unit (MCU), Analog Front (AFE), SPI interface to connect the AFE and MCU.

The system architecture is composed of RTX4140 Wi-Fi module and the module is small that consumes low power compared to the others available Wi-Fi modules. The Wi-Fi module has a single stream, 802.11b/g/n Wi-Fi unit with an ultra-low power processor on board. It is equipped with a 32 bit ARM cortex-M3 processor platform, an EFM32G family with a 1024 kB of flash memory, a 32-bit processor with a clock frequency of 48 MHz, a memory protection unit with wake-up interrupt controller, a 128 KB of RAM, and communication interfaces with low power single stream Atheros AR4100 Wi-Fi. The module supports WEP, WPA/WPA2, and WPS modes. More details on the Wi-Fi module are available from the RTX website

The system includes TI, ADS/ AFE module which incorporates all of the features that are commonly required in portable and low-power Biosignal monitoring system as states in more details at TI web site.

The platform has flexible input multiplexer per channel that can be independently connected to the internally-generated signals for test, temperature, and lead-off detection. The important features of the AFE are 8/10 high-resolution ADCs, (16-bit analog to digital resolution) and each channel is sampled at 1000 samples per second with gain varies from 1 to 12 including it has low power up to 9 mW, input bias current of 1nA, with SPI compatible high-data rate up to 128Kbps serial interface. It has low power operating system that can implement the necessary functionality to host internal tasks as well as the Co-Located Application. The Wi-Fi management component handles all aspects of connection to a Wi-Fi access point including security and key handling for a secure wireless connection.

The prototype is divided into hardware and software units with four sections: Sensor interface, Wireless sensor block, Database application and Web server.

The module we use has low power performance among low power Wi-Fi devices. The operation starts by is the utilization of SPI communicating with ADS1198 for transmitting the digitized data through SPI to a Wi-Fi module. An application processor, EFM32G230, takes care of the reading operation for review. The application processor transmits the measured Biosignal to a remote database using the Wi-Fi module (RF module). The module is implemented using Atheros AR4140.

Fig. 3, shows the general operation flow block diagram for the Wi-Fi module.

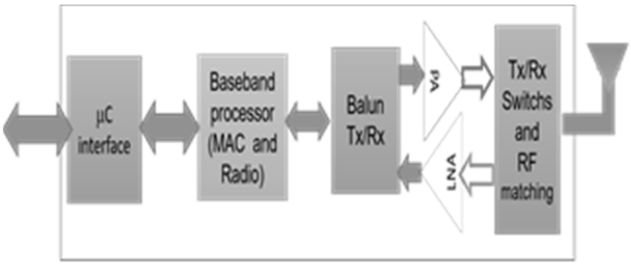

Fig. 3. Block diagram of the Wi-Fi module.

Each unit which is listed at the architecture of the wearable sensor has a different function as explained in the following sections:

- The first step is to connect the Ag/AgCl electrode to the patient skin as illustrated in Figure 4. Proper preparation for the electrode is essential where we placed multichannel electrode. The AFE and MCU unit can work respectively and biosignal can be measured by the prototype.
- The micro-controller (TI CC2538) sends the data to the RTX through the SPI interface. The two AFE unit has 2channel and/or 8 channels where each channel sample rate is set to be 1000 samples per second.
- The units have been integrated into both hardware and software co-design using Co-Located application within the Micro Controller Unit of RTX4140 and the system works well. The UDP server has been built on PC to display the received signal from the Wi-Fi. The UDP (User Datagram Protocol) server receives the data coming from the RTX4140 Wi-Fi module and performs different activities on it.
- The digital output of 16-bit two's complement data is stored in binary format in order later to search the web client. The database can be shared for further analysis after the data export as a text file and presented in waveforms. Using the waveform, signal analysis such as preprocessing and filtering are applied to the signal for further analysis. A practical ECG/EMG signal tested on the system and a GUI software on PC and cell phone is created also in order to collect and to perform the analysis the data.

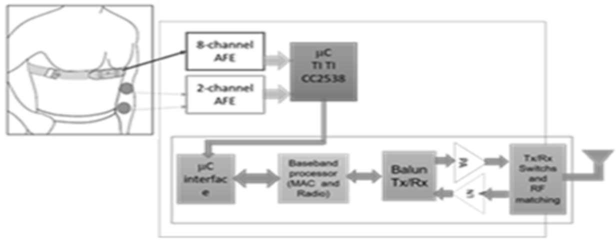

Fig. 4. Biosignal collection

The sensors node (EMG and ECG) in our platform are UDP clients that transmit a raw data over the internet to a remote UDP server. For collecting and holding the captured real times signals are stored on the so-called bigdata4health.net was considered since it can be reached through a web browser. Even though the prototype is capable of processing almost all of the Biosignal, our test was mainly focused on the sEMG signal processing. In the test, EMG signal extraction that performs the signal filtering is bandpass frequency between 20Hz and 250Hz. The filtered data is saved in a MySQL database for further operations

IV. Implementation and results

The prototype has been designed and implemented by a 2-layer PCB board with the thickness of 1.6mm. The board is developed using Eagle SW tool for schematic and layout. The board size is small 60mmx50mmx4mm that is quite small compared to the other similar prototype. In the design, we reduce the noise by splitting the ground plane, decoupling capacitor and by increasing the wire width. However still need the prototype to be smaller by having a more reasonable placement and reducing the power consumption.

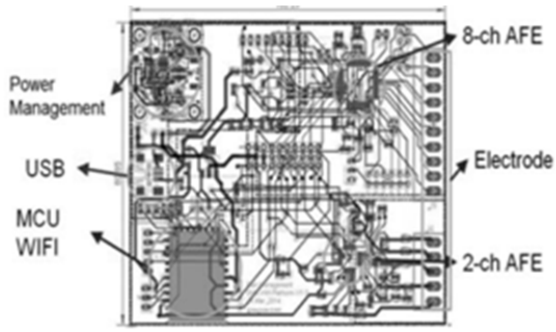

Fig. 5. A prototype of our wearable device

Fig. 5, is the photograph of our prototype. The hardware has five parts: a processor, a Wi-Fi module, two or/and eight channel AFE, a power management, a data flash memory, and two power modules (USB connected to laptop and Lithium polymer battery).

The multi-channel wearable sensor node is tested for sEMG signal acquisition which also performs the digital signal processing.

The software architecture of the sensor interface access is established through the 802.11b/g/n Wi-Fi. The RTX module sends UDP packets to a remote server. The UDP server application, which is written in Python script, continuously connects to the UDP port.

On the other hand, the Co-Located Application (CoLA) app defines the Wi-Fi module and configures the AFE channel 8 or/and channel 2 with a test signal (square at 1 Hz). The data from the ADC is sent as a UDP client to UDP server with IP and port address. A python script for the UDP server is included that takes 5000 samples and saves the data as a text file. The UDP server receives UDP packet from the sensor, which can perform signal extraction in real time and saves it as a function with specific IP address and port number. In this case, the sensor makes a connection to the IP address and start saving the incoming data and updates the database or plots the signal in real time by establishing a full duplex bi-directional communication between the server and the client. Finally, the data can be accessed remotely using a web browser on a Laptop or smartphone also in real time as shown in the next fig. 6.

Fig. 6. Real-time plotting of the updated signal by the web browser

The signals are now saved for further analysis and ready for to perform future analysis after finding the RMS value and similar parameters of the signal which can lead to obtaining the energy level of the signal. Our next work is to perform the feature extraction classification of the signal in order to be able to monitor patient's real-time

During the test, the EMG signal has been collected by using the prototype with an electrode connection for measuring on the movement of the face. We obtained the following signal after applying low pass filtering with cut off frequency 10Hz and the sampling frequency is 1000Hz. (In order to eliminate the movement artifact recommended 10-20 Hz for EMG signal.) . Here, the test result shows that the prototype can read, monitor, and analyze Biosignal in real time

Fig. 7. Shows the raw EMG signals that collected, from the facial expression of body movement caused by penetrating pain for the purpose of experiment and test. This is the initial stage of the experiment which ahead planning to perform more test on the functionality as the real-time feature extraction after we upgraded the module especially on the connection of feature of the electrode.

Fig. 8. Shows the signal sampled at 1 kHz. In Fig. 9. Low pass filtering is applied with cutoff frequency 10Hz.

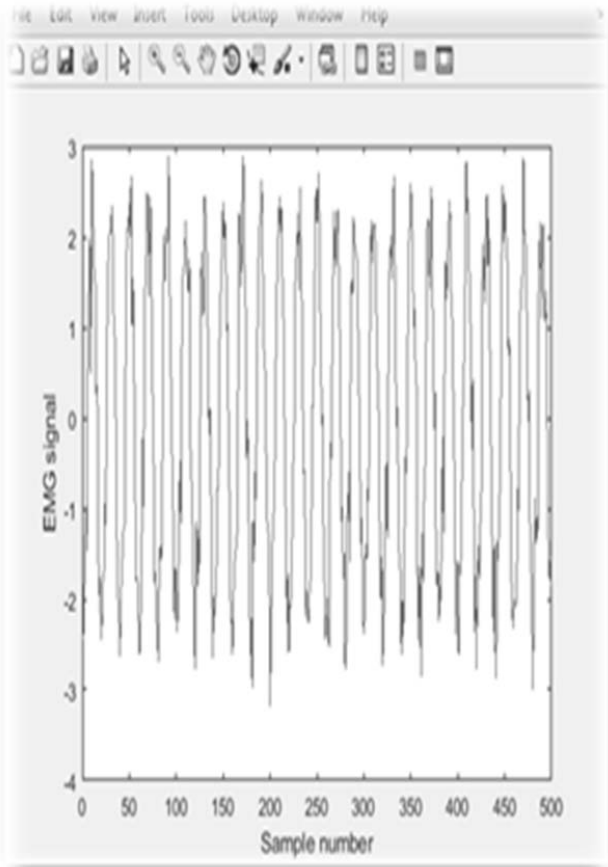

Fig. 7. Test of the functionality of the Prototype on EMG signal, Raw EMG signal collected from face movement

V. CONCLUSION

Smart Wearable devices for e-health are effective solutions to improve health care services. Wireless monitoring of ECG and EMG signals using IoT enabled devices are essential for today's health care system in order to save the vulnerable life of people. In the paper, we present a design methodology and system architecture of IoT based wearable remote monitoring system for healthcare application. The IoT enabled wearable device is tested for real-time monitoring of the sEMG signal. The performance of the proposed system has also been compared with the existing e-health platforms. The platform supports encryption standard and supports 16 ADC channel which makes it the lowest power consumption per channel.

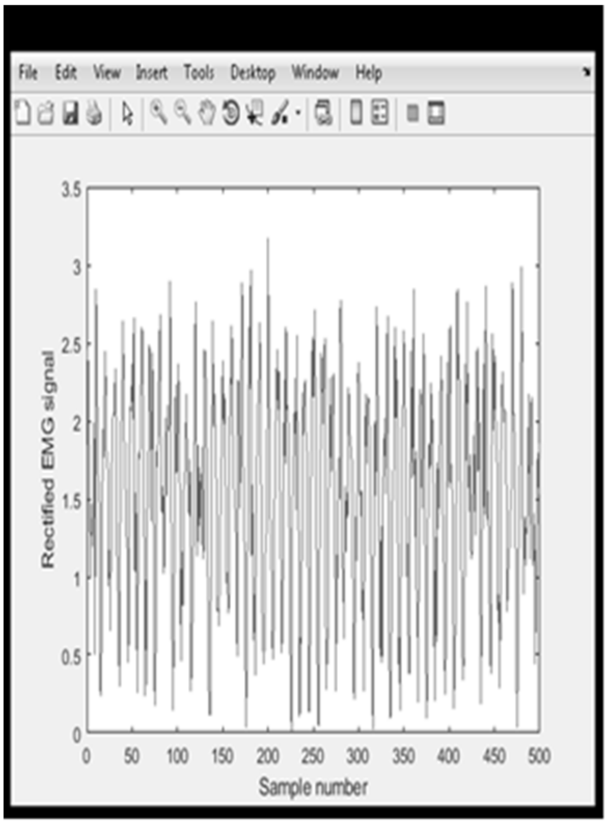

Fig. 8. The sampled Signal

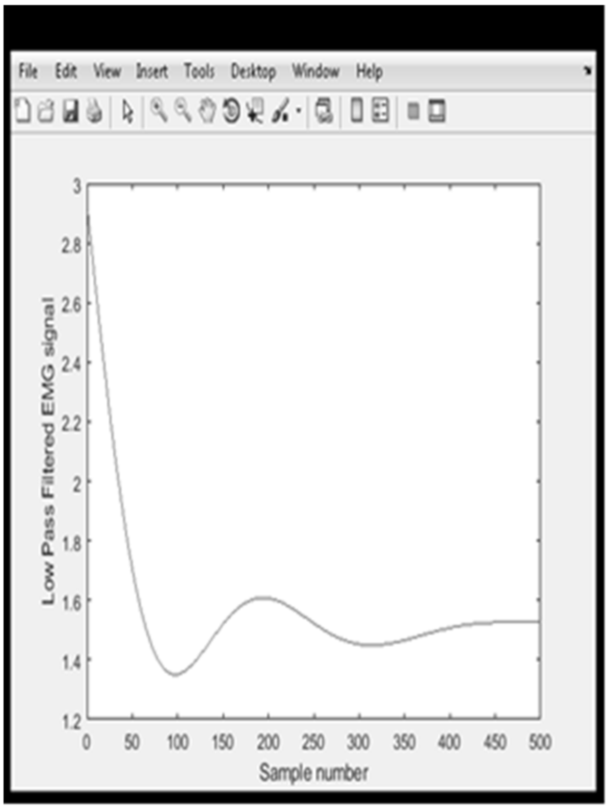

Fig. 9. The filtered EMG signal

The following table compares the performance of our sensor to the latest published ones. The results show that our platform has the lowest power/ channel, acceptable common mode rejection ratio, and secure.

TABLE I. COMPARISONS OF THIS BIOSIGNAL MONITORING SYSTEM CAPABILITIES AND PERFORMANCE TO THE EXISTING AND LATEST PUBLISHED ONES.

REF.	# OF CHANNEL IN ADC	COMMUNICATION PROTOCOL	GATEWAY	CRYPTOGRAPHY	LATENCY (MS)	POWER(NW)	CMRR (DB)
[8]	12	BLE	YES	NO	6	21.48	>100
[9]	10	SIMPLETI	YES	NO	0.7-48	36	>60
[10]	12	BLUETOOTH	YES	NO	100	115	NA
[11]	10	NRF	YES	NO	2.5	1	NA
THIS WORK	16	WI-FI	NO	AES	1.2	9	>74

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REFERENCES

[1] A. J. Camm, G. Corbucci, and L. Padeletti, "Usefulness of continuous electrocardiographic monitoring for atrial fibrillation," *Am. J. Cardiol*., vol. 110, no. 2, pp. 270–276, 2012.

[2] A. Pantelopoulos and N. G. Bourbakis, "A survey on wearable sensor-based systems for health monitoring and prognosis," *IEEE Trans. Syst. Man Cybern. Part C Appl. Rev*., vol. 40, no. 1, pp. 1–12, 2010.

[3] S. M. R. Islam, D. Kwak, H. Kabir, M. Hossain, and K.-S. Kwak, "The Internet of Things for Health Care: A Comprehensive Survey," *IEEE Access*, vol. 3, pp. 678–708, 2015.

[4] F. Conti, R. Schilling, P. D. Schiavone, A. Pullini, D. Rossi, F. K. Gurkaynak, M. Muehlberghuber, M. Gautschi, I. Loi, G. Haugou, S. Mangard, and L. Benini, "An IoT Endpoint System-on-Chip for Secure and Energy-Efficient Near-Sensor Analytics," *IEEE Trans. Circuits Syst. I Regul. Pap.*, vol. 64, no. 9, pp. 2481–2494, 2017.

[5] L. Li, X. Hu, K. Chen, and K. He, "The applications of Wi-Fi-based Wireless Sensor Network in Internet of Things and Smart Grid," *in Proc. 2011 6th IEEE Conf. Ind. Electron. Appl. ICIEA 2011*, pp. 789–793, 2011.

[6] D. Azariadi, V. Tsoutsouras, S. Xydis, and D. Soudris, "ECG signal analysis and arrhythmia detection on IoT wearable medical devices," *In Proc. 5th Int. Conf. Mod. Circuits Syst. Technol. MOCAST 2016*, pp. 1–4, 2016.

[7] E. Spanò, S. Di Pascoli, and G. Iannaccone, "Low-Power Wearable ECG Monitoring System for Multiple-Patient Remote Monitoring," *IEEE Sens. J.*, vol. 16, no. 13, pp. 5452–5462, 2016.

[8] H. Kim, S. Kim, N. Van Helleputte, A. Artes, M. Konijnenburg, J. Huisken, C. Van Hoof, and R. F. Yazicioglu, "A configurable and low-power mixed signal SoC for portable ECG monitoring applications," *IEEE Trans. Biomed. Circuits Syst*., vol. 8, no. 2, pp. 257–267, 2014.

[9] R. S. Dilmaghani, H. Bobarshad, M. Ghavami, S. Choobkar, and C. Wolfe, "Wireless sensor networks for monitoring physiological signals of multiple patients," *IEEE Trans. Biomed. Circuits Syst.*, vol. 5, no. 4, pp. 347–356, 2011.

[10] I. J. Wang, L. De Liao, Y. Te Wang, C. Y. Chen, B. S. Lin, S. W. Lu, and C. T. Lin, "A wearable mobile electrocardiogram measurement device with novel dry polymer-based electrodes," *In Proc. TENCON*, pp. 379–384, 2010.

[11] T. N. Gia, M. Ali, I. Ben Dhaou, A. M. Rahmani, T. Westerlund, P. Liljeberg, and H. Tenhunen, "IoT-based continuous glucose monitoring system: A feasibility study," *Procedia Comput. Sci.*, vol. 109, p. 327–334, 2017.