International Journal of Bio-Science and Bio-Technology
Vol.6, No. 6 (2014), pp.87-96
http://dx.doi.org/10.14257/ijbsbt.2014.6.6.09

Virtual Sensor for Diabetes Meter in U-Health Service

Byung Mun Lee* and Un Gu Kang

Dept. of Computer Engineering, Gachon University, Korea,
**Corresponding Author:bmlee@gachon.ac.kr, ugkang@gachon.ac.kr,*

Abstract

The existing home glucose meters have enabled patients to conduct the self-management of diabetes mellitus by displaying their blood glucose value. However, obtaining a more accurate risk level of diabetes mellitus requires consideration not only of the patient's blood pressure and obesity, but also their first-degree relatives with diabetes. Therefore, in this study, we designed and suggested an intelligent sensor algorithm in order to analyze the risk level of diabetes for IoT-based u-health services. This algorithm is expected to enhance the effectiveness of the patient's self-management provided that it functions effectively in a virtual sensor for diabetes. Finally, based on the findings of the experiment, its effectiveness was confirmed in the proposed model.

Keywords: *Virtual Sensor, u-Heahth, Diabetes, Internet of Things, Intelligent Algorithm*

1. Introduction

Attempts to apply IoT (Internet of Things) technology in various fields are increasing thanks to the development of IoT. Furthermore, the explosive distribution of mobile devices such as smart phones has made IoT-based application services a subject of many studies and has drawn public attention and the u-health field is no exception[1, 2]. IoT-based u-health application services are forecasted to grow significantly along with the rapid aging of society and increase in the prevalence of chronic diseases globally, and are estimated to establish a network with about 774 million u-health devices by 2020.

Diabetes, which is one of the chronic diseases, is a very important disease. A patient with diabetes uses a blood glucose meter to manage his/her diabetes. The blood glucose meter is an indispensable test device for the self-management of patients with diabetes, as well as a necessary medical device for the self-management of metabolic syndrome. However, diabetes associations in Korea and the U.S.A., including international health organizations, recommend that patients consider many complex risk factors, rather than making a diagnosis simply with the measured value of blood glucose[3, 4].

This is because it is necessary to consider the mutual relationships since other factors such as obesity have a significant influence on diabetes. However, most patients determine the risk level of their diabetes simply by using a blood glucose meter for their self-management. In order to improve on this, new u-health services make it necessary to utilize the comprehensively measured blood glucose value obtained by autonomously acknowledging the current state of the patient (their age, sex, blood pressure level, body mass index, extent of obesity, etc.).

This paper proposes a virtual sensor for diabetes performing the above tasks. As the virtual sensor for diabetes should be able to co-link autonomously with required medical devices for IoT-based u-health services, including diabetes meters, an application network protocol is needed for it. Also, an intelligent processing technique is needed that estimates the risk level of diabetes by making use of the various types of health information acquired from relevant medical devices. This paper suggests a protocol and an intelligent algorithm for the virtual sensor for diabetes and confirmed the applicability of the suggested virtual sensor for diabetes through experiments.

ISSN: 2233-7849 IJBSBT

Section 2 of this paper examines the diagnosis criteria of diabetes mellitus, the concept of the virtual sensor, and the characteristics of the IoT-based system. Section 3 explains the service model using the virtual sensor for diabetes and defines an application protocol and an intelligent algorithm in the virtual sensor for diabetes utilizing this model. Section 4 describes the simulation experiment using data, analyzes its outcome and, then, the final conclusions are drawn in section 5.

2. Related Research

2.1. Criteria for Type 2 Diabetes

Diabetes mellitus refers to a disease with higher glucose in the blood resulting from a decreased ability to accommodate insulin in the body caused by lack of exercise, poor dietary lifestyle, and increased stress. Diabetes is a well-known risk factor for cardiovascular disease such as heart attack or stroke[3, 5]. The management of high blood glucose is indispensable for a patient with diabetes, since it is already known that the proper accommodation of blood glucose lowers the morbidity rate of cardiovascular disease. This implies the importance of self-management in diabetes mellitus. This study is based on type 2 diabetes, which covers more than 90% of the cases of diabetes mellitus.

Diabetes mellitus, a type of metabolic syndrome, has a significant relationship with obesity, hypertension, and renal function [5, 6]. For example, the risk of developing diabetes increases 1.8 times in the range of BMI, a measure of obesity, of 22.0 ~ 24.9, as compared with a BMI of less than 21.9, as shown in Table 1. However, it increases sharply to 5.6 times in the range of BMI of 25.0 ~ 29.9 [5]. This shows that the risk of developing diabetes is related to the BMI value even if the measured blood glucose value remains in the normal range. Besides, for a patient with hypertension, the risk of developing diabetes is 2.5 times higher than that of a patient without hypertension. In this way, since the BMI or blood pressure has a close relationship with diabetes mellitus, consideration of this relationship would enable us to obtain a more accurate risk level.

Table 1. Diabetes Risk Rate According to the Range of BMI

BMI	Diabetes risk
18.5~21.9	1.0
22.0~24.9	1.8
25.0~29.9	5.6
30.0~34.9	18.2
>35.0	41.2

The American Diabetes Association suggested the following factors for the diagnosis of diabetes: HbA_{1c}, FPG, 2-hr PG (plasma glucose 2 hours after meals), random plasma glucose, and other risk factors. For example, the FPG means the blood glucose value measured at fasting and a value of less than 100 can be classified as being in the normal range [5]. The 2-hr PG indicates the blood glucose value taken 2 hours after a meal and, if it goes over 200, it is diagnosed as a high risk level of diabetes mellitus. However, for a patient with metabolic syndrome, other risk factors, which influence diabetes mellitus, should be considered. Table 2 shows a classification of the risk factors, which include the BMI, blood pressure, age, first-degree relative with diabetes, and HDL cholesterol. If a patient’s blood pressure measures higher than 140/90, he or she has a high potential to develop diabetes mellitus. If a first degree relative suffers from or has experienced diabetes mellitus, he or she also has a high potential to develop diabetes mellitus. Comprehensively considering other risk factors, rather than simply measuring the blood glucose value, provides more effective help in self-management by enabling a patient to determine his or her potential to develop diabetes mellitus more accurately.

Table 2. Classifications of HbA1c, Glucose and Other Risk Factors

Risk Factors / Criteria	HbA_{1c} (%)	Glucose (Diabetes) (mg/dl)			Other risk factor	
					Hypertension	≥ 140/90
		FPG	2h-PG	Random PG	HDL cholesterol	< 35
NORMAL	< 5.7	< 100	< 140	< 140	BMI	≥ 25
WARN	5.7-6.4	100-125	140-199	140-199	Age	≥ 45
CRITICAL	≥ 6.5	≥ 126	≥ 200	≥ 200	First-degree relative with diabetes	

FPG Fasting Plasma Glucose**, 2h-PG** 2 hours Plasma Glucose, **BMI** Body Mass Index

In general, most patients with diabetes mellitus evaluate the extent of their diabetes with the value measured by a blood glucose meter, then conduct self-management accordingly. However, a new type of measurement technology is required for more effective self-management, which is called a diabetes meter, not a blood glucose meter [5, 8]. This is made possible by utilizing the virtual sensors currently being developed and IoT technology.

2.2. Virtual Sensor Concept

A virtual sensor refers to a sensor that estimates or measures the outcome of abstract conditions by collecting and integrating the measured information from various kinds of physical sensors, as shown in Figure 1 [9][10]. For example, although such a device does not exist yet, if we were to measure the temperature, relative humidity, wind, atmospheric pressure, topography, and altitude and then take account of them comprehensively, we could estimate or forecast the weather and thus build a virtual sensor for the weather. Therefore, a virtual sensor is closer to a software sensor than a hardware sensor, and its potential utilization in various fields, such as the military, medical, industrial, and environmental areas, has triggered much research recently[10][11]. A conventional sensor node in a sensor network relays the measured information in a sink node, whereas a virtual sensor creates various application services by using intelligent processing techniques and cooperative technology between other sensors, rather than using a simple relay function, in order to enhance the value of the measured information. The use of virtual sensors like this is ushering in a new era by grafting them onto IoT technology.

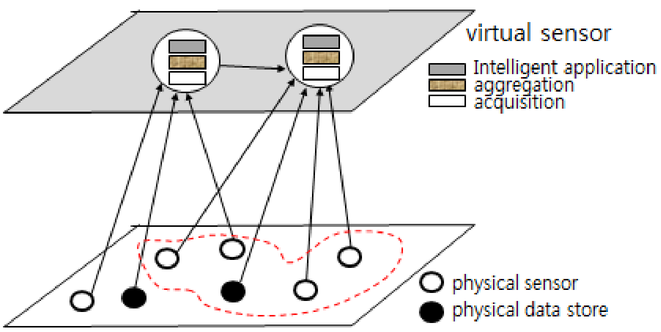

Figure 1. Intelligent Sensor Algorithm for Diabetes

That is, a virtual sensor, which is connected to an Internet of Things, rather than a simple sensor network, can extend to the source of acquiring various information and enlarge the amount of information acquired and offer higher quality and effects in intelligent service.

2.3. Internet of Things

IoT offers a service that enhances the value of self-retaining information through autonomous cooperation with other things by using a network [12]. Everything that forms the IoT is composed through the integration of various technologies. The first technology is a local area network protocol technology, such as Bluetooth, Zigbee, WiFi, and 6lowpan. The second technology is the technology of devices, which should support sensors, actuators, and tags [13].

The third technology is the technology used in the particular service domain, such as healthcare, energy, or retail. This technology handles much more intelligent processing by acquiring measured data from a sensor and needed data from things. However, information security and privacy are also needed to protect the information and power management is another important requirement.

The application of IoT to healthcare provides a lot of benefits [14]. For example, patients can lead a much healthier and longer life if they have access to daily measuring medical information, such as their MRI or CT image information, blood pressure, blood glucose and body fat for patients with chronic disease, and information on the side-effects of any drugs taken. Moreover, patients can acquire their own measurement information either at the hospital or at home and can obtain the latest information on their health by utilizing the latest measurement information. In this context, this study proposes an IoT-based virtual sensor for the self-management of the chronic disease, diabetes.

3. Virtual Sensor for Diabetes

3.1. Healthcare Service Model Using the Virtual Sensor for Diabetes

The virtual sensor for diabetes suggested in this paper is a virtual sensor device which acquires various risk factors using the IoT network and utilizes them to evaluate the risk level of diabetes in real time, and is used in a new healthcare service model. This virtual sensor for diabetes requires two elements to perform these functions. First, it needs a mutually cooperative protocol to acquire the risk factors and, secondly, an intelligent processing algorithm to evaluate them. Figure 2 represents a model that acquires the risk factors from a physical sensor connected to the IoT network and a virtual sensor in order to evaluate the risk level of diabetes mellitus. PS_{XX} is an autonomously and mutually cooperative physical sensor connected to the IoT network where xx is a function retained at each terminal element. For a healthcare service, these elements are physical sensors used for measuring bio-information such as a blood pressure monitor, pulse oximeter, weighing scale, glucose meter, cardiovascular, thermometer, or activity hub. PDS_{XX} refers to a data server that stores these periodically measured values by many physical sensors in a database. VS_{XX} is a virtual sensor connected to the IoT network where xx is a function or a role retained at a virtual sensor.

Figure 2 shows how a virtual sensor operates in the healthcare service. The virtual sensor for diabetes ($VS_{Diabetes}$) acquires the measured blood glucose and weight of a patient from a blood glucose meter (PS_{GL}) and a weighing scale (PS_{WS}), in order to measure the risk level of diabetes. Also, as the patient's test results of HDL cholesterol, HbA_{1c}, and age, and the histories of both the patient and his or her family can be acquired from a server stored at the hospital, these are available upon request to the data server (PDS_{SVR}). If there is an additionally required risk factor such as the blood pressure, it can also be made available by requesting it from the relevant measuring device. In the case where either the power of the measuring device is off or it is outside of the transmitting range of the network, the value can be acquired by requesting it from the data server (PDS_{SVR}) that stored the required information.

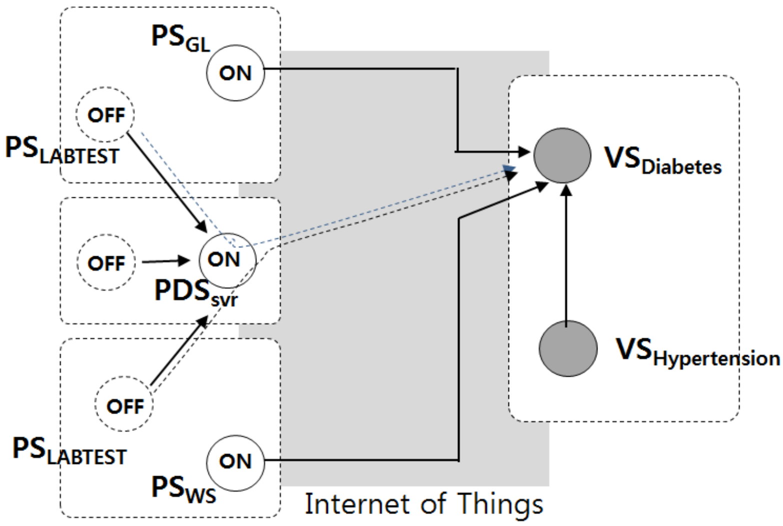

Figure 2. Collaboration Model between Virtual Sensors and Physical Sensors

In order to build this kind of mutual cooperation system efficiently, $VS_{Diabetes}$ should collect the required information in real time. For this purpose, the devices (VS_{XX}, PS_{XX}, PDS_{XX}) should have a seamless mutual cooperation protocol between them.

3.2. Network Application Protocol between Virtual Sensor and Physical Sensor

The IEEE 11073-20601 framework standard is an international standard protocol for the optimized exchange of data between medical devices via a service component (agent) and the client component (manager) that utilizes it. The association procedure defined in this framework standard has an architecture in which only an agent can request its association to a manager. However, since both the virtual sensor and the physical sensor in this paper are agents, information exchange should be done in a peer-to-peer manner. Therefore, the IEEE 11073-20601 framework cannot be used as is. This study aims to define an application network protocol that fits this service model.

An application network protocol plays the role of enabling information exchange between the physical sensors and the data server in order to acquire the risk factors needed for the virtual sensor. Since the devices available at home use a sub-network such as WiFi, Bluetooth or Zigbee, the protocol suggested in this paper is an application protocol using them. This application protocol is divided into three main procedures: the association procedure, data transfer procedure, and release procedure. Figure 3 (a) shows the procedure used to request association prior to requesting data from VS_{XX} to PS_{XX}. The association enables data transmission between the two devices. If there is no reply or failure of association from VSxx to a specific PSxx, VSxx requests association to PDSxx instead. (After/During?) the data transmission procedure of (b), the data being processed is classified into two types, namely one-time and continuous data. Requests for one-time data use the GetRequest service and the requested PS_{XX} transmits the requested data to VS_{XX} while replying through the GetRequest service. Continuous data is requested through SetRequest in order to acquire it steadily, since the data measured by a physical sensor keep changing continuously.

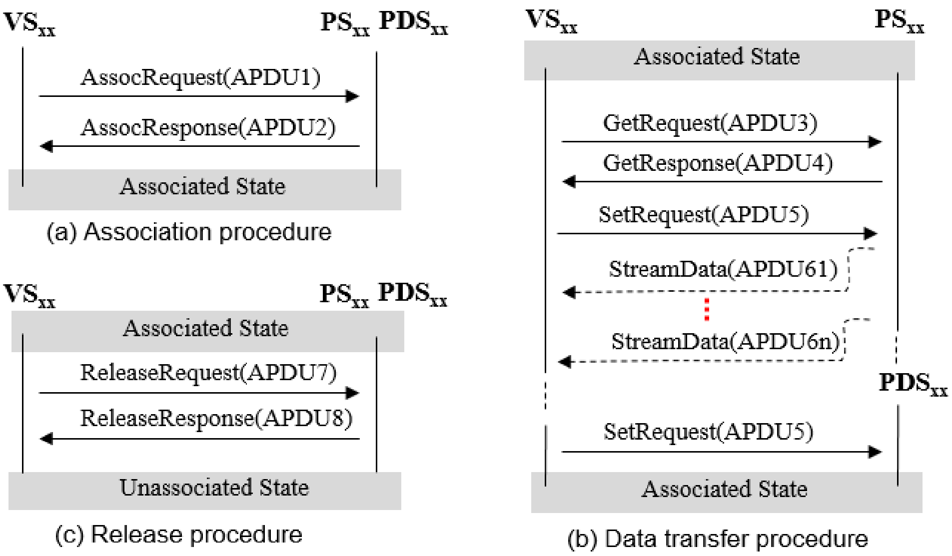

Figure 3. Application Protocol for Data Transfer

For example, the blood glucose value is a one-time data, while the ECG value is continuous data. The risk evaluation data utilized at the virtual sensor for diabetes is one-time data. If the receiver is PDS_{XX}, the virtual sensor has to store the measured information after transmitting it to the data server. One-time data or continuous data contains various risk factors for the virtual sensor to measure. These risk factors are used in an intelligent algorithm. Figure 3 (c) shows the procedure used to release the connected association when terminating data transmission. Another event that association releases is when the transmission terminates abnormally due to failure in either VSxx or PSxx.

Figure 4 defines the APDU (Application Protocol Data Unit) used in this protocol. It classifies the PDU message type (P) of the APDU into 8 types and specifies the association and release without a payload in order to minimize the transmission overhead. The medical data type (M) is classified according to the type of medical (information?), such as the blood pressure, blood glucose, obesity, and weight, and the Source Address (S) and Destination Address (D) of the sensor device are specified. Also, it specifies the payload that contains the sequence number (N) of each message, the length (L) of the payload, and the identification information for the patient and risk factors. It allocates 1 byte to each header field and specifies payloads with a variable size. The information collected with this protocol is used to consider the risk factors and relationships between the diseases. In the next paragraph, we look into the intelligent processing algorithm that processes this procedure.

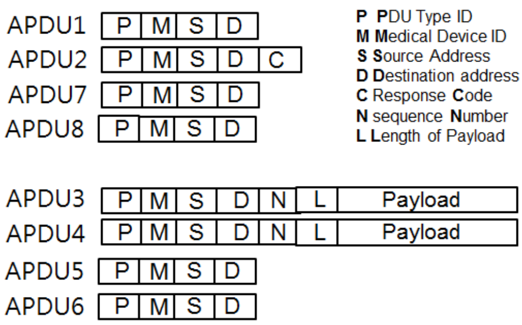

Figure 4. Application Protocol Data Unit Format

3.3. Algorithm for Virtual Diabetes Sensor

The priority of each diagnosis element is in the order of glycosylated hemoglobin, blood glucose value, patient with diabetes, metabolic syndrome, and risk factors. If the measured value is not applicable, the one stored in PDSsvr is used and, if no value is stored in PDSsvr, the algorithm checks and processes the test result of the item as the next priority. Figure 1 shows the processing algorithm. The information on the patient and the test result can be acquired through PDSsvr, and the measured values are acquired from a blood glucose meter (PS_{GL}), a blood pressure monitor (PS_{BP}), and a body fat meter (PS_{WT}).

These measured values are diagnosed as 3 risk levels (NORMAL, WARNING and CRITICAL) through the algorithm shown in Figure 1. This algorithm shows the diagnosis process utilizing many risk factors comprehensively, which differs from the existing methods of diagnosing the extent of diabetes with only the blood glucose value. This is an enhanced version of previous algorithm [15].

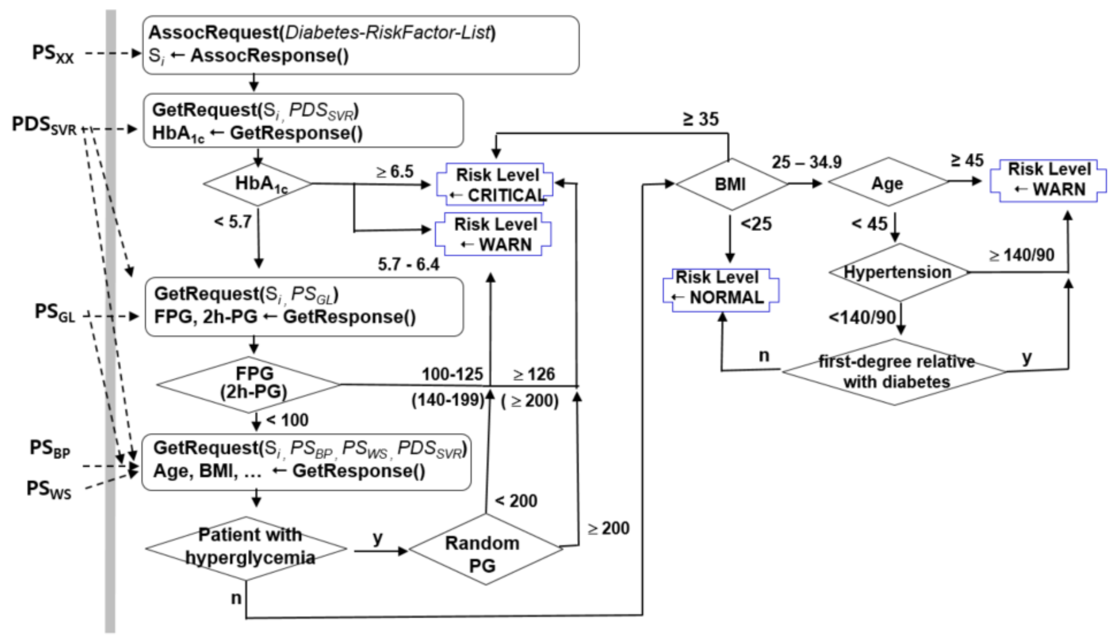

Figure 5. Intelligent Algorithm in Virtual Sensor for Diabetes

Figure 5 illustrates the acquisition of the HbA_{1c} value from PDSsvr by using the GetRequest (PDSsvr) service, which can be measured at the hospital laboratory. The risk level would be determined by this value, but if it is not in the normal range, a blood glucose value is acquired from the blood glucose meter (PS_{GL}) and if the acquired value is not applicable temporarily, the value previously stored in PDSsvr can be used.

Particular care should be taken in the case of a patient with diabetes mellitus, hypertension, and obesity who may show a normal blood glucose value, so it flags the diabetes with the WARNING level. This is based on the clinical diagnosis criteria suggested by the American Diabetes Association.

4. Evaluation

In order to confirm the efficiency of the proposed virtual sensor for diabetes, we compared the results of the evaluation that applied only the diagnosis guideline of the measured blood glucose value and those of the evaluation that covered the overall risk factors. The evaluation results were acquired after 100 experiments materializing the virtual sensor for diabetes and virtual physical sensor in a Linux system and using the acquired data through a mutual cooperation process. The results shown in Figure 6 were obtained from experiments in which the sample data consisted of a total of 1,000 virtual patients per experiment.

Figure 6 (a) shows a drastic decrease (Normal(VS)) in the number of times that the diabetes level was evaluated as normal when the data are considered comprehensively. However, the number of Warning(VS) increased significantly in the figure (b). This means that some of the cases initially evaluated as normal are evaluated as warnings in the integrated evaluation.

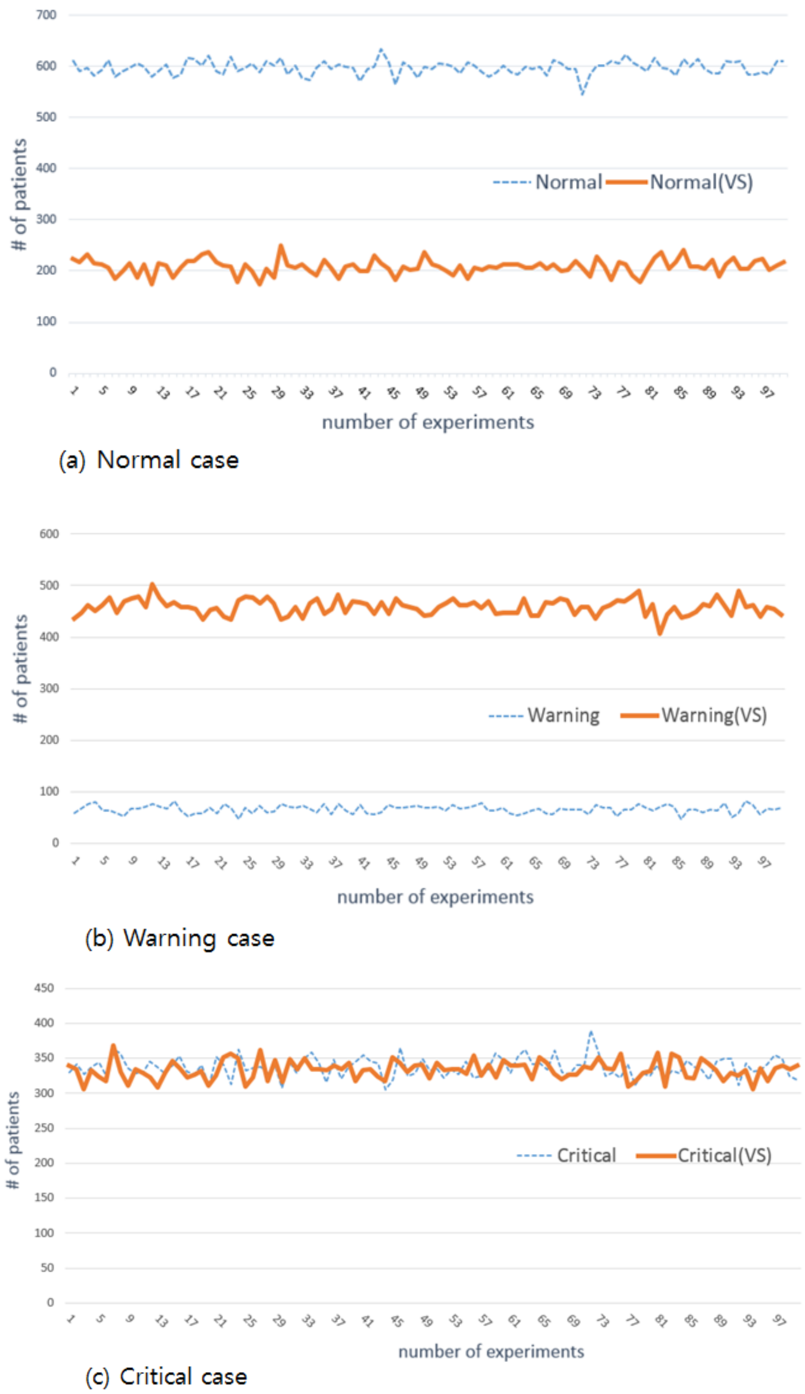

Figure 6. Evaluation of the Experiments

That is, the evaluation of normal when only the measured value is used becomes a warning in the evaluation integrating the other risk factors. Case (c) shows a very small difference.

5. Conclusion

In this paper, we proposed a virtual sensor for diabetes utilizable in conducting effective self-management for diabetes mellitus. The virtual sensor for diabetes is a next generation software sensor which acquires not only the blood glucose value, but also various risk factors, such as the BMI, blood pressure, age, presence of diabetes mellitus in first degree relatives, and HDL cholesterol from a physical sensor connected to the IoT network, and enables an intelligent evaluation to be obtained. (We developed?) an application protocol for this function allowing for mutual cooperation, and designed an intelligent processing algorithm for the integrated evaluation. The new u-health service can be materialized by using this kind of virtual sensor for diabetes. Furthermore, a much more effective model is obtained when a patient conducts self-management using the comprehensive consideration with some risk factors.

However, in the case of an intelligent algorithm, it is very important to achieve seamless information exchange through collaboration with other IoT devices. Therefore, a further study is needed to develop an IoT-based u-health application protocol for mutually distributed processing with other medical devices.

Acknowledgement

This paper is a revised and expanded version of a paper entitled ‘Design of an Intelligent Sensor Algorithm to classify the Level of Risk of Diabetes in a u-Health Service’ presented at the International Conference on Next Generation Computer and Information Technology, Vietnam, October 24-26, 2014.

References

[1] A. Jian, G. Xiao-lin, Y. Jian-wei, Z. Wen-dong, and J. Jin-hua, “Research on a Mobile-aware Service Model in the Internet of Things”, KSII Transaction on Internet and Information Systems, vol. 7, no. 5, **(2013)**, pp.1146-1165.

[2] A. Sarita, and L. D. Manik, “Internet of Things – A Paradigm Shift of Future Internet Applications”, Institute of technology Nirma University, **(2011)**, pp. 1-7.

[3] K. Richard, F. Ele, B. John, and S. Michael, “The Metabolic Syndrome Time: for a Critical Appraisal. Diabetes Care”, vol. 28, no. 9, **(2005)**, pp. 2289-2304.

[4] V. Upkar, “Pervasive Healthcare and Wireless Health Monitoring. Mobile Network Application”, KSII Trans.on Internet and Information Systems, vol. 12, **(2007)**, pp.113-127.

[5] American Diabetes Association, “Standards of medical care in diabetes. Diabetes Care 31 (Suppl 1)”, **(2008)**,pp. 12-54.

[6] Joint National Committee, “Prevention, Detection, Evaluation, and Treatment of High Blood Pressure”, The 7th Report of the JNC, U.S. Dept. of Health and Human Services, **(2004)**.

[7]] M.L. James, C.Y. Donald, A.R. Joseph, and M.D. Ronald, “Obesity: Assessment and Management in Primary Care”, American Family Physician, vol. 63, no. 11, **(2001)**, pp.2185-2196.

[8] L. Byungmun, and O. Jinsong, “Intelligent Healthcare Service by using Collaborations between IoT Personal Health Devices”, International Journal of Bio-Science and Bio-Technology, vol. 6, no. 1, **(2014)**, pp.155-164.

[9] L. Lichuan, S.M. Kuo and Z. MengChu, “Virtual sensing techniques and their applications”, In Procs. of international conference on Networking, Sensing and Control, **(2009)**. IEEE, pp. 31-36.

[10] C. Zeqiang, C. Nengcheng, D. Liping and G. Jianya, “A Flexible Data and Sensor Planning Service for Virtual Sensors Based on Web Service”, IEEE Sensors Journal, **(2011)**, vol. 11, no. 5, pp. 1429-1439.

[11] R. Nikhil, G. Stefano, L. Vitali, G. Raffaele, G. Roberta, S. Marco, J. Roozbeth and F. Giancarlo, “From Modeling to Implementation of Virtual Sensors in Body Sensor Networks”, IEEE Sensors Journal, vol. 12, no. 3, **(2011)**, pp 583-593.

[12] A. Sarita and L. D. Manik, “Internet of Things – A Paradigm Shift of Future Internet Applications”, Institute of Technology, Nirma University, **(2011)**, pp.1-7.

[13] C. Min, W. Jiafu and L. Fang, “Machine-to-Machine Communications: Architectures, Standards and

applications", KSII Trans. on Internet and Information Systems, **(2012)**, pp. 480-497.
[14] L. Byungmun and O. Jinsong, "Application Protocol adapted to Health Awareness for Smart Healthcare Service", In the proc. of International Workshop of Multimedia 2013, Advanced Science and Technology Letters, vol. 43, **(2013)**, pp.101-104.
[15] K. Ungu and L. Byungmun, "Design of an Intelligent Sensor Algorithm to classify the Level of Risk of Diabetes in a u-Health Service", Proc. of The International Conference on Next Generation Computer and Information Technology, **(2014)**.

Authors

Byung Mun Lee. He received a B.S. degree in 1988 from Dongguk University, Seoul, Korea and a M.S. degree from Sogang University and a Ph.D. degree from University of Incheon Korea, in 1990 and 2007. He had worked for LG Electronics for 7 years and was a visiting scholar professor for a year at California State University Sacramento, USA. He is currently a professor in the department of Computer Science, Gachon University, South Korea. His research interests are pervasive healthcare, its network protocol, IoT for healthcare, wireless sensor networks, operating system, etc.

Un-Gu Kang. He received a received a M.S. and Ph.D. degree from Inha University, Korea, in 1998 and 2002. He is currently a professor in the School of Computer Science, Gachon University, Korea. His research interests include Software Engineering and mobile healthcare.