Design Requirements Clarification for Body Area Network: Application to In-Patients

Yea-Dat Chuah, Lian-Hua Kim, Joo-Ling Loo, Pek-Yee Tang, Yong-Chai Tan, Jer-Vui Lee and Ee-Ling Cheah

Department of Mechatronics and Biomedical Engineering, Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, 53300 Kuala Lumpur, Malaysia.

ARTICLE INFO

Article history:
Received 23 December 2013
Received in revised form 25 February 2014
Accepted 26 February 2014
Available online 15 March 2014

Keywords:
Body Area Network,
Design Requirement,
Design Clarification

ABSTRACT

Background: Body Area Network (BAN) has significantly contributed to patients and medical personnel. Objective: This paper clarifies the design requirements of Body Area Network (BAN), which are important in designing the next-generation of BAN.

Results: The method applied in this research was the questionnaire survey method. Discussions includes the best implementation site of BAN in hospitals, the main concern about BAN system, target diseases for BAN system, BAN requirements for Cardiovascular disease patients, BAN requirements for Hypertension patients and the types of post surgery patients suitable for BAN monitoring, the responses of BAN implantation in hospitals and the design requirement clarifications for BAN (In Patient). All these issues had been discussed face-to-face with the medical doctors from Malaysia’s government and private hospitals. Conclusion: Based on the ascertained design requirements, the BAN researchers and design engineers are able to have a clear concept in developing a BAN-based, human friendly and connected health system. The target users of BAN in this paper are limited to the in-patient in the hospitals.

© 2014 AENSI Publisher All rights reserved


INTRODUCTION

Body Area Network (BAN) has significantly contributed to patients and medical personnel. Firstly, patients can be connected to caregivers 24 hours via network according to the patient's needs. Secondly, BAN can be used to monitor chronic but stabilized patients at home ubiquitously (Kumar et al, 2008). Chronic patients discharged from hospitals need to be monitored closely at home. However, not every patient could afford the cost of home visitation of nurses or medical doctors. Hence, remote monitoring of vital signs has demonstrated its benefits to patients at home. In addition, it reduces the frequency of a chronic disease patients visits to hospital/clinic (Jung et al, 2008). Thirdly, there is a situation where hospital beds are unlikely to meet the number of admitted patients. BAN contributes in such a way as to monitor a patient’s vital signs (such as temperature and ECG) in a hospital wherever patient is located. (Francis et al, 2009).

In addition, BAN can be used as an automatic alert signal transmission from personal server to rescue centre by monitoring drastic vital changes in one’s vital signs. (Kumar et al, 2012) BAN can identify emergency and report situations such as heart attacks or sudden falls by real-time monitoring. It can detect if a patient falls and alerts the medical personals in order to avoid lack of attention or late attention (Alemdar et al, 2010). With remote monitoring, BAN system can save the time and cost taken by the hospital (Jamil et al. 2010).

Methodology:

In this BAN study, the raw data were collected through questionnaire survey. A set of questionnaire was designed based on criteria in fulfilling the objectives of this paper. There were three main target BAN users, who were the in-patients including medical tourism, out-patients and health conscious people. This paper focuses on the discussion of in-patients. The full questionnaire is not included in this paper. Nevertheless, the questionnaire consisted of a number of questions which covers the followings:

- Where is the best implementation site of BAN in hospitals?
- What are the main concerns about BAN system?
- What are the targeted diseases for BAN system?
- What are the BAN requirements for cardiovascular disease patients?
- What are the BAN requirements for hypertension patients?
- What types of post surgery patients suitable for BAN monitoring?

Corresponding Author: Dr. Jer-Vui Lee, Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Jalan Genting Kelang, 53300 Kuala Lumpur, Malaysia.
E-mail: leejv@utar.edu.my
• What are the responses of BAN implantation in hospitals?
• What are the physical requirements for the BAN design?

Likert scale (ref) was chosen as the measurement for scaled response in this questionnaire. It is typically a five-point scale as follow: (i) very important, (ii) important, (iii) average, (iv) insignificant and (v) very insignificant. Qualitative data such as Likert scale was then converted to quantitative data using the following equation:

\[ \text{Conversion Formula} = \frac{5N_1 + 4N_2 + 3N_3 + 2N_4 + N_5}{5(N_1 + N_2 + N_3 + N_4 + N_5)} \]

\[ N_1 = \text{Number of respondents with strongly agree} \]
\[ N_2 = \text{Number of respondents with agree} \]
\[ N_3 = \text{Number of respondents with average} \]
\[ N_4 = \text{Number of respondents with disagree} \]
\[ N_5 = \text{Number of respondents with strongly disagree} \]

A total of 25 sets of questionnaire were carried out with respondents from the private and government hospitals in Malaysia. The questionnaires were completed along with interview with the respondents. The functional specifications and design requirements differ in different medical procedures. These were discussed with the clinicians and biomedical engineering personnel as well.

Results:

The Best Implementation department of BAN in hospitals (Importance Index):

Figure 1 shows the best implementation department for BAN in hospitals. Post surgical or rehabilitation departments contributed 60% of the questionnaire responses. 28% of the respondents felt that emergency department would be the best served as the best implementation department. Finally, there were only 8% and 4% to be implemented at normal wards and ICU respectively. 60% of the respondents felt that wireless BAN is suitable for post surgical and rehabilitation usage. They are not chronic as compared to ICU patient. However, they still need intensive monitoring on their health status. Any value above the threshold level will induce an alarm signal so that immediate action can be taken to avoid any late or lack of attention. With such wireless monitoring, patients under rehabilitation can walk around the hospital under close monitoring from the nurses’ station.

Fig. 1: The best implementation site of BAN in hospitals (according to importance index).

Main Concern about BAN System (Rated Responses):

There are several major problems to be considered in order to implement BAN system in the Malaysian context. One is low cost to consumers (patients). As shown in Figure 2, 69% of the respondents felt that cost is the major issue to be considered in BAN implementation. Other 31% feel that Electron Magnetic Interference (EMI) will be another problem instead of the cost. Healthcare service rely on the development of healthcare equipment especially the patient monitoring systems. Its market grows over the years with the systems becoming more and more affordable (Terry, 2005). Therefore, there is a definite market value in implementing the BAN concept into the design of wireless patient monitoring system. The mass production will help in reducing the production cost.
**Target Diseases for BAN System:**

Figure 3 shows the main target disease for BAN system. The top ranked disease with the importance index of 0.96 was the cardiovascular disease. It is followed by post surgical complication with importance index of 0.91. The importance index for Hypertension and Pulmonary disease such as Chronic Obtrusive Pulmonary Disease (COPD) were 0.79 and 0.5 respectively.

**BAN Requirements for Cardiovascular Disease Patients:**

Figure 4 shows BAN requirements for patients with cardiovascular diseases. The data collected from survey questionnaire shows that if BAN is applied on patients with cardiovascular diseases, certain requirements are needed. Firstly, the main requirement would be blood pressure measurement which is top ranked with 100%. It is followed by the measurement of heart rate/ECG at 88%. Other measurements such as pulse rate, respiratory rate and weight are seen as less significant in BAN measurement of heart failure.

**BAN Requirements for Hypertension Patients:**

Figure 5 shows BAN requirements for hypertension patients. The data collected from questionnaires shows that if BAN were to be used by hypertension patients, certain requirements are needed. Firstly, the main requirement would be the blood pressure measurement which is the top ranked with 100%. It is followed by the measurement of heart rate/ECG at 80%. Other measurements such as pulse rate, respiratory rate and weight are seen as not significant in BAN measurement of hypertension patients.
Fig. 5: BAN requirements for hypertension patients (according importance index).

Types of Post Surgery Patients Suitable for BAN Monitoring:

Figure 6 shows BAN design requirements for post surgical patients. For the current state, BAN might be mainly used for rehabilitation of patients after surgery (particularly for medical tourism). In this case, perhaps a real-time sign transmission is not necessary, but all the data should be able to be stored in the memory of the BAN. After conducting the surveys, a conclusion can be made where BAN is only applied on a few types of surgery. Among several surgery list, heart related surgery ranked top of the list. It is shown that heart bypass is ranked at the first place with its importance index at 0.96. It is followed by angioplasty with a total importance index of 0.808. Others non heart-related surgery such as knee/hip replacement and plastic surgery are at lower ranked, both with importance index of 0.4 and 0.216 respectively. Both of them are less significant because since patients undergo knee/hip replacement surgery can go back home directly and perform home rehabilitation. This situation is applied to those plastic surgery patients as well.

Fig. 6: Types of post surgery patients suitable for BAN monitoring.

Responses of BAN Implantation in Hospitals:

Based on the responses as shown in Figure 7, 16% of respondents disagree with the idea of wireless BAN implementation in the hospital. They are satisfied with the current performance of the cabled telemetry system in their hospitals. With the cabled system, there is no risk of data lost. In addition, cabled system has been adapted quite some time and they have gotten used to it. However, 84% of the respondents agreed with the idea of BAN implementation in hospitals. They agreed and supported the innovation of changing the cabled sensor nodes into wireless form in the current telemetry system. This is due to the current cabled sensors are always not in good condition after repeated use in patients. Thus, the cables may be detached, or even loosened after a long period not being in use.

The Design Requirement Clarifications for BAN (In Patient):

The design idea mimics the current telemetry system. It aims to revolutionize the way patient’s vital signs can be measured wirelessly, continuously and comfortably. It is required to include the capability of vital signs processing. The newly designed wireless BAN should also include the simultaneous acquisition of spO2, heart rate/ECG and blood pressure since the current telemetry device available in most of the hospitals in Malaysia can only record the heart rate of the patients. Wireless sensor is used for periodic and continuous measurement (automated measurement) of a patient’s vital sign. It is attached to the patient’s body with the use of medical adhesive dressing as shown in Figure 8. An adhesive patch is secured to the skin-contacting element of the sensor. By simply pasting the disc-like sensor on the body, patient’s vital signs such as heart rate and oxygen
saturation (spO2) can be transmitted to the central server wirelessly for storage, automatic charting and real-time alert. Medical personals can access to these data continuously in real-time with no interferences. Since nurses can focus on improving patient care quality, thus hospitals management can be further improved in term of operational efficiency and manpower savings.

Fig. 7: Responses of BAN implementation in hospitals.

Fig. 8: Wireless body area network system as designed (for in-patients).

Discussions:
The Best Implementation department of BAN in hospitals:

Remote cardiac monitoring has emerged as a possible way to improve healthcare of patients. The remote cardiac monitoring covers a broad area which allowing patients to move freely in a zone located outside the care areas (ECRI, 2007). This system generates visual and audible alarm signals based upon condition changes that exceed established threshold value of a patient (Cale, 2007). 28% of the respondents that felt wireless BAN would be useful in emergency department. In their perception, there is always a large crowd waiting to be consulted by doctors in emergency department. They may have demonstrated unexpected symptoms and condition changes that require continuous or physiologic cardiac monitoring. Many facilities have implemented remote cardiac monitoring to facilitate alarm notification (Patient Safety Advisory, 2009). The implementation of BAN would be useful in monitoring their health status and to avoid cases such as late or lack of attention on those crucial patient with life-threatening diseases e.g. heart attack and cardiac arrest. It may avoid further deterioration of patient conditions.

For example, cardiac arrest may cause blood pressure to drop below minimum levels of 50 mmHg systolic and 35 mmHg diastolic. If not treated immediately, this will lead to a coma followed by death (Chen et al., 2007). In addition, non-intensive telemetry units are used to monitor the life threatening patients. When 70% of the top 10 diseases admitted into emergency department are clinically indicated for telemetry. Hospitals lack facilities to treat the admitted patients and make them suffer from a long emergency room waiting period (Chen et al., 2007). Wired telemetry is not suggested here, since wires would be tangled around the department and it would make the emergency department look messy and doctors would sometimes get upset over this situation. However, telemetry is not indicated for patients in all cases.

Finally, there is a minority of 4% who felt that ICU would be served as BAN implementation department. However, this is not supported significantly for serving ICU patients. ICU units are for those patients who are likely to require advanced respiratory support, and requiring support of two or more organ systems. In addition, ICU units are for patients with chronic impairment, which has affected their daily activities (Cuthebertson et al., 1999). Thus, there is a need for monitoring ICU patients in intensive care with more complex monitoring systems (which is more than 3 vital signs criteria as mentioned in BAN architecture).

Main Concern about BAN System:

A specific frequency transmission band is chosen. As users of medical devices, the radio signals transmitted from patient to the monitoring station are vulnerable to electromagnetic interference (EMI). So it can pose a risk to patients. If these signals are interfered while the patient is suffering a significant adverse health event, the medical response could be delayed and the consequences can be serious for patients. Because of the importance of these signals and the likelihood of EMI with these vital transmissions, the Food and Drug Administration (FDA), the Federal Communications Commission (FCC), medical device manufacturers, and the healthcare community banded together to examine the EMI issue with wireless medical telemetry and develop solutions to reduce the risk of interference (Dyro, 2004). The new Wireless Medical Telemetry Service was established with its separate frequency spectrum and coordination. It was designed to reduce the risk of EMI to the vital patient telemetry signals from other frequency transmission operating in the same frequency bands (Witterset al., 2004).
**Target Diseases for BAN System:**
Cardiovascular disease is top ranked disease with the importance index of 0.96. In Malaysia, heart disease is on the rise despite improvement in health services and facilities in Malaysia. It was the second leading cause of death in the country. In 2001, approximately 20% of all deaths at the government hospitals were due to heart attacks and strokes. It is projected to be the leading cause of death in Malaysia and other developing countries in the next ten years. (National Heart Association of Malaysia, 2008).

Secondly, post surgical was possible, important and yet feasible to be included in wireless BAN system. It is ranked as the second with 0.91 importance index. Post surgical patients suffer from postoperative pain due to the reduced mobility. Because of the ability in monitoring this group of patients and identifying high-risk patients in developing complications, it allows early interventions to prevent harmful outcomes (Pallikonda et al, 2008). In the current state, most of the hospitals have implemented the cabled telemetry system on those rehabilitation patients. However, the wired telemetry system can be improved with the wireless technology. It can be integrated into the BAN system to provide real-time monitoring. Its function would remain the same, which sends vital sign readings to central nurse station. It allows sensor patches to be attached on patients in wireless form. Since there are no wires constraints on patients, thus patients will feel more free and comfortable.

Thirdly, hypertension was rated at 0.79 importance index. High blood pressure usually causes no symptoms and it can be diagnosed by measuring blood pressure. A person is diagnosed to have hypertension if his/her pressure is greater than 140/90 mmHg. Additional test such as electrocardiograms (ECG) will be conducted if required. ECG measures the electrical activity of the heart and to assess the physical structure of the heart. Others such as Chronic Obstrusive Pulmonary Disease (COPD) are seen not as significant for BAN context compared to heart disease and post surgical disease.

**BAN Requirements for Cardiovascular Disease Patients:**
For blood pressure measurement, systolic blood pressure is a readily vital sign in predicting mortality risk and revealing characteristics for heart failure patients. The level of systolic blood pressure indicates the different stages of heart failure. (Champeau, 2006). In such a case, the heart rate increases as one of the compensatory ways of maintaining adequate cardiac output. An ECG is an important tool in evaluating a patient’s heart rate and circadian rhythms. It is able to perform and indicate heart problems by detecting the enlargement of the heart muscle without pain. Electrical signals are generated accordingly to each heartbeat. These electrical signals which are in the attenuated form and it can be detected at the skin of the patient and recorded. Oxygen saturation is another important measure to determine whether it is the physiological result of cardiopulmonary or respiratory distress. It is rated at 60% in the questionnaires carried. Pulse oximetry provides a fast, accurate and non-invasive method to measure a patient’s arterial oxygen level which can indicate physiological stress. However, it cannot be used in certain medical conditions such as carbon monoxide poisoning and cardiac arrest situations. This is because it fails to detect any difference between the oxygen and carbon monoxide bound to haemoglobin in blood.

**BAN Requirements for Hypertension Patients:**
Hypertension is a cardiac chronic medical condition in which the systemic arterial blood pressure is elevated. It is generally diagnosed on the basis of a persistently high blood pressure. Thus, blood pressure measurement is significant for initial diagnosis of hypertension. Exceptionally, if the elevation is extreme, or if the symptoms of organ damage are diagnosed, immediate treatment and close monitoring is necessary.

**Types of Post Surgery Patients Suitable for BAN Monitoring:**
For those patients who have undergone heart surgery, most of them are needed to be admitted to hospital for post surgery care. For example, after heart bypass surgery, the patient is transferred to the cardiac surgical intensive care unit. Then, the patient is monitored continuously with current heart rate and blood pressure monitoring devices for 12 to 24 hours. Thus with the current devices, it is proposed to apply wireless system so the patients are free from wire hassles, and yet they are under close monitor with real time transmission. Any value above the threshold level will induce alarm signal so that immediate action can be taken to avoid any late or lack of attention.

The same situation also is applicable to post-angioplasty surgery as well. The patients need to stay in a special care unit where they are monitored for a few hours or overnight (University of Michigan, 1999). The situation can be improved where BAN can be incorporated into it. In addition to the above mentioned advantages, BAN system can definitely reduces the nurses’ workload and helps to alleviate nurses’ shortage although the patients are not allowed to move around.
Responses of BAN Implantation in Hospitals:

The nurses have to use tape to attach cables firmly on patient’s body. This may leave the cables in poor condition after the usage. Therefore, this condition will be improved if it is replaced with wireless sensor. More importantly, cables are no longer required. Wireless sensor can be attached on the patient’s body for automated and periodic measurement of patient’s vital sign. It is attached to the patient’s body with the use of medical adhesive dressing. The sensor can pick up and transmit the medical or biological data from patient body to a patient-worn transmitter. The data can be stored in a secure digital (SD) card or read by the caregivers and doctors on duty in real time. Any value above the threshold level will induce an alarm signal so that immediate action can be taken. This will avoid any late attention by the caregivers or doctors on duty.

Another limitation of the conventional telemetry system with wire electrodes is the difficulty of wiring, thereby limiting the mobility of the patient. The current cabled telemetry system allows patient mobility within certain monitored areas in the hospital. However, the patient definitely feels uncomfortable with all those cables tangled around on his/her body especially in sweating condition. At this point, there is a need of wireless BAN which enables the removal of restrictive and unreliable wiring, enhanced ease-of-use and increase daily efficiency as well.

There are always some spaces for improvement in the future of medical field. Driven by a strong pressure to improve, the performance targets for the healthcare industry continue to rise. At the time where budgets and resources are restricted, new ways of increasing efficiency, productivity and usability are sought. The cabled telemetry system is suggested to be used in wireless form with all those sensor patches. No matter where the patient is in the hospital, data can be sent to the nurses’ centralized station continuously from the attached wireless sensors. It allows nurses to monitor multiple patients at the same time. The wireless BAN system can collect several vital signs simultaneously with the network formed. For example, a newly innovated wireless BAN is a sensor network system which constitutes of different sensor that can read spO2, heart rate and blood pressure at the same time. The current telemetry device can only record the patient’s heart rate.

In fact, in these few decades, there is always an escalating presence fuelled by changes in the wireless landscape. Firstly, there is a greater economy of scale through global standardization. Cheaper, smaller and more reliable solutions incorporate higher levels of electronic integration. Also, there is an obvious reduced interference in protected medical frequency bands. Lastly, increased awareness and interest in public and especially in medical professionals lead to wider acceptance of wireless BAN system. The main difference between a wired and wireless BAN infrastructure is the existence of physical cabling. A wired network uses wires to communicate but a wireless network uses radio waves without any cabling. The transmission of data via radio waves behaves like a cordless phone. Therefore, the infrastructure of wired networks is easy to be set-up and troubleshoot. However, wireless networks are difficult to be set-up, maintained, and troubleshoot. In addition, the cost of the wired networks increases when the covering area increases. On the other hand, wireless BAN networks do not involve this cost. A wireless BAN network can also save time during installation which deals with a lot of cables. Wireless BAN provides user with a definite convenience of movement, mobility and freedom but wired networks does not. Share space does not allowed within a wired network and but dedicated speeds. On the other hand, wireless BAN network allows the same connection to be shared by multiple users.

The healthcare sector has adopted the wireless technology since the solutions can radically improve efficiency and productivity. Today’s solutions perform better whilst being small and cheaper. Eventually, the final outcome of wireless BAN is at higher volumes, lower costs but greater functionality. As a conclusion, there are always spaces for improvement and innovation in terms of BAN implementation within the hospital. The responses from engineers, medical officers and nurses are mostly positive towards the idea on wireless BAN implementation.

The Design Requirement Clarifications for BAN (In Patient):

Cables are no longer required. The sensor can pick up and transmit the medical or biological data from patient body to a worn transmitter. It enables removable of restrictive wiring, thus enhances the ease-of-use and portable of BAN. The data can be stored in a SD card or read in real-time basis by caregivers or doctors on duty. Any value above the threshold level will induce alarm signal so that immediate action can be taken to avoid any late or lack of medical attention. The transmitter unit is required to be designed in compact and light weight. The role of the transmitter is to pick up vital signs from sensors. It should have the mobility where transmitter can be either carried by patients, or put at the side of patient bed. It should have waterproofing and durability which help to prevent damages in daily activities. In addition, it shall be used with a wireless local area network (WLAN) to transmit the vital signs of patients. After transmitter picks up the data, it will be then transmitted to PC based Central Station on real-time or non real-time basis. BAN should apply energy scavenging techniques. In such a case, a disposable lithium ion battery is recommended. In medical purposes, it is the best ideal for portable devices due to its lightness and high energy density.
Conclusion:

For in-patients in hospitals, wireless BAN is required to be implemented in the departments such as post surgical/rehabilitation department and especially in emergency department. Through the results based on the questionnaire surveys, the idea of incorporating BAN design into emergency department is a useful finding where wires would be tangled around the department and it would make the emergency department look messy and keep doctors get frustrated over this situation. Thus, wireless BAN in the emergency department where it avoids late or lack of attention, and also to alleviate nurses’ shortage as well. Wireless Body Area Network (BAN) provides non-critical patient care such as rapid cardiac data interpretation and the usage of real-time data. Therefore, its wireless monitoring is capable to identify the early physiological changes and enables direct assessment and treatment of patient. In addition, it enhances the patient safety as well as the operating efficiency.

Based on the current data, BAN is recommended for post surgical/rehabilitation department and emergency department. It avoids late or lack of attention, and also to alleviate nurses’ shortage. There would be 3 wireless devices: 3-nodes wireless ECG patches, portable monitor for heart rate and blood pressure readings, and lastly, clip-on spO2 sensor. They do not need to be applied simultaneously. However, their usage is based on the patient’s needs and measurement needed to be monitored during a particular period of time. The wireless BAN must be able to pick up 3 vital signs, which are heart rate/ECG, spO2 and blood pressure while the current telemetry system is able to pick the heart beat of patients.

REFERENCES

Cuthebertson, B.H., N.R. Webster, 1999. The role of the intensive care unit in the management of the critically ill surgical patient. Academic Unit of Anaesthesia and Intensive Care, University of Aberdeen, Aberdeen UK.