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Multi-Point Time-Averaging Data Acquisition of Health Indicators: A Reliable Process for Patient Medical Support

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ABSTRACT

This paper presents a reliable method for accurate health data acquisition using multi-point time-averaging process. The conventional single-point one-time measurement method currently used with today's medical instruments has not given the desired accuracy in healthcare delivery and cannot be used with emerging wireless sensor technology for the future medical services. Wireless sensor nodes can allow more than one body parameter to be measured from a single point in any part of the body and are small enough to be spread all over the body with much convenience that is not possible with conventional instruments. Multichannel sensor node and body area network implementation architectures are equally presented for the proposed method. The paper also took note of the prevalent challenges in the use of wireless technologies in data acquisition and provided a network energy reliability amelioration that will lead to more data reliability and accuracy. Implementation of the proposed method and its applications are presented in this paper.

Keywords: *Multi-point measurement, Data acquisition, Healthcare, Accuracy, Wireless sensor network*

I. INTRODUCTION

Data Acquisition is a veritable aspect in the field of medicine today for efficient health care delivery, especially with the advent of smart devices. Several parameters are used to indicate the health condition of an individual ranging from body temperature, heart beat rate, blood oxygen level, blood pressure to several others. The measurement of these parameters for the establishment of a health condition is very vital and several instruments and equipments have been developed to that regard. However, the method of taking these measurements remains a thing of concern in the use of most instruments in acquiring these health indicators. Measurement of the most common clinical parameter, body temperature, heart beat rate and blood pressure have been mostly subject to measurement errors due to methodic acquisition of data [1, 3].

In the measurement of these ecumenical clinical health indicators, single-point one-time readings are generally acceptable irrespective of influencing factors that may affect such readings. Variations in the human body health indicators are easily caused by factors such as weather condition, time of day, physical activities, food intake, part of the body from which measurements are taken, and so on [2]. Thus, the single-point one-time measurement method cannot be accurate and valid enough for today's health delivery systems. This basic fact seems not to be addressed even with the advent of precision digital devices which have flocked the market for more than a century now, practically because they are made to mimic their analogue counterparts and to follow some laid down measurement principles that have given some sense of accuracy over the years.

While these digital medical instruments eliminate errors due to parallax, improper positioning, wrong timing length, etc [3], measurement methods have remained the same.

Recently, technology has tilted towards the use of smart devices in all works of life and has continued tilting further to the use of smart wireless sensors [4, 5, 6] that can be carried about at ease and even embeddable in the human body and other structures for real-time measurement and data acquisition. These smart wireless sensors seem to have opened a new dimension in the measurement of health parameters for more precise clinical applications [7]. This paper presents a time averaging method of measurement for body temperature, heart beat rate, and blood pressure applicable in smart clinical and at-home medical devices. The use of this measurement system will enable round-the-clock measurement of any parameter and takes care of measurement inaccuracies due to variations in body parameters in various parts of the body at different times of the day.

II. INTERESTS

Numerous efforts have been made over the years to have accurate measurements especially of physiological parameters as they can be life threatening in health care delivery. These efforts span from the use of precision mechanical tools to the present day electronics and digital systems. Ian Smith et al [8] in their work compared manual and electronic means of measurement of respiratory rate in a number of healthy individuals and found that electronic means by far provide more insight to respiratory measurement. However, both processes used the same single-point one-time measurement method which does not eliminate estimation errors due to physiological and time variations. Frommelt et al [9] presented a comparison of accuracy in different human body temperature measurement devices (oral disposable, tympanic, and temporal artery) in monitoring hospitalized patients. Their findings suggest that the oral disposable and temporal artery devices tend to be more accurate than their tympanic counterpart. However, when compared to a reference oral electronically recorded temperature, even the oral disposable and temporal artery devices showed significant differences which limit their use for hospitalized patients monitoring. Because these measurements were taken at a point per device, from various parts of the body, it is argued that the recorded accuracy deviations are not only due to device differences but also due to physiological conditions at the time of measurement. In the measurement of blood pressure with cuff devices, certain conditions such as room quietness, seating position, type of food taken and how long, proper cuff fitting, etc [10, 11] are expected to be observed before measurements are taken. These conditions are however sparsely observed especially due to work pressure. As rightly noted by J. S. William et al [11], normal blood pressure fluctuates over time and accuracy can be improved by taking average of several readings at different times of day. This cannot be achieved easily with the use of conventional measuring devices as human inefficiencies may result to undesirable results.

In the light of today's smart technologies, several works has been proposed for real time 24/7 human health data acquisition. A. Dosinas et al [12] presented measurement of human physiological parameters in the systems of active clothing and wearable technologies, and argued that direct measurement of health indicators at single body locations with empirically calibrated instruments will not produce the required accuracy. They proposed that accuracy of blood pressure values for example may be achieved by direct intra-arterial measurement which is possible both at active and quiescent times. In their work, they supported the use of wearable mobile devices that could measure and relay physiological parameters to a base device in a healthcare center. C. A. Boano et al [13] noted that patients shows signs of stress and anxiety and behave differently from their normal daily life in clinical environments, and proposed a body sensor networks as a solution to accurate temperature measurements for medical research. They claimed ±0.02% accuracy with environmental temperature compensation in their developed device to cater for external temperature changes. While their system effectively measure body temperature on a continuous basis for a long period evaluation of body temperature, the data collected were still single-point temperature information from a fixed part of the body. The work however is a lead to future measurement process in which health services could be given at much convenience.

III. THE BASIC HUMAN HEALTH INDICATORS

The human state of health is generally a measure of several physiological parameters that are self-interdependent. A number of these parameters are difficult to measure and are not viably important in most day to day health check.

Generally, physiological parameters such as cardiovascular movements, pulse rate, blood pressure, body temperature, obesity level, etc are differently used to ascertain patients health in varying conditions. However, in most situations the basic indicators used are body temperature, heart beat rate and blood pressure which gives immediate insight into several health conditions. The measurement of these three parameters lends themselves to the use of various types of devices over the years which are continuously being modified for different purposes. With today's technology, micro-sensing devices that can be conveniently carried about and even capable of embedding into the human body to acquire these parameters have been developed and are still being developed.

IV. SINGLE-POINT ONE-TIME MEASUREMENT

Clinical devices and measurement methods in use today are designed to read body health information from specific parts of the body and at a time. This measurement procedure has resulted to several errors and wrong treatment administration. Some of the basic questions posed by experts with regards to the accuracy of these measurements and validity of values obtained include how were the instruments used, when and where were the readings taken, what was the attitude of the patient and that of the care giver while taking the readings, was the environment conducive, how many times were the readings taken, were they consistent, etc. These many questions are usually unanswered especially when the readings are obtained by a third party care giver. One may assume that automatic instruments are being use and therefore measurement errors of good magnitude do not arise. On the contrary, automatic is not accuracy, of course with the advent of digital devices today, errors due to parallax, timing, and others can be avoided. But it is a known fact that temperatures taken from different parts of the body for example varies by some degrees and will not give the same readings for different time of the day. Errors due to physiological differences, psychological effects, and environmental changes cannot all be detected automatically. Single-point one-time parameter measurements are therefore not suitable for the future health care giving services. Hence, newer methods of accurate measurements must be sort after.

V. PROPOSED MULTI-POINT TIME AVERAGING METHOD

The human health D is composed of several unknown factors that cannot be directly taken. Generally, the basic human wellness indicators such as breathe rate, blood pressure, and body temperature can be used as a measure of the individual's primary health condition. These basic indicators may increase or decrease with time of exposure to certain environmental conditions, body changes, etc. Therefore, the individual's health condition could be represented thus,

$$D = f(\alpha) + f(\beta) + f(\tau) \text{ - - - - - - - - } \quad (1)$$

Where, α = individual's blood pressure indicator. β = individual's heartbeat rate indicator.
τ = individual's body temperature indicator.
When these parameters are taken from various parts of the body, they can be accumulated and statistically represented to show the mean values at all times. Each parameter function could therefore be represented both in time (t) and in the number of parts (n) of the body from which readings are taken. Thus:

$$f(\alpha) - \sum_{n=0}^{N} \sum_{t=0}^{T} \alpha_{nt} \text{ ----------------------------- } (2)$$

$$f(\beta) - \sum_{n=0}^{N} \sum_{t=0}^{T} \beta_{nt} \text{ ----------------------------- } (3)$$

$$f(\tau) - \sum_{n=0}^{N} \sum_{t=0}^{T} \tau_{nt} \text{ ----------------------------- } (4)$$

Where $n = 0, 1, 2,$ - - - - - - - - N and $t = 0, 1, 2,$ - - - - - - - - - - T Hence,

$$D - \sum_{n=0}^{N} \sum_{t=0}^{T} \alpha_{nt} + \sum_{n=0}^{N} \sum_{t=0}^{T} \beta_{nt} + \sum_{n=0}^{N} \sum_{t=0}^{T} \tau_{nt} \text{ ---} (5)$$

Therefore, each parameter could be read in time by the sensors and stored in their number in the aggregating smart device(s). This process will enable users to view the trend of parameter changes as well as be able to more accurately estimate the actual value of the parameter of interest over time using a moving average process as defined by equation (6) to (8).

$$\alpha_{average} - \frac{\sum_{n=0}^{N} \sum_{t=0}^{T} \alpha_{nt}}{N \cdot T} \text{ ------------------------- } (6)$$

$$\beta_{average} - \frac{\sum_{n=0}^{N} \sum_{t=0}^{T} \beta_{nt}}{N \cdot T} \text{ ------------------------- } (7)$$

$$\tau_{average} = \frac{\sum_{n=0}^{N} \sum_{t=0}^{T} \tau_{nt}}{N \cdot T} \quad \text{------------------------} (8)$$

If we represent each of the parameter by λ, equations (6) to (8) can be expressed in their matrix form as shown in equation (9). Where the denominator term represent any number of row and column terms of interest within the matrix.

$$\lambda_{average} = \frac{\begin{bmatrix} \lambda_{1,1} & \lambda_{1,2} & - & - & \lambda_{1,t} \\ \lambda_{2,1} & \lambda_{2,2} & - & - & \lambda_{2,t} \\ - & - & - & - & - \\ - & - & - & - & - \\ \lambda_{n,1} & \lambda_{n,2} & - & - & \lambda_{n,t} \end{bmatrix}}{N \cdot T} \quad \text{------------------------} (9)$$

By taking the sum of any number of terms in the numerator, a moving time average of the parameter of interest can be calculated using equation (10).

$$\lambda_{average} = \frac{sum\left(\lambda_{n,t}\right)}{N \cdot T} \quad \text{-----------------------------------} (10)$$

This average values takes into considerations physiological changes in the various parts of the body when used to measure health parameters.

A. Use of Conventional Instrument

Conventional instruments can only be used with single-point measurements due to their nature and construct. Apart from a few which can be used to determine more than one parameter change, conventional instruments are in principle made to measure one parameter only and must be used on specific parts of the body. Their design nature shows that conventional instruments can only give acceptable results within limits of use. That is, some guidelines must be followed in their application if reliable measurements are to be taken. These guidelines however, are in constant violation by users and have adversely affected treatment administrations and care giving. Conventional health parameter measurement instruments cannot be used with the proposed multi-point time averaging method. The major challenge is how these parameters can be measured in different parts of the body given their complexity and the need for the convenience of both patients and care givers. Smart sensor technology seems to be the only future solution at the moment and is considered for use in this presentation.

B. Wireless Sensor Network Solution

The development of bio-sensors for biomedical sensor networks has gained much ground [14] today but these sensors basically still need to be much reduced in size to accommodate required applications. The physical size of a wireless sensor (node) is determined by its hardware components. With the existence of multichannel analogue-to-digital converters in the market, a number of parameters could be sensed by a single node. Hence, nodes to acquire several health parameters from any part of the body can be developed and deployed as a network on a patient as depicted in Fig. 1. Depending on the structure of the network, data from the sensors can be sent to a smart mobile device from which a software application can be used to aggregate the data for further processing. Hence, it is ease for care givers to access health information from patients without any contact. This also means that patient data can be acquire and used by authorized care givers in their hospitals while the patient is at the convenience of his/her home.

Wireless sensors in themselves posses some low level computational power [15, 16] and can be targeted towards personal health monitoring. An example is when the sensors are developed into the form of everyday body worn materials such as wrist watches, neck and ankle bands, caps, clothes, etc, [17] which are already accepted to be convenient. An overall effect of physiological changes can quickly be tracked and care givers alerted for possible check-ups.

The measurement method suggested in this paper fits into the application of wireless sensor networks in patient biomedical information acquisition. Development of wearable and human body embeddable nodes, capable of reading physiological parameters faithfully, will of course be one of the most advances in the health sector. Accurate health data acquisition for medical treatment of ill persons is much possible with these smart devices and the application of the method described here aggregates results from various nodes for more accurate measurements through statistical averaging.

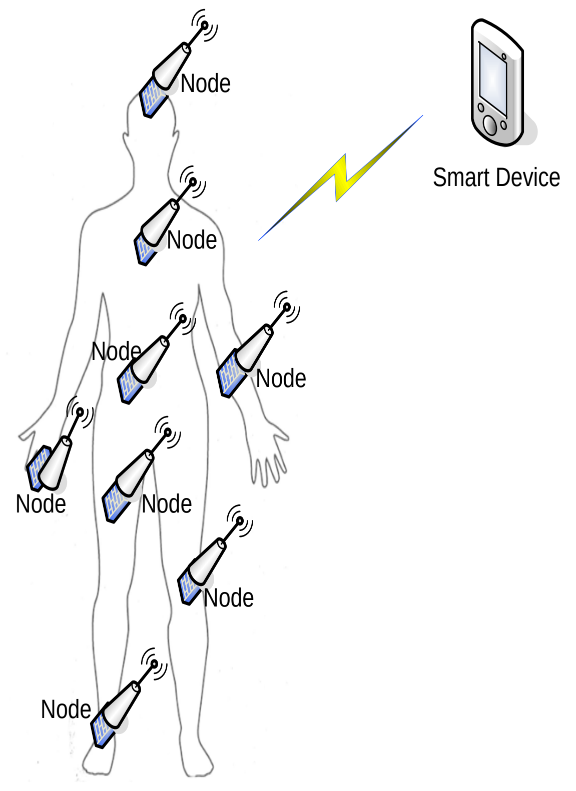

Figure 1: Sensor Network Data Acquisition

VI. MULTICHANNEL NODE HARDWARE ARCHITECTURE

Sensor nodes are basically intelligent devices each of which comprises of a sensing element, a data processing unit, a low capacity storage memory, and a radio unit for sending and receiving data. The sensing element is used to pick parameter variations electronically and usually passed through a signal conditioning circuitry and an Analogue-to-Digital Conversion (ADC) unit to a microcontroller processing unit. In a multichannel sensor node, several sensing elements are to be used to pick-up a number of parameters for processing by the microcontroller. Microcontrollers perform operations on a sequential basis but at high speed, hence a multiplexing process must be used to enable access to all required parameter sensors as shown in Fig. 2. The multiplexing process only require the use of specific address code fixed to each channel input of the multiplexer for identification and access to connected sensors. An addressed sensor internally physically connects to the signal conditioner through the multiplexer, while all others are disconnected. Therefore, as determined by the system's operational sequence, any connected sensor element can be accessed to read a require parameter.

Analogue signal inputs to the conditioner are usually amplified, attenuated, and/or filtered to meet input specifications of the ADC. The conditioned signal is then converted to its digital equivalent value which the microcontroller takes as its input. Recent technologies however has made it possible to achieve multiplexing and ADC functions inside the microcontroller resulting to reduced components count, minimal circuit complexity, lower power demand, and reduced system's physical size. The microcontroller is also made to possess a low memory capacity that can support data storage in most applications of sensor nodes when properly managed. However, interfaces abound in the microcontroller through which external memory can be attached and accessed. The processing unit is made responsible, through software algorithms, for data manipulations, peripheral co-ordination, and communication protocol implementation. Sensor nodes are standalone devices that link to other devices wirelessly. Therefore, a radio terminal is mandatory for data communication to and fro the node. The radio frequency (RF) communication band in used with wireless sensor node is the unlicensed Industrial, Scientific and Medical (ISM) 2.4GHz range. A number of off-the-shelf radio devices operating within this band but implementing different standards such as IEEE802.15.1 (Bluetooth), IEEE802.15.4 (ZigBee) and non-standard specifications are available from several manufacturers. The beauty of these radios is the fact that they can be made with in-circuit printed circuit board antenna which is highly responsible for the ever reducing size of these radios.

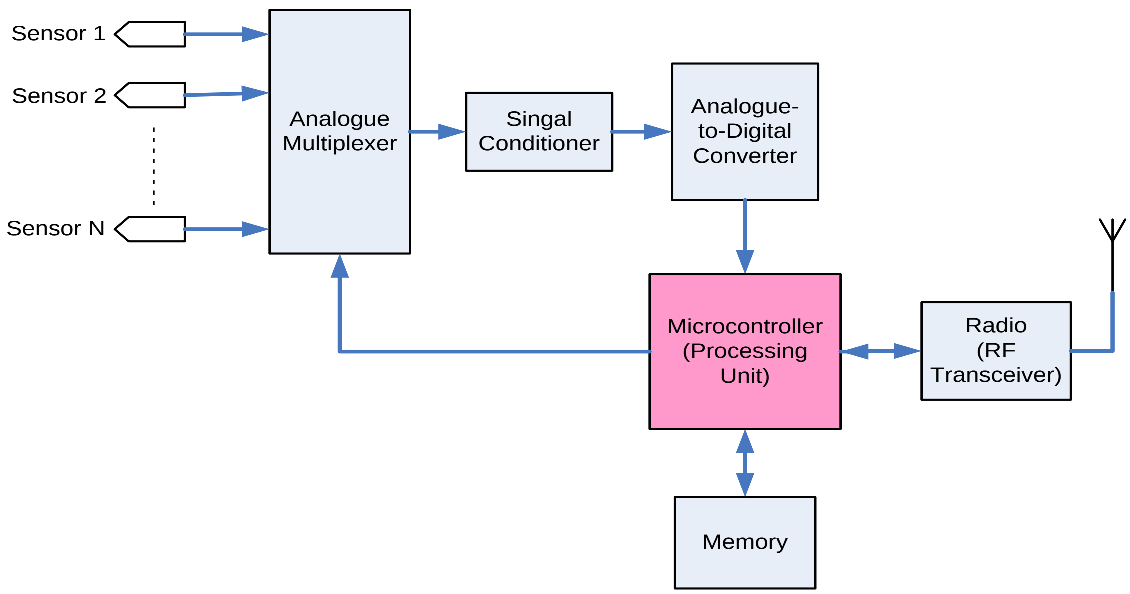

Figure 2: Multichannel Sensor Node Architecture

VII. BODY AREA NETWORK ENERGY RELIABILITY

A number of wireless communication architectures can be deployed for a sensor network [18]. In this paper we present a Body Area Network (BAN) that enable data collection from various parts of the body as depicted in Fig. 3. First, the sensor nodes are prioritized into three communication levels for effective data transfer between nodes and to any smart data collecting device. Usually, the node communication distance is short and much reliability depends on how effective data can be sent and received at low battery power. The priority is therefore used to ensure network power distribution and data reliability during communication. Priority level 3 define nodes around the wrist and lower leg region of the body designed to cope with the constant change of position that is eminent with those parts of the body. They communicate and transfer data to any nearest priority level 2 nodes and maintain such connectivity until data transfer is completed. Priority level 2 nodes are to be placed around the head, arms, and upper leg region to maintain communication between priority level 3 and 1. Priority level 1 co-ordinate the activities of all other nodes and is also responsible for data transfer to a receiving device. This arrangement ensures that overhead communication load on the sink (priority level 1) node is shared and distributed to those of level 2 by shielding those of level 3 away from direct link to the sink. A receiving smart device must make request to the BAN through the sink or by acting on a scheduled timing to be able to read data. This makes it easy for security to be built into the network as access is only granted through authentication.

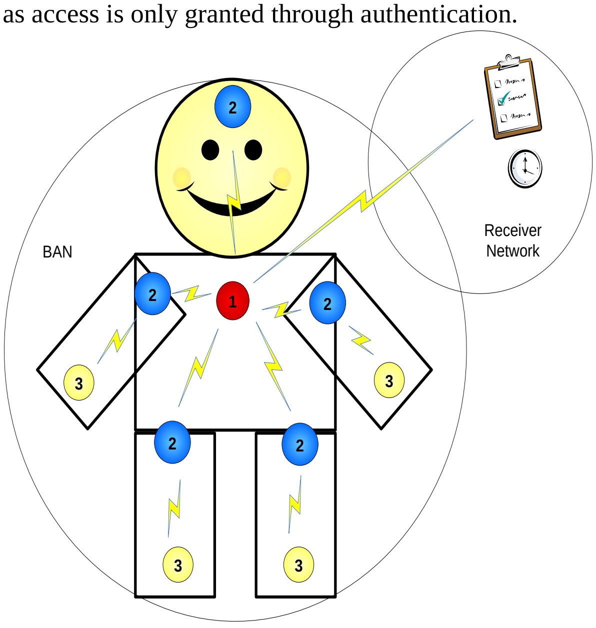

Figure 3: Network node prioritization for energy reliability

Energy reliability is one of the major concerns in setting up of a wireless sensor network. The priority distribution process will greatly improve the network energy reliability. If all nodes are made to forward their data to the sink node, and there are *N* nodes in the network each expending ω amount of energy for establishing a single connection, then total energy expended by the sink in a single data request from a receiving device can be found with Equation (11).

$$Sink_{energyloss} = \omega(N-1) + \mu \qquad (11)$$

Where μ is the energy expended in communication between the sink node and the receiving device.
Of course, all other nodes will only expend ω amount of energy. Hence, the network energy reliability (*NER*) expressed as a ratio of the lowest energy expended in the network to the highest energy expended is:

$$NER = \frac{\omega}{\omega(N-1) + \mu} \qquad (12)$$

Using the priority communication process however, the NER can be well improved since a number of the nodes will be shielded from communicating directly with the sink. If S nodes are shielded away from the sink, then:

$$Sink_{energyloss} = \omega(N-S-1) + \mu \qquad (13)$$

Let the number of shielded nodes equals the number of nodes that have access to the sink, then from equation (13);

$$S = \frac{N-1}{2} \quad \text{and} \quad Sink_{energyloss} = \frac{\omega}{2}(N-1)$$

Hence,

$$NER = \frac{2\omega}{\omega(N-1) + \mu} \qquad (14)$$

This shows that the *NER* can be doubled by shielding half of the nodes with access to the sink away. However, this gives the highest number of nodes that can be shielded to achieve the maximum *NER*. If the number of shielded nodes is further increased, the communication energy overhead may only shift to other nodes and the *energy reliability* will hover around 0 to $NER_{maximum}$ with possible effect on data reliability within the network.

VIII. Reliability and Security Issues

The most challenging factors [19, 18] with the use of wireless sensor networks for health data acquisition today is that of reliability and security. Unfortunately, reliability and security compromises accuracy. No matter how accurately a node measures its parameters, if the data are adjusted from their original values or delayed due to unreliable communication to a receiving device and/or insecurity of the communication link, the accuracy will totally be lost or valueless. Reliability spans how data are acquired, communicated, and interpreted and presented at the terminal device application layer. The primary factor that affects accuracy is how much the sensor node can be depended on to pick and interprets the required signals. In setting up a data acquisition network for health monitoring, the reliability of the sensing devices in judging the acquired signals at all times should be of first priority while developing or selecting nodes for the network. On the other hand, when reliably acquired accurate data are poorly communicated either between the network nodes or to a receiving device, the intended accuracy is lost and could not be useful in medical situations. Communication reliability must be a key factor in searching for a radio technology used in the sensor node development. Furthermore, at the receiving device, the received data could not be relied upon if they are presented wrongly to the user. For example, if temperature values are presented in a textbox marked mmHg and blood pressure is displayed in an area marked ^{0}C instead of the other way round, even if the data are accurate and reliably received they are termed inaccurate. Hence, data presentation at the device application must not introduce any type of misrepresentation.

Security of wireless communication for private data transfer from one point to another is a major concern in several data acquisition scenarios and could be more serious in medical situation [20][17] since it could lead to death. Insecurity could occur in form of delays, introduction of errors, data distortion, and eavesdropping or even data replacement. Therefore, appropriate data security scheme must be implemented to avoid unauthorized access to the network. Data encryption and access authentication are methods used to this respect through different techniques.

IX. CONCLUSION

Accuracy of measured parameters in health care services and care giving is well pursued goal in the medical field since the quality of healthcare services greatly depend on it. Conventional measurement instruments have been used over the years for the acquisition of health parameters which typically support a single-point one-time measurement method. This method, however, cannot be used with emerging future technologies for healthcare delivery. Future care giving needs required multi-dimensional health data acquisition from all parts of the body in order to achieve a more reliable accuracy in medical application. This paper has presented a multi-point time-averaging measurement method that clearly supports emerging healthcare provision through the use of wireless sensor networks. A body area wireless sensor network for multi-point multi-parameter body data acquisition of accurate health data was also presented. Though, several challenges have been identified with wireless sensor networks, the most prominent in medical scenario are those of reliability and security that directly affects data accuracy. Also presented is a network energy reliability improvement process as a grey area that highly affects data reliability. Other areas of reliability and security issues where briefly discussed. An implementation of this method with wireless sensors in underway and its application will form the basis of a future research paper on the subject.

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