Fuzzy Inference System for Remote Health Monitoring Using Wireless Body Area Networks

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ABSTRACT

According to WHO, 22% of the world population, about 2 billion people, will be age 60 years and older in 2050. About 80% of these elderly people will be living in the developing nations (World Health Organization, 2014). Population ageing are faced with challenges such as increased in the cases of chronic non-communicable diseases (NCDs) like cardiovascular diseases, obstructive pulmonary diseases, cancer, diabetes, musculoskeletal problems, and ageing-associated mental health conditions (World Health Organization, 2004). The current healthcare infrastructure cannot cope with the projected increase in demands for health care monitoring and assistance of elderly people. These challenges must be met with improvements in the current health care systems and infrastructure (Mowafey & Gardner, 2012). A wireless body area network (WBAN) that uses a fuzzy inference system (FIS) which can determine the condition of a person by employing sensors to monitor the heart rate, respiration rate, blood pressure, body temperature, and oxygen saturation of hemoglobin in the blood is proposed in this study. Remote patient monitoring with increased patient to health care personnel ratio can be achieved using this method.

KEYWORDS: Wireless Body Area Networks; Fuzzy Logic; Fuzzy Inference Systems; Body Sensors; Health Monitoring

1 INTRODUCTION

According to WHO, 22% of the world population, about 2 billion people, will be age 60 years and older in 2050. About 80% of these elderly people will be living in the developing nations (World Health Organization, 2014). Population ageing are faced with challenges such as increased in the cases of chronic non-communicable diseases (NCDs) like cardiovascular diseases, obstructive pulmonary diseases, cancer, diabetes, musculoskeletal problems, and ageing- associated mental health conditions (World Health Organization, 2004). The current healthcare infrastructure cannot cope with the projected increase in demands for health care monitoring and assistance of elderly people. These challenges must be met with improvements in the current health care systems and infrastructure (Mowafey & Gardner, 2012). A wireless body area network (WBAN) that uses a fuzzy inference system (FIS) which can determine the condition of a person by employing sensors to monitor the heart rate, respiration rate, blood pressure, body temperature, and oxygen saturation of hemoglobin in the blood is proposed in this study. Remote patient monitoring with increased patient to health care personnel ratio can be achieved using this method.

2 WIRELESS BODY AREA NETWORKS

Wireless body area networks (WBANs) are short-range, low-powered, wireless communications network of sensors and devices that is in vicinity of the human body (but not limited to humans) (IEEE Standards Association, 2012). The sensors may be embedded in clothing, medical patches, wearable devices and implants for better mobility and accessibility (Zhang, Wang, Vasilakos, & Fang, 2012). These sensors can communicate wirelessly to a controller or coordinator that will transmit the data to a base station monitored by health care personnel (Jamthe, Mishra, & Agrawal, 2014). Wireless body area networks can provide effective and efficient real-time monitoring of patients in hospitals and home care environments. Information gathered from WBANs can also be analyzed for early detection and diagnosis of diseases (Mouzehkesh, Zia, & Shafigh, 2013) (Dima, Antonopoulos, Gialelis, & Koubias, 2012) (Otal, Alonso, & Verikoukis, 2009).

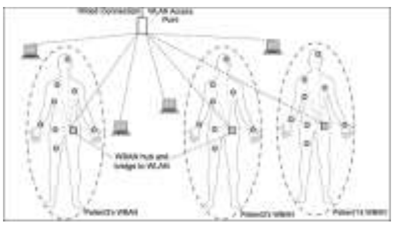

Figure 1: Wireless Body Area Networks

3 BODY SENSORS

In sensor technology, body sensors deals with the measurements of basic body functions like heart rate, respiration rate, blood pressure, body temperature, body motion, and oxygen and sugar levels in the blood. The readings of these sensors are helpful in patient health monitoring, diagnostics of diseases and other clinical studies.

3.1 Pulse Oximetry (SpO_2) Sensor

Pulse Oximetry is a measure of the percentage of the blood oxygen saturation (SpO_2). It uses two light frequencies, red (660nm) and infrared (940nm), to determine the amount of hemoglobin in the blood saturated with oxygen. The sensors can examine extremities like a finger, toe or ear. The sensor measures the amount of red and infrared light received by the detector and calculates the amount absorbed. Oxygenated hemoglobin absorbs more infrared light while deoxygenated hemoglobin absorbs more red light. The readings can vary from 0 to 100%. For a healthy adult, the normal reading is in the range of 94% to 100% (Philips Medical Systems, 2002).

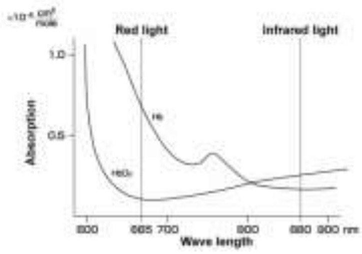

Figure 2: Spectroscopic and Absorptive properties of oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hb)

3.2 Body Temperature Sensor

The body temperature sensor is a device that can measure body temperature. Average body temperature is 37 degree Celsius (98.6 degree Fahrenheit) and can change by as much as 0.6 degree Celsius (1 degree Fahrenheit) above or below the 37 degree Celsius benchmark. A body temperature of 38 degree Celsius (100.4 degree Fahrenheit) or higher indicates that you have fever. The body temperature is a good indicator of a person's health. Most diseases are accompanied by an increase in the body temperature or a fever. Body temperature is commonly measured in the mouth, ear, armpit, forehead and rectum locations (Better Health Channel, 2011) (Healthwise Staff, 2013) (University of Rochester Medical Center, 2014).

3.3 Electrocardiogram (ECG) Sensor

Electrocardiogram (ECG) sensor is a device that is used to trace the electrical activity of the heart. A series of repetitive waveforms are graphed using ECG. The waveforms are derived from a flat baseline, *isoelectric line*. Electrical activity is denoted by a deflection from this isoelectric line. The primary deflections on a normal ECG are denoted by the letters P, Q, R, S and T. A heart cycle starts with a P wave, followed by Q R S wave complex, and ends with the T wave (Vernier Software & Technology, 2004). The P wave to P wave sequence represents one heart cycle. Heart rate is the number of heart cycles in a minute. Typical heart rate at rest is 70-80 beats per minute.

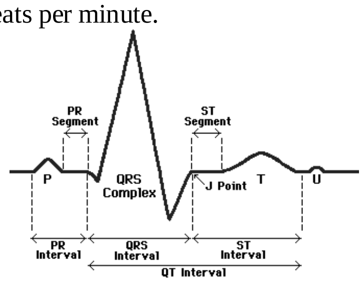

Figure 3: Electrocardiogram (ECG) Waveform

3.4 Nasal Airflow Sensor

Nasal Airflow sensor is a device used to check the airflow rate of a patient in need of respiratory help. This device consists of a flexible thread which fits behind the ears, and a set of two prongs which are placed in the nostrils. Breathing is measured by these prongs.

3.5 Blood Pressure Sensor

Blood pressure is the pressure of the blood in the arteries as it is pumped around the body by the heart. When your heart beats, it contracts and pushes blood through the arteries to the rest of your body. This force creates pressure on the arteries. Blood pressure is recorded as two numbers—the systolic pressure (as the heart beats) over the diastolic pressure (as the heart relaxes between beats).

4 FUZZY INFERENCE SYSTEMS

Fuzzy inference systems (FIS) are knowledge-based systems that deal with imprecise or uncertain information. It is derived from the principles of fuzzy logic that is motivated by the human capabilities of making sound decisions despite the imperfectness, imprecision, incompleteness and conflicting information (Medjahed, et al., 2012) (López-Caloca & Reyes, 2012). Fuzzy inference systems are used as decision making unit of process control systems (Pereira, Oliveira, & Soares, 2012). It uses IF-THEN statements and “AND” or “OR” rule statements for the decision rules. The system consists of a fuzzifier, a knowledge base, fuzzy inference engine and defuzzifier. The fuzzifier converts measured data (crisp values) into fuzzy variables. The knowledge base consists of a database and rule base. The rule base contains the set of fuzzy IF-THEN rules. The database defines the membership functions of the fuzzy sets. The fuzzy inference engine (decision making unit) maps the input space into output space based on the set of fuzzy rules. The defuzzifier converts the processed fuzzy variables back into real values (Efren, et al., 2012) (Shehu & Maraj, 2012) (Ahmad, Siddique, & Tokhi, 2012).

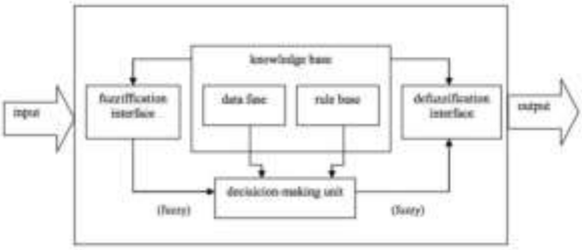

Figure 4: Fuzzy Inference System Architecture

5 IMPLEMENTATION

5.1 Fuzzy Inference System Wireless Body Area Network System (FIS-WBAN)

The Fuzzy Inference System Wireless Body Area Network (FIS-WBAN) will use star topology architecture. The body sensors will be the remote transceiver nodes. These sensor nodes will transmit its readings to the central coordinator node. It can also receive instructions from the coordinator node. A central coordinator node will control the flow of communication from the different sensor nodes to a remote terminal that will process the gathered data. This node will serve as the hub or gateway to remote site or other coordinator nodes from other WBAN users.

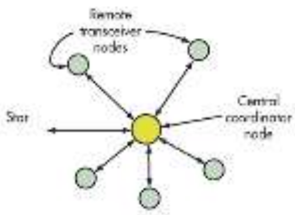

Figure 5: Star Topology Architecture

5.2 Sensor Knowledge Base

The body health condition will be monitored by the deployed sensors. The actual data will be processed in the knowledge base of the fuzzy inference system. The database will contain the typical range of values for the different body sensors.

5.2.1 SpO_2 Range

Table 1: SpO_2 Range (Konica Minolta Sensing, Inc., 2006) (Philips Medical Systems, 2002)

SpO_2 Range	
Low	70%~90%
Medium	91%~94%
High	95%~100%

5.2.2 Body Temperature Range

Table 2: Body Temperature Range (MedGuidance, 2014)

Body Temperature Range				
Location	**0-2 years**	**3-10 years**	**11-65 years**	**65 years and above**
Oral	-	35.5C-37.5C	36.4C-37.6C	35.8C-36.9C
Rectal	36.6C-37.3C	36.6C-38.0C	37.0C-38.1C	36.2C-37.3C
Axillary	34.7C-37.3C	35.9C-36.7C	35.2C-36.9C	35.6C-36.3C
Ear	36.4C-38.0C	36.1C-37.8C	35.9C-37.6C	35.8C-37.5C
Core	36.4C-37.8C	36.4C-37.8C	36.8C-37.9C	35.9C-37.1C

5.2.3 Heart Rate Range

Table 3: Resting Heart Range (Ostchega, Porter, Hughes, & Dillion, 2011)

Resting Heart Rate Range (Male)			Resting Heart Rate Range (Female)		
Age Group	**Average Range (bpm)**	**Total Range (bpm)**	**Age Group**	**Average Range (bpm)**	**Total Range (bpm)**
Under 1	115~137	102~155	**Under 1**	118~137	104~156
1	107~122	95~137	**1**	110~125	95~139
2-3	96~112	85~124	**2-3**	98~114	88~125
4-5	84~100	74~112	**4-5**	87~104	76~117
6-8	76~92	66~105	**6-8**	79~94	69~106
9-11	70~86	61~97	**9-11**	76~91	66~103
12-15	66~83	57~97	**12-15**	70~87	60~99
16-19	61~78	52~92	**16-19**	69~85	58~99
20-39	61~76	52~89	**20-39**	66~82	57~95
40-59	61~77	52~90	**40-59**	64~79	56~92
60-79	60~75	50~91	**60-79**	64~78	56~92
80 or over	61~78	51~94	**80 or over**	64~77	56~93

5.3 Membership Functions

The input membership functions used in this study are age, heart rate, pulse oximetry (SpO2), respiration rate, and temperature. The output membership function is the body condition. Values used in these membership functions came from the sensor knowledge base. Trapezoidal membership function is used for SpO2 input. Triangular membership function is used for age, heart rate, respiration rate and temperature.

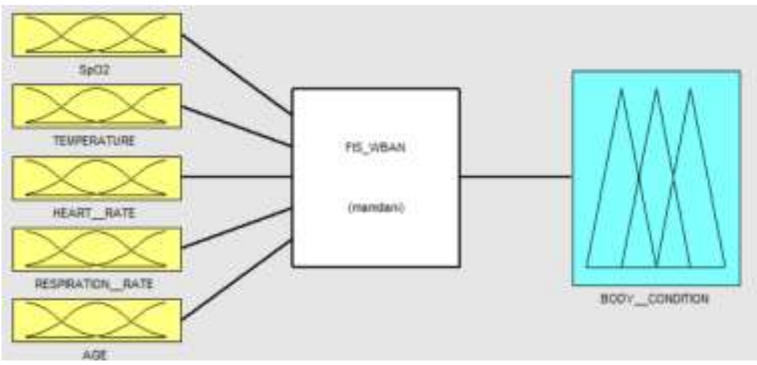

Figure 7 – FIS-WBAN Input and Output Membership Functions

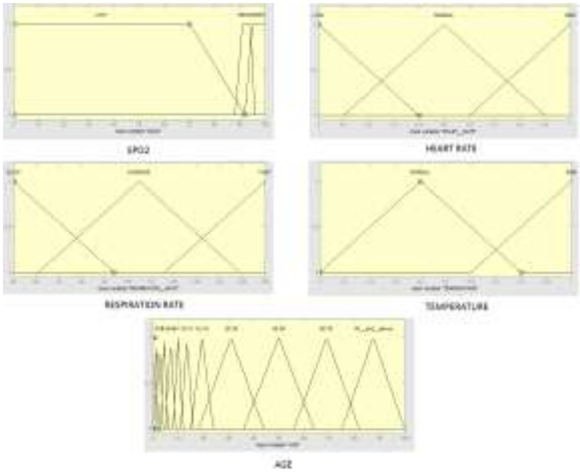

Figure 8: Input Membership Function

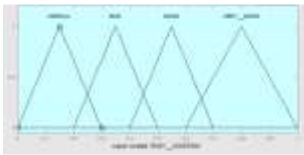

Figure 9: Output Membership Function

6 SIMULATION

MATLAB software is used in the simulation of the Fuzzy Inference System Wireless Body Area Network. Mamdani method is used as the fuzzy inference system type.

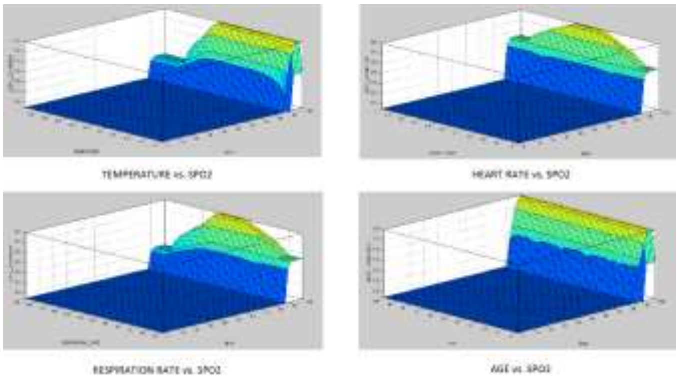

Figure 10 – Body Condition Surface View

7 ANALYSIS OF RESULTS

The results showed that at lower values of SpO2 the body condition will be at critical condition. Medium to high values of SpO2 indicate that the body is in good to very good condition. The heart rate ranged from low, normal and high conditions. The body condition is in good to very good condition when heart rate is normal. Body condition will be at bad to critical condition when heart rate is not normal. The respiration rate ranged from slow, average and fast conditions. The body condition is in good to very good condition when respiration rate is average. Body condition will be at bad to critical condition when respiration rate is not in average condition. The temperature ranged from normal to high. The body condition is in good to very good condition when temperature is in normal condition. Body condition will be at bad to critical condition when temperature is not normal.

8 CONCLUSION

The fuzzy inference system wireless body area networks can determine the body condition of a patient. This study only uses values for heart rate, SpO2, respiration rate, and temperature based on theoretical and research values. Actual clinical data is not used in this study. The fuzzy inference system can be used in the nonlinear values of body condition measured from sensors. The reading of the sensors depends on the age and gender of the patient. Environment condition can also be a factor in sensor readings, which is not included in this study. For future work, monitoring of specific body illness, such as heart attack, stroke, and asthma is recommended.

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REFERENCES

Ahmad, S., Siddique, N. H., & Tokhi, M. O. (2012). Modular Fuzzy Logic Controller for Motion Control of Two-Wheeled Wheelchair. In *Fuzzy Logic - Controls, Concepts, Theories and Applications* (pp. 37-58).

Better Health Channel. (2011, October). *Better Health Channel.* Retrieved November 24, 2014, from http://www.betterhealth.vic.gov.au/bhcv2/bhcarticles.nsf/pages/Fever

Dima, S., Antonopoulos, C., Gialelis, J., & Koubias, S. (2012). A network reliability oriented event detection scheme for Wireless Sensors and Actors Networks. *Industrial Technology (ICIT), 2012 IEEE International Conference on*, 362-367.

Dima, S., Tsitsipis, D., Antonopoulos, C., Gialelis, J., & Koubias, S. (2012). FLOGERA — A fuzzy logic event recognition algorithm in a WSN environment. *Wireless Communications and Mobile Computing Conference (IWCMC), 2012 8th International* , 850-855.

Efren, G.-H., Carlos, P.-O. J., Antonio, A.-F. M., Manuel, R.-A. J., Saúl, T.-A., & Artemio, S.-O. (2012). Greenhouse Fuzzy and Neuro-Fuzzy Modeling Techniques. In *Fuzzy Logic - Emerging Technologies and Applications* (pp. 309-322).

Healthwise Staff. (2013, May 20). *HealthLinkBC.* Retrieved November 22, 2014, from http://www.healthlinkbc.ca/medicaltests/content.asp?hwid=hw198785

IEEE Standards Association. (2012). IEEE Standard for Local and Metropolitan Area Networks - Part 15.6: Wireless Body Area Networks. New York: The Institute of Electrical and Electronics Engineers, Inc.

Jamthe, A., Mishra, A., & Agrawal, D. (2014). Scheduling schemes for interference suppression in healthcare sensor networks. *Communications (ICC), 2014 IEEE International Conference on* , 391-396.

Konica Minolta Sensing, Inc. (2006). How to Read SpO2 - Basic understanding of the pulse oximeter. New Jersey: Konica Minolta Sensing, Inc.

López-Caloca, A. A., & Reyes, C. (2012). Fuzzy Modeling of Geospatial Patterns. In *Fuzzy Logic - Emerging Technologies and Applications* (pp. 287-308).

MedGuidance. (2014, November 24). *Medguidance.com, Medical Information, Health News & Tools.* Retrieved November 24, 2014, from http://www.medguidance.com/thread/Normal-Body-Temperature.html

Medjahed, H., Istrate, D., Boudy, J., Baldinger, J. L., Bougueroua, L., Dhouib, M. A., & Dorizzi, B. (2012). A Fuzzy Logic Approach for Remote Healthcare Monitoring by Learning and Recognizing Human Activities of Daily Living. In *Fuzzy Logic - Emerging Technologies and Applications* (pp. 19-40).

Mouzehkesh, N., Zia, T., & Shafigh, S. (2013). Traffic aware fuzzy-tuned delay range for wireless body area networks medium access control protocol (MAC). *Intelligent Sensors, Sensor Networks and Information Processing, 2013 IEEE Eighth International Conference on* , 60-65.

Mowafey, S., & Gardner, S. (2012). A novel adaptive approach for home care ambient intelligent environments with an emotion-aware system. *Control (CONTROL), 2012 UKACC International Conference on* , 771-777.

Ostchega, Y., Porter, K., Hughes, J., & Dillion, C. (2011). *Resting Pulse Rate Reference Data forChildern, Adolescents, and Adults: United States, 1999-2008. National Health Statistics Reports; no.41.* National Center for Health Statistics.

Otal, B., Alonso, L., & Verikoukis, C. (2009). Highly reliable energy-saving mac for wireless body sensor networks in healthcare systems. *Selected Areas in Communications, IEEE Journal on , 27*(4), 553-565.

Pereira, V. G., Oliveira, R. C., & Soares, F. M. (2012). Fuzzy Control Applied to Aluminum. In *Fuzzy Logic - Controls, Concepts, Theories and Applications,* (pp. 253-278).

Philips Medical Systems. (2002). Understanding Pulse Oximetry - SpO2 Concepts. USA: Philips Electronics North America Corporation.

Shehu, A., & Maraj, A. (2012). Fuzzy Logic Approach for QoS Routing Analysis. In *Fuzzy Logic - Algorithms, Techniques and Implementations* (pp. 149-172).

University of Rochester Medical Center. (2014). *Health Encyclopedia.* Retrieved November 24, 2014, from http://www.urmc.rochester.edu/encyclopedia/content.aspx?ContentTypeID=85&ContentID=P00866

Vernier Software & Technology. (2004). EKG Sensor. Oregon, USA: Vernier Software & Technology.

World Health Organization. (2004, September 6). *World Health Organization launches new initiative to address the health needs of a rapidly ageing population.* Retrieved November 22, 2014, from http://www.who.int/mediacentre/news/releases/2004/pr60/en/

World Health Organization. (2014, September 30). *Facts about ageing.* Retrieved November 22, 2014, from http://www.who.int/ageing/about/facts/en/

Zhang, Z., Wang, H., Vasilakos, A., & Fang, H. (2012). ECG-Cryptography and Authentication in Body Area Networks. *Information Technology in Biomedicine, IEEE Transactions on , 16*(6), 1070-1078.