Telediagnosis: Interfacing Biomedical Diagnostic Devices with the Internet of Things (IoT) using ThingSpeak Web-Based Platform

Zubair, A. R. & Ogunware, A.O.
Department of Electrical/Electronic Engineering
University of Ibadan
Ibadan, Nigeria.

Corresponding Authors Address
ar.zubair@ui.edu.ng

ABSTRACT

Technological advancement in Biomedical Engineering has improved the health care delivery system. Monitoring patients' vital signs are essential for accurate diagnosis and adequate treatment. In the process of diagnosis, a team of health care professionals jointly access and review the conditions and vital signs of a patient before arriving at a treatment plan. A medical team may consist of members who are not in the same geographical location as the patient. Enabling all team members to have remote access to the patient's vital signs would assist the team. Telediagnosis is a medical diagnosis made by means of telemedicine. Interfacing biomedical diagnostic devices with the Internet of Things (IoT) will enhance Telediagnosis. The interfacing of Electrocardiograph (ECG) with IoT is presented as a case study. The electrodes convert the heart signal to an electrical signal known as Electrocardiogram (ECG). The ECG signal is sampled and processed using a microcontroller. The microcontroller interfaces the ECG signal with a Wi-Fi shield which is an Internet of Things (IoT) device. The IoT shield is responsible for deploring the ECG signals on to the web for further analysis. ThingSpeak is a web-based platform which collects the signal and performs a real-time plot over the internet. The patient's vital signs are available anywhere across the globe by accessing the ThingSpeak platform. The Wi-Fi shield is immune to external attack and only the network administrator and other authorized personnel can have access to the medical records. Deploring this technology in African hospitals by African Engineers is found to be feasible and economical. It would improve the African health care delivery system.

Keywords: Telediagnosis, Health care team, Electronic communication, Biomedical devices, Electrocardiogram, Internet of Things

iSTEAMS Cross-Border Conference Proceedings Paper Citation Format
Zubair, A. R. & Ogunware, A.O. (2018): Telediagnosis: Interfacing Biomedical Diagnostic Devices with the Internet of Things (IoT) using ThingSpeak Web-Based Platform. Proceedings of the 13th iSTEAMS Multidisciplinary Conference, University of Ghana, Legon, Accra, Ghana. Pp 141-150

1. INTRODUCTION

Diagnosis is the traditional basis for decision-making in clinical practice (Croft *et al*., 2015). Diagnosis involves information gathering, review, analysis, interpretation, narrowing down the diagnostic possibilities and developing the accurate understanding of the patient's health problem as illustrated in Fig. 1. It's interactive and iterative. It involves feeding information forward and backward. It requires collaboration and teamwork (Baker *et al*., 2006; Riley *et al*., 2008; Xyrichis and Ream, 2008; Manser, 2009; Weller *et al*., 2010; WHO, 2010). Gone are the days when a doctor or a dentist or any other health practitioner in a health organization would be able to solely deliver adequate and satisfactory care to a patient (Babiker *et al*., 2014). Nowadays, diagnosis is a team's work. Evidence suggests that teamwork failures contribute to poor outcomes in hospitals; teamwork is essential in the health care delivery system (Riley *et al*., 2008). A team consists of two or more individuals who have specific roles, perform interdependent tasks, are adaptable, and share a common goal (Baker *et al*., 2006).

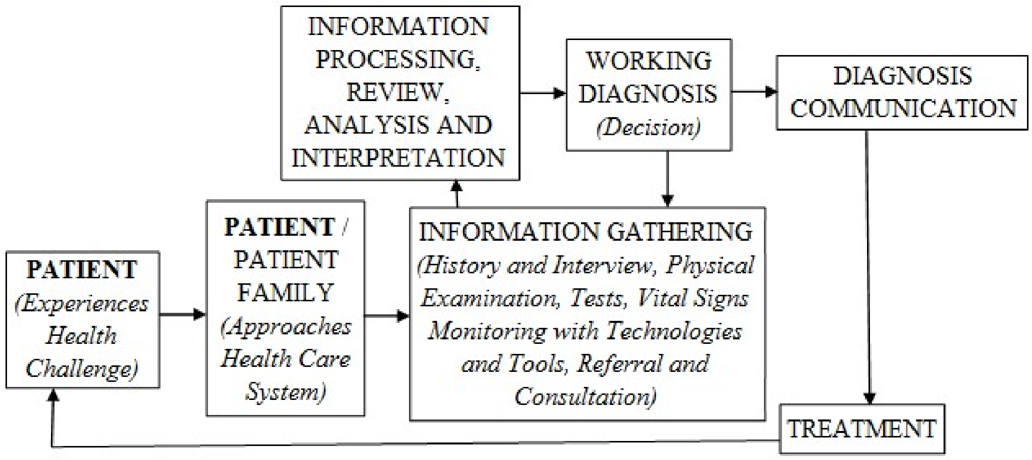


Fig. 1. Diagnosis Process.

Diagnostic health care team members include the patient, his/her family, and all health care professionals involved in his/her care (Henriksen and Brady, 2013; McDonald, Bryce and Graber, 2013; Babiker *et al*., 2014; Graedon and Graedon, 2014). Such health care professionals are doctors, nurses, medical assistants, radiologists, technologists, laboratory scientists, pharmacists, patient navigators, social workers, therapists, nutritionists, biomedical engineers, and biomedical technologists. The composition of the team depends on the needs of the patient.

Teams may be complex in nature and may be composed of people with different knowledge and skills, from different backgrounds and at different geographical locations. Some members of the team can be out of the health care facility for training, workshops, and conferences. It may not be economical or feasible for a health care facility to employ all categories of health care professionals; it may be necessary to consult with experts located in other facilities. The team needs to communicate. The members of the team need to be on the same page with regard to the patient's vital signs, records and other relevant pieces of information which are required for diagnosis.

The role and significance of biomedical technology and electronic communication cannot be overemphasized. Technological advancement in Biomedical Engineering has improved the health care delivery system (Brown and Carr, 1981; Zubair, 2010). Biomedical instruments are devices intended to diagnose, treat, or monitor the patient under medical supervision (Zubair, 2010). There is a need to interface biomedical technology with electronic communication technology. This work is an effort to satisfy this need. African health caregivers need to collaborate with African Biomedical Engineers to improve health for all (Zubair, 2010).

In this work, an Electrocardiograph (ECG) is interfaced with the Internet of Things (IoT) as a case study. An electrocardiograph is a biomedical device that measures electrical potential generated by the electrical activity that occurs due to the heart's pumping action (Zubair, 2010; Zubair and Eneh, 2018). The graphical presentation of the Electrocardiogram (ECG) can be interpreted so that normal and abnormal rhythms of the heart can be detected and diagnosed (Khorovets, 2000; King, 2003; Zubair and Eneh, 2018). Members of the team where ever they are can be granted access to their patient's ECG to enable them to participate actively in decision making (diagnosis). This is to enable Telediagnosis which is the medical diagnosis made by means of telemedicine which is the practice of medicine with the aid of technology when the doctor and patient are widely separated (Merriam-Webster, 2018a; Merriam-Webster, 2018b). The review of a patient's case over the telephone or Skype by two health workers is a simple form of Telemedicine. Real-time consultation between medical experts in two or more countries with the aid of satellite technology and video-conferencing is a complex form of Telemedicine (Bhowmik *et al*., 2013).

2. MATERIALS AND METHODS

Patient Monitoring System

Patient Monitoring System (PMS) is the repeated or continuous observations or measurements of the patient, his physiological functions, and the function of the life support equipment, for the purpose of guiding management decisions, including when to make therapeutic interventions, and assessment of those interventions (Brown and Carr, 1981; Zubair, 2010; Zubair and Eneh, 2018). Regular measurement of the patient's vital signs such as heart rate and rhythm, respiratory rate, blood pressure, blood oxygen saturation, and many other parameters have become part of the health care procedures. When accurate and immediate decision-making is crucial for effective patient care, electronic monitors are frequently used to collect and display physiological data. Increasingly, such data are collected using non-invasive sensors from less seriously ill patients in a hospital's medical-surgical units, labour and delivery suites, nursing homes, or patients' own homes to detect unexpected life-threatening conditions or to record routine but required data efficiently.

Patient Monitoring has always been occupying a very important position in the field of medical devices owing to the importance of continuously monitoring the vital physiological signs of a patient. The continuous improvement of technologies not only helps us to transmit the vital physiological signs to the medical personnel but also simplifies the measurement and as a result raises the monitoring efficiency of patients. In the past, the dominant products manufactured by medical device manufacturers are mainly those for single parameter measurement. Nowadays, however, a multi-parameter patient monitor is commonly used. It can transmit vital signs like ECG, blood pressure and respiration rate. The design and construction of an electrocardiograph (ECG) are presented in (Zubair and Eneh, 2018).

Internet of Medicinal Things

The Internet of Things (IoT) is a network of physical devices and other items, embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data (Farooq *et al*., 2015; Dimitrov, 2016; Salunke and Nerkar, 2017). IoT connects intelligent objects which have unique identifiers, computing and communication abilities (Miorandi *et al*., 2012; Minerva, Biru and Rotondi, 2015; Cambridge, 2018). Fig. 2 shows an IoT network for linking medical devices (Thota and Kim, 2016). Its impact on medicine will be significant. By 2020, 40% of IoT technology will be health-related (Dimitrov, 2016). The convergence of medicine and information technologies, such as medical informatics, will transform health care as we know it, curbing costs, reducing inefficiencies, and saving lives (Dimitrov, 2016). Internet of Medical Things (IoMT) increases human-machine interaction which enhances the real-time health monitoring solutions and patient engagement in decision making. These may contribute to adequate health care for the patient. The IoT architecture comprises three layers: local devices and control layer, device connectivity and data layer, and data analytic solutions layer (Shelke and Sharma, 2018).

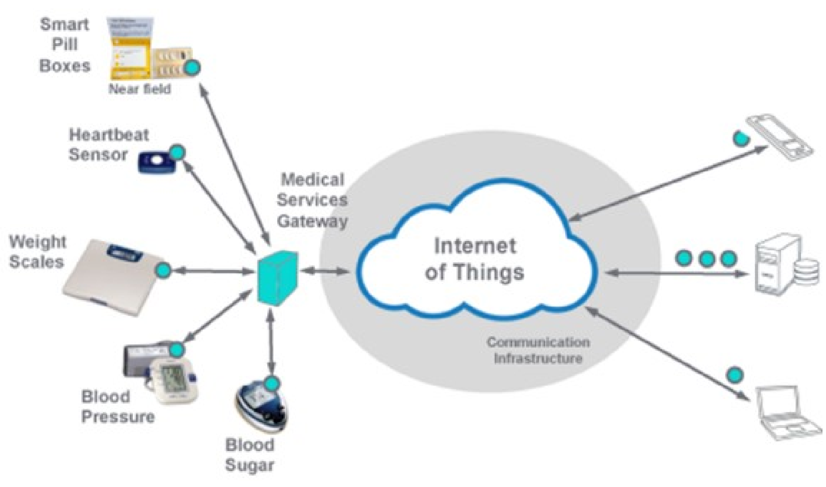


Fig. 2. Internet of Medical Things (Thota and Kim, 2016).

Local Devices and Control Layer
Each of the biomedical devices connected to the IoMT constitutes the local system which is the first layer. These devices are usually enabled with sensors to measure vital signs, actuators, Analogue to Digital Converters (ADC), controllers to make real-time decisions and appropriate software. There is a network interface to share data with other machines and the central server. In this work, an Electrocardiograph (ECG) is the local device.

Device Connectivity and Data Layer
The Device Connectivity and Data layer handles data management solutions and networking solutions. Advanced technologies from networking firms such as Cisco and Oracle are employed. Patient devices are connected to remote locations with the help of technologies such as Wi-Fi, Bluetooth Low Energy (BLE), ZigBee, cellular, NFC, and Satellite.

Analytic Solutions Layer
The central/remote server is the analytic solutions layer which collects data from multiple devices over the networks. Algorithms enable the server to analyze and evaluate real-time data from various connected devices to enable health care solution.

Interfacing Electrocardiograph (ECG) with IoT
Fig. 3 shows the interfacing of the Electrocardiograph (ECG) with IoT. Standard ECG operates with 12-leads. Ten electrodes are usually used. The electrodes usually consist of a conducting gel, embedded in the middle of a self-adhesive pad. The positioning of these ten electrodes is broken down into two categories as illustrated in Fig. 4, the limb electrodes (RA, RL, LA & LL) and the precordial (chest) electrodes (V1, V2, V3, V4, V5 & V6). Nine of the electrodes pick up electrical signals. The tenth electrode, on the right leg (RL), is electrically driven by the ECG circuit as the reference electrode (Zubair and Eneh, 2018). The nine measurements are arranged into twelve views or leads.

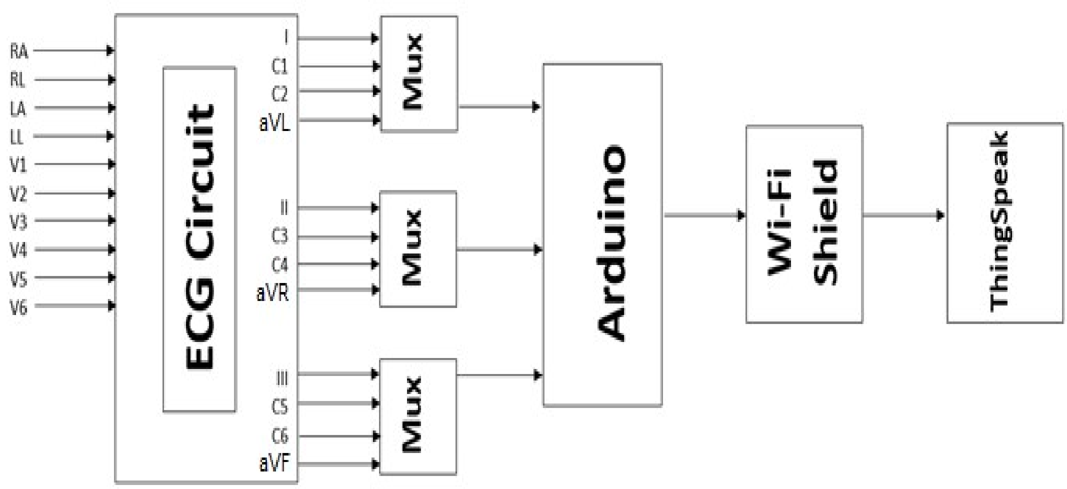


Fig. 3 Interfacing Electrocardiograph (ECG) with IoT

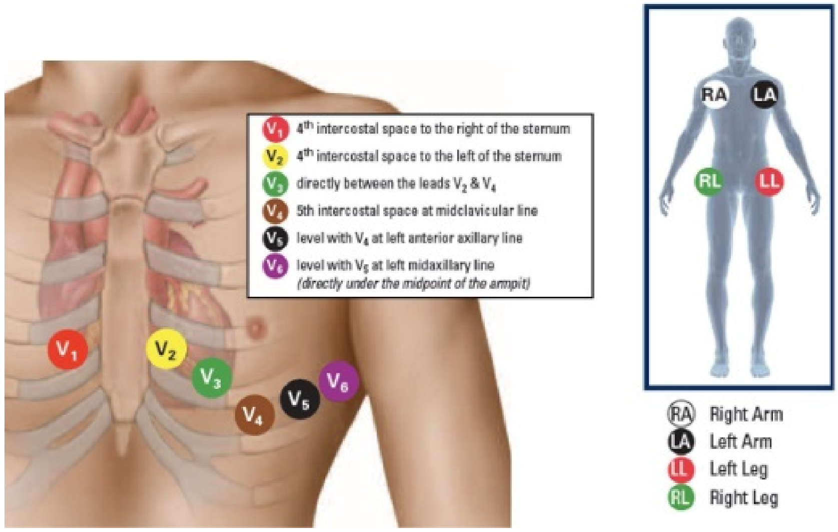
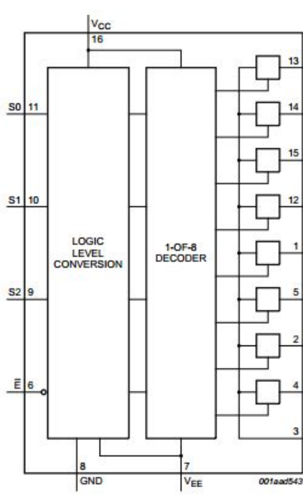


Fig. 4 Positions of the Electrodes (Bloggingforyournoggin, 2016).

Each lead, or view of the heart, is the differential voltage between one electrode and another electrode or group of electrodes. When electrodes are grouped, their voltage is averaged. RA, LA, and LL are averaged for six of the leads (views) and become one side of the differential pair. Three of the leads measure RA, LA, and LL against the average of the other two electrodes. The remaining three leads come from RA, LA, and LL measured as individual pairs (Zubair and Eneh, 2018). The twelve outputs or leads or views are Lead I [LA-RA], Lead II [LL-RA], Lead III [LL, LA], aVL [LA-Average of (LL&RA)], aVF [LL-Average of (LA&RA)], aVR [RA-Average of (LA&LL)], C1 [V1-Average of (LA,LL&RA)], C2 [V2-Average of (LA,LL&RA)], C3 [V3-Average of (LA,LL&RA)], C4 [V4-Average of (LA,LL&RA)], C5 [V5-Average of (LA,LL&RA)] and C6 [V6-Average of (LA,LL&RA)] (Zubair and Eneh, 2018). Three multiplexers of Fig. 5 systematically combine these twelve signals. Table 1 is the truth table of the multiplexer. The Arduino board of Fig. 6 consists of an ATMeg 328 microcontroller of Fig. 7 (Acharya and Kuzhalvaimozhi, 2016; Pasha, 2016). The microcontroller is a mini computer that is application specific and is used to further process the signal for the ESP8266 Wi-Fi module of Fig. 8 (Kumar *et al*., 2015; Acharya and Kuzhalvaimozhi, 2016).



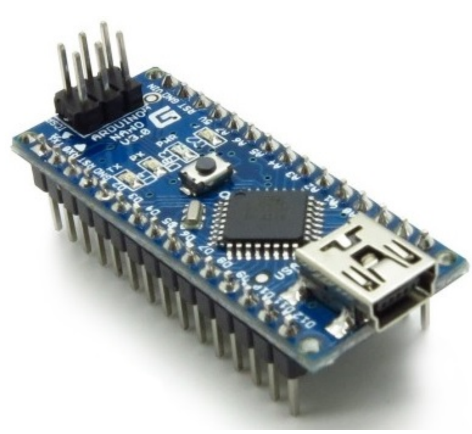


Fig. 5 Multiplexer Block Diagram. **Fig. 6 Arduino Nano Board**

Table 1: The Truth Table of the Multiplexer

Inputs				CHANNEL ON
$\bar{E}$	S2	S1	S0	
L	L	L	L	YO TO Z
L	L	L	H	Y1 TO Z
L	L	H	L	Y2 TO Z
L	L	H	H	Y3 TO Z
L	H	L	L	Y4 TO Z
L	H	L	H	Y5 TO Z
L	H	H	L	Y6 TO Z
L	H	H	H	Y7 TO Z
X	X	X	X	switches off

H= High Voltage Level; L= Low Voltage Level; X= DON'T CARE

The Wi-Fi module is an Internet of Things (IoT) device. The Wi-Fi module is configured to populate the measured parameters to the Web. The ESP8266 Wi-Fi Module is a self-contained System on Chip (SOC) with integrated Transmission Control Protocol/Internet Protocol (TCP/IP) stack that can give any microcontroller access to a Wi-Fi network. It is capable of either hosting an application or offloading all Wi-Fi networking functions from another application processor. Each ESP8266 module comes pre-programmed with a command set firmware. It contains a self-calibrated RF allowing it to work under all operating conditions and requires no external RF parts.

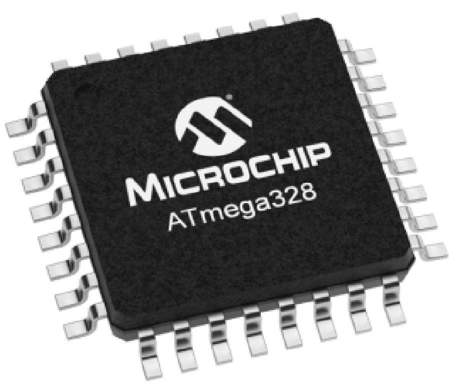


Fig. 7 ATMega 328 Microcontroller

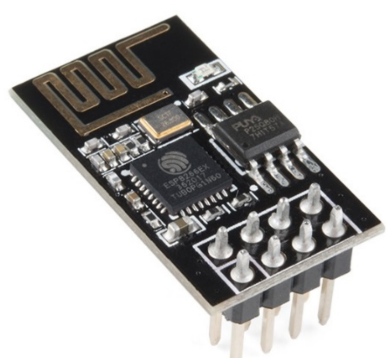


Fig. 8 ESP8266 Wi-Fi Module

ThingSpeak web platform is used and it plots the ECG Waveform for remote monitoring. ThingSpeak is an IoT analytics platform service that allows a user to aggregate, visualize and analyze live data streams in the cloud as illustrated in Fig. 9 (Kumar *et al*., 2015; Nakhuva and Champaneria, 2015; Acharya and Kuzhalvaimozhi, 2016; Pasha, 2016). It provides instant visualizations of data posted by devices to the platform. MATLAB code can be executed on the ThingSpeak platform (Pasha, 2016; Hans-Petter, 2018).

This enables real-time online analysis and processing of data. ThingSpeak is often used for prototyping and proof of the concept of IoT systems that require analytics.

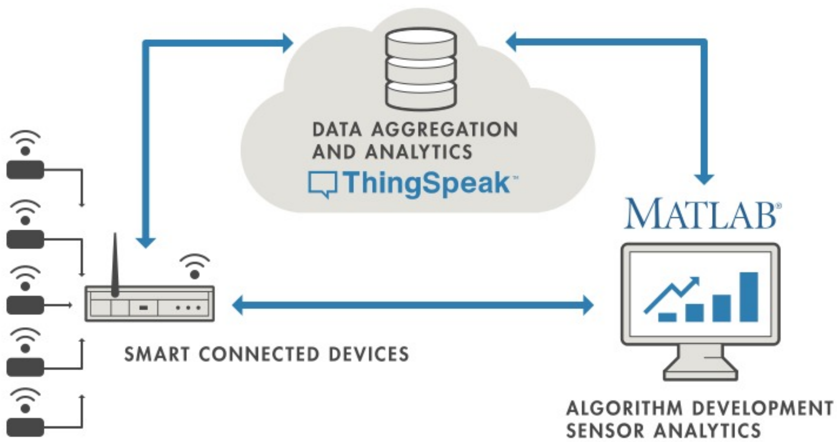


Fig. 9 ThingSpeak Platform (Hans-Petter, 2018).

The platform allows two-way communication between the user and the system. A cluster of Wi-Fi enabled devices can be gated through a router and clouded for further analysis. ThingSpeak leans on MATLAB algorithm for its operation and also supports various plugins for third-party applications.

API Key

In order for communication to take place between the Wi-Fi shield and ThingSpeak, Application Programming Interface (API) gateway needs to be properly configured. The interface authenticates access between both devices and ensures adequate communication.

The Keys were generated by ThingSpeak and they were added to Wi-Fi Module script to ensure that the device is solely communicating with a channel alone. The *Write API Key [B6QVJZ7BYSXW1GHV]* provides authentication to write unto ThingSpeak. The *Read API Key [1KD3TWNT57AX0ICN]* provides authentication to read from ThingSpeak.

ThingSpeak Field

ThingSpeak Field is a graphical area where the plot will be displayed. A channel contains a maximum of Eight (8) fields and several parameters can be plotted and cross-referenced at the same time. Every field has its own ID for easier identification and customized programming. A field is assigned to the patient's temperature. Another field is assigned to the patient's heart's rate.

Security Authentication

The Wi-Fi Shield was programmed to only connect to one Wi-Fi SSID network. This ensures the security and immunity of the device against cyber-attack which is pronounced in the world today. The shield was connected SSID "Ola". The Network name is "Ola". This SSID can also be made hidden such that unauthorized users cannot access the network. The Wi-Fi network also has a password to be made known to only the authorized users. The Wi-Fi module will only connect to a network with the appropriate Network name and password.
The Wi-Fi shield is immune to external attack and only the network administrator and other authorized personnel can have access to the details. The network was set up using the hotspot technology of a mobile phone (either 3G or 4G). The internet is deployed from the mobile phone and the shield readily connects to it in order to push the measured values to the web. The system will also work with the internet from other sources.

3. RESULTS AND DISCUSSION

The technology was deployed. Fig. 10 shows the ThingSpeak Platform displayed over the internet. This is accessible to authorized health care team members anywhere in the world. Field Label 3 shows the patient's temperature while Field Label 4 shows the patient's heart rate. Field Labels 5 and 6 show the patient's Electrocardiogram (ECG) signal over some time intervals. Health care team members can be updated with required information on the patient thereby enabling Telediagnosis. The system can be expanded to include more biomedical devices, more vital signs, and more patients.

5. CONCLUSION

The concept of enhancing Telediagnosis and Telemedicine by interfacing biomedical devices with the Internet of Things (IoT) has been demonstrated. Biomedical technology and electronic communication technology are combined to assist and promote the functions of health care teams whose members may not be located in the same health care facility. Deployment of the Internet of Medical Things (IoMT) in African hospitals is feasible and economical. Collaboration of Health care and Engineering professionals and funding for IoMT research are recommended. IoMT will improve African health care delivery system.

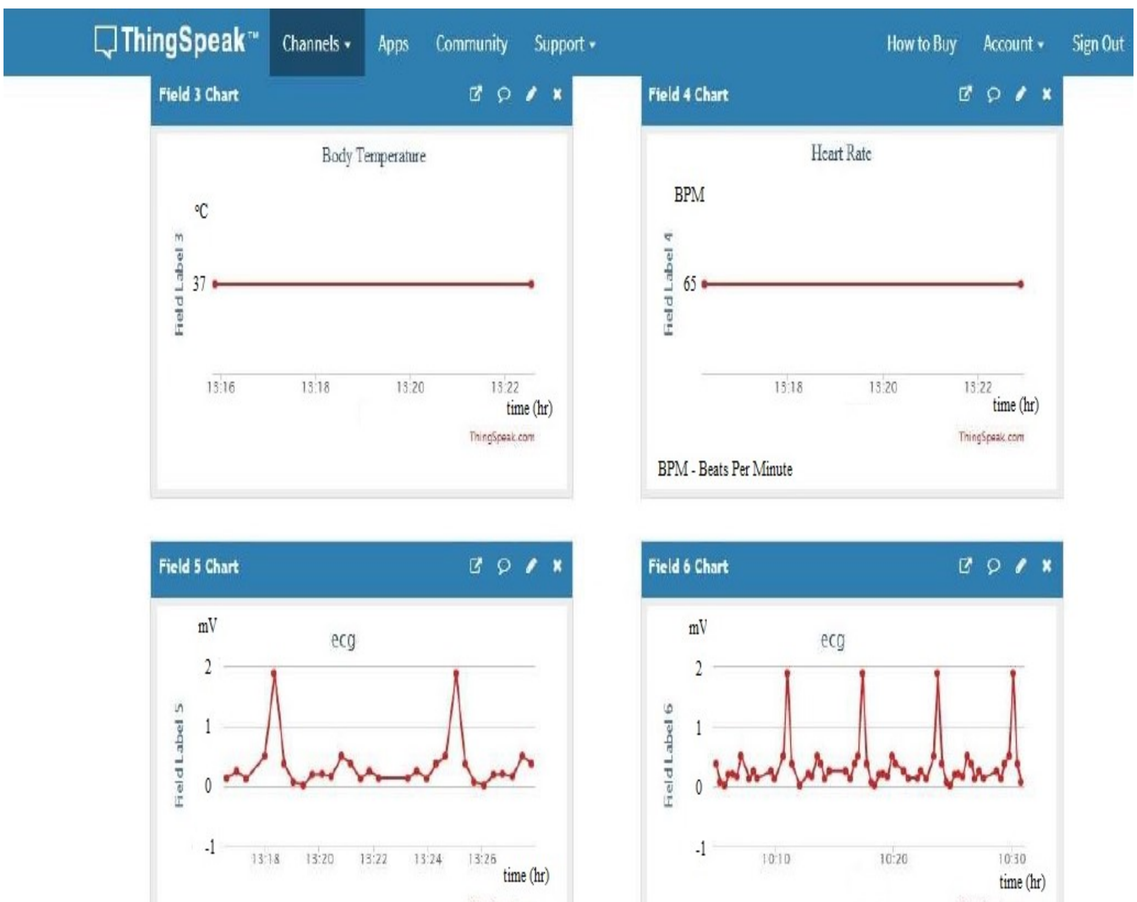


Fig. 10 ThingSpeak Platform displayed over the internet accessible to authorized health care team members anywhere in the world.

REFERENCES

1. Acharya, C. and Kuzhalvaimozhi, S. (2016). Irrigation and Internet of Things Platform. *International Research Journal of Engineering and Technology*, 3(3): 1643-1646.
2. Babiker, A. *et al*. (2014). Healthcare professional development: Working as a team to improve patient care. *Sudanese Journal of Paediatrics*, 14(2): 9–16.
3. Baker, D.P., Day R. and Salas E. (2006). Teamwork as an essential component of high-reliability organizations. *BMC Health Services Research*, 41(4 part II): 1576-1598.
4. Bhowmik, D., Duraivel, S., Singh, R.K. and Kumar, K.P.S. (2013). Telemedicine - An Innovating Healthcare System in India. *The Pharma Innovation - Journal*, 2(4): 1-20.
5. Bloggingforyournoggin. (2016). Demystifying the 12 Lead ECG! Available at https://bloggingforyournoggin.wordpress.com/2016/04/20/demystifying-the-12-lead-ecg/ (accessed 13th February 2017).
6. Brown, J.M. and Carr, J.O. (1981). Introduction to Biomedical Equipment Technology. New York: John Wiley & Sons.
7. Cambridge Advanced Learner’s Dictionary & Thesaurus. (2018). The internet of things. *Available at* *http://dictionary.cambridge.org/dictionary/english/internet-of-things* (accessed on 213th March 2018).
8. Croft, P., *et al*. (2015). The science of clinical practice: disease diagnosis or patient prognosis? Evidence about “what is likely to happen” should shape clinical practice. *BMC Medicine*, 13(20), 1-8.
9. Dimitrov, D. V. (2016). Medical Internet of Things and Big Data in Healthcare. *Healthcare Informatics Research*, 22(3): 156-163.
10. Farooq, M.U., Waseem, M., Mazhar, S., Khairi, A. and Kamal, T. (2015). A Review on internet of Things (IoT). *International Journal of Computer Applications*, 113(1): 1-7.
11. Graedon, T. and Graedon, J. (2014). Let patients help with diagnosis. *Diagnosis*, 1(1): 49-51.
12. Hans-Petter, H. (2018). ThingSpeak. *Available at* *https://www.halvorsen.blog/documents/technology/iot/thingspeak/resources/ThingSpeak.pdf* (accessed on 2nd June 2018).
13. Henriksen, K. and Brady, J. (2013). The pursuit of better diagnostic performance: A human factors perspective. *BMJ Quality and Safety*, 22(2): 1-5.
14. Khorovets, A. (2000). What is An Electrocardiogram?. *The Internet Journal of Health*, 1(2).
15. King, P.H. (2003). EKG analysis techniques, Design of Biomedical Devices and Systems. first edition, New York: Marcel Dekker Publication.
16. Kumar, M.R., Jilani, S.A.K., Hussain, S.J. and Raju.K, P.R.R. (2015). An Automated ThingSpeak System representing MPU6050 Sensor data using Raspberry Pi. *International Journal of Engineering Trends and Technology*, 29(1): 29-34.
17. Manser, T. (2009).Teamwork and patient safety in dynamic domains of healthcare: a review of the literature. *Acta Anaesthesiologica Scandinavica*, 53(2): 143-151.
18. McDonald, K.M., Bryce, C.L. and Graber, M.L. (2013). The patient is in: Patient involvement strategies for diagnostic error mitigation. *BMJ Quality and Safety*, 22(2): 30-36.
19. Merriam-Webster Medical Dictionary. (2018)a. Dictionary meaning of Telediagnosis. *Available at* *https://www.merriam-webster.com/medical/telediagnosis*, (accessed on 2nd June 2018).
20. Merriam-Webster Medical Dictionary. (2018)b. Dictionary meaning of Telemedicine. *Available at* *https://www.merriam-webster.com/dictionary/telemedicine*, (accessed on 2nd June 2018).
21. Minerva, R., Biru, A. and Rotondi, D. (2015). Towards a definition of the Internet of Things (IoT). *IEEE Internet Initiative, Torino, Italy*: 1-86.
22. Miorandi, D., Sicari, S., De Pellegrini, F. and Chlamtac, I. (2012). Internet of things: Vision, applications and research challenges. *Ad Hoc Networks*, 10(7): 1497-1516.
23. Nakhuva, B. and Champaneria, T. (2015) Study of Various Internet of Things Platforms. *International Journal of Computer Science & Engineering Survey*, 6(6): 61-74.
24. Pasha, S. (2016). ThingSpeak Based Sensing and Monitoring System for IoT with Matlab Analysis. *International Journal of New Technology and Research*, 2(6): 19-23.

25. Riley W., *et al*. (2008). The nature, characteristics and patterns of perinatal critical events teams. *Advances in Patient Safety: New Directions and Administrative Approaches*, 3: 131–144.
26. Salunke, P. and Nerkar, R. (2017). IoT Driven Healthcare System for Remote Monitoring of Patients. *International Journal for Modern Trends in Science and Technology*, 3(6): 100-103.
27. Shelke, Y. and Sharma, A. (2018). Internet of Medical Things. *Technology Intelligence & IP Research, Available at https://www.aranca.com/assets/uploads/resources/special-reports/Internet-of-Medical-Things-IoMT_Aranca-Special-Report.pdf* (accessed on 5th March 2018).
28. Thota, P. and Kim, Y. (2016). Implementation and Comparison of M2M Protocols for Internet of Things. *4th Intl. Conf. on Applied Computing and Information Technology*: 43-48.
29. Weller, J., Thwaites, J., Bhoopatkar, H. and Hazell, W. (2010). Are doctors team players, and do they need to be? *Journal of the New Zealand Medical Association*, 123(1310): 109-117.
30. World Health Organization (WHO). (2010). Framework for action on interprofessional education and collaborative practice. *Available at www.who.int/hrh/resources/framework_action/en/* (accessed on 14th May, 2018).
31. Xyrichis, A. and Ream, E. (2008). Teamwork: A concept analysis. *Journal of Advanced Nursing*, 61(2): 232-241.
32. Zubair, A.R. (2010) Biomedical Instruments: safety, quality control, maintenance, prospects & benefits of African Technology. *African Journal of Medicine and Medical Sciences*, 39(Suppl.): 35-40.
33. Zubair, A.R. and Eneh, C.U. (2018). Electrocardiograph: A Portable Bedside Monitor. *International Journal of Modern Research in Engineering and Technology*, 3(7): 1-5.