

Standards for Sensor Technologies that Support Mobile Patient Health Monitoring in Resource Constrained Settings

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Abstract: Diversity in vendors for sensor technologies requires standard, rules and regulations to stir development of interoperable healthcare sensor technologies. In addition, standards are needed for the successful deployment of any technology. Similarly, the success of global standards adoption or their harmonisation to resource constrained context requires a mechanism for determining their suitability of use in a given implementation environment. However, there is limited understanding of requirements for standardization of sensor technologies that support healthcare in a resource-constrained environment. The study conducted a systematised review. 1,741 peer-reviewed articles published 2000-2018 were retrieved from IEEE Xplore and google scholar. However, only 25 of them and 8 grey literature that focused on interoperability of ehealth devices, sensors use in health, standards for ehealth, standards development and or standards selection. The study identified four key areas for standardisation of sensor technology i.e., the semantic data models, ontologies, interfaces, and protocols. Furthermore, we present the use case of standardized sensor technology suitable to support healthcare monitoring in a resource constrained setting. The study anticipates that sensor device resource constraints and constraints of the implementation environment influence the suitability of selected standards. Therefore, recommend that in addition to the focus on the standardisation requirements, the standardisation process pay more attention to available and planned resources.

Keywords: eHealth, Healthcare, Standards, Sensor, Sensor Technology, Resource Constrained.

1. Introduction

The health sector has continued to face resource shortages (physical, financial, human and organisational) limiting possible attainment of one of the sustainable development goals that are good health and wellness for all. Attempts to overcome these resource shortages has propelled the use of ICT to support healthcare (ehealth). Hence the proliferation of mHealth, telehealth, electronic medical records, sensing technologies among others in healthcare. *Electronic health* (ehealth) being the use of information and communication technology (ICT) for health [1], has experienced rapid changes in technologies. eHealth deploys various technologies and applications to support patient management, care and wellbeing [2]. One central technology in ehealth is sensor technology. Generally, sensors are devices that detect a stimulus and translate them to an electrical signal [3]. Their use in

healthcare includes physiological monitoring, remote monitoring, and management of patients with chronic conditions, screening and diagnostics, a collection of client related environmental data, and the transmission / communication of such data [3]–[5] among others. The embedding of sensors in medical devices, equipment, and patient environment provides for improved performance, reliability and lower cost [5] thereby fostering patient-centered preventive care, timely diagnosis, treatment and or management of care.

The sensor technology data communication is greatly supported by the communication paradigm of the Internet of Things (IoT) [6]. In fact, of the estimated annual increase of 21.5% in the IoT connected devices between 2014-2020 [7], 12.7% of the growth rate of sensors is in healthcare [8]. This rapid growth needs to be tailored, governed and directed by a set of standards, guidelines or minimum specifications. However, sensor technologies continue to be deployed with no or little regard for minimum specifications for deployment that ensures the real-time big health data communication requirements, especially in a resource constrained setting. In addition, sensor technologies deployed in healthcare have continued to experience hardware level, physical layer, MAC layer, network layer transport layer and application layer limitations [9]. Other challenges to sensor use in healthcare are lack of interoperability, short sensor energy lifetime, limited network capacity, among others [9]. Bandyopadhyay and Sen [4] referred to them as standards design considerations, but this study considered them as technology design and deployment consideration. In fact, the African region is encouraged to use standards that support sustainable development goals [10]. In this case, standards for sensor technology that promote well-being for all at all ages.

1.1 Sensor Technologies in Healthcare

Advancement in ICT and sensor technologies has made sensing become a central part of the healthcare ecosystem. Multiple sensor technologies exist for the healthcare system [5], [8]. Based on the healthcare requirements, deployment includes use as wearable sensors embedded in accessories and clothes; ingestible embedded in pills; blood sample sensors; external sensors devices for screening samples; tissue embedded sensors; etc [11]. In fact, sensor technologies play diverse roles in healthcare including diagnostics, monitoring, a dynamic collection of patient data, among others [3], [5]. They are used as standalone devices attached to the patient or integrated with other devices like the smartphones, smartwatches, Fitbit, etc carried or implanted in the patient's environment [3], [12], [13]. To attain their full benefits, due consideration must be made of the characteristics, usability, and efficiency during development and deployment [11]. Whereas characteristics may look at the sensor type, hardware composition, usability focuses on the method of application and use of the device and efficiency at the sensor ability to avoid possible waste of resources such as power, communication bandwidth, etc. Table 1 is a categorization of the technologies on the basis of the ehealth application domain. It also identifies possible sensors to be deployed for measuring the physiological or environmental indicators.

Table 1: Categories of Sensor Technology use in Health [3], [14].

Application Area/Usage	Technology	Examples of Sensors
Point-of-care monitoring & diagnostics	Screening & Diagnostics	Biosensors, Biochemical & optical sensors
Wearables: motion-detection, identify balance and falls risk, stroke rehabilitation	Motion and Kinematics	Accelerometer, Gyroscopes, Kinematic sensors, On- fabrics sensors
Measuring physiological indicators	Physiological	IR, Heartbeat, pulse rate sensors, etc
Assess muscular issues and tissue damage	Musculoskeletal	EMG sensors
Imaging	Imaging	CCD, ultrasound sensors & Smart Pills

1.1.1 Application Examples and Challenges

According to healthcare can greatly benefit from sensor networks [15]. Sensor technology application to healthcare includes vital sign monitoring, accident recognition, monitor and or assist clients by use of smart devices [15]. In order to help determine sensors and their standardisation requirements, the study presents two potential application scenarios of sensor technologies in healthcare i.e., the body sensor network and environmental sensors for patient monitoring [6], [16], [17].

- Body sensor networks (BSN) as an advanced healthcare application of sensor technologies used for dynamic sensing and communicating of patient's physiological indicators (Figure 1). It has sensors for collecting EEG, EMG, ECG, BP, temperature, blood sugar, the quantity of motion, breathe, cholesterol, oxygen saturation and etc.

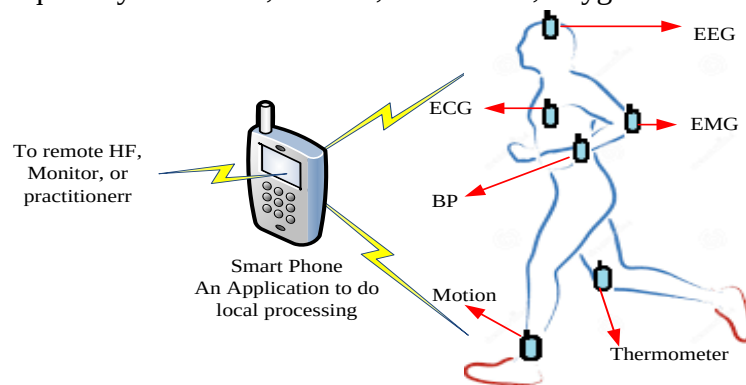


Figure 1: Examples of sensors in a body sensor network [6]

- Environmental patient monitoring like in smart home sensing environment or home assisted living for elderly persons. The study conceived this as an extension of patient monitoring environment to include patient monitoring at the workplace, in-transit (transport) and public places. Examples of possible environmental measurements with the suggestion of likely sensors types to be used for such measurements are presented in Table 2. Measurement of the patient's physical state, activities, interactions with the environment and the environment itself informs their care. In addition, can guide health decisions and service delivery.

Table 2: Example of Sensors for Smart Home Healthcare [18].

Measurement	Sensor Types
Human actions/environmental state	Video cameras
Audio detection	Microphones
Environmental parameters	Temperature sensors, light sensors & humidity sensors
Acceleration/orientation	Wearable inertial sensors
Vital signs	Wearable vital signs sensors
Object and user identification	RFID
User-object interaction detection/movements and location identification	Simple binary sensors

There are challenges to the application of sensor technology in healthcare which reduce benefits of the technology to support patient care. The challenges include hardware-based challenges peculiar to individual devices, like limited sensor lifetime due to the device energy consumption of the limited battery power [4], [13]. Communication and data sharing challenges, like Spatial, intermittent and or unreliable network capacity [13], short-range radio frequency power levels and limited frequency bands and [4], [15], and challenges related to the data sharing environments like lack of sensor device interoperability; worries

of device security and data privacy; low data rate, communication and regulatory constraints among others [4], [5], [18], [19]. Optimal use of available hardware and or communication resources is required for better data collection and communication. A right balance of the resources may prove challenging, e.g., it has been acknowledged that sensing power with low bit-rates reduces sensor power consumption [15], however, some health data may require higher transmission rates. Therefore, the authors argue for a mobile patient monitoring system that is supported by sensor technologies in a network challenged by resources [4], [5], [19] as is common in low and middle-income countries. Thus, the focus on resource limitation relates to the hardware and communication related challenges of the sensor technology.

1.1.2 Standards for Sensor Technologies

In a data collection and sharing environment, standards are needed to ensure interoperability and support information exchange by health information systems, electronic/ communicating devices, sensors devices, the environment, and other digital systems. The standards (specifications) provide a reliable basis for sharing and use of the products or services [20]. Thus, a family of standards has been developed by standards development organisations (SDOs) and governments to support ehealth. Examples of SDOs work groups/technical committees developing ehealth standards include HL7, ISO/TC 215, CEN/TC 251, and IEEE among others [10]. The HL7 family of standards includes messaging, clinical document architecture, content management specification, and fast healthcare interoperability resources (FAIR) [21]. The ISO/TC 215 health informatics standards work cover ISO/IEEE 11073 series of standards, ISO 13606 standards for Electronic Health Record communication, and ISO 12052 DICOM standard [22]. The CEN/TC 251 only focus on EN 13606 for Electronic Health Record communication. The IEEE standards cover personal health device communication specifications (IEEE 11703 standards series) and point-of-care medical device communication (IEEE 11073-x series) [22]. In addition, there are collaborations like Continua Health Alliance and IHE that are umbrella bodies of standards developers who continue to work towards device alignment for chronic disease management, aging independently, and health and fitness by promoting use of established standards like HL7, DICOM, ISO/IEEE 11073 Personal Health Data (PHD), etc [3], [23]. For example, vendor products that are build based on the Continua Health Alliance guidelines are encouraged to use the ISO/IEEE 11073 Personal Health Data (PHD) Standards [23]; the IEEE 1451 standards family that provides for plug-and-play with support for diverse communication interfaces and software solution [14], [24], [25], etc. Health monitoring products, such as blood pressure monitors, and blood glucose monitors among others have embedded sensors like pulse rate sensors, ultrasound sensors, kinematic sensors, etc. In fact, McGrath [3] asserts that “sensors are the key component of any medical device that has a measuring purpose”.

The continued engagement of collaborators in the standardisation of medical devices, communication and fitness devices have recommended sensor device/technology related standards like HL7, DICOM, ISO/IEEE 11073, among others. However, the applicability of such standards ‘as is’ to devices and health data communication in resource constrained settings remains a challenge. In addition, the multiple and overlapping standards in the ehealth environment [26] including the mobile patient/client require a mechanism for selecting those suitable to the particular setting (resource environment). According to [27], overlapping standards may have conflicting provisions that impact on interoperability of systems based on the different standards. Thus, for sensor technologies to provide dynamic monitoring of the mobile patient; control the environment, and assist things, existing international standards must be selected or harmonized to the resource constrained

requirements. The selection/harmonization process needs to be tailored to ensure device interoperability, security, and compliance with regulations. *Sensor device interoperability* guarantees that multiple sensors used in monitoring a health condition should meet the semantic data requirements, ontology, application and hardware interfaces, and data sharing protocols [4]. A common understanding of data across the sensor system will ensure that physiological and environmental data collected presents similar meaning all care givers. The *sensor security* has two components, i.e., the network security and data security. Whereas the network security considers authentication, anonymity, and secure localization; data security handles data privacy, integrity, and freshness [6]. In health, privacy and security of patient physiological data are paramount [28]. Therefore, standards are needed to ensure consistency in both network/data security and privacy of sensor technology. The *regulatory constraint* involving the deployment environment, like allowable frequency bands and radio frequency power levels should be realistic to support secure health data sharing. These constraints either limits or support the innovative deployment of sensor technologies for healthcare monitoring.

Cognisant of the different standardisation levels (business, semantic, functional, technical, and application levels) [27], this study preferred the CEN/CENELEC/ETSI [27] three-layered approach to specifying standards. The upper layer address *business requirements or use cases* also referred to as *interoperability specifications*. The interoperability specifications dictate ways to interface systems (sensor technologies) used for healthcare with the IT infrastructure “The main task of the interoperability specification will be to effectively assemble and combine the right set of Profiles to address the business-level use case” [27]. The middle layer is formed by interoperability building blocks of implementation guidelines or *profiles*. The profiles provide well-specified interoperability service among a number of communicating actors by dictates of how information is processed and ways of exchange. Integrating the Healthcare Enterprise (IHE) focused their ehealth standardisation effort at this layer. The lower layer represents standards that are utilised in the profiles or implementation guidelines (*foundation standards*) such as the standards for terminologies, data structures, and protocols. They are foundational to the delivery of open interoperability. However, sensors are distinguished by their type, hardware composition, how it is embedded and its application protocol; thus, their interoperability requires standardization of the semantic data models, ontologies, interfaces, and protocols [4]. This study considers them as the four layers for ehealth sensor technology standardization.

2. Objectives

The main objective of the review was to identify requirements for standardization of sensor technologies that support health monitoring of a patient in an environment constrained by communication resources. Therefore, the study explored standardisation layers for sensor technologies in answer to the question of what standardization requirement(s) are needed to model sensor technologies that support mobile patients monitoring in resource constrained environments?

3. Methods

This study involved a systematized review of the literature on standardization of sensor technologies and their communication. Articles were search from IEEE Xplore and google scholar for the period 2000-2018. Our search criteria included ehealth, healthcare, standards, sensors, resource constrained and technologies as search words and their synonyms. This resulted in the retrieval of 1,741 peer-reviewed articles following the removal of duplicates, and title and abstract screening. After applying the inclusion and

exclusion criteria, only 25 of them were used in the review. Eight (08) other documents/literature were obtained from the websites of sensors technology and international standards development organisation.

The inclusion/exclusion criteria - For inclusion, only studies that were published in English and discuss interoperability of ehealth devices, sensors use in health, standards for ehealth, standards development and or standards selection were considered. Articles for which full text was not available were excluded from the review.

NVivo software was used to identify common themes regards standardisation of sensor technologies and their communication. Items coded include sensor types, sensor application, sensor challenges, standards, and device interoperability (see Table 3). The table presents a summary of the results (as discussed in the different sections of the paper) and literature sources used in the review of standards for sensors technologies that support healthcare and the requirements for standardisation for a resource constrained setting.

Table 3: Results of the Systematized Review

Key themes and literature sources
Electronic health (ehealth) [1], [2], [7], [8], [9]
Sensor types/technologies [3], [5], [11], [12], [14]
Applications of sensors/sensor technology for health [3], [5], [6], [8], [9], [11], [13], [15], [16], [17], [18], [19], [26]
Challenges to the use of sensors in health monitoring [4], [9], [13], [15], [18]
Resource constrains (device and communication) that impact on sensor implementation [4], [19], [24]
Concept of device interoperability applicable to sensors [22], [23], [27]
Standards for sensors/sensor technology, SDOs efforts and collaborations on standardisation of sensor technology & devices for health [3], [10], [14], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29]
Standardisation requirements (semantic data models, Ontologies, data sharing interfaces and protocols) [4], [19], [27], [28], [29], [30], [31], [32], [33]

We assumed these concepts reflect the phenomenon of sensor technology used to monitor a mobile patient/client. Results of this study identified standardization of semantic data models, Ontologies, data sharing interfaces and protocols as core concepts regard requirements for standardisation of sensor technologies that support healthcare monitoring.

4. Discussion

Support for interoperability of ehealth technologies, *sensor technologies*, health information systems, and other health information and communication technologies, requires standardized semantic data models, ontologies, standardized interfaces, and standardized protocols [4]. Moreover, these standards levels represent different ways that sensors are distinguished, i.e., sensor type, hardware composition, how its embedded and application protocol. Therefore, we argue for a four-layered ehealth sensor technology standardization framework (See Figure 2).

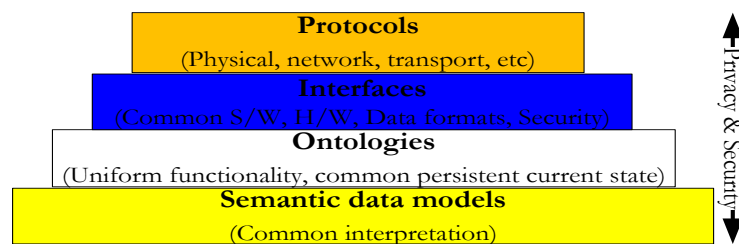


Figure 2: Layers for Sensor Technology Standards

- *Standardized semantic data models*: For the huge amount of health data collected by sensors to be useful, they should share common meaning (semantic meaning). The

semantic model has been defined to be a network of concepts and relationships between those concepts [29]. Health sensor data has more semantic content than the traditional relational data and just as in the smart grid environment [29]; standards are needed to build a common semantic data model for sensor (smart) technologies supporting healthcare. According to Barnaghi et al [30], considerations for scalability of sensor network include interoperability, processing, and interpretation of huge amounts of heterogeneous sensor data. Thus, sensor models need to be standardized to produce common analysis and interpretation of the collected sensor data. Furthermore, the data standards should be harmonized for operation in the limited-resource sensor deployment environment.

- *Standardized Ontologies*: The semantic data model provides a standard data capture. In order to achieve uniformity in sensor data use, the common data format and interpretation should be maintained across systems. **This achieved** by defining common relations, objects and terms applicable across the sensor technology domain. Although [31] claims integration of higher and lower level sensors to increase confidence in the data collected and knowledge generated is still pending; we believe this integration is possible in healthcare. For example, patient physiological parameters which are the most accessed and utilized health information, measured by sensors can reveal additional knowledge about the patient and hence threat to privacy [28]. Therefore, [31] argue for the development of domain specific network ontologies. In this work, the domain is sensor technologies that support healthcare. The standardized ontological model should provide a uniform description of the parts, relationships, and hierarchy of the parts of sensor technologies supporting healthcare. In addition, it should capture key features of the sensor technology that describe the functionality and current state such as sensor communication/radio, power, etc.
- *Standardized interfaces*: Sensors and application software from different vendors need to interoperate in health data/information sharing. The sharing is done through an interface which defines which primitive operations and services one software or hardware offers to the other. Thus, software and hardware interfaces need to be standardized for improved interoperability between the different sensors, aggregation devices and software [3]. Besides, standardized interfaces allow users to select suitable low-cost sensors and software that best fits their needs. All three categories of interfaces should ensure associated interoperability via hardware and software interfaces, health data formats and security schemes [32].
- *Standardized Protocols*: Standards for the communication and application protocols need to be harmonized for limited resource environments. The syntax for sharing health sensor data also needs to be standardized. This ensures correct health data is extracted from the shared documents by recipients. The “standardized protocols are designed for different needs” [19].

Standards for each layer of the sensor technology should provide minimum requirements (standards) that ensure patients privacy and security of patient health data. In fact, standardisation requirement at each layer of Figure 2 allows for proper specification or harmonization of standards that can support health data sharing with a physician, remote monitoring and provision of care to the patient.

Point-of-care monitoring and wearables from Table 1 are used to illustrate the application of the standardisation requirements for sensor technology to healthcare. Sensor technologies used to screen and diagnose and the wearables used in motion-detection collect standardised data based on the semantic data models. Data collected by different sensors is shared and is persistent (i.e., possess common meaning) across systems because of shared ontology. If they are presented to applications and device with standardised interfaces (operations and services) by standard data exchange/communication protocols,

then the sensor technology can support health information exchange for a point of care monitoring. We argue that proper alignment of the standardisation requirements will contribute to the optimal and resourceful collection and sharing of patient data among caregivers and the health system. The standardisation requirements with the suggestion of applicable standards are further explained for the Mobile Client Monitor in Section 4.1.

4.1 User Case Scenario: Mobile Client Monitor

A possible deployment scenario of the sensor technologies in healthcare is a Mobile Client Monitor (CMob) (see Figure 3). This study extends [19] to include a mobile body monitoring system (BP, EEG, ECG, etc); a home monitoring system (sensor network, e.g., cameras, thermometer, etc); location sensors (e.g., mobile phones) and environmental sensors (e.g., cameras at work, in street, which the body systems activate when within the proximity). The main purpose is to improve the quality of a client's healthcare by assisting in full monitoring, and a 24/7 provision of support and reminder services. Besides monitoring the patient's environment conditions, the sensors detect a patient's physiological conditions (e.g., blood pressure, body temperature, pulse rate, glucose level, etc). Advanced implementations include the sensors adjusting environmental conditions like signalling the heater to warm up the room to appropriate temperature; waking up client; making an emergency call (or messaging) with client's location and time; etc.

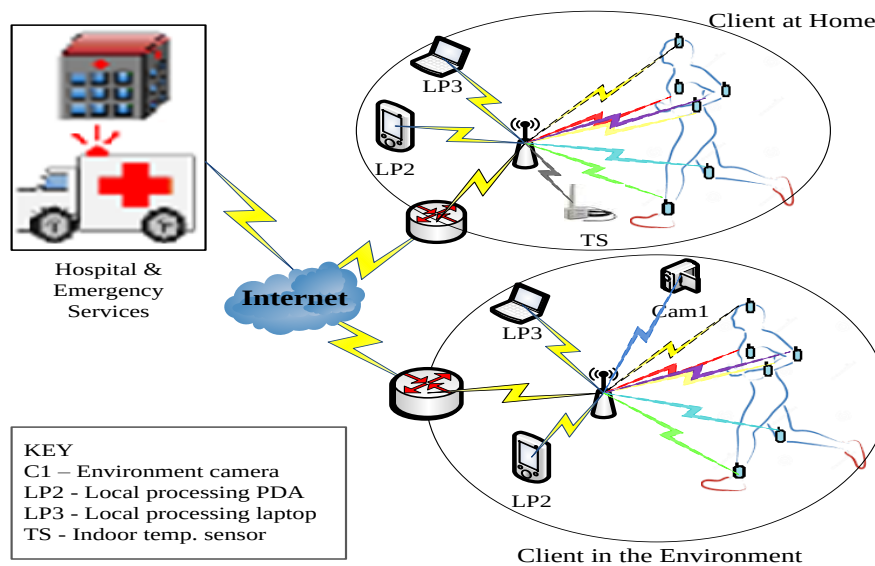


Figure 3. Mobile Client Monitor

In Figure 3, the home monitoring system is represented by wireless sensor devices/nodes, processing devices, communication and application system to respectively accomplish patient data collection (sensing); sensed data processing capabilities; patient data sharing (communication) and processed patient data use. The main components include sensors, gateways, robot assistants, processing hubs among others. Sensors and the communicating component use standardized protocols to communicate with each other. The home monitoring system is expected to function even with limited Internet connectivity by directly interacting with a body sensor and sensor-enabled home devices. Limited Internet is optimized in the event of an emergency. Also, to save the limited sensor device power, home monitoring can switch to sleep mode to conserve energy. To accomplish this, the sensors should use standardized sensor protocols to connect to the nearest gateway; communicate through standardized interfaces; with ontologies (conceptualization and relationships), and based on standardized semantic data models. In fact, the monitoring

sensor technology deploys sensor nodes and gateways based on standardized data models, ontologies, interfaces, and protocols to enable data sharing/communication between the different technology components and the other communication systems. These standards exist at the protocol, interface, ontology, and semantic data model levels and should make consideration for mobile client monitoring under resource-constrained environments. Processing can be done onsite, in the cloud, or remotely by the monitoring health facility.

Besides the widely adopted HL7 for health, [33] recommends IEEE 802.15.4 standards for the protocol levels of a low rate personal area network, WSN with low cost, low power consumption and specified communication range to maximize battery life. However, [10] argues ITU is about to adopt M2M specifications as the main industry driven standards for IoT, mainly composed of sensors devices/technologies. This may not be suitable as is for resource constrained settings. Thus, a choice of suitable standards for the sensor technology needs to be guided by the standardisation requirements. The interface, ontology, and semantic data model levels of the framework also requires standards. This study proposes that adoption of global standards for sensor and communication technologies applicable to health like the IEEE 1451 recommended by [25] should consider to contextualise them to the resource constrained specifications of the deployment environment.

5. Conclusions

Sensor technology is ripe for healthcare. What remains is a model of standardised interoperable sensor technology that supports patient data collection and information sharing with health. This study highlights challenges to the application of sensor technology to healthcare. Furthermore, the study identified requirements for standardization of sensor technologies to support healthcare in a resource-constrained environment. We argue that proper standardisation of the semantic data models, ontologies, interfaces, and protocols will contribute to the optimal and resourceful collection and sharing of patient data among caregivers and health system. We used the Smart Client Monitor case to illustrate the four layers of standardization of sensor technology. It is shown that different standard and needed for the different aspects of the sensor interaction including data collection and communication that meet the resource needs (short range, low bit-rate, etc) of a health data communication environment. We recommend that the standards selection should pay attention to the available resources supporting sensor technology implementation. Future study may focus on developing a collaborative and dynamic method for standard selection or determination that focus on the requirements of the resource environment.

References

- [1] WHO, "WHO | eHealth at WHO," *WHO*. [Online]. Available: <http://www.who.int/ehealth/about/en/>. [Accessed: 13-Mar-2019].
- [2] M. Maheu, P. Whitten, and A. Allen, *E-Health, Telehealth, and Telemedicine: a guide to startup and success*. John Wiley & Sons, 2002.
- [3] M. J. McGrath and C. N. Scanail, "Regulations and standards: Considerations for sensor technologies," in *Sensor Technologies*, Springer, 2013, pp. 115–135.
- [4] D. Bandyopadhyay and J. Sen, "Internet of Things - Applications and Challenges in Technology and Standardization," *Wirel. Pers. Commun.*, vol. 58, no. 1, pp. 49–69, 2011.
- [5] C. Mathas, "The Role of Sensors in IoT Medical and Healthcare Applications," *Digi-Key Electronics*, 2014. [Online]. Available: <https://www.digikey.com/en/articles/techzone/2014/jul/the-role-of-sensors-in-iot-medical-and-healthcare-applications>. [Accessed: 05-Nov-2018].
- [6] P. Gope and T. Hwang, "BSN-Care: A secure IoT-based modern healthcare system using body sensor network," *IEEE Sens. J.*, vol. 16, no. 5, pp. 1368–1376, 2016.
- [7] D. Lund, C. MacGillivray, V. Turner, and M. Morales, "Worldwide and regional internet of things (iot) 2014–2020 forecast: A virtuous circle of proven value and demand," *Int. Data Corp. IDC Tech Rep*, vol. 1, 2014.

- [8] ReportBuyer, "Internet of Things (IoT) Sensors in Healthcare: Global Markets and Technologies," 2018. [Online]. Available: <https://www.reportbuyer.com/product/5352050/internet-of-things-iot-sensors-in-healthcare-global-markets-and-technologies.html>. [Accessed: 17-Jun-2018].
- [9] H. Alemdar and C. Ersoy, "Wireless sensor networks for healthcare: A survey," *Comput. Netw.*, vol. 54, no. 15, pp. 2688–2710, 2010.
- [10] P. Cousin, F. Le Gall, C. Pham, N. Malaguti, P.-Y. Danet, and S. Ziegler, "IoT Standards for Africa and Sustainable Development Goals (SDGs)," in *2018 IST-Africa Week Conference (IST-Africa)*, 2018, p. Page–1.
- [11] "Smart sensors transforms Medical field: Types and its advantages," *TrioTree Technologies Pvt Ltd*, 18-Oct-2016. .
- [12] A. Helwatkar, D. Riordan, and J. Walsh, "Sensor Technology For Animal Health Monitoring," in *Proceedings of the 8th International Conference on Sensing Technology*, Liverpool, UK, 2014, pp. 266–271.
- [13] S. Khera, N. Mehla, and N. Kaur, "Applications and challenges in wireless sensor networks," *Int J Adv Res Comput Commun Eng*, vol. 5, no. 6, pp. 448–451, 2016.
- [14] A. Kumar, V. Srivastava, M. K. Singh, and G. P. Hancke, "Current status of the IEEE 1451 standard-based sensor applications," *IEEE Sens. J.*, vol. 15, no. 5, pp. 2505–2513, 2015.
- [15] D. Puccinelli and M. Haenggi, "Wireless Sensor Networks: Applications and Challenges of Ubiquitous Sensing," *IEEE Circuits and systems magazine*, vol. 5, no. 3, pp. 19–31, 2005.
- [16] M. S. Hossain, "Patient status monitoring for smart home healthcare," in *Multimedia & Expo Workshops (ICMEW), 2016 IEEE International Conference on*, 2016, pp. 1–6.
- [17] M. Aminian and H. Reza Naji, "A Hospital Healthcare Monitoring System Using Wireless Sensor Networks," *J Health Med Inform*, vol. 4, no. 2, pp. 2–6, 2013.
- [18] Q. Ni, A. B. García Hernando, and I. P. de la Cruz, "The elderly's independent living in smart homes: A characterization of activities and sensing infrastructure survey to facilitate services development," *Sensors*, vol. 15, no. 5, pp. 11312–11362, 2015.
- [19] I. Florea, R. Rughinis, L. Ruse, and D. Dragomir, "Survey of Standardized Protocols for the Internet of Things," presented at the International Conference on Control Systems and Computer Science, 2017, pp. 190–196.
- [20] I. Masood, Y. Wang, A. Daud, N. R. Aljohani, and H. Dawood, "Privacy Management of Patient Physiological Parameters," *Telemat. Inform.*, 2018.
- [21] HL7 International, "Health Level Seven International - Homepage | HL7 International." [Online]. Available: <http://www.hl7.org/>. [Accessed: 11-Mar-2019].
- [22] D. Eom and H. Lee, "A holistic approach to exploring the divided standards landscape in E-Health research," *IEEE Communications Standards Magazine*, pp. 1–7, 2018.
- [23] R. Carroll, R. Cnossen, M. Schnell, and D. Simons, "Continua: An Interoperable Personal Healthcare Ecosystem," *IEEE Pervasive Computing*, vol. 6, no. 4, pp. 90–94, 2007.
- [24] P. Hu, R. Robinson, and J. Indulska, "Sensor standards: Overview and experiences," in *2007 3rd International Conference on Intelligent Sensors, Sensor Networks and Information*, 2007, pp. 485–490.
- [25] W. Kim, S. Lim, J. Ahn, J. Nah, and N. Kim, "Integration of IEEE 1451 and HL7 exchanging information for patients' sensor data," *J. Med. Syst.*, vol. 34, no. 6, pp. 1033–1041, 2010.
- [26] F. Adebessin, P. Kotzé, D. Ritz, R. Foster, and D. V. Greunen, "A Method for Selecting E-Health Standards to Support Interoperability of Healthcare Information Systems," p. 11, 2014.
- [27] CEN/CENELEC/ETSI, "eHealth-INTEROP Report in response to eHealth Interoperability Standards Mandate," 2009.
- [28] D. Ernst, "Standards, Innovation, and Latecomer Economic Development—A Conceptual Framework," 2013.
- [29] J. C. Nieves, M. O. de Mues, A. Espinoza, and D. Rodríguez-Álvarez, "Harmonization of semantic data models of electric data standards," in *Industrial Informatics (INDIN), 2011 9th IEEE International Conference on*, 2011, pp. 733–738.
- [30] P. Barnaghi, S. Meissner, M. Presser, and K. Moessner, "Sense and sens' ability: Semantic data modelling for sensor networks," in *Conference Proceedings of ICT Mobile Summit 2009*, 2009.
- [31] M. Eid, R. Liscano, and A. El Saddik, "A universal ontology for sensor networks data," in *Computational Intelligence for Measurement Systems and Applications, 2007. CIMS 2007. IEEE International Conference on*, 2007, pp. 59–62.
- [32] S. R. Islam, D. Kwak, M. H. Kabir, M. Hossain, and K.-S. Kwak, "The internet of things for health care: a comprehensive survey," *IEEE Access*, vol. 3, pp. 678–708, 2015.
- [33] A. A. A. Alkhatib and G. S. Baicher, "Wireless sensor network architecture," in *2012 International Conference on Computer Networks and Communication Systems (CNCs 2012)*, 2012.