A Survey on Integrating Wireless Body Area Network Sensor Data with Semantic Web Technologies

Joy Alatta and Joseph Cann

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Joy Alatta[1[0000-0002-0158-8120]] and Joseph Cann[[]]

[1] Learnatek, Dallas, USA
[2] Herzing University, Wisconsin, USA
[1] joy.alatta@learnatek.com
[2]jocann@herzing.edu

Abstract. Wireless body area network (WBAN) is a subset of the wireless sensor network (WSN). WBAN has a vital role in technology for remotely monitoring human physiological changes in healthcare. Many applications for wearable and plantable devices have used WBAN. Most wearable devices are designed with several sensors to monitor various aspects of the body. A problem of interoperability in WBAN sensor data arises from the many sensing devices from several manufacturers, which may be operating at different frequencies and generating data in various types of formats. The heterogeneous nature of the WBAN sensor data limits the sharing and integration of other clinical data. There are several proposed approaches to address the challenges of the interoperability of the WBAN sensor. This paper presents a systematic review of some of the sensor data interoperability approaches using semantic web technology. The knowledge in this paper is to provide a background for further investigations in the use of semantic web technologies for WBAN data integration.

Keywords: WBAN, Semantic interoperability, Sensor data, Sensor data, Linked Open data Semantic Web Technologies, Wireless Sensor Data

1 Introduction

The dramatic shift towards ubiquitous health monitoring increases the importance of understanding wireless body area networks (WBAN). The data it generates and how the data can add unique value to data-centric clinical decisions. WBAN is described as a great asset in the medical healthcare practice [2], and this could be attributed to the ability to improve the quality of life for people [36]. WBAN is constructed with a set of sensor nodes that monitors human physiological activities and actions with actuators that act on the information from the sensors [17]. A collection of wireless sensor nodes, which are small, lightweight, and low power consumption, are used in the construction of WBAN [10]. The sensor nodes in a WBAN may ring up to thousands of sensors [8]. WBAN sensors can collect data for predicting and analyzing a patient's health status. Wireless sensors embedded into wearable devices have emerged to be promising for continuous monitoring of human physiological changes. WBAN sensors had been used for detecting hypertension and cardiovascular diseases [31]. Wireless sensors can communicate within and with external devices to observe and monitor human physiological changes using stated parameters. In a wireless body area sensor, the observed parameters may be object movements like heart rate or body temperature [8]. [41]. Wireless sensor networks (WSN) applications are commonly used for measurement, tracking, and detection in transportation, healthcare, industrial applications, smart grids, environment tracking, security, and surveillance [18].

The wireless sensor produces data streams in a raw and challenging format [23]. The varieties of the format in which the data is acquired from sensors make it challenging to utilize [30]. The formatting challenge is due to the non-availability of semantics that can be used to describe the data [9]. The wireless sensor networks are deployed and used to capture data about phenomena that relate to domains affiliated with the sensor. There are ample data streams from sensors, but the barriers of sensor data are the inability to understand the data [34].

A wireless body area network is a subfield of the wireless sensor networks. It is used in healthcare for the continuous monitoring of health parameters [32,17], such as object movement, temperature, magnetism, and seismic activities. WBAN is constructed with small size sensors which are placed in diverse parts of the body to communicate within and with external objects [19]. Sensors and actuators play a crucial role in providing a link to bridge the physical world and the digital world [42]. Sensors can facilitate a machine to human and machine to machine communication. WBAN sensors could either be invasive or non-invasive [22] and are currently being applied for enhancing the quality of life of individuals through wearables to assess soldier fatigue, sports training, sleep monitoring, asthma monitoring, fall detection and others [18]. Many applications have been developed from WBAN for smart health care and remote monitoring of patients [27]. Biofeedback is another application area for WBAN [22].

The need for interoperability is a significant challenge because system vendors of the internet of things use different systems architecture and models in manufacturing sensors, which makes it difficult to harvest data from heterogeneous sources. There are noted challenges in accessing and managing sensor data due to the dynamic, volatile environment, noisy, and continuous nature [30]. The data processing and management of sensor data are essential to achieving the potentials of sensor data. However, a significant issue with data generated by sensors is their heterogeneous nature, which requires description and definition to enable it to be integrated with enterprise systems and the linked open data (LOD) cloud [21]. This study is focused on the data from wireless sensor networks used in healthcare, which is described as the wireless body area networks (WBAN).

2 Aim and Scope of Review

This systematic review aims to help identify outcomes, challenges, and guides for scientific research direction on open challenges in the usability of WBAN sensor data. This review aims to understand the various frameworks for integration and WBAN sensor data. In this review, characteristics of sensor data, semantic web technology, and semantic web interoperability methods are discussed.

3 Characteristics of Sensor Data

WBAN sensor data is characterized by large volumes of real-time observations collected from a host or patient [32]. The data could be univariate or multivariate, depending on the number of body areas that sensors are monitoring. Wearable devices may be designed to monitor only one aspect of a patient's health or may be designed to keep track of many aspects of a patient's health [11]. Wearable devices that track various aspects of the body are usually equipped with different types of sensors, which may collect diverse data types [27].

Data from a sensor may be generated at a low or high sampling rate [40] depending on the object that it is monitoring. The low and high sampling rates can also constitute data issues such as noise, data loss, or redundancy. Low data velocity could result in lost data, while high data velocity could also result in data loss without efficient processing techniques. Sensors connect several types of objects, thus resulting in the generation of heterogeneous data with diverse formats. Sensor data is generated rapidly and continuously in a way that can be described as a data stream.

Data streams are continuous and disorderly with changing probability distributions. Differences in format could result in data irregularities, which may ultimately affect the quality of sensor data [12]. There may be ambiguity and inconsistency in sensor-generated data as a result of missed readings, multiple readings, and packet loss. The diverse formats and semantics attached to the data result in interoperability issues [24]. This is where semantic web technologies can be used to enable a deeper understanding of sensor data. Sensor data streams can be processed using data aggregates, data compression, modeling, and online querying. The queries used in sensor data streams include aggregate, join, and continuous queries.

4 Semantic Web Technologies

Semantic web technologies have been used to understand and process data by including structured and machine-readable descriptions. Semantic frameworks are used for annotation and interpretation of sensor data [4]. Many researchers have propagated the semantic web as an option for enriching sensor data [20] to integrate with data from other sources in the LOD cloud. Linked open data is a semantic web standard for publishing and linking heterogeneous data [37].

Semantic web technologies, as developed by the W3C [39], include the use of a resource description framework (RDF), SPARQL, and web ontology language (OWL) for describing web-connected objects or resources. In [12], semantic web technology is described as being critical in enabling interoperability of data from disparate environments through the use of standards or agreements on the format and attached meaning to data. Semantic web technology is expected to proffer solutions to the challenges of extraction of knowledge from heterogeneous data and other knowledge sources to subsequently enable improvement in the quality of by integrating data silos [14].

The publication of sensor data using semantic technologies encompasses mapping the data and converting the data stream to RDF streams. Then the RDF data stream is stored and linked with other data sources in the LOD cloud. RDF data model is used to represent and process linked stream data [44] from sensors. Linked data principles have been suggested as a solution to the challenge in the usability of sensor data [25]. Linked stream data is expected to improve sensor data usability by making provisions for including semantics to enhance searching and exploration [7] of sensor data. Other positives aspects of the linked stream data are that prior knowledge of the data source is not required before using the data, thus enabling the combination of linked stream data with data from other sources [5,28].

4.1 Semantic Interoperability

Semantic interoperability is used to describe the capability of systems to work seamlessly with other systems to interpret information [45]. The seamless interaction is based on a loosely coupled system concept [46] were parts of the system can easily be added or removed without destroying or causing malfunction of the entire system. Semantic principles require strict adherence to certain architectural principles such as separation of concerns and transparency, as can be seen in openEHR [27]. In semantic interoperability, the meaning attached to a piece of data includes a context-aware interpretation of the data and a domain ontology[28].

The semantic interoperability principles specify the unambiguous interpretation of a piece of machine-readable data across software programs, platforms, and domains [14]. It proffers solutions for interaction between various data formats. An unambiguous interpretation provides a framework for understanding heterogeneous sensors without prior knowledge about the data. Interoperability can be syntactic or semantic, where syntactic interoperability ensures intercommunication and data exchange between two or more systems, and semantic interoperability ensures automatic interpretation and meaningful exchange of communication [1]. Enablement of system interoperability provides a basis for internet-connected objects or two interoperable systems to understand each other's functionality [28].

W3C [39] described semantic interoperability from the perspective of enabling different agents, services, and applications to exchange information meaningfully. Wireless devices made of sensors from different manufacturers produce heterogeneous data, ultimately causing problems in data exchange across different gateways and smart hubs. There are instances where the measurement and units of the data are expressed differently. Using a semantic interoperability approach, the incompatibility between data models and information models can be dynamically and automatically resolved [14]. Standardization enables the creation of consistency in the exchange of information among heterogeneous systems. The absence of standard likely significantly increases system complexity [1].

5 Related Work

As discussed in the previous section, the critical point in WBAN is to enhance the remote collection of sensor data from various parts of the human body. Several literature works have been focused on making senor data usable and of good quality to enhance data-driven clinical decision-making.

In [9], a distributed, semantically intelligent, cloud-based, and interoperable mobile health clinical decision support system (CDSS) framework for monitoring diabetes with a mobile device is proposed. The framework was described as having achieved the interoperability of sensor data. The HL7 fast healthcare interoperability resources (FHIR) standards [47] are used in the framework. The value proposition of the project is the ability to integrate real-time sensor data and historical electronic health record (EHR) data. The proposed framework is made up of four loosely coupled modules described as the patient module, cloud-based clinical decision support system module, back end EHR systems module, and the mobile health services module. The cloud-based clinical decision support system module is the core of the framework and has the responsibility for standardization, processing, analyzing, and visualization of sensor data.

An ontology focused solution for describing prior knowledge about the meaning of a piece of data referred to as a domain abstract language is proposed in [6]. Ontologies are the shared vocabularies and relationships for defining and representing data, and shared meaning, and hides heterogeneity to support their semantic meaning 14]. In [19] use of ontologies to facilitate semantic interoperability in healthcare is proposed. The proposed is based on the HL7 FHIR structure to provide shared healthcare data and ontologies, and the authors described the project as creating innovative options to surmounting healthcare data interoperability.

In [37], health information linked open data (LOD) system for querying and visualization is developed. The project used RDF for data representation and SPARQL for query interface. A web ontology language (OWL) based integration [48] is used by modeling health data with HL7 FHIR standard implemented services proposed in [30]. The project applied semantic web technologies to integrate health data and home environment data from heterogeneously built services and devices by annotating the data with semantics and ontological links. In [3], a graph-based semantic web services composition system is proposed, and the approach is used to integrate health data in different health organizations. The authors described the proposed system's main contribution as having the ability to use a rule-based reasoning technique of the semantic web technologies to prepare the WS dependency graph.

6 Conclusion and Future Scope

Improving the interoperability of WBAN sensor data is fundamental for the success of WBAN in healthcare. In this paper, WBAN and its various characteristics have been discussed, including the sensor data that it generates. There are many research projects and proposals on integrating sensor data, but this paper focused on using semantic web technologies to integrate WBAN sensor data. The proposals are diverse, and each promotes different approaches related to the study's objective. A comprehensive systematic review is conducted to present various attempts for interoperability with semantic web technologies. Though there are many approaches to integrating sensor data, the semantic web technology approach seems very promising. Approaching health data interoperability standards using HL7 Fast Healthcare Interoperability Resources (FHIR), OpenEHR, Semantic Sensor Network (SSN), and ontology is gaining traction, but standardization across all the approaches is yet to be attained. Using semantic web technology for integrating WBAN sensor data is still at a nascent stage, and further work is required to identify the best fit for each type of clinical data.

References

1. Ahmad A, Cuomo S, Wu W, Jeon G (2019) Intelligent algorithms and standards for interoperability in Internet of Things. Future Generation Computer Systems, 92, pp.1187–1191. doi:10.1016/j.future.2018.11.015
2. Ali NS, Alyasseri A, Abdi Z, Abdulmohson A (2018) Real-time Heart Pulse Monitoring Technique Using Wireless Sensor Network and Mobile Application. International Journal of Electrical and Computer Engineering (IJECE), 8(6), p.5118. do:10.11591/ijece.v8i6.pp5118-5126
3. Arch-int N, Arch-int S, Sonsilphong S, Wanchai P (2017) Graph-based semantic web service composition for healthcare data integration. Journal of Healthcare Engineering, 2017, pp.1–19. doi:10.1155/2017/4271273
4. Barisevičius G, Coste, M, Geleta D, Juric D, Khodadadi M, Stoilos G, Zaihrayeu I (2018) Supporting Digital Healthcare Services Using Semantic Web Technologies. In International Semantic Web Conference (pp. 291-306). Springer, doi:10.1007/978-3-030-00668-6_18
5. Bizer C, Heath T, Berners-Lee T (2011) Linked data: The story so far. In Semantic services, interoperability and web applications: emerging concepts (pp. 205-227). IGI Global. doi:10.4018/978-1-60960-593-3.ch008
6. Brandt P, Basten T, Stuiik S, Bui V, de Clercq P, Pires LF, van Sinderen M (2013) Semantic interoperability in sensor applications making sense of sensor data. IEEE, pp 34–41. doi:10.1109/cicare.2013.6583065
7. Cimiano P, Chiarcos C, McCrae JP, Gracia J (2020) Applying Linked Data Principles to Linking Multilingual Wordnets. In Linguistic Linked Data (pp. 215-228). Springer, Cham. doi:10.1007/978-3-030-30225-2_12
8. Djemaiel Y, Berrahal S, Boudriga N (2018) A novel graph-based approach for the management of health data on cloud-based WSANs. 16:317–344. doi:10.1007/s10723-018-9438-2
9. El-Sappagh S, Ali F, Hendawi A, Jang J-H, Kwak K-S (2019) A mobile health monitoring-and-treatment system based on integration of the SSN sensor ontology and the HL7

FHIR standard. 19:97. BMC Medical Informatics and Decision Making, 19(1). doi:10.1186/s12911-019-0806-z
10. Ha I (2015) Technologies and research trends in wireless body area networks for healthcare: a systematic literature review. International Journal of Distributed Sensor Networks, 11(6), p.573538. doi:10.1155/2015/573538
11. Haghi M, Thurow K, Stoll R (2017) Wearable devices in medical internet of things: scientific research and commercially available devices. Healthcare informatics research, 23(1), 4-15. doi:10.4258/hir.2017.23.1.4
12. Jara A J, Olivieri AC, Bocchi Y, Jung M, Kastner W, Skarmeta, AF (2014) Semantic web of things: an analysis of the application semantics for the IoT moving towards the IoT convergence. International Journal of Web and Grid Services, 10(2-3), 244-272. doi:10.1504/ijwgs.2014.060260
13. Jiang G, Evans J, Endle CM, Solbrig HR, Chute CG (2016) Using semantic web technologies for the generation of domain-specific templates to support clinical study metadata standards. Journal of Biomedical Semantics. doi:10.1186/s13326-016-0053-5
14. Karami M, Rahimi A (2019) Semantic web technologies for sharing clinical information in health care systems. Acta Informatica Medica, 27(1), 4-7. doi:10.5455/aim.2019.27.4-7
15. Khan RA, Mohammadani KH, Soomro AA, Hussain J, Khan S, Arain TH, Zafar H (2018) An energy efficient routing protocol for wireless body area sensor networks. 99:1443–1454. doi:10.1007/s11277-018-5285-5
16. Khan JY, Yuce MR, Bulger G, Harding B. (2012) Wireless body area network (WBAN) design techniques and performance evaluation. J Med Syst. 36(3):1441-1457. doi:10.1007/s10916-010-9605-x
17. Khan RA, Mohammadani KH, Soomro AA, Hussain J, Khan S, Arain TH, Zafar H (2018) An energy efficient routing protocol for wireless body area sensor networks. 99:1443–1454. doi:10.1007/s11277-018-5285-5
18. Khan RA, Pathan A-SK (2018) The state-of-the-art wireless body area sensor networks: A survey. 14:1550147718768994. doi:10.1177/1550147718768994
19. Kiourtis A, Nifakos S, Mavrogiorgou A, Kyriazis D (2019) Aggregating the syntactic and semantic similarity of healthcare data towards their transformation to HL7 FHIR through ontology matching. International Journal of Medical Informatics, 132, p.104002. doi:10.1016/j.ijmedinf.2019.104002
20. Le Phuoc D, Parreira JX, Hauswirth M (2010) Challenges in Linked Stream Data Processing: A Position Paper. doi:10.1007/978-3-642-33158-9_7
21. Lefrançois M (2018) How my actuator can understand what your sensor says: Revisiting the Web's Architectural and Linked Data Principles for Legacy Services and the Web of Things.
22. Li R, Lai DT, Lee W (2017) A survey on biofeedback and actuation in wireless body area networks (WBANs). 10:162–173. doi:10.1109/rbme.2017.2738009
23. Llanes KR, Casanova MA, Lemus NM (2016) From sensor data streams to linked streaming data: a survey of main approaches. JIDM, 7, 130-140.
24. Nachabe L, Girod-Genet M, El Hassan B, Aro F (2014) Applying ontology to WBAN for mobile application in the context of sport exercises. In Proceedings of the 9th International Conference on Body Area Networks (pp. 204-209). doi:10.4108/icst.bodynets.2014.258224
25. Nagib AM, Hamza HS (2016) SIGHTED: A Framework for Semantic Integration of Heterogeneous Sensor Data on the Internet of Things. In ANT/SEIT (pp. 529-536). doi:10.1016/j.procs.2016.04.251

26. Nakamura M, Nakamura J, Lopez G, Shuzo M, Yamada I (2011) Collaborative processing of wearable and ambient sensor system for blood pressure monitoring. 11:6760–6770. doi:10.3390/s110706760
27. Negra R, Jemili I, Belghith A (2016) Wireless body area networks: Applications and technologies. 83:1274–1281. doi:10.1016/j.procs.2016.04.266
28. Noura M, Atiquzzaman M, Gaedke M (2019) Interoperability in internet of things: Taxonomies and open challenges. 24:796–809. doi:10.1007/s11036-018-1089-9
29. Pahl C, Zare M, Nilashi M, de Faria Borges MA, Weingaertner D, Detschew V, Supriyanto E, Ibrahim O (2015) Role of OpenEHR as an open source solution for the regional modelling of patient data in obstetrics. 55:174–187. doi:10.1016/j.jbi.2015.04.004
30. Peng C, Goswami, (2019) Meaningful integration of data from heterogeneous health services and home environment based on ontology. Sensors, 19(8), 1747. doi:10.3390/s19081747
31. Rangarajan A (2016) Emerging trends in healthcare adoption of wireless body area networks. 50:264–276. doi:10.2345/0899-8205-50.4.264
32. Rassam MA, Zainal A, Maarof MA (2013) Advancements of data anomaly detection research in wireless sensor networks: a survey and open issues. 13:10087–10122. doi:10.3390/s130810087
33. Reda R, Carbonaro A (2018) Design and Development of a Linked Open Data-Based Web Portal for Sharing IoT Health and Fitness Datasets. pp 43–48. doi:10.1145/3284869.3284890
34. Salayma M, Al-Dubai A, Romdhani I, Nasser Y (2017) Wireless body area network (WBAN) a survey on reliability, fault tolerance, and technologies coexistence. ACM Computing Surveys (CSUR), 50(1), 1-38. doi:10.1145/3041956
35. Santos DF, Gorgônio KC, Perkusich A, Almeida HO (2016) A standard-based and context-aware architecture for personal healthcare smart gateways. 40:224. doi:10.1007/s10916-016-0580-8
36. Sindhu S, Vashiath S, Chakarvarti SK (2016) A Review on Wireless Body Area Network (WBAN) for Health Monitoring System, Implementation Protocol. Communications on Applied Electronics, 4(7), pp.16–20. doi:10.5120/cae2016652130
37. Tilahun B, Kauppinen T, Keßler C, Fritz F (2014) Design and Development of a Linked Open Data-Based Health Information Representation and Visualization System: Potentials and Preliminary Evaluation. JMIR medical informatics, 2(2). doi:10.2196/medinform.3531
38. Xu X, Shu L, Guizani M, Liu M, Lu J (2015) A survey on energy harvesting and integrated data sharing in wireless body area networks. 11:438695. International Journal of Distributed Sensor Networks, 2015, pp.1–17. doi:10.1155/2015/438695
39. W3C Semantic Sensor Network Ontology. https://www.w3.org/TR/vocab-ssn/. Accessed March 7, 2020.
40. Williamson J, Liu Q, Lu F, Mohrman W, Li K, Dick R, Shang L (2015). Data sensing and analysis: Challenges for wearables. In The 20th Asia and South Pacific Design Automation Conference (pp. 136-141). IEEE. doi:10.1109/aspdac.2015.7058994
41. Xu X, Shu L, Guizani M, Liu M, Lu J (2015) A survey on energy harvesting and integrated data sharing in wireless body area networks. International Journal of Distributed Sensor Networks, 2015, pp.1–17. doi:10.1155/2015/438695
42. Ali R, Qadri YA, Zikria YB, Umer T, Kim B-S, Kim SW (2019) Q-learning-enabled channel access in next-generation dense wireless networks for IoT-based eHealth systems. 2019:1–12. doi:10.1186/s13638-019-1498-x
43. Kathe KS, Deshpande UA (2019) A Thermal Aware Routing Algorithm for a wireless body area network. 105:1353–1380. doi:10.1007/s11277-019-06148-w

44. Tomaszuk D (2017) RDF Event Stream Processing Based on the Publish-Subscribe Pattern. Springer. doi:10.1007/978-3-319-43982-2_32
45. Lam AN, Haugen Ø (2018) Supporting IoT semantic interoperability with autonomic computing. 761–767
46. Afsari K (2018) Standard-based Data Interoperability of the Building Information Model in Cloud. pp 18–21
47. Braunstein ML (2018) Healthcare in the age of interoperability: The promise of fast healthcare interoperability resources. 9:24–27
48. Hazber MA, Li R, Gu X, Xu G (2016) Integration mapping rules: Transforming relational database to semantic web ontology. 10:1–21