The Requirements to Enhance the Design of Context-Aware Mobile Patient Monitoring Systems Using Wireless Sensors

Mahmood Ghaleb Al-Bashayreh, Nor Laily Hashim, and Ola Taiseer Khorma

UUM College of Arts and Sciences, School of Computing,
06010 UUM Sintok, Kedah, Malaysia
mahmood.g.al-bashayreh@ieee.org, laily@uum.edu.my,
ola_khorma@hotmail.com

Abstract. Designing and developing Context-aware Mobile Patient Monitoring Systems (CMPMS) using wireless sensors are emerging in the biomedical informatics domain. However, previous studies related to this topic are fragmented. In fact, the literature has no standard types and sources of context information. These types and sources are required to design such systems. In addition, there is no standard context reasoning approach to facilitate the development of these systems. To address these absences, this paper is a survey of the CMPMS in the biomedical informatics to identify potential types and sources of context information as well as the context reasoning approaches that are required to be addressed in designing and developing such systems. The results are expected to help researchers to enhance the design and facilitate the development of CMPMS.

Keywords: context awareness computing, mobile patient monitoring systems, context information types, context information sources, context reasoning approach, requirements.

1 Introduction

The concept of context is broad and unclear, thus it must be defined. Literature revealed a large number of context definitions, each of which has different context information. Dey, Abowd, and Salber's [1] general definition of context is the most adopted and referenced definition in the literature. They defined a context as "any information that can be used to characterize the situation of entities (i.e., whether a person, place, or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves. Context is typically the location, identity, and state of people, groups, and computational and physical objects." [1] The term *situation* in this definition refers to "a description of the states of relevant entities" [2]. The term *context-aware computing* originally was coined by Schilit and Theimer [3], then it was elaborated on by Dey [2] to be more general to reflect the system capability to use "context to provide relevant information

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and/or services to the user, where relevancy depends on the user's task" [2]. The main purpose of context-aware computing is to achieve application adaptability [4]. An application is considered context-aware, if it can adapt its behaviors to contextual changes without user interventions [2], [5], [6], [7], [8].

Wireless sensors and mobile technologies have played a primary role in the advancement of context-aware computing [9]. Wireless sensors have been represented as a primary source of context data [10], [8]. In fact, the more sensors are used, the more comprehensive information can be gained from combining the data from these sensors [6], [8]. Similarly, mobile devices such as smart phones and PDAs have been used widely in context-aware applications [11]. They are portable and have become part of users' lifestyles [12]. Additionally, they have the capability to obtain personalized context data from various sources [8], [13], [14], and process them locally [15], [16].

Some context-aware computing studies focus on defining context-awareness, while others focus on building context-aware applications [17]. These applications aim to make daily used appliances, devices, and objects context-aware [18]. Biomedical informatics is considered one of the richest domains for context-aware applications [19]. Context-aware mobile patient monitoring system using wireless sensors is among the application family of biomedical informatics [20]. Examples in this family include applications that monitor patients with chronic diseases, such as hypertension, diabetes, and epilepsy, in terms of vital signs, medication treatment, and disease symptoms.

However, developing Context-aware Mobile Patient Monitoring Systems (CMPMS) is very complex [5], [6], [21], [22]. The literature related to these emerging systems is fragmented. First, there are no standard types and sources of context information that are required to design CMPMS. Second, there is no standard context reasoning approach that is specific to facilitate the development of such systems. Therefore, the objective of this paper is to identify the potential types and sources of context information that are required to help researchers in enhancing the design of CMPMS. In addition, this paper identifies a potential context reasoning approach that is required to facilitate the development of such systems.

The remainder of this paper is structured as follows: Section 2 is a presentation of benefits of using CMPMS. The identified types and sources of context information in CMPMS are presented in Section 3 and Section 4 respectively. Next, context reasoning approach is identified and presented in Section 6. Finally, Section 7 contains conclusion and brief discussion of future work.

2 Context-Aware Mobile Patient Monitoring Systems

The need for personal lifetime health monitoring systems has inspired researchers to study the potential of adopting the technology of mobile devices (e.g. smart phones) and wireless sensors (e.g. wireless body sensor networks) to develop CMPMS [23], [24]. These systems play a key role in monitoring patient responses to any medication [25], managing and protecting them from chronic disease complications. Ideally, these systems continually perform repeatable tasks that are required for monitoring patients to help and complement the role of health care professionals outside the boundary of health care organizations [26].

Patient context can be defined as any information that can be used to characterize a patient medical situation such as high blood pressure (BP). This definition is based on Dey, Abowd, and Salber's [1] general definition of context. The context information in this definition can include patient's vital signs (e.g., body temperature), medical symptoms (e.g., dizziness), risk factors (e.g., cholesterol level), prescribed medications, physical activities (e.g., sleeping), and surrounding environments (e.g., room temperature). However, it was found that characterizing patients' medical situations, such as high BP, depends on patient context information such as vital signs (e.g., BP) and physical activities (e.g., running) [15]. For example, the normal BP during sleeping is less than during running [27], [28]. Therefore, identifying patient context based on context information enables effective characterization of the medical situation, hence, allowing CMPMS to adapt to the changes in a patient's medical situation. An example of such adaptation is to trigger an alarm or contact a health care professional once a critical medical situation is detected [28], [27], [15], [29].

3 Context Information Types in Patient Monitoring Systems

This study aims to combine multiple types of context information to support the design of context-aware patient monitoring systems using mobile device and wireless sensors. To achieve this goal, context information types have to be identified within the biomedical informatics, which are related to context-aware patient monitoring systems. Analyzing literature revealed that there is no consensus on the types of context information adopted in biomedical informatics studies. However, there are three most promising types of context information that are centralized on the patient and can contribute to the design of mobile patient monitoring systems. These types are classified as medical, physical activities, and environmental contexts. They are elaborated in the following subsections. These types of context information were identified using literature search method introduced in [30].

3.1 Medical Context

The medical context includes biomedical information that is required for monitoring patients. This type of context is classified into four subtypes of context information, which are described as follows:

Measurable Medical Context. This subtype of context information mainly represents patients' vital signs, which is widely adopted in the literature to provide continually measured medical personal information [31], [27], [15], [32], [11], [28], [33], [16], [14], [29]. In fact, vital signs represent the signs of life [34], defined in [35], as the "body's physiological status and provide information critical to evaluating homeostatic balance." However, there are five standard vital signs that must be measured and continually monitored. These are: body temperature, respiration rate, heart rate, blood pressure, and electrocardiogram (ECG) [36]. The interpretation of their signs, whether they are normal or not, depends on other types of medical context such as risk factors and prescribed medications context information, which are debated in the following subsections.

Non-measurable Medical Context. This subtype of context information describes medical symptoms that are difficult to be measured by wireless sensors (e.g., dizziness, vomiting, sleepiness, or headache). Thus, it is rarely adopted in biomedical informatics studies. It also provides dynamic medical personal information that is difficult to be measured by sensors [25]. However, it is able to complement the information obtained from the measurable medical context. For example, monitoring hypertension requires monitoring non-measurable medical contexts such as headache and constipation. These non-measurable medical symptoms complement measurable medical contexts such as BP and HR vital signs [25].

Risk Factors Context. This subtype of context information is also known as a health risk that is defined by the World Health Organization (WHO) [37] as "a factor that raises the probability of adverse health outcomes". These factors were adopted in a number of biomedical informatics studies to represent the personal health information that changes infrequently [33], [11], [31], [32]. In fact, risk factors are countless, and each disease has a number of associated risk factors. For instance, there are eight risk factors associated with hypertension, which are: alcohol consumption, tobacco consumption, BP, lack of physical activity, cholesterol level, blood glucose level, fruit and vegetable intake, and obesity. Obesity risk factor is calculated based on the body mass index (body mass index = weight in kilograms / (height in meters)^2) [38]. These eight risk factors are jointly responsible for more than 75% of deaths of hypertensive patients [37]. Furthermore, it was found that the risk factors affect the normal readings of vital signs [37], [15], [39]. For instance, the blood-pressure reading is affected negatively by either alcohol consumption or obesity. Similarly, the normal cholesterol level is affected by either smoking or fat intake [37].

Prescribed Medications Context. This subtype of context information presents the current prescribed medications for a patient [25], [15]. However, it is rarely adopted in biomedical informatics studies. In fact, these prescribed medications have effects on the patient's normal vital signs [25], [15], [39]. Therefore, health care professionals use this context information to assess the effects of the prescribed medications on patients to evaluate the patient's response to the treatment. For example, a health care professional can manage hypertension by prescribing a medication such as Amlodipine, a calcium channel blocker, with suitable frequency and dosage (such as 5 mg every morning). Then, the professional can monitor the effect of such medication on a patient's BP to assess the patient's response to the prescribed medication, and then take an appropriate follow-up decision or action [25].

3.2 Physical Activities Context

This type of context information represents the current patient's physical activities such as walking, running, eating, or sleeping, and it was adopted in several studies previously [13], [27], [15], [28]. In fact, patient's physical activities have direct effects on their vital signs. For example, the normal heart rate while running or climbing up stairs is higher than while walking or lying down [13], [39]. Similarly, normal BP during sitting or sleeping is less than during eating or doing physical exercise, such as running [28], [27], [39].

3.3 Environmental Context

This context type provides information about the surrounding environment that can affect a patient's medical state, such as temperature, light, humidity, and noise. It has been adopted widely in previous biomedical informatics studies [40], [27], [41], [29], [15], [31]. It also contributes to the monitoring of diseases. For instance, patients with Amyotrophic Lateral Sclerosis (ALS), which is "a disease of the nerve cells in the brain and spinal cord that control voluntary muscle movement" [42], can benefit from floor humidity to protect them from falling [27]. In addition, environmental context information also affects vital signs, e.g., room temperature affects the normal heartbeat and consequently, the change of heartbeat affects BP [27].

4 Context Information Sources in Patient Monitoring Systems

This study aims to obtain context information from four various context data sources, which include mobile patient profile, wireless body sensors, wireless environmental sensors, and mobile graphical user interface. These context data sources are adopted based on the literature analysis of studies related to context-aware patient monitoring systems within the biomedical informatics, by considering the identified context information in the previous section. To identify these sources of context information, the literature search method introduced in [30] was used. These context data sources are classified as mobile patient profile, wireless body sensors, wireless environmental sensors, and mobile graphical user interface, all of which are explained in the following.

4.1 Mobile Patient Profile Context Source

This context source is being widely adopted in the biomedical informatics studies as a main data source for obtaining the risk factors and the prescribed medications context [33], [16], [14], [32]. It contributes to the accuracy of context-aware mobile patient monitoring systems [43]. It also plays a primary role in personalizing the patient monitoring process [31], [32]. For example, this source can provide information about alcohol consumption. Alcohol consumption is one of the risk factors associated with hypertension, and negatively affects BP; thus, it has to be considered when monitoring a patient with hypertension [37]. However, if a patient does not consume alcohol, then the patient monitoring process has to be personalized by ignoring the effect of such a factor, thereby optimizing the patient monitoring process. Moreover, using a patient profile hosted on the patient's mobile device can contribute significantly to CMPMS. One advantage is that it supports the privacy protection of the patient's contextual data [44]. Furthermore, it is adequate to avoid continuous network communication costs required to transmit and receive data to and from the backend server [13], [45], [46]. Aside from this, it avoids the problems associated with wireless network interruptions. Moreover, a mobile patient profile can support context awareness and adaptation through direct detection of context changes [44]. Additionally, it supports real-time continuous patient monitoring [46], anywhere and anytime [14].

4.2 Wireless Body Sensors Context Source

This context source was used as a primary data source for measurable medical context information. In fact, it was used in most previous studies that have adopted this type of context information. Additionally, they were also used as a main data source for physical activities context in many previous studies [31], [27], [15], [32], [11], [28], [33], [16], [14], [29].

4.3 Wireless Environmental Sensors Context Source

This context source is also used as a primary data source for physical activities context in most studies that have adopted this type of context [13], [27], [15], [28]. Indeed, it was used as an essential data source for environmental context in most studies that adopted such type of context [40], [27], [41], [29], [15], [31]. They also play a primary role in supporting CMPMS by providing context information that can be measured continuously during the patient normal daily lives [47].

4.4 Mobile Graphical User Interface Context Source

This context source supports obtaining data directly from patients through manual answering of yes/no questions. However, it was rarely adopted in the literature [25]. It is considered as a main data source for obtaining a non-measurable medical context. Moreover, it plays a primary role in supporting context-aware patient monitoring systems that require dynamic context information that cannot be measured by wireless sensors or retrieved from the mobile patient profile [25].

5 Context Reasoning of Patient Monitoring Systems

Patient's context situations that are of interest for context-aware mobile patient monitoring systems using wireless sensors cannot be directly obtained. In fact, identifying this situation based on a single type of context information is not enough without incorporating other types of patient's context information, including: medical context, physical activities context, and environmental context as elaborated in Section 3. For example, various patients' context information types can be used to identify a change in patient situation, such as a change from normal BP to high BP. In other words, deciding that a patient has high BP situation can be inferred by integrating at least three types of context information. First, the medical context types, which include measurable context such as BP, non-measurable context such as headache [25], risk factors context such as overweight [37], and prescribed medications context such as Amlodipine; a calcium channel blocker [25]. Second, the physical activities context such as doing some physical exercises including running [28], [27], [39]. Third, the environmental context such as the room temperature [27].

The inference process used to identify a patient's context situation, as in the previous example, is the core of context-aware reasoning. The new derived context is called high-level context, which is also known as context situation. Meanwhile, all the other context information that is used to derive the high-level context is called low-level contexts, which are obtained directly from the context sources [22], [32].

Context reasoning aims to detect the change in high-level context information based on low-level context information [22], [32]. In the example above, high BP is called high-level patient context information or patient context situation. Meanwhile, the others are called low-level patient context information, which are context information used to derive the high-level context.

First-Order Logic (FOL) is one of the suitable solutions to represent context information and reasoning over the limited resources of mobile devices [44], [6], [32], [29], [31]. FOL is a language to represent knowledge. A potential model for FOL is described by a set of objects, relations among them, and functions that can be applied to them. Among the FOL reasoning algorithms is the resolution-based algorithm, which requires converting each FOL sentence into a Conjunctive Normal Form (CNF) sentence [48]. A CNF sentence is "a conjunction of clauses, where each clause is a disjunction of literals" [48].

In the context of this research, one or more context-aware monitoring queries that are required to detect change in the patient's medical situation (e.g., change from normal to high BP as high-level context information). Each query consists of one or more query elements that represent low-level context information (e.g., non-measurable context such as headache, risk factor context such as obesity, and physical activity context such as running). To facilitate processing such complex queries, they have to be normalized [49]. One of the practical approaches to normalize a query is CNF since it typically includes more AND [49]. To this end, each query is converted to CNF to represent a conjunction of query elements. For instance, while a high BP query is false, a patient's context situations in considered normal. However, once all the query elements in this query become true, then a change in the patient's context situation from normal to high BP can be detected. Using CNF in context-aware monitoring queries was introduced in [44].

6 Conclusion and Future Work

This paper is a discussion of ongoing research on designing and developing CMPMS. It begins by introducing the concept of context awareness and the benefits of using CMPMS. It also presents an overview of context information types, sources, and reasoning in previous studies that designed and developed CMPMS in the biomedical informatics domain. To this end, the results of this paper are twofold. Firstly, a set of context information types and sources were provided to enhance the existing design of CMPMS. Secondly, a recommended context reasoning approach was introduced to be used to facilitate the development of CMPMS. In the future, researchers can further enhance research in this domain by attempting to use the described context information types and sources, as well as the context reasoning approach to design and develop more accurate and more efficient real-life CMPMS.

References

1. Dey, A.K., Abowd, G.D., Salber, D.: A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. Hum. Comput. Interact. 16, 97–166 (2001)
2. Dey, A.K.: Understanding and Using Context. Personal Ubiquitous Computing 5, 4–7 (2001)
3. Schilit, B.N., Theimer, M.M.: Disseminating active map information to mobile hosts. IEEE Network 8, 22–32 (1994)
4. Hervás, R., Bravo, J., Fontecha, J.: A context model based on ontological languages, a proposal for information visualization. J. Univers. Comput. Sci. 16, 1539–1555 (2010)
5. Hoyos, J.R., García-Molina, J., Botía, J.A.: MLContext: A Context-Modeling Language for Context-Aware Systems. J. Electron. Commun. EASST 28, 1–14 (2010)
6. Esposito, A., Tarricone, L., Zappatore, M., Catarinucci, L., Colella, R.: A framework for context-aware home-health monitoring. Int. J. Autonom. Adapt. Comm. Syst. 3, 75–91 (2010)
7. Driver, C., Clarke, S.: An application framework for mobile, context-aware trails. Pervasive and Mobile Computing 4, 719–736 (2008)
8. Zhang, D., Adipat, B., Mowafi, Y.: User-Centered Context-Aware Mobile Applications–The Next Generation of Personal Mobile Computing. Comm. Assoc. Inform. Syst. 24, 27–46 (2009)
9. Preuveneers, D., Victor, K., Vanrompay, Y., Rigole, P., Pinheiro, M.K., Berbers, Y.: Context-Aware Adaptation in an Ecology of Applications. In: Stojanovic, D. (ed.) Context-Aware Mobile and Ubiquitous Computing for Enhanced Usability: Adaptive Technologies and Applications, pp. 1–25. Information Science Reference, Hershey (2009)
10. Paganelli, F., Giuli, D.: An Ontology-Based Context Model for Home Health Monitoring and Alerting in Chronic Patient Care Networks. In: 21st International Conference on Advanced Information Networking and Applications Workshops, pp. 838–845. IEEE Computer Society, Ontario (2007)
11. Kara, N., Dragoi, O.A.: Reasoning with Contextual Data in Telehealth Applications. In: 3rd IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, p. 69. IEEE Computer Society, White Plains (2007)
12. van Sinderen, M.J., van Halteren, A.T., Wegdam, M., Meeuwissen, H.B., Eertink, E.H.: Supporting context-aware mobile applications: an infrastructure approach. IEEE Commun. Mag. 44, 96–104 (2006)
13. Mohomed, I., Misra, A., Ebling, M., Jerome, W.: Context-aware and personalized event filtering for low-overhead continuous remote health monitoring. In: 9th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks, pp. 1–8. IEEE Computer Society, Newport Beach (2008)
14. Meneses, F., Moreira, A.: Technology Enablers for Context-Aware Healthcare Applications. In: Olla, P., Tan, J. (eds.) Mobile Health Solutions for Biomedical Applications, pp. 260–269. Information Science Reference, Hershey (2009)
15. Mohomed, I., Misra, A., Ebling, M., Jerome, W.: HARMONI: Context-aware Filtering of Sensor Data for Continuous Remote Health Monitoring. In: 6th Annual IEEE International Conference on Pervasive Computing and Communications, pp. 248–251. IEEE Computer Society, Hong Kong (2008)
16. Ashford, R., Moore, P., Hu, B., Jackson, M., Wan, J.: Translational Research and Context in Health Monitoring Systems. In: 4th International Conference on Complex, Intelligent and Software Intensive Systems, pp. 81–86. IEEE Computer Society, Kraków (2010)

17. Liu, C., Zhu, Q., Holroyd, K.A., Seng, E.K.: Status and trends of mobile-health applications for iOS devices: A developer's perspective. J. Syst. Software 84, 2022–2033 (2011)
18. Loke, S.W.: Context-aware artifacts: two development approaches. IEEE Pervasive Computing 5, 48–53 (2006)
19. Bricon-Souf, N., Newman, C.R.: Context awareness in health care: A review. Int. J. Med. Informat. 76, 2–12 (2006)
20. Mouttham, A., Peyton, L., Eze, B., Saddik, A.E.: Event-Driven Data Integration for Personal Health Monitoring. J. Emerg. Tech. Web. Intell. 1, 110–118 (2009)
21. Delicato, F.C., Santos, I.L.A., Pires, P.F., Oliveira, A.L.S., Batista, T., Pìrmez, L.: Using aspects and dynamic composition to provide context-aware adaptation for mobile applications. In: ACM Symposium on Applied Computing, pp. 456–460. ACM, Honolulu (2009)
22. Bettini, C., Brdiczka, O., Henricksen, K., Indulska, J., Nicklas, D., Ranganathan, A., Riboni, D.: A survey of context modelling and reasoning techniques. Pervasive and Mobile Computing 6, 161–180 (2010)
23. Villarreal, V., Urzaiz, G., Hervas, R., Bravo, J.: Monitoring Architecture to collect measurement data and medical patient control through mobile devices. In: 5th International Symposium on Ubiquitous Computing and Ambient Intelligence, Riviera Maya, Mexico (2011)
24. Ren, Y., Pazzi, R.W.N., Boukerche, A.: Monitoring patients via a secure and mobile healthcare system. IEEE Wireless Comm. Mag. 17, 59–65 (2010)
25. Koutkias, V.G., Chouvarda, I., Triantafyllidis, A., Malousi, A., Giaglis, G.D., Maglaveras, N.: A Personalized Framework for Medication Treatment Management in Chronic Care. IEEE Trans. Inform. Tech. Biomed. 14, 464–472 (2010)
26. Sneha, S., Varshney, U.: Enabling ubiquitous patient monitoring: Model, decision protocols, opportunities and challenges. Decis. Support Syst. 46, 606–619 (2009)
27. Copetti, A., Loques, O., Leite, J.C.B., Barbosa, T.P.C., da Nobrega, A.C.L.: Intelligent context-aware monitoring of hypertensive patients. In: 3rd International Conference on Pervasive Computing Technologies for Healthcare, pp. 1–6. IEEE Computer Society, London (2009)
28. Roy, N., Pallapa, G., Das, S.K.: An ontology-driven ambiguous contexts mediation framework for smart healthcare applications. In: 1st International Conference on Pervasive Technologies Related to Assistive Environments, pp. 1–8. ACM, Athens (2008)
29. Paganelli, F., Giuli, D.: An Ontology-Based System for Context-Aware and Configurable Services to Support Home-Based Continuous Care. IEEE Trans. Inform. Tech. Biomed. 15, 324–333 (2011)
30. Brocke, J.V., Simons, A., Niehaves, B., Riemer, K., Plattfaut, R., Cleven, A.: Reconstructing the giant: on the importance of rigour in documenting the literature search process. In: 17th European Conference on Information Systems, Verona, Italy, pp. 2206–2217 (2009)
31. Zhang, D., Yu, Z., Chin, C.: Context-Aware Infrastructure for Personalized Healthcare. In: Nugent, C.D., McCullagh, P.J., McAdams, E.T., Lymberis, A. (eds.) Personalised Health Management Systems: The Integration of Innovative Sensing, Textile, Information and Communication Technologies, vol. 117, pp. 154–163. IOS Press, Washington (2005)
32. Ko, E.J., Lee, H.J., Lee, J.W.: Ontology-Based Context Modeling and Reasoning for U-HealthCare. IEICE Trans. Info. Syst. E90-D, 1262–1270 (2007)
33. Roy, N., Gu, T., Das, S.K.: Supporting pervasive computing applications with active context fusion and semantic context delivery. Pervasive and Mobile Computing 6, 21–42 (2010)

34. LeBlond, R.F., DeGowin, R.L., Brown, D.D.: DeGowin's diagnostic examination. McGraw-Hill Medical, New York (2009)
35. Smith, S.F., Duell, D.: Clinical nursing skills: nursing process model, basic to advanced skills. Appleton & Lange, Englwood (1992)
36. Gardner, R.M., Shabot, M.M.: Patient-Monitoring Systems. In: Shortliffe, E.H., Cimino, J.J. (eds.) Biomedical Informatics: Computer Applications in Health Care and Biomedicine, pp. 585–625. Springer, New York (2006)
37. World Health Organization (WHO): Global health risks: mortality and burden of disease attributable to selected major risks. World Health Organization, Geneva, Switzerland (2009)
38. Assess Your High Blood Pressure Related Risks, http://www.heart.org/heartorg/conditions/highbloodpressure/whybloodpressurematters/assess-your-high-blood-pressure-related-risks_ucm_301829_article.jsp#.tv7r63pssyk
39. Ellestad, M.H.: Stress Testing: Principles and Practice. Oxford University Press, New York (2003)
40. Paganelli, F., Spinicci, E., Giuli, D.: ERMHAN: A Context-Aware Service Platform to Support Continuous Care Networks for Home-Based Assistance. Int. J. Telemed Appl. 2008, 13 (2008)
41. Haghighi, P.D., Gillick, B., Krishnaswamy, S., Gaber, M.M., Zaslavsky, A.: Mobile Visualization for Sensory Data Stream Mining. In: Second International Workshop on Knowledge Discovery from Sensor Data, Las Vegas, NV (2008)
42. Bloom, R.L.: A Case-Based Approach to Teaching Evidence-Based Practice and Motor Speech Disorders. Contemporary Issues in Communication Science Disorders 37, 123–130 (2010)
43. Villarreal, V., Laguna, J., López, S., Fontecha, J., Fuentes, C., Hervás, R., de Ipiña, D.L., Bravo, J.: A Proposal for Mobile Diabetes Self-control: Towards a Patient Monitoring Framework. In: Omatu, S., Rocha, M.P., Bravo, J., Fernández, F., Corchado, E., Bustillo, A., Corchado, J.M. (eds.) IWANN 2009, Part I. LNCS, vol. 5518, pp. 870–877. Springer, Heidelberg (2009)
44. Kang, S., Lee, J., Jang, H., Lee, Y., Park, S., Song, J.: A Scalable and Energy-Efficient Context Monitoring Framework for Mobile Personal Sensor Networks. IEEE Trans. Mobile Comput. 9, 686–702 (2010)
45. Lewandowski, J., Arochena, H.E., Naguib, R.N.G., Chao, K.: A Portable Framework Design to Support User Context Aware Augmented Reality Applications. In: 3rd International Conference on Games and Virtual Worlds for Serious Applications, pp. 144–147. IEEE Computer Society, Athens (2011)
46. Mitchell, M.J., Meyers, C., Wang, A.A., Tyson, G.: ContextProvider: Context awareness for medical monitoring applications. In: 33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 5244–5247. IEEE Engineering in Medicine and Biology, Boston (2011)
47. Aziz, O., Lo, B., Darzi, A., Yang, G.: Introduction to Body sensor networks. In: Yang, G. (ed.) Body Sensor Networks, pp. 1–39. Springer, New York (2006)
48. Russell, S., Norvig, P.: Artificial Intelligence: A Modern Approach. Prentice Hall, Upper Saddle River (2010)
49. Özsu, M.T., Valduriez, P.: Principles of Distributed Database Systems. Springer, New York (2011)