A Survey on Success Factors to Design Context-Aware Frameworks to Develop Mobile Patient Monitoring Systems

Mahmood Ghaleb Al-Bashayreh, Nor Laily Hashim, Ola Taiseer Khorma
School of Computing, UUM College of Arts and Sciences
06010 UUM Sintok, Kedah, Malaysia
mahmood.g.al-bashayreh@ieee.org; laily@uum.edu.my; ola_khorma@hotmail.com

Abstract—**Design of context-aware application frameworks to develop mobile patient monitoring systems using wireless sensors (MPMS) is an emerging in the biomedical informatics domain. However, literature about this topic remains fragmented. In fact, there are no categories in the literature to characterize these frameworks. In addition, there are no success factors to identify lacks and gaps in their design. To address these gaps, this paper is a survey of the context-aware frameworks in the biomedical informatics domain to identify the categories that can be used to gain an intensive and extensive understanding of previous studies. Then, use these categories to identify the Factors of Successful Context-aware Application Frameworks (FSCAF), which are a set of designs and domain requirements that must be satisfied to design context-aware frameworks to develop MPMS. The results are expected to help researchers identify lacks and gaps in the literature to design enhanced context-aware frameworks to develop MPMS.**

Keywords- application frameworks design, context awareness computing, mobile patient monitoring systems, wireless sensors, success factors, biomedical informatics domain

I. INTRODUCTION

The emergence of mobile devices and wireless sensor technologies have inspired researchers to study the potential of adopting these technologies to develop Mobile Patient Monitoring Systems using wireless sensors (MPMS) to satisfy the need for personal lifetime health monitoring systems [12, 13]. These systems play a key role in monitoring patient response to any medication [14] and protecting from chronic disease complications. Ideally, MPMS 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 [15]. This has introduced the need to identify patient contexts while a patient is being monitored, including the physical activities (e.g. sleeping or running), and the surrounding environment (e.g. room temperature). Consequently, this need has become as a new challenge to MPMS [8]. In fact, developing such systems is very complex [6, 16-18]. However, to overcome this problem, software frameworks were introduced as an ideal reuse technique to reduce the development complexity through designing context-aware frameworks to develop MPMS [2, 10].

The remainder of this paper is structured as follows: Section II is an introduction of the benefits of using context awareness in MPMS. Section III is an elaboration on the need of context-aware frameworks to develop MPMS. The proposed research framework to satisfy the objectives of this paper is introduced in Section IV. Section V is a presentation of the categories that are used to comprehend the designed context-aware frameworks. The success factors to design context-aware frameworks are then debated in Section VI. Finally, Section VII is a conclusion and brief discussion of future work.

II. CONTEXT-AWARE PATIENT MONITORING SYSTEMS

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 [19] general definition of context. The context information in the patient context definition can include patient 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 environment (e.g. room temperature). Nevertheless, it was found that characterizing the medical situation of a patient, such as high BP, depends on patient contextual information such as the vital signs (e.g. BP) and the physical activities (e.g. running) [8]. For example, normal reading of BP during sleeping is less than during running [20, 21]. Therefore, identifying patient context based on context information enables effective characterization of the medical situation, hence, allowing patient monitoring systems to adapt to changes in a patient's medical situation. An example of such adaptation is to trigger an alarm or contact health care professionals once a critical medical situation is detected [2, 8, 20, 21]. However, despite the benefits of identifying the patient context, developing context-aware MPMS are very complex [6, 16-18].

III. CONTEXT-AWARE FRAMEWORKS

A software framework is an ideal reuse technique that represents the core of software engineering reuse techniques [22, 23]. It is one of the most suitable solutions to simplify application development and overcome their development complexity [10]. In fact, software frameworks benefit application development and enhancement of overall software development quality [24]. For example, using software frameworks reduces development time [25], efforts [26], and cost [27]. In addition, using frameworks decreases line-of-code [25], increases developer productivity [28], and reduces maintenance efforts [29]. However, software frameworks can be classified based on their scope into infrastructure frameworks, middleware integration frameworks, and enterprise application frameworks [30]. The infrastructure frameworks can be used to develop system infrastructure such as operating systems, hardware platforms [31], and communication frameworks [32]. The middleware integration frameworks can be used to develop distributed systems such as message-oriented middleware, and transactional databases [30]. The enterprise application frameworks (or application frameworks for short) can be used to develop applications directly. Aside from this, they address the business activities in a family of related applications in a specific domain [30]. For example, context-aware application frameworks can be used specifically in biomedical informatics to develop a family of MPMS. The MPMS can include monitoring patients with cardiovascular diseases [33], monitoring elder vital signs [34], or monitoring patients with diabetes [35].

Therefore, it can be concluded that using context-aware frameworks can enhance the overall development quality and overcome the development complexity of MPMS. However, previous studies that designed this type of frameworks remain fragmented: first, there is no study identified any categories that can be used to characterize and compare among these designed frameworks; second, there is no study identified the Factors of Successful Context-aware Application Frameworks (FSCAF). These factors are a set of designs and domain requirements that must be satisfied to design context-aware frameworks to develop MPMS. Therefore, there is a need to identify the categories that can be used to characterize the literature to help researchers gain an intensive and extensive understanding of the literature. In addition, there is a need to identify the FSCAF that can be used to judge previous studies to help researchers identify lacks and gaps in the literature. Achieving these two objectives is considered a worthwhile effort and beneficial to help researchers design enhanced context-aware frameworks to develop MPMS.

IV. Research Framework

To achieve the objectives of this paper, two research processes were conducted: review of literature and identify the FSCAF as shown in Fig. 1. The following subsections are a discussion of the steps and methods used in these two research processes.

A. Review of Literature Process

This process is intended to review the literature using two steps: searching literature, then analyzing literature content. The objective of the first step is to collect scholarly articles related to this research and document them. To achieve this objective, this research used the literature search method that was introduced in [36]. The objective of the second step is to identify categories that can be used to characterize previous studies to comprehend the literature. These categories are the primary outcome of this process. To achieve this objective, the inductive approach to content analysis was used. This approach was presented in [37].

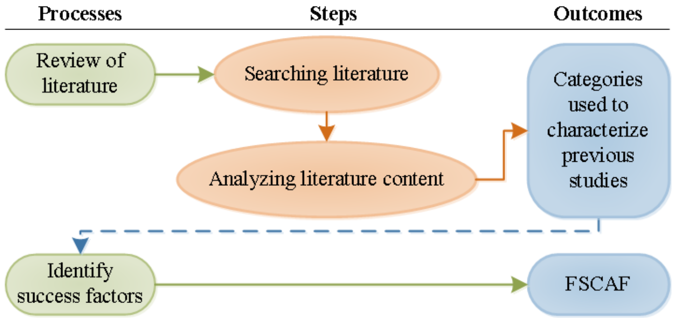

Figure 1. Research framework

B. Identify Success Factors Process

The objective of this process is to identify the FSCAF. To achieve this objective, a selection and comparison technique was proposed and used to compare the related studies based on the identified categories that resulted from the previous process (review of literature process).

V. Categories of Context-Aware Frameworks

This section is a summary description of previous studies that adopted context awareness computing to design software frameworks in the biomedical informatics domain. In addition, it is a presentation of the categories used to characterize these studies, which were generated by following the first research process in the research framework as is shown in Fig. 1. These resulting categories are shown in Table I. They are used to gain an intensive and extensive description of previous studies that adopted context awareness computing to design software frameworks in biomedical informatics. For this purpose, 10 studies were classified and analyzed into three generic categories based on the second and third columns in Table I.

As shown in Table I, the first generic category is the types of context information. This category is subcategorized further into: (1) measurable medical context; (2) nonmeasurable medical context; (3) risk factors medical context; (4) prescribed medications medical context; (5) physical activities context; (6) environmental context. The second generic category is the sources of context information. This category is subcategorized further into: (1) wireless body sensors; (2) wireless environmental sensors; (3) mobile graphical user interface; (4) patient profile; (5) patient profile hosted on the patient mobile device. The last generic category is the reasoning approaches. This category is subcategorized further into First-Order Logic (FOL) reasoning.

VI. Factors of Successful Context-Aware Frameworks

This section is a discussion of the identified FSCAF. To achieve this, a comparison and selection technique was proposed and used. This technique uses the identified categories, which are shown in Table I, as an input to compare among their subcategories to select FSCAF. To identify the comparison criteria to be used in this technique, a pragmatic research approach was applied [38]. Accordingly, the selected comparison criteria focus on supporting context-aware MPMS for elders and patients with chronic disease as the primary

TABLE I. CATEGORIES USED TO CHARACTERIZE PREVIOUS STUDIES

Abstract Main Category	Generic Categories	Subcategory	Related Studies
Context-aware frameworks in the biomedical informatics domain	***Types of context information***	Measurable medical context	[1-10]
		Nonmeasurable medical context	-
		Risk factors medical context	[5, 9, 10]
		Prescribed medications medical context	[7, 8, 10]
		Physical activities context	[3, 4, 7, 8, 10]
		Environmental context	[2, 3, 5, 6, 9, 10]
	Sources of context information	Wireless body sensors	[1-10]
		Wireless environmental sensors	[2, 3, 5, 6, 9, 10]
		Mobile graphical user interface	-
		Patient profile	[5, 7-10]
		Patient profile hosted on the patient's mobile device	[9]
	Context reasoning approaches	First-order logic	[2, 5, 6, 9, 11]

stakeholders. Aside from this, these criteria focus on any comparison criterion that is related to enhancing the overall design of context-aware application frameworks to facilitate the development of MPMS.

However, two procedures were introduced to be used in this technique. The first procedure is performed in case there are alternatives (subcategories in Table I) and only one must be selected. This procedure is conducted based on three steps. First, these alternatives are compared and weighted in terms of their support to a set of comparison criteria. Second, the alternatives that have zero weights are eliminated. Third, the alternative that has the highest weight is selected. Alternatively, the second procedure is performed in case there are different choices (subcategories in Table I) that can be considered together such as the types of context information (generic category in Table I). This procedure is conducted based on a single step, which is a rationale selection of each choice. The results of applying the comparison and selection technique are illustrated in Table II that lists the selected FSCAF. However, all of these identified FSCAF were selected using the second procedure of the comparison and selection technique. Accordingly, the rationale for selecting each factor is discussed briefly in the following subsections.

TABLE II. FSCAF TO DESIGN CONTEXT-AWARE APPLICATION FRAMEWORKS TO DEVELOP MPMS

Categories	FSCAF
Types of context information	Measurable medical context
	Nonmeasurable medical context
	Risk factors medical context
	Prescribed medications medical context
	Physical activities context
	Environmental context
Sources of context information	Wireless body sensors
	Wireless environmental sensors
	Mobile graphical user interface
	Patient profile
	Patient profile hosted on the patient's mobile device
Context reasoning approaches	First-order logic

A. Types of Context Information

In this research, there are six identified types of context information, as shown in Table I, that were used to characterize previous studies that designed context-aware software frameworks in the biomedical informatics domain. These types of context information can be considered together. According to [5], the more context information obtained, the higher the context reasoning accuracy achieved. Therefore, the second procedure of the comparison and selection technique was followed to select all these six types of context information as shown in Table II. Further justification for selecting each of these types is debated as follows.

a) Measurable medical context information

It mainly includes patient vital signs, which is adopted widely in the literature [2, 5, 8, 9, 20, 39]. Vital signs represent the signs of life [40], defined in [41] as "body's physiological status and provide information critical to evaluating homeostatic balance." There are five standard vital signs that must be measured and continually monitored. These are: body temperature, respiration rate, heart rate (HR), BP, and electrocardiogram (ECG) [42]. The interpretation of their values, whether they are normal or not, depends on other types of medical context such as risk factors context information and prescribed medications context information.

b) Nonmeasurable medical context information

It involves medical symptoms that are difficult to be measured (e.g., dizziness or vomiting) by sensors [14]. Thus, it is rarely adopted in the literature. This context information complements the measurable medical context. For example, monitoring hypertension requires monitoring nonmeasurable medical contexts such as headache and constipation. Monitoring these nonmeasurable medical symptoms complements monitoring measurable medical context, which includes vital signs such as BP and HR [14].

c) Risk factors context information

It also is known as a health risk that is defined by the World Health Organization (WHO) [43] as "a factor that raises the probability of adverse health outcomes." These factors are adopted in the literature to represent the personal health information that changes infrequently [5, 9, 44]. These factors are countless, and each disease has a number of associated risk factors. For instance, there are eight risk factors associated with hypertension: alcohol, tobacco, BP, lack of physical activity, cholesterol level, blood-glucose level, fruit and vegetable intake, and obesity. These risk factors are jointly responsible for more than 75% of deaths of hypertensive people [43]. Furthermore, they affect the normal readings of vital signs [8]. For example, alcohol consumption affects the normal BP reading. Similarly, smoking affects the normal cholesterol level [43].

d) Prescribed medications context information

It provides information about the current prescribed medications for a patient [8, 14]. However, it is rarely adopted in the literature. It has effects on the normal patient vital signs [8, 14]. Therefore, health care professionals assess the effects of prescribed medications on a patient to evaluate the patient response to the treatment [14]. For example, health care professional can manage hypertension by prescribing a medication, such as a calcium-channel blocker, with suitable frequency and dosage (such as 5 mg every morning). Then, the professional can monitor the effects of such prescribed medications on a patient's BP to assess the patient response to treatment, and takes the appropriate medical decisions [14].

e) Physical activities context information

It is a representation of the patient current physical activities such as walking, running, or sleeping. It was adopted in several studies [7, 8, 20, 21]. In fact, physical activities have direct effects on the normal vital signs. For example, normal HR while running is higher than while walking [7]. Similarly, normal BP during sleeping is less than during eating [20, 21].

f) Environmental context information

It includes information about the surrounding environment affecting patient medical state such as temperature, light, humidity, and noise. It also is adopted widely in the literature [2, 8, 20, 45]. The environmental context contributes to disease monitoring; for example, 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" [46], can benefit from monitoring floor humidity to protect them from falling [20]. In addition, the environmental context affects vital signs. For instance, room temperature affects heartbeat, which in turns affects BP [20].

B. Sources of Context Information

In this research, there are four sources of context information, as shown in Table I, that were used to characterize the designed context-aware software frameworks in the biomedical informatics domain. These sources of context information can be considered together. Therefore, the second procedure of the comparison and selection technique was followed to select all of these four sources of context information as shown in Table II. Further justification for selecting each of these sources of context information, as well as the types of context information that can be obtained from these sources is debated as follows.

a) Wireless body sensors context source

Wireless body sensors were used as a primary data source for measurable medical context information. In fact, they were used in most previous studies that adopted this type of context information [2, 8, 9, 39]. Additionally, they also were used as a main data source for physical activities context in a large number of studies that have adopted this type of context [7, 20, 21].

b) Wireless environmental sensors context source

Wireless environmental sensors were used as a primary data source for the environmental context. Indeed, they were used in most previous studies that adopted this type of context information [2, 8, 20, 45]. They also played a primary role in supporting context-aware MPMS by providing context information that can be measured continuously during the patients' normal daily lives [47].

c) Mobile graphical user interface context source

Mobile graphical user interface supports obtaining data directly from patients through manual answering of yes/no questions. However, it was rarely adopted in the literature [14]. It was also the main data source for obtaining the nonmeasurable medical context. Moreover, it played a primary role in supporting context-aware MPMS with dynamic context information that neither can be measured by wireless sensors nor retrieved from the mobile patient profile [14].

d) Patient profile context source

Patient profile was used as a main data source for obtaining risk factors and the prescribed medication context. It also is adopted widely in biomedical informatics studies [5, 9, 39, 44]. Using this data source contributes to the accuracy of context-aware MPMS [48]. Moreover, it played a key role in personalizing and optimizing the patient monitoring process [9]. For example, alcohol consumption is one of the risk factors associated with hypertension [43], and it can be obtained from this data source. In fact, alcohol consumption affects BP; thus, it has to be considered when monitoring a patient with hypertension [43]. However, if a patient does not consume alcohol, then the patient monitoring process has to be personalized by ignoring this factor to optimize the monitoring process.

C. Patient profile hosted on the patient's mobile device

This factor added a constraint on the patient profile factor. It insists that the patient's profile should be hosted on the patient's mobile device [48]. Hence, the second procedure of the comparison and selection technique was followed for selecting this factor. Using a patient profile hosted on the patient's mobile device can contribute significantly to the design of context-aware frameworks to develop MPMS. For example, it supports the privacy protection of the patient's contextual data [49]. Furthermore, it is adequate to avoid the continuous network communication costs required to transmit and receive data to and from a backend server [3, 4, 7, 14, 49]. Aside from this, it avoids wireless network interruptions. Moreover, a mobile patient profile can support context awareness and adaptation through direct detection of context changes [49]. Additionally, it supports real-time continuous patient monitoring [3], anywhere and anytime [39].

D. First-Order Logic as Context Reasoning Approach

The objective of context reasoning approaches is to detect the change in high-level context based on low-level context information [9, 17]. However, First-Order Logic (FOL) is one of the suitable solutions to represent context information and reasoning over the limited resources of mobile devices [2, 6, 9, 49]. Among the reasoning algorithms of FOL is the resolution-based algorithm, which requires converting each FOL sentence into Conjunctive Normal Form (CNF) sentence [50]. According to [50], CNF sentence is "a conjunction of clauses, where each clause is a disjunction of literals." In the context of this research, one or more context-aware monitoring queries are required to detect the change in patient medical situations (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. risk factor context such as obesity and physical activity context such as running). To facilitate processing such complex queries, they have to be normalized [51]. One of the practical approaches to normalize a query is CNF since it typically includes more logical 'AND' [51]. CNF is used for each query to represent a conjunction of the query elements. For instance, while the high BP query is false, the patient context situation is considered normal. However, once all of the query elements in this query become true, then a change in a patient's context situation from normal to high BP can be detected. Using CNF in context-aware monitoring queries was introduced in [49].

VII. Conclusion and Future Work

This paper is a discussion of ongoing research about designing a context-aware framework to develop MPMS. It begins with an introduction of MPMS, highlighting the benefits of using context awareness computing in MPMS, and presenting the need for context-aware frameworks to develop MPMS. It also includes the research framework that was used to satisfy the main objectives of this article. An overview of previous studies with frameworks designed in the biomedical informatics domain is presented. The analysis of these studies to identify the FSCAF is demonstrated. To this end, the results of this paper are twofold. First, a set of categories was produced to be used to gain an intensive and extensive understanding of the current designed context-aware frameworks in the biomedical informatics domain. Second, the FSCAF were extracted to be used to identify the lacks and gaps in previous studies. In the future, the researchers will attempt to use resulted FSCAF to identify the current state of the existing context-aware application frameworks to develop MPMS to propose an enhanced design.

References

[1] M. D. Rodríguez and J. Favela, "Assessing the salsa architecture for developing agent-based ambient computing applications," *Science of Computer Programming,* vol. 77, pp. 46-65, January 2012.

[2] F. Paganelli and D. Giuli, "An ontology-based system for context-aware and configurable services to support home-based continuous care," *IEEE Trans. Inf. Technol. Biomed.,* vol. 15, pp. 324-333, March 2011.

[3] M. J. Mitchell, C. Meyers, A. A. Wang, and G. Tyson, "Contextprovider: Context awareness for medical monitoring applications," in *Proc. 33rd Annu. Int. Conf. IEEE Engineering in Medicine and Biology Society*, Boston, MA, 2011, pp. 5244-5247.

[4] J. Lewandowski, H. E. Arochena, R. N. G. Naguib, and K. Chao, "A portable framework design to support user context aware augmented reality applications," in *Proc. 3rd Int. Conf. Games and Virtual Worlds for Serious Applications*, Athens, Greece, 2011, pp. 144-147.

[5] N. Roy, T. Gu, and S. K. Das, "Supporting pervasive computing applications with active context fusion and semantic context delivery," *Pervasive and Mobile Computing,* vol. 6, pp. 21-42, February 2010.

[6] A. Esposito, L. Tarricone, M. Zappatore, L. Catarinucci, and R. Colella, "A framework for context-aware home-health monitoring," *International Journal of Autonomous and Adaptive Communications Systems,* vol. 3, pp. 75-91, December 2010.

[7] I. Mohomed, A. Misra, M. Ebling, and W. Jerome, "Context-aware and personalized event filtering for low-overhead continuous remote health monitoring," in *Proc. 9th IEEE Int. Symp. World of Wireless, Mobile and Multimedia Networks*, Newport Beach, CA, 2008, pp. 1-8.

[8] I. Mohomed, A. Misra, M. Ebling, and W. Jerome, "Harmoni: Context-aware filtering of sensor data for continuous remote health monitoring," in *Proc. 6th Annu. IEEE Int. Conf. Pervasive Computing and Communications*, Hong Kong, China, 2008, pp. 248-251.

[9] E. J. Ko, H. J. Lee, and J. W. Lee, "Ontology-based context modeling and reasoning for u-healthcare," *IEICE Transactions on Information and Systems,* vol. E90-D, pp. 1262-1270, August 2007.

[10] T. Broens, A. V. Halteren, M. V. Sinderen, and K. Wac, "Towards an application framework for context-aware m-health applications," *International Journal of Internet Protocol Technology,* vol. 2, pp. 109-116, 2007.

[11] D. Zhang, Z. Yu, and C. Chin, "Context-aware infrastructure for personalized healthcare," in *Personalised health management systems: The integration of innovative sensing, textile, information and communication technologies*. vol. 117, C. D. Nugent, P. J. McCullagh, E. T. McAdams, and A. Lymberis, Eds., ed Washington, DC: IOS Press, 2005, pp. 154-163.

[12] V. Villarreal, G. Urzaiz, R. Hervas, and J. Bravo, "Monitoring architecture to collect measurement data and medical patient control through mobile devices," in *Proc. 5th Int. Symp. Ubiquitous Computing and Ambient Intelligence*, Riviera Maya, Mexico, 2011.

[13] Y. Ren, R. W. N. Pazzi, and A. Boukerche, "Monitoring patients via a secure and mobile healthcare system," *IEEE Wireless Communications,* vol. 17, pp. 59-65, February 2010.

[14] V. G. Koutkias, I. Chouvarda, A. Triantafyllidis, A. Malousi, G. D. Giaglis, and N. Maglaveras, "A personalized framework for medication treatment management in chronic care," *IEEE Trans. Inf. Technol. Biomed.,* vol. 14, pp. 464-472, March 2010.

[15] S. Sneha and U. Varshney, "Enabling ubiquitous patient monitoring: Model, decision protocols, opportunities and challenges," *Decision Support Systems,* vol. 46, pp. 606-619, November 2009.

[16] F. C. Delicato, I. L. A. Santos, P. F. Pires, A. L. S. Oliveira, T. Batista, and L. Pìrmez, "Using aspects and dynamic composition to provide context-aware adaptation for mobile applications," in *Proc. ACM Symp. Applied Computing*, Honolulu, HI, 2009, pp. 456-460.

[17] C. Bettini, O. Brdiczka, K. Henricksen, J. Indulska, D. Nicklas, A. Ranganathan*, et al.*, "A survey of context modelling and reasoning techniques," *Pervasive and Mobile Computing,* vol. 6, pp. 161-180, March 2010.

[18] J. R. Hoyos, J. García-Molina, and J. A. Botía, "Mlcontext: A context-modeling language for context-aware systems," *Electronic Communications of the EASST,* vol. 28, p. 14, 2010.

[19] A. K. Dey, G. D. Abowd, and D. Salber, "A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications," *Human-Computer Interaction,* vol. 16, pp. 97-166, December 2001.

[20] A. Copetti, O. Loques, J. C. B. Leite, T. P. C. Barbosa, and A. C. L. d. Nobrega, "Intelligent context-aware monitoring of hypertensive patients," in *Proc. 3rd Int. Conf. Pervasive Computing Technologies for Healthcare*, London, England, 2009, pp. 1-6.

[21] N. Roy, G. Pallapa, and S. K. Das, "An ontology-driven ambiguous contexts mediation framework for smart healthcare applications," in *Proc. 1st Int. Conf. Pervasive Technologies Related to Assistive Environments*, Athens, Greece, 2008, pp. 1-8.

[22] M. Fayad, D. S. Hamu, and D. Brugali, "Enterprise frameworks characteristics, criteria, and challenges," *Communications of the ACM,* vol. 43, pp. 39-46, October 2000.

[23] W. Zhang and M. Kim, "What works and what does not: An analysis of application frameworks technology," *Journal of Business Systems, Governance and Ethics,* vol. 1, pp. 15-26, November 2006.

[24] M. Morisio, D. Romano, and I. Stamelos, "Quality, productivity, and learning in framework-based development: An exploratory case study," *IEEE Trans. Softw. Eng.,* vol. 28, pp. 876-888, September 2002.

[25] R. Neumann, S. Günther, and N. Zenker, "Reengineering deprecated component frameworks: A case study of the microsoft foundation classes " in *Proc. 9th Int. Conf. on Business Informatics*, Vienna, Austria, 2009, pp. 737-748.

[26] M. Mattsson, "Comparison of three evaluation methods for object-oriented framework evolution," in *Software evolution and feedback: Theory and practice*, N. H. Madhavji, J. C. Fernández-Ramil, and D. E. Perry, Eds., ed West Sussex, England: Wiley, 2006, pp. 281-312.

[27] D. Parsons, A. Rashid, A. Telea, and A. Speck, "An architectural pattern for designing component-based application frameworks," *Software—Practice and Experience,* vol. 36, pp. 157-190, November 2006.

[28] U. Kulesza, V. Alves, A. Garcia, C. J. P. d. Lucena, and P. Borba, "Improving extensibility of object-oriented frameworks with aspect-oriented programming," in *Reuse of off-the-shelf components*. vol. 4039, M. Morisio, Ed., ed Berlin, Germany: Springer, 2006, pp. 231-245.

[29] D. C. Schmidt, A. Gokhale, and B. Natarajan, "Leveraging application frameworks," *Queue,* vol. 2, pp. 66-75, July/August 2004.

[30] M. Fayad, D. C. Schmidt, and R. E. Johnson, "Application frameworks," in *Building application frameworks: Object-oriented foundations of framework design*, M. Fayad, D. C. Schmidt, and R. E. Johnson, Eds., ed New York, NY: Wiley, 1999, pp. 3-28.

[31] E. Gamma, R. Helm, R. Johnson, and J. M. Vlissides, *Design patterns: Elements of reusable object-oriented software*: Addison-Wesley, 1995.

[32] D. C. Schmidt, "Using design patterns to develop reusable object-oriented communication software," *Communications of the ACM,* vol. 38, pp. 65-74, October 1995.

[33] A. Mouttham, L. Peyton, B. Eze, and A. E. Saddik, "Event-driven data integration for personal health monitoring," *Journal of Emerging Technologies in Web Intelligence,* vol. 1, pp. 110-118, November 2009.

[34] A. Rocha, A. Martins, J. C. F. Junior, M. N. K. Boulos, M. E. Vicente, R. Feld*, et al.*, "Innovations in health care services: The caalyx system," *International Journal of Medical Informatics,* vol. In Press, April 2011.

[35] V. Villarreal, J. Fontecha, R. Hervas, and J. Bravo, "An architecture to development an ambient assisted living applications: A study case in diabetes," in *Proc. 5th Int. Symp. Ubiquitous Computing and Ambient Intelligence*, Riviera Maya, Mexico, 2011.

[36] J. V. Brocke, A. Simons, B. Niehaves, K. Riemer, R. Plattfaut, and A. Cleven, "Reconstructing the giant: On the importance of rigour in documenting the literature search process," in *Proc. 17th European Conf. Information Systems*, Verona, Italy, 2009, pp. 2206-2217.

[37] S. Elo and H. Kyngäs, "The qualitative content analysis process," *Journal of Advanced Nursing,* vol. 62, pp. 107-115, November 2008.

[38] S. Easterbrook, J. Singer, M. Storey, and D. Damian, "Selecting empirical methods for software engineering research," in *Guide to advanced empirical software engineering*, F. Shull, J. Singer, and D. I. K. Sjøberg, Eds., ed Secaucus, NJ: Springer New York, 2007, pp. 285-311.

[39] F. Meneses and A. Moreira, "Technology enablers for context-aware healthcare applications," in *Mobile health solutions for biomedical applications*, P. Olla and J. Tan, Eds., ed Hershey, PA: Information Science Reference, 2009, pp. 260-269.

[40] R. F. LeBlond, R. L. DeGowin, and D. D. Brown, *Degowin's diagnostic examination*, 9th ed. New York, NY: McGraw-Hill Medical, 2009.

[41] S. F. Smith and D. Duell, *Clinical nursing skills: Nursing process model, basic to advanced skills*, 3 ed. Englwood, NJ: Appleton & Lange, 1992.

[42] R. M. Gardner and M. M. Shabot, "Patient-monitoring systems," in *Biomedical informatics: Computer applications in health care and biomedicine*, E. H. Shortliffe and J. J. Cimino, Eds., 3rd ed New York, NY: Springer, 2006, pp. 585-625.

[43] World Health Organization (WHO), *Global health risks: Mortality and burden of disease attributable to selected major risks*. Geneva, Switzerland: World Health Organization, 2009.

[44] N. Kara and O. A. Dragoi, "Reasoning with contextual data in telehealth applications," in *Proc. 3rd IEEE Int. Conf. Wireless and Mobile Computing, Networking and Communications*, White Plains, NY, 2007, p. 69.

[45] F. Paganelli, E. Spinicci, and D. Giuli, "Ermhan: A context-aware service platform to support continuous care networks for home-based assistance," *International Journal of Telemedicine and Applications,* vol. 2008, p. 13, 2008.

[46] R. L. Bloom, "A case-based approach to teaching evidence-based practice and motor speech disorders," *Contemporary Issues in Communication Science Disorders,* vol. 37, pp. 123-130, 2010.

[47] O. Aziz, B. Lo, A. Darzi, and G. Yang, "Introduction to body sensor networks," in *Body sensor networks*, G. Yang, Ed., ed New York, NY: Springer, 2006, pp. 1-39.

[48] V. Villarreal, J. Laguna, S. López, J. Fontecha, C. Fuentes, R. Hervás*, et al.*, "A proposal for mobile diabetes self-control: Towards a patient monitoring framework," in *Distributed computing, artificial intelligence, bioinformatics, soft computing, and ambient assisted living*. vol. 5518, S. Omatu, M. Rocha, J. Bravo, F. Fernández, E. Corchado, A. Bustillo*, et al.*, Eds., ed Berlin, Germany: Springer, 2009, pp. 870-877.

[49] S. Kang, J. Lee, H. Jang, Y. Lee, S. Park, and J. Song, "A scalable and energy-efficient context monitoring framework for mobile personal sensor networks," *IEEE Trans. Mobile Computing,* vol. 9, pp. 686-702, August 2010.

[50] S. Russell and P. Norvig, *Artificial intelligence: A modern approach*, 3rd ed. Upper Saddle River, NJ: Prentice Hall, 2010.

M. T. Özsu and P. Valduriez, *Principles of distributed database systems*, 3rd ed. New York, NY: Springer, 2011.