Context-Aware Mobile Patient Monitoring Frameworks: A Systematic Review and Research Agenda

Mahmood Ghaleb Al-Bashayreh, Nor Laily Hashim, Ola Taiseer Khorma
University Utara Malaysia/School of Computing, Sintok, Kedah, Malaysia
Email: mahmood.g.al-bashayreh@ieee.org, laily@uum.edu.my, ola_khorma@hotmail.com

***Abstract*—Designing Context-aware Mobile Patient Monitoring Frameworks (CMPMF) is an emerging study in the biomedical informatics domain. However, literature on this topic is fragmented: first, there are no categories in the literature to characterize these CMPMF; second, there are no success factors that must be satisfied to enhance the design of these CMPMF; third, there is a need for a research agenda that provides a foundation for further research and development to enhance the design of these CMPMF. To address this gap, this paper is a review of context-aware frameworks in general and a systematic review of 10 designed context-aware frameworks in the biomedical informatics domain. Consequently, in this paper, three results are provided. First, a number of categories to be used to gain an intensive and extensive understanding of the designed CMPMF are identified. Second, a set of success factors, called Factors of Successful Context-aware Application Frameworks (FSCAF) are identified, to be used to enhance the design of CMPMF. Third, a research agenda that shows lacks and gaps in the designed CMPMF and provides a foundation to help researchers to design enhanced CMPMF is presented. The results show that no study integrated all of the FSCAF to enhance the design of CMPMF. Therefore, there is a need for further research to enhance the design of the existing CMPMF.**

***Index Terms*—Context-aware Mobile Patient Monitoring Frameworks (CMPMF), Mobile Patient Monitoring Systems (MPMS), Factors of Successful Context-aware Application Frameworks (FSCAF), wireless sensors, framework design**

I. Introduction

The concept of context is broad and unclear; thus, it must be defined. A review of the literature reveals a large number of context definitions, each of which has different context information. Dey, Abowd, and Salber's [12] general definition of context is the most adopted and referenced. It defines the 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." The term 'situation' in this definition refers to "a description of the states of relevant entities" [13]. The term 'context-aware computing' originally was coined by Schilit and Theimer [14]. Then, it was elaborated on by Dey [13] to be more general, reflecting a system capability to use "context to provide relevant information and/or services to the user, where relevancy depends on the user's task" [13]. The main purpose of context-aware computing is to achieve application adaptability [15]. An application is considered context-aware if it can adapt its behavior to contextual changes without user intervention [6, 16].

The emergence of wireless sensors and mobile technologies has played a key role in the advancement of context-aware computing [17]. Wireless sensors have been represented as a primary source of context data [16, 18, 19]. Similarly, mobile devices such as smartphones and PDAs have been used widely in context-aware applications [20]. They provide local processing for context data [8, 21].

Biomedical informatics is considered one of the richest domains for context-aware applications [22]. Among the application families of biomedical informatics is Context-aware Mobile Patient Monitoring Systems (MPMS) using wireless sensors [23]. 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.

In fact, developing context-aware MPMS is very complex [6, 24, 25]. However, to overcome this problem, designing Context-aware Mobile Patient Monitoring Frameworks (CMPMF) was introduced as a suitable solution to reduce such complexity [2, 10].

A software framework is an ideal reuse technique that represents the core of software engineering reuse techniques [26, 27]. It is one of the most suitable solutions to simplify application development and overcome their development complexity [10].

However, the literature related to these emerging CMPMF is fragmented. There is a lack in designing CMPMF. In addition, there is a need to enhance the design of these frameworks [7, 10]. First, there are no categories in the literature to characterize these frameworks. Second, there are no success factors that must be satisfied to enhance the design of these frameworks. Finally, there is a need for a research agenda

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that provides a foundation for further research and development to enhance the design of these frameworks.

Therefore, the objective of this paper is to identify a set of categories to be used to gain an intensive and extensive understanding of the designed CMPMF. In addition, it identifies a set of success factors called Factors of Successful Context-aware Application Frameworks (FSCAF) to be used to enhance the design of CMPMF. Finally, it presents a research agenda that shows lacks and gaps in the designed CMPMF to provide a foundation to help researchers to design an enhanced CMPMF.

The remainder of this paper is structured as follows: Section II introduction of the concept of context-awareness computing in MPMS. Section III is a presentation of the primary role of CMPMF in enhancing MPMS. The proposed research framework to satisfy the objectives of this paper is introduced in Section IV. Section V is a presentation of a systematic review of context-aware frameworks in the biomedical informatics domain. Finally, Section VI is a conclusion and brief discussion of future work.

II. Context-Awareness Concept in 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 and wireless sensors to develop MPMS [28, 29]. These systems play a key role in monitoring patient responses to any medication [30], managing, and protecting them from chronic disease complications. Typically, MPMS continually perform repeatable tasks that are required for monitoring patients to help and complement the role of healthcare professionals outside the boundary of healthcare organizations [31]. This has introduced the need to identify patient contexts while they are being monitored, including their physical activities such as sleeping or running, and their surrounding environment such as room temperature.

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 [12] general definition of context. The context information in this definition can include patient vital signs such as body temperature, medical symptoms such as dizziness, risk factors such as obesity, prescribed medications, physical activities, and surrounding environment. However, it was found that characterizing patients’ medical situations, such as high BP, depends on patient context information such as vital signs and physical activities [8]. For example, the normal BP during sleeping is less than during running [32, 33]. Therefore, identifying patient context based on context information enables effective characterization of the medical situation, hence, allowing MPMS 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, 32].

III. Application Frameworks in Patient Monitoring

Using frameworks brought a number of benefits to application development and enhancement of overall software-development quality [34, 35]. For example, using frameworks reduces development time [36], efforts [37], and cost [38]. Similarly, using frameworks decreases line-of-code [36], increases developer productivity [39, 40], and reduces maintenance efforts [41]. In addition, frameworks can be designed specifically for mobile platforms, such as smartphones or PDAs [3, 42]. Moreover, frameworks can be used to develop applications directly as well as to address the business activities in a family of related applications in a specific domain. This type of framework is classified as an application framework [40]. For example, application frameworks can be used specifically in the biomedical informatics domain to develop, for instance, a family of context-aware MPMS, including monitoring patients with cardiovascular diseases [23], monitoring elders’ vital signs [43], monitoring epilepsy patients [44], or monitoring patients with diabetes [45]. Therefore, it can be concluded that using application frameworks can enhance the overall development quality and overcome the development complexity of context-aware MPMS.

IV. Research Framework

To achieve the objectives of this paper, three research processes were conducted as shown in Fig. 1. These are: literature review, success factors identification, and lacks and gaps identification. The following subsections are a discussion of the steps and the methods used in these processes, in addition to their outcomes.

A. Literature Review Process

The objective of this process is to review the literature using two steps: literature search then literature content analysis. The objective of the first step is to collect scholarly articles related to this research and document them in a bibliography database as the primary outcome of this step. The objective of the second step is to characterize the previous studies to comprehend the literature through identifying a set of categories as the main outcome of the literature review process. The following subsections are a discussion of the methods used in these two steps.

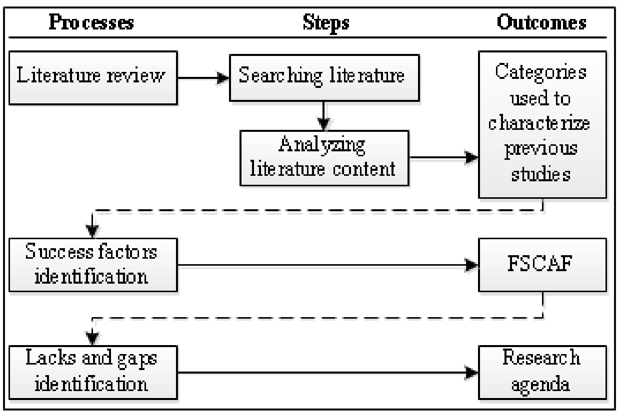

Figure 1. Research framework.

Step 1. Searching Literature: In this step, the literature search method, which was introduced by Brocke et al. [46], was used. This method was conducted in this research by customizing the literature review framework of this method. This framework includes three phases, which focus on searching and documenting the literature to provide comprehensible and credible literature review process. The objective of this process is to increase researcher confidence in using the research outcomes in further research.

In the first phase, the literature scope was defined by identifying the following five characteristics. First, the focus of the literature search involved all scholarly articles related to design research. Second, the goal of the literature search was to identify the various waves of thought in academic research to design context-aware frameworks in biomedical informatics. Third, the perspective of the literature search was neutral, which means it does not reflect any certain opinion that supports a specific idea or principle. Fourth, the audience of the literature search results was the specialized scholars in designing context-aware frameworks in biomedical informatics. Fifth, the coverage of the literature search was a representative sample, which was selected based on specific criteria (i.e., year of publication and leading article source) to represent all research articles of designing frameworks in biomedical informatics.

In the second phase, a set of key terms was identified (i.e., design, application, framework, context-aware, mobile, patient, monitoring, system, and sensors). In the third phase, a literature search process was conducted based on the identified key terms by focusing on scholarly articles from leading journals, conference proceedings, and scholar databases. However, it was difficult to focus on a specialized range of journals because designing context-aware frameworks in the biomedical informatics domain is an interdisciplinary field of study that requires considering a wide range of articles. In fact, the range of journals dealing with designing such frameworks span biomedical informatics journals, mobile computing journals, information systems journals, communication journals, systems and software journals, software engineering journals, computer science journals, ubiquitous computing journals, and even network journals. Therefore, interdisciplinary online databases were chosen to begin the search.

Step 2. Analyzing Literature Content: The objective of content analysis is “to provide knowledge and understanding of the phenomenon under study” [47]. This research adopted an inductive approach to content analysis proposed by Elo and Kyngäs [48]. This approach consists of three main phases: preparation, organizing and reporting.

In the preparation phase, two activities were performed. First, the unit of analysis is selected, which includes: requirements, context-aware, application framework, framework design, framework architecture, patient monitoring systems, wireless sensors, and mobile technology. Second, the content data were read several times to make sense of the data in terms of the identified unit of analysis, to gain a comprehensive understanding and have good knowledge of them.

In the organizing phase, five activities were conducted. First, open coding was performed by writing notes to describe all aspects of the content. Second, the open coding data were collected and stored in a spreadsheet file. Third, the related data of the spreadsheet file initially were grouped based on observing the similarity among them. These groups were called subcategories. Fourth, the subcategories that were identified in the previous activity were organized under high-level categories. These high-level categories were called generic categories. Fifth, the generic categories that were identified in the previous activity were further abstracted based on the similarities or relations with other generic categories to provide a new abstract main category.

In the reporting phase, the analysis process was evaluated, and then the reported analysis results were validated. First, the evaluation was performed by using tables to demonstrate a detailed explanation of all of the categories that were identified in the previous two phases. Second, the validation was performed by experts through publishing the categories in conference proceedings and discussing them with peers.

B. Success Factors Identification Process

The objective of this research process is to identify the FSCAF as a main outcome by using a single step. In this step, a comparison and selection technique was proposed and used to compare the identified categories of factors that resulted from the previous process, to select the success factors among them. This proposed technique applies a pragmatic research approach [49]. Accordingly, a number of comparison criteria were identified and used as shown in Table I. These criteria focus on supporting context-aware MPMS for elders and patients with chronic disease as the primary stakeholders. Additionally, these criteria focus on any comparison criterion that is related to enhancing the overall design of CMPMF to facilitate the development of MPMS.

Two alternative procedures were used in the comparison and selection technique. Whenever there are alternatives and only one must be selected, the following procedure is conducted. First, as shown in Table I, these alternatives are compared and weighted in terms of their support to a set of comparison criteria. Second, these alternatives that have zero weights are eliminated. Finally, the alternative that has the highest weight is selected. Alternatively, if there are different choices that

TABLE I.
COMPARISON AND SELECTION TECHNIQUE

Comparison criteria	Categories		
	Subcategory (1)	…	Subcategory (*n*)
Criterion (1)	+1		0
Criterion (2)	0		+1
Criterion (3)	+1		+1
Criterion (*m*)	+1		0
Selection Result	3	…	2

can be considered together, the following procedure is conducted. All of the choices are selected.

C. Lacks and Gaps Identification Process

The objective of this research process is to identify the lacks and gaps in the literature using a single step. The objective of this step is to synthesize the previous studies that designed context-aware frameworks in the biomedical informatics domain, using the identified FSCAF. To meet this objective, this process uses the concept matrix technique that was introduced by Webster and Watson [50]. This matrix provides a method to organize, analyze, and synthesize previous studies to develop a research agenda. This research agenda provides a foundation for the researchers to extend the state-of-the-art by filling the gaps [46].

In this research, the concept matrix technique was customized as shown in the Table II. The first column in Table II lists the previous studies that represent the designed context-aware frameworks in the biomedical informatics domain. The following columns represent the identified FSCAF. Each tick (✓) indicates that a specific study has satisfied a particular FSCAF. The last column represents the total number of satisfied factors in each study from the total number of all factors. The percentage row represents the percent of studies that have satisfied a particular factor, while the proportion row represents the number of these studied from the total number of studies.

V. A SYSTEMATIC REVIEW

This section is a systematic review of previous studies that designed context-aware frameworks in the biomedical informatics domain. First, it identifies a number of categories to be used to gain an intensive and extensive understanding of the designed CMPMF. Second, it identifies a set of success factors called FSCAF to be used to enhance the design of CMPMF. Third, it presents a research agenda that shows the lacks and gaps in the designed CMPMF, providing a foundation to help the researchers to design enhanced CMPMF. This is achieved by following the three research processes that were discussed earlier.

A. Process 1: Literature Review

By applying the two steps of the literature review process as elaborated earlier in Section IV, a number of studies were collected and documented. Then, the contents of these studies were analyzed. At the end of this process, a set of categories was produced. These categories can be used to gain an intensive and extensive description of the current situation of the designed CMPMF. For this purpose, 10 studies were analyzed and categorized based on the resulting categories that are shown in Table III. This research classified previous studies that designed context-aware frameworks in the biomedical informatics domain into three generic categories as shown in second column in Table III.

TABLE II.
CONCEPT MATRIX

Previous studies	Factors of successful context-aware frameworks			Total
	Factor (1)	Factor (2)	Factor (*f*)	
Study (1)	✓	✓		2/*f*
Study (2)		✓		1/*f*
Study (3)				
Study (*s*)				
Percentages	25%	50%		
Proportions	1/*s*	2/*s*		

B. Process 2: Success Factors Identification

This section presents the identified FSCAF. To achieve this, the results from the previous process were used as an input to identify these factors. Identification of these factors is expected to enhance the design of CMPMF. To identify these factors, a comparison and selection technique was proposed and used in this research as discussed in the success factors identification process in Section IV. The results of applying the comparison and selection technique are illustrated in Table IV, which 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.

1) Types of Context Information: There are six types of context information, as shown in Table III, used to characterize previous studies that designed context-aware frameworks in the biomedical informatics domain. These types of context information can be considered together.

TABLE III.
CATEGORIES USED TO CHARACTERIZE PREVIOUS STUDIES

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

TABLE IV.
FACTORS OF SUCCESSFUL CONTEXT-AWARE APPLICATION FRAMEWORKS

Abstract main category	Generic categories	Subcategories
Application frameworks to develop context-aware mobile patient monitoring systems using wireless sensors	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

According to Roy, Gu, and Das [5], the more context information obtained, the higher the context reasoning accuracy achieved. Therefore, the second procedure of the comparison and selection technique was applied to select all of these six types of context information as shown in Table IV. 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 widely adopted in the literature [2, 5, 32]. Vital signs represent the signs of life, defined in [51] 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) [52]. The interpretation of their values, whether they are normal or not, depends on other types of medical context information such as risk factors 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). Thus, it is rarely adopted in the literature. It also provides dynamic medical personal information that is difficult to be measured by sensors [30]. This context information complements the measurable medical context. For example, monitoring hypertension requires monitoring a nonmeasurable medical context such as headache and constipation. Monitoring these nonmeasurable medical symptoms complements monitoring measurable medical context such as BP and HR vital signs [30].

c) Risk Factors Context Information: It is known as a health risk that is defined by the World Health Organization (WHO) [53] 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, 20]. 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 jointly are responsible for more than 75% of deaths of hypertensive people [53]. 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 [53].

d) Prescribed medications context information: It provides information about the current prescribed medications for a patient [8, 30]. However, it is rarely adopted in the literature. It has effects on the normal patient's vital signs [8, 30]. Therefore, health care professionals can assess the effects of prescribed medications on a patient to evaluate the patient's response to the treatment [30]. For example, a 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's response to treatment, and take the appropriate medical decisions [30].

e) Physical activities context information: It represents the patient's current physical activities such as walking, running, or sleeping. It was adopted in several studies [3, 4, 8]. In fact, these physical activities have direct effects on the normal vital signs. For example, normal HR while running or climbing up stair is higher than while walking or lying down [7]. Similarly, normal BP during sitting or sleeping is less than during eating or doing physical exercise such as running [32, 33].

f) Environmental Context Information: It includes information about the surrounding environment affecting a patient's medical state such as temperature, light, humidity, and noise. It also is adopted widely in the literature [2, 5, 6]. 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" [54], can benefit from monitoring floor humidity to protect them from falling [32]. In addition, environmental context affects vital signs. For instance, room temperature affects heartbeat, which in turns affects BP [32].

2) Sources of Context Information: There are four sources of context information, as shown in Table III, used to characterize the designed context-aware 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 applied to select all of these four sources of context information as shown in Table IV. 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 have adopted this type of context information. Additionally, they were used as a main data source for physical activities context in many studies that have adopted this type of context [1-3, 5].

b) Wireless Environmental Sensors Context Source: Wireless environmental sensors were used as a primary data source for the environmental context. Indeed, they are used in most previous studies that have adopted this type of context information [2, 3, 6]. They also play a primary role in supporting context-aware MPMS by providing context information that can be measured continuously during the patients' normal daily lives [55].

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 is rarely adopted in the literature [30]. It is also the main data source for obtaining a nonmeasurable medical context. Moreover, it plays 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 [30].

d) Patient profile context source: Patient profile is 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, 7, 56]. Using this data source contributes to the accuracy of context-aware MPMS [57]. Moreover, it plays 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 [53], 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 [53]. 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.

e) Patient profile hosted on the patient's mobile device: This factor adds a constraint on the patient profile factor. It insists that the patient's profile should be hosted on the patient's mobile device [57]. Using a patient profile hosted on the patient's mobile device can contribute significantly to the design of CMPMF. For example, it supports the privacy protection of the patient's contextual data [42]. Furthermore, it is adequate to avoid the continuous network communication costs required to transmit and receive data to and from the backend server [3, 4, 7]. 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 [42]. Additionally, it supports real-time continuous patient monitoring [3], anywhere and anytime [56].

3) Context Reasoning Approach - First-Order Logic: The objective of context reasoning approaches is to detect the change in high-level context based on low-level context information [9, 24]. 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, 42]. This is achieved by writing queries in Conjunctive Normal Form (CNF) [58]. Using CNF in context-aware monitoring queries was introduced by Kang et al. [42].

C. Process 3: Lacks and Gaps Identification

This section presents the process used to identify the lacks and gaps in previous studies that designed context-aware frameworks in the biomedical informatics domain. This is achieved by applying the lacks and gaps identification process as discussed in Section IV. The main input for this process is the identified FSCAF to design CMPMF. These success factors were used in this process to analyze 10 studies to identify the lacks and gaps. Table V shows the resulting percentages and proportions of analyzing these studies. The percentages and proportions for each factor were interpreted for analysis as a research trend (from 50% to 100%) or (5 to 10 out of 10), lack (from 1% to 49%) or (1 to 4 out of 10), and gap (0%) or (0 out of 10).

With reference to Table V, it can be seen that there is a trend among the previous studies on addressing five of the FSCAF. First, 100% of the studies have addressed the measurable medical context as a context information type. Second, 100% of the studies have considered the wireless body sensors as a source of context information. Third, 70% or 7 out of 10 of the studies have considered the environmental context as a context information type. Fourth, 70% or 7 out of 10 of the studies have considered the wireless environmental sensors as a source of context information. Last, 50% or 5 out of 10 of the studies have considered the patient profile as a source of context information.

Moreover, it clearly can be seen that there is a lack among the previous studies on addressing five of the FSCAF. First, at most, 40% or 4 out of 10 of the studies have considered the risk factors medical context as a context information type. Second, only 40% or 4 out of 10 of the studies have considered the physical activities context as a context information type. Third, just 40% or 4 out of 10 of the studies have considered first-order logic as a context reasoning approach. Fourth, only 20% or 2 out of 10 of the studies have considered the prescribed medications medical context as a context information type. Last, only 10% or 1 out of 10 of the studies considered hosting the patient profile on the patient's mobile device as a constraint on the patient profile factor.

Furthermore, it can be seen that there is a gap between the previous studies on addressing two of the FSCAF. First, 0% of the studies have considered the nonmeasurable medical context as a context information type. Second, 0% of the studies have considered the mobile graphical user interface as a source of context information.

In summary, it was found that there is a consensus among previous studies on considering the following five factors out of the FSCAF: measurable medical context type, wireless body sensors context source,

TABLE V.
PERCENTAGES AND PROPORTIONS OF PREVIOUS STUDIES THAT SATISFY THE IDENTIFIED FSCAF

	Types of context information						Sources of context information					Context reasoning approaches	
Previous studies	Measurable medical context	Nonmeasurable medical context	Risk factors medical context	Prescribed medications medical context	Physical activities context	Environmental context	Wireless body sensors	Wireless environmental sensors	Mobile graphical user interface	Patient profile	Patient profile hosted on the patient's mobile device	First-order logic	Total
[1]	✓						✓						2/12
[2]	✓					✓	✓	✓				✓	5/12
[3]	✓				✓	✓	✓	✓					5/12
[4]	✓				✓		✓						3/12
[5]	✓		✓			✓	✓	✓		✓			6/12
[6]	✓					✓	✓	✓				✓	5/12
[8]	✓			✓	✓		✓			✓			5/12
[9]	✓		✓			✓	✓	✓		✓	✓	✓	8/12
[10]	✓		✓	✓	✓	✓	✓	✓		✓			8/12
[11]	✓		✓			✓	✓	✓		✓		✓	7/12
Percentages	100%	0%	40%	20%	40%	70%	100%	70%	0%	50%	10%	40%	
Proportions	10/10	0/10	4/10	2/10	4/10	7/10	10/10	7/10	0/10	5/10	1/10	4/10	

environmental context type, wireless environmental sensors context source, and patient profile context source. In addition, it was found that there are common lacks in considering the following five factors out of the FSCAF: risk factors medical context type, physical activities context type, first-order logic as a context reasoning approach, prescribed medications medical context type, and patient profile on the patient's mobile device as a constraint on the patient profile factor. Moreover, it was found that there are common gaps in considering the following two factors out of the FSCAF: nonmeasurable medical context type and mobile graphical user interface context source. However, based on the total number of satisfied factors in each study, it was found that the highest total was 8 out of 12, which were only achieved by two studies [9] and [10].

VI. CONCLUSION AND FUTURE WORK

This paper is a discussion of ongoing research about designing a CMPMF. It begins with an introduction of a concept of context and context-aware computing. Then, the potential of context-aware MPMS is highlighted, and the need for designing CMPMF. It also includes the research framework that was used to satisfy the research objectives of this paper. A systematic review of previous studies that designed context-aware frameworks in the biomedical informatics domain is presented, including the process of literature review, success factors identification, and lacks and gaps identification. The results show that there are few studies that designed CMPMF. Aside from this, they have a severe lack in considering the identified FSCAF. Moreover, there is no study that integrates all of the FSCAF to design CMPMF. Therefore, there is a need to fill the gaps among application framework designs, context awareness computing, and MPMS through designing of CMPMF that satisfies all of the identified FSCAF. In the future, the researchers will attempt to integrate all of the FSCAF in an enhanced design of CMPMF, to help software engineers and developers to design and develop various context-aware MPMS easily for different diseases and with minimal cost.

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