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ISO/IEEE 11073 Personal Health Device (X73-PHD) Standards Compliant Systems: A Systematic Literature Review

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ABSTRACT Since the introduction of the ISO/IEEE 11073 personal health device (X73-PHD) standards, as part of ISO/IEEE 11073 family of standards, it has been applied to many health systems developed for personal use. In this systematic literature review, we review existing literature collected using three databases: Scopus, Pub Med, and Web of Science. We propose a classification for personal health systems based on the location in which they are used, the technology used to develop them, and the purpose which is determined by the targeted users. We found 51% of the devices used in such systems are standardized while approximately 40% are not and five systems did not specify the device status (9%). Various adaption techniques were used for standardization. Besides, the pulse oximeter is the most used device in such systems since it was used in 43% of them. In addition, we present the role of the X73-PHD standards in the Internet of Things (IoT) and tele-healthcare systems, discuss the challenges of utilizing this set of standards in health monitoring systems and converting the non-standardized devices into standardized ones. Finally, we propose the requirements of personal health systems based on our review of the literature.

INDEX TERMS Compliant system, ISO/IEEE 11073 personal health device, standard, X73-PHD, health systems requirements, IoT.

I. INTRODUCTION

The explosion of Digital Twin [1] including IoT and wearable technology and the availability of personal health devices to the general public have a high potential to make healthcare much more efficient in the near future. With this development comes the need for interoperability to allow for more efficient health services and reduce the technological complexity. The X73-PHD standards are the result of a collaboration between the International Organization for Standardization (ISO), IEEE and a group of manufacturers that came at a time when the need for a standard in this domain has never been higher.

The X73- PHD standards target health devices designed for personal use. They aim at facilitating health data exchange while providing plug-and-play real time interoperability. The X73-PHD standards also provide a cost efficient standardization solution for personal health systems used by both the research community as well as industry [2].

Several research discuss the X73-PHD standards benefits in improving health systems capabilities. One of the initial research articles in this regard is the one proposed by Philips Research Europe [3]. It discusses the announcement of the X73-PHD work group, justifies the need for this set of standards and its role in solving the interoperability problem in healthcare systems and elaborates the data model and formats of the standards content.

Many research focus on enhancing this set of standards such as [4] and [5] to solve existing issues and motivate its deployment in healthcare systems. Barrón-González *et al.* [4] attempt to adapt the remote control capabilities from ISO/IEEE 11073 Point-of-Care (X73-PoC) to X73-PHD since it is not covered in the current version of the X73-PHD standards. They proposed an extension package that allows the server to modify the device's settings remotely. The research in [5], which is prepared by the chair of the X73-PHD work group, shows the ongoing work to propose standards for more personal health devices to encourage their utilizations in the healthcare systems.

The 11073 family of standards has been widely utilized in many applications in healthcare monitoring systems and has been discussed in many research reports [6]

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and books [7], [8]. Some research compare this family of standards [9] with other standards in healthcare field. The X73-PHD standards research highlights the importance to guarantee the interoperability in the health field. The research in [10] shows how the X73-PHD standards have been built based on the X73-PoC standards and lists the main technical challenges in the standard's implementation. These challenges are mainly: flow and errors control, errors and alarms management, multiple medical devices connection with one or multiple computer engines, or implantation on micro-controllers.

The development of the X73-PHD standards to facilitate the leveraging of the collected health data has been encouraged by the growing use of personal health monitoring devices. Many standardized personal health devices (PHDs) have been manufactured such as blood pressure monitor, weighing scale and insulin pump. Currently, the usage of these devices is essential to address the widely spread physical inactivity and rapid increase in chronic diseases such as diabetes and high blood pressure [11]. PHDs allow people to track their health status and manage medicine intake, in addition to transmitting the collected information to healthcare professionals if required [12], [13].

Manufacturers use different data formats and electronic features for health devices, which causes integration difficulties with healthcare information systems [2]. This motivated the IEEE and the International Organization for Standardization (ISO) to create a series of standards called ISO/IEEE 11073 Personal Health Device (X73-PHD) [14]. This series of standards aim to regulate the manufacturing of PHDs and control the interoperability among PHDs and systems [15]. A software development kit (SDK) is proposed in [16] to facilitate the adoption of the X73-PHD standards. Using such SDK could facilitate the standardizing task of personal health systems that depend on PHDs to perform their functions such as the system in [17].

In this review, our main objective is to survey the existing X73-PHD compliant systems that are developed for personal use and not for clinical use. Besides, we focus on the utilized devices in each system to determine if they are X73-PHD compliant or not. If not, we determine how the proposed systems adapt these devices to be compatible with the standards. Additionally, we aim to determine the most frequently used device in such systems. Such information is needed to support the trend towards developing standardized personal health systems.

In this paper, we include 11073-related research papers and exclude 11073-related products and patents because they had been covered by a metadata research [11]. Tang *et al.* [11] recommended the conducting of further research on papers since there is no systematic literature review, mapping or survey on the X73-PHD related research papers.

The rest of this paper is organized as follows:

Section II presents the research questions, then Section III discusses the scope and key terms. Section IV explains the SLR methodology and Section V presents the results. Section VI demonstrates the threats to validity. Section VII presents the relationship between the X73-PHD standards and IoT, the challenges faced by the utilization of this set of standards, and how to convert a non-standardized device into a standardized. Section VIII presents the requirements of developing personal health systems as an output of this review. Finally, Section IX concludes the paper.

II. RESEARCH QUESTIONS

To achieve the objectives of this SLR, we formulate the following questions:

RQ1. What are the existing personal health systems compliant with the X73-PHD standards?

RQ2. In each system, is the device itself standardized? If not, how does the system adapt the device to be compatible?

RQ3. What are the most widely used devices in such systems?

III. SCOPE AND KEY TERMS

In the following, we provide an overview on the X73-PHD standards, the key definitions and the literature scope.

A. X73-PHD STANDARDS: BACKGROUND

The IEEE Standards Development Working Group (IEEE-WG) for PHDs defined the series of X73-PHD standards [15], which "addresses a need for an openly defined, independent standard for controlling information exchange to and from personal health devices and managers (e.g., cell phones, personal computers, personal health appliances, and set top boxes)". This series of standards aims to regulate the manufacturing of devices as well as controlling the interoperability between devices and the systems [15]. Under this set of standards, each system consists of three principal models:

- Domain Information Model (DIM): for data representation
- Service Model (SM): for defining data accessibility and command methodologies
- Communications Model (CM): for data communication from an agent to a manager.

B. CONCEPTS DEFINITIONS

In this subsection, we propose definitions of the key concepts.

- **Personal Health Device (PHD):**
  Many definitions can be found for PHDs. One of them is stated in [18] as "Personal Health Devices, wearable or not, are devices with constrained resources, specially related to energy supply and processing power". This definition is from technical point of view and does not take the devices functionality into account. Thus, we define PHD as any device equipped with one or multiple sensors that are able to monitor vital signals of a person's body possibly taking into consideration signals from surrounding environment such as noise.
- **Compliant Systems:**
  They are personal health systems that adhere to the X73-PHD standards in manager sides by complying

with the communication model (CM) of this family of standards as a minimum requirement and optionally with domain information model (DIM) and service model (SM) as a higher level of conformance. Starting from this point, we will use this concept to represent these targeted systems in this review.

- **Agent:**
  In a personal health system, the device that provides the data is called an agent, which is usually the personal health device.
- **Manager:**
  In a personal health system, the device that receives the data is called a manager. This can be a personal computer and a cell phone, etc.

C. INCLUSION AND EXCLUSION CRITERIA

We included different types of publications (journals, conferences, proceedings, workshops, and books) that consider the compliant systems. In addition, we tried to include existing literature related to this set of standards to provide a comprehensive review. Publications about 11073-related products and patents were excluded since they were covered recently [11].

IV. SURVEY METHOD

We describe the methodology in three steps: pre-survey preparation, systematic search, and post-survey analysis, as follows:

A. PRE-SURVEY PREPERATION

To answer the research questions stated above, we followed a "pearl growing" strategy as follow:

- To build an initial knowledge about the publications, we searched the X73-PHD standards name written in various formats using the comprehensive query shown in the following:
  ((TITLE-ABS-KEY ("IEEE 11073 Personal Health Devices" OR "IEEE 11073 PHD Standards" OR "ISO/IEEE 11073 PHD" OR "X-73 Standard∗" OR "IEEE 11073 PHD" OR "X73-PHD" OR "IEEE-X73 Standards")))
- We ran this comprehensive query in Scopus [19]. We found a relatively small number of publications (41 publications). This number is reasonable considering the new emergence of this standard.
- Then, we ran several queries on PubMed [20]. It helped us to select several papers that appeared frequently in the results of queries, such as [21]–[24].
- Lastly, we added more concepts to widen the search range and cover more X73-PHD related publications. Running the comprehensive query on Scopus resulted in the X73-PHD related publications that tackle different topics such as security and IoT. Those research works are presented later in section VII.

B. SYSTEMATIC SEARCH

- **Select source databases:** We selected Web of science [25] in addition to Scopus and PubMed to guarantee the coverage of the related publications.
- **Build the abstract search query:** This query is shown in Table 1. It shows the main parts of the query along with the description and justifications of each part.

TABLE 1. SLR abstract search query.

Phrase	Description and Justifications
TITLE-ABS-KEY	To get the most related publications with a reasonable number of results.
("ISO 11073" OR "X-73 Standard*" OR "IEEE 11073" OR "X73-PHD")	To include different forms of the standards names that appeared in the literature.
("personal health device*" OR "wearable*" OR "sensor*" OR "Pulse Oximeter*" OR "Strength fitness equipment" OR "Independent living activity hub*" OR "Medication monitor*" OR "Peak expiratory flow monitor" OR "Body composition analyzer" OR "electrocardiograph" OR "ECG" OR "Cardiovascular fitness and activity monitor" OR "International Normalized Ratio" OR "INR" OR "Urine Analyzer" OR "Sleep Apnoea Breathing Therapy Equipment" OR "SABTE" OR "Glucose Meter" OR "Insulin Pump" OR "Continuous Glucose Monitor" OR "CGM" OR "Blood Pressure Monitor" OR "Thermometer" OR "Weighing Scale")	To include all the standardized devices mentioned in the IEEE-WG [26].
("system*" OR "propos*" OR "design*" OR "implement*" OR "evaluat*" OR "assess*" OR "measur*" OR "monitor*" OR "track*" OR "control*" OR "exten*" OR "architectur*" OR "framework*")	To include all other possible types in the literature.

C. POST-SURVEY ANALYSIS

Running the above queries on different source databases, following we collected automatically: title, abstract, keywords, and year. Additionally, we collected the following data manually:

1. **Compliant System Type:** shows if the proposed system in the publication is a complete system, which means a fully designed and implemented system, or it is a prototype.
2. **Compliant System Usage**: refers to the usage of the system proposed in the publication.
3. **Compliant System Characteristics:** refers to the characteristics that distinguish the proposed system. The publication's title and keywords were used to extract the characteristics.
4. **PHD Type:** shows if the device(s) used in the proposed system is manufactured to be X73-PHD com-

pliant or adapted by the system. "NA" entry was used when the device type was not mentioned.

5. **Adaptation Technique:** presents how the proposed compliant system adapted the device if it is not compatible with the X73-PHD Standards. "NA" entry was used when the technique was not mentioned.
6. **PHD Name:** shows the name of the device(s) in the system.

The following section demonstrates how the collected data were used to synthesis the answers to the three research questions.

V. LITERATURE REVIEW RESULTS

We collected 106 publications. Then, we investigated them manually one-by-one as follow:

- Two of the authors checked each publication independently considering the inclusion and exclusion criteria.
- Each author individually answered the question: "does this publication represent the review scope?" by selecting one answer: (Yes / No / Not sure), and write comments or justifications if needed.
- The authors conducted a discussion session to check their selections and solve conflicts.

Following these steps, we obtained 53 publications representing the targeted compliant systems. The majority of these publications are journal articles (62%) while the remaining are conference proceedings (36%) and only 1 book section (2%) [27]. Figure 1 illustrates the count of publication types on yearly basis.

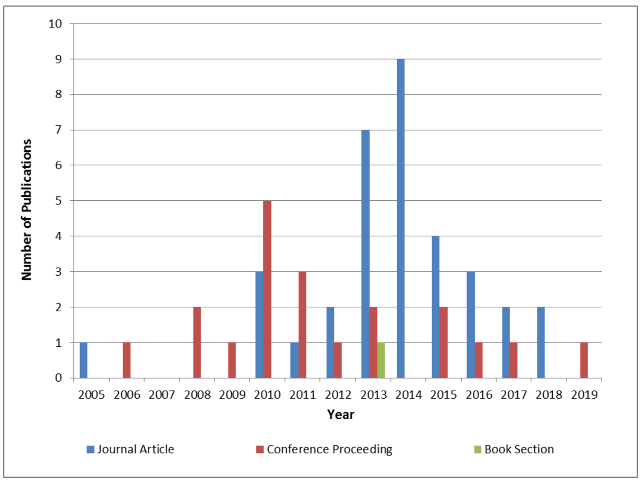

FIGURE 1. Count of publications types.

The answers of the three research questions are discussed in the following:

RQ1. What are the existing personal health systems compliant with the X73-PHD standards?

To answer this question, we utilize the compliant system type, usage and characteristics as follow:

- **Compliant System Type:**
  We found that the majority of existing compliant systems are complete systems (approximately 74%) while the remaining are prototypes (approximately 26%). The first complete compliant system is a patient monitoring system proposed in 2008 [28]. A wearable home health monitoring system proposed in [29] is an example of prototypes. Figure 2 illustrates compliant system types. Mobile systems are mainly Android-based and represent 44% of the complete systems. Only one system is iOS-based system [30].

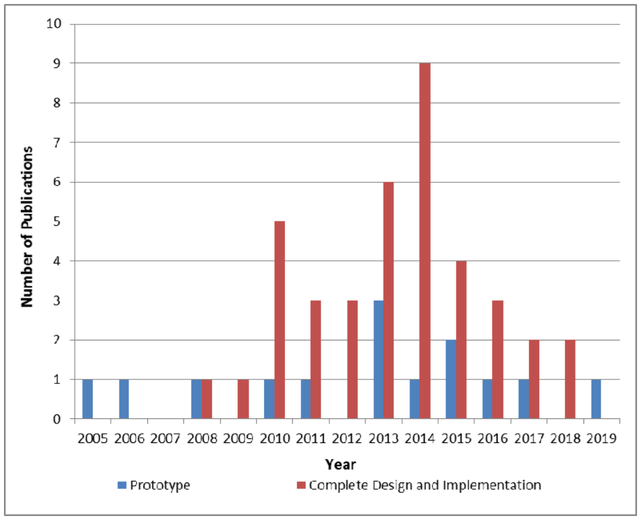

FIGURE 2. Count of compliant system types.

- **Compliant System Usage:**
  we found that the personal health systems can be classified based on the *location* where they are used, the *technology* used to develop them, or the *purpose*, which is determined by the intended users. Thus, we proposed the classification illustrated in figure 3 showing the classes and subclasses described in the following:

1) LOCATION: Personal health systems could be classified as one of three subclasses as follow:
   - **U–Health:** Some research consider providing ubiquitous health services for patients as well as healthy individuals such as the system in [31]. In this review, this subclass refers to ubiquitous personal health systems that can provide health services anytime and anywhere. Systems in [21], [28], [32], and [33] are some examples of this subclass.
   - **In-Home:** Many research consider providing health services to serve patients at their homes such as [34] and [35] and enhance individuals' well-being such as [36] and [37]. In this review, this subclass refers to personal health systems that are developed to be used at home for monitoring purposes. Systems in [22] and [38]–[41] are some examples of this subclass.
   - **Mobile/Tele-Health:** Many research utilize the mobile and tele-health technologies to accelerate health services provision for patients such as [42] and [43] and healthy individuals for their well-being such as [31]. In this review, this subclass

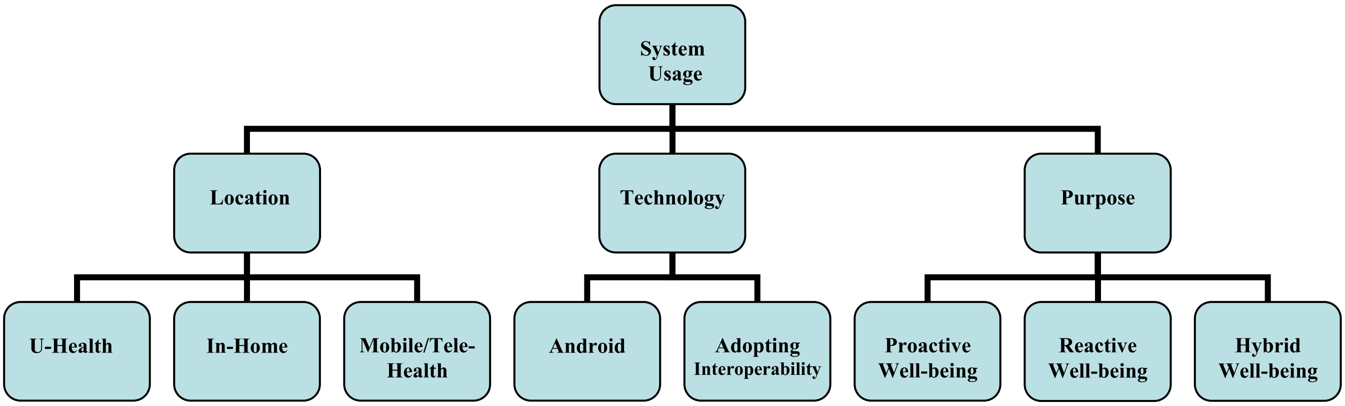

FIGURE 3. Classification of personal health systems compliant with the X73-PHD standards in the literature according to the compliant system usage.

refers to personal health systems that are developed to monitor patient's health remotely. Systems in [30] and [44]–[47] are some examples of this subclass.

2) TECHNOLOGY: Personal health systems could be classified as one of two subclasses as follow:
   - **Android:** Many systems implemented as Android applications to provide health and well-being services, such as systems in [31] and [48]–[50]. In this review, this subclass refers to personal health systems that are developed as Android applications or to interact with Android terminals such as smartphones or tablets. Systems in [23] and [51]–[55] are some examples of this subclass.
   - **Adopting Interoperability:** This subclass refers to personal health systems that are standardized by utilizing various techniques and protocols to fulfill the interoperability condition. Some examples of these techniques are: an agent with appropriate mapping methods between manufacturer and ISO/IEEE 11073 nomenclature systems [56], a standard message generation toolkit to easily standardize existing non-standard healthcare devices [57], and an implementation model of standardization [24]. Other examples are found in [58]–[62].

3) PURPOSE: We proposed this classification to show the how personal health systems could be used for individuals' well-being. Thus, we suggest that compliant systems could be classified as one of three subclasses as follows. Two of the subclasses names are derived from the linguistic meaning of "proactive" vs. "reactive" found in [63] and [64] to differentiate between healthy individual's well-being and patient's well-being.
   - **Proactive Well-being:** Refers to personal health systems targeting healthy individuals to track vital signs and promote healthy practices. Monitoring food intake and daily physical activity level are examples of these practices for healthy lifestyle. These systems may target adults [65]–[67] or children [68]–[70]. In this review, systems developed to monitor vital signs [2], [71] or physical activity level [72] are examples of this subclass.
   - **Reactive Well-being:** Refers to personal health systems targeting patients to monitor their health continuously and remotely. Some examples are systems developed for patients with chronic diseases such as diabetes [43], [73], stroke [74], [75] and obesity [76]. Other examples are systems found in [77] and [79]. In this review, systems developed to monitor cardiovascular diseases [79]–[81] or manage chronic diseases [82] are examples of this subclass.
   - **Hybrid Well-being:** Refers to personal health systems targeting individuals vulnerable to chronic diseases such as high blood pressure and prediabetes. Thus, this subclass includes practices from both other subclasses. Some examples are systems developed for stress management [48], [83], and monitoring elderly people. In this review, systems developed to monitor elderly people who are vulnerable to many diseases such as [22], [46], and [84]–[86] are examples of this subclass. Other examples are systems developed for postpartum well-being [87], and emergency cases [47], [62].

The type and usage of the collected compliant systems are shown in Table 4.

- Compliant Systems characteristics:

We analyzed the titles and keywords concepts of the publications to formulate a set of criteria that characterize the personal health systems. Figure 4 and Figure 5 show the word clouds generated from analyzing the titles and keywords respectively based on the frequency of each word using WordItOut [88].

Figure 4 emphasizes the top five characteristics of personal health systems, which are: being personalized, providing self-monitoring ability, being mobile and ubiquitous systems;

FIGURE 4. Characteristics of personal health systems inferred from publications titles.

FIGURE 5. Characteristics of personal health systems inferred from publications keywords.

following specific protocols such as the X73-PHD standards, and providing self-management ability. Other characteristics are: being wearable systems, utilizing biosensors and supporting interoperability. Figure 5 emphasizes the critical need of these systems to be standardized according to ISO/IEEE 11073 family of standards and to use one or multiple personal health devices.

RQ2. In each system, is the device itself standardized? If not, how does the system adapt the device to be compatible?

We found most systems used standardized devices (51%) whereas the remaining used non-standardized devices (40%) and five systems (9%) did not mention the devices status, found in [10], [18], [28], [41], and [44]. Various techniques and protocols were used to adapt non-standardized devices. Table 2 shows some of these techniques.

RQ3. What are the most widely used devices in such systems?

We found 18 different devices were used in the compliant systems. Most systems used more than one device for evaluation. Some of these devices were considered by the IEEE-WG [26]. They are pulse oximeter, blood pressure monitor, thermometer, weighing scale, electrocardiograph (ECG), independent living activity hub, and glucose meter. The non-standardized devices are physical activity

TABLE 2. Some techniques used to adapt non-standardized PHDs.

Adaption Technique	Reference
X73 adapter	[21], [84]
ZigBee Health Care Profile as the transport layer	[60]. [91]
device connection module	[23]
virtual agent	[24]
agent extension module	[33]
UPnP Health Gateway	[40]
L2CAPprotocol	[58]
IEEE 11073 DIM translator	[52]
a common layer to integrate data	[54]
mapping methods between manufacturer and ISO/IEEE 11073 nomenclature systems	[56]
IEEE 11073 and Bluetooth: device-level Health Level (HL7) and CORBA: system-level	[61]
protocol extension for activity data	[72]
integration model	[92]
toolkit generates standard PHD messages	[93]
Bluetooth LE sensor proxy	[46]

monitors, bed sensors, chair sensors, medication dispenser, fall detection sensor, plethysmogram (PPG), pedometer, smart phone camera and sensors, smart shoe insole, which has been validated to measure gait parameters in [98], iPad system and Wii Balance Board as a weighting scale.

The most widely used device is pulse oximeter, which was used in 43% of the compliant systems. Table 3 shows the devices used in the compliant systems in descending order from most to least used with the percentages.

VI. THRATS TO VALIDITY

Regarding the construct validity, following the steps stated in Section IV helped us to answer the research questions, document interesting findings and draw conclusions.

Regarding the internal validity, the authors selected the papers independently to minimize bias. Also, they discussed their selection to resolve conflicts and agreed on the final set of papers.

Regarding the external validity, the exclusion of products and patents publications could limit the generalization of the findings of this review.

VII. X73-PHD STANDARDS: BEYOND COMPLIANT SYSTEMS

This section presents the X73-PHD research related to IoT, challenges, and converting non-standardized devices into standardized devices, as a result of running the comprehensive query.

A. X73-PHD STANDARDS AND IoT

Many research consider developing health care systems utilizing IoT such as systems in [99] and [100]. A survey presented in [101] discusses this utilization extensively. Currently, the X73-PHD standards are strongly related to the IoT due to the proliferation of the IoT healthcare devices. This relationship leads to the emergence of many IoT-based personal health systems. One research [102] lists the evolving stages of IoT-based healthcare architecture and systems. These four main stages include the IEEE 11073 health

TABLE 3. Different PHDs used in the compliant systems in this SLR.

Personal Health Device (PHD) - Percentage	Covered by IEEE-WG for PHDs	Reference
pulse oximeter - (43%)	✓	[21], [27], [29], [32], [38], [39], [40], [46], [47], [51], [52], [53], [57], [62], [82], [86], [87], [89], [91], [92], [94], [95], [96]
blood pressure monitor - (34%)	✓	[22], [23], [30], [38], [40], [45], [46], [53], [54], [55], [60], [71] [86], [87], [91], [92], [93], [94]
weighting scale - (30%)	✓	[22], [23], [29], [30], [38], [40], [46], [53], [61], [87], [89], [91], [92], [93], [94], [95]
blood glucose meter - (25%)	✓	[22], [30], [33], [38], [40], [54], [60], [71], [84], [85], [86], [91], [93]
electrocardiograph (ECG) - (23%)	✓	[23], [29], [47], [51], [54], [56], [57], [79], [80], [81], [82]
smart phone camera and sensors - (13%)		[2], [33], [51], [58], [90], [94], [99]
Thermometer - (6%)	✓	[55], [86], [96]
physical activity monitors - (4%)		[23], [72]
medication dispensers - (4%)		[91], [95]
bed sensors - (4%)		[91], [95]
Wii Balance Board - (2%)		[24]
fall detection sensor - (2%)		[58]
pedometer - (2%)		[54]
independent living activity hub - (2%)	✓	[56]
Plethysmogram (PPG) - (2%)		[86]
chair sensors - (2%)		[91]
smart shoe insole - (2%)		[97]
iPad system – (2%)		[30]

standard based architecture. These four stages also support the proposed system in [103]. In addition, the research in [104] highlights the relationship between the X73-PHD standards and "IoT health" vision. It proposes a portable, open-source implementation of the IEEE 11073-20601 stack called Antidote to increase the visibility of this standard in IoT health applications. This research was initiated in [105] where a conformance testing framework was generated for the communication model of the X73-PHD standards.

Interoperability is one of the main issues in IoT healthcare communication systems. A recent research [106] addresses this issue. It discusses the complexity of implementing the suggested method to exchange healthcare data in the data model of the X73-PHD standards when using it in the resource-constrained IoT healthcare devices. To solve this issue, the authors designed and implemented a communication system aiming to integrate the X73-PHD standards in IoT. Another research [107] addresses this issue and shows how utilizing the X73-PHD standards can help solve it. A similar research [108] reflects the importance of utilizing the X73-PHD standards between the devices in IoT healthcare services to improve the interoperability and reduce data loss while transmission. It considers this utilization a potential solution for the common challenges of IoT devices such as limited power supply, CPU capacity, and memory in addition to the challenges of IoT constrained network performance such as bandwidth, wireless channel, throughput, payload, etc.

B. X73-PHD STANDARDS AND CHALLENGES

This subsection presents the deployment challenges facing the X73-PHD standards in health systems. Then, it discusses some of the challenges faced by personal health systems and how using this set of standards can help in solving some of them.

This set of standards does not address security or any other related challenges such as the authentication of medical devices and users privacy. Many research tackle these challenges due to its importance in the integrity of the telehealthcare systems while utilizing the X73-PHD standards.

A research in [109] proposes a system developed to serve frail elderly. It uses the Near-field communication (NFC) technology as a validation method for system users. A blood pressure monitor was modified with an NFC scanner to be used with an NFC card for identification purposes. Other research proposes a possible security model for remote patient monitoring devices in [110] to overcome these challenges.

In addition to using NFC technology as a potential solution for lack of security and authentication methods in the X73-PHD standards, a research in [111] proposes a design and implementation of security policy within the standards. It uses Asymmetric-Key Cryptography and the RSA algorithm as the digital signature scheme. Other research in [112] summarizes the latest findings in the development of telehealthcare monitoring systems in Russia using standardized devices, and proposes a compliant secure personal health system.

The set of the X73-PHD standards contributes to solving some of the personal health systems challenges. It plays a critical role in the efficiency of real-time monitoring services, where continuous collection and transmission of large amount of vital health data such as ECG data is fundamental.

In addition to solving the interoperability between agents and managers, the X73-PHD standards paved the path toward developing reliable real-time systems able to transmit big amounts of data from the manager to any remote server [113]. This system proposes an extended agent and manager for data compression while maintaining the compatibility with the X73-PHD standard for ECG. It reflects the importance of developing compatible personal health systems, which helps overcome several challenges such as a limited wireless capacity and unstable channel conditions.

Other than the interoperability between agents, managers and remote services, there is also a need to address the interoperability between various types of data and the multimedia

TABLE 4. A comparison of the X73-PHD compliant systems according to type and usage.

Ref	System Type		System Usage							
			Location			Technology		Purpose		
	Complete	Prototype	U-Health	In-Home	Mobile/ Tele-Health	Android	Adopting Tech.	Proactive Well-being	Reactive Well-being	Hybrid Well-being
[28], 2005		✓		✓			✓	✓		
[61], 2006		✓					✓		✓	
[10], 2008		✓	✓				✓		✓	
[29], 2008	✓		✓				✓		✓	
[92], 2009	✓				✓		✓		✓	
[22], 2010	✓			✓			✓			✓
[24], 2010	✓			✓			✓			✓
[54], 2010	✓		✓			✓				✓
[55], 2010	✓				✓	✓		✓		
[56], 2010	✓			✓			✓			✓
[96], 2010		✓			✓		✓		✓	
[33], 2011	✓		✓			✓		✓		
[47], 2011		✓			✓					✓
[90], 2011	✓				✓	✓			✓	
[93], 2011	✓		✓				✓			✓
[32], 2012	✓		✓				✓	✓		
[44], 2012	✓				✓		✓		✓	
[53], 2012	✓				✓	✓				✓
[27], 2013	✓				✓	✓			✓	
[38], 2013		✓		✓		✓				✓
[41], 2013	✓			✓			✓			✓
[51], 2013		✓	✓			✓		✓		
[71], 2013	✓				✓		✓			✓
[79], 2013		✓					✓		✓	
[81], 2013	✓				✓	✓			✓	
[82],2013	✓				✓		✓		✓	
[95], 2013	✓				✓		✓		✓	
[18], 2014	✓				✓		✓			✓
[21], 2014	✓		✓			✓		✓		
[30], 2014	✓				✓		✓		✓	
[40], 2014	✓			✓			✓			✓
[45], 2014	✓				✓		✓			✓
[2], 2014	✓				✓	✓		✓		
[62], 2014		✓			✓		✓			✓
[80], 2014	✓				✓		✓		✓	
[86], 2014	✓		✓				✓	✓		
[89], 2014	✓			✓			✓			✓
[39], 2015		✓		✓			✓	✓		
[59], 2015	✓				✓		✓			✓
[60], 2015	✓				✓		✓			✓
[72], 2015	✓				✓	✓		✓		
[84], 2015		✓			✓		✓			✓
[85], 2015	✓				✓	✓				✓
[23], 2016	✓		✓			✓				✓
[57], 2016		✓			✓		✓	✓		
[94], 2016	✓				✓		✓		✓	
[52], 2017	✓				✓	✓			✓	
[58], 2017		✓			✓		✓		✓	
[91], 2017	✓				✓		✓		✓	
[46], 2018	✓			✓			✓			✓
[87], 2018	✓				✓	✓				✓
[97], 2019		✓			✓		✓			✓

content in real-time monitoring systems. One research discusses this point in [114].

Cloud-based multimedia services such as in [77] and [115]–[117] consider an efficient model of remote supporting services in personal health systems due to the multimodality nature of health data such as vital signals and medical images.

C. CONVERTING NON-STANDARDIZED PHDs INTO STNADRDIZED PHDs

Several research propose various suggestions to standardize common personal devices used extensively in the health field. The reason is that the majority of existing devices do not yet comply with the X73-PHD standards. Some research explain the standardization process for devices in general such as [118] and [119] while others explain the process for specific devices such as [120]–[123].

The research in [118] and [119] suggest developing a Universal PHD Adapter (UPA) and an UPA interface board to be used in home healthcare services. They proposed the standardization of a glucose meter, a weight scale and a blood pressure monitor. Standardizing the ECG as a personal health device was one of the earliest attempts [120], [121]. Research in [122] discusses the storage and transmission of ECG signals messages, while research in [123] proposes Integrated Healthcare Information System (IHIS) to provide end-to-end standardization for digital ECG signals formats.

VIII. PERSONAL HEALTH SYSTEMS REQUIREMENTS

Analyzing the results collected through this review enabled us to identify the key requirements for designing and developing personal health systems. Based on the characteristics inferred from analyzing titles, and keywords in the answer of RQ1, and from reviewing the literature of the X73-PHD standards, we propose the following list of requirements:

- Interoperability: this is guaranteed by the X73-PHD set of standards [82].
- Usability: to facilitate system's ease of use and being user friendly [82].
- Personalization: to provide self-monitoring and self-management abilities.
- Feedback to the user: to increase users' awareness about their health status and motivate them to improve their physical and psychological wellness.
- Mobility: to guarantee the ubiquitous feature for the developed system any time and everywhere.
- Accessibility: to facilitate system usage by different end-users. Wireless communication can enhance systems accessibility
- Security: to guarantee the authentication and privacy of users and devices.

IX. CONCLUSION

In this paper, we provided a systematic literature review of research related to the X73-PHD Standards. We reviewed personal health systems compliant with the X73-PHD standards and illustrated the findings that we synthesized from the collected data regarding compliant systems types, usage and characteristics. We also proposed a classification of the compliant systems usage based on the location, technology and purpose of use. We found that the majority of these systems used standardized devices and pulse oximeter is the most widely used device. Moreover, we discussed the relationship between the X73-PHD standards and IoT, the deployment challenges that face the X73-PHD standards and the conversion of non-standardized devices into standardized. Finally, we concluded by listing the requirements of personal health systems. The presented results and challenges open doors for future research.

LIST OF ABBREVIATIONS

PHD	Personal Health Device
X73	ISO/IEEE 11073
SABTE	Sleep Apnoea Breathing Therapy Equipment
PPG	PLETHYSMOGRAM
PoC	Point-of-Care
SLR	Systematic Literature Review
IoT	Internet of Things
SDK	Software Development Kit
DIM	Domain Information Model
SM	Service Model
CM	Communication Model
HL7	Health Level (Healthcare Protocol)
IEEE-WG	IEEE Standards Development Working Group
ECG	Electrocardiograph
UPA	Universal PHD Adapter
IHIS	Integrated Healthcare Information System
INR	International Normalized Ratio
CGM	Continuous Glucose Monitor

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