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LONG PAPER

Context-aware solutions for asthma condition management: a survey

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Abstract
The evolution of information technology has allowed the development of ubiquitous, user-centred, and context-aware solutions. This article considers existing context-aware systems supporting asthma management with the aim of describing their main benefits and opportunities for improvement. To achieve this, the main concepts related to asthma and context awareness are explained before describing and analysing the existing context-aware systems aiding asthma. The survey shows that the concept of personalisation is the key when developing context-aware solutions supporting asthma management because of the high level of heterogeneity of this condition. Hence, the benefits and challenges of context-aware systems supporting asthma management are strongly linked to contextual Just-In-Time information of internal and external factors related to a person and the heterogeneity it represents.

Keywords Context awareness · Asthma · Healthcare · virtual assistance · Just-In-Time information

1 Introduction

Information and Communication Technology (ICT) has impacted the health sector in different ways. One of the most beneficial tools that have been applied to healthcare is the electronic health records (EHRs). Although its main purpose is making health records more accessible, secure, and shareable, other decision support functions have been embedded in EHRs, and some of these functions have increased adherence to protocol-based medical care [1]. Studies have also shown that medical centres with greater expenditures on IT are able to increase their revenues [2], shorten waiting times, and are more likely to benefit minority populations [3].

The automation of processes that relates to a decision making in drug discovery is another example of the potential IT application to health. It is expected that automated information processing solutions can reduce major drug discovery bottlenecks by implementing patterns and best practices. This will allow drug discovery scientists to focus on the methodology and/or increasing their knowledge on diseases [4]. Machine learning (ML) is another promising field that can be applied to health, although not in the near future. The ultimate goal of ML is using algorithms able to learn automatically from data and to improve with experience over time. Nevertheless, the problem in the medical domain is the availability of small amounts of data, which makes standard ML approaches to bring insufficient results [5].

Mobile technology has also impacted the health domain by facilitating the development of ubiquitous and user-centred solutions. Mobile health (mHealth) can be defined as a part of eHealth that avoids location boundaries [6] using mobile devices and wireless communication technologies to support healthcare systems [7]. Mobile technology allows the creation of smart environments, which are environments enriched with sensing devices, to collect

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data through sensors [8]. This facilitates the collection of context-related information, where context can be defined as “any information that can be used to characterise the situation of a person, place, or physical or computational object” [9, 10].

Context awareness is an important feature of pervasive/ubiquitous computing applications aiming to deliver personalised services [8, 11–13]. Its importance lays on the fact that now, it is more relevant to analyse, interpret, and understand data, because it is possible to collect huge amounts of data from sensors. Context awareness helps to differentiate data relevant to a specific situation from data non-relevant to that situation to process it in an easier and more meaningful way [11] by exploiting contextual and situational information [14]. Determining context from collected data is a difficult task. An example of this is shown by Ziefle et al. [15], who examine the interrelation of usage context and user diversity on technical interests, purchase criteria, and usage motives. This example shows the complexity of determining context from the perspective of human-centred understanding of technology development and requirement engineering.

Ubiquitous solutions are important to improve the health system. They can help developed countries to make their healthcare programmes sustainable and to reduce the costs related to hospitalisation and specialised institutions. These solutions can also aid in tackling the low doctor-to-patient ratio that exists in rural and inaccessible areas of developing countries [16]. Thus, given the fact that there is the necessity of using context awareness when implementing ubiquitous solutions [8, 11, 14, 16, 17], it is important to develop context-aware solutions supporting health processes.

Asthma is a chronic respiratory disease affecting all age groups and, although hospitalisations and death from this condition have declined in some countries, its prevalence is increasing in many [54]. As there is no cure for asthma [57, 58], its treatment is based on a self-management approach, whose objective is to control the condition. This is challenging, because asthma is a highly heterogeneous disease affecting patients in different ways (i.e., triggers and symptoms vary from patient to patient) [57]. From this perspective, knowing the context of a person suffering from asthma is critical to define and implement their treatment.

Context-aware solutions can aid the monitoring and control processes in chronic diseases and, thus, positively impact the lifestyle management [35, 36]. This survey studies the application of context awareness to support the asthma management process. A simple example clarifying the application of context awareness to asthma is a sensible-to-pollen asthma patient tracking their location to avoid areas with high level of pollen, or sharing their location with their guardian in case of suffering from an acute exacerbation.

This survey is structured as follows to achieve its objective. Section 2 explains the main concepts related to asthma for providing the reader with a good understanding of the condition. This facilitates the explanation of the benefits and drawbacks of using context awareness for asthma management, and the analysis of the existing context-aware solutions supporting asthma management that are shown in Sect. 5.

Section 3 explores the fundamentals and application domain of context awareness. Examples of context-aware-based applications in health and chronic diseases are given. Section 4 shows the challenges of context awareness from the Software Development and the Internet of Things perspectives. Then, these two types of challenges are critically analysed and associated based on its descriptions.

Section 5 describes two groups of solutions supporting asthma management. The first group is made of solutions only tracking asthma symptoms. The second group includes the most recent solutions tracking patients’ context to support their treatment. The existing solutions presented in Sect. 5 are critically analysed in Sect. 6 to find the benefits and existing gaps in using context awareness to support asthma management.

Section 7 presents a discussion based on the findings. Some novel ideas to enhance the benefits and to tackle the gaps in context-aware systems supporting the asthma management process are also proposed. Finally, conclusions and future work are presented in Sect. 8.

2 Asthma

This section addresses concepts related to asthma to facilitate the understanding of the technologies that will be later associated with the management of the condition. This section defines and classifies asthma to provide an introduction. Then, the main approaches to treat it and the main challenges of its treatment are pointed out.

In the International Consensus Report on Diagnosis and Treatment of Asthma, asthma is defined as a chronic inflammatory disorder of the airways that causes some symptoms in susceptible individuals [52]. These symptoms are usually linked to the widespread and variable airflow obstruction, which is often reversible. The inflammation also increases airways responsiveness to a variety of stimuli [52]. The Global Initiative for Asthma (GINA) defines asthma as a heterogeneous disease, associating its definition to a history of variable expiratory flow limitation together with respiratory symptoms such as wheeze, shortness of breath, chest tightness, and cough that vary over time and intensity [54].

In 2015, in the US, 24.6 million people were diagnosed with asthma, 11.5 million people had one or more asthma attacks, and 3000 people died from asthma [56]. In 2015, in the UK, 5.4 million people were diagnosed with asthma, every 10 s someone suffered a potentially life-threatening asthma attack, three people died from asthma every day, and the annual cost to the NHS of treating asthma was more than £1 billion [55].

The origin of asthma is not completely understood, and there is no cure for it yet [57, 58]. However, it can be controlled with a daily plan to avoid triggers and reduce symptoms [59–61]. Understanding the heterogeneity of the condition is the key to acknowledge the importance of the daily plans. The heterogeneity of asthma can be explained by saying that each asthma patient may have different triggers and may experience different symptoms. Triggers' heterogeneity means that many triggers would provoke asthma attacks. However, not all asthmatics are vulnerable to the same triggers. Symptoms' heterogeneity goes beyond as they may even vary from day to day or night to day for the same patient [57].

2.1 Asthma classification

Asthma's heterogeneity makes it difficult to provide a unique classification of the disease. Aetiologically, it can be classified into intrinsic and extrinsic. Symptoms of people suffering from intrinsic asthma cannot be associated with an environmental allergen, and symptoms of people suffering from extrinsic asthma are linked to an environmental allergen [52]. Triggers in intrinsic asthma are non-specific irritants (e.g., stress and exercise) and triggers in extrinsic asthma are specific allergens (e.g., pollen and mould) [57]. Figure 1 shows examples of triggers for intrinsic and extrinsic asthma conditions.

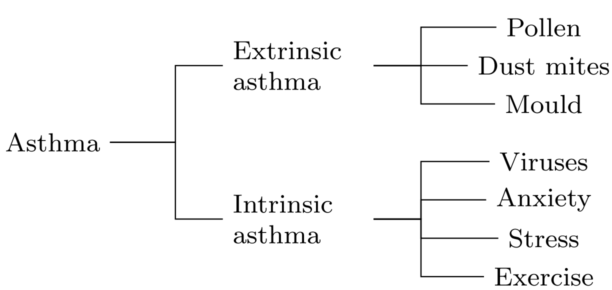

Fig. 1 Examples of triggers according to the aetiological classification of asthma

The aetiological classification helps to define preventive plans, but it does not differentiate levels of severity. A classification based on severity is critical as it aids to define the actions required to reduce symptoms. It also allows differentiating levels of exacerbations, which helps to define the actions to take in emergencies. Asthma can be classified according to its severity by considering the lung function and the clinical features existing before treatment [52]. Lung function is defined by measuring patients' maximum speed of expiration (Peak Expiratory Flow or PEF). This value represents how constricted patients' airways are. Figure 2 shows the types of asthma according to its severity.

People suffering from mild asthma experience both intermittent brief symptoms less than twice a week and nocturnal asthma less than twice a month. They are asymptomatic between exacerbations, their PEF is greater than 80% of the predicted, their PEF variability is less than 20%, and their PEF go normal after using a bronchodilator [52].

People suffering from *moderate asthma* experience exacerbations more than twice a week or nocturnal asthma symptoms more than twice a month. They require to inhale beta$_2$-antagonist almost daily. Their PEF is 60–80% of the predicted, and its variability is 20–30%. Their PEF goes normal after using bronchodilator [52].

People suffering from severe asthma experience exacerbations or nocturnal asthma frequently. Symptoms are continuous or physical activities are limited by the condition. They have been hospitalised for asthma in the previous year, or they have suffered a life-threatening exacerbation before.

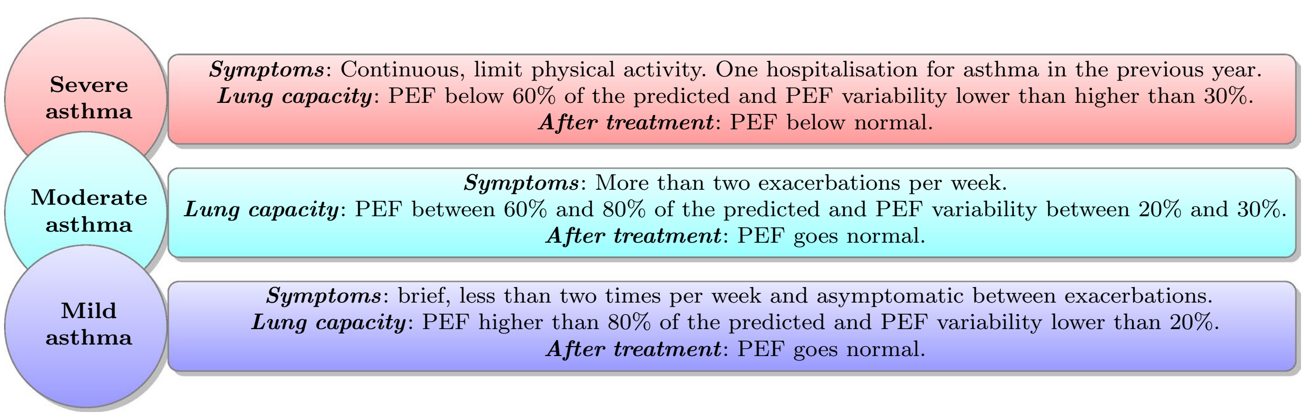

Fig. 2 Classification of asthma based on severity

Their PEF is less than 60% of the expected, and its variability is greater than 30%. Their PEF is still below normal despite applying optimal treatment [52].

The characteristics of these types may overlap given the high variation degree of asthma. However, patients usually belong to the most severe type in which any feature occurs [52]. For example, a person may have all the characteristics of a mild asthma patient, though if they have been hospitalised for asthma in the previous year, then their asthma should be considered as severe.

Knowing the severity of an exacerbation is relevant, as it can be life-threatening and can occur at any asthma severity level. Classifying exacerbations regarding PEF and symptoms is useful in the urgent or emergency care setting. Figure 3 shows the classification provided in [62], where exacerbations are divided into:

- *Mild exacerbations*: Dyspnea appears only with physical activity. PEF is higher or equal to 70% of the predicted or the patient's personal best.
- *Moderate exacerbations*: Patient shows dyspnea interfering with or limiting usual activity. PEF is 40–69% of the predicted or the patient's personal best.
- *Severe exacerbations*: Patient shows dyspnea at rest interfering with conversation. PEF is lower than 40% of the predicted or the patient's personal best.
- *Life-threatening exacerbations*: Patient is perspiring and too dyspneic to speak. PEF is lower than 25% of the predicted or the patient's personal best.

2.2 Asthma treatment

Self-management is a set of tasks people must carry out to live with chronic conditions. When it comes to asthma, it highlights the issues of dealing with a variable condition, and the ability to recognise and act according to the symptoms and signs of asthma deterioration [63].

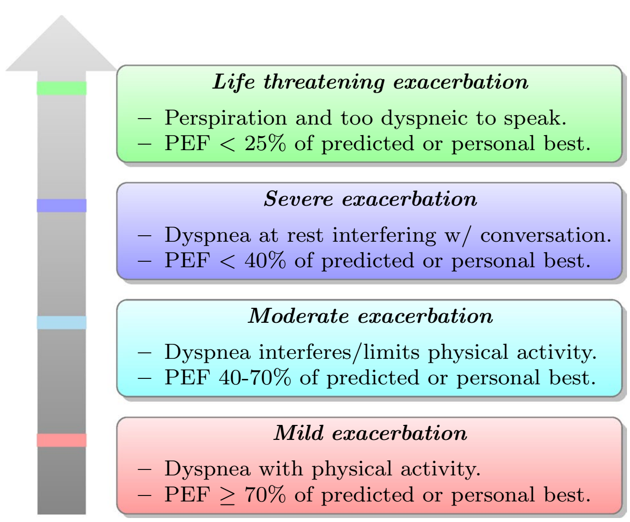

Fig. 3 Classification of asthma exacerbations

The goal of asthma management is to achieve the control of the condition. The British Thoracic Society (BTS) assigns the complete asthma control level to a patient not having daytime symptoms, not waking during the night due to asthma, not needing rescue medication, not experiencing asthma attacks, not limiting their regular activities, having normal lung function, and suffering minimal side effects from medication [63]. GINA assesses the control level of a patient by defining how well controlled their symptoms are and how likely they are to suffer a future exacerbation [54].

BTS and GINA highlight the importance of patients' education in the success of asthma management programmes. They also suggest to include pharmacological and non-pharmacological strategies in these programmes. A pharmacological strategy aims to achieve asthma control through medication, and a non-pharmacological strategy is based on avoiding triggers to improve control and reduce medication usage [54, 63].

GINA suggests using the control-based asthma management cycle that facilitates a stepwise approach to finding the optimal pharmacological strategy for patients. The treatment can be chosen and adjusted from five choices or steps, each one stronger than the previous [54]. Although the BTS does not explicitly suggest the use of a cycle, it recommends using six pharmacological levels in which patients can move up or down until finding their optimal treatment [63].

Table 1 shows a comparison between the pharmacological treatments suggested by BTS and GINA. Explaining how asthma medication is classified is important to understand the table. Controller medications are regularly used to decrease inflammation, symptoms, and future risk. Reliever/rescue medications are used in case of worsening asthma or exacerbations. Add-on therapies must be used on patients, whose symptoms are persistent in spite of having used optimised treatments [54].

2.3 Challenges in asthma treatment

Asthma management plans are difficult to implement, as patients are heterogeneous. The triggers of their symptoms are different, and the development of the condition depends on many factors. Hence, healthcare givers cannot provide a one-fits-all guideline for patients, and conversely, treatments for asthma must be personalised for every patient [45]. Pijnenburg and Szefler [36] clarify the importance of personalisation in asthma management by explaining that sometimes stepping down treatments for patients is as important as stepping up.

One of the main challenges of implementing management plans for asthma is collecting information from

Table 1 Pharmacological treatments: comparison between GINA and BTS guidelines

GINA		BTS	
Step 1	–	Level 1	Monitored low-dose of controller
Step 2	Low-dose of controller	Level 2	Low-dose of controller
Step 3	Low-dose of 2 controllers	Level 3	Low-dose of 2 controllers
Step 4	2 or more controllers in higher doses	Level 4	Regulate the dose of the 2 controllers
Step 5	Add-on treatment	Level 5	Add another drug
–	–	Level 6	Add oral steroids or alternative treatments

All steps and levels include the use of reliever medication as needed

heterogeneous patients to define and adjust their customised treatments. This makes it important to consider context when defining and implementing asthma management plans. However, Osuntogun and Arriaga [44] show that physicians only can know asthma patients' status when they go to the medical centres for regular visits (approx. twice a year) or for emergencies. Hence, it can be argued that collecting data to determine patients' context would allow healthcare givers to deliver better-personalised treatments in less time by analysing more information about patients' current health status.

The inclusion of people interested in the condition of an asthma patient (stakeholders) is another important challenge to tackle. Yun et al. [45] show the example of a mother that left her job, because it was tough to manage her daughter's moderate asthma. In the same study, another mother reported that managing her daughter's mild asthma was interfering with her job. From this, it can be said that implementing an asthma management treatment is difficult, as it involves changing daily activities of families, even when the asthma condition is not severe. Hence, defining the information that the main stakeholders require, the format in which they require it and the right moment when they require it can be extremely useful and should be taken care of whilst developing solutions supporting asthma management to enhance its effectiveness.

This section discusses the fact that the heterogeneity of asthma is one of its most challenging characteristics. This heterogeneity makes patients sensitive to different triggers inducing the disease and to experience different symptoms when they suffer exacerbations. Because of this, the concept of personalisation is important in asthma management, and from this point of view, defining what is relevant to track is the key to implement an efficient asthma management plan. This means that each patient assigns different levels of relevance to the information units building the background to manage their asthma. This set of information units and its relevance frame the context of an asthma patient. Hence, solutions including context-aware features can support the asthma management process, as they can react to what is important for each asthma patient.

Figure 4 shows examples of context for two asthma patients. The set shown on the left is part of the context of

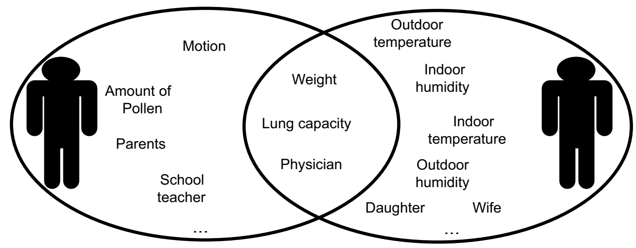

Fig. 4 Examples of context for asthma patients

a male asthmatic child, whose main triggers are exercising and pollen. Thus, his context includes motion and amount of pollen in his nearby to help him to prevent exacerbations. Parents and school teachers are part of his context, as they are interested in knowing his status to take actions in case of an abnormality. His physician is also interested in knowing how his condition evolves. Lung capacity is an indicator of his status, and weight is a long-term indicator helping to improve the control level of the disease.

The set shown on the right of Fig. 4 illustrates the context of a male adult asthma patient vulnerable to high levels of humidity and sudden temperature changes. In this case, knowing the temperature and humidity levels of indoor and outdoor environments is important to prevent exacerbations. These indicators are part of his context. The patient has a wife and a daughter old enough to assist him in case of emergency. Hence, they are part of his context as stakeholders. Lung capacity, weight, and the physician are part of the intersection, as they are common elements for both contexts.

Figure 4 helps to clarify how the contexts of two asthma patients differ, given the heterogeneity of their conditions and their personal situations. The context of a patient is made of the elements that are relevant to manage their disease. Hence, although the contexts of two patients may include some common elements, they are likely to be different.

This section presented relevant concepts to understand asthma. The definition of the condition has been given, and classified according to its triggers and its severity. Two of the most acknowledged treatments to manage the condition have been shown, and the main challenges of implementing these treatments have been described. The heterogeneity of asthma has been analysed and linked to the concept of context. In the next section, concepts related to context awareness are explained to facilitate the understanding of its application to asthma management.

3 Context awareness

This section provides an explanation of context awareness and its main fields of application. Some application examples of context awareness in healthcare and in some chronic diseases are described with the aim of facilitating the description and understanding the existing context-aware systems supporting asthma management (Sect. 5).

Surveys related to context awareness [11, 20] state that the most acknowledged definition for context and context awareness is given in Refs. [9, 10]. Context is defined as "any information that can be used to characterise the situation of an entity, where an entity can be a person, place, or physical or computational object". Context awareness—which is also known as context-aware computing—is defined as "the use of context to provide task-relevant information and/or services to a user".

A person going to a specific supermarket can be used as an example to explain these concepts. The entity, in this case, is the person, and the situation is reaching the supermarket. Some information characterizing this situation is the location of the person and the location of the supermarket (context). Then, a context-aware solution would be a mobile application showing the person the shortest path to get to the supermarket. This example of context would get more complex if we add more elements to the situation. For example, if the person is disabled, the context-aware solution should take into account the disabled access before recommending the path to follow.

One of the main enablers allowing the creation of context-aware solutions is the development of sensor technology. Body sensors are especially important when it comes to gathering data relevant to the health context. Body area networks (BAN) are made of body sensors attached to clothing/body or implanted under the skin. They offer several applications to improve human health and the quality of life. Examples of body sensors are accelerometer, gyroscope, glucometer, pulse oximetry, among others. It is possible to use these sensors because of the miniaturisation of electrical devices and the widespread of wireless networks [14].

3.1 Application fields of context awareness

Context awareness is considered a core feature of pervasive/ubiquitous computing [8, 11]. Acampora et al. [14] also acknowledge context awareness as one of the main characteristics of Ambient Intelligence allowing the use of contextual and situational information to personalise the delivery of services. Furthermore, given the fact that Intelligent Environments are built on the concepts of Pervasive/Ubiquitous Computing, Smart Environments, and Ambient Intelligence [8], context awareness is also associated with Intelligent Environments.

The application of context awareness will be analysed from the Intelligent Environments perspective. Eight emerging applications in which context awareness plays a key role will be explained. These applications are related to Transportation, Education, Production places, Smart offices, Intelligent supermarkets, Energy conservation, Entertainment, and Health [8].

The application of context-aware systems to transportation is already delivering benefits. GPS-based spatial location is one of the best tangible examples of using context to improve the transportation system. With the appropriate algorithm, it is possible to analyse drivers' context (location, speed, route, etc.) for making transport more fluent, efficient, and safe. Waze [22] and Google Maps [23] are two examples of applications gathering and analysing drivers' context with the aim of providing them with services to avoid traffic or hazards. Google Maps also supports users to find the best route using public transport, bicycles, or even walking.

Context awareness can also be applied to education with the aim of supporting staff and students to obtain better results. It can be used to create smart classrooms using innovative learning methodologies that improve the learning process and support students and lecturers' activities outside the classroom. An example of this is given in [24], where a Virtual Assistant able to dynamically interact with users and to provide answers to context-specific questions was designed and evaluated showing positive results.

Workplaces can benefit from context-aware solutions. Companies can improve their Production-Oriented Places using sensors (e.g., RFID) to tag and track products. This aids the supply chain management by providing relevant information to face changes in the demand for the products offered by companies [26, 27]. The implementation of Smart Offices is another application example of context awareness in the workplace. Offices with the right equipment aid employees to increase their efficiency when performing their tasks by taking into account their context [8].

Intelligent supermarkets use context awareness to enhance the shopping experience of customers. These supermarkets are made of objects that interact with customers by interchanging visual and auditory information. This allows the collection of data that will be used to determine customers' context. Then, this context is used to provide customers with more suitable products and services. An example of a model supporting the creation of Intelligent supermarkets is the "Ubiquitous User Model Service" that provides contextual information about customers' profiles, actions, characteristics, and location in the supermarket [25].

Smart homes are the main example of using intelligent environments to control lighting and temperature in an automated way. It helps to improve energy conservation by optimising the consumption of energy resources. A simple example of this is controlling the heating system of a house through a mobile application allowing users to set the desired indoor temperature and the time in which people will be at home with the aim of avoiding turning the heating on when no one is there. Another example is setting the lights to only turn on when someone is inside a room. Context awareness also has the capacity of enhancing users' entertainment experience. Many houses are equipped with devices providing a more immersive gaming experience [8].

Health-related applications of context awareness are able to increase the efficiency of health services and safety. Given the fact that this research is focused on health, application examples of health context-aware systems are shown in separate Sects. 3.2, 3.3, and 5.

3.2 Context awareness in healthcare

Context-aware solutions to support processes improving people's health have been developed. An example of context awareness applied to health is the mobile application called Medication Assistant [28]. This application aids to face the problem of medication non-adherence in older adults. The solution focuses on age-related factors (such as inherent medication increase, cognitive losses, and demotivation) not allowing the elderly to follow proper medication management. Multimodality and context awareness are used to provide advice and support in the medication management of older adults.

The Hefestos wheelchair is an example of a system using context awareness to support people with disabilities in their daily activities. It is the prototype of an intelligent system considering user profile and contexts to provide resources for wheelchair accessibility through a mobile device. In this case, context is mainly linked to physical places, where users interact (e.g., building, room, and street) and its features associated with accessibility (e.g. ramps, lifts, assistance). The results of the qualitative research performed to evaluate Hefestos showed 98% of acceptance in perceived usefulness of the technology. Moreover, it is expected to adapt Hefestos for being able to support different kinds of disabilities [29].

Context awareness has shown potential to help people in emergency situations. SOSPhone is a mobile application allowing users to make emergency calls through an iconographic interface running in touchscreen mobile devices. This solution assists people having problems when making emergency calls. These problems can be caused by disabilities (e.g., hearing loss and deafness) or trauma situations (shock/panic situations under emergencies). To achieve this, the application enables users to contact the emergency centre by choosing the icons representing the occurrence and by answering simple questions. After this, an SMS describing the situation (information selected, the user's profile and location) is created and sent to the emergency centre [31].

There is a strong link between context awareness and Intelligence Environments (IE). The origin of context awareness is associated with the need to improve human–computer interaction in some research areas like Ubiquitous Computing or IE. Context awareness is used to interpret what users need [21]. IEs are built on three concepts: pervasive and ubiquitous computing, smart environments, and ambient intelligence. Pervasive/ubiquitous computing is related to providing users with distributed and context-aware computational services that can be used across different environments. Smart environments are environments enriched with sensing devices, which facilitates the collection of data to determine context. Finally, ambient intelligence involves software assisting people in their daily activities. This software translates context into a set of rules to deliver relevant information regarding the situation [8].

Context awareness—as part of Ambient Intelligence applications—has also been applied to healthcare. Its application is divided into six groups from an Ambient Intelligence perspective [14]. The continuous monitoring group includes systems commonly using non-invasive sensors to monitor patients. Some of these systems monitor health conditions, which is useful to control chronic diseases in which typical measures are taken only during occasional visits. Other systems of this group monitor behaviour and can be used in assisted living settings to monitor individuals with mental disabilities. Finally, others monitor patients with the aim of detecting emergency status (e.g., fall detection).

The assisted Living group is made of Ambient Intelligence solutions using home automation to support people with disabilities in achieving more autonomy in their daily activities. Besides providing continuous cognitive and physical monitoring, it also can assist patients in real time. Most of these services have been used to assist elderly, but there is a potential to create novel solutions that can do both improve medication management and support people suffering from dementia and visual impairment [14].

Ambient Intelligence solutions have the potential to fulfil the rehabilitation needs by delivering systems based on sensor networks. For example, equipping patients with wireless, wearable, or environmental vital sign sensors would allow the collection of real-time data that can be used to enable autonomous rehabilitation and therapy. The existing technology is not even close to being enough to fulfil these needs. Hence, it is important to focus on a consolidated effort in this domain of research. Solutions aiming to close this gap are part of the Therapy and Rehabilitation group [14].

The Persuasive Well-Being and Emotional Well-Being systems are two types of context-aware systems that are more closely related to improving the well-being of people. Persuasive Well-Being systems aim to motivate people to change towards a healthier lifestyle. An example of this is using virtual and augmented reality to treat childhood obesity and improve eating habits using games (e.g., motion sensing controllers). The emotional well-being group is made out of systems using sensors to recognise emotions through physiological changes (e.g., blood pressure, bpm, and respiration), and audio and gesture analyses. It can be used to aid emotions management [14].

Smart Hospitals are built from using Ambient Intelligence technology to ease communication among nurses, doctors, and other stakeholders within a hospital [14]. It uses contextual information (e.g., location, profile, and availability) to provide support in hospitals' daily activities. Holzinger et al. [30] also highlight the importance of context awareness in the creation of Smart Hospitals by acknowledging the adequate use of context as a future challenge in this subject.

3.3 Context awareness in chronic diseases

Given the importance of health in people's quality of life, there is always the concern of developing technologies that can be applied to healthcare processes to improve quality and efficiency. When it comes to chronic diseases, this concern acquires an even higher relevance, because the number of people suffering from it is increasing. Two of the main reasons of this increment include illnesses that were mortal in the past are now treated as chronic diseases [32] and the strong link between the rise of chronic diseases and the ageing population [33].

As there has not been a relevant success in developing cures for chronic diseases like Alzheimer and diabetes, in spite of the resources focused on it [18], other solutions are being used to face these diseases. One of the aims of community-centred care, which is one of the two trends that are converging to shift the US healthcare paradigm, is to focus on lifestyle management to prevent or cope with chronic diseases [34]. From this point of view, context awareness has the potential of improving lifestyle management by enhancing the monitoring and control of chronic diseases [35, 36].

Researchers are aware of the critical role that technology plays in self-management. Osuntogun and Arriaga [44] state that technological solutions supporting continuous care and management of patients with chronic illnesses are increasing. Isakovic et al. [35] suggest using mobile applications as tools for self-monitoring. Samples et al. [34] explain the opportunity of using mHealth to improve health outcomes and reduce costs by empowering patients in their self-management processes. Finally, Harvey et al. [32] describe technologies that can be used to control chronic conditions and to adjust lifestyle by monitoring patients' status in real time.

An example of using technologies to improve lifestyle management is a cardiovascular disease home-based rehabilitation system called HeartHealth. Its aim is improving patients' adherence to prescribed exercises in their rehabilitation process from cardiovascular diseases. The system is loaded with the exercise programme a patient must do at home and simulates a game based on that programme. The system uses a camera and image recognition techniques to assess whether the patient is doing the rehabilitation exercises well or not. After this analysis, it provides feedback to the patient and their healthcare professionals [38].

The development of technology, especially in the field of mobile devices and wireless connectivity, has allowed the creation of context-aware solutions aiding the management of chronic diseases. An example is a context-aware system that increases accuracy when measuring blood pressure [39]. This system is made of four sensors (2 for the feet, 1 for the seat, and 1 for the back), whose aim is to ensure that patients sit and rest for 5 min with their back supported and their feet flat on the ground before measuring blood pressure. The evaluation of the system confirmed that it increases awareness and improves patients' technique.

The Interactive mobile Health System (ImHS) is another example of using context-aware solutions to face a chronic disease. It monitors blood glucose of diabetes patients to determine their health status and to execute actions depending on that status. The ImHS uses a General Packet Radio Service (GPRS) Blood-Glucose Monitor to collect patients' blood-glucose level. This information is uploaded to a cloud server to determine the patient's health status after analysing it. The system also performs automated actions such as notifying caregivers if the patient's status is critical [40].

This section explained the main concepts related to context awareness. Its definition and application fields were described. Furthermore, application examples of context awareness in healthcare and, then, more specifically in chronic diseases have been used to illustrate how context-aware systems can aid people in their daily activities to improve their health. The next section explains the main challenges of context-aware systems.

4 Challenges of context awareness

This section describes the challenges of context awareness from the Software Development and Internet of Things (IoT) points of view. Section 4.1 explains the challenges of contex awareness from the Software Development perspective, and Sect. 4.2 explains the challenges from the IoT perspective. Then, Sect. 4.3 explains the relationship between the

Software Development and the IoT challenges of context awareness.

4.1 Software development challenges of context awareness

The challenges and demands of context-aware systems from the Software Development perspective are divided into three groups [20]:

- *Diverse and specific systems* refers to the fact that context-aware services are usually developed as a feature of an existing system. Thus, its implementation strongly depends on the specifications of the existing system, which makes the context-aware functionality a very ad-hoc solution difficult to reuse in other systems.
- *Context information handling* refers to acquiring context information from several heterogeneous sources, translating the acquired information into a more understandable format (e.g., from GPS coordinates to a street name), inferring conclusions to obtain more meaningful information regarding context, and distributing this information to the consumer. These issues are associated with the context lifecycle proposed in Ref. [11].
- *Technological demands* are related to the high level of reliability required; the high cost of developing, executing, and maintaining context-aware systems; the complex infrastructure needed to ease the development process; and the necessity of making context-aware systems flexible enough to support a requirement that seems invariant.

4.2 IoT challenges of context awareness

Academia and industry have focused their attention on the IoT during the past decade. Context awareness will play an important role in IoT because of the high amount of data to be collected through the billions of sensors that will be connected to the Internet [11]. Hence, it is relevant to analyse context awareness from the IoT perspective. In Ref. [19], IoT is defined as "a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols". In the same context, a more general definition is provided by characterizing IoT as "things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts". The last definition shows a strong link between context and IoT. Perera et al. [11] analyse the challenges and future research directions of context awareness from an IoT perspective:

- *Automated configuration of sensors* Given the fact that IoT conceives billion of sensors to be connected together over the Internet, this challenge refers to the impossible task of connecting these sensors manually to a specific application or Middleware. Research should focus on tackling this challenge, as efforts on this are still immature.
- *Context discovery* A high number of sensors allow to collect more context-related data. However, it brings the challenge of understanding the data collected through sensors with the aim of integrating it. The data collected are expected to be highly heterogeneous because of the wide variety of sensors in the IoT paradigm.
- *Acquisition, modelling, reasoning, and distribution* This challenge is related to the fact that existing techniques used to acquire, model, reason, and distribute context data are not suitable to handle the different context perspectives brought by the IoT paradigm. Hence, there is the necessity of standards able to incorporate and integrate multiple techniques to ease these processes.
- *Selection of sensors in a sensing-as-a-service model* The availability of a high number of sensors will provide people with more options to collect data. Nevertheless, this high availability will become a problem when choosing the right sensor to gather data. This is expected to be the most difficult challenge to tackle when collecting context data in the IoT.
- *Security, privacy, and trust* Context-aware computing increases the security threats and the possibility of misusing context data. The more data collected from people, the higher the risk of endangering their security and privacy.
- *Context sharing* Having a context-aware middleware domain facilitates the sharing of context data among applications connected to it. Sharing context data is also feasible between different middleware. Nonetheless, IoT envisions no central point of control, as heterogeneous middleware will control different solutions. It is important to share context data among all the IoT network, and thus, sharing relationship models among different context-aware solutions is important.

Context awareness is considered a key aspect of the IoT paradigm [11]. As can be seen, all the challenges, but security, privacy, and trust, are related to integrating highly heterogeneous data sources efficiently. The integration concern related to context awareness can be explained by arguing that context-aware solutions acquire heterogeneous data that need to be modelled and translated in a meaningful way, so it can be reasoned to obtain higher level information [21]. Finally, the data need to be ready for different applications on demand.

Some of the integration challenges are associated with integrating equipment developed by different providers using different communication protocols. In this research, these are referred to as hardware challenges. The other integration challenges are linked to the integration of different data models supporting the collection of data for context reasoning and to different applications that should be able to communicate among them to share context data. These integration challenges are referred to as software challenges in this research.

4.3 Software development challenges vs. IoT challenges

This section highlights the existing relationship between the two types of challenges previously explained in Sects. 4.1 and 4.2. This relationship has been built after analysing the description of each challenge. Figure 5 illustrates the relationships among the challenges from the software development perspective and the challenges from the IoT perspective.

The Software Development Challenge (SDC) known as diverse and specific systems is linked to the following IoT challenges (IoTCs): automatic configuration of sensors, security privacy, and trust and context sharing. This SDC is about the high degree of dependency of a context-aware system to the existing system in which it will be implemented as a feature. Then, the task of connecting the existing sensors to the new context-aware system will be more demanding, or even impossible to do, if the number of existing sensors is too high (Automatic configuration of sensors). Moreover, the security, privacy, and trust characteristics of the existing system should be a constraint to consider when implementing the context-aware system as well as the Context sharing tasks among different applications that will benefit from the context-aware feature.

Context information handling is an SDC that can be associated with four IoTCs. These associations are evident given the description of this SDC. Acquisition, modelling, reasoning, and distribution are the IoTC with the strongest link with this SDC. The IoTC selection of sensors is also related to this SDC, because choosing the right sensor to gather data impacts the process of acquiring context information from several heterogeneous sources. Given its relevance to protecting people, security, privacy, and trust are considered as a restriction when defining how to handle context information. Finally, context sharing is relevant to this SDC because of the necessity of distributing information inferred from context to consumers, which may include a set of solutions without a central point of control.

The SDC technological demands have strong links with three IoTCs. From the description of this SDC, it can be said that tackling the automatic configuration of sensors will decrease the cost and improve the reliability and flexibility needed of context-aware systems. The selection of the right sensors in a sensing-as-a-service model is also important to make context-aware systems technologically reliable at an affordable cost. The last IoTC strongly linked to this SDC is security, privacy, and trust, because it is a restriction to define the reliability and flexibility levels of a context-aware system, and it is also capable of increasing its costs.

It is important to state that each software development challenge may be linked to all IoT challenges from a specific perspective. For instance, someone may correctly say that all the IoT challenges are linked with the SDC technological demands, because all of them influence when defining the infrastructure to use in the development process of a context-aware system. Nevertheless, Fig. 5 summarises one of the contributions of this research by showing the strongest links between both types of challenges, which have been analytically inferred from their descriptions.

This section described the challenges of context-aware computing from the Software Development and IoT perspectives. The relationships among the SDCs and the IoTCs have been inferred from their descriptions. The description

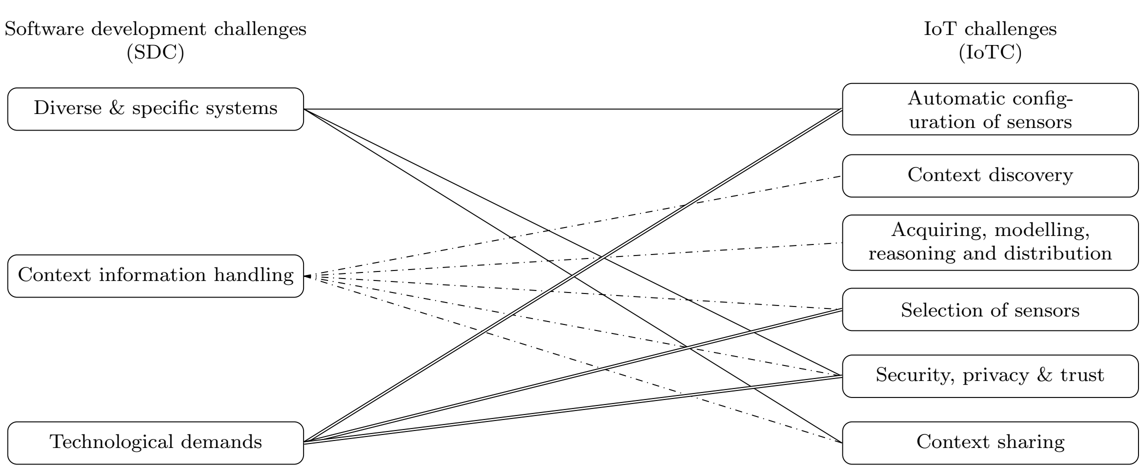

Fig. 5 Context awareness: software development challenges vs. IoT challenges

of these challenges will help to analyse the existing context-aware systems for asthma management that are explained in the next section.

5 Existing context-aware systems for asthma management

The main objective of this section is describing the main features of existing solutions using context awareness to assist people suffering from asthma. However, other interesting research works on the subject are also shown. First, the findings of a research work about the evolution of mobile apps for asthma are described. Then, three novel devices able to analyse symptoms of asthma are presented. Finally, more comprehensive solutions implementing context-aware features linked to the management of the condition are described. The following databases were used in the search process: ScienceDirect, SpringerLink, PubMed, IEEE Xplore, and ACM Digital Library. The results were narrowed down to include research works implementing or suggesting the implementation of context-aware features to support the asthma management process.

Huckvale et al. [43] analysed the evolution of mobile applications for asthma, reaching the conclusion that the market landscape is made of low-quality generic information applications. The information offered by these applications is a concern because of the potential risks of clinically relevant impact resulting from inadequate content. The applications do not support individuals in changing behaviour nor offer tools allowing the communication between professionals and patients. They are not likely to satisfy evidence-based recommendations for information content nor the design of self-management tools. The research also shows that most of the applications offer simple peak flow diaries or very basic background information about the condition. Moreover, the applications do not focus on the gaps in asthma management. Because of this, this survey does not consider these mobile applications as context-aware systems.

Table 2 presents three devices that can be used to track asthma symptoms. The first analyzes cough sound, the second focuses on diaphragm motion, and the third measures lung capacity. An explanation of these solutions is given below.

Al-khassaweneh et al. [37] developed a solution to record and analyse cough sound with the aim of recognising the state of patients. Using cough sound in asthma is important, because it would be the only symptom in some cases. The system uses a keypad to start and stop the process, a microphone to record patient's cough sound, and an LCD to display the diagnosis of cough sound after analysing it with an algorithm developed using MATLAB. The results of the testing process showed that the solution correctly classified about 85–90% of the recordings. The researchers suggested that the proposed system can support parents to monitor their children asthma process.

Liu and Huang [41] used an ultrasound probe to monitor the diaphragm motion in the respiratory process of asthma patients with the aim of discovering patterns. After analysing diaphragm motion, four templates were identified: one template representing normal breathing and the other three representing frequent coughing, breathing faster, and

Table 2 Devices used to track asthma symptoms

Research	Tracked symptom	Devices	Details	Benefits (+) and drawbacks (−)
[37]	Cough sound	Keypad	Analyse cough sound to detect different status of asthma patient An alarm is shown when an asthma attack is present	+ Coughing is the only symptom for some types of asthma – Portability: low – Automation: low – Accuracy: 85–90
[41]	Diaphragm motion	Ultrasound probe	Analyse diaphragm motion in the respiratory process of asthma patients	+ Templates to identify irregular symptoms were developed + Allows real-time analysis + Automation would be high – Portable ultrasound device does not exist yet
[42]	Lung capacity	Audioflow: PEF meter	Audioflow connects to smartphones through the headphone (audio) jack An application processes the audio frequency to know the PEF measure	+ Meets the ATS Standard + Automation: medium–high + Portability: high – Does not allow real-time analysis

shortness of breath. Although no device was developed, it is stated that these templates can be used to design a portable ultrasound device to detect/predict asthma attacks on patients.

Natarajan et al. [42] developed a cost-effective device called Audioflow, which is a PEF meter able to communicate with smartphones through the headphone (audio) jack. This device measures the maximum flow rate exhaled from patients, and can be used to monitor their lungs capacity by measuring their airways obstructions. The device was validated, and met the spirometry standard given by the American Thoracic Society (ATS) Standard regarding PEF meters.

There are research works carried out aiming to develop more comprehensive solutions supporting asthma management. Tables 3, 4, and 5 summarise the details of the research works delivering applicable solutions to monitor more indicators that support decision making for asthma management in a more comprehensive way. More specific details about these research works are given below.

Osuntogun and Arriaga [44] proposed a system that keeps a record of patients' symptoms and medication usage. For doing this, the system sends a questionnaire through SMS asking for these details. Then, the patient replies to the SMS giving information about their symptoms and medication usage. Finally, the system collects, processes, and makes these data available to be reviewed by the patient and healthcare professionals. The research addresses the fact that physicians are only able to know relevant data about their asthma patients in the consultations, hospitalisations, or emergency visits. Thus, the use of a dashboard showing relevant information about patients to physicians (physician dashboard) is proposed. Moreover, it is suggested to send alarms to physicians about specific concerns and to merge the system with the Electronic Medical Record (EMR).

Yun et al. [45] studied how technology probes can be used to manage paediatric asthma patients. A qualitative research including three families was performed after asking them to use a system made of four components: a temporal data management application called Salud! allowing users (patients or families) to enter and visualise data, a Peak Flow Meter (PFM), an indoor quality sensor to monitor indoor air quality, and a multifunction widget installed in the computer allowing user to do both check the outdoor air-quality index based on the ZIP code of their home and register values from the PFM and indoor quality sensor into Salud!

The results of the research were overall positive. It was found that the collected data helped to easily recognise patients' symptoms and triggers, which was also motivating and engaging for patients and their families. It was also shown that the level of technological support should be

Table 3 Patients' indicators tracked by reviewed solutions

Research	PEF	FEV_1	FEV_6	FVC	NO	CO	O_2	Blood O_2 level	HR	RR	Wheezing	Motion	Exercise	Medication	Control level
[44]	–	–	–	–	–	–	–	–	–	–	–	–	–	✓	✓
[45]	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–
[46]	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	✓
[47]	–	–	–	–	–	–	–	–	–	–	✓	✓	–	–	–
[48]	✓	✓	✓	–	✓	✓	✓	–	–	–	–	–	–	–	–
[49]	–	–	–	–	✓	–	–	–	–	–	–	–	–	–	✓
[50]	✓	✓	–	✓	–	–	–	✓	–	–	✓	–	✓	✓	–
[51]	✓	✓	–	✓	–	–	–	–	✓	✓	✓	✓	–	–	–

Table 4 Environmental indicators tracked by reviewed solutions

Research	Overall air quality	Temperature	Humidity	CO	O_3	NO_2	Cl	VOC	Weather announcements
[44]	–	–	–	–	–	–	–	–	–
[45]	✓	–	–	–	–	–	–	–	–
[46]	–	–	–	–	–	–	–	–	✓
[47]	–	–	–	–	–	–	–	–	–
[48]	–	–	–	–	–	–	–	–	–
[49]	–	✓	✓	✓	–	–	–	–	–
[50]	–	✓	✓	✓	✓	✓	✓	–	–
[51]	–	✓	✓	–	✓	–	–	✓	–

Table 5 Other features of the reviewed solutions

Research	Automation level	Notifications	Stakeholders	Virtual assistance
[44]	Low	None	Healthcare professionals	No
[45]	Low	None	Family[a]	No
[46]	Medium	Alert of weather changes and when a PEF reading is less than normal	Healthcare professionals	No
[47]	Unknown	None	None	No
[48]	Medium	None	Healthcare professionals	No
[49]	Medium–high	Reminders to take readings once a day	None	No
[50]	Medium–high	Alert patients when context is not normal	Healthcare professionals	No
[51]	High	None	None	No

[a]Family were subjects in the qualitative research done to validate the proposal. They were not information recipients of the system

personalised to each family depending on the severity of the patient's condition and the users' technological practices. However, the main drawback of the system is that users must enter data about patients in a non-automated way. This means that, after using the PFM or checking the indoor quality index, users needed to enter these values into Salud! using the multifunction widget. This is important, because people tend to stop using systems altering or slowing down their activities. Other drawbacks include the system not allowing communication with healthcare professionals and not detecting potentially risk cases.

Al-Dowaihi et al. [46] proposed mBreath, an asthma monitoring system on the go. mBreath allows patients to use a PFM device that automatically sends measures to a smartphone via Bluetooth. It also allows patients to answer simple questions using the smartphone to know their control level. Then, the system uploads this data, allowing medical staff to check it through a web-based interface. Another feature is notifying patients and their doctors when the PFM readings are less than their normal condition. It also provides users with weather announcements, notifications of relevant weather changes (sand storms) and an educational module.

mBreath was validated through qualitative research. The results show that the application was recognised as satisfactory, useful, and effective in asthma management. The researchers proposed to add more features like integration with pollution sensors and tracking patients location to suggest the location of nearby hospitals in case of emergency [46]. Nevertheless, when comparing mBreath with other solutions, it can be said that the analysis of the patient's condition to identify an emergency could be improved, as it is only based on the peak flow reading, without considering other relevant factors that can enhance decision making to prevent asthma attacks (e.g., air pollution). Moreover, the weather information provided is not specific enough to warn patients about their closest environment, as the weather announcements are related to the city, where patients live in.

Uwaoma and Mansingh [47] proposed a monitoring system that uses only smartphones built-in sensors. It monitors both patients' activity by strategically placing the smartphone on the body and wheeze sound through the smartphone's microphone. An algorithm recognising when the patient deviates from their activity baseline was also developed to monitor activity. The algorithm also classifies the recorded wheeze sounds into three types: normal respiratory sound, baseline sound, and wheeze sound. In that research, it is suggested to include medical knowledge in the algorithm to use machine learning techniques for increasing robustness and to use the built-in capabilities of some smartphones to monitor temperature (thermometer), humidity (hygrometer), and air pressure (barometer).

Using only built-in smartphone capabilities is the main feature of this proposal. Thus, although the human–computer interaction of the system is not specified in the research, it is expected that a highly automated solution can be developed from this research, because it uses only built-in smartphones capabilities. However, developing a solution that fully depends on built-in smartphones capabilities would be difficult to spread and standardise, because mobile devices from different brands and models have different quality levels in the production process of their components. For example, if the microphone and audio processing capabilities of the smartphone are not good enough, then the process to classify a wheezing sound for a specific patient will be unreliable.

Kwan et al. [48] created a system able to connect with mobile devices that work on Android OS. It is made of two components: a portable external mobile device and a software application. The mobile device tracks patients' health status by measuring the PEF, Forced Expiratory Volume in 1 s (FEV_1), the Forced Expiratory Volume in 6 s (FEV_6), and the following chemical breath biomarkers: Nitric Oxide

(NO), Carbon Monoxide (CO), and Oxygen (O_2). The application collects and stores these measures and sends it to a physician by email.

It can be said that the main benefit of this system is its ability to collect different indicators that frames patients' health status. This diversification is important, as it reduces the uncertainty when analysing an asthma patient. The main drawback is that the system does not include the collection of environmental data to support the decision-making process. Adding this feature is critical, because asthma patients are heterogeneous and it will help to identify their triggers and symptoms.

Anantharam et al. [49] adapted kHealth (a platform that enhances decision making and improves health, fitness, and well-being) to control asthma. The proposed system uses two sensors: a NODE sensor to know the inflammation level in patients' lungs by monitoring the NO level from their respiration and a sensor drone to track temperature, humidity, and CO levels from patients' environment. Another component of the system is a mobile application that sends reminders to take readings once a day, collects data from sensors, and takes answers from patients regarding a questionnaire to establish the control level.

It is important to highlight that Anantharam et al. [49] suggest the following to improve the system: adding more sensors to track more indicators, using "all-in-one" and passive sensors to improve usability, allowing patient's doctor to give instructions through the mobile application, and sending alerts to patients and their guardians when an emergency is detected. Moreover, when comparing this system to others, it can be stated that its main advantage is its ability to deal with high level of automation when taking readings, and the inclusion of environmental indicators affecting patients.

Ra et al. [50] developed AsthmaGuide as an ecosystem to monitor asthma and provide advice. The system collects physiological and environmental data that are sent to a smartphone hub that uploads data to the cloud. Wheezing sounds, information about lung capacity and blood oxygen level, are gathered through an electronic stethoscope, a spirometer, and a pulse oximeter, respectively. Temperature, humidity, CO, ozone (O_3), nitrogen dioxide (NO_2), and chlorine (Cl) levels are gathered through a sensor drone. Environmental data are obtained from databases using the zip code provided by the patient. Finally, information about medication dosage and exercise is manually entered by answering ten multiple choice questions.

AsthmaGuide is the most comprehensive system reviewed. One of its most important features is its capacity to classify lung sounds to detect wheezing. The system also notifies healthcare providers and patients when the collected data trigger an alarm as regards patients' health status. Furthermore, it includes a cloud web application that can be accessed by patients and healthcare providers to review patients' data. Other relevant features include alerting patients when air quality is unhealthy and assisting patients depending on their health status with very general and expert advice from existing asthma standards. Doctors that were included in the qualitative research performed to validate Asthma Guide stated that the system could be used to support other lung problems.

Dieffenderfer et al. [51] built a low-power wearable sensor system made of a wristband, a chest patch, and a portable spirometer. The wristband collects motion from the patient, and ozone exposure, Volatile Organic Compounds (VOC) level, temperature, and relative humidity from the environment. The chest patch gathers heart rate, respiratory rate, acoustic signals (wheezing), and skin impedance. The handheld spirometer is used to obtain the FEV_1, PEF, and forced vital capacity (FVC) to know the lung capacity and airways obstruction level. These devices use the Bluetooth low energy standard to connect with an integration device (laptop, tablet, or smartphone) that uploads the data to the cloud.

In spite of the handheld spirometer, this is the most automated system reviewed, and it allows to monitor asthma patients continuously. It is designed to use components consuming less energy, and was successfully tested in a controlled environment. Furthermore, the authors suggest the following: (1) to use the proposed sensor system with the aim of gathering information to develop an algorithm that predicts asthma attacks; (2) to allow physicians to review data for knowing how activity level, ozone, and VOC exposure affects asthma patients; and (3) to keep doing research for reducing the power consumption level of the system.

6 Critical analysis

This section analyzes the existing context-aware applications supporting asthma management that were explained in the previous section (Sect. 5). The analysis will link the features of these applications with the main concepts related to asthma that were explained in Sect. 2. By doing this, the benefits and challenges of using context awareness to support asthma are shown as outcomes of this section.

6.1 Variety of indicators

Tables 2, 3, and 4 show the indicators tracked by the reviewed solutions. The wide variety of indicators tracked by these systems is evidence to re-confirm the heterogeneity of asthma, as explained in Sect. 2. Furthermore, Huckvale et al. [43] show that most of the mobile apps for asthma only offer to record peak flow diaries and to provide information content—whose level of quality is a concern—about the condition. This is considered as evidence confirming that tracking indicators framing asthma patients' contexts are a difficult task. Nevertheless, the findings of [43] also show that this is an emerging area which is worthwhile to explore.

The patients' indicators tracked by the solutions are shown in Tables 2 and 3. It can be seen that these indicators are very different from one solution to another. Thus, different patients would choose different solutions according to the characteristics of their condition as a consequence of asthma heterogeneity. For instance, a patient whose asthma is triggered by exercise will choose to use the solutions proposed in Refs. [47, 50, 51], because they are able to track motion and/or exercise. On the other hand, a patient whose treatment is only using a reliever inhaler when necessary (GINA Step 1 treatment, see Sect. 2.2) would not mind choosing a solution not tracking their medication context.

The environmental indicators tracked by the solutions are shown in Table 4. The research works are arranged from the oldest to the most recent, which means that only the three most recent solutions [49–51] can track environmental indicators. From the others solutions, one considers the overall air quality from a zip code zone but without separating it into more detailed substances [45], while another implemented a weather announcements component warning patients about sandstorms [46]. The fact that only the most recent solutions are able to track environmental indicators would be a consequence of sensors—and the APIs allowing to access the data collected by sensors—being more available and affordable in recent years.

Asthma patients can benefit from context-aware solutions, because it helps to face the high heterogeneity level of the condition. This characteristic makes patients to have different contexts. For example, areas with high levels of pollution could be considered part of the context of a patient, whose asthma is triggered by high levels of CO_2, while temperature could be considered part of the context of a patient sensitive to sudden temperature changes. Hence, solutions implementing context awareness are able to provide patients with services that can be personalised according to the specific characteristics of their condition. Alerting a patient about possible hazards regarding their triggers or notifying a patient to take their medication regarding the specific treatment, they must follow are examples of personalised context-aware features.

This large diversity of indicators that need to be tracked brings relevant challenges when using context-aware systems to support asthma management. First, the heterogeneity of the condition makes patients who need different sets of sensors to track their specific contexts. This counters the suggestion of building "all-in-one" sensors to improve the usability of mHealth systems [49], as it is not cost-effective to build a customised device combining the specific sensors that are needed to gather a specific patient's context. Second, the necessity of using different sensors to model patients' contexts makes the integration of the collected data challenging, as sensors could be from diverse providers. These challenges are linked to achieving the integration among the sensors that will gather the context-related information of different patients.

6.2 Automation level

The automation level is another interesting characteristic to analyse from the reviewed research works. As it can be seen in Table 5, the automation level of the solutions supporting asthma management has increased over time. This also can be considered as evidence of the technological development in recent years allowing the creation of more automated sensors/devices. The systems proposed in Ref. [44, 45] are considered to have a low automation level, as they require users to enter their data manually into the system by using SMS [44, 45] or a widget installed in the computer [45].

The systems proposed in Refs. [46, 48] have a medium automation level. Both systems include a mobile application automatically storing the measurements taken by the patient into the systems. Because of this, they are considered to have a higher automation level than the previous works [44, 45]. Nevertheless, their drawbacks from the automation perspective are: (a) mBreath [46] still requires patients to answer five question to define their control level and (b) the system proposed in Ref. [48] allows patients to send an email with the readings using the native operating system email application instead of automatically notifying stakeholders, and consolidating and uploading data to a server for showing special reports to stakeholders.

kHealth [49] and AsthmaGuide [50] are considered to have a medium–high automation level. kHealth, after being set up to aid asthma management, is able to gather information about the indoor environment, air quality, and exhaled NO through a mobile application automatically. Although kHealth also requires patients to answer questions to define their control level, the number of sensors included in the solution is high, and the fact that it reminds patients to take readings makes it a solution with a higher automation level than the previous ones. AsthmaGuide automatically collects data from several sensors through a smartphone, though it also asks patients to enter their medication dosages and to answer questions to define the control level.

The system proposed in Ref. [51] has the highest automation level from all of the reviewed systems. The chest patch and wristband collect patients' data (heart rate, respiration rate, wheezing, motion, temperature, humidity, and level of O_3 and VOC). Lung capacity (PEF, FEV_1, and FVC) is collected through a spirometer. These data are sent to an integrating device via Bluetooth low-energy technology. Although the system does not include an automated notification system, its architecture to collect data is the most automated. This makes it easier to gather patients' data, which is relevant, as one of the aims of the system is to use this data to develop an algorithm to detect asthma attack onset.

The features of smartphones and tablets aid to build more automated solutions. The devices used in Refs. [46, 48–50] collect data that is later sent to a smartphone or tablet, which are used as devices to integrate the collected data. Isakovic et al. [35] state that smartphones and tablets are the best integration devices because of their processing and storage capabilities, and wireless connectivity features. However, the use of smartphones and tablets as integration devices brings an important challenge: battery duration. These devices usually do not have long working periods because of their battery duration [53]. This does not allow to deliver ubiquitous solutions and delays acceptance of mHealth solutions [66]. The main reason for the high battery consumption is the typical architecture of mHealth applications in which mobile devices and applications exchange data with smartphones/tablets and the Cloud through Bluetooth and wireless Internet connections.

6.3 Notification component

Table 5 shows details about the notification components included in the reviewed research works. It is important to point out that only three [46, 49, 50] out of the eight systems implement some kind of notification features. Although the system proposed in Ref. [44] does not implement any notification feature, the authors suggest alerting physicians by using alarms. Furthermore, the authors in Ref. [49, 50] consider the notification component as a relevant part of the system, and they also suggest to improve that component as future work.

The notification features are different in each system. mBreath [46] sends alerts to patients when their PEF readings are below normal or when the weather is close to change. Being aware of these changes is relevant in some regions, where the weather can be a hazard for patients. The mobile application proposed in Ref. [49] sends reminders to take readings once a day. AsthmaGuide [50] notifies patients if their contexts are not normal, and can also trigger alarms or advice messages depending on how abnormal the context is.

Asthma patients are the main targets of the notifications components; however, other relevant stakeholders in the asthma management process are not included as recipients of the notification systems. Although asthma patients are the main stakeholders, because their lives are the most affected by the condition, other people (or sometimes institutions) would also be targets of some type of notifications. A simple example is parents being interested in knowing when the PEF readings of their asthmatic child are below normal as an indicator of a decrease of their child's lung capacity. By knowing this, parents would be more aware of the situation, and would take actions to avoid life-threatening situations.

6.4 Personalisation

Section 2 shows that the concept of personalisation is strongly linked to asthma because of the high heterogeneity level of the condition. Personalisation is especially important when defining the treatment for each patient. The definition of the non-pharmacological treatment needs to consider the patient's clinical history for knowing both the triggers inducing their exacerbations and the symptoms evidencing a decrease in their health status. Moreover, the level of medication to use for each patient must also be customised by stepping the patient up or down until finding their optimal pharmacological treatment.

Despite the fact that personalisation is the key when it comes to treating asthma, only one research work [45] highlights the importance of customising technology probes to support families of people suffering from asthma. The outcomes of this work suggest that the severity of the patient's asthma and the skills of the family members have to be considered when choosing the right technology to support the family in the asthma management process. If this suggestion is analysed from the concepts explained in this survey, it can be argued that the severity of a patient's asthma defines both the technology required to monitor their context and how frequent their context must be monitored. The technological skills in the families are linked to the mHealth's IT literacy challenge, which can limit the number of potential users [65] as a consequence of people having different ways of adapting to technology [66].

Although it is important to recognise IT literacy as a restriction, the special characteristics of a patient's asthma provide the most relevant constraints when personalising their treatment. However, none of the reviewed research works provides or suggests to allow users to choose the services to use or the indicators to track according to the main characteristics of their asthma. This drawback is linked to the explanation provided in Sect. 6.1, where the high variety of sensors/devices required to track indicators is highlighted. In this section (Sect. 6.4), this drawback is analysed from a requirement engineering point of view, and the requirement of delivering personalised services is stated.

This section provided a critical analysis of the solutions supporting asthma management that are described in Sect. 5. The analysis highlights the main benefits and drawbacks of the systems from three different perspectives to provide insights to develop context-aware solutions aiding the asthma management process in an effective way. Table 6 shows the gaps found when analysing the research works aiming to support asthma management.

Table 6 Gaps in using context awareness to help managing asthma

Gap	Description
Personalisation	None of the solutions allows patients to set up the indicators they need to track according to the characteristic of their conditions
Notifications	The notification components of the reviewed solutions do not consider all the relevant stakeholders in the asthma management process of a patient
Outdoor environment	The reviewed research works do not use the information collected by networks of weather and air-quality stations tracking outdoor environmental data
Location	Solutions do not take advantage of the location-tracking capabilities of the integration devices
Virtual assistance	The use of virtual assistance to aid patients in their asthma management process has not been studied

The following section discusses some concepts related to the development of context-aware solutions supporting asthma management with the aim of explaining how they can be applied to improve services for patients and stakeholders. The concepts discussed expand on the understanding of the benefits of closing the gaps shown in Table 6.

7 Discussion

This section discusses concepts/ideas that can be used to develop context-aware solutions supporting the asthma management process. The use of these concepts/ideas will aid to tackle some critical challenges regarding this subject by enhancing the services that will be delivered to support asthma management.

7.1 Location-tracking capability

The location-tracking capability of smartphones and tablets can be used to aid the asthma management process. Although this capability is already being used to help in other fields like transportation [22, 23], none of the reviewed research works implements features that take advantage of these capabilities. Knowing the location of a patient would be used to suggest suitable emergency departments or medical centres, where the patient can go in case of an emergency (e.g., acute exacerbations, imminent respiratory arrest, and lack of medicine). Moreover, the patient would be able to share their location with stakeholders (e.g., parents, spouse, and guardian) to let them know, where they are in case of an emergency.

PulsePoint Respond, a mobile application using location-tracking capability as the core of its services, is an example of using this feature. This application is offered by the PulsePoint Foundation, and its aim is aiding people with training in cardiopulmonary resuscitation (CPR) to use their skills to save lives. The application notifies users trained in CPR if someone nearby requires CPR. Rescuers are guided to the location of the person needing CPR and to the closest automated external defibrillator (AED) available for public use. PulsePoint AED is another mobile application offered by the same organisation, and can be used to report the location and other information about the AEDs available in the community. This information is uploaded, verified, and shared with PulsePoint Respond users [67].

7.2 Collection of outdoor environmental data

The collection and analysis of data about the environment are especially important to manage asthma helping to prevent exposure to triggers that may put patients in risky situations. Because of this, tracking context about indoor and outdoor environments where patients usually inhabit is relevant when designing context-aware solutions supporting asthma management. The solutions proposed in Refs. [49, 50] use sensor drones to track environmental data, while the one proposed in Ref. [51] uses a wristband with the same purpose. These solutions track environmental indicators in an automated way. However, their architectures make it difficult to track environmental context from several places, particularly from outdoor environments.

This problem can be clarified with the example of a patient wanting to know environmental indicators of several indoor places like home, office, or gymnasium. As the solutions proposed in Refs. [49, 50] use Bluetooth to send data to their mobile applications, the patient will be able to collect the context of the place, where they are at a specific moment, though not the context of other places until they get there and connects the mobile application with the devices. Furthermore, if the patient wants to monitor indicators from outdoor environments (e.g., a specific park or the path from home to work), these architectures will not allow it. The solution proposed in Ref. [51] cannot address this problem either as the wristband only collects data from the surrounding environment.

A potential solution to face this requirement is collecting outdoor environmental data from websites providing information about weather and air quality through their application programming interfaces (APIs). The main advantage of using APIs is the possibility of gathering data from networks of devices that are used to track the environment and weather in different locations. This will allow users to know the status of different outdoor locations without the necessity of being in those specific locations. The main disadvantage of using APIs is that the reliability of a solution built based on APIs will fully depend on the quality and availability of the data provided by these networks. Hence, choosing the right service to use is important to ensure a high-quality solution. This is linked to the selection of sensors in a sensing-as-a-service model challenge explained in Sect. 4.

7.3 Indicators to track

Given the high heterogeneity level of asthma, there is no fixed set of indicators that should be tracked to support the asthma management process of any patient. As explained in Sect. 6.1, patients would choose the solutions to use according to the context that they need to track with regard to the specific characteristics of their asthma. Hence, it is relevant to build solutions flexible enough to track different indicators considering the different needs of patients. To do this, a classification of the indicators to track by a solution supporting asthma management can be useful because it will provide a baseline to develop flexible solutions to track a wider variety of indicators defining the context of an asthma patient.

This research proposes to classify these indicators into three types: patient's indicators, indoor environmental indicators, and outdoor environmental indicators. Figure 6 helps to clarify this classification. Figure 6a represents the real world in which an asthma patient performs they daily activities. This figure helps to describe the places, where the indicators are collected from. Figure 6b shows an onion diagram showing the digital conceptualisation of this classification.

The first type of indicators includes the special characteristics defining the patient's asthma (e.g., triggers, symptoms, and medication), the physiological indicators defining the patient's status (e.g., lung capacity, heart rate, weight, and stress) and information about the main stakeholders linked to the management of their asthma (e.g., parents, spouse, son/daughter, roommate, and personal nurse). The characteristics of the patient's asthma are key in defining the indicators that need to be tracked to support the asthma management plan. Thus, the indoor and outdoor environmental indicators are defined once the patient's asthma is properly characterised.

The second type includes the Indoor Environmental Indicators determining the status of indoor environments to which the asthma patient is exposed. These indicators are defined according to the triggers provoking asthma exacerbations and the symptoms shown by the patient whose context is being modelled. These indicators should target the triggers and symptoms individually or as a set of indicators. A good illustration is a patient susceptible to sudden temperature changes and a patient susceptible to mould. For the first patient, controlling the indoor temperature is enough. However, for the second patient, it is important to control the combination of temperature and humidity as the combination of both indicators set off mould growth [70].

The third type is made of the outdoor environmental indicators modelling the outdoor environments, where the patient develops their activities. These indicators are also defined according to the triggers of the patient. A patient allergic to pollen is a good example to illustrate outdoor environmental indicators. In this case, the amount of pollen in the air is an outdoor environmental indicator that should be tracked to support decision making. Thus, identifying the areas where there is a high amount of pollen in the air will aid the patient to know which places are safe or not with the aim of avoiding or taking preventive measures before going to those places.

The collection of the indicators previously described will allow modelling the contexts of asthma patients in a more comprehensive way. Considering these three types of

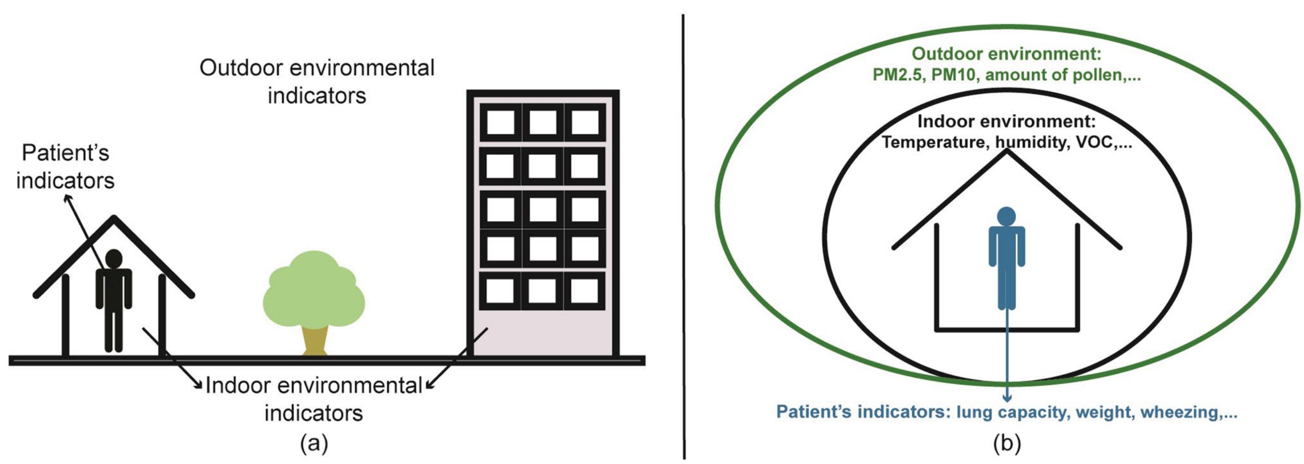

Fig. 6 Type of contexts to support asthma management

indicators as inputs will enhance the decision-making process of patients, which will improve the overall asthma management process. Tracking these indicators will provide real-time information that can be used to make decisions in case of an emergency or to take preventive measures avoiding risky situations. To achieve this, it is important to develop and validate models allowing the collection of these types of indicators according to the special characteristics of each patient's asthma.

7.4 Notifications and assistance

Figure 7 shows the baseline of an architecture that can be used to collect the indicators supporting decision making in the asthma management process. The outdoor environmental indicators are collected through a network of weather and air-quality stations. The indoor environmental indicators are collected through weather and air-quality indoor stations. Finally, patients' indicators are collected through wearable devices. The indicators are sent and stored in the cloud, making them available for being processed by algorithms, whose logic is based on the patient's asthma management plan. The output of the processing is information supporting the decision-making process of the patients and other stakeholders like physicians, personal nurse, guardian, spouse, son, siblings, etc.

The notification component of solutions supporting asthma management is another interesting feature to analyse. Patients may have different stakeholders wanting to be aware of their status. The information needs of these stakeholders also vary depending on different factors. A good example of this is the case of a child suffering from asthma, whose parents would like to be aware of the main indicators reflecting the improvement or deterioration of the child's condition. Other recipients of information would be the child's school teacher and physician. The school teacher would be interested in knowing the child's status to be aware in school times, and the physician would like to the patient's physiological indicators to adjust their treatment.

The identity of the information recipients (stakeholders) would also vary for the same person over time. In the previous example, the parents and teachers are possible interested people. When the patient becomes an adult, their wife, husband or partner will become a stakeholder in their asthma management process. When the patient becomes an elder, other people would be interested in knowing their health status, as the patient would depend on a son or daughter, personal nurse, among others. This fact can be considered another challenge when designing the notification component of a solution supporting asthma management.

Only one of the reviewed solutions [45] includes the family in the qualitative research to know how the proposed

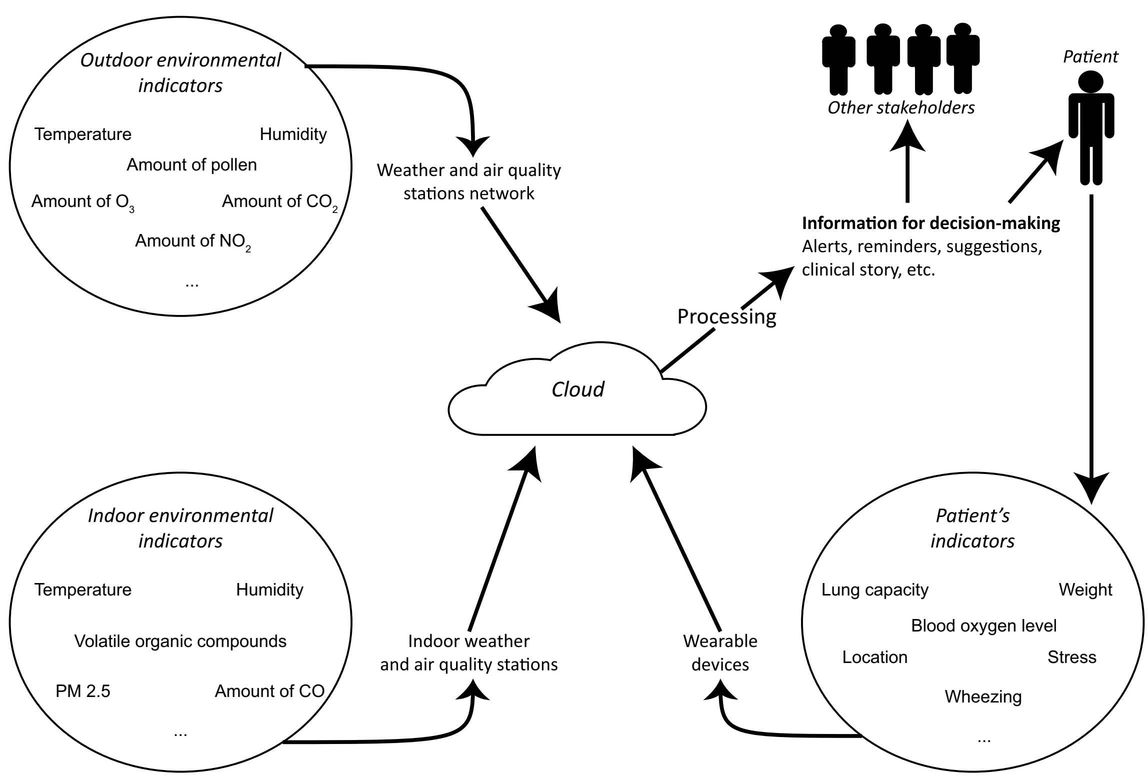

Fig. 7 Architecture to collect and process indicators

technology probes impact patients' management process. This is relevant, because not only healthcare professionals should be considered as stakeholders, especially when it comes to supporting asthma patients that depend on their carers (e.g., children). Hence, it can be argued that there has not been enough research to define the main stakeholders that should be included in the asthma management process as information providers or recipients. The review confirms that an efficient system to deliver notifications and alerts to the main stakeholders still does not exist. Given the fact that every 10 s, someone is having a potentially life-threatening asthma attack [55], preventive strategies to avoid asthma attacks and reactive actions to treat them are highly important to reduce deaths from asthma.

The use of a Just-In-Time (JIT) information approach can aid to tackle the challenges of designing and implementing notification systems to support patients in the management of their condition. The concept of JIT Information is related to the delivery of information within the Information Supply Chain (ISC). The aim of using this approach is balancing the supply and demand of information within an ISC to deliver the right information to the right users at the right time [68]. The concept of cognitive overload can be used to explain the basis of this approach. Cognitive overload occurs when a user gets more information than required, which must be avoided as it reduces the quality of the user's decision-making process [69]. It can be said that having too much data is not always beneficial for users. The JIT Information approach can be used to fulfil users' information needs without reaching to point of cognitive overload.

The definition of the ISC in the asthma management process of a patient is the basis to apply a JIT Information approach to develop a notification component. Kandl and Khan [68] explain some interesting concepts and measures related to ISC and apply them to the drug discovery process. Some of these concepts can be used when defining the ISC of a patient's asthma management process. The most suitable concept to apply is the Information Dependency Relation (IDR) Models, which will help to specify the information units required by the stakeholders, to know the sources needed to build those information units and to define the moment when they need it. The IDR models can be built considering the special characteristics of a specific patient's asthma management process, in which people may have different roles and requirements. This will allow the personalisation of an effective notification system regarding the context of the patient.

The use of virtual assistance to support asthma management can be considered another gap given the fact that it has not been included in previous research works related to this condition. Although some of the reviewed solutions include educational modules [46, 50] to increase patients' knowledge about asthma, none of them has implemented virtual assistance or has done research on this subject. The importance of including this technology lays on the fact that virtual assistants can suggest both preventive actions to avoid asthma attacks and reactive actions to face the attacks when they occur, which is crucial to keep patients alive. This customised real-time assistance would save their lives, as it can be used in key moments. Some examples are providing instructions to patients when they are having an asthma attack, alerting them when air quality in the house is unhealthy, and advising them about the medication to take in case of emergency.

8 Conclusions and future work

Context-aware solutions are improving processes in several application fields, including health. Nevertheless, there are still challenges that must be addressed to consolidate the use of context-aware systems as part of people's daily activities. This research shows how context awareness can be used to support the asthma management process. The main concepts of asthma have been linked to the main concepts of context awareness, and the existing context-aware systems aiding asthma management have been reviewed and analysed. The main benefit of using context-aware systems to enhance the asthma management process is its potential to adapt the services according to the special characteristics of each patient's condition. The main gaps are the integration with other existing systems, allowing the personalisation of the systems according to each patient's condition, and the development of an efficient notification component including the main stakeholders of each patient. Ideas that are related to face these issues have also been proposed and described.

Asthma is a disease mainly characterised by its high level of heterogeneity, which makes patients being sensitive to different triggers and suffering different symptoms. This fact brings the necessity of implementing personalised plans for each patient to control their condition. By definition, a context-aware system is able to perform considering the relevant information (context) of a specific situation. When it comes to asthma, the context of a patient is made of the main characteristics of their condition. From this point of view, the main benefit of using context-aware systems to support the asthma management process is its capability to adapt its services according to the specific characteristics of each asthma patient. Hence, it can be said that context-aware systems are promising in supporting the asthma management process, as the heterogeneity of asthma and the nature of context awareness are strongly related. Another critical challenge to acknowledge is the fact that it will become important in the future to explain why a decision or recommendation has been given by a system. This is a consequence of raising legal aspects—like the General Data Protection Regulation

(GDPR) (Regulation (EU) 2016/679)—that will make black-box algorithms difficult to use [71].

One of the biggest challenges of developing context-aware systems is the integration of hardware and software from different systems. This challenge becomes more significant when using context awareness in asthma management because of the wide variety of indicators that a solution should consider for being able to adapt to different patients' contexts. This variety makes it less financially sustainable for providers to develop devices (or an all-in-one device) able to do both tracking most of these indicators and integrating with other systems. Because of this, it is important to develop models and frameworks facilitating the integration of different systems with the aim of easing the automation of context-aware systems supporting asthma management. This will allow adapting existing solutions (e.g., air-quality APIs, location-tracking capabilities of mobile devices) and use them as part of systems supporting asthma management. At this point, it is important to point out that Patients' Indicators related to activity seem to be the most challenging indicators to monitor. Nevertheless, although they still have challenges to tackle [72], wearable sensors are promising tools to aid in the personalised physical activity monitoring.

Involving the main stakeholders as providers and recipients of information in the ISC of the asthma management process is also crucial to improve it. However, substantial research efforts on this topic have not been made. Given the nature of the JIT Information approach, it is a promising tool that can be used to define the information requirements in the ISC. This approach is able to efficiently address the personalisation and inclusion of the main stakeholders in the asthma management of a patient. Finally, it is important to point out that no research efforts have been made to explore how Virtual Assistance would aid the asthma management process. This technology can be used in preventive and emergency scenarios.

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