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Astmapp: A Platform for Asthma Self-Management

Harry Luna-Aveiga, José Medina-Moreira, Oscar Apolinario-Arzube
(Facultad de Ciencias Matemáticas y Físicas, Universidad de Guayaquil, Cdla. Universitaria Salvador Allende, Guayaquil, Ecuador
harry.lunaa@ug.edu.ec, jose.medinamo@ug.edu.ec, oscar.apolinario@ug.edu.ec)

Mario Andrés Paredes-Valverde
(Tecnológico Nacional de México/I. T. Orizaba, Av. Oriente 9 No. 852, Col. E. Zapata 94320, Orizaba, Veracruz, México
mapv1015@hotmail.com)

Katty Lagos-Ortiz
(Facultad de Ciencias Agrarias, Universidad de Guayaquil, Cdla. Universitaria Salvador Allende, Guayaquil, Ecuador
klagos@uagraria.edu.ec)

Rafael Valencia-García
(Departamento de Informática y Sistemas, Universidad de Murcia, Murcia, Spain
valencia@um.es)

Abstract: Asthma is a chronic lung disease of the airways that makes breathing difficult. Worldwide, asthma is a leading disease among children and adolescents and a leading cause of hospitalizations among adolescents. Asthma self-management is a systematic procedure that allows educating, training, and informing patients to control their disease and avoid it when it is possible and reduce it when it is necessary. Nowadays, there is a need for technological tools for supporting different tasks within the process of asthma self-management, such as education, control, and monitoring, that help patients and their families improve their quality of life and reduce the direct and indirect costs. This work proposes Astmapp, a platform that relies on semantic and mobile technologies and recommender systems to increase the patients' knowledge about asthma regarding topics such as triggers, symptoms, activity restrictions, medications, among others, and to promote the asthma control by means of the monitoring of symptoms and parameters such as physical activity, heart rate, blood pressure, temperature, among others. Likewise, Astmapp recommends educational resources based on the preferences of patients and generates medical recommendations based on the symptoms and health status of the patient aiming to prevent asthma and reduce its exacerbation. Astmapp was evaluated in terms of its ability to recommend asthma educational resources relevant for the patients as well as to provide health recommendations. The evaluation results suggest that Astmapp has the potential to effectively support the asthma self-management process.

Keywords: Asthma, ontologies, mobile application
Categories: H.3.3, I.2.1, M.4, L.3.2

1 Introduction

Asthma is a chronic lung disease of the airways that makes breathing difficult. This disease is characterized by inflammation of the bronchial tubes with increased

production of sticky secretions inside the tubes. Worldwide, asthma is a leading disease among children and adolescents and a leading cause of hospitalizations among adolescents [Nair et al. 2017]. Furthermore, asthma causes a lot of missed days of school and work, play time, and sleepless nights, which reduces the quality of life not only of the patients but also their family and friends.

Asthma self-management is a systematic procedure that allows educating, training, and informing patients to control their disease and avoid it when it is possible and reduce it when it is necessary [Kotses and Creer 2010]. A successful self-management of asthma can represent a reduction of disruptions of daily activities due to asthma episodes, an improvement of the quality of life for patients and their families, as well as a reduction in the direct and indirect costs.

Nowadays, there are technologies that may be combined and included in existing health self-management processes in order to enhance the quality of life for patients. For instance, mobile applications have been adopted by people as a medium for supporting clinical decision-making tasks [Fruehauf et al. 2017, Rahimi et al. 2017], health record maintenance [Andrus et al. 2015, Doukas et al. 2010], medical education and training [Ozdalga et al. 2012, Wallace et al. 2012], as well as the self-management of chronic diseases such as diabetes [Cruz-Ramos et al. 2018]. On the other hand, recommender systems, which have been successfully used in domains such as movie show times [Colombo-Mendoza et al. 2015] and digital libraries [Tejeda-Lorente et al. 2014], represent a tool that can help patients support tasks within asthma self-management. For instance, they can recommend educational resources that help them to increase their knowledge about asthma as well as to prevent asthma attacks. Finally, Semantic Web can help medical applications integrate and reuse quality information from distributed and heterogeneous data sources. The main goal of the Semantic Web is to provide Web information with a well-defined meaning and make it understandable by humans and computers [Berners-Lee et al. 2001]. Ontologies are considered as one of the pillars of Semantic Web since they allow explicit organization of knowledge to develop environments with better access to specific learning. Ontologies have been successfully employed in contexts such as Linked Data querying [Paredes-Valverde et al. 2015], and finances [Salas-Zárate et al. 2017], among others.

It is necessary to develop effective technology solutions that can help patients with asthma to improve their quality of life through a self-management process that includes aspects such as education and the provision of medical recommendations according to the symptoms and health status of the patients. Hence, in this work, we propose Astmapp, a platform for asthma self-management that employs Semantic and mobile technologies as well as recommender systems for two purposes: (1) to increase the knowledge about asthma regarding topics such as triggers, symptoms, activity restrictions, medications, among others; and (2) to promote the asthma control by means of a monitoring process that considers symptoms and parameters such as physical activity, heart rate, blood pressure, temperature, among others, to provide medical recommendations aiming to prevent asthma and reduce its exacerbation. To achieve these goals, Astmapp provides a mobile application that provides patients with asthma educational resources and allows them to record all the parameters above-mentioned. Likewise, Astmapp employs an ontology that models the asthma self-management domain including the abovementioned information. Finally,

Astmapp integrates a rule-based engine that exploits the knowledge represented by the ontology to generate medical recommendations.

The rest of this work is organized as follows: Section 2 presents an overview of research efforts related to asthma self-management. Then, section 3 describes the functional architecture of the Astmapp platform, whereas section 4 presents the evaluation performed on the Astmapp platform regarding the healthcare recommendations generated by it as well as the asthma educational resources recommended by the system. Section 5 presents the general conclusions of this work. Finally, section 6 presents future work that points to improve the platform.

2 Related Work

There is a need for technological tools for supporting different tasks within the process of asthma self-management, such as education, control, and monitoring. In this sense, several organizations and researchers have addressed this issue by employing technologies such as mobile applications, cloud computing, Internet of Things, Big Data, among others. This section discusses the most relevant literature among the context of asthma self-management.

To achieve an effective asthma self-management process, it is necessary that patients understand several aspects of their disease including asthma triggers, symptoms, signs, activity restrictions, food, medication, among others. Improving the patients' knowledge about their disease can augment the patient engagement and improve their clinical outcomes [Nair et al. 2017]. In fact, several organizations state that self-management education is a very important part of the asthma care process [National Asthma Education and Prevention Program 2007]. Nowadays, there are several mechanisms to conduct the asthma education process such as oral presentations, written materials in the form of books and pamphlets, or a combination of both. Recently, computers and mobile devices play an important role in the education process since they encompass several strategies such as applications for teaching asthma self-management [Gomes et al. 2014, Nair et al. 2017], and daily adjustment of medication schedules [Pinnock et al. 2007, Ryan et al. 2005]. Also, computer and mobile devices allow accessing information resources available on the Web such as forums or social networks where people interchange information and experiences about such disease.

In the context of asthma self-care education, the Georgia Institute of Technology, in conjunction with Children's Healthcare of Atlanta, developed Asthma Academy [Nair et al. 2017], a cloud-based application that simulates caregiver-patient interactions to provide healthcare education to asthmatic adolescents. This application considers different education levels and socio-economic statuses. The Asthma Game [Gomes et al. 2014] is a game that provides children with asthma information about asthma triggers at home in order to prevent attacks or exacerbations. This game was developed by using the APEX platform (Rapid Prototyping for user EXperience) that allows prototyping ubiquitous computing environments. MyAirCoach [Kikidis et al. 2015] is a mobile application that aims to educate asthma patients about their disease by emphasizing aspects such as the correct use of the inhaler. Furthermore, MyAirCoach allows patients to manage their prescribed treatment and communicate with family and doctors to share their health history.

The Internet of Things also plays an important role in the self-management of diseases such as asthma. For instance, BREATHE (Biomedical REAl-Time Health Evaluation) [Buonocore et al. 2017] is a wireless health system that incorporates several physiological and environmental sensors to achieve two main goals: monitoring potential asthma triggers and determining the symptoms of asthma patients. The system employs a smartwatch to monitor patient's activities and behaviors. In [Jaimini et al. 2017], the authors presented an Internet of Things based system that allows improving indoor air quality through its continuous monitorization. Specifically, this system can detect asthma-exacerbating activities, such as smoking and cooking activities, by using Foobot, a sensor that collects data about parameters such as temperature, humidity, CO_2, and VOC (Volatile Organic Compounds). AsthmaGuide [Ra et al. 2016] is a system that collects environmental data through sensors. These data, in conjunction with information provided by the user such as medication and exercise, are analyzed to generate alerts when a dangerous event occurs. Also, the system generates reports about such information that can be queried by patients and healthcare providers. Finally, in [Das et al. 2018], the authors proposed a non-invasive monitoring device for predicting asthma attacks based on physiological variables related to respiration temperature. This device is fitted inside a breathing mask. The temperature pattern is processed by a set of simple algorithms embedded in an Arduino-based controller that calculates the breath rate and exhaled breath temperature.

Nowadays, mobile applications are used for supporting tasks of asthma self-management. For instance, in [Do et al. 2015], the authors proposed a mobile application for older adults that aim to help them track asthma triggers and predict asthma attacks. Also, this application improves the communication between patient and healthcare providers through the synchronization with an EHR (Electronic Health Record) system that can be accessed by doctors. Likewise, O2O (Online to Offline) [Hu et al. 2017] is a system that provides a mobile application oriented to two kinds of users: patient and doctor. On the one hand, O2O allows patients to monitor risk factors, lung function, and medication adherence. On the other hand, O2O provides doctors with a telecommunication tool and a patients' management tool. ASPIRA [Thomson et al. 2017] is a low-cost in-home monitoring application focused on asthma patients. This application allows users to identify asthma triggers to reduce environmental exposures within the home. Furthermore, ASPIRA provides a game that encourages the child participation in the process of asthma self-management. On the other hand, BKSpiro [Tran et al. 2015] is an Android-based application that helps measure lung function. For this purpose, the application analyses audio signal to extract the FVC (Forced Vital Capacity), FEV1 (Forced Expiratory Volume in one second), and PEF (Peak Expiratory Flow) quantities. These variables are the most common measures reported in clinical studies since they allow quantifying the degree of airflow limitation in asthma. Finally, in [Wu et al. 2016], the authors presented SPI (Smart Phone Intervention), a mobile application that provides kids information on healthy lifestyle and motivates children and their parents to adopt new behaviors. SPI employs social networks to establish dynamic interactions between patients and healthcare professionals as well as to encourage patients' adherence to the self-management process through social motivation.

According to our literature discussion, we can propose the following conclusions. (1) Few research approaches employ semantic technologies to formally represent the problem and domain they address. In this sense, we propose a system that uses semantic technologies, specifically ontologies, to model asthma self-management domain including aspects such as triggers, symptoms, signs and health parameters. The ontology generated represents the computable knowledge that is used to generate medical recommendations. (2) Current approaches focused on asthma self-management do not provide personalized medical recommendations. To address this limitation, our system implements a rule-based engine that exploits the knowledge domain represented through the ontology proposed in this work to generate recommendations that consider the symptoms and health status of the patient. (3) Some of the systems for asthma self-management reported in the literature rely on electronic devices, such as environmental sensors and an Arduino-based platform [Das et al. 2018], to obtain the necessary data. Since these devices are not easy to obtain and require a great investment, the access to technological tools for supporting asthma self-management is often limited. In this sense, the system that we propose requires only a smartphone or an electronic tablet with Internet access to obtain several educational resources and recommendations that aim to help patients and their family to adopt new behaviors that help them improve their quality of life. (4) Few approaches rely on collaborative filtering techniques to recommend educational resources that help patients understand their disease, control it, and avoid it when it is possible. In this sense, Astmapp implements a recommender module that considers the preferences of the patients to recommend relevant educational resources. As can be noted, Astmapp takes advantage of a collaborative environment where users share their preferences through ratings assigned to educational resources.

3 Astmapp: A Platform for Asthma Self-management

Astmapp is a patient-centered platform based on semantic and mobile technologies as well as recommender systems for supporting asthma self-management tasks such as education and control of the disease. As depicted in Figure 1, the functional architecture of Astmapp relies on a client-server model where the tasks performed by each module are clearly distributed among the clients and the providers of services, thus ensuring an easy maintenance and a high-level of scalability. The Astmapp's architecture comprises three layers: (1) the presentation layer, which provides a mobile application that allows patients to record their symptoms and health parameter, also, it provides health professionals a summary of the data about their patients' symptoms and health parameters; (2) the intelligent services layer; which comprises the modules for education, monitoring and control of asthma, as well as a module for generating medical recommendations; and (3) the data layer, which stores all information generated by the platform including the asthma educational resources, asthma self-management data, and experts knowledge consisting in medical recommendations. The following sections thoroughly describe the most representative components of Astmapp.

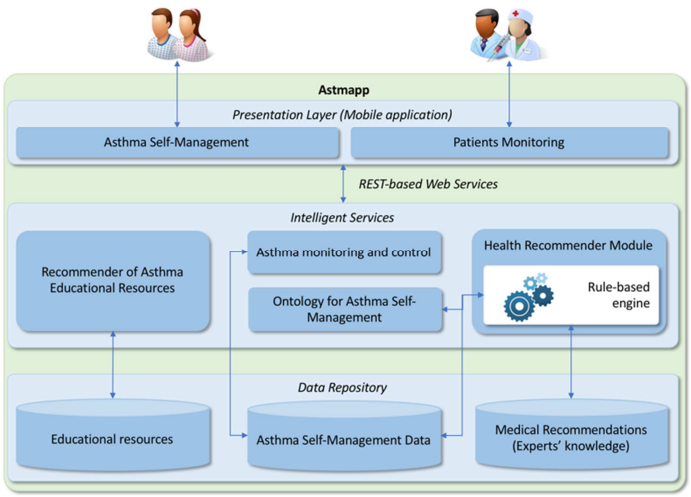

Figure 1: Astmapp's architecture

3.1 Ontology for Asthma Self-Management

Astmapp requires experts' knowledge to generate the correct medical recommendations according to the symptoms and health status of the patient. To this end, Astmapp adopts an ontology-based approach which allows modeling the asthma self-management domain and reasoning over the ontology to provide trusted recommendations. The ontology here proposed was implemented by following the Methontology [Fernández-López et al. 1997] methodology as well as by using the OWL 2 Web Ontology Language [Grau et al. 2008] and Protégé editor [Musen and Protégé Team 2015].

The design of the asthma self-management ontology considered the Asthma Ontology [McNulty et al. n.d.], which models different aspects related with asthma, such as diagnosis, the process of care, risk factors, symptoms, and therapy, among others. More specifically, our proposal reuses the Risk factors (Triggers) and Symptoms classes as well as their subclasses. To adapt the ontology to the purposes of this work, the ontology design process relied on the participation of health professionals with experience in healthcare and asthma treatment, as well as experts in ontologies development. The resulting ontology comprises 72 classes of which stand out: the health parameter, mood, triggers, and symptoms. Figure 2 shows an extract of the ontology for asthma management proposed in this work. The main classes of asthma self-management ontology are described below.

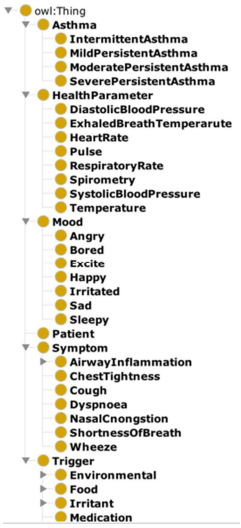

Figure 2: An excerpt of the asthma's ontology

As previously mentioned, the ontology proposed in this work describes the asthma self-management domain through six main axes:

- Patient. A person who is under medical care or treatment.
- Asthma. It represents a classification of asthma according to the severity of clinical features.
- Health parameters. This class represents all those parameters that must be considered in the healthcare process, such as temperature, heart rate, blood pressure, physical activity, among others.
- Mood. It represents the different and temporary states of mind or feeling of patients, such as angry, bored, excited, irritated, sad, sleepy, and happy, among others.
- Triggers. There are many things that can trigger asthma symptoms. The present ontology classifies the asthma triggers as follows:
    - Environmental triggers. It includes allergens from dust, animal fur, mold, pollens, flowers as well as grasses, air pollution, cold air, among others.
    - Irritants. This concept includes triggers such as cigarette smoke, chemicals, sprays such as hairsprays, compounds in home décor products, among others.
    - Medication. This concept refers to all those medicines that can trigger asthma symptoms such as aspirins or other non-selective beta-blocker and anti-inflammatory drugs, to mention but a few.
    - Food. It includes all food that can trigger asthma attacks. Some examples of this kind of food are eggs, peanuts, salt, shellfish, soy, among others.

  - Physical activities. It refers to the activities that involve long periods of exertion, such as soccer, distance running, basketball, among others. Also, this class includes cold-weather sports such as ice hockey, skiing, and ice-skating.
- Symptoms. This class represents common symptoms such as dyspnea, coughing, wheezing, shortness of breath, and chest tightness, pain, or pressure, nasal congestion, to mention but a few.

The ontology for asthma self-management also defines the classes *Recommendation*, which helps the system to provide patients with recommendations to control their disease. Regarding ontology properties, this ontology defines some object properties to establish a relation among the instances of the classes above described. Some of these properties are *hasSymptom* (Patient, Symptom), *hasMood* (Patient, Mood), *hasDiastolicBloodPressure*, *hasHeartRate*, *hasPulse*, *hasRespiratoryRate*, *hasTemperature*, among others.

3.2 Asthma Monitoring and Control

It must be emphasized that Astmapp is a platform that supports the asthma self-management process and not the self-care process. The difference among these processes is that the first one recognizes the importance of physicians and encourage the patient-physician partnership, meanwhile, the goal of the second one is to reduce the participation of such professionals [Kotses and Creer 2010]. Therefore, we can conclude that physicians play an important role in the implementation of self-management methods and tools. However, there are several barriers that should be solved. One of the most important is the patient-physician communication.

Considering the above-discussed, the Astmapp platform aims to improve the patient-physician relationship i.e, to improve the medium in which data are gathered, diagnoses and plans are made, compliance is accomplished, and healing, patient activation, and support are provided [Dorr Goold et al. 1999]. For this purpose, Astmapp provides physicians with all information about the health status of the patient, more specifically, data concerning symptoms and vital signs such as respiratory rate, heart rate, systolic blood pressure, pulse, temperature, among others. All this information is provided by means of graphs that synthesize all this information thus helping healthcare professionals to interpret the health status of the patients in an easy way as well as to detect patterns that indicate possible problems or risk situations that require prompt medical attention. Also, these graphs can help physicians to clarify patients' questions or provide personalized guidance about the control of the disease. Some examples of the graphical interfaces provided by the patients monitoring module are presented in Figure 3. Figure 3a and Figure 3b depict the history of the patient’s blood pressure and pulse respectively. Meanwhile, Figure 3c presents the history of the patient’s mood.

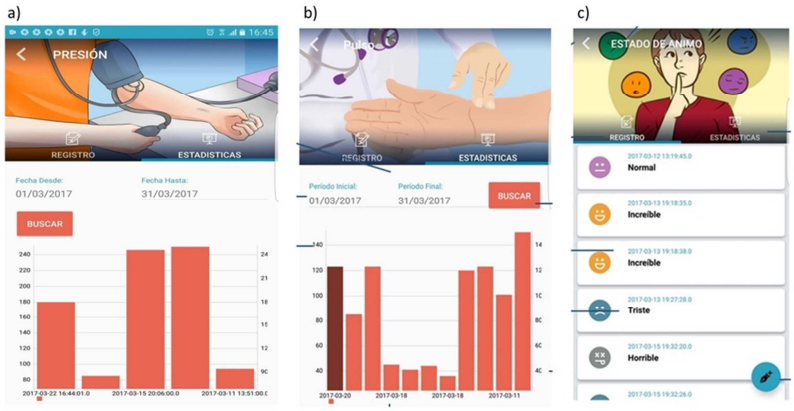

Figure 3: Interfaces for patients monitoring

The development of the asthma monitoring and control module relied on the participation of health professionals with experience in the treatment of asthma patients. One of the main contributions of this group of professionals was the establishment of symptoms and health parameters that must be monitored as part of the asthma self-management process to keep this disease under control and prevent severe asthma episodes. Some of the vital signs that are considered by the present module are the respiratory rate, heart rate, systolic blood pressure, pulse, temperature, among others. For instance, a respiratory rate greater than 30 beats per minute, a heart rate greater than 120 beats per minute, and a paradoxical pulse greater than 12 mmHg are associated with severe asthma attacks. Hence, it is necessary to know the early warning signs that happen before or at the beginning of an asthma attack.

In addition to the parameters mentioned in the previous paragraph, the asthma control module is executed in accordance with a series of symptoms. It is important to consider that not every asthma patient has the same symptoms in the same way and they may not have all symptoms and may have different symptoms at different times. Furthermore, the symptoms may vary from one asthma attack to the next. This being said, the asthma monitoring and control module classifies the occurrences and severity of the asthma symptoms such as follows: (1) asthma occurrences, which can be asthma attacks or exacerbations; (2) days on which do not occur asthma symptoms; and (3) by using next scale of severity: 1-Low-Moderate, 2-High, 3-Very high, 4 – Severe, and 5 -Extreme. It must be mentioned that the current version of this module requires that patients provide all symptoms and their corresponding severity through the mobile application. Based on such information, Astmapp provides health recommendations by means of the health recommender module which is described in section 3.4.

There are other factors that can trigger asthma attacks. For instance, some patients may only have asthma during exercise or when they eat a specific food. Fortunately, these factors can be controlled by the patients i.e., they can choose what to eat or which exercise practice. In this sense, the monitoring and control module allows patients to record their physical activity and food intakes. In this way, the system

advices patients which food and exercise must avoid for reducing asthma attacks. Finally, another important parameter that is monitored by the present module is the patient's mood. It is important to consider the patient's mood in the asthma self-management process since the patient can have continuous mood changes and even depression due to the restrictions imposed in the asthma treatment.

3.3 Recommender of Asthma Educational Resources

An educational resource is an entity that can be used or referred to along a learning process [Anido et al. 2002]. Multimedia contents, books, manuals, programs, tests, software applications, tools, people, organizations are examples of educational resources. Astmapp implements a recommender module that provides patients with educational resources whose main goal is to increase the patients' knowledge about their disease, as well as to encourage the adherence to the asthma self-management process. The current version of Astmapp uses research papers and presentations, which are provided by professionals by means of the mobile application.

The recommender of asthma educational resources relies on the Collaborative Filtering algorithm, which bases the recommendations on the ratings of the users in the system [Ekstrand et al. 2011]. More specifically, the recommender module employs the MSD (Mean Squared Difference) to measure the mean squared difference between two vectors i.e., between two users. The MSD's equation is shown below.

$$sim(x,y) = 1 - \frac{1}{\#B_{x,y}} \sum_{i \in l_u} \left(\frac{r_{x,i} - r_{y,i}}{max - min}\right)^2 \in [0,1]$$

Where $\#B_{x,y}$ represents the number of asthma educational resources that two patients have rated; and $r_{x,i}$ and $r_{y,i}$ represent the rates that were assigned by patient x and patient y respectively. In a nutshell, the recommender process works as follows:

(1) The user expresses his/her preferences through a five-star rating scale i.e. the user rates the asthma educational resources provided by the platform. These ratings represent the user's interest regarding educational resources.
(2) The recommender module finds the most similar users by matching the active user's ratings to the ratings of other users of the platform. This process is performed by using the MSD's equation above described. This group of users is known as the k-nearest neighbors of the active user.
(3) Considering the k-nearest neighbors, the recommender module predicts how active user would rate educational resources that he/she has not evaluated.
(4) Once the predictions are calculated, the N most appropriate educational resources are chosen to be recommended to the user i.e., the educational resources with the highest ratings.

3.4 Health Recommender Module

Ontologies are based on first-order predicate logics as underlying knowledge representation and reasoning paradigm. Astmapp takes advantage of this feature to define a set of rules for inferring from the knowledge described in the ontology

described in section 3.1. For this purpose, Astmapp uses the Pellet reasoner [Sirin et al. 2007] for inferring logical consequences from a set of asserted facts or axioms [Gómez-Pérez and Ruiz 2010].

As previously mentioned, the design of the ontology relied on the participation of health professionals with experience in the treatment of asthma patients. This group of people was also asked to provide a set of health recommendations that help patients to deal with asthma. For the purposes of this work, each recommendation depends on a set of conditions regarding the knowledge described by the ontology, i.e., the conditions are related to the symptoms, vital signs, triggers (environmental, medication, food, physical activities), and mood that are monitored through the platform. Based on such conditions, the authors established a set of rules based on SWRL [Horrocks et al. 2004], a Semantic Web rule language that combines sublanguages of the OWL Web Ontology (OWL DL and OWL Lite) with sublanguages of the Rule Markup Language (Unary/Binary Datalog RuleML). The rules generated follow the format shown below.

$$R_1, R_2, \ldots, R_n \rightarrow D$$

Where R_1, R_2, …, R*n* are atomic formulas depicting conditions and *D* is the resulting recommendation when the conditions are fulfilled. The rule-based engine implemented by Astmapp applies the rules to the symptoms, vital signs, triggers, and mood to generate the recommendation. An example of rule is presented below:

```
patient(?x) ^ hasRespiratoryRate(?x, ?respiratoryRate) ^
swrlb:greaterThan(?respiratoryRate, 30) ^ hasHeartRate(?x,
?heartRate) ^ swrlb:greaterThan(?heartRate, 120) ^ hasPulse(?x,
?pulse) ^ swrlb:greaterThan(?pulse, 12) → hasSevereAsthmaAttack(?x,
true)
```

The above rule specifies that patient (*?x*) with a respiratory rate greater than 30 beats per minute *(?respiratoryRate*), a heart rate greater than 120 beats per minute (*?heartRate*), and a paradoxical pulse greater than 12 mmHg (*?pulse*), had has a severe asthma attack. Finally, once a rule is applied, the system provides patients with health recommendations that help them to control their disease. To that end, Astmapp uses the *hasRecommendation* property.

Regarding the recommendations provided by this module, it should be mentioned that these ones may consist of: (a) behavioral procedures such as avoiding known trigger, ingestion of fluids, relaxation, among others; (b) relaxation training such as breathing exercises, desensitization, progressive relaxation; (c) asthma self-management outside home i.e., to identify and avoid triggers at school or work such as environmental irritants, physical activities, among others. Furthermore, these recommendations can be classified into two main groups: (1) monitoring asthma, which refers to all those recommendations intended to avoid the disease; and (2) attack management, which is focused on reducing the severity of asthma attacks. As can be perceived, the first group of recommendations is focused on prevention tasks. Meanwhile, the second group is focused on the control of asthma attacks.

4 Evaluation

The evaluation described in this section has two main goal: (1) to measure the effectiveness of Astmapp to provide educational resources to the active user considering the similitude between him/her and other users of the platform; and (2) to measure the efficacy of Astmapp regarding the provision of health recommendations. Following sections describe the evaluation process performed. Firstly, the method followed, metrics employed, and people involved in this process are described. Finally, the evaluation results are presented and discussed.

4.1 Method

Since the classification of educational resources as relevant or irrelevant is a subjective judgment task, the evaluation of Astmapp was conducted in a real-life scenario. To this end, 30 asthma patients from Guayaquil were asked to use the mobile application provided by Astmapp to record data about their symptoms, vital signs, and other health parameters, as well as to rate asthma educational resources. The evaluation procedure is described below.

1. To evaluate the asthma educational resources recommender module under a no cold-start scenario, the asthma patients were organized in two groups of twenty and ten people respectively. The first group was asked to rate (scale 1-5) different asthma educational resources provided by Astmapp. This stage was performed for two months resulting in a dataset of 516 ratings assigned to a collection of 97 asthma educational resources.
2. Once the first stage was completed, the second group of patients was asked to rate at least 15 asthma educational resources. The goal of this stage was to collect the preferences of each patient. It must be remembered that all ratings assigned by a user represent his/her interests or preferences regarding educational resources. This stage was performed for 2 weeks.
3. During the third stage, the asthma educational resources recommender module provided patients with a set of educational resources based on his/her preferences and the preferences of other users. From the set of resources provided by the system, the user selected the resources that he/she considered relevant. This process was performed eight times per patient.
4. During the fourth stage, we used the precision, recall, and F-measure metrics to measure the effectiveness of the asthma educational resources recommender module. These metrics are used in the context of information retrieval systems [Salton and McGill 1983]. In this research, the precision represents the Astmapp's ability to recommend as many relevant educational resources as possible. The precision is calculated by using the formula below.

$$Precision = \frac{relevant\ recommended\ educational\ resources}{recommended\ educational\ resources}$$

On the other hand, recall is interpreted as the Astmapp's ability to recommend as few irrelevant educational resources as possible. Recall is calculated by means of the formula below.

$$Recall = \frac{relevant\ recommended\ educational\ resources}{total\ of\ relevant\ educational\ resources}$$

Finally, F-measure is the weighted average of the precision and recall. F-measure is calculated through the formula below.

$$F - \text{measure} = 2 * \frac{precision * recall}{precision + recall}$$

5. To measure the efficacy of Astmapp regarding the provision of health recommendations, we generated a report for each patient containing all information provided by them through the platform as well as the health recommendations provided by the system during the evaluation period (two and a half months). These reports were analyzed by a group of experts outside the research team to determine which recommendations were correctly provided (TP = True positives), which ones were incorrectly provided (FP = False positives), as well as to detect cases when it was necessary to provide a health recommendation (FN = False negatives). We used the precision, recall, and F-measure metrics to measure the efficacy of Astmapp regarding the provision of health recommendations. The precision is calculated by using the formula below.

$$Precision = \frac{TP}{TP + FP}$$

Meanwhile, recall is calculated by means of the formula below.

$$Recall = \frac{TP}{TP + FN}$$

Next section presents and discusses the evaluation results.

4.2 Analysis of Results

Table 1 reports the evaluation results after applying the precision, recall, and F-measure metrics. As was mentioned in section 4.1, the recommendation process was executed eight times per user. Therefore, the results reported in Table 1 correspond to the averages scores of precision, recall, and F-measure. As can be seen in Table 1, the recommender module obtained an average precision score of 0.7695, an average recall score of 0.7820, and an average F-measure score of 0.7694. In the best cases, Astmapp obtained a precision score of 0.9091 for the patient 7, a recall score of 0.8889 for the patients 3 and 9, and an F-measure score of 0.8421 for patient 3.

Patient	Precision	Recall	*F-measure*
Patient 1	0.6250	0.7143	*0.6667*
Patient 2	0.7143	0.8333	*0.7692*
Patient 3	0.8000	0.8889	*0.8421*
Patient 4	0.7000	0.8750	*0.7778*
Patient 5	0.8571	0.7500	*0.8000*
Patient 6	0.7273	0.8000	*0.7619*
Patient 7	0.9091	0.7692	*0.8333*
Patient 8	0.8571	0.6000	*0.7059*
Patient 9	0.7273	0.8889	*0.8000*
Patient 10	0.7778	0.7000	*0.7368*
Avg.	*0.7695*	*0.7820*	*0.7694*

Table 1: Evaluation results of the asthma educational resources recommender module

Based on the results obtained, we can conclude that the recommender module of asthma educational resources obtained encouraging results since it was able to recommend a greater number of relevant educational resources than irrelevant ones. Despite the good results, we are aware that the performance of the recommender module depends on the people involved and the dataset employed. In this sense, it is necessary to evaluate Astmapp using a greater group of asthma patients and a bigger set of educational resources.

Table 2 depicts the evaluation results obtained by Astmapp regarding the provision of health recommendations. The system got a precision of 0.802, a recall of 0., and an F-measure of 0. As can be observed, the system provided patients with 540 recommendations (an average of 18 recommendations per patient). 433 recommendations were correctly provided by the system (TP) and 107 recommendations were incorrectly provided (FP). Finally, the group of professionals detected 27 cases where it was necessary to provide a recommendation given the health information of the patient.

Patients	Total of recommendations	TP	FP	FN	Precision	Recall	F-measure
30	540	433	107	27	0.802	0.941	0.866

Table 2: Evaluation results of the health recommender module

The evaluation results demonstrating a good effectiveness of Astmapp regarding health recommendation provided to the patients. Based on a detailed analysis of all reports used in this evaluation we ascribe the results to the next facts:

1. The information provided by patients (respiratory rate, heart rate, pulse) and their corresponding values cannot match with any rule established. In this

case, the system cannot provide a recommendation because of the lack of rules.

2. The set of symptoms provided by patients match with many rules, or there were many known symptoms which can match with one rule. In this case, because there are several rules that use the same symptoms, the rule-based engine cannot determine which rule should be used, i.e. which recommendation must be provided to the patient.
3. We observed that the health recommender module is more precise when patients provide more information about their symptoms and health parameters. Also, according to the group of professionals involved in the evaluation process, there are symptoms that are not described by the ontology proposed. In this sense, it would be desirable to extend the ontology regarding the set of symptoms. This, in turn, will allow us to generate a bigger set of rules that improve the effectiveness of our proposal.

Finally, it is important to mention that we did not perform a comparison between our proposal and other systems available in the literature since it represents a difficult task because none of the software applications and data are publicly available. Furthermore, the data used for each experiment differ significantly as regards content, size, and topics. A fair comparison of two recommender systems would require the usage of the same testing data. For this reason, we perform an exhaustive search for a standard dataset of asthma educational resources. Despite our efforts, we found only datasets concerning tourism, technological products, among others.

5 Conclusions and Future Work

This work presents Astmapp, a platform that combines mobile and semantic technologies with recommender techniques for supporting asthma self-management tasks such as education, and monitoring and control of the disease. This work arose in response to the need for technological tools that help asthma patients to improve their quality of life. The main contribution of this work is twofold. First, in this work, we propose an ontology that models the asthma self-management process as an effort to facilitate the interchange of information and make it understandable by humans and computer. In this sense, Astmapp implements a rule-based engine that exploits the knowledge described by the ontology to provide patients health recommendations. Second, Astmapp implements collaborative filtering methods to recommend educational resources that help asthma patients to understand their disease as well as to improve their clinical outcomes. Astmapp was evaluated in quantitative terms, and the obtained results suggest that this platform can be a good tool for supporting asthma self-management process. Despite the evaluation results are encouraging, it is necessary to integrate technologies such as the Internet of Things and opinion mining to improve the quality of the platform. Next section provides a discussion concerning future work.

As future work, we will take advantage of the patient's information stored by the system to implement a knowledge-based recommendation approach that helps us to deal with the cold-start issue. Also, we are considering using opinion mining techniques that allow Astmapp to identify and process opinions from social networks such as Twitter and Facebook. The goal of this task is to provide patients with

information about the opinion that the community has about physical activities and food related to the asthma self-management process. This information could help patients to improve their knowledge about their disease as well as to make decisions in conjunction with their physician. Likewise, we plan to integrate devices based on the Internet of Things that allows monitoring the quality of air in the home and, based on such information generate new health recommendations in real time. In this sense, we also plan to integrate mechanisms that allows Astmapp to access to the location of the patient i.e., to identify when the patient is in school, work or home or if he/she is traveling and then, generate the appropriate recommendations that consider the weather and air pollution of the place. Finally, we plan to implement Astmapp in a hospital from the Guayaquil city during a one-year period. We will make sure that our proposal works correctly in a real environment. Also, we will document if Astmapp helps patients to improve their quality-of-life. Based on such information, health professionals could decide whether to recommend or not recommend using our proposal as part of asthma self-management process.

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