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u-MCHC: A predictive framework for ubiquitous management of exacerbations in chronic diseases.

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Abstract— **Exacerbations are crucial events in chronic diseases that require continuous management. Knowledge of the exacerbation risk enhances patient's quality of life and enables self-management and self-organizing of unscheduled doctor visits and/or hospitalization. This paper proposes a new framework for ubiquitous management of chronic diseases named u-MCHC. The proposed framework incorporates monitoring, decision-making, notification and management processes in order to deliver personalized therapeutical options and services. The delivery of services is realized by means of Next Generation Service Delivery Platform (NG-SDP). A prototype implementation of u-MCHC and its performance is demonstrated in a real world case for Chronic Obstructive Pulmonary Disease (COPD).**

I. INTRODUCTION

An exacerbation is defined as an acute event characterized by a worsening of the patient's symptoms that is beyond normal day to day variations. Exacerbations are crucial events in the chronic diseases [1, 2] because: (a) they negatively affect a patient's quality of life, (b) they have effects on symptoms that take several weeks to recover from, (c) they are associated with significant mortality, particularly in those requiring hospitalization and finally (d) they have high socioeconomic costs [3]. As a consequence, risk exacerbations are crucial for preventing the onset of chronic conditions, or anticipate complications of clinical signs that have already been developed. Knowledge of the exacerbation risk provides the opportunity to healthcare professionals to inform patients about their health severity and disease prevention.

In response to the emerging challenges posed by chronic diseases and exacerbation risks, it is required a patient-oriented care model where the doctors work in partnership with the patient and other healthcare professionals (e.g. nurses, etc) so as to meet the rising demand for personalized healthcare services and improve patient's quality of life [2]. On the other hand, network operators and service providers (3rd party providers, content providers, etc), aim to develop new models for creating and delivering personalized healthcare services.

The first care model for chronic condition management was a conceptual evidence based framework named Chronic Care Model (CCM) [4]. The CCM model presents a structure for organizing healthcare to improve outcomes among patients with chronic illness. The World Health Organization (WHO) proposed the Innovative Care for Chronic Conditions (ICCC) framework which enhances the CCM in order to meet the needs of the international community [1].

With the evolution in information and communication technologies as well as the ambient intelligence (AmI), these care models were adopted and integrated into context aware and user friendly service platforms aiming to support chronic care patients [5]. Commercial solutions [6, 7] enable self monitoring and managing of chronic diseases but lack any intelligence and ubiquitous characteristics. Several efforts and research have contributed to the deployment of home based ubiquitous healthcare service delivery platforms (SDPs) for supporting elderly people [5, 8, 9]. ERMHAN [5] is the most complete SDP based on service oriented architecture and is aligned with the CCM. However, the deployed healthcare systems are mostly home based and tightly coupled with an acute and episodic model of care. That's the reason why they do not achieve to meet the requirements of chronic health problems.

Moreover, CHRONIOUS [10, and 11] is a wearable platform for monitoring and managing patients suffering from chronic disease both indoors and outdoors. CHRONIOUS categorizes the health level of Chronic Obstructive Pulmonary Disease (COPD) patients [3]. Finally, in [12] we have proposed a NG-SDP platform based on a Context Decision Making Enabler (CDME) that acquires knowledge from user's context so as to provide personalized treatment. The above systems are efficient in monitoring, categorizing and managing the current patient's health status, nevertheless, are unlikely to prevent exacerbations or minimizing distressing symptoms.

This paper proposes a new framework for the ubiquitous management of chronic healthcare (u-MCHC). This framework predicts exacerbations in the chronic diseases and delivers personalized therapeutical options for individual patients. It is based upon an advanced structure of the CDME module of the NG-SDP platform that uses an additional symptomatic diagnosis, which affects the chronic disease, as the key feature for categorizing the current patient's health status. Through u-MCHC, any patient is capable of self-managing and self-organizing unscheduled doctor visits and/or hospitalization. The u-MCHC is based on the Random Forest (RF) machine learning technique for the detection and prediction of exacerbation risk. The exacerbation risk is calculated through the estimation of the severity level in correlation with symptoms assessment and the history of exacerbations. A prototype implementation has been proposed for predicting and anticipating exacerbations in patients suffering from COPD. The performance of u-MCHC has been evaluated through the analysis of real world conditions.

The rest of the paper is organized as follows: in section II the architecture of u-MCHC is described. Section III analyzes

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the implementation of u-MCHC based on COPD and the assessment of exacerbation risks. Finally, the evaluation of the u-MCHC implementation is discussed in section IV.

II. u-MCHC Architecture Overview

U-MCHC is a predictive framework that acquires and evaluates user contextual information so as to determine the severity of the disease, its impact on patient's health status and the risk of future events (such as exacerbations, hospital admissions or death) in order to assist therapy. Fig. 1 depicts the general architecture and the process modules of U-MCHC framework.

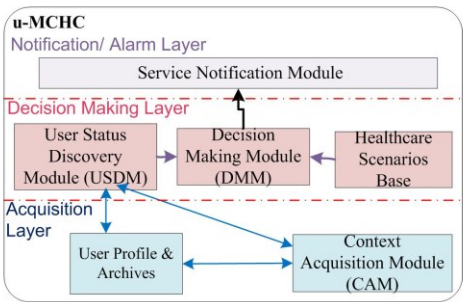

Figure 1. The architecture of the u-MCHC framework.

Acquisition Layer contains the Context Acquisition Module (CAM) and the User Profile and Archives. CAM collects vital bio-signals and environmental contextual data from sensors (e.g. humidity, temperature, etc), as well as services through web providers (e.g. weather, traffic, questionnaires, etc) (Fig. 2, step 1). Then it stores temporarily this information into to a database named Context Data Base (Fig. 2, step 2) for recovery purposes. Simultaneously, CAM sends a request to User Profile & Archives in order to retrieve data (e.g. medical history, patient's lifestyle and profile, history of exacerbations, etc) related with the patient's same ID (Fig. 2, step 3). The aggregated data from CAM and User Profile & Archives triggers the decision making layer so as to characterize the severity level of the disease (Fig. 2, step 4).

Decision Making Layer is triggered by the acquisition layer and is composed of the User Status Discovery Module (USDM), Decision Making Module (DMM) and the Healthcare Scenarios Base. The major aim is to reduce symptoms, the frequency and the severity of the exacerbations and improve patient's health status. The USDM provides the routine patterns [12] that correspond to permanent indicators of the disease. The routine patterns are combined with the user's indications from the acquisition layer (CAM) so as to determine the severity level of the disease using RF regression technique (Fig. 2, step 5, step 6). According to the (a) severity level, (b) symptoms assessment and (c) history of exacerbations (data from User Profile & Archives), the risk of future exacerbations is assessed by means of a strict rule-based system i.e. IF-THEN-ELSE rules (Fig. 2, step 7). The exacerbation risk is related with a list of healthcare scenarios stored in the Healthcare Scenarios Base. Each healthcare scenario is composed of a list of therapeutic options, services and the participants involved in patient's treatment. A decision control is used to assign the most suitable healthcare scenario according to the exacerbation risk (Fig. 2, step 8).

Notification/ Alarm Layer is triggered by the decision control (Fig. 2, step 9). It is based on an alarm system that notifies the platform system for determined healthcare scenario that will be activated. It sends an alarm and an event based message to the message broker of the platform (Fig. 2, step 10) for the group of entities and services that should be activated in order to deliver the most suitable personalized services for the treatment of the symptoms or the avoidance of an exacerbation episode (such as changing in medication).

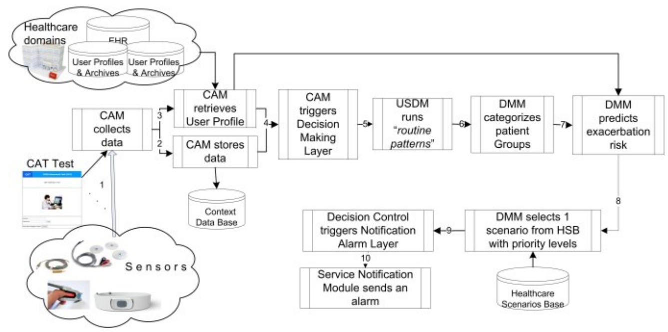

Figure 2. The u-MCHC workflow diagram.

III. Implementing u-MCHC

For the development of the u-MCHCM, we thoroughly studied the COPD disease and specifically we focused on the management and prediction of the exacerbation risk in COPD patients. COPD is characterized by persistent airflow limitation that is usually slowly progressive and associated with an enhanced chronic inflammatory response in the airways and the lung to noxious particles or gases. COPD differs among patients in its development and pathology. The COPD exacerbation risk assessment consists of the following action points: (a) determine the severity level of the disease, (b) estimate the intensity of symptoms and (c) take into consideration the history of previous exacerbation episodes and/ or hospitalization.

Normally, the assessment of the COPD exacerbation risk and the COPD severity level are based on Post-Bronchodilator FEV_1. It is reliable only if: (a) the intervals between measurements are at least 12 months and (b) it is measured in the hospital by healthcare professionals [3]. However, in order to manage and predict exacerbations efficiently, it is recommended to monitor patients more frequently. In this case, the FEV_1 is not reliable. Instead of FEV_1, real time measurements (bio-data- bio signals) are acquired under free-living conditions.

A. COPD Acquisition Layer

The COPD acquisition layer retrieves the following data: (i) real-time bio-data, (ii) symptoms and (iii) Electronic Health Records (EHR).

The portable devices used for the ubiquitous acquisition of bio-data are: pulse oximeter (SpO_2), accelerometer, body temperature sensor, airflow sensor, blood pressure sensor and an electrocardiograph ECG. The measurements are temporarily stored in CAM and then they are correlated with the patient's EHR stored in the hospital.

For the characterization of the intensity of symptoms, each patient is called to describe his current health status through the completion of a special questionnaire. It includes a set of 8-questions that are aligned with the COPD Assessment Test (CAT) [13] and recommendations suggested in [3]. Each question refers to a different COPD symptom and the corresponding answer indicates the strength of this symptom. Upon submission of the questionnaire, a total score is calculated, namely CAT score. All variables have the same impact on the calculation of the CAT score. Fig. 3 depicts the 8-questions that are correlated with the symptoms (e.g. cough, plegm, chest pain etc) of COPD. This questionnaire is accessed and completed via a human-friendly web interface implemented in PHP. The provided answers and the calculated CAT score are stored in a MySQL database in order to be used in the prediction process and also for future reference.

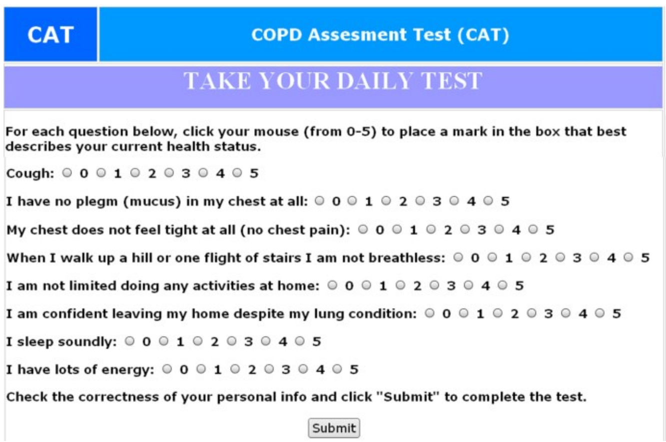

Figure 3. The CAT symptom related questionnaire.

B. COPD Decision Making Layer

The COPD disease usually coexists with other diseases. A simple flu or a respiratory or cardiovascular episode influence the SpO_2, the respiratory rate or the heart rate measurement and introduces errors in the prediction of exacerbation risk. In order to meet this challenge and predict more accurately the exacerbation risk, the history of exacerbations is used in conjunction with the CAT score and the bio-data measurements. Note that in this work, we have not considered the effect of other comorbidies, such as diabetes, lung cancer, anxiety, etc. The treatment of these conditions results in a reduction of symptoms and as a consequence of the CAT score.

According to GOLD [3], a decrease in the CAT score is observed after 14 days from an exacerbation episode. In addition, this is the minimum time period for a change in the CAT score by 2 points between two consecutive measurements. Therefore, the results of the CAT test are assessed every 14 days. Given this fact, we estimate the probability of an exacerbation in the next 14 days period. However, the CAT test is performed on a daily basis and the evolution of the intensity of symptoms is used for the appropriate delivery of services such as medication. Fig. 4 depicts the interactions between the functional entities that are involved in the decision making process.

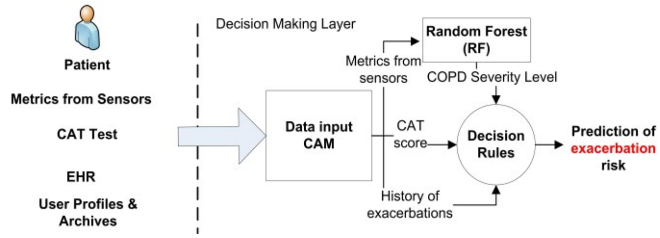

Figure 4. The decision-making process

At first, we categorize the patient's current health status by calculating the COPD severity level (mild, moderate, severe and very severe- GOLD 1, 2, 3, and 4 respectively). The severity level is defined by the real time metrics from sensors. The severity level classification is handled by decision rules based on RF techniques [11]. Training data acquired from multiple patients are used in the construction of a set of decision trees. Each tree is fed with a random subset of the available variables, i.e. the bio-data metrics and the resulting GOLD level. The outcome of this regression process is a set of decision rules than can be used to estimate the COPD severity level.

According to the COPD severity level and the CAT score, the patients are categorized into four distinct groups, namely A, B, C and D. Each group determines the appropriate medication as suggested in [3]. Table I represents the Association between Patient Group, COPD Severity levels and Symptoms [3].

TABLE I: ASSOCIATION BETWEEN PATIENT GROUP, COPD SEVERITY LEVELS AND SYMPTOMS.

Patient Group	**Characteristics**		**COPD Severity levels**	**CAT**
	Risk of disease	**Symptoms**		
A	Low	Less	GOLD 1, 2	<10
B	Low	More	GOLD 1, 2	≥10
C	High	Less	GOLD 3, 4	<10
D	High	More	GOLD 3, 4	≥10

For the efficient prevention and anticipation of exacerbation episodes, it is recommended to correlate the patient's group with the history of exacerbation and the history of hospitalization during the last 12 months [3]. Table II presents the decision rules and the healthcare scenarios for the appropriate delivery of services and the involved participants.

TABLE II: DECISION RULES

Rules	**Decision**
IF patientGroup=A AND historyExac≤1 THEN	Exercise
IF patientGroup=A AND historyExac≥2 THEN	Appointment with doctor next week
IF patientGroup=B AND historyExac≤1 THEN	Strength & endurance training
IF patientGroup=B AND historyExac≥2 AND PaO_2≤55mmHg THEN	Oxygen therapy & appointment with doctor

Rules	Decision
IF patientGroup=C AND historyExac≥2 AND historyHosp≤1 THEN	Exercise & respiratory muscle training
IF patientGroup=C AND historyExac≥2 AND historyHosp≥2 THEN	Immediate appointment with doctor and/or Hospitalization
IF patientGroup=D AND historyExac≥2 AND historyHosp≤1 THEN	Exercise & respiratory muscle training & notification for medication
IF patientGroup=D AND historyExac≥2 AND 55<PaO2 ≤60mmHg AND historyHosp≥2 THEN	Oxygen therapy & Immediate appointment with doctor and/or Hospitalization

IV. RESULTS/ DISCUSSION

It is highly recommended to monitor patients after the first hospitalization due to COPD, since the probability of another exacerbation or hospitalization is crucial for patient's quality of life. Moreover, smoking cessation is recommended to all patients independently of the disease risk.

The proposed u-MCHC has been implemented as prototype to provide monitoring, predicting and anticipating of exacerbations for chronic diseases in cooperation with specialists of the Pulmonary Department and the Department of Emergency Medicine, Rion University Hospital.

In order to validate the proposed u-MCHC framework, data from 30 patients suffering from COPD has been recorded. The data has been acquired on a daily basis during the period of one year. The 30 patients were placed in 2 groups as follows: (1) Group 1 includes 22 patients for whom we have all the required information such as EHR, history of exacerbations and history of hospitalization and (2) Group 2 includes 8 patients for whom there are missing data such as metrics of sensors or EHR. The aggregated data was being sent to a medical doctor who verified the validity of the results from the Decision Making Layer.

The final assessment is oriented towards the prevention of the highest-risk situations. Consequently, false positive alarms are far less important than false negative ones. This is due to the fact that respiratory muscle and exercise training reduce the frequency and severity of exacerbations. The final diagnosis held by the doctor, confirmed 75.74% success ratio for the Group1 and 50.87% for Group 2 (Fig. 5).

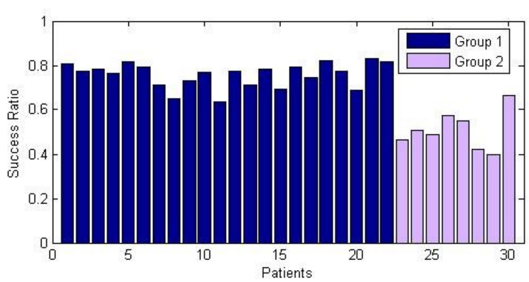

Figure 5. Evaluation of u-MCHC

The difference in the success ratio is justified by the lack of sensor data and/or EHR for the patients of Group 2 which leads in errors in the calculation of the severity level via RF. Moreover, the presence of comorbidies has a major impact to the prevention and management of the exacerbations.

It is important to note that the internal processes and decision rules in the Decision Making Layer can be adapted according to current advances in healthcare domain. Moreover, the proposed u-MCHC framework can handle various chronic diseases that require continuous management and periodic predictions by delivering services in order to anticipate future exacerbations.

V. CONCLUSION

In this paper, a framework for ubiquitous management of exacerbations in chronic diseases was presented. The proposed framework aims to deliver services for management, prevention and anticipation of exacerbations. It may serve as a valuable tool for healthcare professionals, when deciding on appropriate therapy. Moreover, it enhances quality of life since it enables any patient to self-manage and self-organize unscheduled doctor visits and/or hospitalization. A prototype has been implemented and it was evaluated in real world conditions. Results verify the effectiveness of the proposed framework. As a future work the system will be enhanced in order to take into consideration all the comorbidies that may exist.

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