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An autonomous mobile system for the management of COPD

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ABSTRACT

Introduction: Managing chronic disease through automated systems has the potential to both benefit the patient and reduce health-care costs. We have developed and evaluated a disease management system for patients with chronic obstructive pulmonary disease (COPD). Its aim is to predict and detect exacerbations and, through this, help patients self-manage their disease to prevent hospitalisation.
Materials: The carefully crafted intelligent system consists of a mobile device that is able to collect case-specific, subjective and objective, physiological data, and to alert the patient by a patient-specific interpretation of the data by means of probabilistic reasoning. Collected data are also sent to a central server for inspection by health-care professionals.
Methods: We evaluated the probabilistic model using cross-validation and ROC analyses on data from an earlier study and by an independent data set. Furthermore a pilot with actual COPD patients has been conducted to test technical feasibility and to obtain user feedback.
Results: Model evaluation results show that we can reliably detect exacerbations. Pilot study results suggest that an intervention based on this system could be successful.

1. Introduction

Increasing demands on health-care and continuous pressure from health-care authorities and insurance companies to reduce costs while maintaining quality of care has created a situation in which automation of particular parts of the patient's care process has attracted attention. Especially the provision of computer-aided assistance in the management of the patient's diseases is an attractive option. In the context of chronic diseases, patients are continuously at risk of deterioration of health, requiring regular medical checkups and monitoring of their health status by the treating medical doctor. Providing computer-aided support to the patient can relieve work-load of health-care workers, while helping patients self-manage their disease. However, the provision of computer-aided support to patients poses questions with respect to whether or not patients are able to profit from the support, how the patient data needed for that purpose can be collected and interpreted, and which technical infrastructure is most effective.

The idea to offer computer-aided support to patients at a distance from the treating hospital or practice is not new. Remote care facilitated by telecommunication technology has existed for some time already under different names such as: 'telehealth', 'telemedicine' and more recently 'eHealth' (electronic health) and 'mHealth' (mobile health). The exact scope and definition of all these terms varies, as exemplified by the review of Oh et al. [1] that identifies 51 definitions of the term 'eHealth'. Although different definitions will place different emphases we can summarise the definitions as *facilitating health care irrespective of location by means of technology*. Practically speaking this means that information and communication technology assists in disease management, patient-doctor communication, patient education or any other application that promotes health.

The research described in this paper aimed at developing methods for computer-aided assistance, including event detection, alerting, monitoring and treatment advice, as part of chronic disease management at a distance from the hospital. Patients with diseases such as diabetes mellitus, chronic obstructive pulmonary disease (COPD), asthma and heart failure can benefit from assistance. We have applied it here to assist COPD patients, but the general framework is applicable to many other health-care situations. For COPD we collect data on respiratory symptoms, measure lung function and interpret these data by a probabilistic model to assess the risk of a clinically relevant worsening of symptoms due to an exacerbation.

The main challenge addressed by the research was to develop a computer-aided disease management framework that allows finding a proper balance between self-management by the patient and support in various forms by health-care workers. This depends on the patient's demands and wishes, the disease being managed and

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the requirements of health-care workers. One of the implications of the resulting requirements was that disease-related patient data had to be interpreted automatically as part of the patient's self-management support. The system had to be capable of delivering autonomous assistance in disease management without being intrusive. Hence we decided for data monitoring and interpretation directly on a smartphone. Thus, the smartphone became the device of choice, enabling instant feedback to the patient. To cover the whole spectrum from complete self-management to distance support by health-care workers, collected patient data can also be relayed to health-care providers through a central server for both disease management configuration and inspection.

Use of a smartphone makes it possible to forego the need for a personal computer (PC) with internet connectivity. This has the advantage that whereas most people are used to responding to phone alerts, sending reminders via email or a website may have little effect on the patient's behaviour. This is also very much in the spirit of health care that is no longer tied to a particular location.

If we compare this to usual care we see that patients have regular but fairly sporadic contact with their physician unless there is an acute reason for an unscheduled visit. Our system is capable of advising patients to take measures at an earlier stage than usual and enables easier communication between patients and health-care providers. Although parts of what the system provides has been used before in the context of eHealth or decision-support systems meant for health-care workers as user, the idea to place both healthcare users and workers on an equal footing by offering patients sophisticated, mobile decision support is new. The more common eHealth systems are mainly focussed on sending small sets of measurements from the patient to health-care providers, who still have to interpret these findings [2]. In the system described below, clinical knowledge is incorporated by means of a probabilistic graphical model in the smartphone, making it possible to provide relevant clinical advice automatically, to assist in patient self-management.

The following questions are explored in the rest of the paper. It is investigated in what way patients can be empowered with disease management assistance to prevent exacerbations of COPD. Another relevant question is whether it is feasible to automatically interpret monitoring data by probabilistic models to detect clinically relevant events. This question is explored by means of statistical model validation methods. As a prerequisite we examine choices with respect to the important features of the disease management system in terms of hardware and software. Finally, the usability of the system was investigated with the help of COPD patients. Summarising, we report on a system for COPD exacerbation management, that has the novel feature of including automatic data interpretation by a probabilistic risk model, enabling autonomous operation to support patient self-management.

In the next section, we start with some background on the clinical problem addressed in the research. Then the architecture of the disease management system is described in Section 3, focussing on its design and technical capabilities. Furthermore we report on a pilot study that investigates technical and clinical feasibility with a number of patients. The probabilistic model that is used for data interpretation is explained and evaluated in Section 5. Then in Section 6 we compare our system with telemonitoring requirements laid out by Peirce et al. [3] and with existing work on COPD telehealth, followed by a general discussion in Section 7.

2. Chronic obstructive pulmonary disease

Chronic obstructive pulmonary disease, or COPD for short, is a chronic lung disease with high impact on patient well-being and with considerable health-care related costs [4]. Exacerbations – acute events of worsening of COPD-related health status – are important events in the progression of COPD, such that monitoring patients in a home setting to detect exacerbation onset may be warranted [5]. In this paper we focus on disease management and specifically on detecting and managing the occurrence of exacerbations of COPD at an early stage. We aim to decrease the impact of COPD on the patient's quality of life, and prevent unscheduled doctor visits and hospitalisation due to exacerbations.

Chronic obstructive pulmonary disease is estimated to affect some 64 million people worldwide[1] and is one of the major chronic diseases in terms of both morbidity and mortality. COPD affects the respiratory system, decreasing lung capacity and obstructing airways, thus interfering with normal breathing. Patients often suffer from a combination of emphysema and chronic bronchitis, causing shortness of breath and therefore reducing their capability of performing day-to-day activities. The main cause of COPD is prolonged exposure to tobacco smoke; other causes include severe air pollution. COPD is currently not curable, but treatment does reduce the burden considerably. For further information on COPD see e.g. the Global Initiative for Chronic Obstructive Lung Disease (GOLD).[2]

An important aspect of COPD which is particularly relevant in the present context is the progressive nature of the disease. Specifically exacerbations have a profound impact on the patient's well-being and on health-care costs [4]. These exacerbations are mainly caused by airway infections resulting in symptom worsening [6]. Important to note is also that patients with frequent exacerbations usually have faster disease progression, which makes exacerbation prevention a particularly relevant goal. Additionally, a faster treatment response to exacerbations leads to better recovery [7]. We can distinguish different clinical approaches to defining exacerbations. Due to limited observability it is not feasible to give a practical definition in terms of pathophysiology, hence exacerbations are usually defined as an increase in symptoms; in terms of use of medication; or in terms of unscheduled health care use. We will return to this point in Section 5.

The state of the respiratory system is observable via symptoms including dyspnea (breathlessness), productive cough, wheezing breath and decreased activity due to breathlessness. Besides these symptoms a number of physiological signs are relevant, in particular the forced expiratory volume in 1 s (FEV_1) and blood oxygen saturation. FEV_1 measures airway obstruction by testing to what extend the patient can overcome obstructive and restrictive resistance during forced exhalation. A number of other indicators of deterioration exist, like blood oxygen pressure, inflammatory proteins and white blood-cell counts. However, measuring these factors requires hospital-grade equipment and incurs considerable inconvenience for the patient. Blood oxygen pressure can be observed by proxy with a pulse-oximeter that measures blood oxygen saturation.

3. Remote disease management

The long term nature of COPD and associated exacerbation risk require that any system, deployed in a home-care setting, takes into account not only efficacy, but also usability as important factors in the design. This section describes the current system design, the choices we made and some of the issues that arose during the development and implementation.

3.1. System overview

3.1.1. General architecture

In Fig. 1 a graphical representation of the general idea behind our disease management setup is shown. The system consists of

[1] World Health Organization http://www.who.int/mediacentre/factsheets/fs315/en/index.html. Accessed: January 2013.

[2] www.goldcopd.com.