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Possibilistic activity recognition with uncertain observations to support medication adherence in an assisted ambient living setting

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ABSTRACT

A recent trend in healthcare is to motivate patients to self-manage their health conditions in home-based settings. Self-management programs guide and motivate patients to achieve self-efficacy in the self-management of their disease through a regime of educational and behavioural modification strategies. To improve self-management programs effectiveness and efficacy, we must consider Ambient Assisted Living (AAL) technologies (smart environments, activity recognition, aid acts planning), since they alleviate issues related to unreliable self-reported data by monitoring self-management activities. To improve self-management programs in smart environments, it is necessary to recognize the occupant behaviour from observed data. Observed data/attributes generated from various sources (sensors, questionnaires, low-level activity recognition) are certain to uncertain (imprecise, incomplete, missing), where several values are plausible instead of only one. Thus, activity recognition must consider heterogeneous observations (sources' types) and uncertainty in the activity recognition inputs (observations). To address this challenge, we propose an activity recognition approach based on possibilistic network classifiers with uncertain observations. We believe that this is the first work to consider possibilistic network classifiers for the recognition of activities in smart environments using uncertain observations. We have validated the approach on 780 synthetic scenarios illustrating behaviours related to medication adherence. The activity classifiers, based on knowledge and beliefs about the activities related to medication adherence, can correctly recognize 79% of an activity current state, which is comparable with approaches based on data-driven naïve Bayesian classifiers. Furthermore, the classification performance only decreases when we have highly partial to complete ignorance about the observations values. Hence, the validations results show the interest of activity recognition based on possibilistic network classifiers for handling uncertain observations.

1. Introduction

Ambient intelligence systems (such as smart homes) are digital environments, leveraging artificial intelligence and pervasive computing technologies for continuous and unobtrusive in-home monitoring of patients to assist them by providing timely alerts, reminders, interventions and rapid emergency calls [1–3]. Ambient Assisted Living (ALL) tools [4] aim to maintain and improve the Quality of Life (QoL) of individuals by assisting them to self-manage their health in a home-based setting [5], such as reminding them about impending healthcare activities, healthy lifestyle reminders and provision of timely support at the opportune moment. Recently there is a growing emphasis to encourage patients to self-manage their health conditions in home-based settings. Self-management programs allow to guide and motivate patients to achieve self-efficacy in the self-management of their disease through educational and behavioural modification interventions. Disease self-management is an important aspect of lifetime healthcare, where the intent is to engage and empower the patient to self-manage their condition by adhering to their therapeutic plan (such as taking medications regularly), keeping a healthy lifestyle, performing health activities (such as follow-up visits, investigations) punctually and mitigating risk factors. Self-management programs are designed to help individuals with health issues to get engaged in their care process and play an active role in managing their condition, and via a dynamic and continuous process of self-regulation enhance their efficacy to self-manage their condition [6]. Ambient services, such as activity recognition [7], provide the functionality to establish the situational context of an individ-

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ual and then to provide context-sensitive self-management support to the individualized needs of the patient [8].

Medication adherence is defined as "the extent to which patients follow the instructions they are given for prescribed treatments" [9]. Sub-optimal medication adherence among patients; particularly those with chronic diseases and receiving long-term therapies, leads to increased healthcare costs to the extent of $300 billion annually in US [10] and discomfort for the patient [11]. Studies have shown that around 20%–30% of all medication prescriptions are never filled and about 50% of medications for chronic disease are not taken as prescribed [12]. This trend is particularly acute in patients with cardiovascular diseases and asthma, where the non-adherence rates are 50% for cardiovascular patients [13], and between 30 to 70% for asthma patient [14], with <50% of children adhering to their prescribed inhaled medication regimen [15]. The opinions of patients on adherence to medication have an impact on medication adherence [16]. For instance, a web-based survey has shown that almost half of patients with hypertension and diabetes mellitus did not report missed doses to their doctor [16]. A number of strategies to promote medication adherence have been presented in literature [17]. The most significant of these construct include: (i) simplifying the drug regimen [18]; (ii) providing simple and effective patient education in order to enhance patient's understanding of the drug regimen and health consequences of non-adherence [19]; (iii) improving communication with the patient and if necessary, involving patient's families in discussions regarding the regimen and building trust in patient-provider relationship [20]; (iv) helping patient modify behaviours that contribute to poor medication adherence by addressing patient's beliefs, intensions, confidence, social support, environment etc. [21]. Such strategies can improve the opinions of patients on adherence to medication, which will also improve medication adherence and self-management [22]. Sentiment analysis [23] can be used to assess opinions and other facets of sentiment (e.g. patient is feeling better) in documents (e.g. social media, clinical documents…) in the context of medicine [24]. Sentiment analysis is an approach to automatic identification and extraction of opinions and sentiments from text based on data mining and natural language processing (NLP) techniques [25]. Sentiment analysis has been used in medical settings to detect the mood of cancer patients (*SentiHealth-Cancer*) [26], to detect adverse drug reactions (*ADRMine*) [27], and to allow patients to evaluate their health status and experience (*Sentic PROMs*) [28].

Despite a range of medication adherence interventions, almost half of the interventions seem to fail [12]. One of the reasons of sub-optimal outcomes of these interventions is the inability to accurately find out whether patients are taking their medications since most approaches rely of self-reported data and prescription refills which are both unreliable accounts of medication adherence. We believe that one approach to improve medication adherence is to (a) unobtrusively monitor patient's intake of medications, (b) proactively remind them in case they are non-compliant to their medication regimen and (c) improve compliance via behaviour modification strategies that target improving their motivation and efficacy towards medication adherence. We posit that pervasive computing technologies and AAL tools, can be leveraged to develop computerized self-management programs [29,30] for improving medication adherence amongst patients by (a) observing the daily activities of a patient (in a specific smart home setting), (b) based on the observed activities inferring whether the patient has taken his/her medications, and (c) reminding the patient in a timely manner to take their medications [31].

In this paper, we present an AAL framework that aims to improve medication adherence in patients by monitoring their activities and reminding them to take their medications. We have implemented an AAL environment comprising multiple sensors to monitor a patient's activities, coupled with a series of dedicated activity recognition agents to infer the patient' medication adherence based on the observed activities. Our approach is based on activity recognition, where we have developed multiple activity recognition agents that use observations (data) collected from connected sensors to infer whether the patient's monitored activity supports the possibility that the patient has taken his/her medication [5]. Given that we are dealing with uncertain observations – i.e. the patient may be performing activities in a non-deterministic manner, sensor malfunction and abnormal situations – the inferring of the patient's activity needs estimating the possibility of actuation of a series of related low-level sub-activities based on the observed contextual information (such as locations, high-level sub-activities) about the smart environment. To recognize the activity of the patient, activity recognition agents incorporate activity models that are developed using possibilistic network classifiers, based on possibility theory [32], since they can better handle uncertain and incomplete data for recognizing the current state of an activity [33]. Possibility theory is an uncertain theory that can handle poor data since possibility distributions characterise imperfect knowledge, from complete knowledge (only one value plausible) to complete ignorance (all values plausible) about an attribute value. Since the monitored activities have different expected durations and impacts, we have developed multiple activity models, where each activity model uses targeted contextual attributes relevant to a specific activity. Therefore, each agent watching a specific activity only retrieves relevant contextual events that occurred within the expected duration of its monitored activity. Our AAL framework employs self-management agents that use the activity recognition results to evaluate if the patient is following the medication schedule and then delivers assistive acts (motivational messages, reminders, target achievement notifications) to the patient's smartphone. The rest of the paper is organized as follows. Section 2 presents related works that handle uncertain observations for activity recognition. Section 3 presents how smart environments can improve medication adherence, describing activities to monitor and contextual information to retrieve. Section 4 presents the activity model, with description on the activity classifier. Section 5 presents a validation of our proposed approach for activities related to medication adherence. Finally, we conclude the paper, and suggest future perspectives of this work.

2. Related Work: activity recognition methods

Activity recognition can be described as the process of inferring an agent's ongoing activities from the observed environmental changes triggered by the agent's behaviour [5]. Activities can be monitored by several sources, such as vision-based [34], sensor-based [35], and self-reported-based [36]. There are two main categories for activity modelling, representation, and inference approaches: data-driven and knowledge-driven activity recognition. Data-driven activity recognition uses machine learning techniques in order to obtain activity models from annotated datasets [37]. Activity inference is usually based on probabilistic and statistical reasoning such as Dynamic Bayesian Networks (DBN) [38]. Data-driven activity recognition approaches, such as DBN, support the modelling and inference of complex activity patterns (interleaved activities) and are considered better in handling noisy, uncertain and incomplete data [39]. However, the main drawback of data-driven approaches is that significant amounts of preliminary training data are needed to learn the activity models. Since the same user can carry out activities in diverse ways, all variants must be present in the dataset to learn properly the activities models. Also, we need to adapt/retrain the learnt models, since the user can change its behaviour. Finally, since different users do not share the