JOURNAL OF INNOVATION IN DIGITAL ECOSYSTEMS 3 (2016) 48–56

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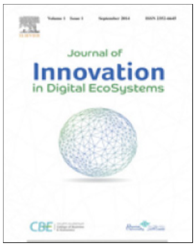

CogWatch: Automatic prompting system for stroke survivors during activities of daily living[☆]

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HIGHLIGHTS

- The contribution of this paper is to provide further knowledge about how an artificial intelligent rehabilitation system such as CogWatch can be conceptualized.
- The process through which CogWatch can learn how to properly provide guidance to stroke survivors during the tea-making task will be explained.
- The algorithms developed for action planning and human error recognition will be evaluated and compared with other techniques.

ARTICLE INFO

Article history:
Published online 1 December 2016

Keywords:
POMDP
Planning under uncertainty
Error recognition under uncertainty
Assistive technology

ABSTRACT

This paper presents CogWatch - an automatic prompting system designed to guide stroke survivors during activities of daily living, such as tea-making. In order to provide guidance during such activities, CogWatch needs to plan which optimal action should be done by users at each step of the task, and detect potential errors in their behavior. This paper focuses on the CogWatch Task Manager, which contains the modules responsible for action planning and human's error detection under uncertainty. We first give an overview of the global assistive system where the Task Manager is implemented, and explain how it can interact with a user during the tea-making task. We then analyze how novel algorithms allow the Task Manager to increase the system's performance.

1. Introduction

Each year, there are more than 100,000 new stroke cases in the UK [1], with over half of all stroke survivors depending on others to carry out Activities of Daily Living (ADL); for example, cooking, grooming, teeth-brushing or making a drink. Stroke survivors face difficulties due to the loss of physical and cognitive functions caused by Apraxia or Action Disorganization Syndrome (AADS) [2–4]. In [5], it is estimated that such cognitive deficits affect 46% of stroke survivors during ADL. For example, when preparing a cup of tea, individuals with AADS may forget to pour water into the kettle then switch it on, skip steps, or misuse objects with possible safety implications. These errors can relate to

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Peer review under responsibility of Qassim University.
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http://dx.doi.org/10.1016/j.jides.2016.10.003

the defective use of tools and objects [6], the inability to correctly select tools for a task [7], or the inability to complete sequences of actions [8]. These neurological deficits impact on stroke survivors, relatives, caregivers and society as a whole.

Rehabilitation interventions can mitigate the effects of AADS and improve stroke survivors' conditions [9,10]. During such interventions, skilled clinicians guide stroke survivors through ADL by observing their behavior, provide appropriate assistance and prompt them when necessary. However, rehabilitation is costly in both economic and human terms. In the UK, the annual cost of stroke to society is estimated to be £8.9 billion, with about half linked to indirect costs of ongoing support [11]. Beyond this economical aspect, the loss of independence affecting stroke survivors' personal privacy also needs to be highlighted. Indeed, caregivers may go to stroke survivors' homes to deliver rehabilitation and recovery care. Some stroke survivors may perceive this as an invasion of their personal space, and be unwilling to accept this overreliance on caregivers as a long-term solution [12].

Therefore, there is a need for technology that can provide assistance automatically; to reduce AADS related disabilities, and help stroke survivors regain self-sufficiency and independence while keeping their dignity.

2. Related work

In the field of assistive and rehabilitation technology, several Artificial Intelligent systems have been designed to increase independent completion of ADL by individuals with cognitive deficits. Extensive literature reviews focusing on assistive technology for cognition have been published and updated [13,14]. In 2011, 63% of the studies reviewed by Gillespie et al. [14] focused on assistive systems designed to provide reminding and prompting interventions to users. This supports the conclusion of Hart et al. [15] that clinicians saw more potential for devices in the areas of learning/memory, planning/organization and initiation.

The interest in this area led to the development of complex systems such as COACH [16], which provides instructional cueing to guide users during hand-washing. The COACH Markov Decision Process (MDP) based planning system is described in [16,17]. Its goal is to provide appropriate cues to the user during the task. In a new COACH system, a Partially Observable MDP (POMDP)-based planning system [18,19] was implemented to accommodate uncertainty in the system's inputs. The POMDP-based system was evaluated via simulations of hand-washing [18], and compared with heuristic policies and the MDP. Results showed that the POMDP-based planning system performed best, but not significantly better than the heuristic policies. More recently, Peters et al. [20,21] developed the TEBRA system to support mildly impaired people during teeth-brushing. A user study was performed with 7 participants suffering from cognitive deficits. The results showed that users made significantly more independent steps when they had access to the system's prompts [21].

The CogWatch system [22–24] was designed to guide stroke survivors during tea-making. The first CogWatch prototype used a MDP-based planning system [25], which was evaluated with 12 stroke survivors. In a first scenario, stroke survivors completed the tasks by themselves, while in a second scenario they had access to the system's prompts. Results showed that stroke survivors made fewer errors when they were guided by the system [24]. Subsequently CogWatch was enhanced with a POMDP-based planning system to cope with incorrect interpretations of users' behavior. In a planning system (or Task Manager), the module responsible for action planning is the Action Policy Module (APM). The second main component of the Task Manager is the Error Recognition Module (ERM), which is responsible for detecting users' errors during a task. Similarly to the POMDP-based COACH system, the POMDP-based CogWatch system was evaluated via simulation [26]. Results showed that the novel Nearest Neighbor Search (NNS) technique developed by CogWatch's authors (i.e., "SciMK") systematically improved the planning system's performance under uncertainty. However, the POMDP-based ERM did not perform significantly better than the MDP-based ERM [26].

This paper focusses on the CogWatch Task Manager; its POMDP-based APM and ERM. The main contribution is to provide further understanding of how an intelligent rehabilitation system such as CogWatch can be conceptualized. More precisely, SciMK is compared with other techniques in a novel system configuration, and another algorithm for error recognition under uncertainty is proposed and evaluated. The results presented in this paper extend our previous work [26] by demonstrating that "SciMK" outperforms 6 alternative techniques and by verifying its ability to improve planning system performance. In addition, this paper focuses on the techniques used to train the ERM, and their impact on its ability to correctly detect user errors.

For clarity, a summary of the main abbreviations used in this paper is given in Table 1.

Table 1 – Nomenclature.

AADS	Apraxia or action disorganization syndrome
ADL	Activity of daily living
AI	Artificial Intelligence
CW	CogWatch
SimU	Simulated User
ARS	Action Recognition System
TM	Task Manager
APM	Action Policy Module
ERM	Error Recognition Module
MC	Monte Carlo
MDP	Markov Decision Process
NNS	Nearest Neighbor Search
POMDP	Partially Observable Markov Decision Process
BT	Black tea
WT	White tea
BTS	Black tea with sugar
WTS	White tea with sugar

3. The CogWatch system

The workflow in the CogWatch system is as follows (Fig. 1):

1. The user is given a task to complete.