Future Generation Computer Systems 34 (2014) 97–109

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs

Ontological user modelling and semantic rule-based reasoning for personalisation of Help-On-Demand services in pervasive environments

Kerry-Louise Skillen [a,*], Liming Chen [b], Chris D. Nugent [a], Mark P. Donnelly [a], William Burns [a], Ivar Solheim [c]

[a] School of Computing and Mathematics, University of Ulster, United Kingdom
[b] School of Computer Science and Informatics, De Montfort University, United Kingdom
[c] Norwegian Computing Center, Norway

HIGHLIGHTS

- User modelling and service personalisation in pervasive environments are unique.
- We create ontological user models for changing intelligent pervasive environments.
- We develop a rule-based mechanism for context-aware service personalisation.
- We implement, test and evaluate the service-oriented system prototype.
- Initial results from case studies have shown that the system is working and promising.

ARTICLE INFO

Article history:
Received 16 February 2013
Received in revised form
11 October 2013
Accepted 25 October 2013
Available online 15 November 2013

Keywords:
Ontology
Personalisation
Context-awareness
User profile
SWRL
Rule-based reasoning
Help-On-Demand
User modelling

ABSTRACT

Existing context-aware applications are limited in their support of user personalisation. Nevertheless, the increase in the use of context-aware technologies has sparked the growth in assistive applications resulting in a need to enable adaptation to reflect the changes in user behaviours. This paper introduces a systematic approach to service personalisation for mobile users in pervasive environments and presents a service-oriented distributed system architecture. The developed approach makes use of semantic technologies for user modelling and personalisation reasoning. In the paper we characterise user behaviours and needs in pervasive environments upon which ontological user models are created with special emphasis being placed on ontological modelling of dynamic and adaptive user profiles. We develop a rule-based personalisation mechanism that exploits semantic web rule mark-up language for rule design and a combination of semantic and rule-based reasoning for personalisation. We use two case studies focusing on providing personalised travel assistance for people using Help-on-Demand services deployed on a smart-phone to contextualise the discussions within the paper. The proposed approach is implemented in a prototype system, which includes Help-on-Demand services, content management services, user models and personalisation mechanisms in addition to application specific rules. Experiments have been designed and conducted to test and evaluate the approach with initial results demonstrating the functionality of the approach.

1. Introduction

The miniaturisation of technology has become increasingly prevalent in recent years, where various mobile-based 'smart' technologies are rapidly being developed. These include the development of smart-phones, tablets or wireless sensors that are continuously being used to realise pervasive environments [1]. Consequently, people are becoming more dependent on the use of these technologies as they become an integral part of Ambient Assisted Living (AAL)—an emerging technology-driven solution for assisting with activities of daily living (ADLs). With increases in the use of mobile and sensor technologies, research within the area of Pervasive Computing [2] has shifted from low-level hardware-related technologies for sensing and communication, towards middle level intelligent data processing and further towards high-level context-aware applications. Pervasive computing systems are built upon the fact that the relevant contextual information is used to adapt

* Corresponding author. Tel.: +44 2890368918.
E-mail addresses: skillen-kl@email.ulster.ac.uk (K.-L. Skillen), l.chen@ulster.ac.uk (L. Chen), cd.nugent@ulster.ac.uk (C.D. Nugent), mp.donnelly@ulster.ac.uk (M.P. Donnelly), wp.burns@ulster.ac.uk (W. Burns), ivar.solheim@nr.no (I. Solheim).

0167-739X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.future.2013.10.027

to various user traits or behaviours over a period of time [3]. This vision of pervasive computing includes the availability of personalised, adaptable information that can meet user needs at different times, based on their context [4]. In order to achieve this, context-awareness alone is insufficient, highlighting the need for service personalisation amongst pervasive applications.

Personalisation refers to the manner in which an application provides the 'right' information for the 'right' user at the 'right' time and in the 'right' way [3]. A personalised service can be described as one that is able to provide evolving, tailored assistance to a user based on their unique preferences, needs or desires [5]. A key enabler of personalisation is the knowledge of the context that is used to drive such services. In a world where the information is not only growing every day, however, is available in a variety of formats and through various media channels, users find it difficult to find the information that they require in a way that suits their individual needs or wants at a particular time [6]. Context is most commonly defined using the definition by Dey and Abowd [7] as the information that is used to characterise people, places or objects when a user interacts with an application within a particular environment. Context-aware applications therefore interpret the contextual information based on changes in environments for the purpose of providing a particular service to a user [8].

The main aim of any context-aware system is to be adaptable and therefore change its services or content to suit an individual's preferences. This need for personalisation is intensified by the rapid development of mobile-based technologies and user-adapted services. This area, known as user modelling, has sparked the development of a variety of personalised applications to include user targeted mobile advertising, user recommendation systems, personalised Help-on-Demand systems and adaptive user interfaces [9]. Challenges currently exist which focus on how to provide the best quality of service to the user. As a result, issues such as these have directed research into the areas of HCI, user-adapted modelling and context-aware personalisation.

The emergence and rapid, continuous development of mobile technologies and adaptable user interfaces has sparked research into enhancing user-based applications that are personalised to suit the changes in user needs over time. This increase in smart, mobile-based technologies has led to an increase in user dependence upon such technologies; an increase in dependence fuels the need to develop new methods of user personalisation to cater for the demand. Consequently, this has enabled an increase in both the demand and need for user modelling for service personalisation. User modelling also needs to address the dynamic lifestyles of users within different environments.

In recent years, ontological user modelling has emerged as an important enabling technology for personalisation. Ontological user models have been developed for use within personalised web information retrieval systems, adaptive user interface design and for public services such as digital museum guides or electronic, customised libraries [10–12]. Nevertheless, these models have not been adopted to implement the personalisation of assistive services for mobile users. Existing methodologies that are used to personalise a service include work within the area of case-based reasoning in context-aware applications [13], rule-based reasoning for situation inference [14] and collaborative filtering (CF) techniques [15]. In particular, rule-based reasoning approaches are highlighted, where current work exploits the specified rules to infer the information about user context [16] or within the area of activity monitoring and recognition [17].

Rule-based reasoning enables a more expressive method of inference when reasoning about the user profile information such as changing preferences. While techniques such as CF or case-based reasoning (CBR) make good use of past user interactions or feedback to personalise future services, they fail to provide a complete model of the user and can be inconsistent. The use of production rules is a powerful way to represent additional attributes that cannot naturally be inferred using traditional ontological models.

To address the growing need for service personalisation in pervasive environments, this paper proposes a novel approach based on a service-oriented distributed system architecture. This approach makes use of semantic web technologies for the purposes of user modelling and reasoning for personalisation. We analyse user behaviours and needs for the purposes of enabling a more effective context-aware service. The paper aims to enhance existing approaches to personalisation by focusing on the dedicated user profile model for the purpose of providing a 'Help-on-Demand' (HoD) service. Specifically, it proposes a method that represents user needs and provides a personalised service component to suit the changes in these needs. We aim to provide personalised assistance to healthy users that may or may not have minor vision or hearing impairments.

The remainder of the paper is organised as follows: Section 2 discusses existing related work within the area of ontological user profile modelling, user personalisation and context-awareness. This section also highlights the key knowledge contributions from this study of work. Section 3 provides a detailed description of the overall system architecture for the proposed HoD application. Section 4 focuses on the use of ontological user profile modelling for the purposes of user personalisation. Section 5 introduces the area of rule-based personalisation, where a novel personalisation component is described. Section 6 discusses the system implementation, testing and evaluation of the HoD service, preceded by two case studies presenting the potential of the ontology model and personalisation service. Section 7 concludes the paper and provides a summary of future work.

2. Related work

In recent years there has been a significant increase in user reliance upon smart technologies related to the area of AAL. Consequently, this has enabled the emergence of several research projects focusing on the development of pervasive solutions to enhance overall quality of living for individuals. The AAL Joint Programme is a funding body that aims to create better condition of life for the older adults and to strengthen the industrial opportunities in Europe through the use of ICT (e.g. MobileSage [18]). The EU Framework Programme [19] outlines an ICT research agenda, which has funded and aided the development of both the UniversAAL [20] and EvAAL [21] projects. UniversAAL proposes an open platform that provides a standardised approach to develop AAL solutions for users in their homes. EvAAL is an initiative proposed by the UniversAAL FP7 project that aims to enable the comparison of AAL solutions by establishing various evaluation metrics and benchmarks to help improve standards.

Two of the core aspects within the personalisation of service consist of the user models and the personalisation mechanisms. There are two main categories of approaches in the area of user modelling—namely knowledge driven approaches and machine-learning approaches. Ontology-based modelling has attracted increasing attention within the area of user modelling in context-aware applications. This is largely due to its interoperability facets and ability to enable knowledge sharing and reuse across several application domains [22]. Chen et al. [23] developed the COBRA-ONT ontology as part of the Context Broker Architecture, which provides knowledge sharing and context-reasoning support for context-aware applications. This architecture was successfully used to enable sensors, devices and agents to share contextual knowledge and to provide the relevant information to users based on their contextual needs. Razmerita et al. [24] presented work on