

Ontological User Modelling and Semantic Rule-Based Reasoning for Personalisation of Help-on-Demand Services in Pervasive Environments

Future Generation Computer Systems

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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 behaviors. 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.

Keywords

Ontology, personalisation, context-awareness, user profile, SWRL, rule-based reasoning, help-on-demand, user modelling

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 relevant contextual information is used to adapt 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 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 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 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 modeling, 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, customized 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 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 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 relevant information to users based on their contextual needs. Razmerita *et al.* [24] presented work on user modelling with a generic ontology-based architecture called OntobUM.

Sutterer *et al.* [10] introduced the concept of dynamic user profiles with the development of the User Profile ontology with Situation-Dependent Preferences Support (UPOS). This ontology model proposed the idea of supporting the situation-dependent personalisation of user services in pervasive environments, however, as of yet no further progress has been made within this area. Similar to this, another ontology known as the Unified User Context Model (UUCM) [25] was introduced for the purposes of cross-system personalisation. This work presented an extensible user model that could be used for modelling various characteristics of the user and their situations (i.e. the user context) along different ‘dimensions.’ While this approach demonstrated benefits in allowing different applications to use the same profile, maintaining the user profile proved difficult without an overall standard.

The other category of approach to user modelling relies on probability-based analysis, which has a key advantage of handling the uncertainty of user behaviour. Some existing approaches

in this area include the use of a Bayesian network [26] or the Dempster-Schafer theory of evidence [27]. In general, current research relating to user modelling and personalisation has focused more so on improving aspects such as a user's experience via information retrieval methods [28] or interactions via personalised user interfaces [3].

While ontological user profile models provide the computational representations of user needs, reasoning mechanisms are required to infer the best way a service should be delivered in terms of the user model and application context. There are currently three categories of personalisation reasoning techniques that can be categorised as CBR, CF and rule-based reasoning. CBR is a known method of solving a new problem by analysing previous solutions or similar problems within the same area [29]. It is concerned with adapting services to new situations through remembering previous situations or cases.

The work in [30] used CBR to provide context-awareness within a smart home environment. Within their research, this reasoning technique was used to adapt specific services to suit the changing needs of users according to their preferences. Despite its ability to enable a personalised service according to the previous history of results, the method can be generic. Without the support of statistically relevant data or a solid understanding of the user (i.e., taking information from a specified user profile), there is no guarantee that the service provided is accurate or correct. CF relies on the idea of collecting user opinions and feedback in order to provide future recommendations or services [15]. Users which exhibit similar interests or preferences may be grouped and classified according to these concepts, introducing the idea of social profiling, which can be useful in over-coming the common 'cold-start' [31] problem in the area of context-aware personalisation. The inference methods in which CF is implemented may differ; however, the fundamental concept is that users with similar interests/preferences are highly likely to agree in their feedback or opinions given. In contrast to the user modelling techniques previously discussed, CF does not create an explicit model of the user preferences; it suggests services based on previous user similarity results.

There has also been an emergence of rule-based approaches to user personalisation. Rule-based techniques make use of domain knowledge and heuristics to define causal relationships between user profiles and service output through a set of rules. While such approaches have been used in various sectors such as the area of e-commerce and web personalisation, or mobile tourism, these techniques are a relatively new method for Help-on-Demand personalisation in context-aware, mobile computing.

Though there are different methods for user modelling, we have adopted the use of semantic technologies to model, represent and reason about user profiles. Semantic technologies enable interoperability across different platforms, are highly expressive when modelling complex relationships, they support semantic reasoning and have the ability to reuse information from several application domains [32]. Semantic technologies enable us to reason about various data, that is, to draw inferences from existing knowledge about a particular area for the purposes of creating new knowledge. The use of semantic data is also beneficial when integrating information from various sources. By developing semantic 'mappings' between

different schemas of information across various applications, it is possible to create interoperable systems. At the heart of semantic-based technologies is the use of ontologies.

Semantic Web Rule Language (SWRL) is a combination of Rule Mark-up Language (known as RuleML) and OWL (Web Ontology Language) [33]. SWRL rules have also been used in other works by developing applications to assist those with dementia in healthcare [34] and within the area of multimedia service provisioning and situation inference [35]. Based on the aforementioned discussion it is evident that less work has been undertaken for service personalisation for mobile users in pervasive environments. The most relevant work in this area, presented in [36], focuses on the development of a framework which enables the creation of adaptable applications that can be tailored to suit different user needs, wants or capabilities over time.

Service personalisation, particularly for mobile users in pervasive environments, presents a range of unique challenges that need to be addressed. In order to personalise a service, both the functionality and presentation of the service should be adapted to suit the user's unique preferences [37]. These challenges include (1) how to infer and analyse relevant information about a user and determine which information is suited to personalisation for a certain service, (2) how to ensure a high quality and accuracy of services is delivered to users and (3) how to know where the relevant user information is stored and how it can be distributed to use in the service personalisation.

Applications such as personalised mobile guides [38] provide rich, contextual information delivery to users and enable assistance via navigational services, multimedia feedback and adaptive user interfaces. Other existing 'Help-on-Demand' applications include those created from the APSIS4ALL-project [39] or the ASK-IT project [39]. These projects focus on the development of smart-phone technologies to personalise the interactivity of user activities with Public Digital Terminals (PDT) via the use of user profiles and adaptive interfaces. These are effectively used to leverage the power of mobile computing to enable the provisioning of adaptive services and mobile 'learning' of contextual user preferences.

In addressing the aforementioned issues, this paper makes a number of key knowledge contributions. Firstly, a systematic approach and associated service-oriented distributed system architecture that supports service personalisation for a wide range of complex application scenarios is presented. These include the changing environment surrounding users, multiple assistive services, evolving user behaviours over time and development of user habits, and dynamic contexts. Secondly, the development of a flexible ontological user model to represent the specific user characteristics of the application domain. These models can be used to enable the personalisation of context-aware services, due to their use of semantic reasoning to allow the models to infer additional assistive services for different users within changing environments. Thirdly, we developed a unique personalisation mechanism using a combination of semantic and rule based reasoning techniques to enable context-aware services to be tailored to suit the changes in user needs over time.

This novel personalisation mechanism makes use of user-specified semantic rules and a dedicated reasoning service to provide Help-on-Demand services to users within pervasive environments via smart-phone technologies. The mechanism differs from existing work as it is combined with ontological user modelling and semantic web-based rules/reasoning, and is linked to pervasive mobile services to provide on-demand assistance to different users.

3. System Architecture

Personalisation involves multiple entities, such as the users, their situated environments, the application contexts and services and the interactions and causal relationships between these entities. A typical real-world application scenario is presented to contextualise the discussion of the system architecture. The scenario is based on the research context of the EU AAL funded research project MobileSage [18], capturing the unique characteristics and requirements of service personalisation in pervasive environments. MobileSage aims to provide elderly people with personalised assistive tools, which will allow them to undertake everyday tasks and enhance their overall quality of lifestyle. To do this, the project provides older people with context-aware, personalised services that allow them to perform everyday routine tasks with minimal effort.

A typical application scenario can be described as follows to illustrate the use of HoD. A person travels to a foreign country and needs to use a local train ticket machine. Nevertheless, the person does not understand the language displaying the instructions, and also has a vision problem. Consider that the ticket machine is a smart object with embedded sensing and interaction capabilities, such as Near Field Communication (NFC) or Quick Response (QR) code. The person also holds a smart device, such as a smart phone or tablet, which has sensing capabilities (through built-in GPS or accelerometers) and contains service front-ends of on-demand services deployed in the cloud. In this case the person can start relevant HoD services on the smart device and use the device to interact with the smart object under concern. The HoD service could then infer the type of assistance the user requires and deliver this assistance to them in terms of that particular user's profile, environmental circumstances and the object involved.

Figure 1 presents the architecture of the service orientated distributed system. It consists of four components, each interacting with each other to achieve HoD service personalisation [40]. The main objective of the architecture is to provide a clear flow of information between the HoD application (within pervasive environments) to the user via the use of personalisation and user profile services. This architecture highlights four core elements that focus on the application scenarios (pervasive environments), the User Profile services, the Personalisation services and the HoD services.

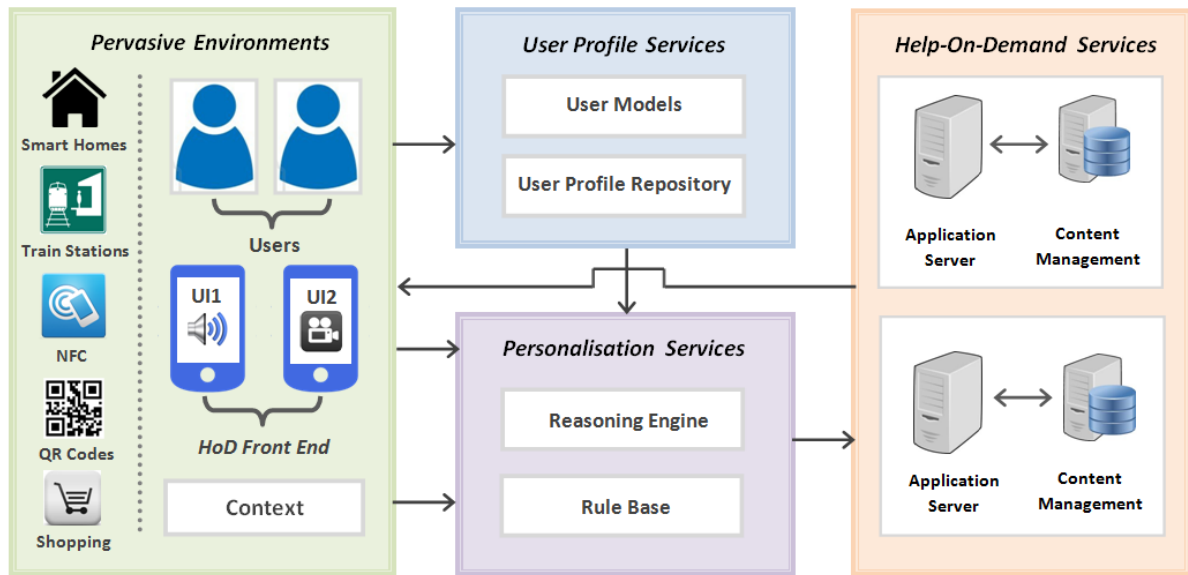


Figure 1. The Service-Oriented Distributed System Architecture for Service Personalisation.

The User Profile service contains user models, user profile repositories and service interfaces. User models are data structures or templates composed of generic properties that provide a computational representation of users or a specific class of users [41]. For each individual, their user profile can be created by instantiating a user model with the individual's personal attributes, for example, their preferences, capabilities and interests. The generated user profiles can be saved thus forming the user profile repositories (which are stored alongside the user models within the user profile services). Within the Pervasive Environments component, the users are in different situations (different contextual surroundings) and interact with the HoD application front end on their smart-phone to send various help requests to both the User Profile Services and the Personalisation Services. A mixture of contextual information, user profile information and the specific requests made are sent to these two key components. The user models and profiles are generally created through knowledge engineering processes and the resulting user profiles can be used by Personalisation services to tailor specific services. The service interfaces within the User Profile service provides standard APIs for other services to access to, share and reuse user profiles.

The Personalisation service consists of a rule base and a reasoning engine to enable inferences. The rule base contains a set of rules defining the causal relationships between the user profile, environmental and application context and service outputs. After the rules are created, they can be tested by a Reasoner tool. The reasoning engine will take as inputs user profiles, context and user requests of assistance to reason against the rules to decide how on-demand services provide assistance for the user. The personalised service requests will then be sent to HoD services for processing [42].

The HoD service contains various assistive services that can be used by users to help manage daily activities. Example services include monitoring and analysing wellbeing, fall detection, medication reminders, navigation and HoD for travelling. Such services can be deployed in the cloud and accessed via standard service interfaces (such as HTTP). HoD services take as

inputs the personalised requests from Personalisation services and provide, after processing based on specific business logic, personalised assistance to the user. This component makes use of the specified user rules reasoned information and user information (plus the original help request) to send information back to the user front-end in the form of personalised assistance.

The Pervasive Environments component refers to various intelligent environments, which contain sensors, smart objects, intelligent communication and interaction devices. Examples of such environments and technologies include smart homes equipped with Radio Frequency Identification (RFID), NFC tags, QR codes, smart phones, and tablets. A pervasive environment usually contains context management middleware, which can monitor users' activities and their interactions with environments and situated objects. Context middleware can provide contextual information at a specific point in time to support context-aware applications. Within the system architecture, the context of the user is captured and processed to derive high-level contextual information from low-level information. This middleware is used to query the current location, radio connectivity levels (Wi-Fi/3G/GSM) and surrounding environment of the user at any point in time. In this work, the context-aware service provided via the HoD application listens for new contextual information that is sent by the context providers.

Users within pervasive environments normally have some form of smart device, for example, a smartphone for interacting with HoD services. The user interface of the device can be adapted to user preferences as part of the service personalisation. Alternatively, the device can be used to communicate with smart objects to activate service requests or control objects in terms of returned service instructions. Though the system architecture is motivated and discussed based on the typical application scenario, the rationale and principle can be applied to any application domain in pervasive environments. The following section presents the technical details of the core services of the architecture in further detail.

4. Ontological User Profile Modelling

As previously highlighted, user profile modelling is central to service personalisation. It involves the creation of a data structure that can hold the characteristic attributes of specific types of users. This data structure is usually referred to as a user model that serves as a template for generating specific user profiles for different individuals. These user profiles can be viewed as digital representations of data associated with a particular person [12].

User modelling is related to the user's behaviour and the purposes of user models in the specific application context. For context-aware service personalisation in changing pervasive environments, user modelling presents several novel aspects. People in different environments normally exhibit different behaviours. For example, in a supermarket people are concerned with shopping while in a residential setting people mainly carry out ADLs.

To adapt to the changing needs of a specific user within different settings, a system needs to understand the specific aspects of the user profile particularly relating to its situated

environment. When modelling human users, their individual characteristics can be broken down into various levels of granularity. An example of this would be the concept of a 'food' preference, which could contain the sub-preferences 'Asian', 'European', 'Western' or 'Italian'. This in turn suggests that the user profile should also be broken down into various levels to enable the development of a more complete and extensive user model. When modelling the user, temporal and environmental contexts should be taken into account, in order to provide a more comprehensive model of dynamic user attributes that change as they move between mobile environments. For example, if the location of the user is modelled at different times, it can be determined if they want to go to sleep or go shopping at some specific location.

Ontology-based modelling involves specifying a number of concepts related to a particular user, along with any number of properties or relationships associated with those concepts. In essence, ontologies provide a 'representation vocabulary', where these user concepts are structured in a taxonomy based on various user aspects. Ontological models can be used by logic reasoning mechanisms to deduce high-level information from raw data and have the ability to enable the reuse of system knowledge. This is particularly important when modelling user aspects that can be remembered and reused later [43].

The process of ontological user modelling can be summarised as the following steps, namely to 1) analyse users' characteristics and needs in context-aware environments; 2) establish interrelationships among core entities of the domain, namely, users, environments, application scenarios and services; 3) identify and define key concepts that can model and represent these entities and further define properties that can be used to describe these concepts; 4) classify the concepts and properties into hierarchical structures; and 5) use ontology development tools to encode these concepts and interrelationships and represent them in a formal ontology language. Typically, the ontological user modelling process follows a traditional ontological engineering process [44] and as such, can be classed as a generic process. Nevertheless, while the process follows a typical engineering style through the conceptualisation/specification stages, we have adopted a unique format for our user ontology model and took inspiration from related ontology models within this domain. In this study user focus groups [45] from three countries (namely Spain, Romania and Norway) were formed within the MobileSage project and various questionnaire and interview techniques were used to extract and analyse users' characteristics, preferences and habits. Based on this analysis we have been able to specify concepts, interrelationships, properties, and a set of commonly shared vocabularies.

A traditional top-down design approach was implemented where high-level, generic user concepts are selected (e.g., *Capability*, *Health_Conditions*) and further broken down into a series of specialised concepts (e.g., *Capability_Level*, *HealthCondition_Type*). Within the model, each defined parent class may or may not contain further sub-classes forming a hierarchy of related information about one user. To build the ontology, we firstly identified the key terms for describing a user and modelled these as ontological classes and sub-classes as shown in Table 1.

Table 1. Extract of the key ontology classes of the conceptual user models.

Concept	Usage
User	Every user has one associated user profile.
UserProfile	Associated concepts related to one particular user.
Locale/Context	Concepts related to the user's current location.
Preference	Individual likes/dislikes that the user has specified concerning media type, media content and media formatting.
AssistanceObject	The type of object involved in the interaction between the smart-phone and the help delivery (e.g. Bus Ticket Machine or Hotel Self Check-In Machine).
Activity	Any activity/action or interaction that the user performs to enable a request to be sent to the application (e.g. HelpRequest).
MediaContent	The type/format of content that is delivered to the user; Audio, Video, Imagery or Text.
HealthCondition	Any existing health conditions associated with a user that may affect the media content type or delivery feedback for a particular service. Categorised into cognitive conditions and physical conditions.
QualityScale	This refers to the level of quality of media output to the user, defined as 'High', 'Medium' or 'Low.'
UIFormatting	This is the formatting placed on the user interface of the smart-phone device running the application. The two entities that can be formatted include 'ScreenBrightness' and 'ScreenContrast.'

The `UserProfile` class denotes the central concept within the ontology, from which all of the relevant information concerning the user's preferences, locale, personal information, demographics, activities and health conditions. Relationships between the classes are set-up for the purpose of facilitating more logical inferences when reasoning about the user concepts. The `AssistanceObject` class contains several sub-classes relating to the type of object involved in the interaction between the smart-phone and the `HelpDelivery` class (for example, this could be a bus ticket machine or an airport self-check-in machine). The `AssistanceObject` is the object in which the user must interact with to perform some task and is key to enabling the personalisation of the help request to the server. Within the `Preference` class, there are several sub-classes (such as `PreferredMediaType` or `PreferredLanguage`) and these are linked via appropriate data and object properties. For example, the `PreferredLanguage` class is linked to the `UserProfile` via the object property of `hasPreferredLanguage`, which can also be linked to the `User` class. By including such relationships and different levels of granularity, services/tasks can be tailored to suit an individual's own specified needs or wants.

Within Protégé[46], several instances of the 'User Profile' class were defined, each of which

holds specific attributes or properties concerning a particular individual. In this work, an instance of the user profile class would be created, where all of the concepts regarding the user’s personal information, health history, preferences and characteristics are held and linked via various object and data properties.

As can be seen in Figure 2, the user ontologies describe the key concepts related to a user’s activity and interaction with an assistive context-aware service and enable the personalisation of the content provided to them.

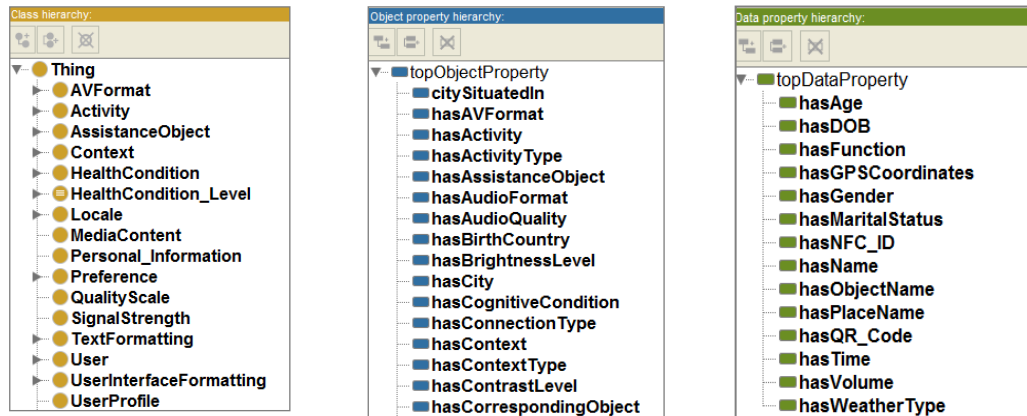


Figure 2. An overview of the User Profile Ontology classes, object and data properties.

Figure 3 presents an excerpt of the key relationships shown between the ontology model classes, subclasses, data and object properties. This is just a fragment of the full ontology model, showing the key level relationships.

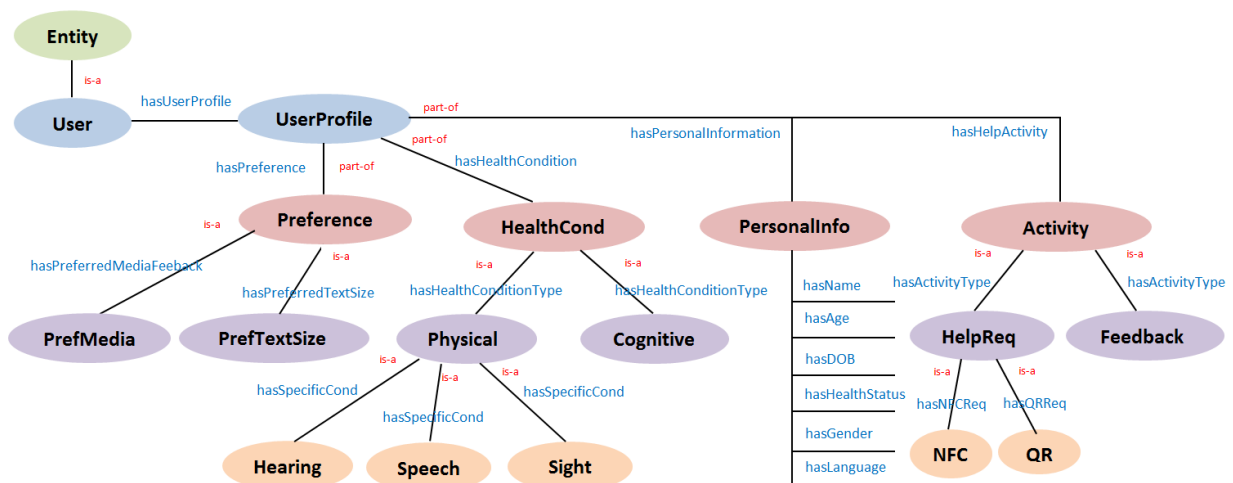


Figure 3. An excerpt of the key relationships within the User Ontology Model.

Every User has one unique UserProfile and an associated Context or Locale, which details their Location, and nearby WirelessConnections. Within the

Ontology, each `Activity` is linked to a specific type of request that the user invokes. The two main requests are triggered via NFC tags or QR codes. Every `Assistance Object` (e.g., `TicketMachine`, `TouristInfoMachine`) is linked via properties to a specific `NFC_ID` or a `QR_CODE_ID`. Depending on the information associated with the `UserProfile`, once a request is triggered it is sent to the user via some form of media delivery format or `MediaContent` format. For example, if a user has a health condition stating that they are blind, then this is stored in the `HealthCondition` class of the user ontology and according to the relationships and restrictions placed in the model, only certain media delivery types are sent to the user. In this case, the media content may be in the format of `Audio` only due to their condition.

Nevertheless, should a user specify a preference in the `Preference` class to always have `Video`, and then the ontology can infer this information and deliver the appropriate format. By including a series of generic user concepts, the model can be easily used across different application domains. For example, the model can be tailored to suit a user travelling between places or it could be used in a user's home to provide personalised assistance with ADLS. By formally defining the classes using semantics, the ontology can be used as a key component to infer what services/assistance the user needs at any moment in time. While the use of ontological modelling is beneficial within this area, rule-based reasoning to enable personalisation is another important feature that is used to infer additional logical concepts concerning a user.

5. Rule-Based Personalisation

The pre-conditions for a Help-on-Demand service to be delivered in a user-specific way can be defined in a set of logical expressions. Each expression is constructed based on logical operators such as variables representing user profiles and service requests. In the case that a service request is initiated, the conditions expressed within these logical expressions will be evaluated to be true or false. If all pre-conditions are evaluated to be true, it will then lead to a consequence. The consequence could be anything pertaining to the application, e.g. a specific way or format to present a service. This cause-effect relation is commonly modelled as a set of rules. The next section describes an approach to creating personalisation rules by making use of semantic web rule language and ontological user models. A personalisation mechanism that can perform production rule reasoning to derive personalised services based on specified requests.

5.1 Personalisation Rule Design

Rule design is a practice of knowledge modelling, which involves the analysis of the application domain, to identify application processes and related core entities, and further establish interrelationships among these entities. Each rule defines a cause-effect relation among these entities, e.g. how services are delivered under a specific context with a specific user. The SWRL language specifies a rule in the following format:

```

rule ::= 'Implies(' { annotation } antecedent consequent ')'
antecedent ::= 'Antecedent(' { atom } ')'
consequent ::= 'Consequent(' { atom } ')'

```

```

Example rule: UserProfile (?up), hasHealthCondition (?up, Blind), ->
             HelpDelivery(PlayAudio), hasMediaType(PlayAudio, Audio),
             hasMediaVolumeLevel(PlayAudio, VolLevel_5)

```

Each rule is made up of a body (known as an antecedent) and a head (the consequent) [47]. The syntax of a SWRL rule may appear simple in nature, however, the formulation and design of these rules overall is a complex procedure. The designer should normally envision every possible personalisation scenario that the rules would cover and design each SWRL rule with a different purpose to cover all possible service personalisation outcomes.

Realistically, this is both a time consuming and tedious task but if there is a solid base rule set that can be generically applied to several applications, the reasoning engine can then be used to infer additional rule sets over time. This means that the designer does not need to develop rules to cater for every scenario and works more efficiency as a result. SWRL rules are stored as a series of OWL individuals (instances) within the ontology model.

The antecedent of the rule can be constructed to represent a conjunction of various user preferences. For example, in the example RULE1 the first line constrains any individuals from the `UserProfile` class that have a health condition (via the `HealthCondition` property). In this case, the variable name `'?up'` is assigned to the class `UserProfile`. In this rule, the User must be `'Blind'`, where this individual name is assigned to the `hasHealthCondition` property. In the rule consequent, it specifies that if the individual meets all these aforementioned constraints, then the `HelpDelivery` class is affected. The `Audio` class within the `HelpDelivery` class will have two major property changes. The `MediaType` will be set to `Audio` as default and the `MediaVolume` will be set to level 5. The `hasMediaType` property is linked within the Ontology to the `HelpDelivery` class (detailed as an object property). The `hasMediaVolumeLevel` is also linked to this class, but its range is set to `VolLevel15` and its domain is set to `PlayAudio`.

5.2 Personalisation Reasoning Mechanism

Rules only establish cause-effect relationships. A reasoning engine is required to decide if the pre-conditions of a rule are met, thus leading to a consequence. In addition, the reasoning engine also needs to decide if the consequence of a previously fired rule results in another rule being fired. Once the pre-conditions of the antecedent are met, then the rule is fired and the consequence is held. SWRL rule reasoning supports both forward chaining or backward chaining reasoning. Forward chaining reasoning starts with a series of facts about involved entities and then looks for rules to apply to such facts. Then the generated consequences can be used as facts to activate other rules and this process continues until no rules can be fired. The consequences of the last fired rule will be the ultimate results of the forward chaining reasoning. Conversely, backward chaining reasoning begins with a goal and then searches for rules that can be applied to that goal until a conclusion is reached at the end.

Rule-based reasoning approaches have several key advantages within this domain over the use of other techniques, such as CF. One advantage of using rule-based reasoning is that it reduces the effect of the ‘cold-start’ issue with CF techniques. Data scarcity is a challenging issue within this domain and rule-based approaches do not need to worry about basing their services on previous information (for example, basing personalisation on previous user information, in our case, a unique user data model is set up initially to overcome this problem). Secondly, rule-based reasoning has an element of uniformity, where all knowledge within the system is expressed in exactly the same format. CF techniques can be inconsistent and reliability is always a factor as the techniques rely on the accessibility and accuracy of previous user interactions and/or information.

On-demand service personalisation in pervasive environments is based on forward chaining reasoning, and the process can be described as follows. As presented in Figure 1, the Personalisation Services take as inputs: the rules from the Rule Base, user profiles from the Profile Services, contextual information from Pervasive Environments and user requests from the front-end of on-demand services. The reasoning engine has an in-memory working space within which a copy of rules and user profiles are imported. Other inputs such as user service requests and contextual information are dynamically captured and imported into the working space where logical operations of the forward chaining reasoning take place. When a user makes a request through the front-end of the on-demand services, the request is passed onto the personalisation services, which is then used as a variable in the logical operation of the antecedent of rules. Meanwhile, the contextual information within the pervasive environment is captured and used in a similar way to the service request as variables to be bound to the atom logic expressions of antecedents.

At this stage, the reasoning engine will check if the antecedent of any rule in the rule base is met prior to firing the appropriate rule. The consequence of the fired rule is then used for firing other rules. In this way, the forward chaining reasoning can take into account user preferences, environmental and application context and the requested services to provide personalised services based on domain knowledge and heuristics.

6. System Implementation

Within this section the process for the implementation of the existing HoD application is detailed. The core aspects of the application's functionality are highlighted, with testing followed thereafter.

6.1. Implementation

Within the current study, implementation has been undertaken in six key stages, as shown in Figure 3, namely 1) the conceptualisation and creation of an ontological user model, 2) the design of the required SWRL rules, 3) the development of the user ontology model, 4) the development of the personalisation reasoning component and 5) the creation of the HoD assistive application in the context of a (6) real-life application scenario.

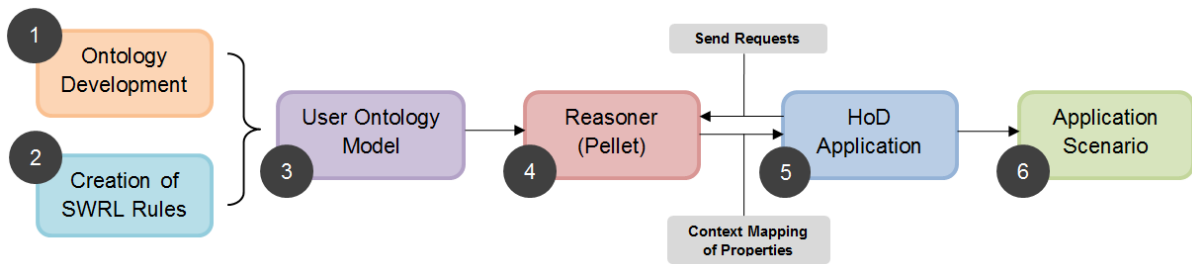


Figure 4. This figure shows the implementation processes of the Personalisation System.

In Stage 1, ontological user models are created based on the specific scenario of providing assistive services via personalised media feedback to travelling users. Nevertheless, the model can be tailored to suit other scenarios through easy manipulation of the ontology concepts via Protégé. In Stage 2, we follow the rule design method in Section 5.1 and use the SWRL editor within Protégé to design a set of rules for the application scenario. When SWRL rules are created, they can be tested and checked for inconsistencies using Protégé. The rules are then reasoned where the results are shown as new individuals grouped into classes or if the rules are inaccurate, Protégé will highlight where and why inconsistencies occur. Figure 5 shows an extract of the rule creation process, where specific rules are associated with individual classes, instances of classes or object/data properties in the ontology.

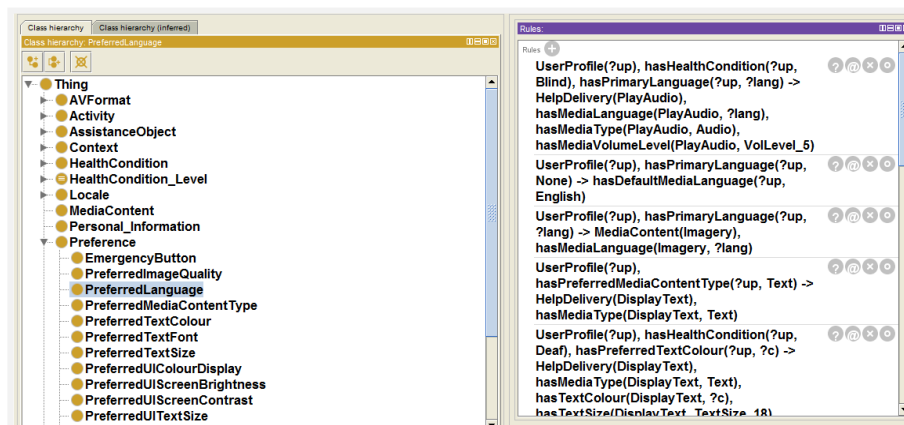


Figure 5. Excerpt of the SWRL rule creation process as shown within Protégé

Table 2 presents a subset of the SWRL rules developed in this study for the outlined application scenario. These include: rules to restrict the language of the feedback sent to the User (Rules 1 and 2), the type of feedback sent to the user and which format should be sent (Rule 3), and the content sent to the User and the appropriate personalisation (or formatting) depending on their preferences or contextual information (Rules 4 - 7).

Table 2. Excerpt of SWRL rules used within the Ontology.

No.	SWRL Expression
1	UserProfile(?up), hasHealthCondition(?up, Blind), hasPrimaryLanguage(?up, ?lang) -> HelpDelivery(PlayAudio), hasMediaLanguage(PlayAudio, ?lang)
2	UserProfile(?up), hasPrimaryLanguage(?up, ?lang) -> UserProfile(?up), hasFeedbackMediaLanguage(?up, ?lang)
3	UserProfile(?up), hasPreferredMediaContentType(?up, Video) -> HelpDelivery(PlayVideo), hasMediaType(PlayVideo, Video)
4	UserProfile(?up), hasHealthCondition(?up, PartiallyBlind), hasPrimaryLanguage(?up, ?lang) -> UserProfile(?up), hasFeedbackMediaLanguage(?up, ?lang), hasHelpFeedbackType(?up, PlayAudio), hasMediaType(?up, Audio), hasMediaVolumeLevel(?up, Vol_Normal)
5	UserProfile(?up), hasPreferredMediaContentType(?up, Text) -> UserProfile(?up), hasHelpFeedbackType(?up, DisplayText), hasMediaType(?up, Text), hasTextColour(?up, Black), hasTextFont(?up, Arial), hasTextSize(?up, 12)
6	UserProfile(?up), hasPreferredMediaContentType(?up, Video) -> hasHelpFeedbackType(?up, PlayVideo), hasMediaType(?up, Video), hasMediaVideoVolume(?up, Vol_Normal), hasUIScreenBrightness(?up, 50), hasVideoQuality(?up, HighQuality)
7	Context(?c), User(?u), hasSignalStrength(WIFI, StrongSignal), hasWirelessConnectionType(?c, WIFI) -> MediaContent(Video), hasVideoQuality(Video, HighQuality)

Stage 3 focuses on the implementation of personalisation reasoning. In this study, we use an existing open-source semantic reasoning engine called Pellet [48] for personalisation reasoning. Stage 4 and 5 of the implementation process involves a service-oriented development and deployment for the presented system architecture, as shown in Figure 6, which was used to enable the personalisation mechanism for the specified application scenario. The system was developed using Java and the OWL-API [49]. The HoD services run on the server-side, which provides the storage and usage of the Ontology model (.owl file), a set of pre-defined SWRL rules, the Reasoner, and the Application Server (Apache Tomcat).

On the client-side, the user is presented with a smart-phone application tailored for Android (Version 4.1 or above) OS. The smart-phone will take contextual information as it is input to enable the discovery of machines within a certain parameter and to determine the nearby Wi-Fi connectivity level and strength. When a user scans a nearby NFC or QR tag, the application is triggered and automatically sends an HTTP Help Request to the Application Server. A link is also made between the web servlet and the server via a specified socket connection. The HTTP Request is sent to the server and the Personalisation Service handles how that request is managed. The personalised service manages the request using a combination of the ontology reasoning and rules to determine which user profile is associated with which rule set. The user has their unique User Profile that has associated with it a set of individual SWRL rules that are used to tailor services to that person. All of this information is stored in the model itself and the Java application is used to implement and enable the functionality of the Reasoner and rules to provide this personalisation.

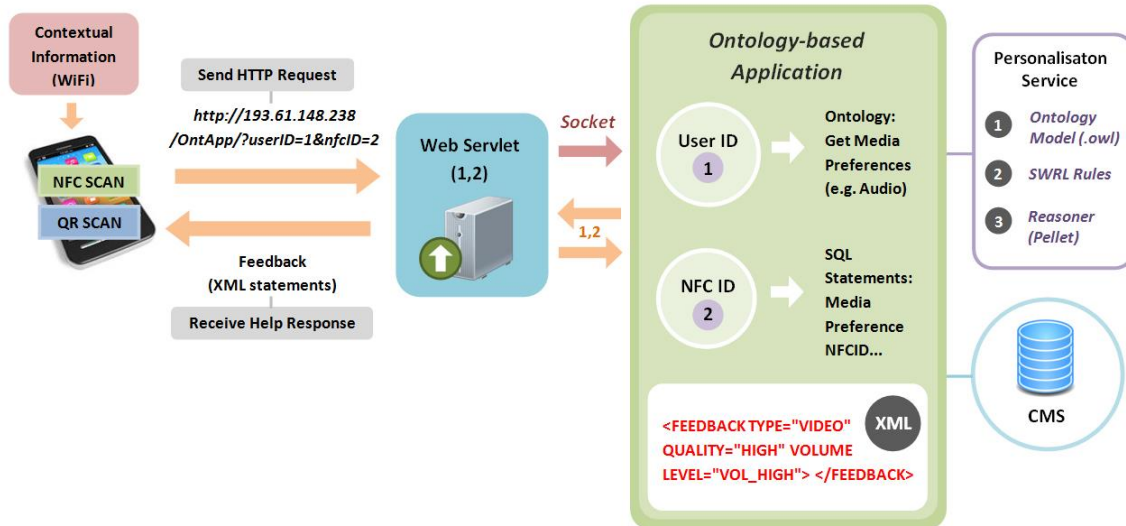


Figure 6. Service-oriented system deployment architecture.

In the following section, we present two case studies that demonstrate the personalisation aspects of the proposed system in the context of the HoD services.

6.2. Experiment Setup & Testing

We evaluated the functionality of the personalised services by deploying the application onto three Android-enabled smart-phones and presented the application to three separate users. The two case studies discussed below were used to highlight the utility of the proposed personalised assistive services for users and to test our proof of concept HoD application.

6.2.1 Case Studies

(1) HoD Assistance for Automated Ticket Machines

Jack is a 46 year old IT project manager. He is often required to travel abroad for project meetings but also enjoys travelling in his spare time. Jack has a partial vision impairment and diminished hearing and as a result finds it difficult to read small text and hear things, which poses a number of everyday challenges. He has been able to adapt the preference settings of his smartphone so that applications are displayed in a larger font and use inbuilt audio commands where possible. The parameters related to these preferences are stored in a User Profile. The User Profile is stored on an Application Server in addition to the ontology model of information.

Jack is required to travel from the UK to Germany and when he arrives, he attempts to purchase a train ticket from an automated machine. The default language on the machine is German and the text size is too small to read. Instead, Jack scans the NFC tag on the ticket machine using his smart phone. This activates his travel application, which passes the NFC_ID of the ticket machine to the CMS (Content Management System), located on the Server. The CMS reasons (using Pellet and the associated SWRL rule-set) on the NFC_ID received, taking into consideration Jack's current location (using GPS) and his available

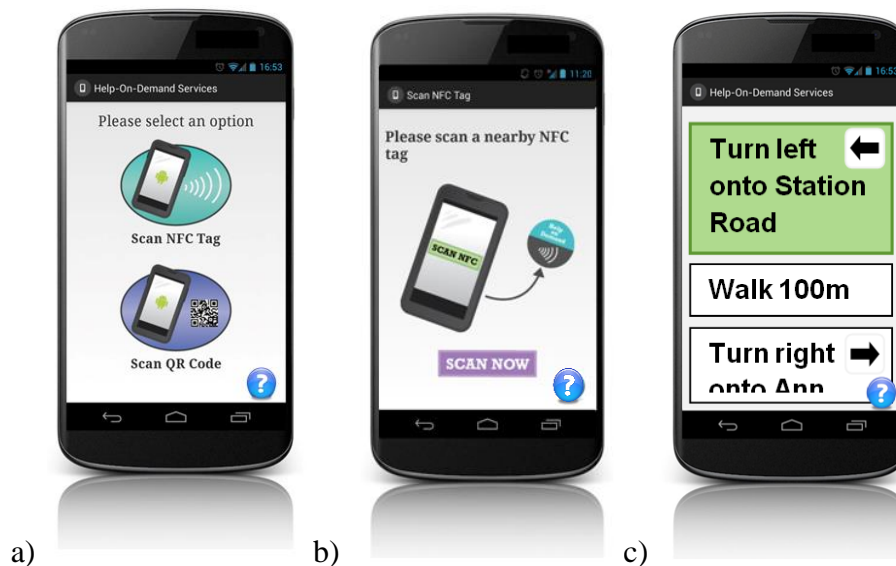
connectivity and compares this to Jack's User Profile. In this case, Jack's User Profile highlights that he always requires assistance in a video format with English closed captions.

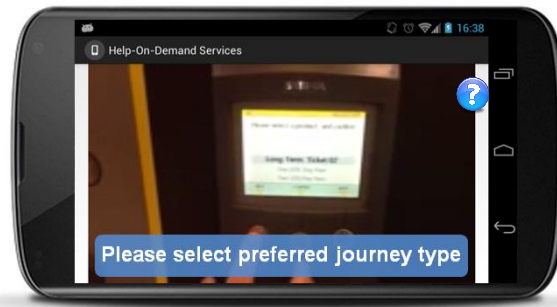
Consequently, the required instruction, detailing how Jack should proceed with his purchase is delivered to his smart-phone in video with closed caption format and with the required font size Jack requires. Jack's interaction with the HoD application enables the system to understand what stage of the booking process that he is current at. Consequently, Jack is able to follow the onscreen instructions in his own language (English) while also receiving video support. Figure 7d presents a screen shot of the feedback presented to Jack in this scenario.

(2) HoD Assistance for Personalised Route Guidance

Jane is a 63-year-old retired schoolteacher who now enjoys travelling a lot. Jane prefers to take the train as opposed to planes and as such spends a lot of time moving to and from train stations. Jane has diminished eyesight and finds it difficult to make out small details and font, especially on screens. As such, her User Profile has a preferred feedback mode of text with the largest font size. When she arrives at her destination Jane enters the location of local hotels into her HoD application. Jane's search query is sent to the CMS for information retrieval. In addition to this, her User Profile is reasoned and the content she has requested, directions and her preferred method of feedback are returned to her device.

Jane is presented with the directions to the nearest hotel, in a text based step-by-step list. The font size reflects her requirements as defined in the User Profile to address her diminished eyesight. Due to Jane's eyesight problems, directions overlaid on a map would be difficult for her to see. Figure 7c shows the directions to the nearest hotel on Jane's smart-phone.





d)

Figure 7. Screen shots of the User Interface for the Help-on-Demand application, showing (a) the initial options available when upon application launch, (b) the ‘Scan NFC’ screen where the user is instructed to scan a nearby tag and the media feedback screen that presents the appropriate form for (c) Jane (text based directions) and (d) Jack (video with closed captions).

6.2.2 Methodology, Results and Discussion

The HoD application was used to simulate the two motivating case scenarios described within Section 6.2.1, within the Smart Environments Research Group (University of Ulster, UK) lab, to test the technical functions of the system. The application was installed on three smartphones and presented to three different users, each with different user profiles. These experimental 'set-ups' were designed and conducted to test the efficiency and correctness of the underpinning technologies, e.g. user profile models, reasoning or rule capabilities. The application was tested to determine how well the personalisation service worked when presented with different test user profiles and/or scenarios. The personalisation service enables the appropriate assistance (media feedback) to send back the required help response in the user's designated language.

The retrieval of specific media formats; based on an individual's user profile was subsequently evaluated. Specifically, the time taken to retrieve information from the HoD service in addition to the effectiveness of the Personalisation service, in terms of matching media type to a user profile. Each user tested the utility of the case studies presented previously by using the HoD application to (1) purchase a train ticket from an automated ticket machine and to (2) enable personalised route directions from a specified location to another place of interest. Users 1 and 2 tested the first scenario and user 3 tested the second scenario. Upon testing via these case studies, the aim of the HoD application was to retrieve the appropriate help feedback, in terms of the content sent back and what format it was in (i.e. video, text only, audio and text). Furthermore, user experience was quantified in terms of the speed and accuracy at which the appropriate media feedback was sent back to each user.

Within the user ontology model, user profiles for each participant were added, specifying the differing media preferences, health conditions and personal information. This is shown in Table 3.

Table 3: A description of user profiles evaluated within the HoD application experiment

User ID	Profile Name	Media Type Preference	Health Status	Sex	Default location	Age	Language Preference
1	Jane	Audio	Vision Impairment	Female	Northern Ireland	55	English
2	Jack	Text	Hearing Impairment	Male	UK	37	Spanish
3	Elizabeth	Video	None	Female	Northern Ireland	24	English

Table 4 presents a description of the initial results from the HoD experiments. These highlight the impact of the WiFi or 3G/GSM speed on the accuracy and efficiency of results to the end-user and also show which media type was returned, based on user profile information and the use of ontological reasoning.

Table 4: A description of the results from the HoD application experiment

User ID	Media Type Preference	Returned Media Type	WiFi Speed ¹ (kbps)	GSM Speed (kbps)	Time WiFi (ms)	Time GSM (ms)
1	Audio	Audio (4.7MB mp3)	DL 15267 UP 3861	DL 2488 UP 1433	6066	8384
2	Text	Text	DL 5035 UP 6563	DL 780 UP 1524	2245	3870
3	Video	Video (8.7MB 3gp)	DL 13737 UP 16171	DL 2319 UP 1512	6512	9532

The correct requests were retrieved via the user enabling the 'Scan NFC' functionality, where the correct media feedback file was sent to the application upon each request. The user tests showed that the media feedback delivery type was highly accurate, displayed the appropriate media to each individual user according to set preferences as stored within the ontology profile model. Users 1, 2 and 3 requested different media types (Audio, Text and Video) and each of the returned types matched their specific request (via the `hasPreferredMediaType` property within the model).

These initial results from Table 4 show that the ontological and reasoning aspects of the service function accurately. The reasoning service worked efficiently by inferring the preferences of all users when they made a help request. This service was able to correctly infer which specific media formats to send back to the user application upon execution of associated rules in the ontology model, with User 1 inhabiting a health condition of partial blindness, allowing the model to infer that they would require Audio by default. The application was tested by all users with both Wi-Fi and 3G/GSM connections. Initial results show that the performance was statistically significantly higher when the smart-phone was connected through WiFi, due to obvious bandwidth increases. This increase in speed provided a better overall user experience, as stated by the users

¹ Obtained using Speedtest.net Android application

https://play.google.com/store/apps/details?id=org.zwanoo.android.speedtest&referrer=utm_source%3Dstnet%26utm_medium%3Dmobile%26utm_campaign%3Dstnet

Upon testing the HoD application using the two case study scenarios, the initial results indicate that text content was delivered in just over 2 seconds, a much quicker rate than audio or video content. This was due to content size and bandwidth available. While the correct media was sent to the users, the waiting time could be improved on the server-side. Both forms of audio and video content (4.7MB and 8.7MB of data) were sent within 6 seconds to the smart-phones (via Wi-Fi). These times could be improved further through the use of media optimisation. According to a usability research study conducted within the area of user waiting time for web technologies [50], an acceptable standard waiting time for web-page downloads would be between 3 – 5 seconds. This depends on the content being retrieved and will differ for smart-phone communications. Our testing shows that the speeds are above average; however, we aim to improve this further at future user evaluations with the HoD service. Another method to enable the optimisation of the delivery speed could be to reduce the file size of the media or change the formatting of the media to make it more suitable for mobile-phone delivery.

While this may improve user waiting times (and therefore make the Help-on-Demand service much more efficient), there would be a compromise on the quality of content sent (i.e. file size, aesthetic quality). At the moment both the audio and video media content are streamed via the web, with the link to each file stored in the content management database. We could also provide dialog boxes to show on-screen if the user is waiting any longer than 3 seconds for content to show. These dialogs would tell the user that the content is coming soon. Another limitation of the current application includes the inability to determine how Wi-Fi or 3G/GSM signal strength affects the quality or speed of content transmission from server to smart-phone.

We have described the process of personalising the application upon scanning the appropriate NFC tags or QR Codes; however, we did not discuss how to support a visually impaired person to initially use the application. If we were to target those with severe visual impairments, we could include aids to help such users locate the required NFC tag or QR code on the object in question. Aids such as the use of braille (for example, attaching braille to various ticket machines), or the use of tag magnifiers to make the tags appear larger can potentially be used to help overcome the problem of initially accessing the HoD service. The smart-phone itself will also contain built-in user accessibility options (these are found within the settings of any Android-enabled smart-phone) where the user can tailor specific settings to suit their abilities.

For using the QR code option, the scenarios that we have presented targets those who have more minor visual impairments (such as partial blindness or long-sightedness). Applying this HoD application to those with full blindness, for example, is out of the scope of our work at this time. For a user with a minor vision problem, the smart-phone can be adapted to make instructions larger, the QR code/NFC tags can be enlarged, braille can be used as an additional aid and audio instructions on how to use the application can be played back to the user.

A full-scale user evaluation focusing on usability and acceptance of the technological solution rather than the technologies themselves will be conducted within MobileSage. The usability, functionality and impact of the application of real-life users across different user groups will be tested and assessed.

While we have described two key user scenarios previously, our approach is not limited in this case and can be applied to multiple scenarios. These include smart-home living situations (for example, personalised instructions on how to initially set up a complex coffee machine, or how to use a washing machine). While we have only included two key scenarios for the purposes of explaining the functionality of the components, the application is built to be versatile for other areas proposed in line with the Internet of Things.

7. Conclusions

This paper details the conceptualisation and development of a novel user profile ontology model and a personalisation component. The service provides an extensible model capable of integrating itself into a number of context-aware assistive applications. The component and model can be adapted to numerous scenarios through the use of personalised semantic rule-based reasoning. To demonstrate the utility of the service, a personalised HoD service is presented through a smart-phone application. Emphasis is placed on the use of semantic web rules used to enable a more accurate and efficient personalised service for the user. SWRL further enhances the personalisation capabilities of the component expressing additional concepts that cannot be directly inferred from the existing ontology language.

Rule-based reasoning enables a more functional representation of the user and allows for the creation of a highly expressive personalisation component. In particular, the application detailed within the paper facilitates the application's potential within smart, changing environments using smart-phone technologies and context-based reasoning. The ontology model has been adopted by the MobileSage research project for providing personalised HoD services. Initial evaluation results indicate that the current application, utilising the personalisation mechanism and the ontology model, provides a quick and accurate response to the test users within the study. Furthermore, the study has further highlighted the utility of personalisation components for use within context-aware assistive applications.

Future work will aim to further develop the range of personalisation services used to incorporate a wider user audience and extending the model to incorporate a more comprehensive set of user concepts. A comprehensive user evaluation will take place in-line with MobileSage. MobileSage will be conducting user trials testing both the efficiency and impact of the personalisation and adaptation components. User trials will take place, where the case scenarios detailed within this paper will be used to highlight and test the functionality of the HoD services.

Acknowledgements

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