User-Centric Personalization and Autonomous Reconfiguration Across Ubiquitous Computing Environments

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Abstract—**In the era of Ubiquitous Computing (UbiComp), during our typical daily routines we may encounter multiple, shared and heterogeneous UbiComp environments across various locations. As these environments are meant to be shared between multiple users, interaction control methods (gestural, touch, voice commands, etc.) and the contexts (light, temperature, sound, informational services, etc.) of the environment are not personalized for individual users naturally. Typically, users are required to manually configure interaction preferences and conditions each time they encounter UbiComp systems. This however, refers to a tedious and redundant reconfiguration procedure, which is against the concept of UbiComp. In this paper, we present our work targeting on improving the personalization and reconfiguration procedure. Firstly, a user-centric personalization approach is proposed for facilitating users in determining how an UbiComp environment should adapt to their own preferred configurations. Then, an autonomous reconfiguration procedure is proposed, ensuring that a user's preferences are maintained and accessible across multiple ubiquitous computing environments seamlessly.**

Keywords-Ubiquitous Computing; personalization; reconfiguration; human computer interaction.

I. Introduction

Current approaches for personalization in Ubiquitous computing (UbiComp) environments are mostly based on determining a user's context in order to provide customized content or services. Dominated by developer-centric approaches, users are provided with content and services, which are statistically or commonly meant to be suitable for their current situation. However, a user's preferences can often conflict with these provided services. Therefore, even though applications may enable many proactive services, users still expect to personalize applications further to suit their own particular preferences [1, 2, 3, 4]. Conventional developer-centric approaches towards personalization in UbiComp environments constrain users in taking an active role in determining their own preferences for interaction controls and conditions. We believe that in UbiComp environments it is necessary that users should be supported in taking a dominant role in further personalizing how the environment needs to be interacted with and how the conditions of the environment should suit their preferences accordingly.

There is another issue that so far, personalization approaches have been quite isolated, and demonstrated partially without considering maintaining the consistency of personalized interaction controls and conditions across multiple environments. UbiComp envision a world where implicit interactions between humans and computers naturally take place across multiple interfaces of multiple environments [5, 6]. As UbiComp environments proliferate in size and diversity across many locations, taking a holistic approach in designing personalization approaches turns out to be more and more important [7]. Ensuring personalized interaction control and condition preferences are consistent and memorable across multiple UbiComp environments are also reflecting the importance for adhering to existing usability design principles as founded from the HCI research domain [8, 9, 10, 11, 12]. Meanwhile, the usability standards need to be extended further and applied towards personalization approaches for UbiComp, as they will be integral for ensuring effective usability and user experience in the future. However, conventional personalization approaches demonstrated are impractical for users within a shared UbiComp environment. For instance, once a system is personalized, user's preferences are mostly stored with it, which potentially may be shared and used by many other users, to whom the UbiComp system may have to be manually reconfigured each time. Many other issues have been highlighted revealing how the identification and ownership of users' profiles may become susceptible to privacy and security concerns as users' preferences are left stored on UbiComp systems.

In this work, we primarily focus on a user-centric personalization approach for personalizing and reconfiguring conditions and interaction controls across UbiComp environments. The proposed approach indicates a way where personalization is determined by the user, who takes an active role in defining how UbiComp environments need to be interacted with, and how the environments should be configured based on their own preferences. An autonomous reconfiguration procedure has also been proposed as to seamlessly maintain consistency of users' personal preferences across multiple shared UbiComp environments. Environments are automatically reconfigured according to current users' preferences each time they encounter them. This ensures that a user does not have to explicitly and manually reset each system each time. To demonstrate more practically, we have developed a testbed with a personal wearable device, which stores a user's preferences and provides them to the UbiComp environments.

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Approaches suitable to resolve privacy and security concerns, where UbiComp environments resources and users profiles are protected from unauthorized access, have been considered as separated research topics in regards to the focus of our work. The provisioning of user profiles between the UbiComp environments and the user is only available when authentication is firstly accomplished. The personal device for keeping user's preferences can be integrated with many authentication subsystems, such as biometric checking, to prevent unauthorized usage. Therefore, a user is not required to repeat authentication through the more typical approaches. Another consideration we have made is the management of concurrency issues of an UbiComp environment, which can be modeled separately and solved systematically on the backend so that end users are protected from the complexity of potential interactivities. Finally, it is proposed that systematically, ownership and privacy of user's preferences are protected; as user's "profiles" are only shared during the session when the user is active in the UbiComp environment.

The rest of the paper is organized as follows: we position our work against other related research in Section II. Then, the user-centric methodology is presented in Section III. Technical implementation details are explained in Section IV. To demonstrate, a user case scenario is described in Section V, where evaluations from two experiments are presented. At the end of the paper, our findings and future work are discussed in Section VI.

II. Related Work

In this work, we primarily focus on user-centric personalization and autonomous reconfiguration of interaction control and condition preferences across UbiComp environments. This is distinctive from most personalization research in the UbiComp domain, which has concentrated primarily on personalization of information (graphical user interfaces and informational content) displayed on interface screens.

Research has explored how user-centric personalization approaches can support users in configuring user preferences further due to the versatile characteristics of UbiComp. Such work from Atia and Tanaka [13] has demonstrated this where context parameters affect gesture-based interaction in UbiComp environments. Their experiments show positive results of how user interaction performance and experience is impacted when context parameters in UbiComp change. They also highlighted that people like to customize hand gestures accordingly when context parameters change in a situation. Kawsar and Nakajima have presented Persona [4], which is a portable tool that enables existing proactive systems applications to become extended to support multimodal personalization. These user centric approaches have illustrated the core concept of personalization and its necessity. However, once a user specifies one personalized configuration on one system, it is typically inaccessible across multiple systems, as the personalized settings are only stored on local system repositories. The user, therefore, has to manually personalize each system they encounter, new or shared interactive systems. Protecting ownership and access to personalized settings are in potential risk in this way also.

We focus on related research, which advocate user-centric personalization approaches, which address the challenges users experience interacting across multiple UbiComp environments. A key challenge addressed in the related research focuses on how the UbiComp environments should also automatically adapt enabling users to access their preferences across multiple UbiComp environments. However, to adhere to the ethos of UbiComp this transition should happen seamlessly without interrupting users natural activities within environments. Adapting UbiComp environments is primarily based on the provisioning of user preferences (user profiles) to UbiComp systems. As mobility support is fundamental to the principles of UbiComp, approaches towards provisioning and accessing user profiles across multiple UbiComp systems has become an issue for contention. Some approaches [4, 13] have stored user profiles on individual stationary systems; however, as mentioned previously user profiles become inaccessible and more vulnerable towards privacy and security concerns in this way. Other approaches propose storing user profiles on remote centralized repositories where access is dependent on Internet connectivity [14]. Microsoft has submitted a patent titled "Gesture Personalization and Profile Roaming" [15] which details how Microsoft's Kinect system learns a user's movements and stores this information as personalized gestures in a roaming profile. This ensures that when a user is using any Kinect System regardless of locations, personalized gestures can be accessed remotely over a network (Gesture Roaming). Since the user's personalized gestures are recognizable to the system, the system can perform more responsively and accurately. However, gesture profiles are inaccessible if there is no connection to the remote profile repository.

More related approaches to our work focuses on storing user preferences as user profiles on users' personal mobile devices. Personal devices such as mobile phones are now equipped with supporting technology and carried with the user, therefore it seems like a suitable approach for provisioning user profiles to UbiComp systems practically. Such work by [7, 14, 16] has used personal mobile phones, where users profiles are shared between the user's mobile phone and a UbiComp System. In our work, we have considered the impracticalities of this approach from a usability and user experience perspective. The mobile phone is used as a peripheral device as it is carried and held by the user for the provisioning of user profiles to UbiComp systems. The natural interaction flow is therefore interrupted as the user is required to engage with the mobile phone device in order for the UbiComp system to be reconfigured suiting users preferences, however this apporach conflicts with the principles of UbiComp which seek to maintain seamless and

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natural interaction. Also, a mobile device itself is a peripheral device to a user; it is susceptible to risk like other peripherals, like being stolen and unintentional exposure of private information to others. Therefore, we considered an autonomous reconfiguration approach, which would be more seamless, and natural, unhindering implicit interaction between the user and the UbiComp environment.

A major aspect of UbiComp is mobility, as users naturally interact with a variety of shared systems across many locations, user profiles should be seamlessly and safely accessable where UbiComp systems they encounter do not require explicit manual reconfiguration by the user. In our work, we believe that a user's profiles should be stored, maintained and utilized with minimum effort from the user. For this work, a specifically designed device is dedicated to the role of keeping profiles and exchanging profiles with the UbiComp environments when user encounters them. Ideally, any carriable devices, such as mobile and PDA can fulfill the tasks as long as they are not interrupting user's natural interaction with environments.

III. USER-CENTRIC METHODOLOGY

A user-centric methodology describes standardized approaches for user-centric personalization and autonomous reconfiguration of interaction control and conditions across UbiComp environments.

A. User-Centric Personalization

User-centric personalization is embodied through enabling users to determine themselves how conditions such as (light, temperature, sound, information services, etc.) in a UbiComp environment, should respond concurring with their own personal preferences for particular contexts. Also, through enabling users to map interaction control techniques (gestural, touch, voice commands, etc.) with actions to be performed, conditions such as (light, temperature, sound, information services, etc.) can be explicitly controlled based on users interaction control preferences.

A primary form factor intrinsic to supporting our user-centric personalization approach will be a wearable NFC device, which can be carried by a user. This device will be used for bridging the gap between the user and the UbiComp environment for the purpose of personalization of environmental conditions and control interactions. We apply a user-centric personalization procedure where the user is provided with a personalization management capability through an application deployed on a touchable interface (NFC enabled Smartphone).

1) User Personalization Profile (UP Profile)

Through the personalization management application, the user can create new or update existing "User Personalization Profiles" for UbiComp environments and particular contexts. A "UP Profile" consists of two parts, the User Profile and the Personalization Profile, which are shown in Figure 1. A User Profile consists of a unique ID, user's name/title, location, visual profile and access control permissions. A Personalization Profile consists of defined parameters of data that pertains to users personal preferences for environmental conditions (light, temperature, sound, etc.) and interaction controls (interaction/action pairs). Individual "UP Profiles" are created to determine how conditions in the UbiComp environment should react for particular contexts such as working, relaxation or sleeping. For example, an instance of "UP Profile"-"working profile"-is created through the personalization manager of the application, parameters such as light intensity, light colour, which are comfortable for user's working context are configured and documented.

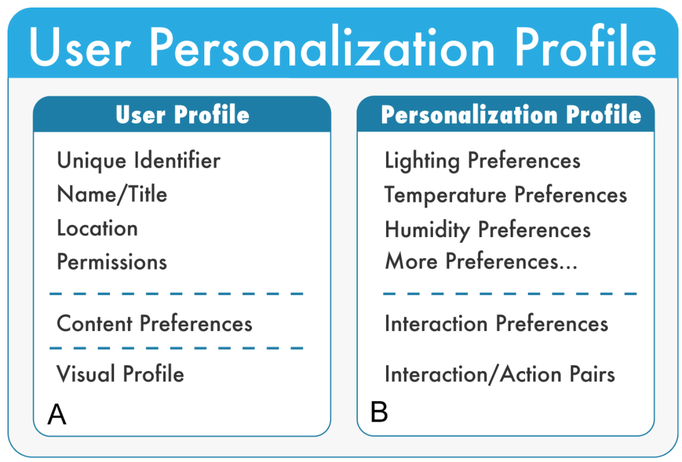

Figure 1. A User Personalization Profile

2) Interaction/Action Mapping

Although not practically implemented in this work, our user-centric personalization procedure incorporates a method of mapping interaction techniques with actions to be initiated. To support consistency and memorability of interaction control across multiple shared UbiComp environments our user-centric personalization procedure describes a method of pairing interaction techniques with actions, which will be practically implemented in our future work. Through this method users can create logical mappings between interaction techniques and actions to be initiated. This method affords users to make more cohesive pairings, which are compatible with their own personal habitual interpretation of interactions for controlling UbiComp environments [8, 9, 10, 12]. Through the personalization management application they can select an explicit interaction technique from a menu and map it with an action, for example (light on/off). Once the user explicitly performs the selected interaction technique in the UbiComp environment the selected mapped action is initiated. For example, a user could select a gesture technique such as a hand wave up/down motion from the personalization manager application menu and pair it with the light intensity increase/decrease action.

Once a user has completed configuring their preferences for interaction control and conditions these are then saved as a "UP Profile" called 'working profile" by the user. This "working profile' is locally stored on the user's wearable device, where it can be automatically queried in the UbiComp environment again and in the future and across other shared UbiComp environments, which are capable and compatible to load this format of profile.

B. *Autonomous Reconfiguration*

Autonomous Reconfiguration describes a procedure following which multiple shared UbiComp environments automatically reconfigure interaction control methods and conditions to suit a user's preferences. The activity logic of our approach for Autonomous Reconfiguration is illustrated in Figure 2.

Algorithm 1 Workflow of User-centric personalization

Require: User A has a carry-on device D which is able to store profiles P(s). UbiComp U is able to be configured.

```
if A has a profile then
    U loads a configuration C1 that is stored as a P1 from D
else
    U prompt to configure its contexts
    A specifies the configuration C2
end if
U adjusts the contexts to the configuration
if Update the C1/C2 then
    U prompts the save option
    if A wants to save then
        U prompts to confirm to save
        Updated C1/C2 is saved as a P2 on D
    end if
end if
if A leaves U then
    U removes C1/C2
end if
```

Figure 2. Activity Logic

Through wireless local communications, "UP Profiles" are uploaded from the user's carrier device to the UbiComp system. Existing configurations on the UbiComp system are substituted with user's "UP Profile". Based on the configuration saved as the "UP Profile" the UbiComp environment responds accordingly adapting to suit the user. As the "UP Profile" is stored on the device which is constantly with the user, it is roaming together with him/her; then connectivity and the provisioning of "UP Profiles" to UbiComp systems depends on users physical location and movement as they share their "UP Profile" with UbiComp systems. We call this "User Profile Roaming", due to the profile being linked with the user. Subsequently, a "UP Profile" is readily available as the user encounters multiple shared UbiComp environments across other locations. Therefore, the user does not have to manually reconfigure shared UbiComp systems each time they encounter them to suit their preferences for interaction control and conditions. Also, to ensure that ownership and privacy concerns are maintained, "UP Profiles" are only shared during the session when the user is active in the UbiComp environment. Once the user has completed the session within the UbiComp environment, "UP Profiles" are automatically cleared from the UbiComp System.

IV. Implementation

There are various ways to practically build up a prototype system which can realise the proposed methodology. In this section, we present both the structure and the implementation components of our testbed system.

A. *System Architecture*

The options for building a UbiComp system are only limited by people's imagination nowadays. System developers are provided with an abundant of technologies and also technical commodities which aim to be integrated into something useful requiring minimum effort. Therefore, simplicity is the main characteristic of the system structure we have decided. As described in Section V, two physical small scale models representative of two UbiComp environments are transformed as our UbiComp testbed where a few major components are embedded as catagorised below and illustrated in Figure 3.

- Profile interface, through which user's preferred settings, stored as a structural profile file, are uploaded to the environment; also when user adjusts the settings and decides to keep it for a longer term, the updated settings are downloaded to the user through this interface. Different communication methods can be applied in practical implementation.
- Control GUI is a visual interface that enables the user to explicitly manage controlling the settings of the encountered environment.
- Manipulatable contexts are typical adjustable utilities, which normally function differently according to various users, in the environment, such as lights and heating.
- Backend computing, which is invisible to users, orchestrates all other components, such as loading current user's profile, displaying the information on the control GUI and interpreting the user profile into manipulation commands to the contexts. Linkages can be both wired and wireless.
- Structural profile is the file stored on the user carry-on device, recording user's preferences of the context setting.

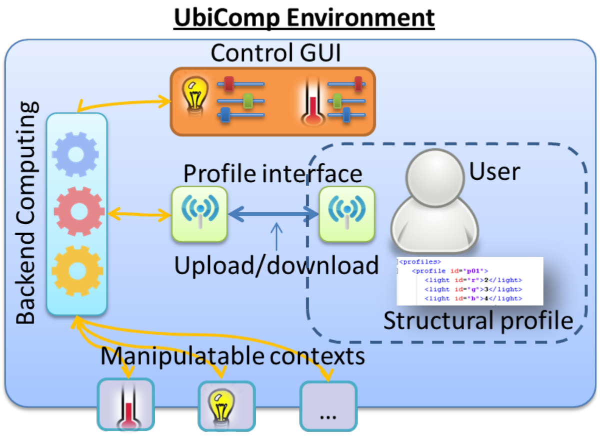

Figure 3. System structure of an UbiComp system

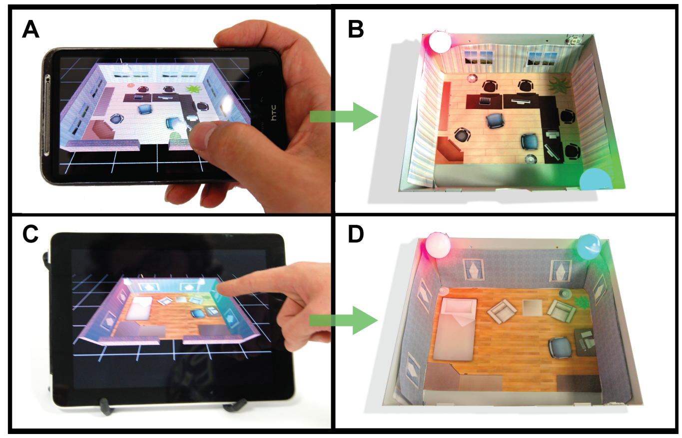

Figure 4. Experimental Testbed Setup

B. *Testbed implementation*

In building our testbed, we choose LAMP (Linux, Apache, MySQL and PHP) based web services and python based interface program as the backend computing. NFC (Near Field Communication) is selected as the communication method between profile interfaces; one interface is embedded within the UbiComp environment, while the other is on the user's carry-on wearable device. Lighting is set as the demonstrative manipulatable context. And wired connection is used to deliver control signals to the individual lighting device. Control GUI is implemented with a game engine – Unity3D – which generates a virtual 3D indoor environment with intuitive control functions that enable users to adjust the context lighting and save their preferences. "User Personalization Profiles" are the structural profile, where components of the "User Personalization Profile" are defined in an XML schema.

V. CASE STUDY

In this section, we firstly describe a possible user-case scenario, which we use to indicate how our methodology could be applied more practically across remote UbiComp environments in the future. We then validate our methodology with two sets of experiments; firstly the user-centric personalization experiment; and secondly, the autonomous reconfiguration experiment. The experiment testbed setup is described also and illustrated in Figure 4.

A. *User Case Scenario*

"Mr. Jones's job requires him to travel abroad quite frequently. He spends much time staying and working from different offices and hotel rooms across many locations. When Mr. Jones is working or relaxing he prefers the ambient lighting conditions of his accommodation to suit his preferences for such contexts. He would prefer the ambient lighting conditions in all environments he stays in to automatically adapt to suit his preferences for working, relaxation and sleeping, rather than having to adjust all the lights manually each time."

B. *Experiment Testbed Setup*

The possible user-case scenario described is demonstrated in a way more feasible for our experimentation purposes. The experiment testbed setup consists of two small physical scale models representative of two UbiComp environments. For descriptive purposes, the physical scale model as illustrated in Figure 4(B) is used as the first location representative of a user's local office environment, whereas the physical scale model illustrated in Figure 4(D) is used as the second location representative of a hotel room. In Figure 4(A, C) we show screenshots of the control GUIs taken from the personalization management application. Control GUIs provide virtual 3D environments indicating the users current physical environment, as to comprehend more meaning to the user. In both Figure 4(A) and Figure 4(C) the control GUI is deployed and accessible from touchscreen platforms, which are already part of both UbiComp environments.

C. *User-Centric Personalization Experiment*

To demonstrate the user-centric personalization procedure as shown in Figure 4(A, B), we firstly share a default UP Profile with the UbiComp System (Local Office), when there is a pairing between the wearable carrier device and the UbiComp system (Local Office), this is achieved through the profiling interface as illustrated in Figure 3. In our testbed setup, we consider the profiling interface to be already a part of the UbiComp system. In this experiment we firstly consider the user, Mr. Jones, to be initially carrying a default UP Profile, which has not been previously configured by him beforehand. When he encounters the first UbiComp System (Local Office), once a pairing between his wearable device and the UbiComp System (Local Office) is initiated, the default UP Profile is uploaded to the UbiComp System (Local Office). Once uploaded, the UbiComp environment's lighting conditions adapt according to the information stored as the default UP Profile. This is also comprehended in a meaningful way through a virtual 3D environment as displayed to Mr. Jones on the Control GUI, see Figure 4(A). The default

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lighting conditions may not be suitable towards his preferences; through the Control GUI interface he reconfigures the light intensity by directly selecting each light from the 3D virtual environment interface. User interface control buttons are mapped according to each light, which are used to increase/decrease the light intensity, see Figure 4(A). As described in the user-case scenario, Mr Jones is enabled to configure the light intensity to suit his contexts such as for working, relaxation or sleeping. Therefore, once satisfied with the light intensity he is then enabled to save these as UP Profiles where they can be updated, saved and uploaded to the his carrier device for future usage.

D. Autonomous Reconfiguration Experiment

To demonstrate autonomous reconfiguration, in our experimental testbed setup we use a second small-scale model representative of a remote hotel UbiComp environment, see Figure 4(D), as it is demonstrates how UP Profiles can be reused again to maintain consistency of Mr. Jones's preferences across multiple UbiComp environments. When there is a pairing between the user's wearable carrier device and the second UbiComp system (Hotel Room), Mr. Jones's working UP Profile as created previously is uploaded from the wearable device to the UbiComp system (Hotel Room). The light intensity in this second UbiComp environment automatically dimmers to the exact parameters matching the light intensity configured previously for a working context in the first environment (Local Office). This ensures that Mr Jones does not have to manually adjust the light intensity again to suit his working context, as his preferences for environmental conditions automatically remain consistent across multiple UbiComp environments. When he has completed interacting with an UbiComp environment, his personal UP Profiles are removed from the UbiComp system repository, as UP Profiles are only permanently stored on the user's wearable device.

VI. CONCLUSION

In this paper, we have presented a new methodology of user-centric personalization and autonomous reconfiguration across multiple shared ubiquitous computing environments. Through this methodology, it is emphasized that users should play a dominant role in deciding their own preferences for interaction control and the environmental context. Another aspect highlighted in this paper is the seamless maintenance of consistency of user experience across multiple UbiComp environments. Scenario based experiments have shown how the methodology is practically implemented and the effectiveness it brought into the real-life scenarios. For this stage of our work, room models have been used for simplicity in demonstrating the concept. In the following work, deployment within a real-life environment will be carried out, including optimization of GUI designs and reliability of the pairing procedure on the profile interface. More modalities of interaction controls (gestural, touch and voice) and more contexts (temperature, sound and humidity) will be included into the real-life deployment.

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