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Resolving User Conflicts in Multi-user Context-aware Home Environment

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ABSTRACT

Context-awareness is an enabling technology of pervasive computing that allows applications to adapt themselves in response to contexts (e.g. activity, location, temperature level, etc.). However, an issue of user conflicts in context-aware applications may arise when multiple users want to access the same application. Our research focuses on this issue and proposes a conflict resolution approach that resolves the conflicts in context-aware home applications. The proposed approach takes into consideration the users' special case contexts (e.g. illness of user) along with their priorities and preferences. The proposed approach is also useful in cases where multiple users with multiple special cases try to access one application or service. To show the usefulness of the proposed approach, we have integrated the proposed conflict manager with the UbiREAL, a simulated context-aware home environment. The conflict manager utilizes different strategies and different approaches to resolve user conflicts according to the involved situation to suit the need of the family. The prototype evaluation shows that the users are satisfied with the proposed system and suggests that the use of users' special case contexts in detecting and resolving the user conflicts is essential and necessary in the context-aware smart home environments.

1 Introduction

In 1991, Mark Weiser put forward the vision of ubiquitous computing¹, now also known as pervasive computing. The core of his vision was that computing would move beyond desktop and be available everywhere and invisible to the users, to support and facilitate their daily life activities without requiring continuous instructions from them. In other words, pervasive computing is a computing paradigm that supports and helps us in everyday life activities at work or at home without demanding our attention. What makes this vision possible, among other things, is context-aware computing (also called context-awareness). Context-aware applications are the applications, which use contextual information to provide the users with the service(s) of their interest, or to perform a specific task or action on behalf of users^{2,3}. While context-awareness plays a central role towards realizing the vision of pervasive computing, there are various interesting research challenges (e.g., user control, context inconsistencies, power consumption, etc.) in the field of context awareness that are being investigated by research community to fully realize vision of Pervasive Computing.

Smart environment is a place, which comprises interconnecting sensors, computing devices, appliances and services, which adapt themselves according to contexts (occupancy, activities, weather, etc), to improve comfort, safety and security for its occupants⁴. While smart environments are well suited for satisfying needs of one user at a time, introducing multi-users to such environments is a challenging task. It is because the multiple users share time, place, appliances and computational resources of the same environment and the environment is expected to coordinate and manage the resources to fulfill the users' needs in an effective and productive manner.

An issue of user conflicts in smart environments arises when multiple users try to use one context-aware application or service, which provides a customized service for only one user based on contextual information. For example, when a user A enters a living room, the room lighting and the temperature control applications adapt themselves according to the preferences of the user A, but what if another user B enters the same living room and she has a different set of preferences for the lighting and temperature of the living room. These situations lead to user conflicts in smart environments.

One of the examples of smart environments is a smart home, which adapts itself to the needs of the family and helps them perform everyday home activities with a minimal or no distraction. In the home environment, the priorities are commonly assigned to family members based on their roles i.e. the parents (father and mother) will have higher priority than their children, and the elder brothers and sisters will have higher priorities than the younger ones etc. For example, in the aforementioned

example scenario, in presence of both father and son in the living room, temperature and lighting of the living room may be adjusted according to father's preferences as he has higher priority than his son. However, there may be various common situations that might arise in the smart home environments, which need to be considered in detecting and resolving users' conflicts. For example, in the same scenario, what if both the father and son are in the living room and its temperature is set according to father's preference for temperature (e.g., cold environment) as the former has higher priority than the latter, but the latter is ill and the cold environment may worsen his health conditions. Many other such common situations in the home environments might occur, such as exam preparation, visits of the other families or friends at the home or the user herself is not interested in using the application(s). Such situations in the context-aware homes call for user conflict resolution schemes that takes into account such situations in detecting and resolving user conflicts.

Moreover, in smart environments, there might come situations where users' conflicts require users' involvement and discussion for resolving conflicts. As advocated in the literature⁵⁻¹⁵, involvement of users in conflict resolution is essential as it increases the harmony of the home inhabitants. This requires the environment to recommend the users with the best possible resolution candidates to resolve a particular conflict based on the involved users' preferences and conflicting situations. In this research paper, we propose a conflict resolution manager to resolve different conflicting situations that occur in the smart home environments when the multiple users share the same environment. The conflict resolution manager also takes into account aforementioned common situations. To the best of our knowledge, none of the existing literature has considered these special situations to resolve users' conflicts. The proposed system has been tested and evaluated and the usability findings suggest that the proposed system is usable in resolving the different conflicting situations and can provide comfort to the users by conveniently resolving their conflicts.

The reminder of the paper is organized as follow: Section II presents related works that address the multi-user conflict resolution in smart environments. Section III presents our proposed approach to resolve the multi-user conflicts. The prototype implementation is discussed in section IV, while the usability evaluation and its procedures are discussed in section V, followed by the results and discussion in section VI. Conclusion remarks and future directions are presented in section VII.

2 Related Work

This section provides a brief overview of research works focusing on multi-user conflicts detection and resolution. The authors in¹⁶ suggests that various research efforts have focused on priority-based automatic resolution of multi-user conflicts without active users' involvement, in the smart home environments. In¹⁷, the priorities are assigned to the actions according to certain rules at the time of conflict, and the system selects the highest priority action as the resolution of the conflict or according to the importance of the action. Some of the existing systems resolve the conflict using conflict manager, where the priorities are assigned according to their importance, user preferred service, or by user specific way supported by using history of user selections¹⁸. Other researchers have focused in resolving the conflict by maintaining conflict history records and assigning the priorities based on the conflict history as presented in^{5,19}.

Some researchers have tried to resolve the conflicts by developing different algorithms (techniques), which use the priorities in some situations, and preferences in some other situations, or a combination of both depending on the profile and culture of the family. The approach in²⁰ has proposed three strategies to resolve the conflict: (1) by fair principle, which is based on the preferences of the users, (2) use first, which assigns the priorities to the user who comes first to the environment and (3) by preference priority, where it gives priorities to the preferences and resolves the conflict by selecting the highest priority preference. The authors also suggest the need for considering the illness of the user to adjust priorities or preferences, by giving the highest priority to the ill user at the time of the conflict. The work in²¹ has considered the user preferences and intentions in resolving multi-user conflicts, and their algorithm minimizes the reluctance of all the users by computing the deviation in users' preferences and applies the result that has the lowest deviation from what each user wanted.

However, there are situations where it is very difficult to assign the priorities such as public spaces and gatherings. For such situations, the researchers have focused on resolving conflicts considering the satisfactions of the majority of the users' preferences. MusicFX²² is an arbitrator system, which automatically selects the music station for the members of fitness center indirectly through their profiles. The system allows the users to influence, but not directly control the selection of the music station through their preferences gathered from their profiles. Jukola²³ is a music mediator system for public space, which allows customers to influence the selection of songs that will be played in a cafe. The system provides the customers with a device in every table and mediates a list of songs for all the users on a shared display screen. It allows the customers to select the songs, and after selection, it plays the most rated song. The system also allows the customers to upload their own songs, which will be added to the list, so the other customers can rate these songs. This approach requires active participation of all the users to resolve the conflict. However, private spaces (i.e. smart home environment) require different kind of mediation as the home members can easily resolve the conflict by discussion.

The authors in^{6,7} argue that discussion is an effective and natural way of resolving the conflict because it allows the users to exchange information to reach a solution, which include an agreement and preference of all the users. The work in⁸ has

proposed a user-centric conflict management system, which considers different contexts and personal companion to resolve multi-user conflicts. The system allows the users to select from the recommendations using their personal companion. Mediation process enables the users to exchange their opinion regarding media content, and to agree upon an item, which reflects all users' preferences. In⁵, the authors resolve the conflict by merging the involved users' profiles using Group Preference (GP) algorithm. The system then recommends the list to the users, and the users then discuss among themselves and agree on one content. The authors in⁹ have proposed a system that focuses on recommendation for digital TV. The system merges the involved users' profiles and constructs a common user profile, which reflects the group preferred contents. The system then recommends the common user contents and based on users' feedback, it selects and plays the common program. The authors in¹⁵ have proposed a mediation technique, using a recommendation based on a consistent media content of every user involved in the conflict and service profile. It rearranges the recommendations using GP algorithm and mediates it to the users as discussed in⁸.

In a home environment where different conflicting situations may occur, resolving conflicting situations using one resolution approach will not produce satisfactory results for all the users. This arises the need for a system to support multiple approaches with multiple schemes to deal with different conflicting situations. The authors in²⁴ have proposed a system that resolves multi-user conflicts in explicit user interaction through input control device. Their solution uses different approaches to deal with multi-user conflict such as (a) giving the priority to one person only to have the input control device, (b) allowing the person who entered first into the environment to have the input control device, (c) giving a specific time to every person to have the input control device, (d) involving every person to actively participate in the conflict through mediation using Personal Digital Assistant (PDA). In the last case, the system involves all the users even if they are not involved in the conflict and it then adapts itself according to the input, which all the users agreed on.

The authors in²⁵ resolved the conflicting situation automatically based on Constraint Satisfaction Problem (CSP), which finds the resolution based on involved users' preferences. The constraints are valid range of values for user preferences and services that enable performing the activity. In case of non-satisfiable constraints, the system assists the users in resolving the conflict by mediating asset of resolution candidates. The research work in²⁶ also uses CSP for conflict resolution to find the appropriate resolution by performing constraints solving. The difference is that the latter uses ontologies to detect and satisfy the constraints imposed on the environment. Ontologies are one of the mechanisms used in multi-user conflict detection in the smart environments, which allow to categorize the devices according to their similarities (i.e. device type, device location, etc.)²⁷. The work presented in²⁸ focuses on detection of the multi-user conflicts in the smart environment. The detection of multi-user conflict is formulated as ontology conflict by detecting whether the conflict occurred in one application or in multiple applications, and whether the conflict is a functional conflict or a non-functional conflict.

The authors in²⁹ have used the concept of entropy and information gain from information theory based on the user usage habits of the devices and services, and developed an algorithm based on temporal proximity to detect the multi-user conflict. The research work in³⁰ developed *Kratos*: a multi-user and multi-device-aware access control mechanism. The system has three components: (a) user interaction component to allow the user to specify their access control settings, these settings are converted into policies in the second component, (b) backend server, and (3) policy manager that analyzes these policies to negotiate the conflict between users and generates final policies that will be used to resolve the conflicts.

The authors in¹⁰ have proposed a conflict manager, which resolves the conflict by either of two ways – (1) by assigning priorities to the users' contexts and choosing the user context based on the highest priority at the time of conflict and (2) by recommending the users' recommendations based on their profiles and letting the users select one of the recommendations. The authors of¹² have proposed a socially aware TV in which the conflict is resolved in either of two methods – (1) by automatically resolving the conflict based on users' profiles and (2) by recommending the users a common group profile. The system provides a remote control that allows the users to mediate the final decision and the system then makes a final decision after the users selected one of the recommendations. In¹¹ the authors have proposed a system that resolves the users conflict based on service recommendations. When the conflict occurs, the service recommendation selects the highest preferred services and recommends them to the users. The system gathers users' feedback and adapts according to the users' selection after discussing the recommendations.

The authors of¹³ have developed the mixed initiative conflict resolution approach that resolves the conflict in either of three ways: (1) an automatic selection with priority, (2) an automatic resolution with preferences and (3) mediated resolution approach with profile merging. In the first approach, the system adapts according to the highest priority user and if the difference in priorities of the involved users is less than a specific threshold value. Also in case if the deviation between each user preferred value and the group's best item is greater than a specific threshold value. The second approach is an automatic resolution with preferences, which is further divided into two approaches: (a) if the context attribute is numerical (i.e. Air Conditioner), the best optimal solution is used because it is easy to compute with the help of computing the lowest deviation of each user preferred value with the resolution result and (b) if the context attribute is symbolic (i.e. fan speed) and the deviation of the user preferences is less than a specific threshold value, the group's best item is used as a resolution of the conflict. The third approach, mediated resolution approach with profile merging, the system recommends the users with some resolution candidates based

Figure 1. High-level architecture of the proposed system.

on their profiles merging. The users are then engaged into face-to-face discussion and select one of the resolution candidates. The work in¹⁴ resolve the conflict by either of two methods: (a) profile based automatic approach or (b) by the use of social mediation. In social mediation approach, the users engage in negotiating for a proper resolution. The system has a balance model to evaluate a group feeling to reduce a discussion time.

Literature review presented above suggests that a multitude of research has been conducted in the proposed research area, resulting in proposition of different resolution algorithms (based on priorities and/or preferences) and approaches (automatic, mediated, and mixed) to detect and resolve the multi-user conflicts. Some of the proposed algorithms are suitable for public spaces (e.g. restaurants), while others are suitable for the private spaces (e.g. homes). The importance of the mediated resolution approach in the private spaces is stressed in the reviewed literature, but the context-aware home environment dictates the need for minimizing the involvement of the users to reduce their distractions, especially in the situations where users may have special cases (i.e. illness, preparation for examination and guests). In the existing systems, if the automatic resolution is applied for such special cases, it may lead to unpleasant results for those special case users. Moreover, if the mediated resolution approach is applied, this will lead to discussion among home users and the result will most likely be the home users conceding their right to the special case users as a resolution for the conflicts to provide them comforts. These special cases are temporary situations, which can be active for specific amount of time. The family members show care for the other family members by conceding their right of using the application to the other family member who is having a special case (i.e. illness). This will allow the family to live in more harmonic situations as it will provide the special case users the feelings that the other home members are caring for them. In order to lessen the user involvement, mediation can be minimized by allowing the application to automatically adapt to the preferences of the special case users. also, an important but neglected aspect is considered in this research, in case if the user is not interested in the application available at the vicinity such as the TV, maybe because of work overburden or some other reasons. We consider this as an important aspect of multi-user conflict detection and resolution and embed this in our proposed approach to multi-user conflict detection and resolution. While the mixed approach to multi-user conflict detection and resolution has been used in the literature in which some conflicts are resolved using automatic resolution approach and others using mediated approach, none of the existing systems have considered use of special cases in the decision making of the selection of the resolution approach. The proposed approach takes into account special cases in determining a resolution algorithm and an approach to be applied to detect and resolve the multi-user conflicts in the smart home environment.

3 The Architecture of the Proposed System

The architecture of the proposed system comprises three main components as shown in the Figure 1: the UbiREAL (i.e. simulated sensors, applications), Users' Profiles and User Conflicts Manager.

UbiREAL simulator³¹, is one of the components of the proposed architecture, which includes simulated sensors and applications. The simulated sensors detect the users' movements and track their locations.

Users' Profiles component is a general-purpose component, which is responsible for maintaining the profiles of the smart

Figure 2. Approach determination structure.

home users. Each profile will contain the required information, which is needed to be considered in resolving the conflicts among the users.

The Conflict Manager component is responsible for detecting and resolving the multi-user conflicts. Its working involves detecting a conflict by getting the required information from the simulated sensors and users' profiles component, deciding appropriate approach using determination algorithm and then resolving the conflict. It resolves the conflict in either of two ways: (1) based on the information gathered from users' profiles without user involvement (automatic approach) or (2) through mediation by generating some resolution candidates based on users' preferences, recommending these resolution candidates to the users, then gathering users' selections and delivering the final resolution to the appliances, which adapt according to the resolution.

The Conflict Manager component has three sub-components: (1) Conflict Detection Component, (2) Determination Approach Component and (3) Resolution Component. The Conflict Detection Component is responsible for detecting the conflict, which obtains users' location from the sensor component, gathers the required information about the conflicting situations like name of the users, the conflict location, and the involved users' profiles, and passes these pieces of information to the Determination Approach component.

The Determination Approach Component is responsible for selecting an appropriate resolution approach based on the information received from the Conflict Detection Component. Once resolution approach is selected, it will then be used to resolve the conflict. The Resolution component is responsible for making the resolution. The conflict might be resolved automatically without active involvement of the users based on the information gathered from their profiles, or by mediating some resolution candidates based on users' preferences, letting the users discuss among themselves and selecting the appropriate resolution from the resolution candidates. The application then adapts according to users' selection.

The Application, a part of the UbiREAL, is responsible for publishing the name of the applications/devices and the actions, which can be performed on these appliances. Every device must publish its name, actions that can be performed on those devices and the variable name, which is passed as an argument to the application. The conflict manager, after resolving the conflict, passes the values to the application, which will adapt itself according to these values.

3.1 Approach Determination Algorithm

The proposed system uses three approaches to resolve conflicts: (1) an automatic approach, (2) a mediated approach and (3) a mixed approach. We have designed an algorithm, which selects an appropriate approach to adopt for resolution of conflicts according to the conflicting situations, as shown in the Figure 2.

Figure 2 shows that the approach determination structure is only responsible for selecting the appropriate resolution approach for resolving the conflict as it is detected. It selects automatic resolution approach in four cases: (1) if there is no special case user involved in the conflicting situation, (2) if there is only one special case user from the involved users, (3) if there are multiple special case users and the deviation in their preferences is low and (4) if there are different special case users with a high deviation in their preferences.

The determination approach selects the mediated approach when the involved users have the same special case and the deviation in their preferences is high. The determination approach selects the mediated resolution approach when there are

Figure 3. Structure of UbiREAL simulator.

multiple special case users with the multiple applications present in the environment and the automatic resolution approach is not applicable. This type of resolution as a whole is considered as the mixed resolution approach.

For example, two users with special cases are present in the same room and there are three appliances (light, temperature, and TV) in the room. One user is ill while the other prepares for examination. The proposed system will detect the conflict, gather the information about the users and the environment, and resolve the conflict as follows. The ill user will control the temperature appliance, while the user preparing for examination will control the light appliance. As the TV appliance has equal impact on both users' special cases, the mediated approach resolution will be chosen for this appliance, which will generate some resolution candidates based on both users' preferences and recommend them to the users. The users will then engage in discussion and select one of the resolution candidates and the system will adapt according to users' selection.

4 Prototype Implementation

As a proof of concept, we have designed and implemented our approach using Java language. Since our research is focused on handling the issue of detecting and resolving user conflicts in smart homes, our proposed system does not provide any support for developing context-aware applications and for this purpose we have used UbiREAL³¹ simulator, which provides a simulated smart home environment for development and execution of context-aware applications. The proposed system can broadly be divided into two main parts: (1) UbiREAL simulator and (2) support for detecting and resolving user conflicts. The design and implementation of the latter is our main contribution.

The reason for using UbiREAL is the fact that it is a very expensive and time-consuming process to develop a real test-bed environment for testing context-aware applications, since it requires installing many sensors and appliances to meet the requirement of the smart environment.

One of the promising solutions for resolving this problem is testing these types of applications on the simulators. We have chosen the UbiREAL simulator³¹, a java-based 3D virtual environment, to test our proposed Conflict Manager. UbiREAL simulator provides a suitable environment to test the context-aware applications and allows to visualize the state change of devices through the 3D GUI. UbiREAL simulator was made public with the source code in the year of 2012. We have implemented the conflict manager on top of the UPnP component shown in the Figure 3. The proposed conflict manager is integrated with the UbiREAL simulator to detect and resolve the multi-user conflicts, using the UPnP protocol. The conflict manager, an UPnP client control point, subscribes to the events of the sensors to get the notifications about the devices state changes (user locations). Based on this information along with users' profiles (which we have developed using an XML as shown in Figure 4), the proposed conflict manager detects and resolves multi-user conflicts.

The proposed conflict manager is integrated with UbiREAL simulator to detect and resolve the multi-user conflict issue, using the concept of UPnP protocol, which allows the application to implement the phases needed to develop an application compatible with the context-aware environment. The conflict manager is developed as UPnP client control point, that subscribes to the events of the sensors to get the notifications about the devices state changes (context - specially the sensors - user locations). Based on this information along with users' profiles (which we have developed using XML as shown in Figure 4.) we proposed a resolution to resolve the user conflicts issue.

We also have developed a GUI to edit the XML files for user preferences. As shown in the Figure 5, the simple XML Editor has only two buttons (Open and Exit). When the open button is clicked, a new dialog appears that allows to choose one of the

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<profile>
  <user>      <name>Mahmoud</name>                                </user>
  <pref>      <specialcase>Ill</specialcase>                      </pref>
               <casevalue>true</casevalue>
  <pref>      <specialcase>ExamPreparation</specialcase>          </pref>
               <casevalue>>false</casevalue>
  <pref>      <specialcase>Guest</specialcase>                     </pref>
               <casevalue>>false</casevalue>
  <pref>      <specialcase>WishToUseTheService</specialcase>      </pref>
               <casevalue>true</casevalue>

  <action id="0"> <actionName>priority</actionName>              </action>
                  <value>1</value>
  <action id="1"> <actionName>LivingLamp1</actionName>            </action>
                  <value>2.4</value>
  <action id="2"> <actionName>LivingFanSetPower</actionName>      </action>
                  <value>1.0</value>
  <action id="3"> <actionName>LivingAirconSetPower</actionName>   </action>
                  <value>true</value>
  <action id="4"> <actionName>LivingAirconSetTemperature</actionName> </action>
                  <value>30.0</value>
  <action id="5"> <actionName>LivingAirconSetHumidity</actionName> </action>
                  <value>60.0</value>
  <action id="6"> <actionName>LivingTVSetPower</actionName>       </action>
                  <value>true</value>
  <action id="7"> <actionName>LivingTVSetChannel</actionName>     </action>
                  <value>5</value>
</profile>

```

Figure 4. XML-based user profile sample.

XML files to edit. The users are then able to specify their names and preferences through the GUI without the need to edit the XML file manually.

We have also developed a Java-based GUI that allows the users to select the resolution from the recommended resolution candidates at the time when conflict occurs, as shown in Figure 6.

5 Evaluation

We have evaluated the proposed approach by performing the usability study of the implemented system.

5.1 Usability Study

The participants of the usability study are divided into 22 groups and each group consist of four (04) participants. Every participant from the group was given a role to play in the usability study scenario according to their role in the family (i.e. parents were given a parent role; children were given a child role). We have executed the scenario twice for each group of participants, first time with a low deviation in the users' preferences, while the second time with a high deviation in the users' preferences.

We projected the smart home environment as shown in Figure 7. The participants interacted in front of the projected smart home environment to imagine that they are in a smart home environment as shown in the Figure 8. In case of recommendations, the recommendations popped up on the screen and the users discussed among themselves and told the actor (Who was responsible for running the system) to apply the selected resolution candidate.

In addition, we added the GUI based utility as shown in Figure 9 to set the preferences of the users, which will be saved as a separate profile for every participant. Then we controlled the experimental situation involving the applications and the degree of deviations in the users' preferences. By using all those components, we built a virtual smart space, which mimics a real smart home. The three applications (as shown in Figure 10) were selected and projected on the wall screen by the simulation: 10 (a) simulated Air Conditioner and 10 (b) simulated Television application, and 10 (c) simulated Light application. When conflict occurs, the conflict manager detects that conflict and respond immediately to the automatic or mediated conflict resolution results.

All methods were carried out in accordance with relevant guidelines and regulations as well as all experimental protocols were approved by University of Sindh, Jamshoro. Ethics approval and participant consent was taken as per policy of the University of Sindh, Jamshoro. All subjects in the database were enrolled at the university and have given informed consent, and if under 18, consent was taken from parent and/or legal guardian. Additionally, all the subjects have given the right to withdraw form the study at any time. Furthermore, an informed consent was taken from all subjects and/or their legal guardian(s) for publication of identifying information/images.

Figure 5. GUI-based for user profile XML-based editor.

Figure 6. Recommendations of the resolution candidates based on the involved users' profiles.

Figure 7. Living-room like environment in UbiREAL.

Figure 8. Users interaction with the simulated environment.

Figure 9. GUI utility for user's preference setting.

Figure 10. Projected (a) Air Conditioner (b) TV Screen (c) Light Appliance.

5.1.1 Selection of Scenarios

Different scenarios were selected considering multi-user home conflicting situations, which also consider special cases. The first scenario was selected with two family members and their two friends.

Every participant was given a role and a special case to evaluate the proposed system with multiple applications and multiple users, which have different special cases. The first user entered the environment was a home member and having an illness special case. The second user entered the environment was a friend of the first user who came to visit him at his home and that user will be having a guest special case. The third user was a brother/sister (home member) of the first user, and she is having an examination preparation special case. The fourth user was a friend of the second home member who will ultimately be having a guest special case, but at that instance of time she was not interested in using the applications in the environment. This scenario was executed twice, first time with a low deviation in users' preferences and the second time with a high deviation in users' preferences.

The second scenario requires four home members: a father, a daughter, and two sons. The first user entered the environment was a son and he does not have any special case (normal). The second user entered the environment has an illness special case who is the brother of the first user. The third user entered the environment was the father and he is not interested in using the applications running in the environment. The last user entered the environment was the daughter and she had an examination preparation special case. This scenario is also executed twice, first time with a low deviation in users' preferences and the second time with a high deviation in the users' preferences.

Every scenario was executed twice as discussed above to examine the system behavior of selecting the appropriate resolution approach based on the users' special cases and the degree of deviations in the users' preferences.

The reason of using only two scenarios in the usability study is to avoid users' exhaustion. Every single scenario takes around fifteen minutes to complete. Executing only two scenarios allow us to get a reasonably realistic data without taking much time of the participants. In summary, we selected the two scenarios to evaluate the special cases with their preferences, which allow us to examine the three different approaches in resolving the multi-user conflict.

These three approaches are: (1) Automatic Resolution Approach, which resolves the conflicts based on users' profiles without involvement of the users in the resolution processes, (2) Mediated Resolution Approach, which always involves the users in the resolution processes, recommends them some resolution candidates and they have to discuss and select one of the resolution candidates to be applied as the conflict resolution and (3) Mixed Resolution Approach, which considers the resolution when the conflict occurs for multiple applications, the system selects the automatic approach for some of those applications and for the others the mediated approach is used. We also selected these scenarios to examine the efficiency of the resolution determination approach for selection of the appropriate resolution scheme to resolve the conflicting situation.

5.1.2 Test Procedures

We conducted the test in a room, which simulates a living-room like environment. Before start of the experiment, we took a little time to explain and demonstrate the goal of the experiment and the conflict resolution along with different approaches used in the conflict resolution. We also explained different strategies used in resolving the conflict automatically. Then we explained the need of including the special cases in detecting and resolving the multi-user conflicts, which happened regularly in the home environment. However, we also provided a brief introduction about the proposed system to each participant at the time of recruiting.

At the experiment time we administrated three questionnaires to the participants, (1) pre-test questionnaires, which were filled by the participants before conducting the test case. The pre-test questionnaire was used to collect the demographic information of the participants. (2) after scenario questionnaire (ASQ), which used to collect the opinion of the users for different aspects of the proposed system, and (3) post-test questionnaire to gather the broader aspects of the multi-user conflict resolution with the feedback and suggestions.

Each experiment consisted of two scenarios as explained earlier. The group of four users participated in executing the scenario twice. The first execution of each scenario was done with low deviations in users preferences, while the other was executed with high deviation in users' preferences to cover all the aspects provided in the proposed system. Some of the resolutions were selected by the conflict manager using mediated resolution approach, which recommended the involved users some resolution candidates and the users had to discuss and select one of the candidates. Then the system adapted according to that selection. After completing the scenario each participant was given after scenario questionnaire (ASQ) to gather the satisfactions of the participants with different aspects of the proposed system.

Finally after completing the test case, every participant was given a post-test questionnaire that contained only two questions, one about the approach that will be adapted by the conflict manager in case there is no any user from the involved users having a special case. The other question was about the rating of the different resolution approaches the user experienced while executing the scenarios.

Figure 11. Overall average satisfaction of the users with different aspects of the proposed system.

6 Results and Discussion

In this section, the results obtained from the usability study and the analysis based on the results are presented. The usability analysis of the proposed system provide an assurance whether the system is easy to use and the intended users are satisfied with the way the system works for detecting and resolving the multi-user conflicts.

The data obtained from both ASQ and post-test questionnaires reflects the participant's opinion about the overall usability and capability of the proposed system. It also reflects the efficiency of selecting the appropriate resolution scheme and approach for conflict resolution in different scenarios. The selection of seven-step likert scale is based on^{32,33}, which captures the best discrimination of the users. Less than 7-scale or greater than 9-scale results in losing of discrimination from the participants point of view, which results in unproductive and unreliable results. The satisfaction of the users with the proposed system is expressed in terms of rating score on 1-7 scale in which 1 reflects the lowest score and 7 reflects the highest score or the most satisfactory score.

In the literature of the usability evaluation, the score of 5.6 on seven-step scale, and the score of 4 on five-scale is very well known and considered for the system to be satisfactory and acceptable³⁴.

Graph shown in Figure 11 is drawn from ASQ to present the summary of overall average scores for all the aspects with the standard deviation. The Figure 11 also shows that the highest average score (i.e. 6.16) from all of the previous aspects is the time taken by the system to complete the resolution processes. The second highest score is for the satisfaction with the automatic resolution approach (ARA) that achieved an average score of 5.85. The appropriate selection of automatic resolution approach achieved an average score of 5.81, followed by the mechanisms used in the automatic resolution approach with 5.79 average satisfaction score. While the lowest two scores were for the satisfactions with the mixed resolution approach (MRA) and the appropriate selection of the mixed resolution approach that achieved an average satisfaction score of 5.55, 5.51 respectively.

We can conclude from the results that the users prefer automatic resolution approach over mixed resolution approach. This might be due to the fact that mixed resolution approach composed of the mediated and the automatic resolution approach that involves the users directly in the resolution. However, the previous research efforts^{10,12-14,14,24,35,36} use both resolution approaches in resolving the multi-user conflicts. Their results show that the users give higher satisfaction rate for the mediated approach over the automatic approach. The reason might be that the previous research efforts did not consider different special cases in detecting and resolving the multi-user conflict that regularly occur in the home environment. Without considering the

Figure 12. Age group wise analysis of the overall average satisfaction of the users.

special cases, the system chooses the mediated approach to resolve the conflict. It is because the user preferences change as she gets any special case, which makes the preferences very different. The change in the preference leads the system to use the mediated approach to resolve the conflicts.

The involvement of the users in every detected conflict disturbs the users and takes their attentions away from their current activities, since it demands users' attention in resolving the conflicts. The special case users can not compromise on their preferences and mediation ends up with the system being allowed to work according to the special case user preferences. To illustrate the situation in an example, let us take two members from a family, one of them is having an illness special case and so she does not like the cold environment. The other does not have a special case and likes the environment to be cold. Here, the special case user can not compromise on the average value or the cold environment. The family members show care for the other family members by conceding their right to use the application for the special case user (i.e. illness). That results in the applications to adapt themselves according to the special case preferences for a specific time, as long as they have that special case. When the special case user recovers from her illness, the normal working algorithm will be used. After recovering, the user will be able to compromise on her preferences for the other family members when they have the special case. This allows the family to live in more harmonic situations with the feelings that the other family members are caring for them.

As for the conflict determination approach, results showed that the users are satisfied with approach determination structure for selecting the automatic approach and the mediated approach for resolving the conflicts, their average satisfaction scores are 5.81 and 5.51 respectively.

6.1 Age Group Wise Analysis of Results

Age wise group investigation and analysis of the obtained results is also performed. The results are divided into two groups according to the age of the participants. Figure 12 shows the age wise group analysis of the results produced earlier.

Age wise group results shows that the young people who are aged 25 years or below give higher satisfaction for all the aspects of the system, except the mixed resolution approach. It might be because the young participants lived and were raised in the era after Mark Weiser's vision of pervasive computing¹, which advocates fulfillment of user tasks with no or a minimal user distraction

7 Conclusion and Future Directions

context-awareness plays a central role towards fulfilling the vision of Pervasive Computing outlined by Mark Weiser¹, there are various interesting research challenges in the field of context-awareness³⁷. Among other research challenges in context-awareness, an issue of user conflicts in context-aware environments is very interesting and being investigated by the research community.

We have identified that detecting and resolving the user conflicts in smart environments is essential. It enhances the system to support and coordinate the activities being performed by multiple users at the same time sharing the same space. Consideration of the special cases (illness, user preparing for examination, etc.) that the different users might have in

context-aware environments, is very important in detecting and resolving the multi-user conflict issue especially in the home environment. Despite their importance in multi-user context-aware environments, the existing works by not considering such situations do not clearly exhibit a comprehensive solution for multi-user conflict detection and resolution for the context-aware home environment as per requirement of the multi-user activities.

In this paper, we have proposed and implemented multi-user conflict detection and resolution system that addresses the above-mentioned conflicting situations. The system is able to meet the needs of the home members even if they have different conflicting situations that may change from time to time. The evaluation results clearly show that the proposed system is usable, and the intended users are satisfied with the working of the system.

We suggest that the work presented in this paper can be extended in following directions:

- The proposed work on multi-user conflicts targets smart home environments, where only family members are the users of the environments. In this case, solution provided in the form of mechanisms and supporting infrastructure cannot be exploited in other smart environments, e.g., smart office, thereby requiring researching into an issue of multi-user conflicts in other context-aware environments
- Detection of special case conditions (e.g. illness of the user) and automatic update of detected special case conditions in the user profiles: Currently, in the proposed work the information about special case conditions of the users is manually inputted into their corresponding user profiles. We suggest the development and integration of infrastructure that will interact with body sensors (e.g. temperature sensor) to detect special case conditions and update this information into its corresponding profile.

References

1. Weiser, M. The computer for the 21st century. *Sci. american* **265**, 94–104 (1991).
2. Abowd, G. D. *et al.* Towards a better understanding of context and context-awareness. In *Handheld and ubiquitous computing*, 304–307 (Springer, 1999).
3. Emmanouilidis, C., Koutsiamanis, R.-A. & Tasidou, A. Mobile guides: Taxonomy of architectures, context awareness, technologies and applications. *J. Netw. Comput. Appl.* **36**, 103–125 (2013).
4. Vahdat-Nejad, H., Zamanifar, K. & Nematbakhsh, N. Context-aware middleware architecture for smart home environment. *Int. J. Smart Home* **7**, 77–86 (2013).
5. Shin, C. & Woo, W. Conflict resolution method utilizing context history for context-aware applications. *COGNITIVE SCIENCE RESEARCH PAPER-UNIVERSITY OF SUSSEX CSRP* **577**, 105 (2005).
6. Easterbrook, S. M. *et al.* A survey of empirical studies of conflict. In *CSCW: Cooperation or Conflict?*, 1–68 (Springer, 1993).
7. Poole, M. S., Homes, M. & DeSanctis, G. Conflict management and group decision support systems. In *Proceedings of the 1988 ACM conference on Computer-supported cooperative work*, 227–243 (ACM, 1988).
8. Shin, C., Yoon, H. & Woo, W. User-centric conflict management for media services using personal companions. *ETRI journal* **29**, 311–321 (2007).
9. Yu, Z., Zhou, X., Hao, Y. & Gu, J. Tv program recommendation for multiple viewers based on user profile merging. *User modeling user-adapted interaction* **16**, 63–82 (2006).
10. Shin, C. & Woo, W. Service recommendation for conflict resolution in context-aware media services. In *the seventh ubicomp conference* (2005).
11. Oh, Y., Shin, C., Jung, W., Woo, W. & Kim, Y. ubitv scenario for a family in smart home. *UbiComp05 Video session 000* (2005).
12. Shin, C. & Woo, W. Socially aware tv program recommender for multiple viewers. *Consumer Electron. IEEE Transactions on* **55**, 927–932 (2009).
13. Shin, C., Dey, A. K. & Woo, W. Mixed-initiative conflict resolution for context-aware applications. In *Proceedings of the 10th international conference on Ubiquitous computing*, 262–271 (ACM, 2008).
14. Shin, C., Dey, A. K. & Woo, W. Toward combining automatic resolution with social mediation for resolving multiuser conflicts. *Cybern. Syst. An Int. J.* **41**, 146–166 (2010).
15. Shin, C., Yoon, H. & Woo, W. Media service mediation supporting resident's collaboration in ubitv. In *International Conference on Human-Computer Interaction*, 953–962 (Springer, 2007).

16. Haya, P. A., Montoro, G., Esquivel, A., García-Herranz, M. & Alamán, X. A mechanism for solving conflicts in ambient intelligent environments. *J. UCS* **12**, 284–296 (2006).
17. Ranganathan, A. & Campbell, R. H. An infrastructure for context-awareness based on first order logic. *Pers. Ubiquitous Comput.* **7**, 353–364 (2003).
18. Lee, H., Park, J., Park, P., Jung, M. & Shin, D. Dynamic conflict detection and resolution in a human-centered ubiquitous environment. In *Universal Access in Human-Computer Interaction. Ambient Interaction*, 132–140 (Springer, 2007).
19. Shin, C., Oh, Y. & Woo, W. History-based conflict management for multi-users and multi-services. In *Context2005 Workshop (Proc. of the Workshop on Context Modeling and Decision Support)* (2005).
20. Groppe, J. & Mueller, W. Profile management technology for smart customizations in private home applications. In *null*, 226–230 (IEEE, 2005).
21. Park, I., Lee, D. & Hyun, S. J. A dynamic context-conflict management scheme for group-aware ubiquitous computing environments. In *Computer Software and Applications Conference, 2005. COMPSAC 2005. 29th Annual International*, vol. 1, 359–364 (IEEE, 2005).
22. McCarthy, J. F. & Anagnost, T. D. Musicfx: an arbiter of group preferences for computer supported collaborative workouts. In *Proceedings of the 1998 ACM conference on Computer supported cooperative work*, 363–372 (ACM, 1998).
23. O'Hara, K. *et al.* Jukola: democratic music choice in a public space. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques*, 145–154 (ACM, 2004).
24. Otto, F., Shin, C., Woo, W. & Schmidt, A. A User Survey on: How to Deal with Conflicts Resulting from Individual Input Devices in Context-Aware Environments? (na, 2006).
25. Paulo Carreira, A. C. S., Sílvia Resendes. Towards automatic conflict detection in home and building automation systems. *Pervasive Mob. Comput. J.* **12**, 37–57 (2014).
26. Camacho, R., Carreira, P., Lynce, I. & Resendes, S. An ontology-based approach to conflict resolution in home and building automation systems. *Expert. Syst. with Appl.* **41**, 6161–6173 (2014).
27. Elenius, D. & Ingmarsson, M. Ontology-based service discovery in p2p networks. In *P2PKM* (2004).
28. Chaki, D., Bouguettaya, A. & Mistry, S. A conflict detection framework for iot services in multi-resident smart homes. In *2020 IEEE International Conference on Web Services (ICWS)*, 224–231 (IEEE, 2020).
29. Chaki, D. & Bouguettaya, A. Fine-grained conflict detection of iot services. In *2020 IEEE International Conference on Services Computing (SCC)*, 321–328 (IEEE, 2020).
30. Sikder, A. K. *et al.* Kratos: Multi-user multi-device-aware access control system for the smart home. In *Proceedings of the 13th ACM Conference on Security and Privacy in Wireless and Mobile Networks*, 1–12 (2020).
31. Nishikawa, H. *et al.* Ubireal: realistic smartspace simulator for systematic testing. In *UbiComp 2006: Ubiquitous Computing*, 459–476 (Springer, 2006).
32. Lewis, J. R. Ibm computer usability satisfaction questionnaires: psychometric evaluation and instructions for use. *Int. J. Human-Computer Interact.* **7**, 57–78 (1995).
33. Bierton, R. & Bates, R. Experimental determination of optimal scales for usability questionnaire design. *Proc. Hum. Comput. Interact.* **2**, 55–56 (2000).
34. Nielsen, J. & Levy, J. Measuring usability: preference vs. performance. *Commun. ACM* **37**, 66–75 (1994).
35. Wang, Y., Shen, Y., Guo, M. & Zhang, D. A context conflict resolution with optimized mediation. In *Advanced Information Networking and Applications Workshops (WAINA), 2010 IEEE 24th International Conference on*, 842–847 (IEEE, 2010).
36. Shin, C. & Woo, W. Service conflict management framework for multi-user inhabited smart home. *J. UCS* **15**, 2330–2352 (2009).
37. Chang, E. Y. Context-aware computing: opportunities and open issues. *Proc. VLDB Endow.* **6**, 1172–1173 (2013).

Author contributions statement

M.A., L.D.D. and Y.A.M. contributed to the conception and design of the study. M.A. conducted the experiment(s), L.D.D., Y.A.M. and S.M.S. analysed the results. All authors reviewed the manuscript.

Additional information

Competing interests The authors declare no competing interests.