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Towards the design of personalized adaptive user interfaces for smart TV viewers

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ABSTRACT

Smart TV is a lean-back and shared device with diverse viewership, cultural acceptance, interaction modalities, input/output characteristics, and contextual use. Researchers, developers, and vendors constantly add new features and functionalities to its user interface (UI) to get higher market shares. However, the current smart TV UIs are static and follow a one-size-fits-all approach, where adding new features makes it cluttered and complex with limited learnability, usability, and greater cognitive overload. Another issue is the limited support for adaptive UIs to customize these features, functions, and services as per user needs. This article fills these gaps in the literature by designing a framework of personalized adaptive UIs for smart TV users capable of changing the UI layout and structure per the user needs and contextual details. The framework was tested on an Android-based smart TV and evaluated using a real-world dataset and an empirical study involving 75 household members in a mixed-mode questionnaire-based survey. The results were analyzed using Cronbach alpha, Kendall's tau-b, and principal component factor analysis. It was observed that personalized adaptive UIs are perceived positively in terms of attitude, usability, user experience, accessibility, learnability, user satisfaction, intension to use, and reduced cognitive overload.

1. Introduction

The user interface (UI), under the umbrella of human–computer interaction (HCI), has been researched as one of the essential components of interactive systems (Eichler 2014) and enables users to communicate, interact, and carry out the desired operation easily, quickly, and reliably (Hussain et al., 2018). A successful UI makes the user experience simple and intuitive, requiring minimal effort on the user's part to achieve the maximum desired result. A user interface is either static, having a one-size-fits-all approach (Hussain et al., 2018), or adaptable/adaptive. Both adaptable and adaptive UIs enhance usability, learnability, and user experience by reducing the cognitive overload on users resulting from the cluttered and over-enriched UIs due to various features, functionalities, and services (Lavie and Meyer 2010, Hussain et al., 2018, Machado et al., 2018, Khan et al., 2022). However, in the case of adaptable UI, the user can make customization and adaptation decisions through explicit user intervention (Gullà et al., 2015, Soui et al., 2017). On the other side, an adaptive UI personalizes and customizes itself according to the users' needs, preferences, goals, and context without explicit user intervention (Gullà et al., 2015, Soui et al., 2017). It enables users to interact easily with the system by modeling user experience (Langley 1999). It can adapt to user needs, expectations, and contexts by adjusting interfaces, elements, components, font size, color, contrast, theme, app settings, etc., according to user requirements, skills, experience, and context (Hussain et al., 2014, Rathnayake et al., 2019). The aim is to address the problems of usability, accessibility, learnability, and cognitive overload and to provide personalized assistance to users according to their needs and preferences (Machado et al., 2018). In addition, it reduces the usability issues and challenges of complex and cluttered user interfaces and improves the satisfaction and performance of the users (Alvarez-Cortes et al., 2007). This work focuses on designing adaptive UIs for the smart TV domain.

Smart TV (Bures et al., 2020) is a lean-back and shared device that family members can enjoy individually or in groups. The

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technological advancement of smart TV has changed the environment of traditional TV systems by offering advanced features and functionalities, including computational power, storage, Web 2.0 features, and internet connectivity. It is the dominant part of home entertainment in developed and developing countries, evident from the exponential growth in connected TV devices (Bures et al., 2020). It has revolutionized the environment of traditional TV systems by offering additional features and functionalities, including computational power, storage, internet connectivity, and Web 2.0 features (Wang and Chen 2018). Its users are different from those of other digital devices, including smartphones and personal computers, in terms of their use, needs, preferences, and interaction behavior (Alam et al., 2017, Wang and Chen 2018, Jang and Mun 2019). These inherent and basic differences led researchers, developers, and vendors to develop various features, functionalities, and services to make smart TV watching an enriched and more enjoyable experience. However, when it comes to the smart TV UI, managing these features, functionalities, and services on the traditional one-size-fits-all UI is a challenging task.

This clutter and complexity in the smart TV UI are evident from the availability of various operating systems (OSs), including Android TV, WebOS, and Tizen. On top of these OSs, many home-screen launchers have also been developed, such as HALauncher-Android TV,[1] Smart TV Launcher,[2] UNICA TV Launcher,[3] and Smart TV Launcher.[4] Each vendor and manufacturer try adding new features and functions to smart TV to gain a higher market value and attract users (Alam et al., 2019a, 2019b). This competition has confused users regarding content search, selection and operation due to complex UIs and related issues, including usability, learnability, user experiences, and cognitive overload (Khan et al., 2017, Kaya et al., 2021). Several vendors have developed their proprietary UIs and overlays in the smartphone industry, such as Samsung One-UI,[5] Huawei EMUI,[6] and Microsoft WinUI,[7] to make their products easier to use and operate. However, no vendor has contributed such overlays regarding smart TV. Therefore, smart TV UIs are at an infant stage and need to focus on the various aspects of the user characteristics, including age, gender, skill-level, knowledge, disabilities, viewing angle, viewing distance, screen size, etc., and environmental factors with different varying contexts such as light, color, noise, date, and time.

To address these issues, several user-based studies, including online surveys, think-aloud methods (Bruun and Stage 2015, Jang and Mun 2019), model-based automated approaches, dairy approaches, and user-centered approaches (Larusdottir et al., 2019, TC Lin 2019, Lee et al., 2020, Lin and Liang 2020, Altin Gumussoy et al., 2022, Habes et al., 2022, Kim and Merrill Jr 2022, Habes et al., 2023), have been used to evaluate consumer usage habits, attitudes, and interactions to gather comprehensive data for enhanced smart TV User Experience (UX) (Jang et al., 2016). However, their findings are limited to understanding user behavioral aspects, with almost no utilization from the developmental perspective of adaptive UIs for smart TV users. In addition, researchers (Design 2015, Flaherty 2015, Choudhary 2017, Seungho et al., 2018, TV 2020, Kaya et al., 2021) have proposed and developed various guidelines and principles to overcome the issues of usability and accessibility in smart TV UIs. However, these guidelines and principles only focus on the general problems of users with limited attention to the adaptivity of the UI for a specific user. However, smart TV is a different device and platform than a computer, web, or mobile. It requires a unique set of considerations, including screen size and distance, technical constraints, and context of use (Lafferty 2016). The current smart TV UIs are generalized, static, and designed with no regard for users' individual needs, including privacy and security. For example, mostly smart TV users (s) use a single email address for various services such as downloading apps from an app store, features on/off in smart TV settings, themes select, apps/channel priority, and setting on the home screen, etc. However, this setting and arrangement of smart TV features and functions may not be relevant to each family member.

The reason behind this limited user support in terms of personalized smart TV-watching experience is the lack of an adaptive UI that is user-friendly and meets the requirements of family members by exploiting their age, gender, mental model, cultural values, attitudes, and disabilities as well as by learning from their interaction patterns, browsing and usage behaviors(Reinecke and Bernstein 2011, Alam et al., 2019a, 2019b, Khan et al., 2022). Such an adaptive UI should remove the usability and accessibility barriers in achieving their goals effectively, efficiently, and satisfactorily regarding the specified context. It should reduce the issues of usability, learnability, and cognitive overload for an improved user experience (Reinecke and Bernstein 2011, Alam et al., 2019a, 2019b, Khan et al., 2022). This article fills these gaps in the literature by developing a personalized adaptive UIs for smart TV users that considers their needs and preferences. More specifically, we make the following research contributions to the body of knowledge on adaptive smart TV UIs.

- We present a personalized adaptive smart TV UIs to address the issues of usability, learnability, and cognitive overload.
- We use our developed SmartLog logging app, designed specifically for smart TV, to create a dataset with details about 75 users, their age groups, interaction, and smart TV watching history to evaluate the proposed adaptive smart TV UI.
- We evaluate the proposed personalized adaptive smart TV UI through a mixed-mode questionnaire-based survey of 75 household members. We apply tests, including Cronbach alpha, Kendall's tau-b, and principal component factor analysis.
- We demonstrate that using adaptive UIs can provide better usability, user experience, learnability, and accessibility and reduce cognitive overload.

The rest of the paper is organized into four sections. Section 2 discusses the related works on adaptive user interfaces for smart TV. Section 3 presents the materials and methods, including the proposed personalized adaptive smart TV UI framework, implementation, experimental settings, and evaluation methodology. Section 4 presents the results and discussion. Section 5 concludes the paper, followed by references and appendices.

2. Related works

The concept of adaptive UIs is not new. Rather, it has a long history of research and development rooted in the emergence of technological advancements in features and functions in various computing devices such as computers, smartphones, tablets, and smart TVs (Ahmad et al., 2004, Suopellonmäki 2017, Hussain et al., 2018). These devices have embedded UIs and apps that provide enriched services, functions, and features. However, due to complex, cluttered, and poorly-designed UIs, users cannot benefit from these functions, features, and services properly. One of the prominent reasons behind this limited accessibility is the personal, social, and cultural differences among users with varying tastes,

[1] https://play.google.com/store/apps/details?id=net.i.akihiro.halauncher&hl=en.
[2] https://play.google.com/store/apps/details?id=com.govind.androidtvlauncher.
[3] https://play.google.com/store/apps/details?id=xtvapps.launcher.
[4] https://play.google.com/store/apps/details?id=com.karthik.launcher.
[5] https://www.samsung.com/pk/apps/one-ui/.
[6] https://consumer.huawei.com/pk/emui-11/.
[7] https://microsoft.github.io/microsoft-ui-xaml/.

preferences, information needs, interaction behavior, knowledge, age, skills, and mental model. It makes it challenging for HCI experts and UI designers to overcome the barriers in designing user-friendly UIs due to variations in user information needs, platforms, interaction modalities, input/output methodologies, mental models, age, experience, and context of use (Ahmad et al., 2004, Hussain et al., 2018). In this regard, a one-size-fits-all UI approach is neither available nor possible (Sili et al., 2016). On the other hand, designing multiple UIs to address the needs of various user groups is challenging due to the aforementioned reasons (Leventhal et al., 1996, Yigitbas and Sauer 2016, Machado et al., 2018).

To address this need, researchers have introduced the concept of adaptive UIs and proposed several UI design guidelines and principles for various computing devices, including computers, smartphones, and tablets (Ruiz et al., 2021). The adaptive UIs (Alvarez-Cortes et al., 2007) enhance user interactions with the system by building a model based on partial user experience (Langley 1999). They can adapt and adjust themselves according to the user's needs, preferences, and context by modifying layouts, elements, components, font size, color, contrast, theme, and arrangement of apps (Hussain et al., 2014, Rathnayake et al., 2019). This way, they overcome usability and accessibility issues of complex and cluttered UIs and the associated cognitive overload by providing tailored assistance to the users (Gullà et al., 2018, Machado et al., 2018). The adaptive UIs have been developed for desktop computers(Hussain et al., 2018), web applications(Kolekar et al., 2019, Alves et al., 2023), smartphones(Khan and Khusro 2019, Khan and Khusro 2022a, 2022b), and tablets, yet very little attention has been given to the smart TV domain (Alam et al., 2019a, 2019b, Khan et al., 2022).

Smart TV is a lean-back and shared device that family members can enjoy individually or in groups. It has replaced traditional TV systems by offering advanced features and functionalities, including computational power, storage, Internet connectivity, and Web 2.0. It is considered one of the dominant home entertainment devices in developed and developing countries, which is evident from the exponential growth in connected TV devices (Bures et al., 2020). It is a hybrid of computer and legacy TV that provides various modern technological features, functions, and services for users (Wang and Chen 2018). These include the ability to install apps, play games, access TV channels, and watch TV shows, online games, sports, video on demand, personalized content recommendation, voice control, cloud computing, face and gesture recognition, social media, and support for N-screen and smart homes (Wang and Chen 2018). It can also be made clearer from Table 1, where a smart TV is comparable to personal computers and smartphones regarding various features. However, besides these features and functionalities, creating adaptive UIs for smart TVs has received little attention. The need is to consider and utilize these features and functionalities in developing adaptive UIs for smart TV users so that their information needs and preferences are honored, and the current usability, user experience, accessibility, and cognitive overload issues can be resolved.

Smart TV also provides a diverse set of content from numerous sources through various smart TV apps, and each app offers specific functionalities, features, and services (Jang and Mun 2019). These apps are developed for domain-specific purposes and are used by various household users. However, most apps are unsuitable for fulfilling each family member's compelling needs. For example, users' interaction and watching behavior differ due to variations in age, gender, knowledge, viewing distance, viewing angle, and mental model. In addition, the environmental factors with varying contexts, including light, color, noise, time of the day, time of the week, and weather, can also affect watching behavior.

Table 1
Comparison of smart TV features/ sensors/applications with other devices.

Features	Smart TV/TV-Box	Smartphone	Computer/ Laptop
Methods of Interaction	Remote control, keypad, voice, gesture, touch	Touch, keypad, voice	Keyboard, mouse
Central Processing Unit	✓	✓	✓
Operating System	✓	✓	✓
Storage Capacity	✓	✓	✓
Installing and using apps and browsers	✓	✓	✓
Connectivity through WiFi, Bluetooth, InfraRed, Internet	✓	✓	✓
Motion, ambient-light, and eco sensors	✓	✓	✗
Microphone, camera, and speakers	✓	✓	✓
Peripheral devices, interfaces, ports	✓	✓	✓
Sharing/multiple users support	✓	✗	✗
Web 2.0/3.0 features	✓	✓	✓
Smart home	✓	✗	✗
Personalization and interactivity	✓	✓	✓
History and logging	✓	✓	✓
Programming and development platforms	✓	✓	✓

Moreover, the experience gained in developing the smartphone and tablet domain could not be directly applied to the smart TV domain as it is not primarily a single-user device. Moreover, a user should be treated differently when interacting with a smart TV having Internet connectivity, processing capabilities, system software, support for development technologies, integration with Web 2.0 features, and third-party apps (Alam et al., 2017, Wang and Chen 2018, Jang and Mun 2019). These activities should be treated different from those occurring on personal computers, Web, smartphones, and tablets, as summarized in Table 2. They should be considered while thinking and bringing adaptive UIs to the smart TV domain.

As discussed in Section 1, Smart TV manufacturers have developed various OSs, for which several home-screen launchers have been developed. Each manufacturer tries adding new features and functions to a smart TV to attract users and gain a higher market value (Alam et al., 2019a, 2019b). However, this competition has resulted in many products and services with complex UIs that make selections hard for users and introduce issues of usability, learnability, and cognitive overload (Khan et al., 2017, Kaya et al., 2021). The current smart TV UIs are unable to utilize the various characteristics of users and environmental factors with varying contexts, such as light, color, noise, time of the day, and weather (Khan et al., 2022).

In this regard, researchers have taken some initial steps to come up with adaptive UIs using various approaches, which can be classified as model-driven (Akiki et al., 2016, Sarcar et al., 2016), user-driven (Roy et al., 2016, Association 2017), context-driven (Jain et al., 2013), ontology-based (Furtado et al., 2001, Soui et al., 2017) and machine learning-based (Dudley et al., 2019, Rathnayake et al., 2019) approaches. However, these smart TV UIs are at an infant stage and need to focus on the various aspects of user characteristics, including age, gender, skill-level, knowledge, disabilities, viewing angle, viewing distance, screen size, etc., and environmental factors with different varying contexts such as light, color, noise, date, and time. Researchers have also

Table 2
A brief account of user activities on smart TV.

User functions/operations/tasks on smart TV	Interaction method			History and logging
	Remote control	Keyboard	Voice	
On/Off	✓	✓	✓	✓
Profile, system, and connection settings	✓	✓	✓	✓
Switching an account	✓	✓	✓	✓
Searching and browsing content	✓	✓	✓	✓
Social networking activities	✓	✓	✓	✓
Gaming activities	✓	✓	✓	✓
Opening/closing, navigating, and managing apps	✓	✓	✓	✓
Channels search, switching, and management	✓	✓	✓	✓
Screen casting/mirroring	✓	✓	✓	✓
Offline/online gaming	✓	✓	✓	✓

carried out several user-based studies, including online surveys, think-aloud methods (Bruun and Stage 2015, Jang and Mun 2019), model-based automated approaches, diary approaches, and user-centered approaches (Larusdottir et al., 2019) to evaluate consumer usage habits, attitudes, and interactions to gather comprehensive data for enhanced smart TV user experience (UX) (Jang et al., 2016). However, their findings are limited to understanding user behavioral aspects with almost no utilization from the design perspective of adaptive UIs for smart TV users.

In addition, to address the accessibility and usability issues in smart TV UIs, various guidelines (Design 2015, Flaherty 2015, Choudhary 2017, Seungho et al., 2018, TV 2020, Kaya et al., 2021) have been developed. Still, they focus on general problems with almost no or limited attention to UI adaptivity. Some guidelines focus on replacing the one-size-fits-all approach with some good alternatives. For example, MyUI (Peissner et al., 2012) accessibility project proposed abstract UI descriptions and interaction design patterns for senior citizens to mainstream the accessibility of everyday ICT products. The framework automatically generates and configures multi-modal personalized UIs and performs adaptations to diverse user needs, devices, and environmental conditions during the run time (Peissner et al., 2012). However, the designer could not control the rendering process of the final result. Besides the adaptation rules created during development, the system needs to be redeployed whenever any new rules are added, which is an expensive process (Akiki et al., 2014). A similar project is GUIDE (Jung and Hahn 2011), which proposes an adaptive UI to automatically integrate and configure multi-modal interface technologies (visual gesture control, speech input, and output, etc.) according to senior citizens' skills, needs, and capabilities or special people. However, it is not guaranteed to be accessible to the intended users because of no support for real-time adaptation (Costa et al., 2012). Also, it is only suitable for a single user and cannot be extended to group users (Alam et al., 2019a, 2019b); hence, not practical in the smart TV environment. SUPPLE[8] is another accessibility system that automatically creates user interfaces according to user capabilities, preferences, tasks, and device attributes (Gajos and Weld 2004, Gajos et al., 2010). However, it suffers from the same issues experienced with MyUI and GUIDE.

Kim et al. (Kim et al., 2016) proposed an adaptive UI for personalized channel navigation in a smart TV. It allows a single user to manage her channel list. It is unable to support user groups. It is static, and time-consuming as prior to its use, the users must specify their preferences. In addition, no run-time adaptations are supported. Another similar approach proposed by the researchers (Dudekula et al., 2023) introduces a CNN-based personalized program recommendation system for smart TV users, both individuals and groups, which takes into account their preferences and interests. The CNN algorithm utilized in this research achieves an impressive training performance of around 95% for the recommender system. However, its only recommend the contents of the channels/apps to users and their UI is static and has no support for adaptation. Seungho et al. (Seungho et al., 2018) examined the content, structure, and interface characteristics of UIs of different smart TVs based on five parameters to identify usability issues. Based on the problems identified, they designed a new four-way menu-structured UI, where users can easily recognize and learn the menu structure. However, their UI is generalized and has no support for adaptations. Similarly, (Guo et al., 2023) proposed an effective smart TV navigation UI considering the emotional needs of users. They employed the laddering interview technique to identify the emotional needs associated with smart TV navigation interfaces, subsequently characterized by the concept of "Kansei distance." They employed a two-stage strategy to define and optimize the design elements for rapid adaptability and responsiveness. They reported that the proposed approach addresses a wide range of user requirements, and design innovations, and facilitate mass customization and differentiated design. However, it is generalized, static and based on user opinion. The lack of adaptability makes this study least significant in our case.

Ouyang and Zhou (Ouyang and Zhou 2018) developed two menu layout variations, mega and tiled menus, to enhance the navigation experience of older adults when using Smart TV. An experimental study was conducted to examine these menu layouts' impact on older adults' user experiences. The validity of both menu layouts was assessed through eye-tracking techniques. To gain insight into the cognitive models of users, a card sorting method combined with a path diagram was employed. They reported that the mega menu required lesser effort for key pressing. The tiled menu layout led to higher satisfaction among older adults. However, these menu layouts are generalized for all senior citizens based on user interviews and opinions and lack adaptability. Song and Cho (Song and Cho 2013) proposed the context-adaptive UI to manage devices in ubiquitous home environments using a Bayesian network capable of predicting the custom devices in each situation.

Several projects and initiatives have also been taken to offer adaptive UIs for smart TV and other digital devices. The Cloud4all project (Friberg 2015) presented a cloud-based platform to store and manage user preferences and needs and allow apps and devices to access them for their respective functionalities. This way it personalizes the apps but not the UI of the smart TV. Also, privacy is a major concern as it stores user preferences in the cloud. Malai (Blouin and Beaudoux 2010) is a model-driven approach that generates UI based on various parameters, including actions, interactions, instruments, and presentations. It regards UIs as first-class objects that help to decompose an interactive system to increase

[8] https://iis.seas.harvard.edu/projects/supple/.

the object's reusability. However, the runtime adaptation is not managed with changes in context. The European Active and Assisted Living (AAL)-project presented AALuis (Mayer et al., 2011, Mayer et al., 2012), an adaptive UI application, to build an accessible adaptive UI that enables dynamically adapted, customized interaction between the elderly user and any form of service, with various types of input and output devices and modalities. It considers the physical and cognitive capacities of users, their interests, and context models and uses fuzzy logic to choose a suitable modality of the UI.

Reviewing the current literature on smart TV UIs reveals that the existing UIs are generalized, primarily static, and designed with no particular regard for changing users' requirements and preferences, with privacy as a major concern. Like any other interactive system, where the importance of developing adaptive UI cannot be challenged (Gullà et al., 2015, Gullà et al., 2018, Gullà et al., 2019), a smart TV should be equipped with such a UI so that the cluttered, complex, static, and cognitively overloaded interface can be replaced with a more user-friendly and privacy-preserving entertainment environment. Such an adaptive UI for the smart TV domain should be user-friendly and meet the requirements of diverse users by exploiting their age, gender, knowledge, mental model, and attitudes and learning from their interaction patterns, browsing, and usage behaviors. It should remove the usability and accessibility barriers in achieving the users' goals effectively and efficiently regarding the specified context. This research aims to design and develop an adaptive UI for reducing the cognitive overload of the users and improving their smart TV usability and learning experience.

3. Materials and methods

This section presents the proposed personalized adaptive smart TV UIs framework, its development, and evaluation methodology. The research framework, we adopted to carry out this study has several steps. In this first step, we performed a detailed and comprehensive survey of the literature and reported them in Section 2. It helped us understand the domain and identify the challenges and issues in the smart TV UIs (Khan et al., 2022). We identified the factors affecting the usability of smart TV UIs from the user perspective. In the next step, we need to design and develop a personalized adaptive UI to meet their needs according to their age, mental model, gender, skills, experience, and preferences. In the final step, we need to test and evaluate the proposed solution. These details are outlined in the coming two sections in detail.

3.1. The proposed adaptive UIs framework

This section presents the proposed personalized adaptive UIs framework as a pluggable context-aware layered architecture. The architectural components have been designed to be abstract, implying that new features can be added and removed easily. New sensors and features can be easily integrated. Fig. 1 presents the architecture of the proposed adaptive UIs for smart TV, having four layers: data curation layer, data processing layer, business logic layer, and UI layer. Fig. 2 presents a schematic diagram of the proposed framework to visualize its information flow among components. The following subsections explain the layered architecture and schematic diagram.

3.1.1. Data curation layer

This layer aims to capture the interactions, contextual, and operational data of various household members, generate their user profiles, and obtain data from multiple data sources to be further processed for upper layers. This layer comprises three submodules: user profile management, user smartLog, and sensors data acquisition and pre-processing. The *user profile management module* generates and manages household members' profiles. The second *user smartLog module* logs data about each household member's profile, including interactions history, operation history, apps/channel history, watching behavior, and preferences. The *sensors data acquisition and the pre-processing module* is responsible for acquiring the data from various smart TV sensors such as ambient light, speaker, motion, infrared, etc., along with online data sources, and pre-processes it for the next layer. The following paragraphs add further details to these modules.

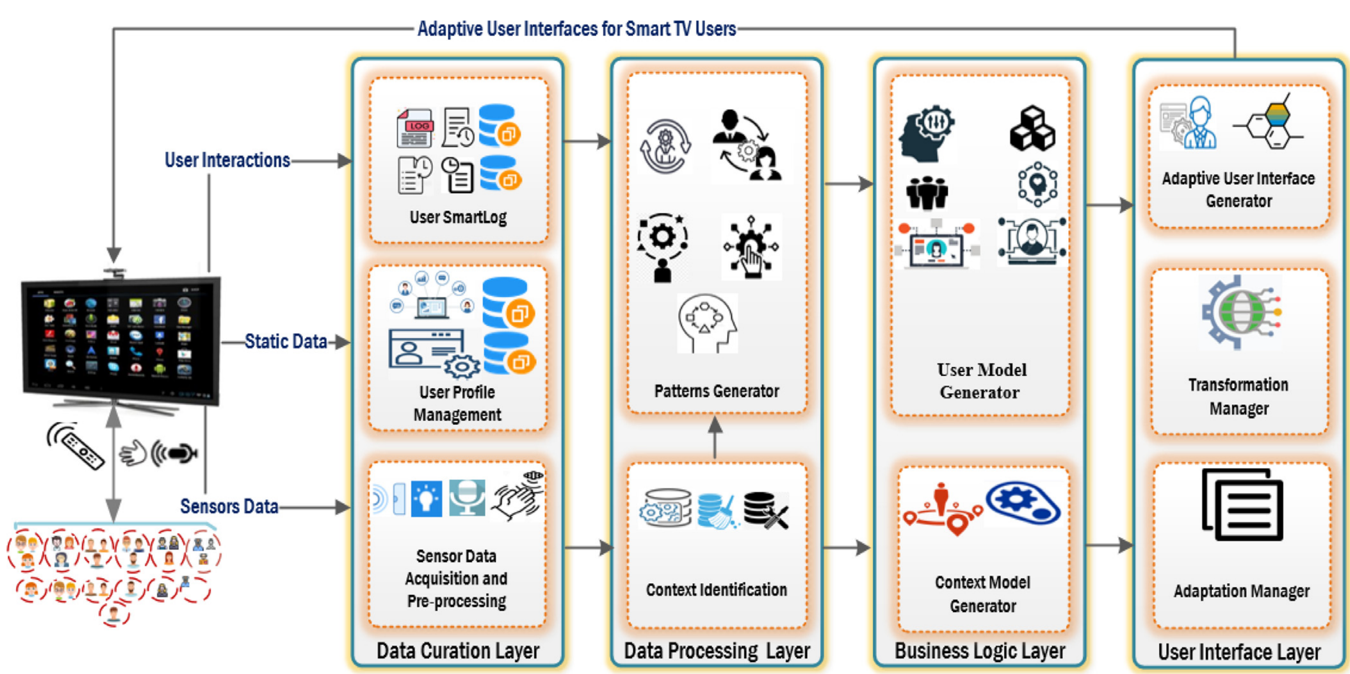


Fig. 1. The framework of the proposed adaptive UIs for smart TV viewers.

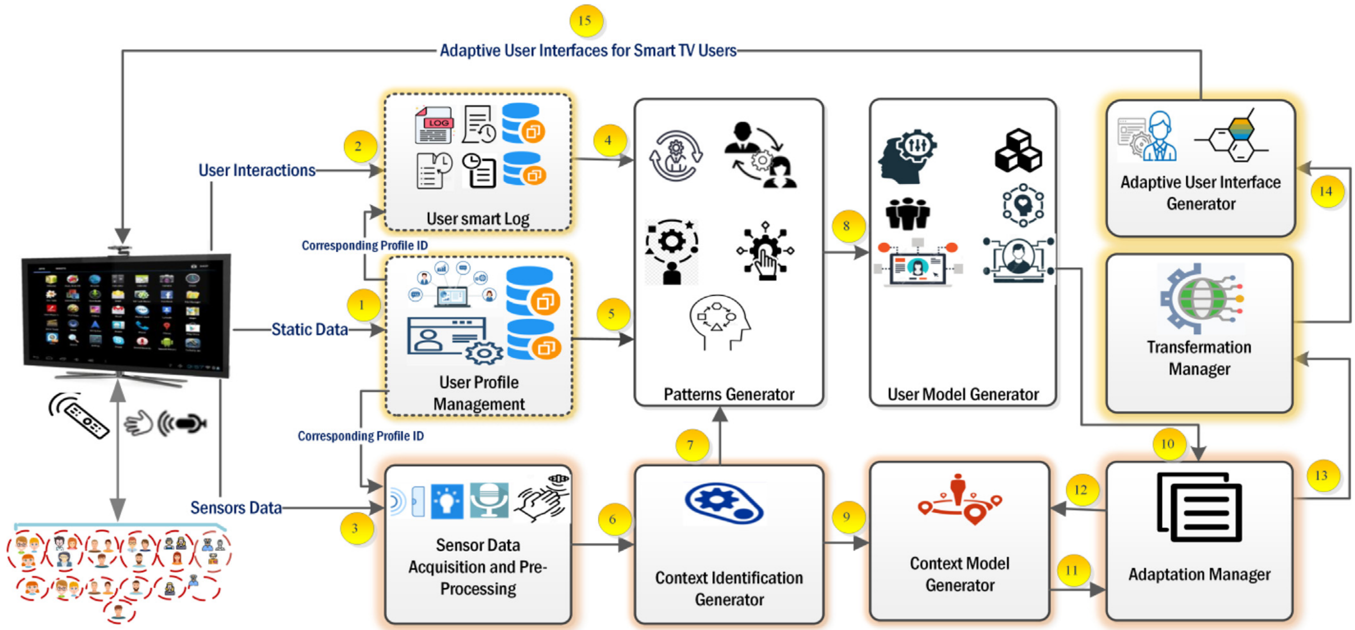


Fig. 2. Schematic diagram of the proposed adaptive UIs for smart TV viewers.

The user profile management module creates real-time profiles of individuals and groups for household members based on age, gender, and number via the smart TV's built-in capabilities, including integrated/embedded camera, processing, and storage. It creates user profiles by detecting and identifying individual and group members of the household (Haq et al., 2021) using OpenCV Haar feature-based cascade classifier [164], DeepFace learning algorithm, and Open-CV CNN [165]. The anonymous and consolidated profiles of individual and group household members are created, and their viewing, searching, and interactions are recorded in the user SmartLog module for further use in identifying patterns and user models. Eq. (1) is used to create the profiles of family members (individual, groups), where **P** represents the profiles of household members (individual, groups), **r** represents the profile number for household members (individual, groups), and **n** indicates the total number of household members (Alam and Khusro 2020). The process of household members' profile creation is depicted an Algorithm 1.

$$P_r = 2^n - 1 \quad (1)$$

Table 3 shows the detail of household members' profile creation. The average number of family members per household is required for profile generation, which varies from region to region. However, as per the work in (Kim et al., 2016), the average number of family members ranges from two to six. As per Eq. (1) and by following the prior work (Alam and Khusro 2020), for any two users, M_1 and M_2, the individual profiles are $P_1 = M_1$ and $P_2 = M_2$, whereas the possible grouped profiles are one, i.e., $2^2 - 1 = 1$, which can be expressed as $P_3 = M_1M_2$, as shown in Fig. 3. However, we extend this criterion, as explained in Table 3, fifth & sixth columns, by introducing the intersection concept. Here, the grouped profile of the two individuals can be obtained by $P_3 = M_1 \cap M_2 + M_1M_2$. Similarly, for any three users M_1, M_2, and M_3, Eq. (1) gives $2^3 - 1 = 7$ profiles, in which three are individuals, i.e., $P_1 = M_1$ and $P_2 = M_2$, and $P_3 = M_3$, and the remaining four are grouped profiles, i.e., $P_3 = M_1 \cap M_2 + M_1M_2$, $P_4 = M_1 \cap M_3 + M_1M_3$, $P_4 = M_2 \cap M_3 + M_2M_3$, and $P_4 = M_1 \cap M_2 \cap M_3 + M_1M_2M_3$, as shown in Fig. 3.

Algorithm 1 (*Creating user profiles for household members*).

Input: Detected household members using the camera
Output: User profiles of household members stored in user profile management
1. Detect the household members' faces N (house_memeber_size)
   a. IF N = 1
      Identify the **age** of the viewer.
      Identify the **gender** of the viewer.
      Go to Step 2.
   b. ELSE
      Identify the number of viewers NV.
      Identify the **age** of the viewers.
      Identify the **gender** of the viewers.
      Go to step 2.
2. Calculate the number of possible profiles by using Eq. (1)
   possible_profile_size = (2^**household_member_size**) – 1
3. Initialize two variables **counter** and j as 0
4. Start an outer loop to repeat the **counter** from 0 to **possible_profile_size**
   a. Start an inner loop to repeat **j** from 0 to **household_member_size**
      i. if **j**th bit in the **counter** is set
         Insert the **j**th household member from profiles into the **profile** repository
   b. End the inner loop
5. End the outer loop

The user SmartLog module in the Data Curation Layer aims to log and record household members' (individuals, groups) various activities and operations, such as watching, searching, and interactions performed on smart TV. The family members (individual or group) interact with a smart TV through various input methods, such as remote control, keyboard, mouse, smartphone, and voice commands, to accomplish different operations and activities. The

Table 3
Real-time profile creation of household members using Eq. (1).

Family	Viewers	Profiles of individual and grouped members	Possible user profiles (individual, group)	The Proposed Enhanced Group Profiles Creation	The Proposed Enhanced Group Profiles
A	M_1, M_2	$P_r = 2^2\text{-}1 = 3$ Individual: M_1, M_2 Grouped: M_1M_2	P_r= {$P_1 = M_1$, $P_2 = M_2$, $P_3 = M_1M_2$} Individual: P_1, P_2 Grouped: P_3	Group profile = The intersection of individual profiles + group profile For example, as per Eq. (1), the group profile is obtained as $P_3 = M_1M_2$, a profile generated and updated when both individuals watch smart TV together. However, both individuals may have some common interests. Therefore, their profiles should contain common interaction and watching data from their individual profiles + the data that represent the interactions when they watched smart TV together. In other words, $M_1 \cap M_2 + M_1M_2$. A similar logic is repeated throughout this column and simplified in the next column.	$P_3 = P_1 \cap P_2 + P_3$
B	M_1, M_2, M_3	$P_r = 2^3\text{-}1 = 7$ Individual: M_1, M_2, M_3 Grouped: M_1M_2, M_1M_3, M_2M_3, $M_1M_2M_3$	P_r= {$P_1 = M_1$, $P_2 = M_2$, $P_3 = M_3$, $P_4 = M_1M_2$, $P_5 = M_1M_3$, $P_6 = M_2M_3$, $P_7 = M_1M_2M_3$} Individual: P_1, P_2, P_3 Grouped: P_4, P_5, P_6, P_7		$P_4 = P_1 \cap P_2 + P_4$ $P_5 = P_1 \cap P_3 + P_5$ $P_6 = P_2 \cap P_3 + P_6$ $P_7 = P_1 \cap P_2 \cap P_3 + P_7$
C	M_1, M_2, M_3, M_4	$P_r = 2^4\text{-}1 = 15$ Individual: M_1, M_2, M_3, M_4 Grouped: M_1M_2, M_1M_3, M_1M_4, …, $M_1M_2M_3M_4$	P_r= {$P_1 = M_1$, $P_2 = M_2$, $P_3 = M_3$, $P_4 = M_4$, $P_5 = M_1M_2$, $P_6 = M_1M_3$, $P_7 = M_1M_4$, …, $P_{15} = M_1M_2M_3M_4$} Individual: P_1, P_2, P_3, P_4 Grouped: P_5, P_6, … P_{15}		$P_5 = P_1 \cap P_2 + P_5$ $P_6 = P_1 \cap P_3 + P_6$ $P_7 = P_1 \cap P_4 + P_7$ … $P_{15} = P_1 \cap P_2 \cap P_3 \cap P_4 + P_{15}$
D	M_1, M_2, M_3, M_4, M_5	$P_r = 2^5\text{-}1 = 31$ Individual: M_1, M_2, M_3, M_4, M_5 Grouped (26): M_1M_2, M_1M_3, M_1M_4,…, $M_1M_2M_3M_4M_5$	P_r= {$P_1 = M_1$, $P_2 = M_2$, $P_3 = M_3$, $P_4 = M_4$, $P_5 = M_5$, … $P_{31} = M_1M_2M_3M_4M_5$} Individual: P_1, P_2, P_3, P_4, P_5 Grouped: P_6, P_7, P_8, … P_{31}		$P_6 = P_1 \cap P_2 + P_6$ $P_7 = P_1 \cap P_3 + P_7$ $P_8 = P_1 \cap P_4 + P_8$ … $P_{31} = P_1 \cap P_2 \cap P_3 \cap P_4 \cap P_5 + P_{31}$

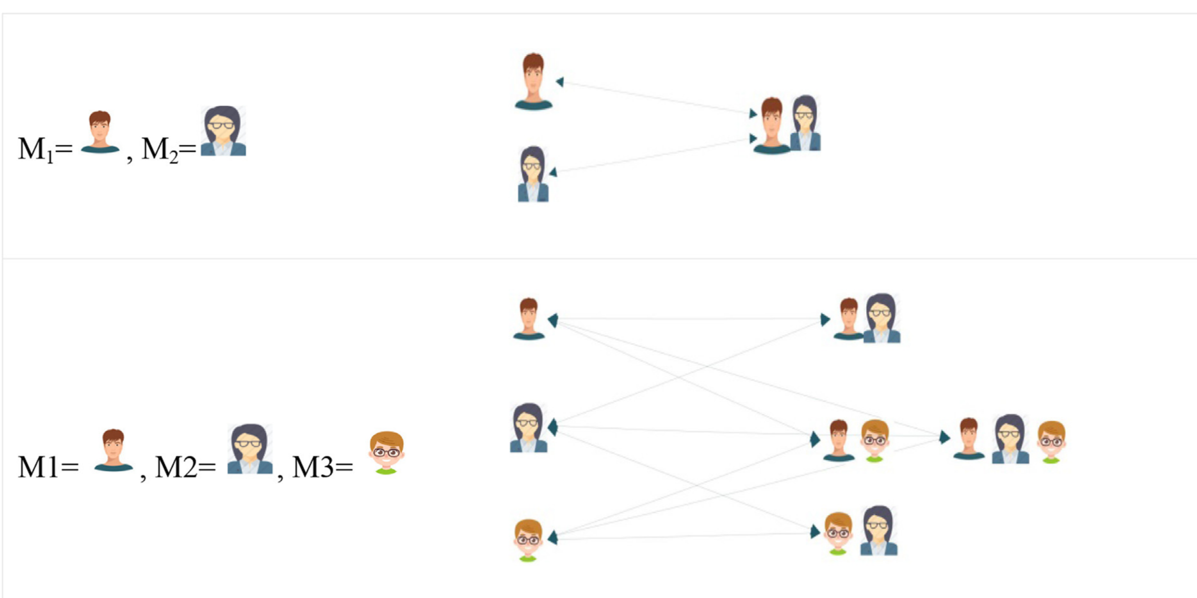


Fig. 3. Possible numbers of users profiles for two and three household members.

user smartLog module aims to log various data of family members (individual or group) to their respective profile (s), including interaction histories, apps/channel histories (using smart Remote, simple remote, using voice through google assistant, gesture etc.), watching history, facial features, age, gender, number of occupants, viewer angle, and viewer distance (using camera or motion sensor or, Infra-Red sensor). The process of household members smart TV usage data is depicted an Algorithm 2.

Algorithm 2 (*Smart TV usage data collection of household members*).

Input: User profiles $\mathbf{P_r}$ of detected/active household members stored in user profile management
Output: Usage history of household members stored in user smartLog
1. IF P_r = True
   Identify the **distance** of household member(s) from smart TV
   Identify the **viewing angle** of household member(s) towards a smart TV
   Identify the **interactive device** household members use to interact with a smart TV.
   Go to Step 2.
2. IF action behavior = True
   Go to Step 3 and repeat.
3. Loop and store usage history of household members $\mathbf{P_r}$ in SmartLog (app id, name, description, category, searching text, browsing text, watching activity, start-time, and end-time).
4. End Loop

The sensors data acquisition & pre-processing module performs two tasks. First, it collects various contextual and environmental data such as time-of-the-day, day-of-the-week, day-of-the-month, year-of-the-events, weather, noise, location, and light intensity in the room. At the same time, the users watch or interact with smart TV either individually or in groups using embedded sensors in the online/offline data sources. Second, it preprocesses the collected sensory and related data before storing it. Pre-processing is essential as sensors might generate inaccurate data due to various factors such as noise, power failure, programming mistakes, and device failure. For this sort of filtering, low-pass filters transform data into a format that enables events to be easily identified. This data collection and preprocessing aims to add contextual information to the user profiles of household members according to their watching behavior, interaction, and usage behavior. This process of sensor data acquisition and pre-processing is further explained in Algorithm 3.

Algorithm 3 (*Smart TV contextual data collection of household members*).

Input: User profiles $\mathbf{P_r}$ of detected/active household members stored in user profile management
Output: Contextual history of household members stored in sensors data acquisition & preprocessing module
1. IF P_r = True
   Identify the ambient light level **AML** of the room
   Identify the noise level **RNL** of the room
   Identify the weather **W** details
   Go to Step 2
2. IF AML = true & RNL = true
   Go to Step 3 and repeat.
3. Loop and store contextual data (time, date, AML, RNL, and W) of the user profile(s) of a household member
4. End the Loop

3.1.2. Data processing layer

The data processing layer preprocesses the data received from the data curation layer. The sensory and smartLog data is converted into a format with meaningful patterns for the next layers. The data from the data curation layer creates and identifies various meaningful patterns and contexts for the household members corresponding to their profiles. It has two sub-modules, namely, *patterns generator* and *context identification*. The patterns generator module identifies and extracts significant interaction patterns of the household members based on their consolidated profile histories already stored in the user SmartLog module. It also uses the data of the context identification module, which identifies and extracts meaningful contextual details associated with the user profiles of the household members. The following paragraphs further explain these modules.

The patterns generator module identifies meaningful patterns for the household members. These include personalized (individual), group-wise (groups), learnability (individual, groups), user experience (individual, group), usability (individual, groups), and interaction (individual, groups) patterns corresponding to their consolidated profiles. It also uses contextual data from the context identification module to enrich the patterns of household members (individuals, groups). These patterns create usage rules corresponding to their consolidated profiles, which are subjected to novelty measures. The novelty measures extract only interesting patterns for profiles (individual, groups). These patterns are used to update user models for the household members (individuals, groups). The patterns are identified and recognized using machine learning and pattern recognition approaches. Although, any machine learning algorithms can be employed, we used Hybrid Filtering approach and Support Vector Machine (SVM). Algorithm 4 further explains this process.

Algorithm 4 (*Identifying and generating interaction patterns of household members*).

Input: User profiles $\mathbf{P_r}$ of detected/active household members stored in SmartLog
Output: Identified patterns of household members
1. User profiles $\mathbf{P_r}$ of detected/active household members stored in user profile management
2. Retrieve data from SmartLog & context identification modules
3. Find patterns for household members' profiles (individuals, groups) using Hybrid Filtering approach and SVM.

The context identification module identifies meaningful contextual and environmental data. This collected data contains time-of-the-day, day-of-the-week, day-of-the-month, year-of-the-events, weather, noise, location, and light intensity in the room, recorded while users were watching the smart TV. It finds and extracts meaningful contextual patterns for the household members (individuals, groups) corresponding to their user profiles. This process is further explained in Algorithm 5.

Algorithm 5 (*Identifying the context of the household members*).

Input: User profiles $\mathbf{P_r}$ of detected/active household members stored in SmartLog
Output: The identified context of household members
1. User profiles $\mathbf{P_r}$ of detected/active household members stored in user profile management
2. Retrieve data from the data acquisition & pre-pressing module
3. Find context information for household members' profiles (individuals, groups).

3.1.3. Business logic layer

The business logic layer creates various models for household members (individuals, groups). These include the personalized, group-wise, learnability, and contextual models, created using patterns generated in the data processing layer. Fig. 4 depicts the main classes of each model. In addition, context data for personalized adaptive UIs consists of household members, smart TV, and contextual data, as shown in Fig. 5. These models and associated rules could be considered the baseline requirements for the proposed personalized adaptive UIs for smart TV viewers according to their preferences, needs, ability, skills, age, and gender. This layer has two modules. The *user model generation* creates various information models for household members. The personalized and group-wise models store information about the household members (individual, groups), such as age, gender, skills, preferences, and needs, learnability level, interactions. The learnability model stores information about the learning curve score of household members (individual, groups) operations and behaviors on smart TV UI. The process of user model generation is further explained in Algorithm 6.

Algorithm 6 (*Generating user models of household members*).

Input: User profiles $\boldsymbol{P_r}$ of detected/active household members
Output: User models of household members from their user profiles $\boldsymbol{P_r}$
1. Retrieve data from the patterns generation module.
2. Develop user model for household members' profiles (individuals, groups).

The *context model generator* produces a context-aware model for household members (individuals, groups) corresponding to their consolidated profiles. The context-aware model stores various contextual information (i.e., time-of-the-day, day-of-the-week, day-of-the-month, year-of-the-events, noise level, light intensity in the room, weather, and location) collected through smart TV built-in sensors and from other data sources. The process of generating context models is explained in Algorithm 7.

Algorithm 7 (*Household members Context Model*).

Input: User profiles $\boldsymbol{P_r}$ of detected/active household members
Output: Context models of household members from their profiles User profiles $\boldsymbol{P_r}$
Retrieve data from the context identification module.
Develop a context model for household members' profiles (individuals, groups).

3.1.4. User interface layer

This layer generates the personalized adaptive UIs for household members (individuals, groups) according to their profiles by utilizing the various modules, including *adaptation manager*, *transformation manager* and *adaptive UI generator*. It attempts to fulfil the requirements of each individual and group according to their needs, preferences, age, mental model, skills, and environmental variability to improve usability, UX, accessibility, and learnability. It produces the adaptive UIs in real-time by adjusting layouts, elements, components, font size, color, contrast, theme, apps, menu structure, content, and information presentation according to the viewers, needs and preferences. Its three layers are discussed in the following paragraphs.

The adaptation manager module receives the required user models from the user models generator and combines them into a consolidated user model with varying contexts. It selects various concepts from the input user models and correlates them with each other using different characteristics and properties of the user into a compact model. For generating adaptive UIs, we employ a rule-based approach, as it has been widely used in the relevant literature (Bongartz et al., 2012, Hussain et al., 2018). These rules can be specified as events, conditions and actions (Bongartz et al., 2012, Ali et al., 2017). The event part of the rule comprises associated events that specify when the rule should be triggered. The condition is a Boolean condition that must be satisfied for the action part to be executed. The action portion may lead to one or more basic actions with instructions on modifying the description of the proposed adaptive UI to complete the adaptation process. These rules can be activated by various perspectives (e.g., preferences, needs, age, gender, skills, and contextual variability) of household members. Table 4 depicts the proposed adaptation rules for the real-time generation of personalized adaptive user interfaces for smart TV viewers (individuals, groups). The n number of rules means that the proposed pluggable architecture supports any arbitrary number of rules which may be added from time to time as the research progresses. Table 5 describes their threshold values.

The transformation manager module takes the user and context models as input from user model generator and context model generator, respectively, using adaptation rules and transforms them into an appropriate compact model for adaptive UI generator module. It ensures the transformation of a personalized adaptive UI for smart TV viewers (individuals, groups) while watching the smart TV. The perspectives, such as preferences, needs, age, gender, skills and contextual variability of the household members (individuals, groups), change with time. Therefore, the adaptation manager automatically fires the rules and generates a personalized adaptive UI in real-time. The automatic UI transformation identifies and transforms typical UI components/features (i.e., UI layouts, elements, components, font size, color, contrast, theme, apps, menu structure, content, and information presentation based on the viewer's needs, requirements, skills, experiences, age, and context into special UIs using a set of adaptation rules. These rules comprise a knowledge base system for household members (individuals and groups) and the transformation generator module, which handles household members' issues (i.e., usability, learnability, and cognitive overload) while watching smart TV.

The adaptive UI generator module creates personalized adaptive UIs for smart TV viewers (individuals, groups) in real-time using defined rules and models from the transformation manager and adaptation manager. It dynamically changes the existing smart TV UI into a simplified adaptive UI suitable for household members (individuals, groups) according to their context, needs, abilities, preferences, age, and gender.

3.2. Development and availability of the source Code

The proposed personalized adaptive UIs framework for smart TV viewers (individual, groups) is implemented on the Android platform. The work presented in this study is based on the PhD work of the first author, who has been responsible for designing and implementing the graphical user interfaces, the underlying functionality and features, integrating with relevant technologies, and conducting extensive testing and evaluation. Various technical complexities and design considerations were addressed. These include ensuring compatibility with different smart TV platforms, optimizing performance for various device specifications, and incorporating privacy and security measures. The screenshots of the proposed framework are depicted in Fig. 6, and Fig. 7. The pro-

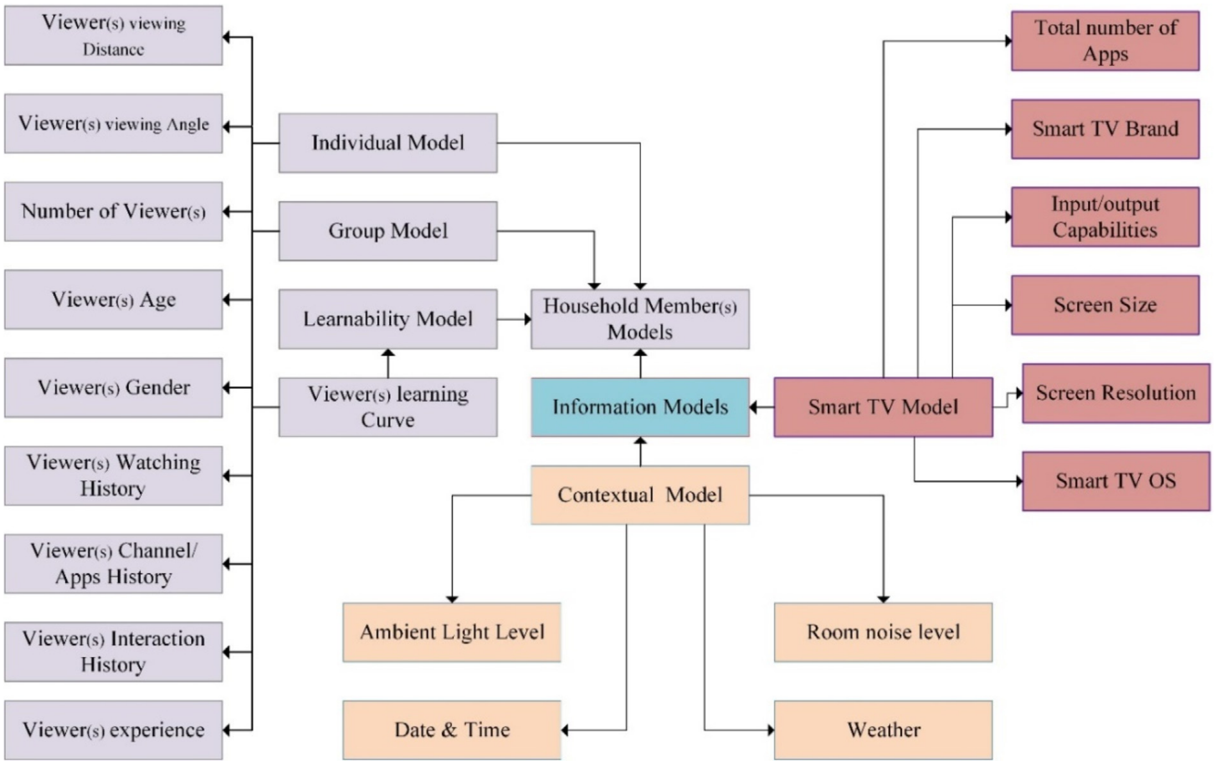


Fig. 4. Information models for smart TV household members, smart TV and environment context.

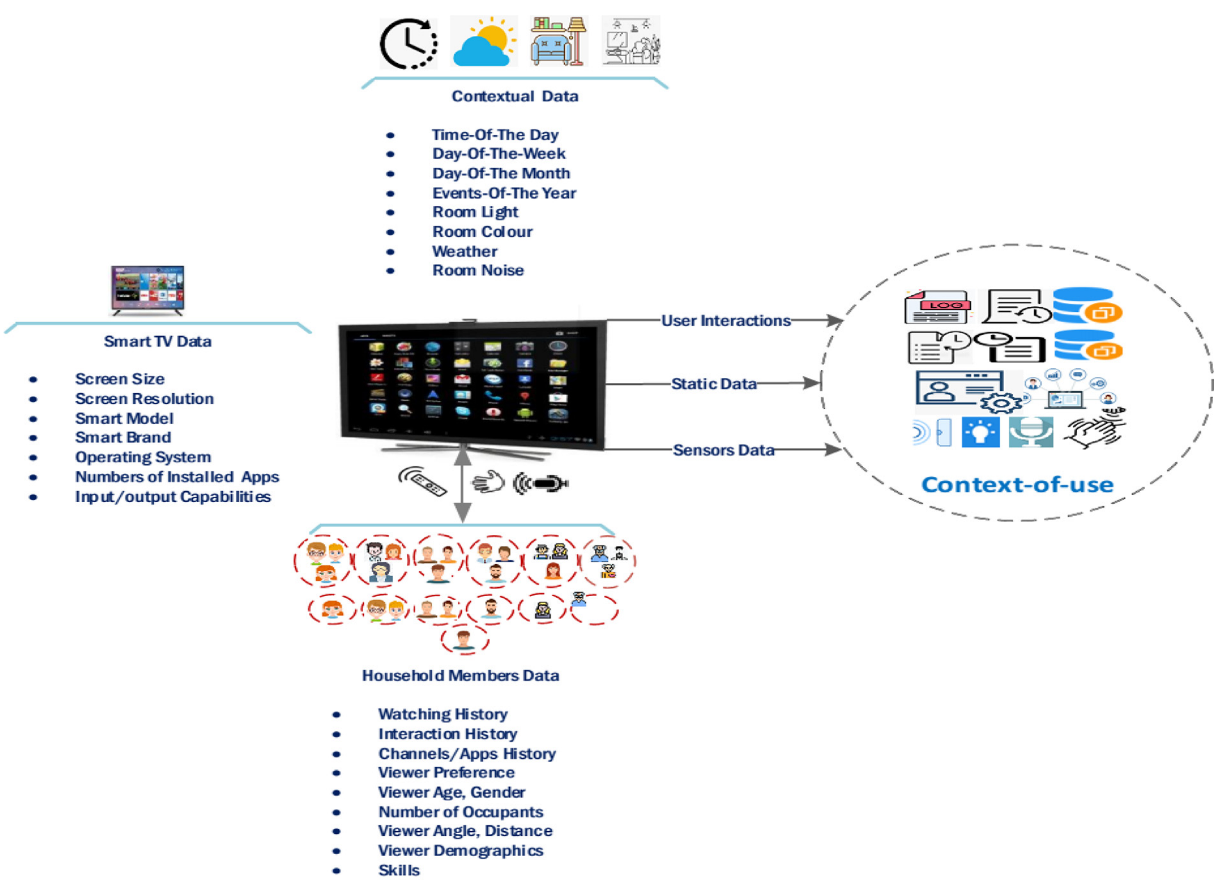


Fig. 5. Contextual data for adaptive UIs.

Table 4
List of proposed adaptation rules for PAUI-smart TV Users.

Rule ID	Rule Name	Description	Event	Condition	Action (s)
R_1	Profile creation	Creating individual and group user profiles if household members are detected	Household members detected	No previous profiles exist	The PAUIs-smart TV app creates their profiles according to the said criteria
R_2	Profile activation	Activate user profiles after creation	An individual or group of viewers detected and their stored profiles matched	Stored profiles matched against the detected individual or group	The PAUIs-smart TV app will activate the individual or group profiles
R_3	Home screen personalization	Personalize the home screen as per the preferences stored in the user profile	A stored user profile is activated	An active user with stored user profile has started watching or interacting with smart TV	The PAUIs-smart TV will personalize the home screen layout according to the user profiles
R_4	Apps/ channel personalization	Personalize the list of apps and channels as per the preferences store in the user profile	A stored user profile is activated	An active user with stored user profile has started watching or interacting with smart TV	The PAUIs-smart TV will personalize the list of apps and channels according to the user profiles
R_5	Volume adjustment	Adjusting volume with respect to the noise level and environment of the room	Changes in noise level and environment in the room are detected	Noise level and other changes in room environment exceeds a specified threshold	The PAUIs-smart TV app will automatically adjust the volume of smart TV according to the room environment
…	…	…	…	…	…
R_n	Screen brightness adjustment	Adjusting screen brightness with respect to changes in light intensity of the room	Changes in the light intensity of the room detected	The light intensity of the room exceeds or lowers down a certain threshold	The PAUIs-smart TV app will automatically adjust screen brightness with respect to changes in light intensity of the room

Table 5
Contextual threshold values for PAUI-smart TV Users with smart TV size of 55 in.

Terms	Context	Threshold Value
Room noise	Room environment is noisy	If noise in the room more than 60 dB
Viewing angle	Minimum and Maximum viewing in degree	15 to 45°
Viewing distance	Minimum and Maximum viewing distance in feet	8–10 feet
Room light intensity	The minimum and maximum light intensity level in the room	30–45 dB

posed framework aims to be adaptive, personalized, flexible, and context-aware in different watching scenarios. The framework components have been designed to be abstract, implying that new features and functions can be easily added and removed. In other words, the architecture of the proposed system has been designed so that users can integrate new sensors or configure existing ones. In addition, the design and development have fully considered both technical constraints (updating a user profile, browsing and searching, and user attributes) and non-technical restraints (privacy, security, storage, and processing).

The developed solution makes an assessment of household members (individuals, groups) based on their needs, preferences, and contextual details and produces adaptive UIs in run-time by adjusting layouts, elements, font size, color, contrast, volume, theme, app arrangements, menu structure, contents, and presentation. The home screen presents the most frequently used apps. It organizes and categorizes them according to the need and preferences of household members, where adaptations are based on user profile usage histories and contexts. It deals with the problems of learnability, usability, and user experiences that result from the cluttered, static, and complex smart TV UIs by differentiating among and adjusting for the household members, including kids, adults, senior citizens, male and female, etc. For example, based on the viewing angle, room light, distance from the smart TV, age and gender, the proposed solution automatically adjusts its UI, such as adjusting font size, contrast, screen light, volume, etc. For instance, if the household members (individual, group) are sitting in front of a smart TV with a distance of 8 to 10 feet, angle of 0 to 30, and ambient light level of 30 to 45 dB, then the font size of icons, menu and contents will be normal font (22) and adjusted with variations in these aspects.

3.3. Experimental settings and evaluation

The proposed solution is tested using HCI guidelines, such as using basic research-oriented techniques and user-based evaluation to demonstrate its effectiveness, accuracy, and usability. This research also investigates the systematic understanding of the user experience in using smart TVs and provides personalized adaptive UIs to household members according to their perspectives and measures the HCI set of usability parameters such as user interactions, satisfaction, attitude, and cognitive overloads, etc. Various relevant literature precedence and antecedents are available (Gajos 2008, Im et al., 2014, Jang and Mun 2019, Khan and Khusro 2020, Khan and Khusro 2022a, 2022b) for assessing the HCI set of usability parameters of personalized adaptive user interfaces using hypotheses, which can be followed and adapted in evaluating the PAUI-smartTV. The following hypotheses are considered to evaluate the proposed solution, where PAUI-smartTV means our developed smart TV application, namely, personalized adaptive UIs for smart TV. By providing a clear formulation and development for each hypothesis, we establish a solid foundation for testing and interpreting the results of the study. The formulation specifies the null hypothesis, while the development elaborates on the meaning and implications of the hypothesis, including the alternate hypothesis, where applicable.

Hypothesis H1. Formulation:

$\mathbf{H_0}$: The PAUI-smartTV does not improve smart TV viewers' satisfaction.

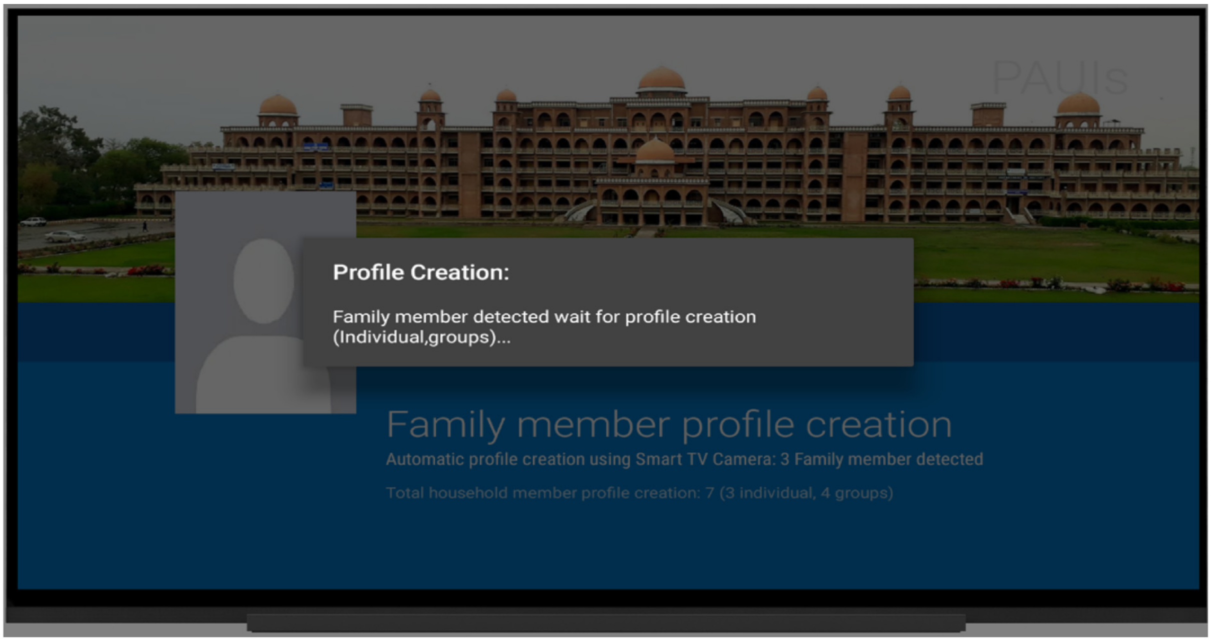
Development:

The null hypothesis ($\mathbf{H_0}$) proposes that there is no significant improvement in smart TV viewers' satisfaction as a result of using the PAUI-smartTV. This hypothesis assumes that the PAUI-smartTV has no effect on enhancing the satisfaction levels of users compared to other existing methods or interfaces.

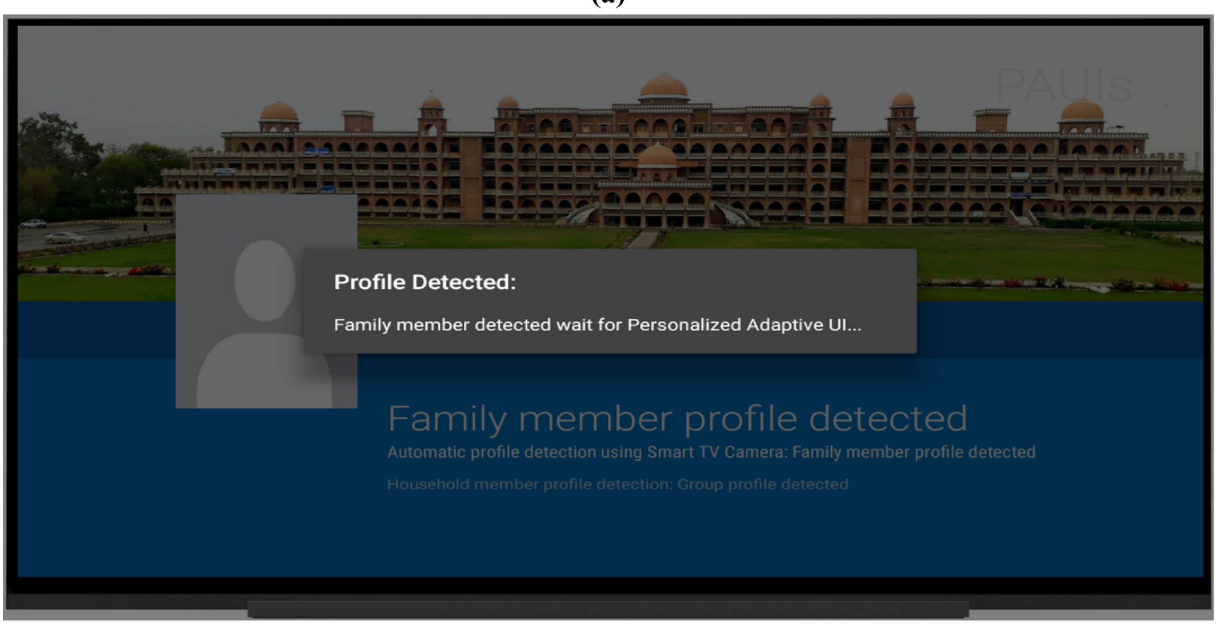
Alternate hypothesis:

$\mathbf{H_1}$: The PAUI-smartTV will improve smart TV viewers satisfaction.

In contrast, the alternate hypothesis (H_1) suggests that the PAUI-smartTV will indeed improve smart TV viewers' satisfaction. This hypothesis assumes that using the PAUI-smartTV will result in higher levels of satisfaction among users compared to alternative methods or interfaces.



(a)



(b)

Fig. 6. Profile (a) creation, and (b) detection of PAUIs-smart TV users.

Hypothesis H2. Formulation:

H_0: Most of the Smart TV viewers do not have a positive attitude towards the usage of PAUI-smartTV.

Development:

The null hypothesis (H_0) states that the majority of Smart TV viewers do not hold a positive attitude towards PAUI-smartTV. This hypothesis assumes that the general perception among Smart TV viewers is neutral or negative regarding the usability and benefits of the PAUI-smartTV interface.

Alternate hypothesis:

H_1: Most of the Smart TV viewers have positive attitude towards the usage of PAUI-smartTV.

In contrast, the alternative hypothesis (H_1) proposes that most of the Smart TV viewers have a positive attitude towards the usage of PAUI-smartTV. This hypothesis assumes that the majority of Smart TV viewers perceive the PAUI-smartTV interface favorably and consider it beneficial for their viewing experience.

Hypothesis H3. Formulation:

H_0: The PAUI-smartTV has not minimized user interactions.

Development:

The null hypothesis (H_0) suggests that the PAUI-smartTV has not successfully reduced the level of user interactions required during Smart TV usage. This hypothesis assumes that the PAUI-smartTV interface does not effectively minimize the number of

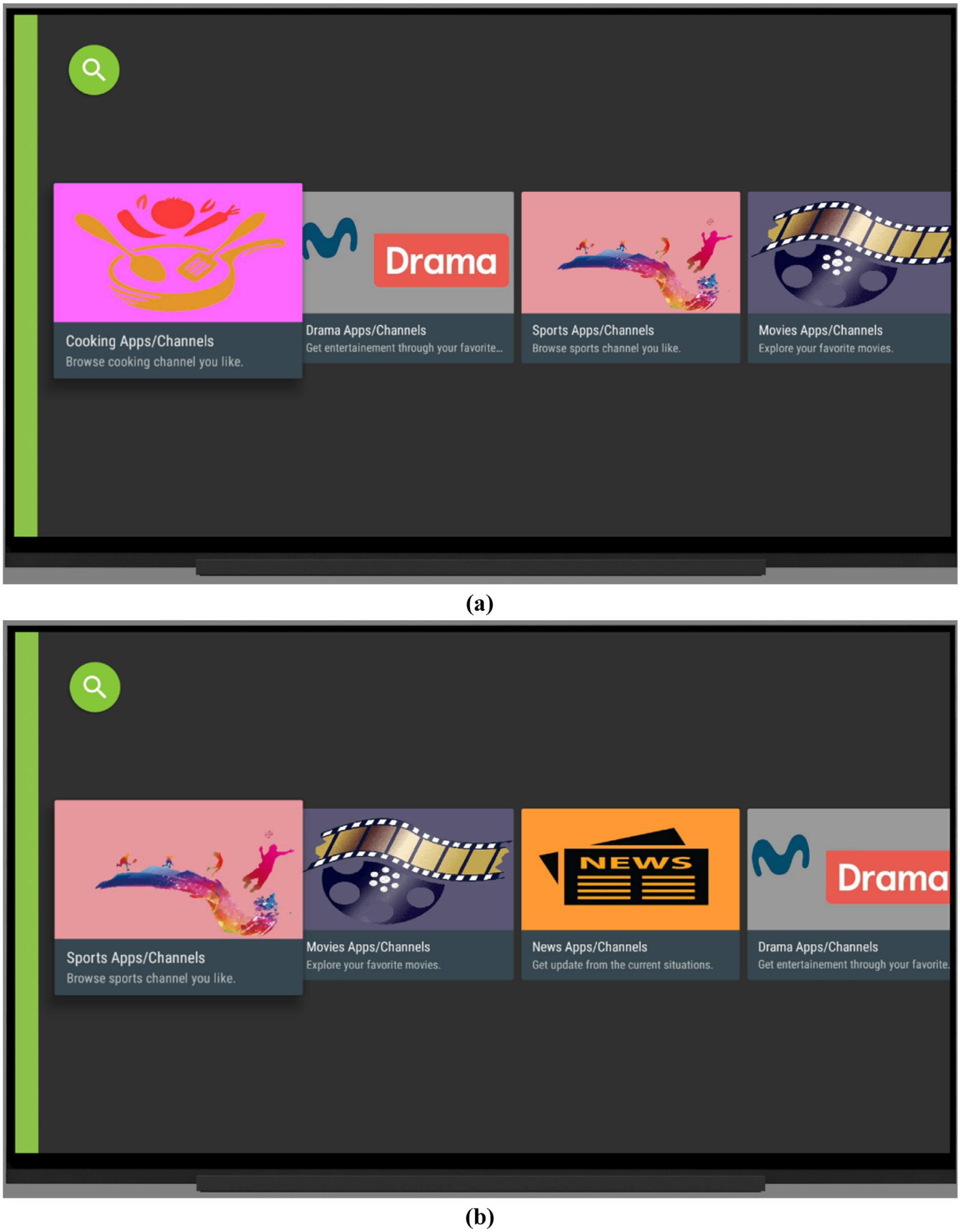


Fig. 7. The PAUI-smart TV UI for (a) house wife, (b) senior citizen.

actions or commands needed from the user compared to other interfaces or methods.

Alternate hypothesis:

H_1: The PAUI-smartTV has minimized the user interactions.

In contrast, the alternative hypothesis (H_1) proposes that the PAUI-smartTV has indeed minimized user interactions. This hypothesis assumes that the PAUI-smartTV interface significantly reduces the effort and interaction requirements for users, making it a more user-friendly and efficient method for Smart TV usage.

Hypothesis H4. Formulation:

H_0: The PAUI-smartTV has not minimized cognitive overload.

Development:

The null hypothesis (H_0) states that the PAUI-smartTV has not successfully reduced cognitive overload experienced by users during Smart TV usage. This hypothesis assumes that the PAUI-smartTV interface does not effectively reduce mental strain or cognitive demands compared to other interfaces or methods.

Alternate hypothesis:

H_1: The PAUI-smartTV has minimized the cognitive overload.

In contrast, the alternative hypothesis (H_1) proposes that the PAUI-smartTV has minimized cognitive overload. This hypothesis assumes that the PAUI-smartTV interface significantly reduces mental strain and cognitive demands, allowing users to have a more streamlined and effortless Smart TV experience.

To summarize, the formulation and development of each hypothesis are listed below.

H_0: Most of the Smart TV viewers have not a positive attitude towards the usage of PAUI-smartTV.

H_1: Most of the Smart TV viewers have positive attitude towards the usage of PAUI-smartTV.

Table 6
Demographic characteristics of the individuals involved in the evaluation.

Participants	Demographics	Number of Participants	Percentage
Gender	Female	18	24 %
	Male	57	76 %
Age Group	12 to 20 years	16	21.33 %
	20 to 28 years	24	32 %
	29 to 37 years	25	33.33 %
	>37 years	10	13.33 %
Background	Educated	67	89.33 %
	Literate	08	10.66 %
Experience	1	19	25. 33 %
	2	17	22.66 %
	3	13	17.33 %
	Others	26	34.66 %

We evaluate the proposed framework using our developed PAUI-smartTV and SmartLog application (Khan and Khusro 2023). These applications were installed on participants' smart TVs. The participants were instructed that SmartLog (Khan and Khusro 2023) would be running in the background to record the tasks related to smartTV interactions. The participants were also ensured that the recorded data would be automatically anonymized before storing it into the database and would stop logging when smartTV is turned off. To further satisfy the participants about their activities, we have instructed that the recorded data will only be used for evaluation purposes and will compare the interactions performed by smartTV native UIs with the PAUI-smartTV interactions. After completing the exercise for five months, the participants were asked to fill out the questionnaire (see Appendix) to see the effectiveness of PAUI-smartTV.

$$H1:\left\{\begin{array}{c} H_0\text{: The PAUI} - \text{smartTV does not improve smart TV viewers' satisfaction.} \\ H_1\text{ : The PAUI} - \text{smartTV will improve smart TV viewers satisfaction.} \end{array}\right\}$$

$$H2:\left\{\begin{array}{c} H_0\text{ : Most of the Smart TV viewers have not a positive attitude towards the} \\ \text{usage of PAUI} - \text{smartTV.} \\ H_1\text{ : Most of the Smart TV viewers have positive attitude towards the usage} \\ \text{of PAUI} - \text{smartTV.} \end{array}\right\}$$

$$H3:\left\{\begin{array}{c} H_0\text{ : The PAUI} - \text{smartTV has not minimized the user interactions.} \\ H_1\text{ : The PAUI} - \text{smartTV has minimized the user interactions.} \end{array}\right\}$$

$$H4:\left\{\begin{array}{c} H_0\text{ : The PAUI} - \text{smartTV has not minimized the cognitive overload.} \\ H_1\text{ : The PAUI} - \text{smartTV has minimized the cognitive overload.} \end{array}\right\}$$

We evaluate the proposed PAUI-smartTV application through an empirical study by collecting data from different family members. As per the practice, usability methods are the most common parameters to evaluate applications related to user interactions. These methods include heuristic evaluation, end-user-usability test, survey and cognitive modelling (Rohrer 2008). Similarly, a range of alternative methods are used for evaluating usability, user experiences, and accessibility. These include automated checking of conformance to guidelines and standards, using models and simulations, user studies, expert evaluation, and keystroke analysis (Petrie and Bevan 2009). The proposed PAUI-smartTV solution is evaluated through the established set of methods and usability parameters defined by human–computer interaction. These usability parameters are ease of use, perceived usefulness, intention-to-use, operability, understandability, and learnability.

We have selected different groups of family members with different gender and age to conduct empirical evaluation. A sample of 75 participants (18 female and 57 male) participated in the evaluation process. The selection criteria have been restricted to the one who casually views smart TVs in their daily routine life. To get participants' willingness, they were briefed about the purpose of the study and research. Table 6 details the participants' demographic profile, educational background, smart TV usage experience, and gender.

Various HCI questionnaires are available such as User Experience Questionnaire (UEQ) (Schrepp et al., 2014), System Usability Scale (SUS) (Brooke 1996), and Questionnaire for User Interaction Satisfaction (QUIS) (Chin et al., 1988), which may be used in evaluating the PAUI-smartTV. However, they are generally used to collect the data of users regarding UX and User Interaction Satisfaction of computers and smartphones. They are unable to fulfill the requirements to collect the relevant data regarding the smart TV domain. Yet, PAUI-smartTV can be evaluated through the already established set of methods, metrics, and usability parameters suggested by HCI. These include attitude, willingness to use, perceived usefulness, learnability & understanding, operability, ease to use, minimal cognitive overload, system usability scale, minimal user interaction, and satisfaction of user satisfaction. Therefore, in the design of the questionnaire for PAUIs-TV, we have taken some of the questions from these already-developed questionnaires and incorporated several additional questions by learning from prior studies (Albert and Tullis 2022).

4. Results and discussion

To properly evaluate our proposed solution, we collected the data through questionnaires and the SmartLog application (Khan and Khusro 2023) and performed empirical and dataset-based analyses. We have performed various statistical tests for empirical evaluation using STATA, SPSS, and AMOS. We evaluated the empirical data and used descriptive tabulation with reported frequencies and percentages for each variable. A cross-tabulation test has been performed with cell percentages and cell Likelihood Ratio Chi2 tests to analyse the relationship among multiple variables. The findings show a significant importance in how it results two-way (2×2) cell frequency count and percentages. Cronbach alpha test has been performed to investigate the variable's scale reliability. To simplify data, we have also performed factor analysis in which Iterated Principal Factor Analysis (IPFA) was found very satisfactory amongst the other factors. Finally, we have estimated the structural models to test the study hypotheses.

4.1. Descriptive statistics

Table 7 shows descriptive statistics of all variables with their frequencies and percentages of the categorical indicators. The attitude variable has been evaluated, and almost 30% to 40% of participants have a positive attitude (i.e., strongly agree and agree) towards using PAUI-smartTV. The important aspect is to investigate the willingness to use the proposed solution, for which about 52% of participants agreed while approximately 25% showed less willingness (including 10% neutral, 8% disagreed, and 7% strongly disagreed). Regarding perceived usefulness, 60% of participants agreed, whereas minimum numbers (i.e., 13%) showed disagreement. About 68% of participants have found the PAUI-smartTV solution understandable and easy to learn its usage, while 50% to 60% of participants reported that this is a viable solution. An average of 70% of participants agreed that the solution is easy-to-use. Regarding usability, 40% agreed, while 15% strongly agreed with the proposed system's usability. About 80% of participants have reported that the proposed solution will minimize cognitive overload, and 75% have responded that it will never violate user privacy. Regarding minimizing user interactions, we received very positive feedback from the participants, as 80% agreed that the proposed solution would minimize user interactions. Finally, regarding user satisfaction, more than 60% of participants showed their satisfaction with the proposed solution. These statistics reveal that users are more likely and willing to use personalized adaptive UIs with smart TVs as they perceive it more useful, understandable, easy-to-use, and usable than traditional UIs with lesser cognitive overload. In addition, they lead to lesser privacy issues and the user interactions are minimized.

4.2. Data reliability and internal consistency

To measure the data reliability and factor analysis, Cronbach alpha test was performed to measure the internal consistency of the scales of measurement items (Likert 1932, Cronbach 1951). We calculated the alpha value for each measurement item, i.e., each factor, which represents the squared correlation of one scale of an item with all other scales. The achieved alpha score for each item ranges from 0.9611 to 0.9621, which seems that our scale items are reliable and internally consistent. For reference, the alpha value ranges from 0.70 showing good and above 0.80 is considered excellent (Likert 1932, Cronbach 1951). As shown in Table 8, observations represent the number of non-missing values of the items, while sign shows the direction of scale correlation.

Similarly, the item-test coefficient represents the strength of the correlation of each item with the scales of all other items. The items will be best fit if higher items-test and item-rest correlation coefficients are achieved. The average inter-item correlation (i.e., the correlation between the measurement items) results in an average correlation between the items.

4.3. Factor analysis

There is a solid theoretical relationship between the scale reliability of the measurement items and factor analysis, as it has been assumed that factors contribute to almost the same/equal information about the score (Zinbarg 2005). In this research, we performed almost all types of factor analysis of the measurement items, including Principal Factor Analysis (PFA), Iterated Factor Analysis (IFA), Maximum Likelihood Analysis (MLA), and Principal Component Factor Analysis (PCFA). Still, we reported the PCFA because it retained 64 factors, and the results were found satisfactory and appropriate compared to other factor analyses. As shown in Table 9, the retained factors in PCFA show the contribution of variations by a specific factor in total variations. The Eigenvalue of maximum factors is greater than 0, meaning maximum factors have been considered important.

We calculated Kendall's tau-b rank correlation coefficient for each categorical items in Table 10, to look for patterns in data ordering after ranking them by their quantities. We can see that there is no multicollinearity problem in the data. The independence of the responses to the factor's scales is represented by Kendall's tau-b correlation coefficient, which is satisfactory in terms of analysis. The values with an asterisk (*) indicate a significant correlation, i.e., these factors are highly correlated. In terms of independence compared to the saturated model, the PCFA results are comparable to the results of the correlation matrix.

4.4. Model summary and fitness

For the model assessment of 73 items and 11 latent variables, we estimated the absolute and relative value, parsimony and non-centrality fit indices, i.e., Chi-square/d.f., Comparative Fit Index (CFI), Increment Fit Index (IFI), Normed Fit Index (NFI), Tucker-Lewis Index (TLI), Relative Fit Index (RFI), Parsimonious Comparative Fit Index (PCFI), Parsimonious Normed Fit Index (PNFI), and RMSEA. The results in Table 11 show good model fitness with Chi-Square/d.f. = 2.112, CFI = 1.345, NFI = 0.832, IFI = 0.821, TLI = 0.5, PCFI = 0.5, RFI = 0.42, PNFI = 0.642, RMSEA = 0.06. The results indicate that the estimated covariance metrics of the proposed and observed models seem significant and satisfactory.

4.5. Assessment through hypothesis

Table 12 shows that the structural model has significant positive estimates concerning H1, H2, H3, and H4, so we reject the null hypotheses. The structural model indicates a p-value less than 0.05 seems that the PAUI-smartTV will minimize the cognitive load and will improve user satisfaction. For the H1, we have achieved a p-value of 0.021, which means that the proposed system has greatly improved the user satisfaction level. In terms of attitude, we have significant positive estimates with a p-value of 0.033, which shows that participants have a positive attitude towards using PAUI-smartTV. Regarding user interaction, we have significant positive

Table 7
Descriptive statistics.

Usability Parameters	Variables (Questions)	Scales	Frequency	Percentages
Attitude	ATD1, ATD2, ATD3, ATD4, ATD5, ATD6, ATD7	Strongly agree	**20.29**	**27.05**
		Agree	**30.86**	**41.14**
		Neutral	13.14	17.52
		Disagree	8.43	11.24
		Strongly Disagree	2.29	3.05
Willingness to use	WTU1, WTU2, WTU3, WTU4, WTU5	Strongly agree	**16.40**	**21.87**
		Agree	**39.00**	**52.00**
		Neutral	8.00	10.67
		Disagree	6.20	8.27
		Strongly Disagree	5.40	7.20
Perceived usefulness	PU1, PU2, PU3, PU4, PU5, PU6	Strongly agree	**21.00**	**28.00**
		Agree	**30.83**	**41.11**
		Neutral	12.17	16.22
		Disagree	7.33	9.78
		Strongly Disagree	3.67	4.89
Learnability & understandability	LAU1, LAU2, LAU3, LAU4	Extremely comfortable	**23.50**	**31.33**
		Very comfortable	**27.75**	**37.00**
		Moderately comfortable	**14.50**	**19.33**
		Lightly comfortable	6.50	8.67
		Not at all comfortable	2.75	3.67
Operability	OT1, OT2, OT3, OT4, OT5, OT6, OT7, OT8, OT9, OT10, OT11, OT12	Strongly satisfied	**17.75**	**23.67**
		Satisfied	**30.75**	**41.00**
		Neutral	**13.83**	**18.44**
		Dissatisfied	8.17	10.89
		Strongly dissatisfied	4.50	6.00
Easy to use	ETU1, ETU2, ETU3, ETU4, ETU5, ETU6, ETU7, ETU8, ETU9, ETU10	Strongly agree	25.00	**33.33**
		Agree	35.78	**47.70**
		Neutral	7.56	10.07
		Disagree	4.11	5.48
		Strongly Disagree	2.56	3.41
System usability scale (sus)	SUS1, SUS2, SUS3, SUS4, SUS5, SUS6, SUS7, SUS8, SUS9, SUS10	Strongly agree	**12.70**	**16.93**
		Agree	**29.60**	**39.47**
		Neutral	**17.70**	**23.60**
		Disagree	6.00	8.00
		Strongly Disagree	9.00	12.00
Minimal cognitive overload	MCO1, MCO2, MCO3, MCO4, MCO5, MCO6, MCO7, MCO8	Strongly agree	**29.13**	**38.83**
		Agree	**32.75**	**43.67**
		Neutral	**6.63**	**8.83**
		Disagree	4.00	5.33
		Strongly Disagree	2.50	3.33
User privacy	UP1, UP2	Strongly agree	**24.00**	**32.00**
		Agree	**32.00**	**42.67**
		Neutral	**5.50**	**7.33**
		Disagree	7.50	10.00
		Strongly Disagree	6.00	8.00
Minimal user interaction	MUI1, MUI2, MUI3, MUI4	Completely agree	**21.75**	**29.00**
		Significantly agree	**37.00**	**49.33**
		Slightly agree	**8.25**	**11.00**
		Moderately agree	5.25	7.00
		Completely disagree	2.75	3.67
Satisfaction of user	SOU1, SOU2, SOU3, SOU4, SOU5, SOU6	Strongly agree	**23.17**	**30.89**
		Agree	**27.33**	**36.44**
		Neutral	**13.50**	**18.00**
		Disagree	6.50	8.67
		Strongly Disagree	4.50	6.00

estimates with a p-value of 0.028, which shows that PAUI-smartTV has significantly minimized user interaction. Similarly, in terms of cognitive overload, we also have significant positive estimates, with a p-value of 0.029, which shows that PAUI-smartTV has significantly minimized the cognitive load.

4.6. SmartLog dataset-based analysis

The SmartLog app (Khan and Khusro 2023) collects and records the various daily activities and events (selective lifelogging) from individual and group viewers as they watch and interact with a smart TV. The collected and logged data contains information about various operations performed by household members on smart TV, such as usage history, interaction history, channel/app history, age, gender, number of occupants, facial expression log, viewer angle, and viewer distance. The data that was logged through the native UIs of smart TVs were analyzed and compared against the data acquired from the PAUI-SmartTV App regarding the performance of common tasks and operations on smart TVs. The PAUIs-smart TV App was found to be less complex, having minimal user interactions and input steps for performing common operations and tasks as they watch and interact with a smart TV. We have analyzed the SmartLog data of 75 participants, who willingly participated in the empirical evaluation and shared the SmartLog Data. Table 6 shows the demographics of the participants.

Table 13 compares the performance of PAUIs-smart TV and the Smart TV native UIs of 75 participants. To evaluate and compare the efficacy of the PAUIs-smart TV, the SmartLog dataset generated from this interface during the common operations and tasks carried out by household members was analyzed and compared

Table 8
Data reliability and internal consistency (Cronbach alpha).

Variables	Measurement Items	Observations	Sign	Item-test correlation	Item-rest correlation	Average Inter-item correlation	Alpha
Attitude	ATD1	75	+	0.7919	0.7817	0.2548	0.961
	ATD2	75	+	0.6028	0.5856	0.2576	0.9615
	ATD3	75	+	0.2885	0.2641	0.2623	0.9624
	ATD4	75	+	0.514	0.4942	0.2589	0.9618
	ATD5	75	+	0.5325	0.5131	0.2587	0.9617
	ATD6	75	+	0.5929	0.5754	0.2578	0.9615
	ATD7	75	+	0.6357	0.6196	0.2571	0.9614
Willingness to Use	WTU1	75	+	0.181	0.1552	0.2639	0.9627
	WTU2	75	+	0.2222	0.1968	0.2633	0.9626
	WTU3	75	+	0.181	0.1552	0.2639	0.9627
	WTU4	75	+	0.2712	0.2465	0.2625	0.9624
	WTU5	75	+	0.2478	0.2228	0.2629	0.9625
Perceived Usefulness	PU1	75	+	0.647	0.6312	0.257	0.9614
	PU2	75	+	0.5828	0.5649	0.2579	0.9616
	PU3	75	+	0.5559	0.5372	0.2583	0.9616
	PU4	75	+	0.7611	0.7496	0.2553	0.9611
	PU5	75	+	0.4777	0.457	0.2595	0.9619
	PU6	75	+	0.5843	0.5665	0.2579	0.9616
Learnability and Understandability	LAU1	75	+	0.1707	0.1449	0.264	0.9627
	LAU2	75	+	0.2309	0.2057	0.2631	0.9626
	LAU3	75	+	0.1837	0.158	0.2638	0.9627
	LAU4	75	+	0.1798	0.1541	0.2639	0.9627
Operability	OT1	75	+	0.3037	0.2794	0.262	0.9624
	OT2	75	+	0.5313	0.5119	0.2587	0.9617
	OT3	75	+	0.4788	0.458	0.2595	0.9619
	OT4	75	+	0.4468	0.4253	0.2599	0.962
	OT5	75	+	0.3517	0.3283	0.2613	0.9622
	OT6	75	+	0.3088	0.2846	0.262	0.9623
	OT7	75	+	0.4752	0.4544	0.2595	0.9619
	OT8	75	+	0.2016	0.1761	0.2636	0.9626
	OT9	75	+	0.5638	0.5454	0.2582	0.9616
	OT10	75	+	0.4698	0.4489	0.2596	0.9619
	OT11	75	+	0.4439	0.4224	0.26	0.962
	OT12	75	+	0.3855	0.3627	0.2608	0.9621
Easy to Use	ETU1	75	+	0.7228	0.7098	0.2558	0.9612
	ETU2	75	+	0.7509	0.739	0.2554	0.9611
	ETU3	75	+	0.5804	0.5625	0.2579	0.9616
	ETU4	75	+	0.594	0.5765	0.2577	0.9615
	ETU5	75	+	0.5949	0.5774	0.2577	0.9615
	ETU6	75	+	0.6141	0.5973	0.2574	0.9615
	ETU7	75	+	0.747	0.735	0.2555	0.9611
	ETU8	75	+	0.5334	0.5141	0.2586	0.9617
	ETU9	75	+	0.6374	0.6214	0.2571	0.9614
System Usability Scale	SUS1	75	+	0.3734	0.3503	0.261	0.9622
	SUS2	75	+	0.6003	0.583	0.2577	0.9615
	SUS3	75	+	0.4296	0.4077	0.2602	0.962
	SUS4	75	+	0.5222	0.5026	0.2588	0.9617
	SUS5	75	+	0.1162	0.09	0.2648	0.9629
	SUS6	75	+	0.6156	0.5988	0.2574	0.9615
	SUS7	75	+	0.595	0.5775	0.2577	0.9615
	SUS8	75	+	0.6444	0.6286	0.257	0.9614
	SUS9	75	+	0.5835	0.5657	0.2579	0.9616
	SUS10	75	+	0.5843	0.5665	0.2579	0.9616
Minimal Cognitive Overload	MCO1	75	+	0.7111	0.6977	0.256	0.9612
	MCO2	75	+	0.5162	0.4964	0.2589	0.9618
	MCO3	75	+	0.701	0.6872	0.2562	0.9612
	MCO4	75	+	0.623	0.6064	0.2573	0.9615
	MCO5	75	+	0.7473	0.7353	0.2555	0.9611
	MCO6	75	+	0.5964	0.579	0.2577	0.9615
	MCO7	75	+	0.6919	0.6777	0.2563	0.9613
	MCO8	75	+	0.5816	0.5637	0.2579	0.9616
User Privacy	UP1	75	+	0.6756	0.6608	0.2565	0.9613
	UP2	75	+	0.5187	0.499	0.2589	0.9618
Minimal User Interaction	MUI1	75	+	0.6368	0.6207	0.2571	0.9614
	MUI2	75	+	0.7068	0.6932	0.2561	0.9612
	MUI3	75	+	0.6777	0.663	0.2565	0.9613
	MUI4	75	+	0.6937	0.6796	0.2563	0.9613
Satisfaction of User	SOU1	75	+	0.6807	0.6661	0.2565	0.9613
	SOU2	75	+	0.5456	0.5266	0.2585	0.9617
	SOU3	75	+	0.7019	0.6881	0.2561	0.9612
	SOU4	75	+	0.6443	0.6285	0.257	0.9614
	SOU5	75	+	0.5731	0.5549	0.2581	0.9616
	SOU6	75	+	0.4037	0.3812	0.2606	0.9621
Test scale						**0.2589**	**0.9623**

Table 9
The PCFA results.

Measurement Items	Factor	Eigenvalue	Difference	Proportion	Cumulative	Variable	Uniqueness
Attitude	Factor1	22.23707	16.68094	0.3106	0.3106	ATD1	0.0213
	Factor2	5.55614	0.36473	0.0776	0.3882	ATD2	0.01
	Factor3	5.19141	1.94132	0.0725	0.4608	ATD3	0.0489
	Factor4	3.25008	0.48996	0.0454	0.5062	ATD4	0.0252
	Factor5	2.76012	0.37506	0.0386	0.5447	ATD5	0.0176
	Factor6	2.38507	0.16513	0.0333	0.578	ATD6	0.0103
	Factor7	2.21993	0.35906	0.031	0.609	ATD7	0.0196
Willingness to Use	Factor8	1.86088	0.11613	0.026	0.635	WTU1	−0.0003
	Factor9	1.74475	0.07011	0.0244	0.6594	WTU2	−0.0007
	Factor10	1.67464	0.06475	0.0234	0.6828	WTU3	−0.0003
	Factor11	1.60989	0.15756	0.0225	0.7053	WTU4	0.0115
	Factor12	1.45234	0.04901	0.0203	0.7256	WTU5	0.0423
Perceived usefulness	Factor13	1.40333	0.09415	0.0196	0.7452	PU1	−0.0007
	Factor14	1.30918	0.16659	0.0183	0.7635	PU2	0.011
	Factor15	1.14258	0.07218	0.016	0.7794	PU3	0.0186
	Factor16	1.0704	0.09448	0.015	0.7944	PU4	0.0226
	Factor17	0.97592	0.02912	0.0136	0.808	PU5	0.0136
	Factor18	0.9468	0.01611	0.0132	0.8212	PU6	0.0152
Learnability and Understandability	Factor19	0.93069	0.09682	0.013	0.8342	LAU1	−0.0015
	Factor20	0.83387	0.04546	0.0116	0.8459	LAU2	0.0393
	Factor21	0.78841	0.03974	0.011	0.8569	LAU3	−0.0015
	Factor22	0.74868	0.07971	0.0105	0.8673	LAU4	−0.0011
Operability	Factor23	0.66897	0.01252	0.0093	0.8767	OT1	0.013
	Factor24	0.65645	0.04323	0.0092	0.8859	OT2	0.0115
	Factor25	0.61322	0.03202	0.0086	0.8944	OT3	0.0087
	Factor26	0.58119	0.01863	0.0081	0.9025	OT4	0.0354
	Factor27	0.56256	0.03253	0.0079	0.9104	OT5	0.0341
	Factor28	0.53003	0.07254	0.0074	0.9178	OT6	0.0218
	Factor29	0.45748	0.01697	0.0064	0.9242	OT7	−0.0011
	Factor30	0.44052	0.02322	0.0062	0.9304	OT8	0.0567
	Factor31	0.41729	0.02345	0.0058	0.9362	OT9	0.0167
	Factor32	0.39384	0.01832	0.0055	0.9417	OT10	0.0688
	Factor33	0.37552	0.04075	0.0052	0.9469	OT11	0.0781
	Factor34	0.33477	0.02647	0.0047	0.9516	OT12	0.0195
Easy-to-Use	Factor35	0.3083	0.01834	0.0043	0.9559	ETU1	0.0288
	Factor36	0.28996	0.02307	0.0041	0.96	ETU2	−0.001
	Factor37	0.26688	0.0128	0.0037	0.9637	ETU3	0.0175
	Factor38	0.25408	0.0085	0.0035	0.9672	ETU4	0.0263
	Factor39	0.24558	0.02319	0.0034	0.9707	ETU5	0.0199
	Factor40	0.22239	0.01156	0.0031	0.9738	ETU6	−0.0006
	Factor41	0.21083	0.01143	0.0029	0.9767	ETU7	−0.0007
	Factor42	0.1994	0.02332	0.0028	0.9795	ETU8	0.0098
	Factor43	0.17608	0.01763	0.0025	0.982	ETU9	0.0278
System Usability Scale	Factor44	0.15845	0.00754	0.0022	0.9842	SUS1	0.0579
	Factor45	0.15092	0.00978	0.0021	0.9863	SUS2	0.0264
	Factor46	0.14114	0.01423	0.002	0.9883	SUS3	0.0469
	Factor47	0.1269	0.00765	0.0018	0.99	SUS4	0.0543
	Factor48	0.11925	0.01869	0.0017	0.9917	SUS5	0.0374
	Factor49	0.10057	0.00612	0.0014	0.9931	SUS6	−0.0006
	Factor50	0.09444	0.01672	0.0013	0.9944	SUS7	−0.0015
	Factor51	0.07772	0.01117	0.0011	0.9955	SUS8	−0.001
	Factor52	0.06655	0.00651	0.0009	0.9964	SUS9	−0.0016
	Factor53	0.06004	0.00642	0.0008	0.9973	SUS10	−0.0006
Minimal Cognitive Overload	Factor54	0.05362	0.00239	0.0007	0.998	MCO1	0.0176
	Factor55	0.05123	0.00292	0.0007	0.9987	MCO2	0.0591
	Factor56	0.04831	0.01412	0.0007	0.9994	MCO3	−0.0011
	Factor57	0.03419	0.00803	0.0005	0.9999	MCO4	0.039
	Factor58	0.02615	0.00524	0.0004	1.0003	MCO5	−0.0007
	Factor59	0.02092	0.00338	0.0003	1.0005	MCO6	−0.0016
	Factor60	0.01754	0.0048	0.0002	1.0008	MCO7	0.0096
	Factor61	0.01274	0.00363	0.0002	1.001	MCO8	−0.0006
User Privacy	Factor62	0.00911	0.005	0.0001	1.0011	UP1	0.0281
	Factor63	0.00411	0.00257	0.0001	1.0012	UP2	0.0269
Minimal User Interaction	Factor64	0.00154	0.00154	0	1.0012	MUI1	0.0241
	Factor65	0	0.00334	0	1.0012	MUI2	0.0195
	Factor66	−0.00334	0.00161	0	1.0011	MUI3	0.0213
	Factor67	−0.00495	0.00241	−0.0001	1.0011	MUI4	0.0114
Satisfaction of User	Factor68	−0.00736	0.0021	−0.0001	1.001	SOU1	−0.0011
	Factor69	−0.00946	0.00206	−0.0001	1.0008	SOU2	−0.0007
	Factor70	−0.01153	0.00224	−0.0002	1.0007	SOU3	0.0116
	Factor71	−0.01377	0.00207	−0.0002	1.0005	SOU4	−0.0004
	Factor72	−0.01584	0.00231	−0.0002	1.0003	SOU5	0.0097
	Factor73	−0.01815	.	−0.0003	1	SOU6	0.0258

Table 10
Interitem correlation/Kendal Tau-b rank correlation matrix.

	ATD	WTU	PU	LAU	OT	ETU	SUS	MCO	UP	MUI	SOU
ATD	0.367										
WTU	0.114	0.478									
PU	0.1759*	0.167	0.478								
LAU	0.049	0.171	0.127	0.702							
OT	0.1881*	0.095	0.137	0.088	0.284						
ETU	0.160	0.138	0.085	0.150	0.1805*	0.418					
SUS	0.123	0.146	0.162	0.215	0.1766*	0.163	0.467				
MCO	0.123	0.185	0.104	0.120	0.094	0.126	0.164	0.545			
UP	0.1953*	0.121	0.103	0.079	0.131	0.148	0.107	0.162	0.622		
MUI	0.1971*	0.077	0.064	0.115	0.1910*	0.180	0.145	0.157	0.094	0.500	
SOU	0.1802*	0.130	0.094	0.137	0.1434*	0.171	0.115	0.101	0.2058*	0.2303*	0.422

Table 11
Measurement and structural model fit indexes.

Fit Index	Structural Model	Recommended Range
CMIN/DF	2.112	≤3.00
CFI	1.345	≤3.00
NFI	0.832	≥ 00.90
IFI	0.821	≥0.90
TLI	0.5	≥0.50
PCFI	0.5	≥0.50
RFI	0.42	≤1.00
PNFI	0.645	≥ 00.50
RMSEA	0.06	≤0.08

against the SmartLog dataset derived from the native UIs of the smart TV. The examination of data from both datasets revealed that a less complex user interface characterizes PAUIs-smart TV App and requires minimal user interactions to execute typical tasks and operations while viewing and interacting with a smart TV, as graphically depicted in Figs. 8 and 9. PAUIs-smart TV App UIs are deemed more user-friendly, adaptive, and consistent, and require fewer user interactions and input steps to execute common tasks and operations on smart TVs because a majority of these tasks can be carried out automatically based on context. This reduces the need for extensive user interactions and minimizes usability barriers for household members. The ensuing sections will expound upon the results obtained from the analysis.

4.7. Contextual personalization

Most tasks are carried out automatically because PAUIs-smart TV UIs adjust their tasks/operations in response to how household members interact with and utilize the device. According to an anal-

Table 12
Model/hypotheses testing.

Hypothesis	Unstandardized Coefficients	Standardized Coefficients	Standard Errors	P-value
H1->User Satisfaction	0.253	0.347	0.424	0.021
H2–>Attitude	0.685	0.218	0.357	0.033
H3–>Minimal User Interaction	0.305	0.124	0.153	0.028
H4->Minimal Cognitive Overload	0.475	0.466	0.242	0.029

Table 13
Comparison of smart TV native UIs with PAUIs-smart TV App.

Task ID	Function / Operation / Task	Smart TV Native UIs				PAUIs-smart TV Viewers			
		Average Task Completion Time in Minutes	Average Steps for Tasks	Average Wrong Steps/ Irrelevant Steps	Adaptation	Average Task Completion Time in Minutes	Average Steps for Tasks	Average Wrong Steps / Irrelevant Steps	Adaptation
T1	Profile Creation/ Account Creation for Household Members	5	17	4	No	0.5	2	0	Yes
T2	Account Switching	1	8	3	No	0.5	0	0	Yes
T3	Apps/Channel Customization	5	20	5	No	0.5	0	0	Yes
T4	Apps/Channel Categorization	8	45	8	No	0.66	0	0	Yes
T5	Home Screen Customization	6	44	5	No	0.82	0	0	Yes
T6	System Setting	12	60	9	No	5	30	3	Yes
T7	Apps/Channel Inter-Intra Navigation	3	12	3	No	1	5	2	Yes
T8	Apps/Channel Searching	3	14	3	No	1.5	6	2	Yes
T9	Adjust Screen Brightness	1	8	2	No	0.5	0	0	Yes
T10	Adjust Font Size According to Viewing Distance and Angle	1.5	9	2	No	0.5	0	0	Yes

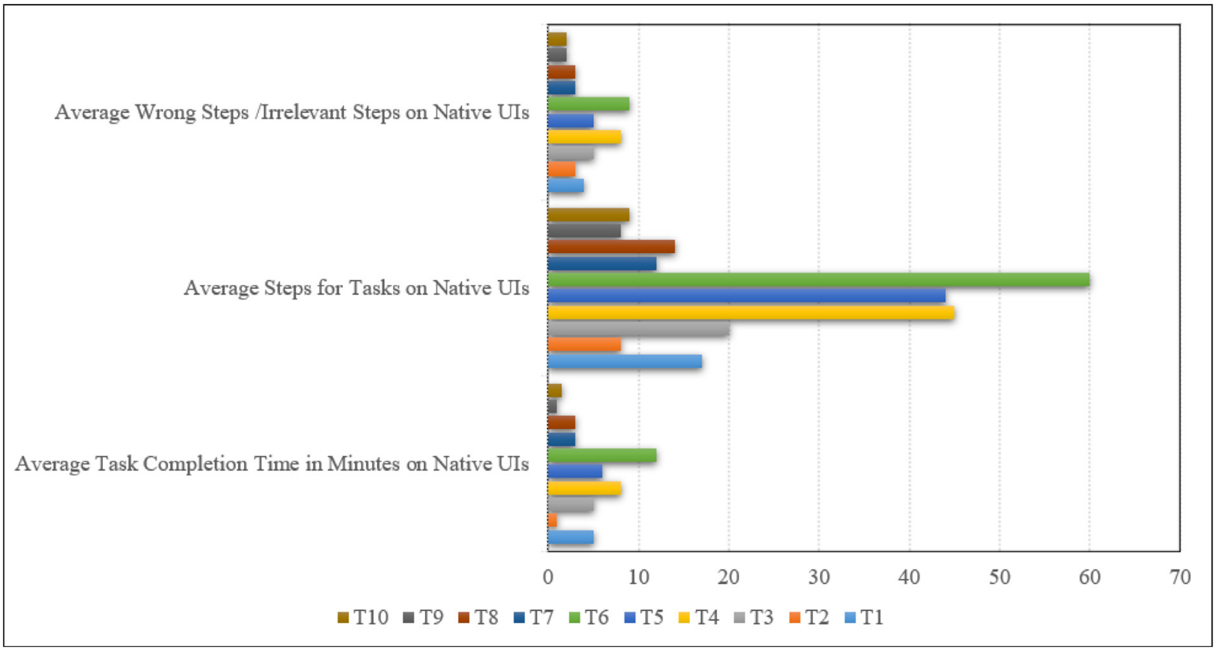


Fig. 8. Average Steps for Task Completion Time on Native UIs.

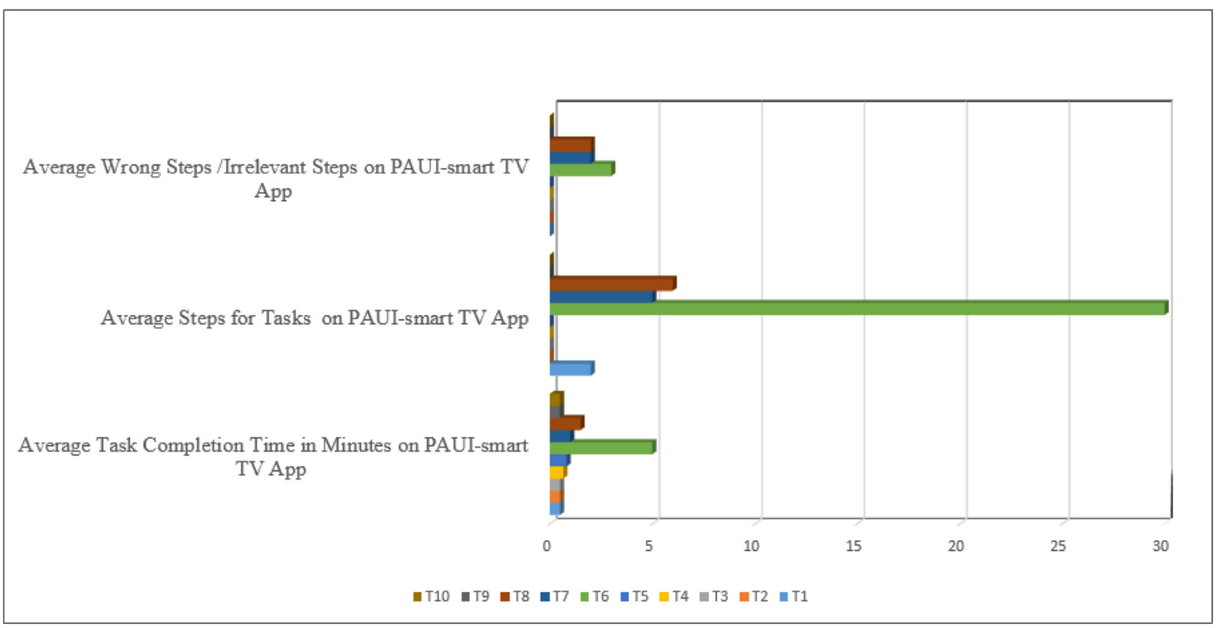


Fig. 9. Average Steps for Task Completion Time on PAUIs-smart TV.

ysis of the SmartLog dataset, the PAUIs-smart TV automatically performs the following tasks as users watch and interact with it. These include app/channel categorization, volume control, home screen customization, household member account creation and switching, screen brightness adjustment, and font size according to viewing distance and angle. The PAUIs-smart TV tasks/operations were compared to smart TV native UIs. Table 14 displays the outcomes. These outcomes indicate that designing personalized adaptive UIs enables smart TV users to better manage their activities on smart TV, such as switching accounts, personalizing home screen, apps, channels, and adjusting settings according to contextual changes.

5. Conclusion and future work

Smart TV is a lean-back and shared device for household members who face various issues and challenges while interacting with its static, complex, and cluttered UI due to numerous factors. These factors include a diverse range of viewers, user interests, cultures, modalities of interaction, inputs/outputs capabilities, contextual details, and limited features of traditional remote controls. Although manufacturers and vendors have attempted to develop various UIs for smart TVs that offer a wide range of functionalities and features, their complex nature and one-size-fits-all UI design have made them less useful and least accessible, and less

Table 14
Contextual Personalization for household members.

Name of Activities	Smart TV Native UIs	PAUIs-smart TV App
Account switching	×	✓
Home screen personalization	×	✓
Apps/Channel personalization	×	✓
Auto adjust volume adjustment according to room noise level	×	✓
Auto adjust font size according to household member viewing distance and angle	×	✓
Auto adjust the screen brightness according to room light intensity	×	✓

manageable. In response to these issues, this research work proposed that a personalized adaptive UI should be developed to improve users' smart TV usage and watching experience. We presented a personalized real-time adaptive UIs framework for smart TV users by learning from their needs, preferences, and other contextual details, such as age, gender, skills, mental models, and contextual variability. The proposed framework was implemented in the form of a PAUIs-smart TV app installed and used on the smart TVs of users who participated in its evaluation. The proposed solution was evaluated on our developed dataset and empirical study by collecting data from 75 household members with different age groups through a mixed-mode survey using a questionnaire. The results were analyzed using tests, including Cronbach alpha, Kendall's tau-b, and principal component factor analysis. The results show that personalized adaptive UIs are perceived positively in attitude, usability, user satisfaction, and intention to use. Adaptive UIs can provide better usability, user experience, learnability, and accessibility and reduce cognitive overload. In other words, users are more likely and willing to use personalized adaptive UIs with smart TVs as they perceive it as more useful, understandable, easy-to-use, and usable than traditional UIs with lesser cognitive overload. In addition, they lead to lesser privacy issues and user interactions are minimized. Moreover, this research expands the understanding of user interface design by incorporating a comprehensive set of individual and contextual factors to create adaptive, personalized, flexible, and context-aware user interfaces. This contributes to the advancement of user-centered design principles and the integration of various user-specific requirements. In practical terms, our framework offers tangible benefits for improving user experiences with smart TVs.

Limitations include the unsuitability of the proposed solution in public places such as cafés, hostels, and roadside rest stops. Camera resolution and low brightness also make it difficult to determine the viewer's "age," "gender," and "number." The dataset that serves as the foundation for machine learning algorithms can also influence the detection of viewers' age, gender, and various faces. Furthermore, the effect of distance and angle between a smart TV and the viewer(s) was noted. The proposed approach is designed for both individuals and families/groups. In the current study, we reported our findings on the responses from 75 participants, 18 female and 57 male respondents.

In the future, we plan to extend the capabilities of PAUI-smartTV with deep learning models to produce a more personalized and enriched user experience. We are working on adding more adaptation rules and contextual parameters to enhance the functionality and services of PAUI-smartTV. We are also working on enriching the dataset to derive more valuable insights from smart TV usability, learnability, and user experience. In addition, we plan to come up with a more balanced female/male ratio in the evaluation process to generate more insights regarding PAUIs-smart TV.

Availability of Code and Data

The source codes of the PAUI-smartTV and SmartLog apps as well as the dataset will be made available upon request to the corresponding author.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Usability Parameters (5 Scale)

	Question	5	4	3	2	1
ATD	**Attitude:** SA: Strongly agree, A: Agree, N: Neutral, D: Disagree SD: Strongly disagree					
ATD1	In general, I think that using a PAUIs-smart TVs is a good idea.	SA	A	N	D	SD
ATD2	Overall, I have a favorable attitude toward using PAUIs-smart TVs.	SA	A	N	D	SD
ATD3	PAUIs-smart TV is a reliable and efficient way to interact with my TV.	SA	A	N	D	SD
ATD4	Overall, I felt that PAUIs-smart TVs met my needs.	SA	A	N	D	SD
ATD5	I would recommend using the PAUIs-smart TV to others.	SA	A	N	D	SD
ATD6	I am satisfied with the features and functionality offered by PAUIs-smart TV.	SA	A	N	D	SD
ATD7	I enjoy using PAUIs-smart TV and feel it enhances my viewing experience.	SA	A	N	D	SD
WTU	**Willingness to use:** SA: Strongly agree, A: Agree, N: Neutral, D: Disagree SD: Strongly disagree					
WTU1	I intend to use PAUIs-smart TV regularly in the future.	SA	A	N	D	SD
WTU2	I intend to use a PAUIs-smart TV in the future as it displays relevant apps/channels to me.	SA	A	N	D	SD
WTU3	I am planning to use PAUIs-smart TV more often in the future.	SA	A	N	D	SD
WTU4	I can see myself using PAUIs-smart TV frequently in the long term.	SA	A	N	D	SD
WTU5	I am likely to recommend PAUIs-smart TV to others.	SA	A	N	D	SD
PU	**Perceived usefulness:** SA: Strongly agree, A: Agree, N: Neutral, D: Disagree SD: Strongly disagree					
PU1	PAUIs-smart TV has improved my ability to find and access my favorite TV Apps/channels or streaming	SA	A	N	D	SD

(*continued on next page*)

Usability Parameters (5 Scale) (*continued*)

	Question	5	4	3	2	1
	services.					
PU2	PAUIs-smart TV provides the features and functions that meet my needs.	SA	A	N	D	SD
PU3	PUIs-smart TV provides a better viewing experience.	SA	A	N	D	SD
PU4	Using PAUIs-smart TV has improved my ability to find and use common applications easily.	SA	A	N	D	SD
PU5	PUIs-smart TV provides better viewing and interaction experience.	SA	A	N	D	SD
PU6	PUIs-smart TV has made it easier to navigate through different channels and apps.	SA	A	N	D	SD
LAU	**Learnability and Understandability:** EC: Extremely comfortable, VC: Very comfortable, MC: Moderately comfortable, SC: Slightly comfortable, NC: Not at all comfortable					
LAU1	I found comfort and pleasure while learning and understanding the features such as customization and adaptation.	EC	VC	MC	SC	NC
LAU2	How confident do you feel in using the PAUIs-smart TV?	EC	VC	MC	SC	NC
LAU3	How quickly were you able to complete basic tasks using the PUIs-smart TV?	EC	VC	MC	SC	NC
LAU4	How easy was it for you to learn how to use the PUIs-smart TV?	EC	VC	MC	SC	NC
OT	**Operability:** SS: Strongly satisfied, S: Satisfied, N: Neutral, D: Dissatisfied, SD: Strongly Dissatisfied					
OT1	I could quickly and easily perform the tasks I wanted to do using the PAUIs-smart TV.	SS	S	N	D	SD
OT2	The layout and design of the PAUIs-smart TV made it easy to find the desired features and options.	SS	S	N	D	SD
OT3	The PAUIs-smart TV was flexible enough to accommodate my different preferences and needs.	SS	S	N	D	SD
OT4	The PAUIs-smart TV had a clear and intuitive user interface.	SS	S	N	D	SD
OT5	Overall, the PAUIs-smart TV is reliable and stable in its performance.	SS	S	N	D	SD
OT6	The response time of the PAUIs-smart TV is satisfactory for my needs.	SS	S	N	D	SD
OT7	II found it easy to navigate through the various menus and options within the PAUIs-smart TV.	SS	S	N	D	SD

Usability Parameters (5 Scale) (*continued*)

	Question	5	4	3	2	1
OT8	The PAUIs-smart TV responds quickly to my commands and inputs.	SS	S	N	D	SD
OT9	It is easy to find what I am looking for in the PAUIs-smart TV.	SS	S	N	D	SD
OT10	I have accomplished subtasks with accuracy in PAUIs-smart TV.	SS	S	N	D	SD
OT11	I have completed tasks within the expected time frame using the PAUIs-smart TV.	SS	S	N	D	SD
OT12	The PAUIs-smart TV provides the best ways to accomplish tasks to accommodate different user preferences and needs.	SS	S	N	D	SD
ETU	**Easy to Use:** SA: Strongly agree, A: Agree, N: Neutral, D: Disagree SD: Strongly disagree					
ETU1	Overall, I found the PAUIs-smart TV user-friendly and easy to navigate.	SA	A	N	D	SD
ETU2	It is simple to use.	SA	A	N	D	SD
ETU3	It is user friendly.	SA	A	N	D	SD
ETU4	Did you find the PAULI's-smart TV interface to be clustered or overwhelming?	SA	A	N	D	SD
ETU5	Would you recommend the PAUIs-smart TV to a friend or family member based on its ease of use?	SA	A	N	D	SD
ETU6	It needs the fewest steps to accomplish what I wanted to do with the PAUIs-smart TV.	SA	A	N	D	SD
ETU7	It is flexible.	SA	A	N	D	SD
ETU8	I do not need to consult any external resources (e.g., manuals, online tutorials) to use the PAUIs-smart TV effectively.	SA	A	N	D	SD
ETU9	I felt confident and comfortable using the PAUIs-smart TV after only a short period of time.	SA	A	N	D	SD
ETU10	Compared to other smart TV UIs, I have used, I found the PAUIs-smart TV to be much easier to use.	SA	A	N	D	SD
SUS	**System Usability Scale (SUS):** SA: Strongly agree, A: Agree, N: Neutral, D: Disagree SD: Strongly disagree					
SUS1	I expect that I will use this PAUIs-smart TV frequently.	SA	A	N	D	SD
SUS2	I did find the PAUIs-smart TV unnecessarily complex.	SA	A	N	D	SD
SUS3	I thought the PAUIs-smart TV was easy to use.	SA	A	N	D	SD

Usability Parameters (5 Scale) (*continued*)

	Question	5	4	3	2	1
SUS4	I would require the assistance of a technical person to able to use this PAUIs-smart TV.	SA	A	N	D	SD
SUS5	I found that the various features of this PAUIs-smart TV were well integrated.	SA	A	N	D	SD
SUS6	I felt very confident using the PAUIs-smart TV.	SA	A	N	D	SD
SUS7	I found the PAUIs-smart TV somewhat cumbersome to use.	SA	A	N	D	SD
SUS8	I needed to learn many things before I could use this PAUIs-smart TV effectively.	SA	A	N	D	SD
SUS9	I thought there was too much inconsistency in this PAUIs-smart TV.	SA	A	N	D	SD
SUS10	I would imagine that most people would learn to use this PAUIs-smart TV very quickly.	SA	A	N	D	SD
MCO	**Minimal Cognitive Overload:** SA: Strongly agree, A: Agree, N: Neutral, D: Disagree SD: Strongly disagree					
MCO1	How easy is it to remember how to perform certain tasks in the PAUIs-smart TV?	SA	A	N	D	SD
MCO2	Did you find the features and functions on the PAUIs-smart TV helpful or useful?	SA	A	N	D	SD
MCO3	Did you find the amount of information on the PAUIs-smart TV screen helpful or useful?	SA	A	N	D	SD
MCO4	Are the features and functions of the PAUIS-smart TV easy and quick to use?	SA	A	N	D	SD
MCO5	I found the apps and channels on PAUIs-smart TV are organized.	SA	A	N	D	SD
MCO6	I found it easy to remember the steps needed to complete a task on the PAUIs-smart TV compared to other UIs.	SA	A	N	D	SD
MCO7	Are the abbreviations and acronyms used in the PAUIs-smart easy to interpret?	SA	A	N	D	SD
MCO8	I found the PAUIs-smart TV to be too complex for my needs.	SA	A	N	D	SD
UP	**User Privacy:** SA: Strongly agree, A: Agree, N: Neutral, D: Disagree SD: Strongly disagree					
UP1	Does the PAUIs-smart maintain user privacy while using the smart TV?	SA	A	N	D	SD

Usability Parameters (5 Scale) (*continued*)

	Question	5	4	3	2	1
UP2	To what extent do you feel that your privacy is protected on PAUIs-smart TV?	SA	A	N	D	SD
MUI	**Minimal User Interaction:** SA: Strongly agree, A: Agree, N: Neutral, D: Disagree SD: Strongly disagree					
MUI1	Does the PAUIs-smart TV is smart enough to minimize user interaction?	SA	A	N	D	SD
MUI2	Does the PAUIs-smart minimize user interaction while performing common tasks?	SA	A	N	D	SD
MUI3	How much has the Automatic UI generation and adaptation option reduced the user interaction needed to use the PUIs-smart TV?	SA	A	N	D	SD
MUI4	Does the personalized features and functions of PAUL's-smart TV lead to extra complexity user interaction?	SA	A	N	D	SD
SOU	**Satisfaction of User:** SA: Strongly agree, A: Agree, N: Neutral, D: Disagree SD: Strongly disagree					
SOU1	Overall, I am satisfied with this PAUIs-smart TV.	SA	A	N	D	SD
SOU2	How satisfied are you with the features and functions of the PUIs-smart TV?	SA	A	N	D	SD
SOU3	The user interaction with PAUIs-smart TV is easy to use.	SA	A	N	D	SD
SOU4	The PAUIs-smart TV provided me with the features and functions that I needed.	SA	A	N	D	SD
SOU5	I would recommend using PAUIs-smart TV for other household members.	SA	A	N	D	SD
SOU6	The PAUIs-smart TV is easy to learn.	SA	A	N	D	SD

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