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A Mobile-Programmable Smart Mirror for Ambient IoT Environments

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***Abstract*—The purpose of this paper is to present a smart interactive mirror interface. In this paper, we describe the design and development of a futuristic mirror that offers simplified and customisable services to the home environment. On a par with the recent advances in the Internet of Things standards and applications, the mirror is designed to enable residents to control the household smart appliances and access personalised services; ensuring convenience in accessing these services with the slightest possible user intervention. The multipurpose user-friendly functionalities of the proposed mirror interface provide users with the versatility needed for better management and integration of daily tasks. A service oriented approach is adopted in the architecture of the proposed system. It consists mainly of two mobile applications devoted to the customisation of user profiles, which are displayed on the smart mirror interface once successfully paired. Moreover, in the proposed system, emphasis is particularly given to the user profile personalisation, as well as planned system interactivity and adaptability. Hence, the proposed system is set apart from others for its ease of use as well as its provision of various customised information services for user profile generation.**

Keywords: Smart mirror, ambient intelligence, IoT, mobile computing

I. INTRODUCTION

Emerging digital and communication technologies have paved the way towards the prevalence of service-oriented and versatile systems; only to lead to adopting the idea of ubiquitous computing as one of the most important aspects of our everyday lives [1]–[3]. Ubiquitous computing aims at embedding computational capabilities into everyday objects and environment, allowing them to effectively collect and process data, as well as communicate. Thus, such a networked environment, often called "Internet of Things (IOT)", is capable of understanding its surroundings, which consequently leads to improving our experience and quality of life [4]. Traditionally, ubiquitous computing involves wireless communication and networking technologies, mobile devices, wearable computers, cameras, gaming consoles, radio-frequency identification (RFID) tags, etc.

Recently, ubiquitous and pervasive computing has expanded to further include smart furniture, walls, doors, as well as specialised rooms, equipped with sensors and computing devices for recognising human activity and providing a variety of automated services [4]. This has evolved into a new paradigm, referred to as Ambient Intelligence (AmI), where humans are surrounded by intelligent and natural interfaces, forming a smart environment capable of responding to human actions [5]. Consequently, the role of emerging communication and information technology supersedes being limited to productivity and functionality growth. Its usability has to extend further to where it plays a significant role in enhancing peoples' lives by advancing the development of convenient and accessible products and services. Thus, AmI views human needs as the foundation of innovation in ubiquitous and pervasive technologies. As such, the main objectives to be considered while developing AmI services include interactivity through multi-modal user interfaces, interoperability by allowing seamless integration and access to other services, scalability, adaptability, social connectedness, and distributed design through an effortless access to a variety of services that support human interactions [6].

Even though the required technology for developing AmI systems through ubiquitous computing is rapidly evolving, its seamless integration with everyday objects in an unobtrusive manner in accordance with the above-mentioned objectives still remains a challenge. Many attempts have been made towards the implementation of smart ambient-aware technologies [7]–[14], with the main focus being on integration of ubiquitous computing with furniture or context-aware rooms. Many of these systems utilise mirrors as smart devices to provide a user-friendly interface allowing intelligent interaction between the object and the user. This allows a commonly utilised object to not only have a traditional role of image reflection, but also to process and display information in an intelligent and interactive manner. As such, some studies focus on developing interactive mirror-displays, which present information tailored to the user's personal preferences [5], [14]. Additionally, smart mirrors are often utilised for promoting a healthy lifestyle, as well as controlling household appliances [5], [15]–[17]. To allow for personalised services and customisation, such systems need to identify the users in their close proximity, which is followed by the ability to access and display their customised personal information (schedules, lists, appointments, and news). Proposed automatic methods for user recognition include face recognition [5], [11], [17], tag-based identification, biometric data, and personal belongings (e.g., toothbrush) [12]. Moreover, different methods for achieving interaction proposed in the literature include touch-based commands [5], voice commands [14], [15], gestures [18], and physical widgets [12].

The majority of the existing systems, particularly smart mirror technology, do not fully integrate all of the main objectives of AmI services. Most of the proposed solutions rely on complex sensors for localisation and identification purposes, which can be energy-inefficient and computationally expensive, as well as inaccurate given that it needs to satisfy a variety of conditions to produce accurate recognition. Moreover, these systems are often not scalable, nor adaptive, which limits the amount of offered services. Thus, this paper proposes an interactive mirror interface with highly adaptable and scalable services, which is at the same time efficient in terms of computational cost and utilised resources. Our system especially focuses on emphasising user profile personalisation and interactivity through a simplified approach for user identification and human-computer interaction. To achieve this, we propose a client-centred architecture consisting of a client mobile application for user registration, identification, and customisation of diverse services. In addition, a mobile application is integrated with the smart mirror for the purpose of user identification and displaying the user-selected services as stored in the server database.

The remainder of the paper is organised as follows. Section II presents the proposed system, Section III discusses our results, and Section IV concludes the paper.

II. Proposed Smart Mirror System

The proposed smart mirror system aims to provide users with an interactive interface for simplified and personalised services in the comfort of the user's home. It is a smart and user friendly solution presented in the form of a mirror that also acts as a gateway to interactive services, particularly those of information oriented nature, such as multimedia and news feed among others. Hence, the proposed system allows users access to customisable services, all while they are performing other tasks (i.e. grooming). As such, it serves as a convenient time-saver. Consequently, the proposed system performs the following functionalities: (i) act as an interactive mirror interface; (ii) distinguish between all users and provide the corresponding customised services; (iii) allow for custom user profile management where the user creates his/her own profile that is to be stored on the database server of the proposed system; (iv) provide the users with instantaneous real-time updates of the services that they have added, such as in the form of Real Simple Syndication (RSS) feeds.

The proposed smart mirror system has a server-client architecture, where it mainly constitutes of a web server and a database server. The database server stores the preferences of each user as well as the user's unique identification number, allowing them access to their personalised services, which will be consequently retrieved from the web server. In what concerns the client, there are two variants: two dedicated mobile applications and a hardware infrastructure. The latter is made up of a two-way mirror, a television screen, and a shadow box. An overall diagram of the architecture of the proposed system is shown in Fig. 1.

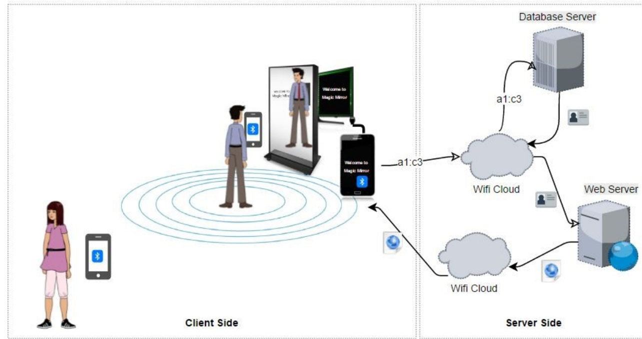


Fig. 1. Overall system architecture.

A. Mobile Application

The first variant of the developed and dedicated mobile application is to be installed on the smart phone of each user for user registration, automatic identification, and various customisation of services that are to be shown to and used by the users. The other variant is connected to the television screen for receiving and displaying the back-end information and user personalised services. Consequently, this application is in a constant state of search; scouring for nearby users and establishing a connection over Bluetooth protocol to identify the user. The closest user is the one that the proposed system serves. This is identified through finding out the strongest broadcasted signal, which automatically implies that distance to be the minimum to the proposed system. The measurement is computed through the received signal strength indicator (RSSI) of each of the media access control (MAC) addresses of the discovered nearby devices.

This setup implies that the MAC addresses of the user smart phones are already allocated in the server. Hence, each user needs to initially register, as well as identify the corresponding service preferences that he/she wishes to view on the proposed system. To register, the user utilises the dedicated mobile application installed on his/her smart phone, i.e. the first mobile application variant in the proposed system. The user needs to enter name, email, and password information, which are sent along with the MAC address of the smart phone to the server where they are consequently stored in the database server for later use and information retrieval.

Moreover, the mobile application contains a variety of services that the user can choose from by simply adding and dropping the desired ones to their created profile. This is also saved and linked to the corresponding MAC address of the user's smart phone. Moreover, our library includes many modules that have day to day interactive services that users may wish to include and customise their profile accordingly. These modules include the calendar, date and time, stop watch, calculator, Instagram, motivational quotes, music player, and stock market. Such services can be added with a simple drag and drop in the target zone (user profile), split into a grid with three rows and three columns.

Upon establishing the Bluetooth connection, the second variant of the mobile application connected to the television screen within the two-way mirror, requests the server side for the user's information and desired services for display. This is carried out over WiFi communication with the use of the MAC address for information retrieval.The mobile application then receives the required data to successfully operate and activate the system services according to the user. When users forget to create accounts on their smart phones, they will not find their personalised profiles. In such cases, they receive a message stating that there is no corresponding user profile for the smart phones in question, followed by a prompt or a reminder to create a new profile. This is shown in Fig. 2.

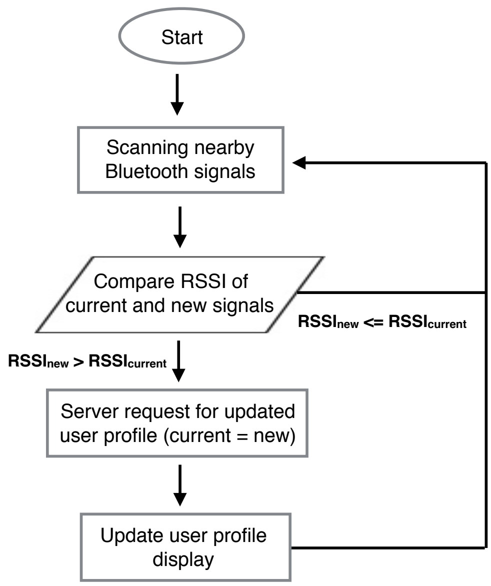


Fig. 2. Flowchart of the mirror-connected mobile application. The mobile application is constantly scanning for nearby Bluetooth signals, unless the mobile phone is turned off.

B. Proposed System Design

The proposed design of the smart mirror can be discussed in terms of two perspectives. One is in relation to the mirror's interface while the other is related to the mirror's underlying features by which services are provided.

The two-way mirror has a thin reflective coating that allows passage to an amount of light while reflecting the rest as shown in Fig. 3. It is partly reflective from one side, and is glass-transparent from the other. The reflective side is lighter in shade with a darker transparent side to prevent the reflection of light. This enables users facing the dark side of the mirror to see through, unlike the vision from the reflective (lighter) side of the mirror, through which the users can only see their reflection. We use such a mirror with a television screen for the user-personalised profile display through the connected smart phone with the dedicated mobile application. To ensure the clarity of the displayed content, we utilise a television screen with a light emitting diode technology. The screen is located behind the mirror where the light rays from the television pass

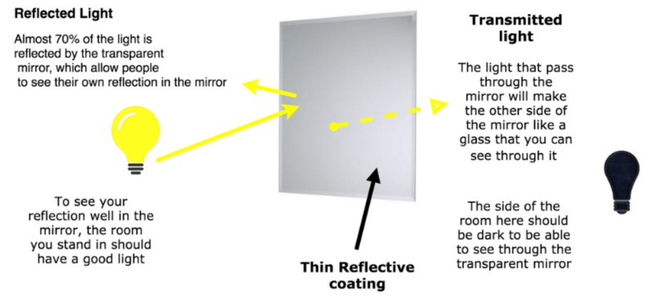


Fig. 3. Two-way mirror explained.

through the mirror since the mirror is transparent as shown in Fig. 4. Hence, while the user can see himself/herself via the smart mirror's regular mirror functionality, the user can still view the profile as per the proposed system. Moreover, to handle noise and enhance display quality, we employ a real-time sigma filter for noise reduction in digital TV signals [19].

In order to assemble the proposed system and set it up, we designed and built a shadow box, or a wooden box container. The shadow box has enough depth allowing it to hold the television screen, with the front facing side of the box being hollow to fix the mirror in it. The box also has small holes in its back to provide access to the various connectors needed such as the power chord of the television screen, as well as for the ventilation purposes to prevent overheating. Furthermore,

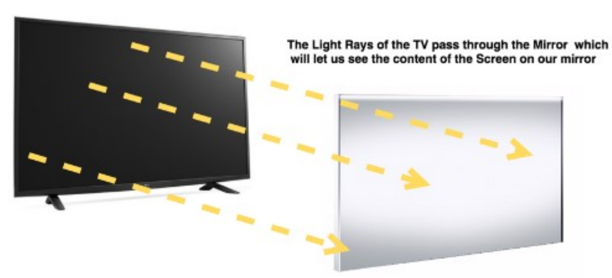
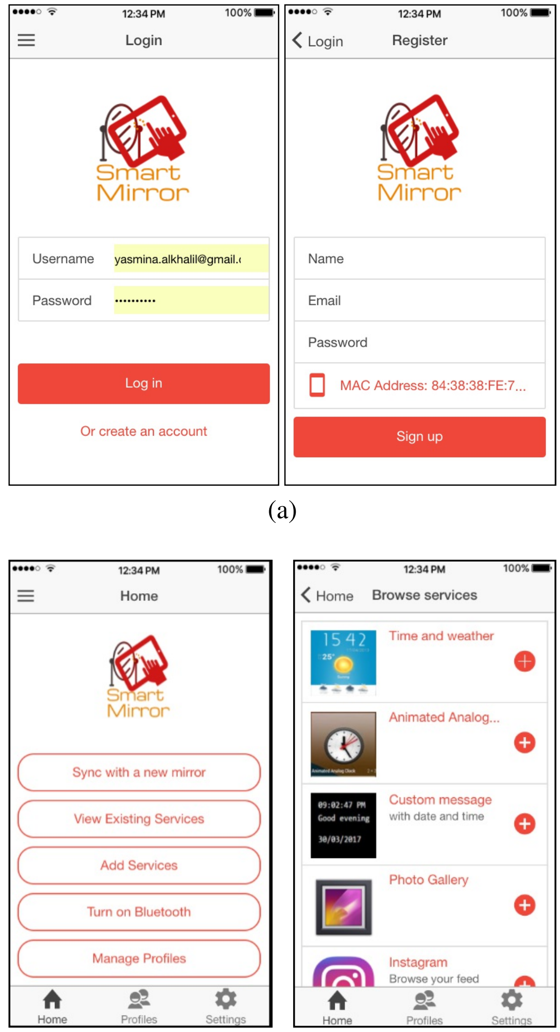


Fig. 4. Television screen for proposed system display.

the design of the shadow box consists of a wide base for maximum stability, and wheels for ease of setup regardless of the location. This further adds to the customisability and interactivity features that our proposed system fosters. More importantly, the design adheres to safety measures in terms of protection of the mirror and the complete proposed system interface. The resulting setup can be seen in Fig. 5.

One key use of the smart mirror is addressing the need to maintain a healthy lifestyle and medication plan for diabetes patients. Designing custom services allows us to integrate the mirror to medicine tracking mobile applications to remind patients of the importance of following their diabetes control plan. Fitness trackers collect other readings such as weight,

Fig. 5. Proposed system design.



(a)

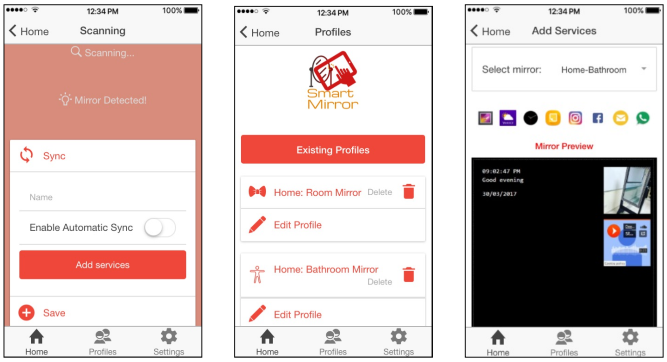
(b)

Fig. 6. Proposed mobile application work-flow. (a) shows the user log-in and registration screen and (b) the main menu and the available services to be displayed on the mirror.

heart rate, sleep quality, blood pressure, and glucose levels. An m-Health widget showing a graph of these readings provides an opportunity to create a needed feedback loop to help users lead a healthy lifestyle. The centralised server used to store user profiles along with the uniqueness of the identification of smart phones means that a user can continue to carry their custom smart mirror design everywhere a participating mirror exists. This is similar to the centralised storage of user extensions in browsers.

III. Results

Our proposed system utilises the versatility and functionality of smart-phones to integrate them with everyday objects, thus forming a smart-ambient object in an interactive, adaptive, and unobtrusive manner. More specifically, we propose a smart interactive mirror platform, which allows users to view a variety of electronic information, while performing everyday tasks, such as personal hygiene and grooming. Compared to other systems, the proposed platform is highly adaptable, scalable, easy-to-use, as well as efficient. The system is completely deployable by utilising two smart-phones paired through Bluetooth, as well as dedicated mobile applications proposed in this paper. As discussed in section II, the first variant of the mobile application is designed to provide users the ability of customising the information displayed on the mirror based on personal preferences. Moreover, it allows the user to upload the desired profile to the server and pair it with the mirror-based mobile application. As seen in Fig. 6 (a), to use the mobile application and retrieve their saved preferences from the database server, users are required to log-in with their user-name and password. On the other-hand, first-time users fill up a small registration form, where the MAC address of the user's device is automatically detected and stored in the database with the remaining information, forming a unique identifier for information retrieval and display on the smart mirror. Upon successful log-in/registration, the user is presented with a user-friendly navigation menu, shown in Fig. 6 (b). First, the user can view all of the services (or widgets) available to display on the smart mirror. These services are comprised from installed widgets or applications on the mobile phone itself. Moreover, users can add services to any existing profiles, where each profile represents a specific smart mirror that user has previously paired his device to. To pair with any smart mirror in the close proximity of the user, the user mobile application automatically syncs with the mirror-based mobile application over the Bluetooth network. Once the two devices are successfully paired, as shown in Fig. 7 (a), the user can personalise the profile, as well as permit automated syncing, which enables the user's smart phone to immediately pair with that particular smart mirror whenever it is in its' proximity. Thus, each user can setup a number of profiles, depending on



(a) (b) (c)

Fig. 7. Main functionality of the proposed mobile application. (a) shows the process of pairing with the nearby smart mirror, (b) all existing profiles created by the user, which are utilised for displaying the designated services, and (c) the preview of the services displayed on the mirror for a particular profile.

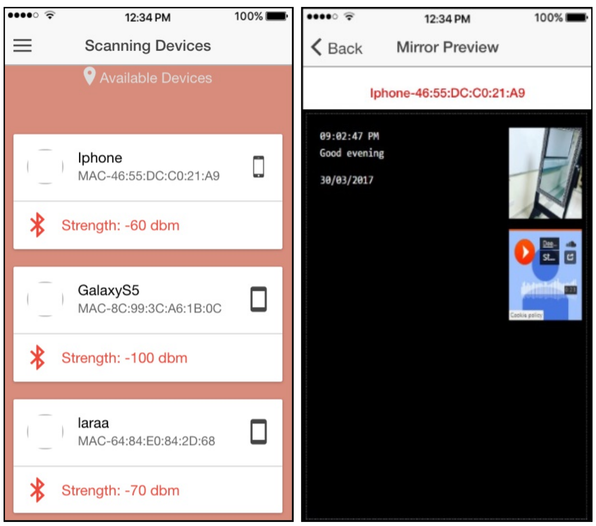


Fig. 8. Work-flow of the second variant of the mobile application connected to the television screen within the two-way mirror.

the number of distinct smart mirrors which the user's mobile phone has been paired with. A sample of multiple profiles can be observed in Fig. 7 (b), where each profile can be further edited or deleted, as needed. These profiles are stored in the database under a unique identifier consisting of the user's MAC address, user-name, and password. Finally, users are able to preview their profiles with the services as displayed on the mirror. This is shown in Fig. 7 (c). This view further provides the users with a drag-and-drop functionality, allowing them to place any available service on the preview grid of the mirror display. Consequently, this automatically updates the selected profile on the database, while the set-up of the preview reflects the current display shown on the smart mirror.

The work-flow of the second variant of the mobile application, which is connected to the smart mirror can be seen in Fig. 8. This application is constantly scanning for any nearby Bluetooth-enabled devices and measuring the RSSI of

Fig. 9. Different user profile layouts displayed on the smart mirror prototype.

each device. The device with the highest value of the signal strength is automatically served by the smart mirror, given that the devices have previously been paired. When paired with a particular device, the mobile application retrieves the preallocated, customised profile of the user and displays the chosen services on the smart mirror. While the display is enabled, the mobile application is constantly updating the list of nearby devices. As soon as a new device with a stronger RSSI value is detected, the smart mirror display is updated with the new profile belonging to the new user on the condition that the device has been previously paired with the mirror. Thus, the connection with the previous device is automatically dropped. This ensures automatisation, ease-of-use, and seamless integration, thus fulfilling one of the most important objectives of the AmI paradigm.

Services customised by the user using our dedicated mobile application can be seen displayed on the smart-mirror in Fig. 9. These can be placed anywhere on the mirror layout, allowing for adaptability, personalisation, and real-time updates. With dedicated mobile applications that automate the complete process of syncing with the smart mirror, as well as updating all services, users have an easy access to all the latest updates, ranging from social media accounts to news outlets. Thus, our proposed solution can smoothly integrate with other widgets and mobile applications installed on the user's smart-phone, as well as allow multi-modal user interfaces, personalised as per the user's desires. Moreover, our system does not require any additional devices, such as sensors; making it simple, but at the same time computationally efficient. Finally, the dedicated mobile applications are multi-platform, as well as bilingual (Arabic and English), catering to a variety of users, but also allowing for a wider selection of services and widgets to be placed on the mirror display.

Future work involves testing the system on a variety of users and in diverse settings. As such, based on user perception, the design of the system can be improved to be more user-centered, especially considering the choice of customisable services and personalisation of profiles. Furthermore, with the current framework, we have the ability to address the need for efficient and automated health plans, by integrating our system with existing mobile health and medicine tracking applications. Having a user-friendly widget, displaying the latest changes in the user's biometric and fitness data, would significantly improve health awareness and allow for early risk detection. As such, we plan to expand and test the current system in the light of health management and awareness services, especially when it comes to medicine reminder services, such as in the case of diabetic patients.

IV. Conclusion

This paper proposes a futuristic smart mirror system that provides users with an easy-to-use mirror interface, allowing users access to customisable services in a highly interactive manner, while performing other tasks simultaneously. This facilitates the vision of ubiquitous and pervasive computing, as well as paves the way towards instilling the paradigm of Ambient Intelligence and smart environment concepts in our everyday lives. The proposed system allows users to utilise a commonly found household object as an interactive interface for displaying a variety of information services and regular updates from different domains of social media and news outlets. These can be customised by utilising a dedicated mobile application, which allows users to create and manage their profiles based on what they wish to display on the smart interactive mirror. The personalised profile is then stored in the database server, from which it is retrieved by the mobile application connected to the television screen within the two-way mirror. This happens in an automated manner as soon as a new device is detected in the close proximity to the mirror. In the event of multiple nearby devices to the smart mirror, the profile of the closest device is displayed, based on the measurement of the RSSI strength. Overall, the proposed smart mirror system incorporates various functionalities to grant users access to personalised information services and a control of household smart appliances.

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