Realization of Personalized Services for Intelligent Residential Space based on User Identification Method using Sequential Walking Footprints

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ABSTRACT

A new human-friendly assistive home environment, Intelligent Sweet Home (ISH), developed at KAIST, Korea for testing advanced concepts for independent living of the elderly/the physically handicapped. The concept of ISH is to consider the home itself as an intelligent robot. ISH always checks the intention or health status of the resident. Therefore, ISH can do actively the most proper services considering the resident's life-style by the detected intention or emergency information. But, when there are more than two residents, ISH cannot consider the residents' characteristics or tastes if ISH cannot identify who he/she is before.

To realize a personalized service system in the intelligent residential space like ISH, we deal with a human-friendly user identification method for ubiquitous computing environment, specially focused on dynamic human footprint recognition. And then, we address some case studies of personalized services that have been experienced by Human-friendly Welfare Robot System research center, KAIST.

Keywords: Personalized Service, Intelligent Residential Space, Footprint Recognition, Intelligent Door, Interactive Robot, Intelligent Mirror

1. INTRODUCTION

In recent days, a new technology called as ubiquitous computing has appeared as the rapid growth of computer and network technologies. Ubiquitous computing can be explained with three keywords: everywhere, invisible, and unconsciously [1].

- Computer will be embedded everywhere.
- Computer will come to be invisible to common awareness.
- People will simply use computers unconsciously to accomplish every task.

By this ubiquitous computing technology, we can experience a new kind of service in the near future which can be called as a personalized service based on active user identification. In here, personalized service can be understood as a service which is customized by the user's own taste or interest [2]. Let's imagine an example as following:

(Example) A person comes in a GAP store, a representative store for selling jean wears. A service system in the GAP store finds actively who he/she is by checking his/her iris. And then the service system extracts his/her previous purchase data using the GAP's customer database. After that, the system tells him by voice like this: "Hello, Mr. Yakamodo. Welcome back to the GAP. How was the tank-top of GAP for you?"

The above example was borrowed from a Hollywood SF movie, "Minority Report." It is just a fiction. But, this is exactly the situation that can explain the meaning of the term "personalized service" and the effectiveness of this personalized service system based on ubiquitous computing.

The next one is real story. Fig.1 shows the appearance of intelligent residential space (IRS) which has been developing in HWRS-ERC, KAIST, Korea. The concept of IRS is to consider the home itself as an intelligent (parent) robot. IRS has 6 components: Intelligent Bed, Intelligent Wheelchair, Mechatronic Transfer Robot, gesture-based human-robot interface (Soft Remocon), voice-based management system, and continuous health monitoring system. IRS always checks the intention or health status of the resident. Therefore, IRS can do actively the most proper services considering the resident's life-style by the detected intention or emergency information. But, when there are more than two residents, IRS cannot consider the residents' characteristics or tastes if IRS cannot identify who he/she is before.

To realize a personalized service system, which will be explained more in Section 2, we deal with active, human-friendly user identification method for ubiquitous computing environment in Section 3. And then, we address some case studies of personalized services, in Section 4, that have been experienced by Human-friendly Welfare Robot System research center, KAIST.

Fig.1 Intelligent Residential Space, HWRS-ERC, KAIST

2. PERSONALIZED SERVICE

With advance of technology and society, each person cannot manage such tremendous information and resources. According to recent trends, each person prefers specialized service for himself/herself and many software companies also try to make such specialized services for their purpose. For example, ‘Customer Relationship Management (CRM)’ aims to manage good eternal relationships with their customers by adopting ‘Next generation personalization’ [3]. In here, it is important to recognize each person’s need and preference as soon as possible for providing them the best service. As another real-world example for personalized service, we can talk about the waiter who serves for customers in the restaurant. The waiter has to provide the best service for each regular customer even though their different culture, habits, distinct, sex and so on. For this purpose, he tries to learn each person’s characteristics through many trials and errors.

The personalized service has some features as follows [4]:
- Personalized service is used to satisfy the service of a special (or specific) person.
- The data in personalized service should be “private.”
- The more personalized the service, the higher clients’ interest.

As a general structure for the personalized service, we propose architecture as shown in Fig.2 [5][6]. In here, the user’s various behaviors are sensed by the service agent who provides the personalized service for the user. Through this sensing step, core behavioral information is extracted and personal identification is performed. For personal identification, we can also adopt so many previous works on fingerprint, footprint, facial shape, voice, iris information and so on. Through the personal identification, personal ID is acquired to search the appropriate service in the service pool for currently identified person. In the service pool, various kinds of different services are already stored through learning and modification. Thus, after this step, the service agent can provide necessary personalized service (the best service) for the user.

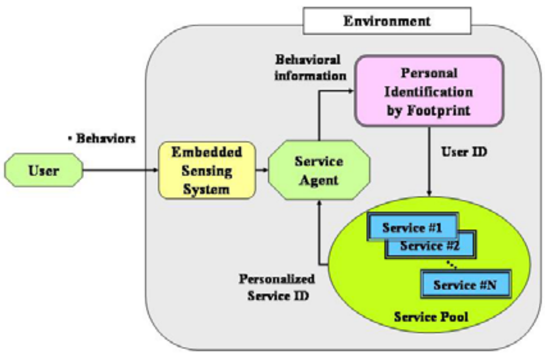


Fig.2 Structure of Personalized Service

3. USER IDENTIFICATION

As for the user identification method, many diverse methods have been developed for the purpose of security [7] and personalized service [8]. Starting from person’s possession like keys and person’s knowledge like passwords, many kinds of automated methods are started to be used in many places. Biometrics is the automated use of physiological or behavioral characteristics to determine or verify identity [8]. Many biometrics has been developed like palm print, face, retina, voice, signature, keystroke, ear, gait, etc. And these techniques are verified as a good or bad one in the view of universality, uniqueness, permanence, collectability, performance, acceptability and circumvention [9]. Table 1 shows the comparison of various biometrics in these points of view.

Table 1. Comparison of Various Biometrics

Biometrics	Univ.	Uniq.	Perm.	Col.	Perf.	Acc.	Cir.
Face	H	L	M	H	L	H	L
Fingerprint	M	H	H	M	H	M	H
Hand Geometry	M	M	M	H	M	M	M
Keystrokes	L	L	L	M	L	M	M
Hand Vein	M	M	M	M	M	M	H
Iris	H	H	H	M	H	L	H
Retinal Scan	H	H	M	L	H	L	H
Signature	L	L	L	H	L	H	L
Voice Print	M	L	L	M	L	H	L
Thermograms	H	H	L	H	M	H	H
Odor	H	H	H	L	L	M	L
DNA	H	H	H	L	H	L	L
Gait	M	L	L	H	L	H	M
Ear	M	M	H	M	M	H	M

Univ.=Universality, Uniq.=Uniqueness, Perm.=Permanence, Col.=Collectability, Perf.=Performance, Acc.=Acceptability, Cir.=Circumvention, H=High, M=Medium, L=Low

And, biometrics could be divided into two groups, physiological data-based (body odor, face, retina, iris, fingerprint, palm print, hand geometry, skin pores, and wrist/hand veins) and behavioral data-based (signature, keystrokes, voice, gait, gesture) [10]. But, it is important to note that the behavioral/physiological distinction is slightly artificial. Behavioral biometrics is based in part on physiology, such as the shape of the vocal chords (voice) or the dexterity of hands and fingers (signature). Physiological biometric technologies are similarly informed by user behavior, such as the manner in which a user presents a finger or looks at a camera.

If we see Table 1 as above two groups, we can find characteristics of two groups. Physiological biometrics is more universal, more unique, more permanent, and have better performance generally. Besides, behavioral biometrics is more acceptable, i.e. human-friendly. Therefore, we can confirm that behavioral biometrics is better than physiological one in the acceptability, in other words, easy-to-useness or human-friendliness. Among the widely known behavioral biometrics, use of gait has many advantages in the application area since signature or keystroke require the user to use specific device such as Keypad, PDA, or Keyboard but gait is basically measured without consciousness of the user. Therefore, use of gait is one of the most appropriate methods for the application which acceptability or human-friendliness is strongly emphasized like home environment. In addition, use of gait could be applied in the ubiquitous computing environment which is based on three keywords: everywhere, invisible, and unconsciously. In here, we use ‘dynamic footprint’ as a clue for user identification, which can be understood as 2D projected type of human gait information.

A. User Identification Method using Sequential Walking Footprints

To extract human footprint during natural walking, we use a mat-type pressure sensor array. Mat-type pressure sensor (MAT sensor) is more human-friendly than shoe-type one since it does not need to be equipped by human, and is more robust to noise than shoe-type sensor since the sensor is fixed on the floor. In addition, since the shape of left foot and right foot are not symmetric generally [11], we use not a single foot's print but one-step footprints which includes both left and right foot regardless that which foot appears first during walking. Fig.3 shows an example of one-step walking footprints.

Fig.3 Example of a One-step Footprint

Feature Extraction

To deal with the problem more easily and skillfully, we make five assumptions (A-1) ~ (A-5) [12].

(A-1) There is no other object on the MAT sensor except the walking person.

(A-2) There is only one walking person on the MAT sensor in each trial.

(A-3) During one's walking one the MAT sensor, at least one element of the MAT sensor is fired.

(A-4) Normally, users always walk along the designated direction (outdoor-to-indoor) on the MAT sensor.

(A-5) User's step length (the distance between the Center Of Area, COA, point of the first foot and that of the second foot) is greater than a maximum foot length, L_{MAX_FOOT}.

By the assumptions (A-1) and (A-2), we can find the starting time of the one-step walking on the MAT sensor, $t_{FIRST\_FOOT\_START}$, by checking when the total pressure value is greater than the threshold value. The assumption (A-3) indicates that the total pressure value is always greater than the threshold value during a single gait cycle. This assumption (A-3) is a constraint of maximum walking speed and is generally valid during walking, but not during running. And, by the assumption (A-3), we can check the ending time of the one-step walking on the MAT sensor, $t_{SECOND\_FOOT\_END}$. The assumption (A-4) helps us easily to find the reference direction for directional alignment of each foot. And (A-5) is for discriminating the left foot and the right foot part in the one-step footprint. Here, maximum foot length, L_{MAX_FOOT}, is determined according to the analysis of the user group. In our experiment, L_{MAX_FOOT} is determined as 300mm.

The procedure for extracting overlapped foot shape and COP trajectory of each foot in the one-step walking footprint is as follows:

At time t, $t_{FIRST\_FOOT\_START} \leq t \leq t_{SECOND\_FOOT\_END}$:

Step1) Labeling of each blob

We make a label for each blob in the current footprint image using the scanning line method [13]. When the scanning line meets a segment, a number is given to the segment.

Step2) Finding center of area (COA) point of each blob

We find COA points of all labeled blobs. The COA points are used to determine whether the current blob is a part of the first foot or the second foot.

Step3) Discrimination of the first foot and the second foot

A k-means clustering algorithm is used to discriminate the first foot and the second foot. If the distance between the current blob's COA point and the previous COA point of the first foot is greater than the maximum foot length L_{MAX_FOOT}, the current blob is considered as a part of the second foot. And, we re-estimate the first foot's COA point and the second foot's COA point with these additional blobs.

Step4) Checking whether the time of current frame, t, is $t_{FIRST\_FOOT\_END}$ or $t_{SECOND\_FOOT\_START}$

We determine $t_{FIRST\_FOOT\_END}$ by using the number of blobs in the first foot ($t_{SECOND\_FOOT\_START}$ is determined from the second foot). This process is valid under the assumption (A-3).

Step5) Updating COP trajectory of each foot

We calculate the COP points of the first/second foot and update the COP trajectories of each foot.

Step6) Updating overlapped footprint image

We update the overlapped footprint image by doing OR operations on all partial footprint images during $t_{FIRST\_FOOT\_START} \leq t \leq t_{SECOND\_FOOT\_END}$.

At time t = $t_{SECOND\_FOOT\_END}$:

Step7) Determination of the orientation of each foot using the principal axes of the overlapped footprint image

We find the principal axes of each foot using the overlapped footprint images of each foot. The principal axes of a region are the eigenvectors of the covariance matrix obtained by using the pixels within the region as random variables [13].

Step8) Finding the aligned overlapped foot shape

We translate each foot part in the overlapped footprint so that COAs of each foot part become fixed points. And we rotate each foot part with the result of Step7.

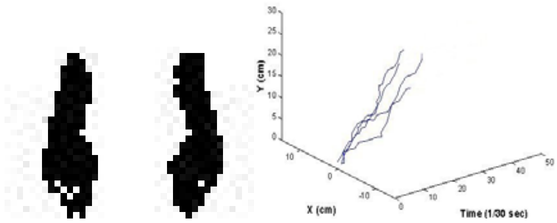
Step9) Creation of the aligned COP trajectory (COPT)

We translate the original COP trajectory so that the starting point of the trajectory becomes the origin and we rotate the translated COP trajectory to eL2 (or eR2) degrees for directional alignment. The directionally aligned COP trajectory is represented like equation (1) and (2):

$$TRAJFIRST\_FOOT\ (t) = [x, y]^T, \quad \text{where } t_{FIRST\_FOOT\_START} \leq t \leq t_{FIRST\_FOOT\_END}. \tag{1}$$

$$TRAJSECOND\_FOOT\ (t) = [x, y]^T, \quad \text{where } t_{SECOND\_FOOT\_START} \leq t \leq t_{SECOND\_FOOT\_END}. \tag{2}$$

From Step1~Step9, we can obtain the aligned overlapped foot shape (result from Step8) and COP trajectories of each foot (result from Step9) such as Fig.4 from a one-step walking footprint. And, this information can be used as cues for user identification.



(a) Overlapped foot shape (b) COPT of right feet (4 users)

Fig.4 Exemplary Template for User Identification

User Identification: Use of Overlapped Foot Shape
Given the templates like Fig.4 (a), we can compare these templates I_A with new overlapped footprint I_B by Nakajima et al.'s dissimilarity measure [15] like equation (3).

$$DM = \sqrt{\sum_{x,y} \{I_A(x,y) - I_B(x,y)\}^2} \qquad (3)$$

User Identification: Use of COP Trajectories
Since the COP trajectories of human footprint like Fig.4 (b) are temporal sequences with variable length and noisy information, we used hidden Markov model (HMM) [14] to compare two COP trajectories. In addition, even in the same person, the left foot and the right foot are not symmetric and have different COP trajectories [5][12]. So, we used two set of HMM models for the first foot and the second foot in one-step like Fig.5.

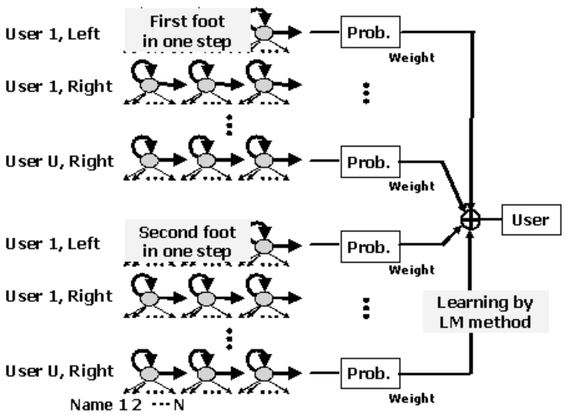


Fig.5 COPT Recognizer using HMM [16]

User Identification: overlapped foot shape + COPT
Combining previous two recognizers, we made the combined recognizer like Fig.6. After comparing the given sequential footprint with N existing templates, we got $2N$ comparison outputs in the case of N users. Using these $2N$ outputs and proper weights which were updated by Levenberg-Marquart learning method [18], we can get the final decision output.

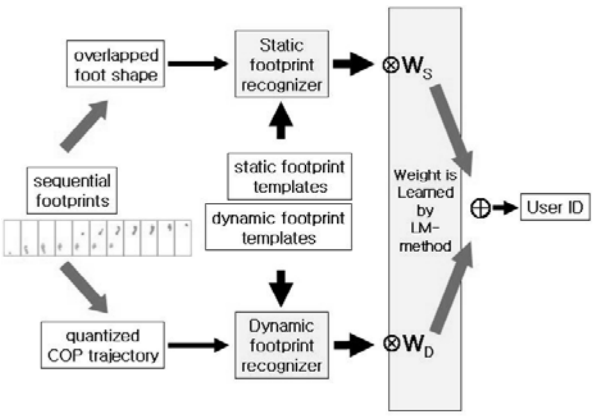


Fig.6 Combined Recognizer for Dynamic Footprint [17]

Experimental Results
For the performance test of dynamic footprint-based user identification method, 11 subjects were participated. The average weight and height of all subjects are 67.0 (±15.2) kg and 170.4 (±6.4) cm. As a MAT sensor, we used FOOT ANALYZER (TechStorm Inc., Korea) as shown in Fig.7. The size of sensor is 80×40 cm^2 including 80×40 sensors (1×1cm^2 resolution) and the frame rate is 30 Hz. In each trial, each subject gives 10 one-step footprints using MAT sensor. During two months, 40 one-step footprints are acquired from each subject. Among 40 one-step footprints, first 20 footprints of each user in one month are used as learning samples to make templates and the other 20 footprints of each user in the next month are used for test.


Fig.7 Mat-type Pressure Sensor, FOOT ANALYZER

For the performance test, we used FRR (False Rejection Rate) and FAR (False Acceptance Rate) concepts [9][10] like equation (4) and (5) which are the most famous performance measures in biometrics area. The results of performance test are summarized in Table 2. Finally, the minimum FRR error of the combined recognizer is 1.36%.

$$FRR = \frac{NFR}{NAA} \times 100 \quad (\%) \qquad (4)$$

$$FAR = \frac{NFA}{NIA} \times 100 \quad (\%) \qquad (5)$$

where *NFR* and *NFA* are the numbers of false rejections and false acceptances, respectively. *NAA* and *NIA* are the numbers of authorized attempts and impostor attempts, respectively.

Table 2. Dynamic Footprint-based User Identification Errors (num. of users = 11, unit: %) [17][18]

User ID	Foot shape		COP trajectory		Foot shape + COP trajectory	
	FRR	FAR	FRR	FAR	FRR	FAR
Average	8.64	0.86	20.45	2.05	1.36	0.14

4. CASE STUDIES ON THE REALIZATION OF PERSONALIZED SERVICE

The proposed user identification method using sequential walking footprints can give us the user ID repetitively, regardless of whether the user is standing or walking. Using this user ID, various types of personalized services can be realized. Here, three successful applications are introduced which has been realized by our team.

A. Personalized Greeting Generation by Intelligent Door
Using the suggested user identification method, we have implemented an Intelligent Door System [19] which is a personalized service system for the futuristic ubiquitous residential space and can recognize the permitted user group and open the door automatically when the permitted user comes. Fig.8 shows the conceptual and real shapes of

Intelligent Door System. When a person walks on the hidden and embedded sensor before the door, the control system like a home server notice who he/she is or whether this person is permitted or not. If the person is permitted, then the system opens the door and tells him a personalized greeting including his name and about new messages for him such as titles of non-read e-mails and if not permitted, the system does not open the door.

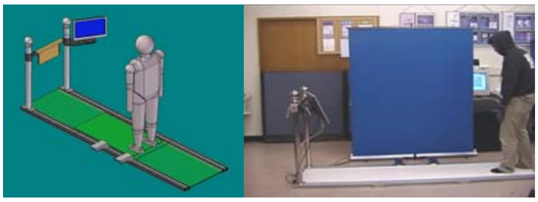


Fig.8 Intelligent Door System [19]

The administrator of Intelligent Door System can register a new person to the permitted group using the administrator interface like Fig. 9. The administrator can select the user identification mode among the use of overlapped foot shape, the use of COP trajectories, and the use of both overlapped foot shape and COP trajectories. For the registration of overlapped foot shape, more than two walking actions are required. And for the registration of COP trajectories, more than 10 walking actions are recommended.

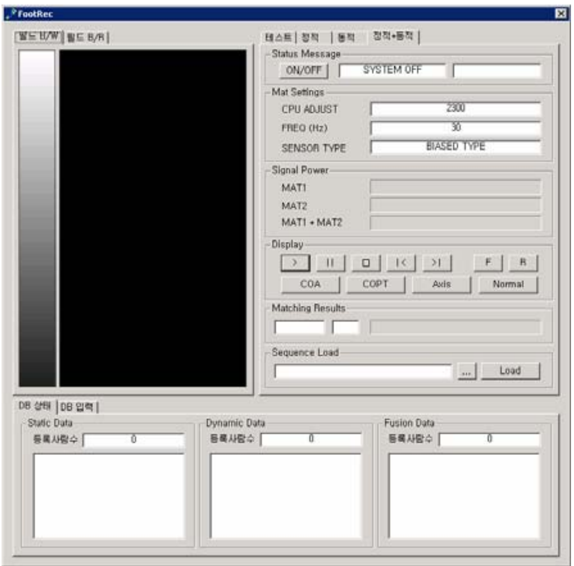


Fig.9 Administrator Interface of Intelligent Door System [20]

B. Personalized Music & Dance Generation by Interactive Robot Dancing "Becky"

The purpose of the interactive robot, "Becky", is to help human mentally and emotionally. To achieve this goal, Becky has been made to be able to observe the user's behavior by giving emotion invoking actions to human and to estimate user's emotional state and finally to provide the user with appropriate actions taking into account the estimated emotional state. I.e., the notion of "emotion" is applied to service robot. By the help of neural network structure, Becky can understand the user's emotional condition using environmental sensor data (temperature and humidity sensor) to check the discomfort index and behavioral sensor data (CCD camera, ultrasonic sensor, and photo transistor) to check user's stroke or smooth motions to the robot and a facial direction with respect to the robot. And Becky shows its reaction by the form of music and dancing among genres of Dance, Ballad, and Rock, depending on the user's emotional state [21].

Since each person has his/her own taste or preference on music, separate reaction model for each user is made to realize a personalized service as the given ID from the proposed user identification method. If the current user is already registered, Becky gives a pre-learned music and dancing service depending on the user's emotional state (See Fig. 10). And, if not registered, Becky asks the user to register and starts the learning process. In here, reinforcement learning is used with the user's behavioral data as reward.

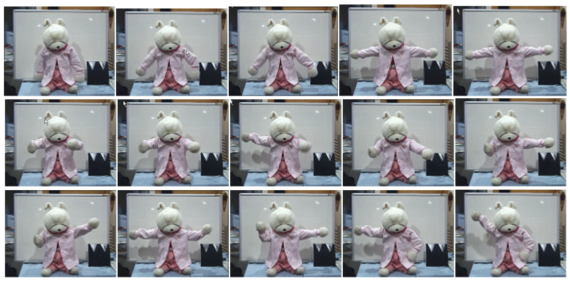


Fig.10 Dancing Example of Interactive Robot, "Becky"

C. Personalized Information Retrieval & Makeup Support by Intelligent Mirror System

Intelligent mirror system is a human-friendly human-computer interaction system using a half-mirror and voice interface. Half-mirror interface system [22] based on computer vision consists of several elements such as a half-mirror, 2 LCD monitors, one USB camera, a microphone, two speakers, processing unit, etc (See Fig. 11).

When a user stands up in front of the intelligent mirror system, the MAT-type pressure sensor can recognize him/her by the user identification method only using the overlapped footprint. Given the user ID, this system can do two operation modes in accordance with the condition that it receives facial information from USB-camera. One mode is activated as a mirror like Fig. 12 (a) when USB-camera detects the face. And it mainly provides 2 functions. One function is magnification of facial components, providing with personalized makeup guide. Another function offers daily information such as weather or news as the taste of the current user.

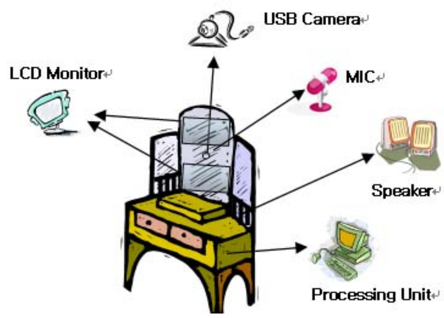
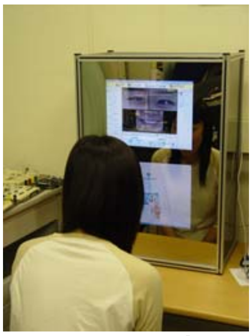
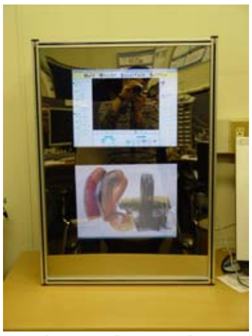


Fig.11 Structure of Intelligent Mirror System [22]

Another mode is activated as a display unit like Fig. 12 (b) when USB-camera doesn't detect the face. It also provides two functions for the user. For the purpose of decoration, it provides canvas where decorative arts or photographs are shown. With soothing music played, user can comfortably enjoy his life. Healing window named because it provide specially designed picture and music which has psychological healing capability was introduced. It gives psychological comfort to user who gets under pressure and fatigue. All functions operate based on voice interface which uses commercial product.





(a) Mirror Mode (b) Display Mode

Fig.12 Mirror / Display Mode of Intelligent Mirror System [22]

5. CONCLUDING REMARKS

Dynamic footprint-based user identification method is a new, human-friendly biometric technique which is good at ubiquitous computing environment. In this paper, the concept of personalized service was introduced and the realization method for personalized service was explained with dynamic footprint-based user identification method. From the successful case studies of personalized services such as personalized music & dance generation robot, personalized greeting service by Intelligent Door and personalized information retrieval and makeup support by Intelligent Mirror, we can expect that these personalized services with user identification method using sequential footprints can enhance the quality of our life in the near future. As further works, more studies on measuring user satisfaction degree and enhancing the degree are required.

ACKNOWLEDGMENT

This work is partially supported by the SRC/ERC program of MOST/KOSEF, Korea (Grant #R11-1999-008).

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