A Feasibility Study of Sixth Sense Computing Scenarios in a Wearable Community

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Abstract. We propose a communication method for more abundant interaction using a sixth sensory channel for diffusion of multimedia files in a wearable computing environment. We suggest applications connecting people with their possessing media files as the most suitable applications for introduction of the wearable computer to the public. Sixth sense computing is a name that we use for the study of new possibilities that will be enabled by a wireless multimedia channel between wearcomp users. Scenarios enabled by sixth sense computing are developed and implemented in a wearable computer platform. We demonstrate possible requirements for new types of interaction style, an interface for a wearable computer application, and dynamic variation of society by varying system parameters such as the media selection method for diffusion.

Keywords: Wearable computer, ubiquitous computing, wearable community, sixth sense computing, new interaction style.

1 Introduction

There have been two parallel flows in the evolution of small computers. One is the cell phone, which, starting as a communication device, has begun to evolve into a full-fledged computer. The other flow is the PDA, which is evolving into basically the same form but started as a digital assistant device. Despite having the same ultimate destination, the two paths taken by the two different devices shows significant contrast: the cell phone has been the incomparably dominant flow. The main difference lies in their main applications: connecting people vs. augmenting people.

A wearable computer is still in its infancy, and is expected to take similar paths as the cell phone and the PDA. The main application of wearable computer thus far has been augmenting people, while it has played a relatively minor role in connecting people. The history of small computers tells us that the wearable computer should adopt a right application timely, and we believe such an application is connecting people. A right application will enable early entrance of the wearable computer into the consumer electronics market, which in turn will fuel its further accelerated evolution.

We have been exploring new possibilities of the wearable computers as a communication device. In particular, we are interested in new modes of communication with the “Six-sensory channel (SS)” enabled by the network of

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wearable computers, as illustrated in figure 1. People may "wear" pictures, music, and movies. A bench may become older with multimedia "stains". People may "infect" family with news. All these new scenarios raise many new questions about a new interaction model, new multimodal interfaces, and new information dynamics. These aspects are being studied under the name of Sixth Sense Computing (SSC), and we report here some early results including a few scenarios and their implementations with Ubiquitous Fashionable Computers (UFC) [1].

2 Proximity-Based Communication

Some researchers have proposed proximity-based communication for computer-supported cooperative work for enhancing work efficiency. Others have suggested the concept of an 'aura' in a short ranged network connection providing a digital communication link in face-to-face encounters, or enhancement of social networks [2, 3, 4]. The sixth sensory channel that connects UFC wearers is basically the same as the short-ranged network connection described in these earlier studies. In SSC, however, the use of the channel is generally not implemented for work efficiency or information sharing but more for changing communication, e.g., transforming strangers to friends and for experience diffusion between generations. Also, the new channel is not only between people but also between people and ubicomp devices.

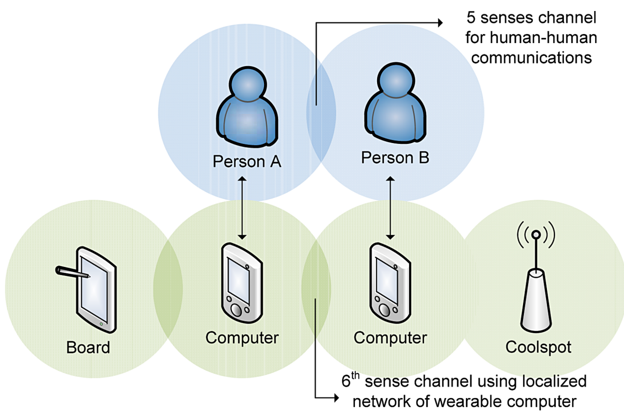

Fig. 1. In addition to the existing 5 senses for communication between people, there is a 6th sense channel that makes possible communication with others, various devices, and the environment around UFC wearer

3 SSC Scenarios

We have developed nine scenarios - SS Media, SS Fashion, SS Tag, SS Vision, SS graffiti, SS Couple, SS Coolspot, SS Commercial, and SS Says - that can be enabled by SS with a localized network, and three have been implemented and studied by a computer simulation.

We can use SS to spread multimedia contents representing ourselves, such as tags, music, photos, and news for better communication, to people nearby much like we wear perfume. The scenario where SS serves such purposes is called “SS Fashion.”

The next is about spots where people come and go and/or spend time together. Such a spot may serve multimedia contents, and these may be selected from multimedia worn by people in or near the spots. With a suitable algorithm for selecting representative items from a media pool gathered from the people, the spot can develop its identity autonomously. Such a spot and the scenario are called “SS Coolspot.”

The last means is a more large-scale scenario that can be expected in a wearable community. With SS, a multimedia file can migrate from person to person just like a rumor or a cold spreads. As suggested by many marketers’ research about WOM [5, 6], SS can play an important role to popularize media items reflecting social distances between people. If some people spend more time together, there is more chance to exchange experiences, e.g., photos, music, or news they like and/or possess. The scenario of information diffusion by SS is called “SS Says.”

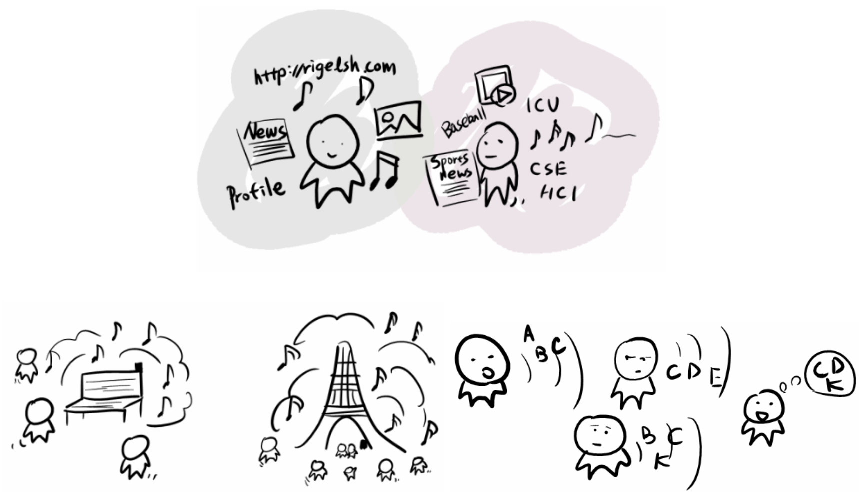

Fig. 2. People who wear UFC can show their media items to people nearby (*upper figure*). The media files carried by people can be accumulated at a Coolspot; a bench in a park, a coffee shop, or a bus stop can be a Coolspot (*left figure*). Media diffusion is possible through Sixth Sense Computing (*right figure*).

4 Implementation

We implemented the first two scenarios, SS Fashion and SS CoolSpot, on a wearable computer platform (UFC). The last scenario SS Says is studied by a computer simulation as it requires long-term investigation via a large-scale experiment with a large amount of wearable computers, and the current UFC platform could not support the scale required for SS Says. This chapter shows the system design and initial system implementation on the UFC platform.

4.1 Platform

UFC[1], a wearable computer platform developed by the present authors, is an ARM-based computer that supports multi-mode network connection: WLAN, Bluetooth, and Zigbee. It has a LCD display, a camera, a microphone, earphones, and a 3 × 4 keypad, and the computing modules are weaved into clothes as shown in figure 3. The location information of all wearable computers is provided by a multi-modal network, and is utilized to find other wearable computers in proximity. The wearable computer as well as the network infrastructure is illustrated in figure 3.

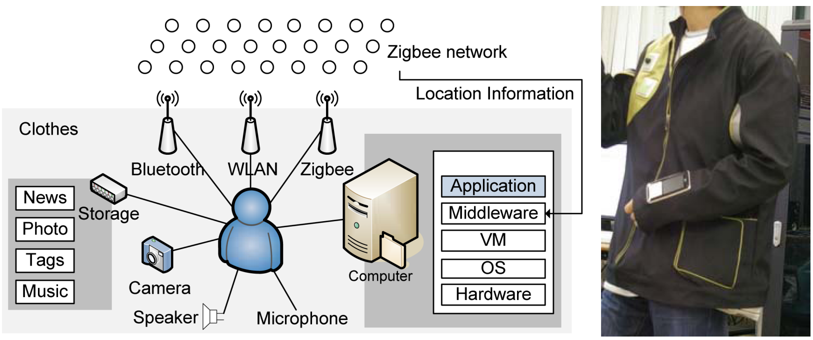

Fig. 3. The scenarios, SS Fashion and SS Coolspot, are implemented as an application on the UFC platform, and a bundle running on middleware. All the items in the outside gray rectangle are included in the UFC clothes (*left figure*). The main computing module is located on the wearer's wrist and other devices are connected to WearNet, the device network in the clothes.

4.2 SS Fashion

The wearcomp has a 320 × 240 display on the wrist and a VGA output for HMD. As a person approaches others, his/her display shows neighbors' name tags, favorite news, and saved or taken photos, as shown in figure 4, and one of the songs owned by

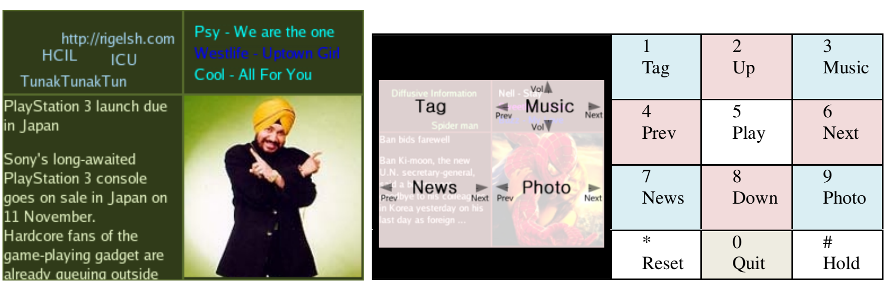

Fig. 4. Screenshot of UFC display that contains tags, news, photos, music list (*left figure*) and the method to see all items using 4-direction buttons (*key 2,4,6,8 in 3 × 4 keypad*). The mode selection among 4 different modes is possible with keys on the corner (*key 1,3,7,9 in 3 × 4 keypad*).

neighbors will be played on the earphones. When a person meets a new neighbor, a whole tag item is delivered and one of his/her multimedia files are selected and transferred. For multimedia file selection, the probability of transmission is assigned to multimedia files linearly according to their rank. Multimedia files are piled on a stack as people move around, and the wearer can select one of 4 display modes or see all items using a keypad. Because function selection with a small pointer or menu navigation with an arrow key can occupy the user's intention too much [7], 4 buttons are directly matched to the position of each media arrangement, i.e., each corner of the display.

4.3 SS Coolspot

SS Coolspot tracks neighbors and collects multimedia data; specifically, only music data in the current version. While collecting music from neighbors, it forms the most representative cluster using a spherical k-means algorithm, where a music item is represented by an n-dimensional feature vector. As shown in figure 5, the music item at the center of the largest cluster is selected and played as background music, and one of the items in the largest cluster are selected and passed to neighbors with regard for individual musical taste.

The more detailed algorithm of Coolspot is as follows. Coolspot collects N music items until the N music items develop a certain distribution in the feature space. Coolspot then identifies 'k' clusters in the collected music distribution with the spherical k-means algorithm. In a pilot experiment, 56 music items were collected and each of them was represented as an 80-dimensional binary vector with genre, artist, year, and mood attributes. Classified 'k' clusters have k centers, and thus N music items are labeled as the nearest center of the clusters. From this point, Coolspot continuously collects music items and those items are temporally labeled as soon as

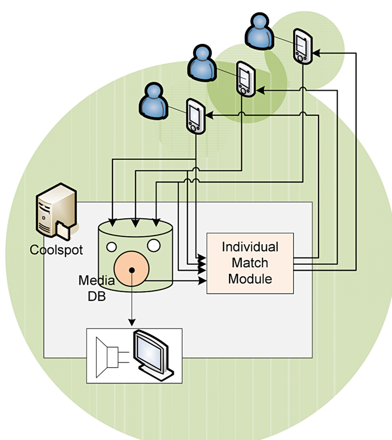

Fig. 5. The music item that is nearest to the center of the largest cluster is selected and played as background music, and items in the largest cluster are selected with individual match modules and passed to neighbors of Coolspot

they are collected in media database as the cluster having the nearest center. When every M music items is collected in the database, the centers of clusters are reconfigured reflecting the effects from temporally added music items. The next step is the same as the step of finding convergence in the k-means algorithm – all music items are re-labeled with reconfigured k centers until the centers of clusters are converged and stable. After convergence of clusters, a music item that is closest to the center of largest cluster is selected as the most representative music for that moment.

The implemented Coolspot algorithm has been running in a virtual 3-D environment in which people can experience the communication enabled by SSC. The Coolspots gather music from visitors and serve selected music from the accumulated music pool.

4.4 SS Says

We designed a series of computer simulations for studying the dynamics of information flow in a community linked by SS. We anticipated the results will depend on the algorithm for music selection as well as many other parameters reflecting individual characters and geometric constraints. Although this is a simplistic simulation, we attempted to make it as realistic as possible with various features of the person model, space model, and interaction methods.

Person Design. Each person has a musical taste that is expressed by a 3-dimensional vector – we can choose the three most influential, quantitative attributes in finding music from existing commercial systems. Each attribute is matched to red, green, and blue values, and thus one person is expressed by a color point representing musical taste. Like a person's musical taste, each music item is expressed in the space with unique color according to its musical characteristics. At the initial state, musical taste is allocated to people, and they start to move around with initial music items that are similar to their musical taste, as shown in the right side of Figure 6. As people gather music from other people nearby, they add different kinds of music from neighbors to the music list. Sometimes they delete music items that are very far from their musical taste, maintaining a minimum number of music items. Also, in a longer period, they tend to adapt their musical tastes partially toward the average color of their music lists. Each model has their own rate of musical taste variation, frequency of musical taste variation and music list adjustment. With these variable parameters, we could make various models with different musical characteristics.

Space Design. The virtual space where virtual models with music items live is modeled as a graph with nodes and links. Each node has transition probabilities to adjacent nodes, and people move according to the probabilities given to the node. Also, typical time to stay is considered when a person is willing to stay, not just pass by the node. We attempted to create a more realistic space with this simple probabilistic space model. The transition probabilities give characteristic to each node as a place in which people crowd or where people pass by. For example, the duration of time people spend in a lecture room, cafeteria, and dormitory is generally long, whereas the space in front of a vending machine or in a lobby can be a place to meet friends, where people spend several minutes. With observations on numerous simulation runs, we found that this simplistic space model similarly reproduces real

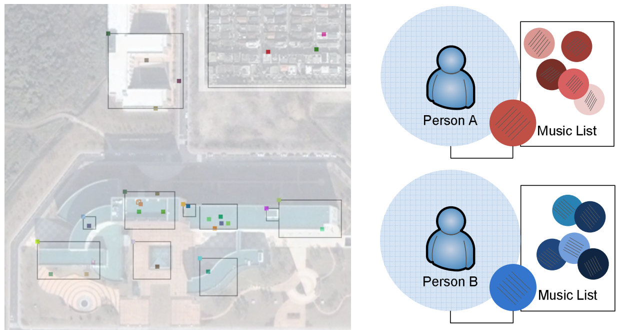

Fig. 6. Several principal places in the university campus are expressed as linked nodes (*left figure*) admitting people who are expressed by their musical taste (*right figure*)

world daily life. The left side of figure 6 shows a screenshot of virtual space with people expressed as color points. The distribution of people in the campus space imitates the real world.

Interaction Design. The simulation results can be affected by the interaction algorithm parameters including the range of communication, the frequency to adjust the music list, the music selection algorithm, and so on. We expected that the simulation results can be diversified according to various parameter values, which are selectable before each run. First, we devised three kinds of algorithms to select music for neighbors: selecting music with some probabilistic formula that reflect the ranks of music items, selecting random music among all music items, and selecting only top ranked music items. Other system parameters were suggested as a reference for this kind of system/service designer. There are two kinds of parameter groups: parameters for interaction and parameters for music list revision. In interaction parameters, the range of communication was fixed within 10, 20, 35 pixels in the 750 × 750 space. Another interaction parameter is connection frequency, which means waiting time for the next music file transmission after one transmission when people stay in the same node. The waiting time is selected among 5, 20, and 70 minutes; for example, the number of sending music items to neighbors changes 12 times, 3 times, and 1 time in a node where people usually spend 60 minutes. For parameters for music list revision, we defined two kinds of deletion range for music items that do not match peoples' musical taste, and three different frequencies for music list revision. The people model starts the simulation with a specified initial number of file lists, and then adjusts the music lists with initial music and gathered music. The time between every revision is selected among 30 minutes, 1hour, and 2 hours. The longer the revision period, the higher the probability of maintaining various music items. Number of files to be deleted among n files is random, between 0 to n – (initial list) × k when k is 1 or 2. Hence, when k is 1, the file list guarantees the number of initial music. In the case of k is 2, twice the number of initial music with gathered music is guaranteed after every music list revision.

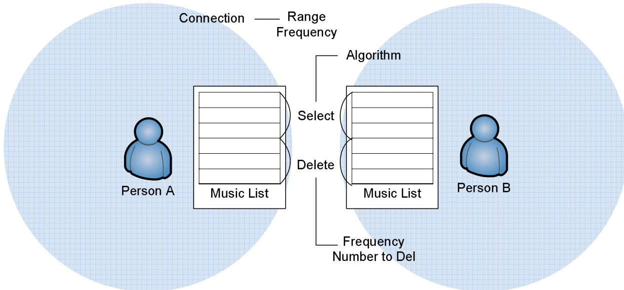

Fig. 7. Interaction parameters include parameters for connection, music selection algorithms on encounter, and policy of periodical music deletion

Hypothesis. Before SS Says simulation, we expected that media diffusion will be influenced by physical distance or shared time in near proximity, and musical taste matching as people who share more time can acquire more information in the real world. Moreover, the musical taste will be reflected in the music list gathered from neighbors, and people can get more diverse music than they would from their own closed music list. The consequence of this service is expected to be different with different music selection algorithms; probabilistic selection brings music diffusion reflecting physical distance and musical taste distance, random selection brings broader music diffusion in the whole space, and we speculate that delivery of only top-rank items cannot bring music diffusion.

5 Simulation Results

The music list of a random person at a random point during the simulation was checked to assess the effect of music diffusion with various selection algorithms. Figure 8 shows normalized values of musical taste difference (orange, the brightest line in black-and-white print), the number of times a multimedia file is received (red, the darkest line in black-and-white print), and the time shared with people (blue). The shape of the graph is similar to the expected result that reflects both individual characters and geometric constraints, which are expressed in time in the communication range. In figure 8, the left-side figures are sorted by musical taste difference in descending order, and thus the person at the rightmost is the person who has the most similar musical taste. The number of media transmissions is negatively related to the musical taste difference, and thus tends to be high for a person who has similar musical taste except people whom one could not meet with.

To assess the correlation among number of music transmissions, shared time, and musical taste difference, we designed the correlation function as follows:

$$Correlation(Time\ in\ the\ comm.range, Number\ of\ survived\ music)$$

As figure 8 shows, the file list after file transmission with each selection algorithm shows different correlation values for the four groups of people who have ascending musical taste similarity; people from 1 to 29 are grouped into 4 groups, and the fourth

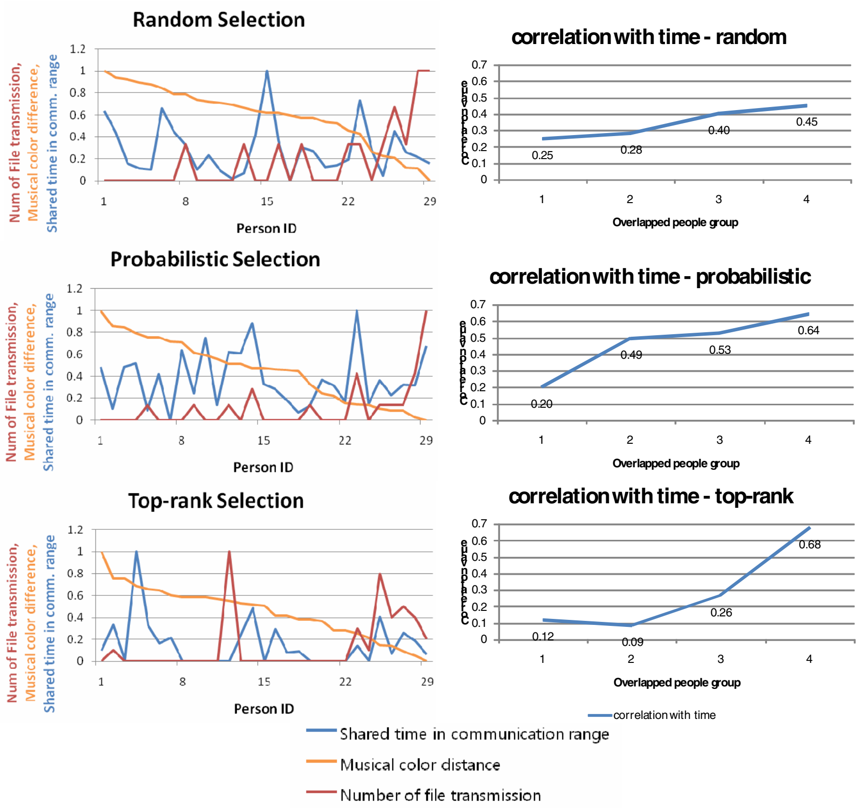

Fig. 8. The music list lineups with three different selection algorithm (*left figure*) and variation of correlation values according to musical taste similarity (*right figure*)

group has the highest musical similarity. Random selection shows no considerable change of correlation for people who have high musical taste similarity and low similarity, and hence the slope is gentle. On the other hand, the top-rank selection algorithm shows a sudden increase of slope for the people who have high musical taste similarity. A person with the top-rank selection algorithm can gather highly matched music items to his/her musical taste at the end of the simulation, and another person who uses the random selection can gather music items with almost equal probability from people whom they have met. The former experiences ‘music recommendation’ from the SS Says service while the latter experiences ‘mood reminder’ from the same service with different system parameters. The probabilistic selection algorithm used in this simulation is a linearly assigned probabilistic model – the top-ranked music has the highest probability to be sent, and the bottom in the list has the lowest probability as the sum of probability of music items is maintained at 100%. Other probability model shapes including exponential or logarithm shapes are expected to bring variety of service provided by top-rank selection and random selection.

6 Conclusion and Future Research

In order to explore new modes of communication that may be enabled by SS in the future wearable community, we developed nine SS scenarios, and studied three of them either by physical implementations or computer simulation. The two implementations using the UFC platform provided tools for studying new interaction styles with SS including a user interface for wearcomp and a representative music selection algorithm, and the simulation results guided the subsequent, physical realization of the scenario.

The authors plan to refine the user interface for use in many types of wearcomp as well as the Coolspot algorithm with a real wearcomp platform, UFC. Also, more simulation results with various system parameter combinations are expected to clarify the possible services that can be applicable to cell phone based service with WPAN in the near future.

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