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Study ~~on~~ of Wireless Device Connection Problems and Design Solutions

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Abstract

Users, especially the non-expert users, commonly experience problems when connecting multiple devices with interoperability. During device connection, the user is required to manage not only the device functionality but also the interaction between devices. The existing design approach to improve single-device interaction issues, such as computer guidance or improvements to graphical user interfaces, cannot help users to handle problems between multiple devices, while studies on multiple device connections are mostly focused on spontaneous device association with a focus on security aspects and the research on user interaction for device association is still limited. More research into understanding people is needed for designers to devise usable techniques [1].

In this paper, we apply the Research-through-Design method into our user interaction study on multiple device connections. First, we adopt the “Learning from Examples” concept to develop a study focus line by learning from expert users’ interaction. This focus line is then used for guiding researchers to explore the non-expert users’ difficulties in each stage on the focus line. Finally, we use the Research-through-Design approach to understand the user difficulties, gain insights of design problems and devise usable solutions. We studied the user interactions of the non-expert users in establishing wireless connections between devices through case studies in this structural way and found that this well-structured way of study can be applied to other device association studies.

Based on learning from failures, here we propose a wireless connection method in which images of two devices function together with a system image to provide the user with feedback on the status of the connection, which allows them to infer any required actions.

Keywords

Wireless connection, device association, user-multiple device interaction, Research through Design, learning from examples

1. Introduction

Wireless products are widely used as parts of interconnected systems, which provide multiple functions and convenience. For example, a printer can quickly provide a printed photograph by operating with a mobile device over a wireless network; a person can control a television using their smartphone; and a Bluetooth car stereo system can play a song from the user’s smartphone. Although these wirelessly connected multiple-device systems provide rich functionality, the experience of combined devices is often marred by difficulties in interoperability, as Chong and Gellersen reported [1]. A range of troubleshooting guidance for connecting wireless devices is available on the Internet and in magazines [e.g., 2-4], and it has been reported that the difficulties in device connectivity make users hesitant to adopt new technologies [5-6].

Problems that non-expert users face with multiple wireless device connections are an important challenge that requires resolution. To streamline the research problems, we first develop a focus line to guide our study with the required user actions. This is based on learning from examples or experts principles. Furthermore, to identify a solution that would improve user interaction, we approached the problem using a Research-through-Design framework. As part of the design process, we consider the difficulties that non-expert users experience in identifying and implementing the required actions. Through learning from the failures, we suggest a design solution to improve user interaction, which is tested using paper prototypes.

2. Related Works on Device Connection

Several studies have proposed user interactions with devices that connect in a direct, natural, and intuitive way. Many researchers have focused on providing device connections using collocated human movements or continuous actions. These interfaces include pressing buttons simultaneously on both devices [7], pressing buttons sequentially [8], bumping devices together [9-11], shaking devices together [12-13], and stroking the device [14]. The spatial proximity of the two devices is sensed via infrared or radio frequency identification (RFID) technology [7]. Additional devices, such as Universal Serial Bus (USB) memory sticks may also be used for authentication [15].

Although techniques have been proposed to reduce difficulties in identifying a target device and authenticating the connection, a natural and intuitive method of device interconnection remains challenging. First, much existing work has assumed that associated devices have primitive connections to other devices or services [7-8, 13-14]. It follows that help is not available to the user when they have a problem with the primitive connection. Additional sensors or out-of-band channels that have been employed in addition to an original network connection result in increased complexity and, hence, further potential problems when an error occurs with the connection. Second, advanced techniques have some barriers to widespread use because of variations in hardware and requirements because most of the proposed technologies target specific interaction scenarios [1].

More importantly, it is not yet clear what constitutes the natural actions of users. It appears that no single approach is preferred for representing a connection. In a study in which users produced natural actions for device association using plastic prototypes as thinking aids, Chong and Gellersen found that no single action dominated in spontaneous association among five prominent categories of actions (i.e., search and select, proximity, button event, device touch, and gesture) [16]. Ion et al. reported a similar result, in which the preferred actions for device connection depended on the user and situation. They asserted that a technically secure and easy-to-use method does not always benefit the user [17].

Some research has been reported that aimed to help interaction designers choose association techniques and interactions by informing others of influential factors. By surveying a number of proposed models in the field, Chong and Gellersen discussed various components of device association technology, user interaction and application context [1]. Their work helped designers and researchers understand the complexity of the problem. Ion et al. argued that designers need to be aware of the users' mental model, needs and social situations. They found that user interaction is influenced by the sensitivity of the data involved, the time constraints of the user, and social conventions that are appropriate for a given environment [17].

Classified and specific knowledge of complex situations does not guarantee the resolution of user interaction difficulties. Although it aids designers in understanding the complexities of design situations, creating interaction methods remains a significant design challenge, and the designer requires to make connections and see relations within the complexity [18]. While research efforts have succeeded in classifying components, they have not informed designers as to how to comprehend the interaction of multiple devices nor how to approach complex design problems. Interpretation of the features of the target user–system interaction is required as part of the design process.

3. Develop a focus line for studying multiple-device interactions

3.1 Need for a focus line

To investigate multiple-device interaction problems, we need a clear guide line in our study. First, we want to compare differences between single-device interaction problems and multiple-device interaction problems.

Figure 1 illustrates the different situations in single-device system and multiple-device systems. We found that the connecting devices require different user–system interactions, which differ from single-device interaction. Fig 1a shows Norman's explanation of the interaction between a user and a single device that is commonly used in human–computer interaction (HCI) research [22-23]. The user controls the function by interacting with a system via a single device. The guidelines [2] for studying single device connection and its interface design are well developed.

While for multiple device connections, a user needs not only to deal with individual devices but also their interactions. Fig 2b shows two-device interaction. The user manages not only the device function but also the interfacing/interacting between the two devices (i.e., Device A and Device B) [24]. When the user interacts with a system in which two devices are to be interconnected, the user must go through a complex procedure.

As Chong and Gellersen showed, many factors are involved in wireless device interconnectivity, and the effects of these factors are interrelated [1]. We do not yet have a clear view of which are the key factors, or how to control them. Until design insight into how to deal with these interrelated factors is gained, many experiments and much analysis will be required. Therefore, there is a need for a focus line the help explore the problem spaces and possible solutions.

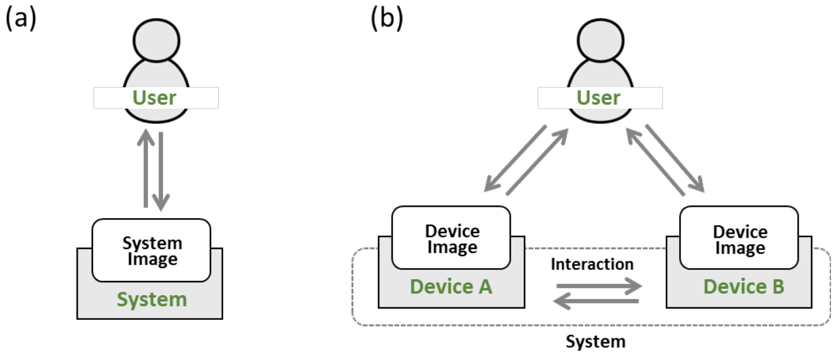


Fig. 1 User interaction in (a) single-device system and (b) multiple-device system

3.2 Establish a focus line by learning from examples

In order to develop a focus line to guide our study, we employed learning from example principles to study how expert users to easily connect multiple devices and what are the required user interaction.

We interviewed technicians who are skilled in Bluetooth and network configuration to determine how current wireless connections are established in practice. Four in-depth interviews were conducted: one with a PhD student at an engineering school who was an expert in short-range wireless connection protocols, including Bluetooth, two with technicians from a university's network-management team, and one with a technician from a computer agency that sets up devices and provides after-sales technical support. The interview questions concentrated on the key knowledge or knowhow required to configure wireless devices, common problems users encounter when asked to connect products, and how the technicians would approach these problems. The interviews were conducted individually.

Fig. 1 shows common connection procedures of Bluetooth devices. This figure summarizes user-related requirements and interconnection procedures, rather than Bluetooth hardware specifications or signal transmission packets.

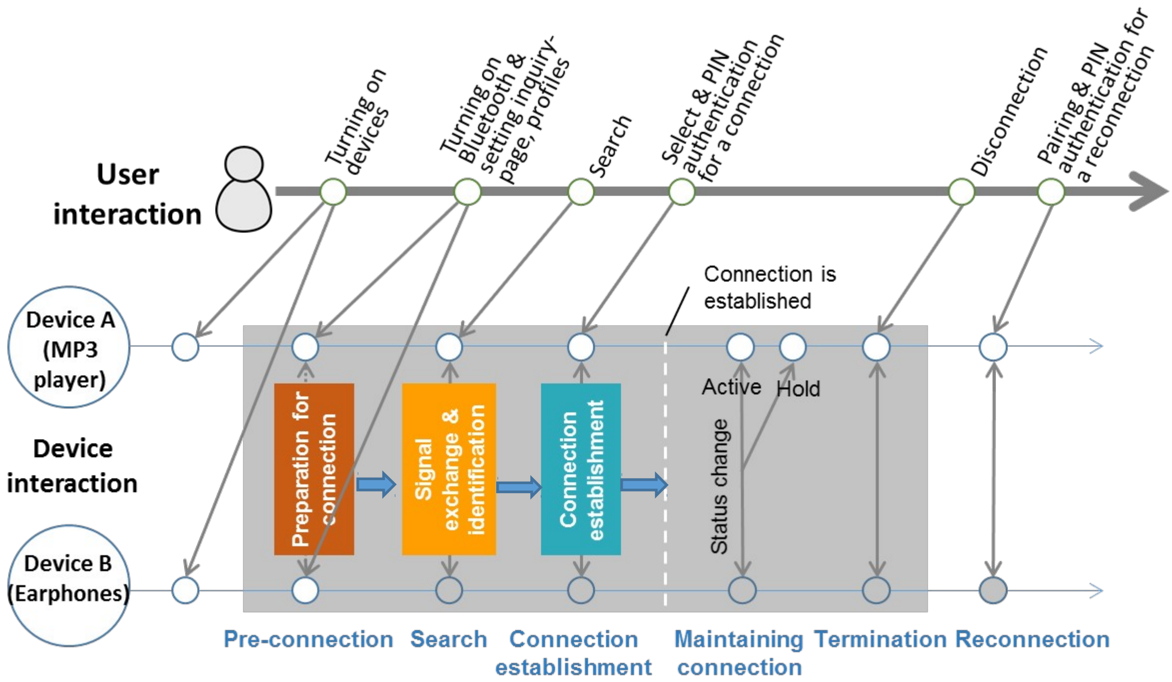


Fig. 2 Common user-device interaction focus line for Bluetooth connection
(Time flows from left to right along the x-axis and the devices are shown in the y-axis. The connection requirements are given as text along the y-axis between the devices, and the stages of interaction are shown as the required user interaction along the focus line.)

Device connection has several stages *along a focus line*: *pre-connection*, *search*, connection establishment, *maintaining the connection*, and *disconnection*. In the pre-connection stage with Bluetooth, the user must ensure that each device allows exchange of communication signals by setting up device standby and inquire-page modes. Profiles specify the Bluetooth services, such as hands-free, stereo headset or file transfer. The connection between devices is initiated when the user targets one device from another, once the devices recognize each other. The connection is established when the devices are paired, often requiring the users to select which device is intended or to enter an authentication code (usually a Personal Identification Number or PIN).

When a user wishes to connect a printer to a notebook computer or an iPad wirelessly, a popular method is to use a router and establish a small network of devices. Wirelessly connecting a notebook computer and a printer requires communication between, and mutual approval of, two appropriately prepared devices. However, with this connection method, Wi-Fi networks have the additional requirement that is connections of each device to the same mediating network device, such as a router. There are two sets of connections: one between the router and the computer, and the other between the router and the printer.

In spite of the different technological requirements, the user interaction from the Bluetooth connection and Wi-Fi wireless network connections require similar procedures along the focus line: 1) preparing each device for a new connection during the pre-connection stage; 2) exchanging signals and identities between the two devices during the search stage; and 3) selecting and establishing a connection during the connection stage. These tasks are the required user interactions.

4. Understanding user interaction when connecting devices

We started the research work by considering why non-expert users have difficulties in connecting multiple devices following the focus line. Instead of following experimental research methods, here we apply Research through Design.

Research through Design is a unique method of reflective intellectual inquiry into human conditions [18-19]. It is an approach employing processes and methods of design thinking that are effective for complex problems. Knowledge construction in design research is a distinct process in which a researcher develops comprehension of a problem by working on an artifact; i.e., the researcher envisions a desirable state and assesses the results of the proposed solution [20]. By reflecting on the resulting situation they create, and what caused any unexpected results, the researcher derives new insights relating to design. Forlizzi et al. argued that proposed solutions in design research not only function as a conceptual tool to aid the designer in a complex situation but also force the researcher to actively construct new possible futures [21].

Following the design inquiry and reflection process, we approach the user interaction problem of establishing wireless connections between devices. First, by examining the required user interactions of non-expert users to connect two audio devices using Bluetooth technology, and establishing printer connections via WLAN, we gain a basic comprehension of user–system interaction and of user difficulties. Second, through proposing design alternatives and reflecting on the results, we gain further insight into the design situation of a device in guiding user interaction. Finally, we suggest a design approach from an alternative perspective, and assess the proposed solution using paper prototypes.

4.1 Difficulties of non-expert users

To understand the difficulties of non-expert users, we observed their interaction as they tried to establish connections between two devices. Inquiry in the design process aims to understand a complex reality, which can provide a good foundation for design [20]. We observed four cases of device connections, with different devices and strategies, as listed in Table 1 and shown in Fig. 3. The aim was to comprehend a broad range of user–device interactions. We considered establishing a connection between a smartphone and earphones, and establishing a connection between a printer and an iPad. Another case establishing a connection between an MP3 player, a loudspeaker, and earphones was observed as the participants attempted to establish connections among multiple devices. The latter case (establishing a connection between a notebook computer and a printer) was observed when teams of two people undertook the tasks collaboratively. This was intended to investigate what influenced their understanding and decision-making naturally. Because the goal was to understand the potential for improved designs, none of the four observations were controlled experimental studies. Rather, the observations were made to reveal user interactions and provide a broad overview of the complex problem.

Table 1. Observed device connection cases

	Observed connection	Devices used	Participants and method
Case 1	Audio device connection via Bluetooth	MP3 player (Samsung Yepp R1) – Speaker (Motorola EQ5), earphones (TSW-MH-806)	Five participants, observed individually
Case 2		Smart phones (various models) – earphones (iriver BT S-10)	Four Android users and three iPhone users, observed individually
Case 3	Wireless network printer connection via Wi-Fi	Notebook computer (Windows XP) – printer (Samsung CLX-3185WK)	Six participants in three teams
Case 4		IPad (iOS 7.0) – printer (Samsung SL-C462FW)	Five participants, observed individually

Fig. 3 Observations of user interaction

Because we aimed to develop solutions to improve device interfaces, we focused on non-expert user interactions to reveal problems associated with information and the interfaces of the devices with limited influences from previous knowledge and experiences. Participants were recruited who had no previous experience in connecting similar devices. They were in their 20s, who feel relatively comfortable handling new technologies. All the think-aloud protocols and user tasks were carried out in the native language of the participants (i.e., Korean). Using Nielsen's guidance on design inquiry (i.e., that observing three to five users reveals the majority of important design problems) [25], observations were terminated when we considered that the observations provided sufficient information.

4.1.1 Findings

By comparing the actions of non-expert users with the required actions on the focus line, we found the following. First, participants had difficulties in recognizing and performing the required sequential interactions with both the Bluetooth and wireless network connections. Although all twelve participants accomplished the Bluetooth connection of the audio devices, most participants experienced difficulties during the pre-connection stage of setting up the inquire-page mode on both the tested models of earphones, and proceeded to the search step before accomplishing the pre-connection stage. Performing the device search of the loudspeaker connection was less difficult than connecting the earphones, because the speaker could be found by the MP3 player without requiring another preparation step, as long as the speaker was switched on. Four of the five participants expected to see a completed connection when a device was identified on the Yepp MP3 player. The participants were not able to recognize that the connection establishment step was required, and experienced problems in figuring out how to establish pairing.

When connecting the printer to the computer or iPad using the wireless network, the two devices required the appropriate wireless technology, which had to be properly prepared and required connections of each device to the same mediating network device (i.e., router). Eight of the participants (four individual participants with the iPad and two teams with the notebook computer) were not able to infer how the two devices connected via another mediating device, and experienced difficulties in preparing the required sub-connection.

Second, the images of the devices did not provide effective guidance in establishing the connections. The devices did not provide adequate visual clues that a particular action was required. The interfaces of the MP3 player and smartphones did not indicate adequately which steps in the connection procedure needed to be taken. The required preparation of the earphones and which action was required to trigger the connection were not easily recognized from device interfaces. Incomplete guidance confused the users. The Samsung CLX-3185WK printer used for connection with the notebook computer provided a printed guide for "one-touch networking", which guided the search and connection stage of the procedure, but did not include any pre-connection steps. All three teams attempted to establish the connection, but all failed because they did not realize that the one-touch networking could only be established using an existing pre-connection.

Third, the users were provided neither with adequate information, nor adequate feedback on the device interaction status. When the Bluetooth connection failed, for example, the MP3 player only showed the short message "Connection Failed". The feedback messages did not provide useful information regarding what had caused the problem, nor what the user could do to fix the connection. Participants experienced difficulties in interpreting what, for example, the blinking light signals or sounds from the earphones or printers meant, or even whether these signals conveyed any meaning at all. For example, when the printer presented operational feedback when searching for a Wi-Fi signal, the participants confused the devices were ready to use. In short, the feedback messages were not useful to the users.

Fourth, the participants were not able to recognize where the problem occurred in the procedural sequence. They attempted several measures to determine the reason why the connection was not functioning, such as turning the device on and off, changing the volume, changing the profile of the connection, waiting longer for the search to be completed, trying several buttons, and varying the distance between devices. The participants' remarks included "Uh? It (my action) seems right, but (why is it not working) …" or "What is the problem?" They had to ask the moderator for assistance or tried to learn by themselves through several iterations of trial and error. One team using the network printer connection explicitly pointed out that they could not identify the cause of the problem after the team failed to configure the connection, and remarked that, "The biggest problem (of the interaction) is that I cannot infer what the problem is. I cannot find any clues."

5. Learning from failed design suggestions

5.1 Primitive design suggestions

Our first design suggestion focused on guiding the user through the required procedural interaction through a graphical model or specific step-by-step guidance. Although we are interested in solutions to general wireless connection problems, the examples described in this section were developed for the MP3 player and earphones connection scenario. Figure 4 shows one of the proposed design alternatives in the first phase, which was carefully designed using step-by-step guidance to provide helpful information to guide the user through sequential interactions. The dotted line connecting the symbols of the two devices shows the required four steps of the connection sequence. In each step, the interface guides the non-expert user as to what to do and what to check if they have problem.

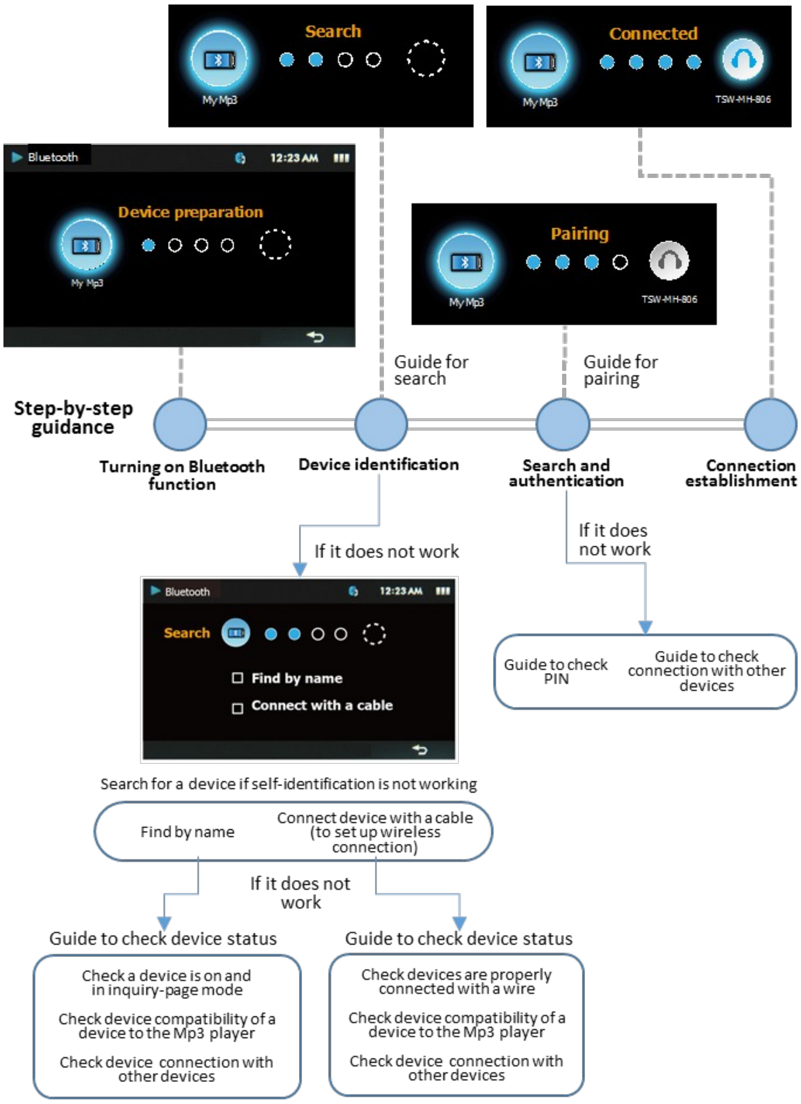


Fig. 4 An example solution in the first ideation phase

The proposed design solutions were assessed based on whether they could guide the user through each of the required steps of the connection procedure; i.e., preparing the MP3 player for connection (turning on the device and turning on the Bluetooth function), preparing the earphones (turning on the device and setting it up in inquire-page mode), searching for the earphones from the MP3 player, selecting the earphones, and establishing a connection between the two devices. We also evaluated whether the option improved the performance, such as reducing or eliminating difficulties in setting up the inquire-page mode of the earphones and triggering the connection of the MP3 player. These options were also investigated as to whether the proposals could help when the device was not searched for on the MP3 player and when a connection was not established.

We found that none of the proposals provided sufficient guidance for the required user actions. For example, the interface of the MP3 player shown in Fig. 4 did not effectively help the users to set up a connection with the earphones if the user failed to search for the device, if the device failed to connect for an unknown reason, or if there was a connection to the wrong device. For all the proposals, the MP3 player could not provide sufficient guidance as to how the user should interact with the other device (e.g., the earphones).

5.2 Reflections on failure: design situation of connecting devices

The reasons for failure provide insight into the design situation. The shortcomings of our designs occurred because the MP3 player could not obtain information on the other device. The MP3 player may be asked to connect to a computer, earphones, loudspeakers, smartphone, or some other unknown device that did not exist when the MP3 player was designed. If the device to which the MP3 player is to be connected is not switched on, then it is impossible to obtain any information about it, or even to know whether it exists. The MP3 player cannot monitor information on what tasks the earphones require, or control the function of the device until a connection has been established. In other words, when a user requires information on the earphones during the connection procedure, the MP3 player cannot provide any assistance.

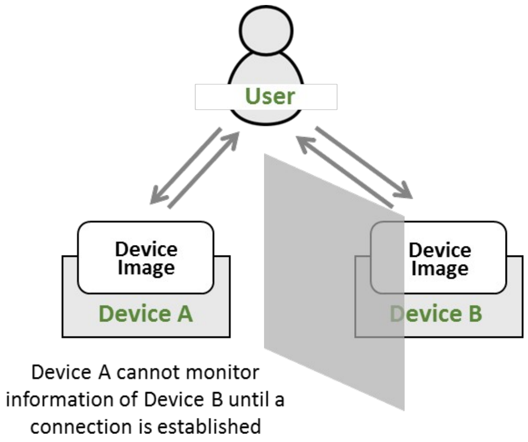


Fig. 5 Interaction before accomplishing connection

This presents a significant design problem, as shown in Fig. 5. Before a connection has been established, the individual devices cannot acquire the information necessary to guide the user through the connection process, neither via a well-prepared interface to guide the user, nor through an automatic process. This represents a design situation that makes the interface for connecting multiple devices significantly different from that involved in user–system interactions with a single device. The problem of connecting multiple devices cannot be solved with the approaches used in designing single-device interactions, such as computer guidance, automatic configuration, or improvements on the graphical user interface of a single device. To overcome these design constraints, it is necessary to solve the user interaction problem from a new perspective.

6. Search for alternative design

6.1 System interface using images of two devices

When designers face problematic situations, they should consider new design perspectives [26]. Ghazali and Dix suggested that if we look at some of the properties of “real world” interactions with physical objects, we can use this knowledge to improve digital interactions [27]. Here an alternative point of view is considered, based on sequential assembly of physical devices.

When a user connects a USB drive to a USB port, the physical shape of the devices aids the connection task by helping the user evaluate the state of the devices. Before we attempt physical assembly, we check the preparation of the devices, i.e., whether the USB port is available, as shown in Fig. 6. Not only can images from each device reveal the status of the device, they can also show the relations between components, i.e., whether they are properly assembled. By evaluating the status of their physical appearance, we can infer the necessary actions intuitively, without requiring a guide. Providing a visible connection status for wireless devices may therefore help users in establishing connections.

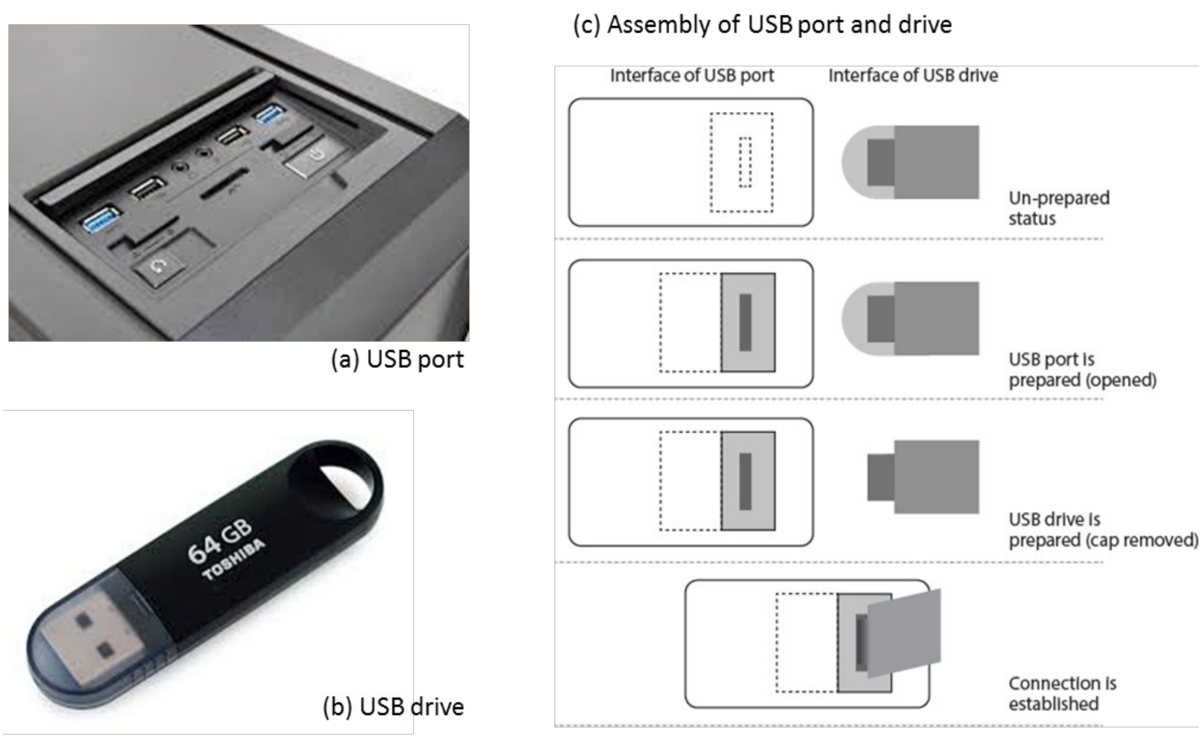
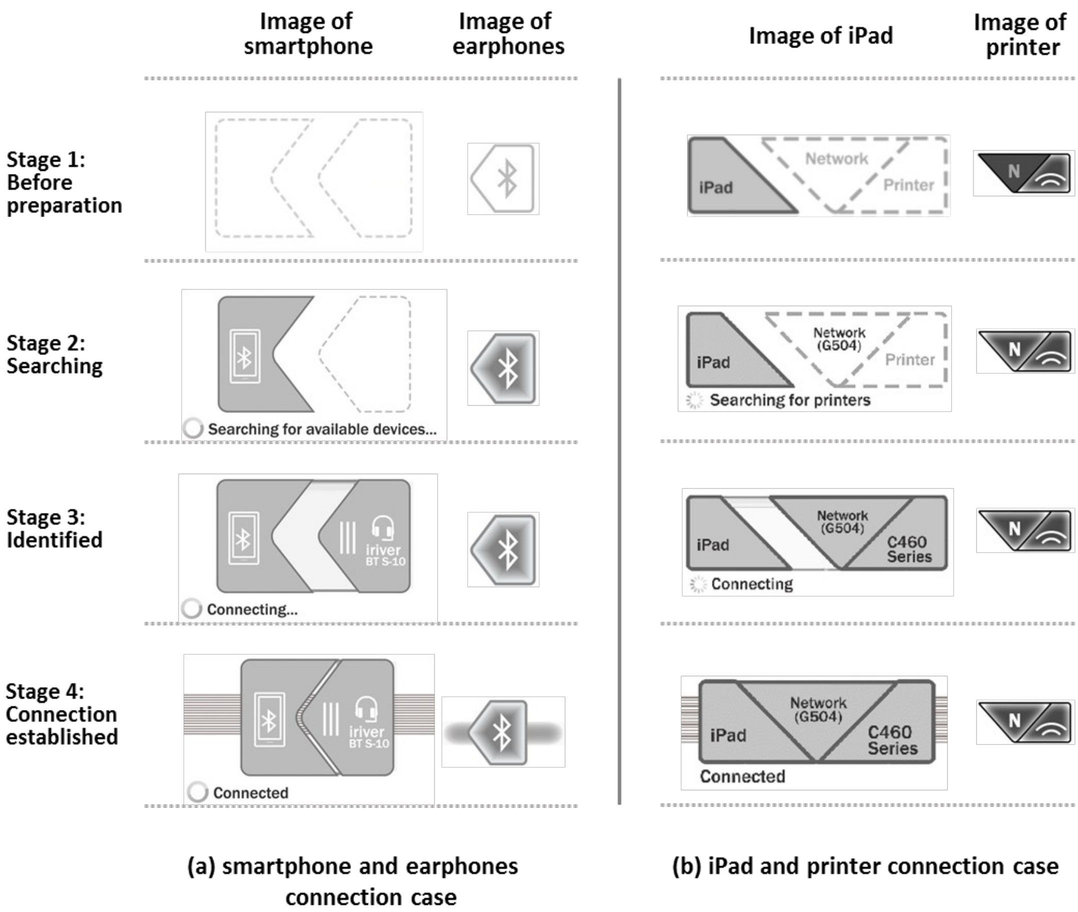


Fig. 6 Devices for physical connection. The physical forms of a USB drive and a USB port reveal visually the status of the connection

Based on considerations of physical device connection, here we propose solutions for wireless device connection for two cases: a) the connection between earphones and a smartphone, and b) the connection between a printer and an iPad. Our solution uses images of both devices, as shown in Fig. 7a, to illustrate the connection status of the two devices, thus helping the user to gain feedback on the interaction status and infer the requirements for the setup process. In Stage 1, the devices are not ready for connection, but can reveal their status as requiring preparation for connection, including whether they are switched on, ready to exchange signals, or technologically identifiable. If both devices are prepared to connect, the two devices will show images of pieces that are appear ready to be assembled. This is Stage 2. During the search step (Stage 3), a shadowed piece will appear if a device has been properly searched for and identified by another device. However, this stage may show unassembled pieces, meaning that a connection has not yet been established. Finally, Stage 4 shows the assembled model, and provides information indicating that a connection has been established between the two devices, and they are ready to function as a system. Compared with existing systems, which show signals telling the user whether a function is operating, our proposed system provides much more information that can be mapped onto device-connection stages. The solution for a printer connection (see Fig. 7b) consists of three pieces, which represent two target devices (i.e., the printer and iPad), as well as a mediating network. This aids the user in matching the network and the two devices.



(a) smartphone and earphones connection case

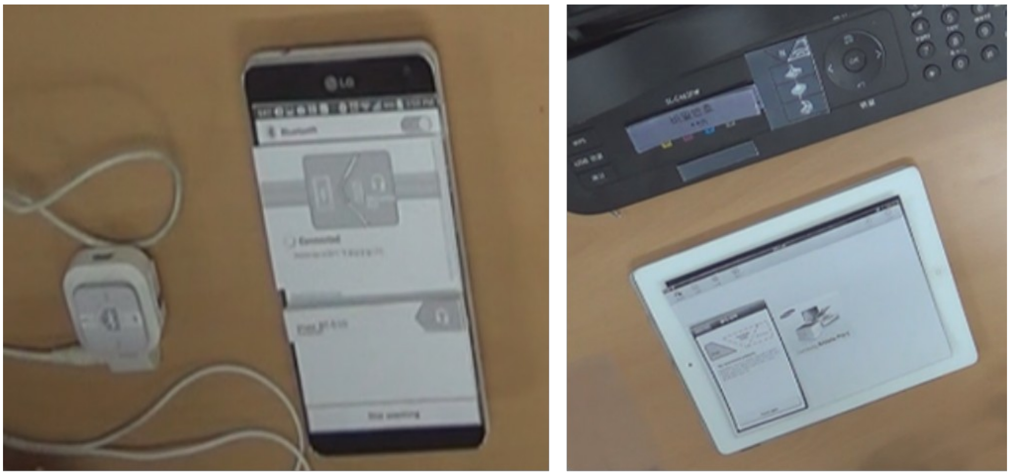
(b) iPad and printer connection case

Fig. 7 Proposed solution: system images using two devices in different connection stages

6.2 Assessment of design solution using a paper prototype test

6.2.1 Study method

The proposed solution was investigated using paper prototypes. A user study was carried out to assess how information and feedback from the revised interface are interpreted and evaluated by users, and whether such information is helpful. The ten non-expert user participants (five participants for the smartphone–earphones connection and five participants for the printer–iPad connection) were asked to configure a connection between devices with the interfaces shown in Fig. 8. Table 2 lists the circumstances provided to the participants, who were then asked to explain how they would proceed and why.



(a) smartphone and earphones connection case **(b) iPad and printer connection case**

Fig. 8 Paper prototypes used in the assessment

The graphical assembly models were enhanced with textual information to communicate the device connection states more clearly. The prototypes were prepared in black and white in order to reduce the influence of color on the perception of the participants. Note that the modified interfaces did not consider all technological specifications, customer needs, or usability requirements; in practice, the designer should consider many potential conflicts relating to device function, manufacturing issues, and marketing perspectives. All participants carried out the tasks in their native language (i.e., Korean). The main language of the device interface and paper prototypes was also Korean.

Table 2. Test circumstances

Connection task	Circumstance for diagnosis
Smartphone and earphones	The smartphone could not identify the earphones (the earphones were not prepared) The connection failed (the earphones maintain a connection

	with a different device)
IPad and printer	The printer failed to connect to the network The printer and iPad were connected to different networks The iPad was not properly connected to the network

6.2.2 Results

Case 1: Bluetooth connection of a smartphone and earphones

The five participants used the proposed interface of the smartphone–earphones Bluetooth connection. The participants proceeded to the device preparation and search steps with few problems compared with the original devices. All participants were able to determine whether the earphones were prepared for connection. We observed that the participants interpreted the graphical information, text messages, and signals on the earphones and smartphone effectively to evaluate the device interaction status. The following quote shows how a participant understood the interaction:

> *"This (earphones) is off. (The Bluetooth of the) Smartphone is on, but the Bluetooth of this (the earphones) is off. So it (the smartphone) couldn't search and it was not in the list."*

The two participants waited for the device to be found by searching without checking the earphones and turning them on. However, when they checked the status of the earphones, they easily proceeded to the preparation stage, switching them on and checking for the Bluetooth light.

Based on this evaluation of the connection status, the participants determined how to proceed. When the participants were asked to diagnose the interaction errors (listed in Table 2), they decided to switch the earphones on and check the preparation status (all five participants did so when the earphones' Bluetooth signal was off) or disconnect the existing connection of the earphones (which they did when the earphones signal showed an active connection).

A participant who had experience with Bluetooth connections between different devices described the improvements of the proposed interface as follows:

> *"When I used Bluetooth (before), it was difficult. Sometimes the device, would suddenly not work properly, although it had been working before. I think this (the revised interface) is easier because I can see if the devices are working or not. I think it is much better."*

Although some problems were observed, such as difficulties in interpreting text information or in recognizing that the smartphone did not operate the search function, it is clear that the improved device interfaces made the user evaluation easier.

Case 2: Connection between iPad and printer (via wireless network)

The three components of the interface showing the iPad and printer connection helped participants to evaluate which network was mediating the connection in four cases out of five. One participant described how the network information of the central piece helped her to determine the mediating network as follows:

> *"It (the iPad) shows (information on the network) here (the representation of the assembling parts). It (determining the network status) was not difficult because of the way they were represented. It shows (network information) here (on the iPad) and there (on the printer). I knew this because they were shown, and I tried to match them."*

Another participant realized that she was required to connect the devices to the same network by testing the device search function, and evaluating the situation. She thought that the iPad could search for devices from several nearby networks. When the iPad only searched for devices from the connected network, she recognized that the two devices should be connected to the same network.

When the moderator asked participants to diagnose a problem whereby the iPad failed to search for the printer on the network (when the printer failed to connect to the network because of an incorrect password), all participants narrowed their suspicions to connection problems between the printer and router, based on the failure message and the signal from the printer. Participants responded that they would retype the password, or that they suspected problems with the router. Providing clear information indicating the success or failure of a connection step helped the participants to proceed with the interaction.

Problems during the connection stage were rare; however, one participant became confused and thought that all of the printers from the list of searched-for printers were connected to the iPad without selecting and connecting a printer. However, when he found no printers were connected to the iPad, he quickly understood that he needed to select one from the list and establish a connection. The tests showed that the proposed design solution helped participants to evaluate the device connection status, allowing them to more easily determine how to proceed.

The three participants did not check the device interface at the beginning of the task. Two participants experienced difficulties searching for the correct menus within the small display of the printer. Despite a few problems, the overall interaction showed that the proposed interface helped the users to evaluate the status of the connection.

6.2.3 Reflection on the assessment

From the assessment of the proposed design solution, we observed that the participants effectively interpreted the signals from the graphical assembly model and the textual information to determine device status. In doing so, they diagnosed the problems and inferred the required action. Participants said that the proposed interface clearly showed the current status of the device interaction. They understood whether a device was prepared for connection, identified devices, selected them and connected them. They also identified when a device was not prepared, or had not been searched for by another device, as well as where a connection had not been established. Participants used their evaluations of the device connection status to determine where the problem occurred and how to proceed. Overall, the proposed interface improved user interaction significantly. This testing of the proposed interfaces confirmed that the system image showing the connection status by both devices provided clear feedback on the interaction between devices, as shown in Fig. 9.

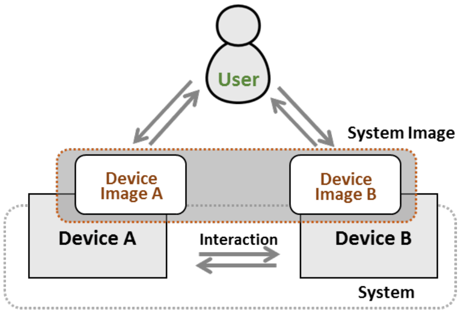


Fig. 9 The proposed system image for desired user interaction

7. Conclusion

Through the design inquiry process, we found that the interaction issues of two devices differ from the problems of a single-device system. This requires designers to follow a focus line guide and use different approaches for the user interfaces. The main insights into user interaction, and the proposed desirable features of the system, can be summarized as follows.

1) When a user interacts with a system in which two devices are connected to one another, they manage not only the functions of each device but also the interaction between the two devices. The user, therefore, must handle a complex connection procedure along the focus line, including preparing the connection, as well as searching, selecting, connecting, and using it, based on their interpretation of the images of the two devices.

2) A device cannot acquire the information necessary to aid the user before a connection is established. Thus, a single device cannot provide effective help in establishing a connection.

3) By revealing the connection status of both devices, images indicating how the devices operate together can provide the user with helpful information on the system status. This aids the users in determining the required action.

This study aimed to provide a design framework for interpreting and resolving complex user interactions. Because we did not approach the user interaction problem with reduced focus on a specific phenomenon, the perspectives from which to approach the problem, select design methods, and proceed with data handling differed significantly from previous HCI studies. Therefore, conventional criteria that ensure research progress via careful experiments and statistical validity are not necessarily appropriate to evaluate the success of this research project [19-20, 23, 28-29]. Knowledge obtained through design research is assured by an iterative process of ideas and assessment, in which an understanding of device connection problems is iteratively developed through design alternatives.

By reflecting on the design solutions proposed here, we generated knowledge for designers with respect to how to deal with user interaction problems. The work is expected to contribute to broadening the options for user-interaction systems that are realizable using current technology, as opposed to proposing techniques that require advanced technologies. However, we do not neglect the potential benefits to be derived from advanced technologies and device association techniques, which the field of HCI endeavors to develop. A wide exploration of the design space, searching for solutions, as well as discussions of benefits and costs of each design alternative, are important aspects of the future development of user-interaction systems. Moreover, an improved understanding of device connection problems would provide important insight into future device-association techniques.

We have assessed the benefits of the proposed design, but did not evaluate a practical implementation, nor assess it using a real-world user-interaction between devices. Further work is required, therefore, to develop design examples and test them in practice. The proposed interface should be implemented based on the context, situation, and particular issues relating to each device. An assessment of the improvements in a practical situation will require much work, but is expected to provide important further insights. When the initial exploration of this study is developed into more mature theory through persistent tests, it will require conventional experimental research approaches, together with statistical analyses of the results, in order to verify, refine, and optimize the proposed design solutions.

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