Touch-driven Interaction Between Physical Space and Cyberspace with NFC

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***Abstract*—Nowadays, natural and intuitive interactions between physical space and cyberspace have become increasingly important in our daily life. In this paper, we propose touch-driven interaction, which translates touch action into information flow in cyberspace, and result in media activity in physical space. Using NFC technology, user can simply touch smartphone with NFC tags to interact with TV, stereo, digital frame, etc. Compared with recognition-based interactions, touch-driven interaction features full user controllability, fine-grain accuracy and high usability. We also present several applications, including Touch&Connect, Touch&Watch, Touch&Listen and Touch&MakeFriends, to demonstrate touch-driven interaction, and conclude that such interaction is both intuitive and convenient in daily life.**

I. Introduction

Modern living environments are equipped with large screen TV sets, high definition stereo systems, tablet computers, etc. These devices, together with the network connecting them, create a virtual space surrounding our physical space, which is named cyberspace. In cyberspace, people can exchange ideas, share information, conduct business, and so on. The basic objects in cyberspace are various kinds of media, such as videos, music, photos, mails, etc. These media are connected by networks, making communication and social interaction easy and convenient.

Devices provide various interfaces for us to interact with cyberspace from physical space. These devices usually have specialized controllers, and interactions must follow some special instructions. However, these controllers and instructions make daily actions complicated and inconvenient. Consider putting a favorite photo in the digital frame, which requires connecting the frame to a computer, downloading the photo, and then select the photo in the frame. These interactions are neither intuitive nor convenient, reflecting the gap between physical space and cyberspace[1].

Many technologies have been developed to enable more convenient and more intuitive interactions between the two spaces, Near Field Communication (NFC) is among one of them. NFC operates at the radio frequency, using electromagnetic wave to detect object approximation at a distance of about 4 cm. NFC communication generally requires one party to provide power, hence the other party can take very simple form such as tags, stickers, or cards. Compared to other technologies such as Bluetooth and WiFi, NFC does not require discover or pairing process, thus interactions can be initiated with just a tap.

State-of-the-art smartphones are supposed to bridge the cyber-physical space gap. These phones are equipped with powerful processors, high definition cameras, large touch screens, and most importantly, near-field-communication (NFC) chips. In cyberspace, the smartphone can be regarded as a digital identity to access personal media resources, while in physical space, the NFC enabled smartphone can interact with devices via touch actions[2]. Combining both features, a smartphone can be used to enable touch-driven interaction by translating touch actions into cyberspace activities. For instance, we may find ourselves visiting friends and families and wish to share photos and videos on our phone with them. The living room TV is perfect for sharing since it has much larger screen. The touch-driven interaction can be triggered by touching the phone with the TV, and accomplished by playing the phone videos on the TV automatically.

This paper makes the following contributions:

1) We propose touch-driven interaction between physical space and cyberspace with NFC. The interaction method translates touch event into information flow in cyberspace, which is in turn reflected by media activity in physical space. The touch-driven interaction features full user controllability, fine-grain accuracy and high usability.
2) We present several applications to demonstrate touch-driven interactions. These applications enable intuitive and convenient touched based interactions between phone and devices.

II. Related Work

A. Cyber-Physical Space Interaction

In order to bridge the gap between cyber and physical spaces, many applications and systems have been developed[1], [3]. These systems are designed to interact with, and expand the capability of physical space through sensing and behavior learning[4]. Noury et al. developed a system for monitoring and modeling human behavior during daily life through infrared position sensors and magnetic switches[5], while Lymberopoulos et al. presented an automated methodology for extracting the spatiotemporal activity model of a person using a wireless sensor network deployed inside a

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home[6]. However, behavior monitoring and extracting by sensors is inaccurate, intrusive, and difficult to control. We argue that modeling user behavior using explicit user action, such as touching devices or putting phones together, gains better accuracy and gives user full control of the system.

Other approaches focus on extending user modalities by augmenting interaction methods. Bolt et al. introduced voice and gesture interactions at the graphics interface for a concerted, natural user modality[7]. The problem is that voice and gesture recognition tends to be inaccurate due to environmental noise and algorithm incapability. In the HBCI (Human Build Computer Interaction) system, Hsu et al. use QR codes to identify objects in the room[8]. QR codes are physically compact, easy to deploy, and can be accurately recognized[9]. However, QR code scanning draws user attention heavily to the camera view, and may fail in dark environments. In contrast, Our NFC based solution uses touch interaction to read information from tags, resulting in fast, intuitive and convenient interaction experience.

B. NFC Applications

Tag based interaction and communication, including near-field-communication (NFC) based applications, have been extensively studied in the literature[10]. The Touch & Interact[2] project presents an interaction technique in which a mobile phone is able to touch a display, at any position, to perform selections. Several interaction primitives, such as select & pick, select & drop and push action, were defined in the paper, which inspired our action classification model. Coulton et al. explored player experiences relating to the interaction with objects using NFC based mobile phones included as part of mobile mixed reality games[11]. The player experience highlights that the simple interface of touching the phone to the tag on an object is both readily understandable and very simple to use for game players. These advantages hold for interaction with devices and other phones, making action abstraction and classification intuitive and natural. A field experiment is conducted by Häikiö et al.[12] to study the suitability of touch-based user interface for elderly users, in which an NFC enabled mobile phone was used as a user interface element so as to enable home-dwelling elderly people to choose their meals to be delivered by means of a home care service. The results show that the touch-based user interface was easy to learn and adopt and the users were able to successfully use it regardless of their physical or cognitive weaknesses. In the work of Iglesias et al.[13], a health monitoring system is shown where users can identify themselves by simple touch with an NFC-enabled device and different health information can be wirelessly collected and associated with the identified user. We adopt the concept of using an NFC reader as a user identifier, and furthermore, we integrate the identifier with the smartphone to gain direct access to services and networks in the user's cyberspace.

There are also concerns about touch based interaction, especially in public places[14]. O'Neill et al. reported that sometimes users were unsure of the location of the NFC reader in the mobile phone, but an initial training period would overcome users' lack of familiarity with the NFC technology, leading to better performance[14]. It is also reported that users sometimes feel awkward or embarrassed reaching out to use the tags in a public place[14]. In touch interaction applications, target size had a substantial effect on performance, while distance had a substantial effect on remote interaction[2]. Our research focuses on interactions between smartphone and devices in household environments, where privacy concerns are less important issuers, and interaction accuracy can be augmented.

III. Challenges in Cyber-Physical Space Interaction

Although cyberspace and physical space are well developed and studied today, the gap between them has become increasingly wide. The diverse nature of these spaces raises significant challenges in cyber-physical space interaction. In this chapter, we discuss three major aspects of these challenges and compare different efforts and technologies employed to address these challenges.

A. Controllability

Action detection is a key challenge in cyber-physical space interaction. Most activities in cyberspace are triggered by actions in physical space. For instance, a check-in activity in a location based social network is always triggered by a user arriving at a specific place. Various technologies have been developed and employed to detect physical actions, which can be classified by user controllability, i.e., intrusive and controllable action detection.

1) Intrusive action detection: Intrusive action detection approaches use sensors deployed in the environment or affixed to the user to monitor and analyze user actions. Cameras, WiFi routers and infrared receivers are widely used as infrastructural sensors to track user location in the environment[15], [16], [17], and wearable motion sensors are employed to capture user behaviors[18], [19]. The disadvantages of these intrusive action detection strategies are that the systems have to run in the background all the time, and users are not able to control or pause the detection procedures. These disadvantages raise privacy concerns and significantly affect user experiences.

2) Controllable action detection: Controllable action detection approaches, on the other hand, do not monitor user behavior in the background. Instead, action detection procedure is triggered by user explicitly performing some specific action such as pushing a button or touching a device[2]. This gives the user full control of when their actions are performed, and what actions are supposed to be detected. Although performing such actions explicitly may increase the cost of interaction, we argue that using a smartphone to perform touch actions is not disturbing since the phone is a hand-held device and easy to carry.

B. Accuracy

Physical actions are always triggered by an intent. For instance, people may want to exchange personal information or play games together when they put their phones together. The accuracy of determining the intent of an action is also a challenge in cyber-physical space interaction. Computer vision based action detection strategy is not reliable and inaccurate, especially when lighting conditions are poor. Location-aware frameworks are capable of reconstructing spatial relation between user and their ambient, but lacks for critical information to perform action detection and classification[20]. QR-code and NFC technologies, in contrast, require a distance of about 4 cm (1.6 inch) or less to operate in, which is precise enough for action modeling and classification[14].

The other concern is the accuracy of user intent modeling. When a user sits down in the living room couch, their intent can be either watching TV or listening to music, which can not be inferred merely from the action itself. In this case, a smartphone can play a key role in providing user action context. Being a user's digital identity in cyberspace, a smartphone can provide context including user's profile, digital media and social relationship, thus enabling accurate intent modeling[21].

C. Usability

The difficulty of providing intuitive interaction methods between cyberspace and physical space is also a challenge. Text-based interaction is the most common method. Currently, most information are inputted using text, such as sentences, links, and even location descriptions[22]. However, text input on mobile phone is both painful and time consuming, and it is not intuitive to check in by typing in the phone while the user is at the very place[23]. Voice-based interaction is enabled in major smartphone platforms, but the response time of recognition is long and the accuracy is not good enough.

Recently, QR-code and NFC tags are used to help smartphones access contents in the cyberspace, especially in Japan[9]. QR-codes can be printed on posters or displayed on screens, and then be scanned by smartphone cameras. However, reading QR codes takes time and requires user attention heavily[8]. NFC tags are small enough to be attached on posters or badges, and then be read by smartphones via simple touch actions. These information may contain text or URLs, providing the possibility of interacting with cyberspace.

IV. Touch Driven Interaction

To address these challenges outlined above, we introduce touch-driven interaction between physical space and cyberspace with NFC. The concept of touch-driven interaction is that events are triggered by touching smartphone with devices, and then translated into information flow in cyberspace, which in turn reflected by corresponding activity in physical space. Figure 1 illustrates the interaction concept.

A. Physical Space

Physical space is the abstraction of our living environment, including humans, devices, etc. Human interactions with physical space, such as touching and moving, are considered natural and intuitive since these gestures express our intent directly. However, interactions with digital devices, such as smartphones and TVs, usually require specialized controllers and instructions. Some devices provide buttons and dashboards for operation and instruction, while others don't even have a control panel, but instead relying on another device to setup and configure. These interactions require a training process, and may be difficult and confusing for elder users.

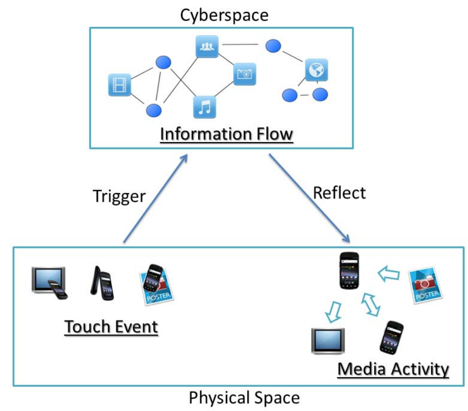


Figure 1. Touch-driven interaction between physical space and cyberspace

Therefore, we propose touch-driven interaction with digital devices, trying to interpret user intent from the touch action, and translate it into media activity without explicitly instruction and control. In order to detect touch events, devices are attached with NFC tags, which contains the device descriptions; a NFC enabled smartphone is used as an active scanner, which will detect tags in its range, and trigger an interaction. With touch-driven interaction, a digital frame can be setup via a touch after selecting a photo on the phone, and videos and music can be streamed from phone to TV or stereo by touching the devices together.

B. Cyberspace

cyberspace is defined more by the media resources and social networks rather than its technical implementation. In cyberspace, individuals can interact, exchange ideas, share information, provide social support, conduct business, direct actions, create artistic media, play games, engage in political discussion, and so on. By immersing computational systems into physical space, cyberspace is becoming increasingly ubiquitous.

Media resources are people's digital assets in cyberspace, including music, photos, videos, as well as personal profiles and contacts. These resources are stored in nodes, which are the digital representations of physical devices in cyberspace. Nodes are then inter-connected by networks, as illustrated in Figure 1. Networks provide elastic platforms for media resources to be shared among nodes, resulting in the flow of information. Information flow is an abstraction in cyberspace, and can be reflected in cyberspace by media activities between devices.

C. Touch-driven Interaction

As illustrated in Figure 1, the touch-driven interaction is triggered by a touch event, then translated into information flow, and finally reflected as activity on physical space.

1) Touch Event: We use NFC technology to detect and interpret touch events between smartphone and devices. First, we store device descriptions such as device type and name in NFC tags, and attach these tags to the corresponding devices. Second, an NFC enabled smartphone is used as a scanner to detect tags within its range. When a touch event occurs, the smartphone detects the tag, and read the device description in a short time. Finally, some user context is collected at the time the event occurs, such as the activity on the phone, the user input, and the environmental parameter from sensors, etc. With all the information, a touch event can be used to infer the user intent precisely.

2) Information Flow: The touch event is handled by the smartphone, and translated into information flow in cyberspace. First, we locate the node in the network representing the device according to the device description read from the NFC tag. The node representing the phone is regarded as the pivot node holding the user's most media resources, thus we don't need to explicitly address it. Second, we determine the media resources to be shared between the phone and the device. An intuitive approach is to use the currently accessed media on the phone. For instance, the user intent of touching the phone with a stereo while playing music is most likely to play the music on the stereo. If no media is being accessed on the phone, however, a list of available media can be filtered out based on the device description, or from user selection explicitly. Finally, we share the selected media between the nodes representing the phone and the device respectively, making an information flow in the network.

3) Media Activity: Information flow is reflected in physical space as media activity, which is participated by both the phone and the device. Some activities uni-directional, such as streaming video from the phone to TV, while some activities are bi-directional, such as exchanging social information between phones. These activities represent the user intent when they perform the corresponding touch actions, giving them a natural and intuitive interaction experience.

D. Advantages

The advantages of touch-driven interaction are discussed here. First, touch-driven interaction is triggered by user touching the phone with devices, thus it is controllable action. According to the experiment, the action is detected when the two parties are in a distance of about 2 cm, which is reasonable for defining a touch action. Second, given that the device descriptions are precisely read from NFC tags, and the media information is fairly discovered based on the context, the touch-driven approach is relatively accurate in inferring user intent. Finally, the usability of touch-driven interaction is better than QR code-based or voice-based interactions, since the touch action is intuitive, and can be detected quickly, requiring no pre-configuration or setup.

V. Implementation

A. NFC Hardware

The smartphone we use in our implementation is Google Nexus S, which is the first NFC enabled smartphone in the market. It features 1GHz CPU, 512M memory, a 4.0-inch touchscreen, and near field communication capabilities, making it the outstanding platform for NFC-based applications. The NFC chip is mounted on the back of the phone, so touching it with a tag is easy and natural (Figure 2). Furthermore, the chip can also be used to write information to tags, thus we don't need another specialized tag writer hardware.

The NFC tag we use is the MIFARE Classic, consisted of a storage chip and several coils of antenna in a size of about 5 cm^2, as shown in Figure 2. The MIFARE Classic offers 1024 bytes (1K) of data storage with simple security mechanisms for access control, which is suitable for storing device descriptions. Based on our experiment, the Nexus S NFC reader recognizes the tag in a distance of about 2 cm in average. This distance is good enough for defining a touch action, unlike that of other RFID tags, which may operate in a distance of about several meters.

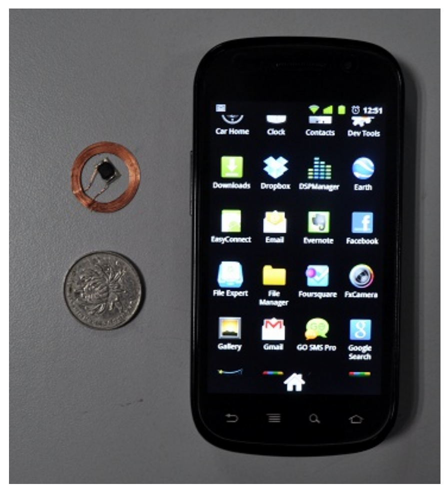


Figure 2. An NFC tag and the Google Nexus S smartphone

B. Device Connection

In our living environment, various devices have been deployed to enable access to media resources in cyberspace. These devices can be connected via WiFi, Bluetooth, Infrared Radio (IR), etc. Usually, connecting to these devices requires setup and configuration, making the interaction complicated and inconvenient. We try to automate these connection procedures with the assist of NFC tags and smartphones. First, we write device descriptions into tags, including device name, network type, communication protocol, etc. Second, we affix these NFC tags to devices. Since the tags are relatively small, they can easily attached on the surfaces of TV, digital frames, stereo system, and so on. To improve accessibility, the tags are covered by paper stickers with colorful NFC logo.

Figure 3 illustrates the procedure of connecting to devices via WiFi and Bluetooth. Information about connection type, network name and security key are all read from the tag, and used in the procedure. After connection established, information can be transferred between phone and device, resulting in information flow and media activities.

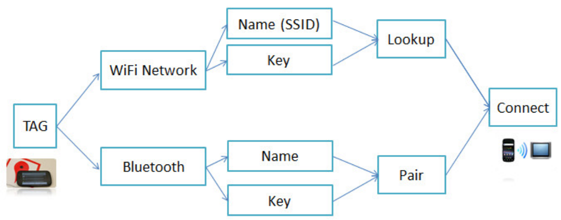


Figure 3. The procedure of connecting to devices via WiFi and Bluetooth

C. Data Exchange Protocol

Data exchange occurs between the tag and the phone when a touch event is triggered. To understand the information the tag carries, a data exchange protocol is required. We define the data as device descriptions, and encode them using the JSON data format. JSON is a compact data format with simplicity, extensibility, interoperability and openness[24]. JSON strings can be written to tags, and converted into Java objects directly. Generally, device descriptions include the following fields:

- NAME: Device name field, such as “Felix’s TV”.
- CONNECTION: The connection object for this device, including the following fields:
  - TYPE: Connection type, such as WiFi or Bluetooth.
  - NAME: The SSID of the WiFi network where the device is connected to, or the network name of a Bluetooth device, etc.
  - KEY: The key required to connect to the WiFi network, or to paired with the Bluetooth device, etc.
  - PROTOCOL: Protocol for communication between the device and the phone, such as UPnP discovery or Bluetooth pairing.
- MEDIA: the media type the device can handle, such as “video”.
- EXTRA: extra information about the device, such as screen size of a TV.

Figure 4 shows the implementation details of the tags and its contents, which is the data exchange protocol between the TV and the phone.

D. Media Discovery

Based on the device descriptions read from tags, we can locate devices in the network. Also, the address of the phone can be figured out from Android API. The next step is to discover the media to be shared between the phone and the devices. We perform this task by the following strategies sequentially:

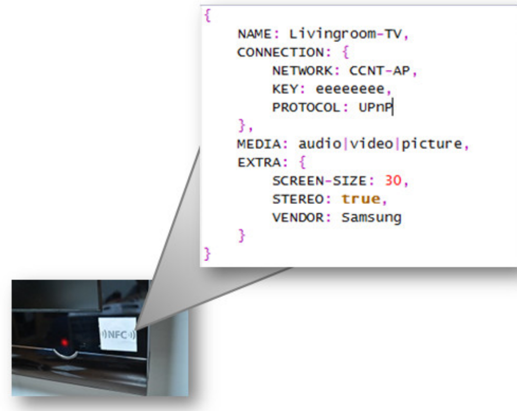


Figure 4. Data exchange protocol for an NFC enabled TV

- Query the phone’s current application for media: Android applications such as Gallery and Music use media URI to access resources on the phone or in the Internet. When these applications are running, the media URI can be determined and passed to our application.
- Filter out media based on device descriptions: Device types and media types can be used to help discover media. For instance, a TV is described to accept audio, video and pictures, so we can filter out these types of media on the phone and make sure that such media can be played on the TV. For devices carrying personal identities such as phones, the identity can be stored in the “EXTRA” field of the phone’s NFC tag or chip, and then used to locate the personal profiles in social networks.

E. Media Sharing

Finally, we translate the touch action into media sharing activity in both cyberspace and physical space. Media sharing can be implemented from phone to device, such as playing video on the TV, or streaming music to the stereo. Such sharing activities are started by the phone, but accomplished with the participation of devices. Other types of media sharing are implemented to be bi-directional between two phones. Such activities include user identities exchange between phones, mobile payment through NFC supported phones, and NFC based device pairing, etc.

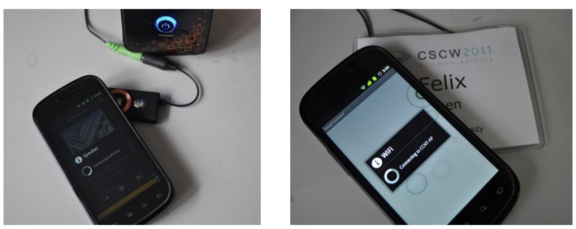
VI. Applications

In this chapter, we present several applications to demonstrate touch-driven interaction. First, we introduce Touch&Connect, which enables connection between phone and device via a simple touch. On this basis, we implement Touch&Watch, Touch&Listen, and Touch&MakeFriends, to provide intuitive and convenient media interaction between phone and devices.

A. Touch&Connect

Connecting a smartphone to a WiFi network or a Bluetooth device is not an easy task. For security concerns, many devices require passwords or keys for authentication. For instance, many Bluetooth devices have pairing-keys, and private WiFi access points are usually encrypted with passwords. However, typing these passphrases on a phone is slow and mistakable. Furthermore, it is always troublesome to get users to know these passphrases, especially in public places such as coffee house or conference halls.

With Touch&Connect, these passphrases can be stored in tags, and attached to these devices, or distributed to users along with invitation cards or badges. Touch&Connect then reads the passphrases and other device information from the tags, and connects to the devices automatically. As illustrated in Figure 5(a), pairing and connecting to the Bluetooth speak can be done by touching the phone to the tag attached on the Bluetooth receiver. In Figure 5(b), we touch the phone to a conference badge with a NFC tag to connect to the WiFi network in the environment. Here, we modified several Android system services to enable automatically connection without user intention.



(a) (b)

Figure 5. Touch&Connect: Pairing with Bluetooth device (a) and connecting to WiFi Access Point (b) by putting the phone on the tags

B. Touch&Watch

Thanks to the powerful hardware, state-of-the-art smartphones are able to take high resolution photos and record fine quality videos. Chances are that we want to share our phone videos and photos with friends and families on TV. However, sharing phone media with other devices are never easy. Usually, specialized data cables are required to connect phone to device, and configuration steps are complicated. Syncing media between phone and device takes time, and the playing status is not preserved.

The Touch&Watch application allows phone videos and photos to be shared on TV via a simple touch (Figure 6). This is done by the following steps. First, we connect the TV to a windows host which supports the UPnP protocol for device discovery and control. Then, we encapsulate the TV's video playing and photo displaying functionality into a UPnP service, which can be discovered in the entire WiFi network. After that, we encode the TV descriptions in a NFC tag, and attach it to the TV. These descriptions include the WiFi connection information and the details about the TV, and so on. Finally, we implement the Touch&Watch application on the Android system. This application reuses the connection procedures of Touch&Connect to enable automatic WiFi connection, and obtains media information by querying the Gallery3D application. It then communicates with the TV host using UPnP protocol, and shares photos and videos with the TV. Here, we have hacked the Gallery3D application to add some media query interfaces, including media name and video playing progress, etc.

Figure 6. Touch&Watch: Sharing photos and videos between phone and TV via a simple touch

C. Touch&Listen

High-Definition stereo systems provide great music experience both in car and in the living room. These systems are usually connected with CD players, radio, or PC, but not with mobile phones. On the contrast, more and more music and podcast can now purchased and listened on the phone, using applications such as Apple iTunes or Google Music. Instead of manually transfer these audio resources from phone to those players, we try to stream the audio directly to the stereo systems by touching the phone with them. In this way, the user can relief from complicated configuration, and get much better music experience since the streaming is seamless.

We implement the idea as the Touch&Listen application, as shown in Figure 7. The speakers are Bluetooth enabled, and support the A2DP protocol. An NFC tag is affixed to the speakers, containing the connection information as well as speaker parameters. The Touch&Connect procedures are also reused to establish connection between the phone and the Bluetooth device. When the touch event occurs, Touch&Listen reads device descriptions from the tag, and queries the Music application for the music being played, including the progress and other details. At last, music is routed to the Bluetooth speakers seamlessly without other user actions.

D. Touch&MakeFriends

Smartphones not only boast multi-media capabilities, but also serve as the digital identities of users. User information, contacts and social networks can be accessed by smartphones with ease, but sharing them across phones are troublesome. In most cases, when two persons first meet, they exchange their business cards, and manually input the other person's name, phone number, and email address to phone. They may further

Figure 7. Touch&Listen: Streaming music seamlessly from phone to Bluetooth speakers by touching them

add each other on social networks such as Facebook by searching names. However, the personal and social identities are in their phones respectively, what they need is just exchange the information.

Touch&Friend makes the information exchange simple enough via a tap between two phones. As illustrated in Figure 8, tapping two NFC enabled phones together triggers an event of identity exchange. The identity not only includes basic information such as user name, phone number and email address, but also includes user identities on social networks. Following the touch-driven interaction process, the identity is first used to create a new contact in the phone's address book, and then queried in social networks to find the person and get connected. This happens quickly and naturally by just a touch, and no user input is required.

Figure 8. Touch&MakeFriends: Exchanging personal information and social network identities via a tap between two phones

VII. Conclusions

As cyberspace becomes increasingly important in our daily life, the possibility of providing intuitive and convenient interaction with the cyberspace is now extensively studied in the literature. In this paper, we explored challenges in cyber-physical space interaction. These challenges include user controllability, accuracy and usability.

We discussed several interaction methods and proposed touch-driven, NFC-based interaction to address these challenges. This interaction method translate touch action into information flow in cyberspace, which is in turn reflected in physical space as media activities. We argued that this touch-driven interaction brings full user controllability, fine-grain accuracy and high usability.

We also provide several applications to demonstrate the interaction method. These applications enable intuitive and convenient interaction with devices through NFC-enabled smartphone.

We believe that more and more smartphones will be supporting near field communication technology, and various applications will be discovered and developed in the near future. The touch-driven interaction proposed in this paper is supposed to help promote the design and development of these applications, and make the interaction between physical space and cyberspace much more intuitive and convenient.

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