Sensing Techniques for Multi-Device Interfaces

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BIOGRAPHY

I am a research scientist at Microsoft Research. I have published widely on input devices and interaction techniques. My recent interests have included sensing techniques for mobile interaction. It is my assertion here that sensing techniques and multi-device interfaces complement one another; indeed, sensing may be essential to providing responsive, effective, and highly dynamic interaction with distributed mobile devices, whether those devices are worn or carried. Portions of this workshop submission come from our 2-page formal video proposal that was accepted to UbiComp 2003.

INTRODUCTION

As computing becomes more and more ubiquitous, there has been a trend for computing resources to become fragmented into small, specialized pieces: from mainframes, to personal computers, to an explosion of tablet computers, handheld devices, cell phones, pagers, wrist watches, and ear buds. Yet wireless networking acts as a medium that potentially can tie all of these pieces back together, enabling users to dynamically combine multiple devices to provide new capabilities that otherwise would not be possible. Jeff Pierce has a wonderful phrase for this vision of dynamically forming multi-device interfaces: *opportunistic annexing* [12]. In short, wireless networking will lead technology in entirely new directions that are difficult to foresee: in 100 years, I expect the phrase *wireless networking* will sound a lot like the phrase *horseless carriage* does to us now..

This proposal contributes to workshop goal (2), enabling software and architectures, as well as goal (3), the design of multi-device interfaces, in two significant ways. First we discuss the general strategy of recognizing synchronous gestures as an approach that can allow users to intuitively form connections (associations) between distributed mobile devices. Forming meaningful sets of devices is a key challenge for opportunistic annexing. Second, we discuss how sensors might be used to sense when and how the user is employing multiple devices, and to sense transitions between active use (when the user is attending to the device), versus disuse, when the user may be ignoring or only partially attending to the device. Sensing such transitions may be essential if we are to design multi-device systems that do not distract user's from their current tasks.

CONNECTING DEVICES: SYNCHRONOUS GESTURES

Establishing meaningful connections between devices is a problem of increasing practical concern for ubiquitous computing [9][13]. Wireless networking and location sensing can allow devices to communicate and may provide information about proximity of other devices. However, with many devices nearby, how does a user specify which devices to connect to? Furthermore, connections need semantics: What is the connection for? Is the user collaborating with another user? Is the user combining the input/output resources of multiple devices to provide increased capabilities? Users need techniques to intuitively form semantically rich connections between devices.

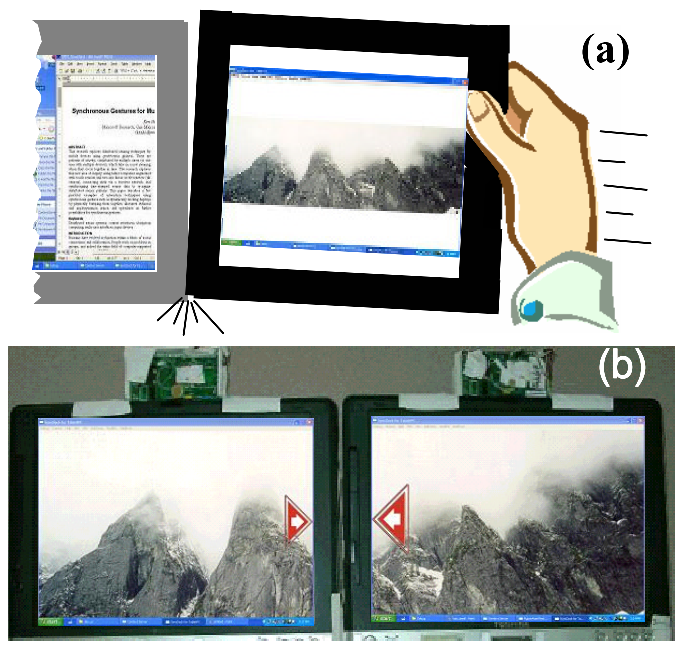

Fig. 1 (a) Dynamic display tiling by bumping together two tablets that are facing the same direction. (b) The tablets form a temporary larger display.

In recent work, I have proposed *synchronous gestures* as a unique strategy to the problem of connecting ubiquitous devices. Synchronous gestures are patterns of activity, contributed by multiple users (or one user with multiple devices), which take on a new meaning when they occur together in time, or in a specific sequence in time [4].

For example, physically bumping two devices together can act as an effective means to form privileged connections between devices. Wireless communication implies the ability for devices to sense the proximity of other nearby devices via signal strength triangulation [1], so why use bumping when proximity is available? Bumping introduces an explicit step of intentionality, which users have control over, that goes beyond mere proximity of the devices to form a specific type of connection. For example, dynamic display tiling [4] enables users to combine the displays of multiple devices by bumping a tablet into another one lying flat on a desk (Fig. 1). Users can also establish a collaborative face-to-face workspace [3] by bumping the tops of two tablets together (Fig. 2).

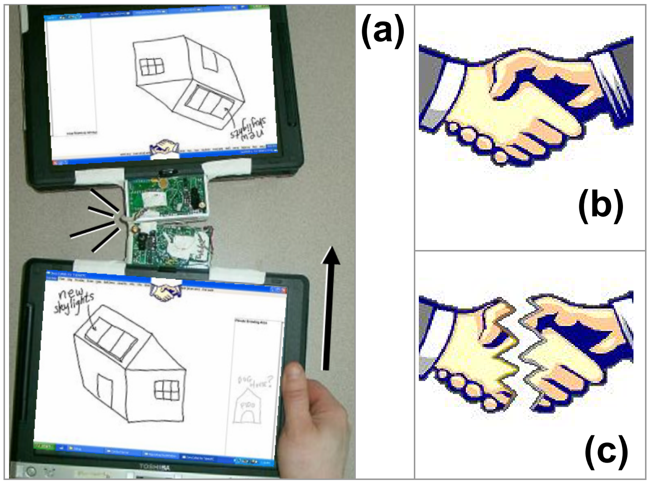

Fig. 2 (a) Face-to-face collaboration by bumping the tops of two tablets together. The sketch is shared with the other user for annotation. Also shown: feedback for (b) making or (c) breaking a collaboration connection.

Bumping generates equal and opposite hard contact forces that are simultaneously sensed as brief spikes by an accelerometer on each tablet. The software synchronizes the data over an 802.11 wireless connection; two spikes are considered to be simultaneous if they occur within 50ms of one another. The two orthogonal sensing axes of each accelerometer provide enough information to determine which edges of the tablets have collided, allowing tiling of displays along any edge (left, right, top, or bottom) or sensing that the tablets are facing one another when bumped together in the case of face-to-face collaboration. Example accelerometer data from bumping two devices together is shown in Fig. 3, as well as simultaneous but incidental handling of the devices. The software can ignore most such sources of false-positive signals. Details of synchronization and gesture recognition appear in [4].

For dynamic display tiling, one tablet (the *base tablet*) rests flat on a desk surface, and a second tablet (the *connecting tablet*) is held by a user and bumped into the base tablet along one of the four edges of its screen bezel. Note that this creates a hierarchy in the connection. The connecting tablet temporarily annexes the screen real estate of the base tablet. The software currently distinguishes the connecting tablet from the base tablet using capacitive touch sensors to determine which of the two tablets is being held.

For display tiling, picking up a tablet removes it from the shared display. By contrast, for face-to-face collaboration, users may want to move their tablets apart but continue collaborating; hence moving the tablets apart does not break the connection in this case. Instead, users can explicitly break the connection, or the system automatically breaks the face-to-face connection if one of the users walks away (walking can be sensed using the accelerometer [3]).

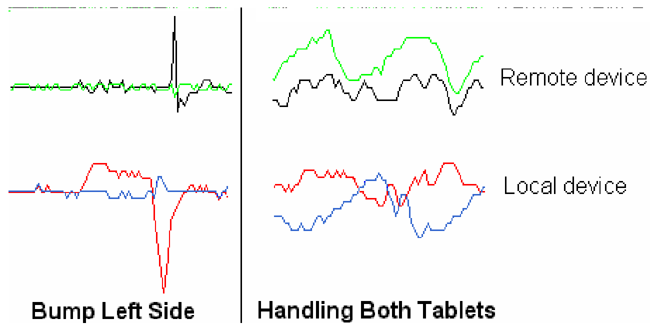

Fig. 3 **Left:** Example accelerometer signature for bumping two tablets together, with forward-back and left-right accelerometer axes for the local and remote devices. **Right:** Incidental handling of both tablets at the same time results in signals that are distinct from intentional bumping.

More Than Two Devices & Heterogeneous Devices

I have recently extended the system to support bumping between more than two tablets. For example, users can dynamically construct a 2x2 tiled display, or even unusual shapes, by bumping one tablet at a time into the existing structure.

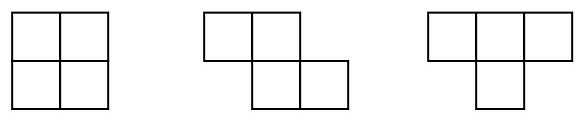

Fig. 4 Some display configurations that users can construct by dynamically bumping together four tablets.

I have only implemented these techniques for multiple Tablet PC's, but we believe bumping could be extended to work with other mobile devices, thus potentially allowing users to easily specify connections between heterogeneous devices. New interaction techniques for dynamic sets of heterogeneous devices seems a promising area for future research, but we have not yet explored these possibilities due to the pragmatic difficulties of porting our sensing hardware and system architecture to myriad other devices.

Stitching for Pen-based Computers

Connecting devices by using synchronous gestures other than bumping may be possible. In ongoing work, the author and colleague Gonzalo Ramos have investigated *stitching* [8] together multiple Tablet PC devices by making a pen gesture that starts on one screen, continues across the screen bezel, and completes on the screen of another Tablet PC. The system recognizes that the segments of the gesture observed by the two distributed Tablet PC's are actually part of a unitary pen stroke performed by the user, and hence can determine that the user is trying to exchange information or otherwise connect the two machines.

SENSING ATTENTIONAL TRANSITIONS FOR INTERACTION WITH MOBILE DEVICES

In past work, the author and colleagues have explored sensing techniques for mobile devices, including PDA's [7] and cell phones [5]. In the scenario proposed for this workshop, a wirelessly connected PDA and a watch work together to give the user enhanced access to their information. Although we have not yet explicitly incorporated our sensing techniques into a multi-device system including a PDA and watch, this is a scenario we have thought about and we believe some of our techniques could be beneficial to such systems.

In our work with cell phones, we can sense when the user picks up and looks at the device in response to an incoming phone call. We use this to infer when the user has noticed an incoming phone call; the system automatically softens the ring volume, since the system knows that ringing loudly is no longer necessary to get the user's attention. We recognize the gesture using touch sensors to confirm that the user is actually holding the phone, and then look for a transition to tilt angles that suggest the user is attending to the display (we find that users invariably tilt the screen toward themselves when using a device). Similarly, we can sense when the user puts the phone down or otherwise puts it away, indicating that they no longer want to attend to it.

This example shows how sensors have the potential to inform the system about transitions between the user's attention to the device in the *foreground*, versus inattention or partial attention as the device drifts into the *background* of attention [2][6]. Note that when a device is in the background, it still may be held, carried, or worn by the user, but is not being directly attended to.

With similar sensors and a small variation in the sensed gesture, it should be possible to sense when a user looks at his watch: to look at a watch, people lift their arm and rotate their wrist so that they can see it. Hence when the user looks at their watch, the system knows it is time to deliver notifications or start displaying priority-ordered information. When the user holds their arm back down, the system knows it is very unlikely the user is attending to it. In this situation the system could exhibit a strong preference not to interrupt the user's activity. These simple sensing techniques could transform a device that might be a nuisance into device where the user instead actively polls for information by glancing at their watch when they want to know something.

Of course, in some cases high-priority messages or background reminders might need to have some way to "break through" even when the user is not attending to them; other work in our organization has investigated these problems using Bayesian reasoning [10][11].

CONCLUSION

The workshop proposal states that "the most interesting and novel interface design challenge is how to divide functionality across multiple devices" which I completely agree with. A fascinating further twist on this occurs when the devices may be owned by different persons – the problem becomes that of *combining functionality*, as well as dividing it. Our face-to-face collaborative workspace is one example of what becomes possible; the system provides a unique form of *dual display groupware* that enables shared, public use (when the devices are together on a table) as well as separated, private use of each tablet by its owner [3]. Thinking further along these lines, providing UI for impoverished or simplistic devices could be as simple as bumping one's watch into a display that happens to be nearby. The strategy here is opportunistic annexing of devices in the environment as proposed by Pierce [12]. Techniques for users to dynamically combine multiple heterogeneous devices represents a largely unexplored design space, and could represent the next wave of compelling new applications for mobile devices.

Our current and ongoing work has explored novel uses for sensors on mobile devices. Applications of relevance to the workshop include connecting devices and sensing attentional transitions. Bumping offers a novel and intuitive mechanism to form specific types of connections between mobile devices. When bumping two tablets together, a connection is formed in the physical world by manipulating the actual objects of concern, so no naming or selection of devices from a list is needed. Bumping can support several different types of connections, including dynamic display tiling, face-to-face collaboration, or exchanging and "pouring" data between tablets. This represents an advance over related work [9][13]. Furthermore, the same sensors used for bumping can be used to help sense transitions in user attention to a mobile device (whether carried like a PDA, or worn like a wristwatch). This seems like an extremely promising direction for future multi-device systems; otherwise, the devices do not know how or when to respond or provide information to the user.

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