Communiclay: A Modular System for Tangible Telekinetic Communication

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Abstract

We introduce Communiclay, a modular construction system for tangible kinetic communication of gesture and form over a distance. Users assemble a number of Communiclay nodes into unique configurations, connect their creations to each others' Communiclay creations on a network, and then physically deform one creation to synchronously output those same gestures on the other networked creations. Communiclay builds on trends in tangible interfaces and explores the ways in which future actuated materials can enable a variety of tangible interfaces. We present applications that stem from past research in tangible media, and describe explorations that address ways in which people make meaning of remote communication through gesture and dynamic physical form. Our hypothesis is that current research in programmable matter will eventually converge with UI research; Communiclay demonstrates that we can begin to explore design and social issues with today's technologies.

Keywords

Communication, Modular Robotics, Programmable Matter, Programming by Demonstration, Tangible Interface.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation: Miscellaneous. H.4.3. Communications Applications.

General Terms
Design

Introduction
Movement is a natural means through which the physical world displays information. We feel that the development of tangible interfaces is pursuing a path similar to the development of motion graphics. The visual representation of information through 2-D images has progressed from static representation (paintings) to dynamic representation (motion pictures) to interactive dynamic representation (motion graphics). This might be described as a trend for the image to more authentically represent life. Where the image once captured a moment, film captures a temporal narrative and motion graphics give the narrative (or character, or object) a behavior, social context, or response to its environment. Physical objects are undergoing a similar history. Where sculpture once captured a static moment in a physical form's existence (e.g. a Greek figurative statue), mechanized automata of the 18th - 20th c. gave those forms life. The trend in tangible interfaces to use objects' movement to represent both abstract information [12, 21] and human intention [5, 10] paves the way for more recent work [15] which explores the potential for the object to reflect life and become an interactive part of a culture's social fabric.

Many tangibles use mechanical movement as an element of the interface. InTouch, a system of two sets of remotely coupled physical rollers on stationary bases, creates the illusion that two people, separated by a distance, are interacting with the same physical object [6]. Pinwheels use the spinning motion of an array of these familiar objects to represent real-time internet data such as stock market activity or ocean waves [21]. Super Cilia Skin explores how dynamic texture can be used both as a gestural input medium or as a kinetic display [15].

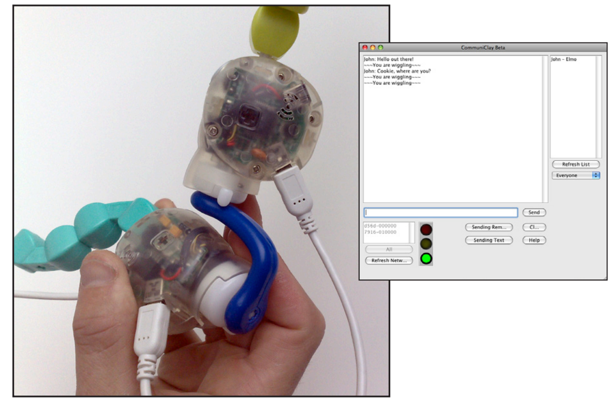

Figure 1. Left, physical kinetic input with the TUI. Right, a GUI supports kinetic communication and text messaging over the internet.

The prevalence of mechanical movement as an interface leads us to raise the question whether mechanical movement is a fundamental quality of tangibles. In contrasting tangible interfaces with the graphical interface and pixel [12], Ishii implied that we do not yet know the fundamentals of display for tangible interfaces. For images it is color and light, modulated by an array of computer controlled pixels. Certainly color and light are a fundamental quality of TUIs. Is mechanical movement - and its many manifestations such as temperature (molecular movement) - another fundamental quality of TUIs?

Figure 2. Flower motions signal mood and initiate conversations.

Communiclay

Communiclay is a system of modular actuators that form a physical communication channel with similar actuators over a distance. The basic interaction design is inspired by InTouch [6] a system for remote haptic communication, and Topobo [14] a 3d constructive assembly system with kinetic memory. Communiclay nodes can be (1) assembled into various physical configurations (2) networked into a single ad-hoc creation (3) programmed by physical demonstration and (4) share kinetic information (as both input gesture and output robotic motion) with other creations over a network connection.

Design Guidelines

We sought a scalable, flexible, and topology-agnostic system that was simple enough for anyone to use. Our goal was a system that was easy to assemble and experiment with, and could gracefully recover from technical ambiguities or limitations. We wanted the system to function in a "local" mode that would encourage experimentation and learning about the system, and in a "shared" mode that communicated gestures with other networked Communiclay systems. Most importantly, we wanted to support remote communication, and investigate how a kinetic medium would affect people's interpretations of their telecommunications.

System design

Topobo hardware is modified with custom firmware to communicate with a PC-side Java client (figure 3). The tangible interface (Topobo system) supports a local record/playback interface for experimentation, similar to Topobo, and switches to a shared transmit/receive configuration when it is connected to a computer.

A PC-side Java client connects to Topobo hardware via a USB-serial connection which passes through a dedicated RS232-Topobo protocol translation module. The Java client performs a number of tasks. Topobo is an ad-hoc sensor network with no central communications bus, and the client is responsible for maintaining the current network topology and routing information to and from individual nodes ("Actives") in a creation. Users can change the network topology of their creation on the fly and the Java client will automatically reconfigure its routing scheme to match the actual topology. The client manages local state of the Communiclay network, and connects with other Communiclay systems by broadcasting to a shared multicast group. Data is transmitted via UDP/IP to other members of the multicast group. With optimizations in serial data transmissions to the hardware, the system achieves low latency (<40 ms) communications across the network. By applying periodic remote updates to local motor feedback loops, Communiclay creates accurate and "real time" representations of remote actions. The associated Java client GUI gives users feedback about the system, allows users to manage multiple individual Communiclay creations, and allows users to link their creations to other users' specific creations (Figure 1).

Iterative design

Based on early user feedback, we made several design adjustments to simplify interactions and make communications more explicit. Users found that kinetic information alone was often not enough to understand the remote person's gestural or kinetic meanings, and users requested other channels of communication. We added a text chat box to the GUI to support simple text communication between group members, and included text feedback about whom in a network was controlling the movement of the Communiclay system (e.g. "~~~ Bob's flower is wiggling! ~~~"). Users suggested the inclusion of a voice communications channel as well, to support screen-free communication.

In early evaluations, users were confused about controlling local state changes of the Topobo nodes. Topobo uses a single button interface to change from "record" to "playback" to "off" modes. This interface did not make sense to Communiclay users, who are either "transmitting" or "receiving" movements through the tangible interface. We modified the hardware to automatically switch modes: Communiclay Actives are usually in "off" mode; if a user grasps and manipulates an Active, it will sense the movement and signal all of the Actives in the structure to switch to "transmit" mode; after the user stops moving, it will automatically return to "off" mode. If the system receives commands from another networked Communiclay creation, the Java

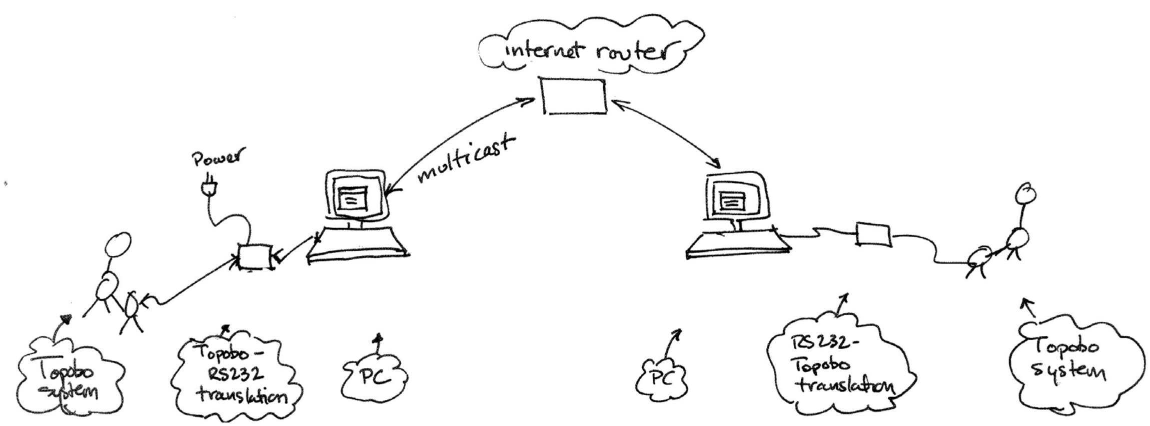

Figure 3. Communiclay system architecture.

client will set it into "receiving" mode. This results in a system that is automatically "off" when it is ignored, "transmitting" if a user grasps and moves the system, and "receiving" if another networked user is transmitting.

In normal use, Communiclay users must take turns transmitting motions, like a call-and-response system similar to SMS. However, if one user is "hogging" the system, another user can interrupt and assert control of the networked motion by pressing a button on any one of their Topobo Actives.

Technical limitations

A modular, reconfigurably system introduces a fundamental technical challenge: there often exists ambiguity in mapping motions between creations. For instance, if one user uses 3 Actives in a creation and her partner uses only one Active, how shall motions be mapped across creations? Or, in a scenario where two remote partners have creations with 3 Actives, the creations may have different network topology. Currently, the system guesses how to map motions between creations, but must sometimes make an arbitrary decision between choosing to map across a network topology's breadth or depth.

Related Work

Communiclay builds on communication trends in tangible interfaces and enabling technologies from modular robotics and programmable matter.

Ambient displays were first coined via Pinwheels [12], and the idea was incorporated into communications devices with projects like ComTouch [7]. Super Cilia Skin [15] explicitly uses motion to convey both ambient and foreground communication, and we continue this trend, exploring how kinetic interfaces can transition from peripheral to foreground awareness, and support communication in a style consistent with "calm computing" [20].

Haptic interpersonal communication was demonstrated by InTouch [6] and we are inspired to apply this concept more generally to a reconfigurable medium, so that the particular instantiations of the interface can be more easily explored. InTouch supported rotating wooden rollers on a stationary base. In general, Communiclay addresses kinetic forms and form-changing rather than pure gestural communication via a "shared object." Unlike inTouch, Communiclay is not a fully duplexed haptic system; the system is either in transmit or receive mode. While any user of the system can seize control (transmit), users cannot "feel each other's interactions" in real time, as with inTouch. This is due to technical limitations introduced by network latency. Despite this limitation, users elicited some behaviors reminiscent of haptic communication.

The automated animation of physical objects often falls within the realm of robotics, which provides foundational conceptual and technological examples, and our character animation explorations are firmly situated within the research realm of human-robot interaction. Robot phone [16] addressed how kinetic forms, both abstract and character-like, can communicate gesture over a distance, and we continue this trend by introducing a modular and reconfigurable robotic system to this research domain. RUI research also explored techniques for managing network latency in kinetic communications devices [17] that are relevant to our investigation.

Both the robotics and V.R. communities have pointed out that a primary distinction between communications and robotic representations is the distinction between people and machines [16, 18]. Communication must support robotic “avatars” rather than “agents.” The Communiclay user is intended to be aware that the motion is generated by a remote partner, and can take control of the system at any time.

The technical implementation of a modular robotic system is informed by the modular robotics community, for example PolyBot [23]. This community also investigated the implementation of a “digital clay” [22] which overlaps with our desire to have a more universal tangible medium for kinetic expression.

Our work also bears upon animation fundamentals (both 2d and 3d) since animators are experts at manipulating form and giving it kinetic behavior to convey emotion [8].

Applications

As the motivation of our work is to explore social interpretations of tangible telekinetic communication, we outline cultural and sociological experiments to inspire future research in the context of various application themes.

Haptic interpersonal communication

We learned from inTouch that non-representational interfaces can support interpersonal communication by supporting users to invent meanings for another user’s gestures [6]. Since Communiclay has the ability to be formed into kinetic objects, users can create organic forms whose motions can be interpreted visually as well as tactilely. For instance, a spider-like form can bounce up and down by constricting its feet together, eliciting a bouncing motion. Depending on the speed and nature of the motion, this may be interpreted as the spider being angry, tired, or happy. Keepon [13] demonstrated how simple kinetic gestures can communicate a range of intentions to a wide audience, including children.

Alternately, we have experimented with wearing the system with a partner as sensor/actuator exoskeletons, which allow partners to sense one another’s body movements in a visceral, haptic manner. These experiments point to a new mode for distance “connectedness” and new opportunities for HCI.
We imagine distant excercise partners who can be motivated by the sensory awareness one another’s physical routines, getting up to run “together” in the morning despite a geographical separation. Researchers in remote haptics [5] have noted that haptic channels alone are sometimes too ambiguous to support rich communications. Pairing haptics with voice, video, and text channels can provide users with more modalities and means to express their ideas with each other.

We similarly imagine how wearable sensor/actuator systems can support kinesthetic learning. A remote athletic coach may guide an athlete’s body how to move by performing the proper motion herself. Today, a coach will physically grab and guide a novice’s body to properly perform a motion (such as a golf swing). In the future, aspiring golfers may purchase a one-hour lesson from a remote expert trainers, or even “download” and feel the motion of Tiger Woods’ perfect 300 yard drive so that they may feel impulses that help them train their own muscles to move.

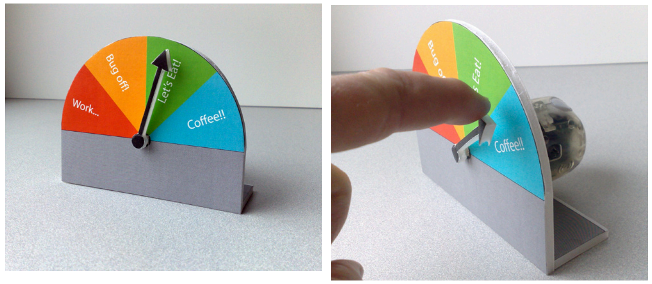

Figure 4. Communiclay is appropriated to support explicit task signalling between office-workers. At left, text output; at right, text selection.

Ambient displays

Investigations into ambient displays [1, 6, 7] have explored how the modular system can use haptics for visual and aural display. Communiclay is configured to represent state through it's physical orientation. Examples in this category span from metaphorical (i.e. flower, figure 2) to explicit, such as using Communiclay to point towards one of a number of text messages (figure 4). While many of our examples support one-to-one communication, one-to-many and many-to-one communication is also possible.

Ambient displays are, by design, abstract representations of complex ideas. Ishii's pinwheels represented invisible solar radiation by spinning motorized fans in response to abstract scientific data. The Ambient Orb [1] represents stock market activity as color (red = market falling, green = market rising). Another approach is to make the display explicit, e.g. by using text as in figure 4. In more ambiguous representations, designers assume that users understand - or even invent - metaphorical meanings for the display of their action. This element of ambiguity is a central pivot for our work with ambient Communiclay displays. How will users invent interfaces and meanings of their devices if they can easily reconfigure them to reflect their own creative motivations? Will users invent their own metaphors for physical pose when given the tools to do so, or must designers pre-define such symbolism?

Character Animation

By clothing Communiclay with a familiar children's puppet (Figure 5), the system can animate a communicative robotic doll or remote-controlled puppet. Motions to one doll are mimicked by other connected dolls. These characters can then communicate a user's intentions via the shared understanding of the puppet's personality. For instance, Elmo is tired when he looks down; Cookie Monster is inquisitive when he looks up and reaches for you. Puppeteering suggests that eye gaze and posture are fundamental gestures to control.

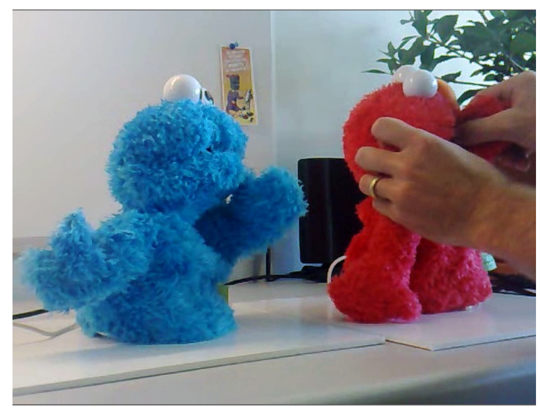

Figure 5. Communiclay skeletons are embedded in puppets to facilitate multiple DOF bidirectional communication via character-based avatars.

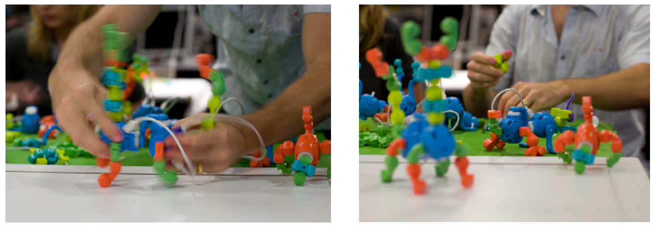

Figure 6. Remote topobo learning: a topobo expert user remotely programs a novice's horse to walk.

The V.R. community has addressed some related themes, e.g. they have distinguished avatars from agents, noting that users respond differently to depictions of other people than they do to personifications of machines [18]. Embodying a person's gesture as the gesture of a third character raises questions related to our work, especially issues of source identity and embodiment. If Elmo is moving, is it Elmo's movements, or the movements of a remote person, as mediated by Elmo? Designs of agents and avatars must be carefully chosen to help users understand with whom they are communicating, and how they are to interpret movement and posture of the character.

Distance robotics learning and mentoring

Communiclay has retained the basic functionality of the Topobo system, and it is possible to use it for remote teaching about robotics concepts. For example, a novice user may build a horse and have trouble figuring out how to program it to walk. By physically connecting it to the Communiclay system and then joining a group with an expert user, the expert user can remotely program the novice's moose to successfully walk (figure 6). The novice can both visually observe the motion, as well as grasp and feel the movement of the Moose in his own hands. The ability to feel the motion can support kinesthetic learning so that the novice can more successfully reproduce the walking motion himself in the future.

Issues of ambiguity

In multicast scenarios, users in a pilot study encountered ambiguity regarding source identification. In a group with many people subscribed, who was a gesture coming from? Currently users can read the text box on the GUI, but a more integrated solution was desired. This points to the lack of explicit expression in our current system, and suggests that source identification will be a central social concern when atoms can be remotely controlled to physically interact with us. There is a general desire to know how others are interpreting your gestures, suggesting at least one richer form of communication to be paired with the telekinetic system (i.e. voice or video).

Conclusion

Communiclay is a platform to explore ideas made accessible by kinetic modeling and communication. We have presented a number of experimental applications in this paper, including ambient communication, haptic communication, the use of avatars to convey action, and possibilities for remote learning. Our research begins to address a future in which people can augment their remote communications by controlling distant atoms to dance, change shape, and move.

We are exploring the hypothesis that a computer-controlled, scalable, actuated modeling system could be a display and interface for an entire class of tangible interfaces. While Communiclay does not replace the long-sought "digital clay," that eludes the best materials scientists and engineers, our current system lets thos of us in HCI beging to explore and experiment with how a general purpose senseing/actuation system can support new forms of user interaction. Current research in programmable matter and robotics [3, 21] will eventually converge with UI research, and Communiclay demonstrates that we can begin to explore relevant design and social issues with today's technologies.

Acknowledgements

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