Tangible User Interfaces: Technology You Can Touch

Lee Garber

To make computer and communications technology easier to work with, vendors are beginning to release products utilizing tangible user interfaces, in which users interact with physical objects that both represent and control digital information.

Researchers are always looking for new and better ways for users to interact with computing and communications technology, to make the process easier, as well as more satisfying, engaging, and effective. Because of this, interfaces—including punch card and paper tape readers, switches, keyboards, mice, GUIs, touchpads, and joysticks—have become a critical technology.

One avenue of research that is beginning to be adopted commercially is the *tangible user interface*. With a TUI, users interact with a digital system by manipulating physical objects linked to and directly representing some aspect of the system. Thus, the objects are both representations of and controls for digital information.

For example, a land developer using a TUI-based interactive table could manipulate tokens that look like buildings and that cause changes directly to the computational model of an entire development plan. The interface thus provides direct input and output.

With a GUI, mice or keyboards enable input only. And neither onscreen icons nor their manipulation physically represent either the data being processed or the actions being taken with the information.

"Tangible user interfaces have emerged as a new interface type that interlinks the digital and physical worlds by computationally augmenting tangible objects to serve as representations of digital information, allowing users to quite literally grasp data with their hands," noted Wellesley College assistant professor Orit Shaer.

"This allows users to apply technology to things you do in a very natural way," said Microsoft Surface director Somanna Palacanda. For many tasks, TUI proponents say, this enables more effective interaction with digital systems.

TUIs have been the subject of research since the 1970s but are only now starting to appear in products, as discussed in the "Microsoft Surface," "Reactable," and "Sifteo" sidebars. Shaking Apple's iPod to shuffle the music it plays is one example of a commercial TUI implementation.

"TUIs are starting to be applied to lots of different domains, from creative expression to tools for professionals to learning systems and games," noted David Merrill, president and cofounder of TUI vendor Sifteo.

Although vendors and researchers say they expect TUI implementation to increase, the technology still must clear several hurdles before it is ready for widespread use.

Driving the TUI

GUIs have been the most popular interface approach for years. However, some TUI developers say this approach is limited and doesn't take advantage of users' experience and skills working directly with physical objects.

Early work

Many experts credit work by CAD and architecture researcher Robert Aish and design pioneer John Frazer in the 1970s as inspirations for modern TUI research.

An early example of a TUI system is the Marble Answering Machine, which Durrell Bishop—now an owner of Luckybite, a product design and innovation company—developed in 1992 while working on his master's degree at the UK's Royal College of Art.

The device released a marble for each message left on the answering machine. Users could drop a marble

MICROSOFT SURFACE

Microsoft has been selling its Windows-based Microsoft Surface (www.microsoft.com/surface/en/us/default.aspx) collaborative platform to various companies on a small scale since 2008. Now, the company will begin mass-marketing the technology in Samsung's SUR40 for Microsoft Surface. Surface—which utilizes what Microsoft calls a *natural user interface*—is a computer with a multitouch, high-definition display that lets up to 50 people interact with it simultaneously.

The product weights 36.4 kilograms (80 pounds) and measures 108.5 × 69.9 × 10.2 cm (42.7 × 27.5 × 4 inches). It can be used as a table, hung on a wall, or embedded in other objects such as furniture.

The product recognizes items placed on its display area and can take a set of actions based on how users manipulate the objects, noted Microsoft Surface director Somanna Palacanda.

Surface uses the company's PixelSense technology, which enables a display to recognize fingers, hands, and objects placed on the screen, thereby allowing vision-based interaction without the use of cameras.

When a user places an object on the display, an infrared light provides illumination. Sensors detect light reflected from the surface and convert it into an electrical signal. The system then uses the reported signal values to create an image of what is on the display. Image-processing software analyzes and identifies the image and then sends the information to a computer.

To make it easier for designers to create applications that work with the product, Microsoft has released its Surface 2.0 software developer's kit.

Palacanda said, "Now customers and retailers can interact together; a doctor and a patient can have a more immersive consulting experience, and a banker and a customer can sit together and work on a simulation whereas in the past the banker would be the only one in control."

REACTABLE

Pompeu Fabra University researchers developed Reactable (www.reactable.com), an interactive TUI-based tabletop musical/sound-effects instrument, and are now selling it via their spinoff company, Reactable Systems.

The system's core is a round, translucent table that serves in part as a backlit display. Users put single-function flat or multifunction cube-shaped blocks called *tangibles* on the table. Some tangibles represent different musical-synthesizer tools, including audio frequency voltage-controlled oscillators, low-frequency oscillators, voltage-controlled filters, and sequencers.

The tangibles have bar-code-like markers that let the system identify the block's functions, noted Reactable Systems cofounder Günter Geiger. When a user puts a tangible on the display table, he explained, animated symbols—such as waveforms or circles—show either the block's capabilities or what the block is doing at the moment.

Users create different tunes and effects by manipulating the tangibles in various ways. For example, Geiger said, rotating an object will cause an oscillator or simple tone generator to change the frequency it emanates.

The blocks can interact, depending on their distance from or orientation to one another. Thus, Geiger said, putting a filter object close to the oscillator object will connect the two and enable the filter to change the oscillator's signal. Meanwhile, the display table provides feedback as to what is going on.

The system includes a camera pointed at the bottom of the table that relays video of objects to a PC. According to Geiger, the Reactable developers designed their reacTIVision computer-vision software to analyze the incoming video and detect and identify the objects via their markers. The software also identifies users' actions.

The computer utilizes custom-built software to assign specific functionalities to objects. The system produces the intended sounds via an audio engine written using the Pure Data and SuperCollider multimedia-application programming languages.

Reactable Systems sells three products. Reactable Live is a portable unit the size of an end table. Reactable Mobile is an application that can run on iOS or Android wireless devices. Reactable Experience is a larger product—already used in several places (www.reactable.com/products/reactable_experience/)—that was designed for public facilities such as museums and schools.

into a callback slot to either play back the message or contact the person who left it.

Favorable factors

Multiple factors are contributing to TUIs' increased popularity.

"The advent of touch-enabled personal computing devices has increased the need to allow people to interact with digital content in a more natural way," said Microsoft's Palacanda.

"Customers and consumers are becoming very familiar with natural-gesture [controls] and are comfortable using them to interact with digital content," he continued. "This suits itself to a more collaborative type of environment, whereas mouse and keyboard environments are limited to single-user input."

TUIs bring a familiar, easily usable physical element to the interface, whereas the GUI approach is very abstract, said Günter Geiger, a cofounder of TUI vendor Reactable Systems.

Improvements in design and prototyping technology have made it easier for users to affordably build systems that use new technologies such as TUIs," noted University of Strathclyde lecturer Eva Hornecker. "Toolkits such as the Arduino open source electronics prototyping platform have helped with this."

"The popularity of smartphones has driven down the costs on parts like accelerometers and other sensors, allowing them to be built into products that can sell at reasonable prices," added Sifteo's Merill.

"Technological advancements such as increased connectivity, processing power, storage capacity, and sensing abilities, as well as a better understanding of the psychological and social aspects of human-computer interaction, have led to a recent explosion of next-generation interaction styles that diverge from the traditional desktop paradigm and draw on users' skill of interaction with the real, nondigital world," explained Wellesley's Shaer.

Inside the TUI

Shaer identified four basic types of TUI systems.

In the *interactive-surfaces* approach, tangible objects are placed and manipulated on flat surfaces, where the system can interpret their spatial arrangement and their relationship—such as their proximity—to one another.

Tangible tabletop interaction systems combine multitouch capabilities and tangible interaction.

With the *constructive-assembly* technique, users attach modular and connectable elements, and the system interprets factors such as their spatial organization and the order in which they are manipulated.

Token-and-constraint systems use physical tokens and structures—such as slots or racks—that limit how users can place and move objects.

The technology

TUIs utilize sensors to help detect how users change what's happening in the system's physical environment. Some work with multitouch technology, which enables a touch-sensing surface to recognize the presence of two or more points of contact from one or more users.

According to Shaer, the systems also utilize approaches such as RFID or fiducial tags to detect objects. For example, a reader could scan information on an object's RFID tag to determine what it is. Gesture-recognition technologies help systems identify object movement, Shaer noted.

Computer vision is often used with spatial, interactive surface applications because the technology recognizes the position of multiple objects in real time and provides information about them such as their orientation, color, size, and shape.

Microcontrollers receive information from sensors and send commands to actuators—including LEDs, speakers, motors, and electromagnets that produce light, sound, motion, or haptic feedback—to change the system's environment as desired.

Getting physical

To let users affect digital information by manipulating objects, the objects must be computationally coupled to the data, explained Hornecker. TUI users manipulate data by working with various physical aspects of objects, including their shape, size, position, and orientation relative to one another.

Shaer noted that TUI systems use physical objects in different ways.

"Some application domains such as architecture, urban planning, and chemistry have inherent geometrical or topological representations that can be directly employed," she explained. "Other domains such as economics, biology, and music do not have inherent physical representations but have representational conventions that may lend themselves to spatial representations. Finally, domains such as information navigation or media authoring do not have inherent or conventional spatial representations but may be tangibly represented using symbolic or metaphoric mapping."

Benefits

"TUIs let users leverage their natural ability to manipulate familiar physical objects to work with various systems and data," noted Shaer. "This makes the activities more intuitive."

"You get your hands and brain working together," added Sifteo's Merrill.

With TUIs, users don't have to look at the interface, as they do with a GUI, to know what they are doing, which is an advantage for many applications, said Reactable's Geiger. In addition, he said, the technology can be embedded into existing objects and environments that people are already used to interacting with.

"They support a multiuser interaction paradigm to allow people to collaborate, communicate, and connect in a social way," added Microsoft's Palacanda.

"GUIs take a lot of visual attention," Hornecker said. "TUIs make use of several parallel sensory modalities and can thus lower cognitive demands."

SIFTEO

While graduate students at MIT, David Merrill and Jeevan Kalanithi developed the Siftables TUI platform. Siftables were small computers that displayed graphics and sensed how users moved them and where they were in relation to one another. They were the prototype for the commercial Sifteo product.

Sifteo Inc. now manufactures intelligent cubes with which users can play games. The blocks are 1.5 inches on each side and include a clickable, color LCD display, as well as motion sensors.

The cubes have a 32-bit ARM-based CPU and connect to a nearby computer—which runs SiftRunner desktop software—via a compact wireless USB radio with a 20-foot range. They also contain a three-axis accelerometer that detects shaking, rotating, flipping, or other types of movements that control game actions.

The cubes have 8 Mbytes of flash memory and use Sifteo's near-field object-sensing technology. This technology "identifies when cubes are placed next to one another, which is Sifteo's iconic game-play gesture," explained company president Merrill.

Moving cubes near each other can help arrange letters into words or build a path for a character to move in a game. Each cube has a rechargeable battery that enables three hours of play between charges. The system comes with a recharging dock that can serve six blocks at once.

Users can buy games from Sifteo (https://www.sifteo.com/games#), which currently has 19 available, or create their own with the Sifteo Creativity Kit.

"The more modalities a computer uses to communicate with users and with the environment, the smarter they can be and the better they can compute," said Steven Bathiche, director of research in Microsoft's Applied Sciences Group.

LOOKING AHEAD

Expanding commercial TUI use faces several important challenges, including the technology's limited scalability, the risk of losing objects, and user fatigue resulting from handling objects for long periods of time, said Wellesley's Shaer.

Building a TUI is a complex process that requires multidisciplinary knowledge including computer science, art, and social sciences. Also needed are skills in areas such as human-computer interaction, noted Hornecker.

Nonetheless, proponents say the technology will have a bright future.

For example, TUIs could help with public safety. NTT Comware, a Japanese system-integration company, developed the Tangible Disaster Simulation System, a collaborative tool for planning disaster and evacuation measures. The tool works with a computer, a simulation engine, a video projector, geographic-information-system technology, and a tabletop sensing surface.

Users place objects that represent disasters on the table, which can wirelessly and electromagnetically detect their location and orientation. The objects have dials that let users tune various disaster parameters, such as tsunami wave height.

The system can analyze what specific problems a disaster might cause and identify potential assistance efforts based in part on the location and capacity of emergency shelters.

Shaer noted, "Driven by advances in flexible input technologies, such as electrophoretic ink, recent research has attempted to move TUIs from employing a collection of rigid discrete objects to using organic and malleable materials."

"The big trend now seems to be actuation: tangibles that move or change form using transitive materials, as well as novel materials like paper or fabric," said Hornecker.

"Whole body interaction and performance are further trends that go beyond the original TUI vision," she added. "Early TUIs tended to be a few small blocks on a table. If we embed TUIs into an environment, suddenly the TUI surrounds us and you might interact by moving around this environment."

Said Shaer, "I anticipate that within a decade TUIs will have a significant impact not only on the ways in which we learn and play but also on our workplace." C

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