# News

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# T-Engine: Japan's Ubiquitous Computing Architecture Is Ready for Prime Time

*Jan Krikke*

Japan is quietly positioning itself for the next phase in digital technology: ubiquitous computing. A sign of things to come is T-Engine, arguably the most advanced ubiquitous computing platform in the world. T-Engine enables the distribution of software resources, including middleware developed on T-Kernel, its compact, real-time operating system. The platform also features standardized hardware and tamper-resistant network security.

Ubiquitous computing (one person, many computers) is the third era in computing. It follows the mainframe era (one computer, many people) and the PC era (one person, one computer). T-Engine's developers consider it the first platform to offer a complete end-to-end solution for ubiquitous computing.

## THE T-ENGINE FORUM

The project is an initiative of five leading Japanese chipmakers and 17 other Japanese tech firms. In 2002, they formed the T-Engine Forum, the consortium that developed the specifications for T-Kernel and T-Engine's development boards.

T-Engine enables developers to rapidly build ubiquitous computing solutions by using off-the-shelf components. Among them are four standard T-Engine boards of varying dimensions for different application areas:

- Standard T-Engine (75 mm × 120 mm) for portable information devices with comparatively advanced user interface features, such as smart phones;
- Micro T-Engine (60 mm × 80 mm) for devices with relatively basic user interface features, such as home electronic appliances and musical instruments;
- Nano T-Engine (coin-sized) for small home electronic appliances; and
- Pico T-Engine for the smallest units in a ubiquitous computing environment, such as switches, lighting equipment, sensors, and valves.

**Interest has shifted from desktop computers to mobile computers such as cell phones, wearable computers, and advanced PDA-like devices such as Ubiquitous Communicator terminals.**

In 2003, the Forum adopted standards for ultrasmall (0.4 mm$^2$) tags capable of holding 6,000 times more data than bar codes. The chips, part of the T-Engine family, are equipped with tiny antennae that can transmit data to a reading device about 30 cm away.

A growing library of middleware is available for T-Engine. According to the T-Engine Forum Web site (www.t-engine.org), it includes network protocol stacks, filing systems, Japanese language processing, eTRON-specified security software, a GUI, and audio processing. Other middleware will soon be added to support speech recognition, MP3, and digital watermarks. The platform has also attracted support from American software makers. Sun Microsystems ported Java to T-Engine, MontaVista did the same with its real-time version of Linux, and Microsoft followed suit by porting Windows CE to T-Engine. The ports are referred to as non-native kernel extensions or, informally, as "guest operating systems."

## FROM TRON TO ITRON

The spiritual father of T-Engine and chairman of the T-Engine Forum is University of Tokyo professor Ken Sakamura, one of Japan's most famous computer architects. Sakamura is a veteran in ubiquitous computing. In the 1980s, he launched the TRON Project, an open computing and communications architecture. TRON was designed to make computing a utility, like electricity and water. It included ITRON, a real-time operating system for embedded devices, CTRON for multitask network processing, and BTRON, a multitask, multiuser OS with a GUI. TRON's security

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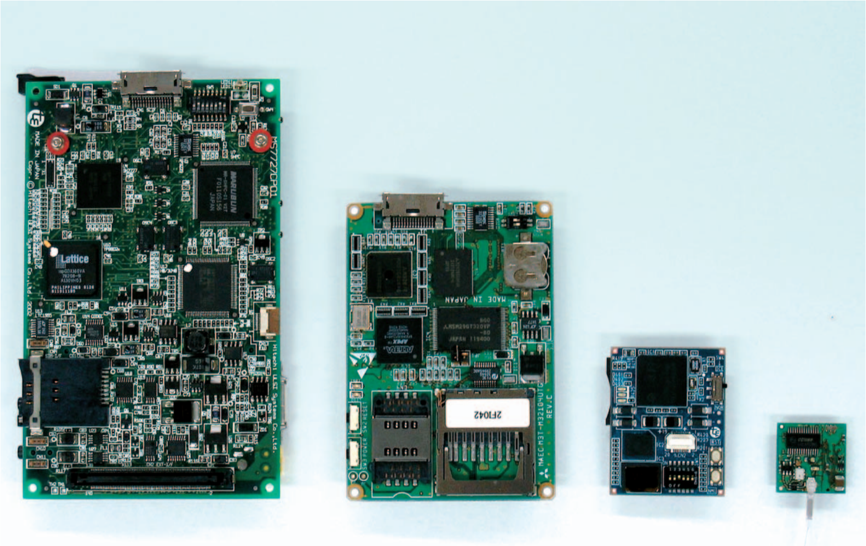
architecture, eTRON, was introduced in the 1990s.

Asked what led him to ubiquitous computing before the term gained currency, Sakamura says, "I envisioned that the microprocessor, which had appeared in [the] 1970s and had become more powerful each year, would be embedded in many things. It was already obvious that industrial equipment like assembly line controllers and robots would have embedded computers, but I thought common objects like sunglasses and furniture could benefit from embedded computers." For example, Sakamura and his colleagues built many microprocessors into the TRON Intelligent House. He explains, "When sensors detected a breeze outside, the windows opened. When they detected rain, the windows closed and the air-conditioning was switched on."



The four standard T-Engine boards were designed for different application areas, from smart phones and home appliances to sensors and switches.

TRON had mixed success, but its operating system for embedded systems, ITRON, became the most widely used OS in the world—it's used in robots, fax machines, digital cameras, and a host of other devices. Prior to the introduction of ITRON, Japanese electronics makers wrote their own OSs for embedded chips, a time-consuming process. Moreover, it resulted in a plethora of incompatible software. ITRON addressed this need. It offered specifications for a standard real-time kernel that could be reused for different devices with minor adjustments. According to estimates by the Japanese media, three to four billion microprocessors are running ITRON.

Despite its popularity, ITRON has a major flaw. It was based on the concept of "weak standardization," so developers could modify the OS to suit their own requirements. TRON was meant to allow for competition while maintaining compatibility, but as middleware grew in size, weak standardization made it difficult to create a unified development environment.

"When we produced the ITRON specification," Sakamura notes, "we didn't spell out the implementation details. As a result, there were subtle differences between the behaviors of two different implementations of [the] ITRON OS under certain conditions that were never explicitly mentioned in the specification. The subtle difference between implementations is akin to the different varieties of Posix-based Unix flavors we have had in the past."

To address this problem, T-Kernel is governed by the T-License, which allows developers to alter the code for specific devices. However, altered code can't be distributed without Sakamura's permission, because he holds the copyright. Software written for one T-Kernel device should in principle run on all T-Engine devices. Unlike the GNU license, T-License doesn't require developers to make their code public. T-Kernel is primarily used in embedded systems, and product know-how is often tied up with the software.

## GROWING SUPPORT

The T-Engine Forum has grown from 22 members when it was founded in 2002 to nearly 500 members today. Among them are nearly all of Japan's blue chip companies and a growing number of global tech giants such as Sony, Toyota, Microsoft, and IBM. The Forum has development centers in China, Korea, and Singapore. Asked why membership has grown so rapidly, Sakamura says T-Engine is an idea whose time has come.

"Interest has shifted from desktop computers to mobile computers such as cell phones, wearable computers, and advanced PDA-like devices such as Ubiquitous Communicator terminals," he says, adding that advances in chip technology are also a factor. "If today's CPU's were not powerful enough to run a lite version of Oracle database programs, Oracle would not have joined the T-Engine Forum. The same applies to Sun Microsystems. Java can now run on small embedded computers. This is why Sun has joined the Forum."

Windows and Linux, not real-time OSs, are tweaked to simulate real-time behavior. But Sakamura believes that serious real-time embedded system development requires T-Kernel or another real-time OS kernel.

"The task dispatch time in the T-Kernel is in the sub-microsecond range," he says. "RTLinux's task/process switch time is larger than this. In MontaVista's scheme, the events that need to be addressed with real-time response—say, sub-microsecond range—are handled by native T-Kernel tasks. Application pro-

NEWS

in brief...

## Virtual Displays and the Future of Mobile and Portable Devices

*Bernard Cole*

A postage-stamp-size computer display incorporated into eyeglasses—the visual equivalent of a 32-inch to 40-inch screen at 10 feet—might soon be possible in a form that will appeal to the average user's imagination and pocketbook.

According to Ross Rainville, product manager at IO Display Systems, there's always been a modest market for wearable displays that use stamp-sized LCDs positioned close to the eye. But the cost of the basic silicon, liquid crystal building blocks, and glass optics—plus the weight—have made their use practical only in industrial, military, and limited consumer markets such as gaming.

With headset prices from US$1,500 to $10,000 depending on resolution (ranging from 640 × 480 to 1280 × 1024 pixels), companies such as IO Displays have survived and grown on selling a few hundred to a few thousand viewers per month.

### PUSHING THE PROTOTYPES

Auguring the emergence of wearable virtual-display eyeglasses into mainstream consumer electronics, most of the current players were at the recent Consumer Electronics Show. On the eyepiece side, this included Inginio, IO Display, Incuiti, Liteye, and WorldViz. On the technology side, the four most active companies were Brillian, eMagin, eLCOS, and Kopin, each with prototypes and reference designs for technologies they're championing.

The most mature technology is Kopin's transmissive LCDs. They're designed to transmit light from a backlight through the liquid crystal layer and out through the front to the user's eye. Brillian and eLCOS are now using LCOS (liquid crystal on silicon), originally developed for large-screen flat-panel displays, for headset and eyeglass viewer displays.

Organic LEDs, championed by eMagin, generate self-luminous displays that don't require backlighting.

### LOWERING COSTS

Although the technology is moving into the mainstream, how soon is still a matter of debate. Rainville is cautiously optimistic that it might happen in the next three to four years, while Vincent Sollitto, Brillian's president and CEO, thinks it could be as soon as next year or mid-2007. Most optimistic is John C.C. Fan, Kopin's CEO and founder. "I think we will likely see the first affordable virtual display eyeglasses for use with mobile wireless devices and portable media players as soon as this Christmas, at a price that will be attractive to the average consumer," he says. "By the following 2006 Christmas season at the latest it is likely that every new portable player and mobile device sold will be offering virtual display eyeglasses as part of the package or as an optional accessory."

The reason, Fan believes, is that all the critical elements are converging to make such devices a reality: the decreasing cost of the basic building blocks, one or more high-volume markets that will help lower costs, and one or more "hot apps" that are ideally suited to drive adoption of virtual displays for mobile and portable media players.

"The problem we have always faced in the headmounted virtual display market is the chicken and egg one of needing a high-volume market to drive down the cost of the components and needing low-cost components to drive up the volume," notes Stephen Glasser, Incuiti's vice president of marketing. Now, Fan says, manufacturers of the basic silicon and LCD materials are taking advantage of the demand in the video camera and mobile-phone markets for high-resolution pixel viewfinders to drive down the cost of the postage-stamp-sized display elements.

Today, plastic is replacing the optics, which previously required expensive and heavy glass components. "The combination of plastic optics and low-cost display elements will allow providers of the eyeglass-mounted display units to very soon reach the magic [US]$100 to $200 price point that will be needed to appeal to the mass market," Fan says.

According to Sollitto, Brillian has a prototype reference platform design for an 800 × 600 pixel resolution LCOS-based 3D viewing headset. The bill for materials is around $350 now, but the company says it soon will be able to drive costs down further. Kopin offers transmissive LCD-based 640 × 480 pixel headsets for $500 eyeglass viewers for use with portable media players.

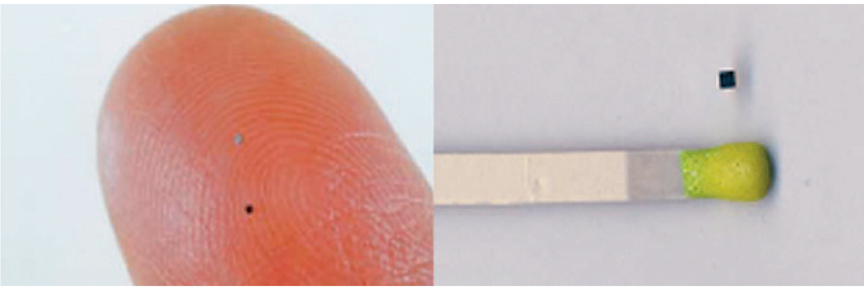
In terms of "hot apps," Fan says there's a neat conjunction between market needs and the display resolutions possible in near-eye viewers. "Multimedia is the big thing right now in both the portable media player and 3G/4G mobile markets, with high-quality color displays of about 352 × 240 pixels (CIF) and 176 × 120 pixels (QCIF), respectively, at 30 frames a second," he notes. "Current near-eye display technologies are more than adequate to these requirements and at a price that will be attractive."

cessing that doesn't require such stringent real-time response such as mail delivery would be handled leisurely in the Linux task that runs on top of T-Kernel. Microsoft had a similar mechanism in mind when they announced the port of Windows CE .NET to the T-Engine hardware platform. Real-time events are handled by T-Kernel, and only those that don't require real-time response are handled by [the] Windows CE side."

Microsoft's decision to join the T-Engine Forum surprised many people in Japan and beyond. The company had been antagonistic toward TRON. But Sakamura welcomed the software giant, saying, "The 21st century will be the age of cooperation and not the age of competition." In September 2004, Microsoft and seven chipmakers announced their support for an embedded development platform based on Windows CE 5.0 and T-Kernel. A Microsoft spokesperson explains: "The collaboration between the T-Engine Forum and Microsoft will enable our embedded partners and developers to extend their software, hardware assets, and knowledge in two operating systems. T-Engine Forum encompasses many working groups and topics besides software implementation. We anticipate our participation beyond Windows CE 5.0."

## TAGS EVERYWHERE

One of the "topics" Microsoft might be referring to is the Ubiquitous ID Center, T-Engine's sister organization. The UID Center provides the infrastructure for managing electronic tags embedded in or attached to objects in a ubiquitous environment. The center developed the *ucode*, a multicode tag that automatically identifies information stored in bar codes, RFID chips, smart cards, and electronic tags embedded in virtual entities such as software and electronic money. Comparable to the ISBN (International Standard Book Numbering) code used in the publishing industry, the UID Center assigns unique numbers to each tag and stores data relating to the object in database



The Ubiquitous ID Center has authorized Hitachi's mu-Chip and Toppan's T-Junction ucode tags for embedding in or attaching to objects in ubiquitous environments.

servers. The ucode tags use a 128-bit code that can be extended in 128-bit units, creating a virtually limitless string of numbers.

The UID Center is conducting verification tests of the technology in several industries, among them transportation, housing, agriculture, and health care. Earlier this year, Japanese farmers, wholesalers, and retailers implemented a food traceability scheme using T-Engine's UID technology. Interest in the technology has increased in recent years, in part due to concerns about mad cow disease, bird flu, and the mislabeling of food items. UID technology lets retailers and consumers trace every phase of the production process. A tag on a packet of soybeans provides information about where the beans were grown, what chemicals were used, and when.

To navigate this tagged environment, the UID Center developed the Ubiquitous Communicator, a PDA-like device that reads ucode tags and retrieves the relevant data from the UID Center's server database. The standard UC has a host of features, including wireless LAN, Voice over Internet Protocol, infrared data communication, and a biometric reader. Apart from the PDA-like version, the UID Center developed a cell phone model and a watch style. All are built with standard T-Engine boards.

The multifunctional UC anticipates an environment in which electronic tags are embedded in every conceivable object. In a restaurant, the UC might read a tag attached to a menu and display today's special. At home, it will serve as the remote control for home entertainment systems and appliances. In the office, it will read a printer's tag and order a replacement cartridge as needed.

The Ubiquitous ID system is protected by eTRON (Economy and Entity TRON), a wide-area distribution system architecture based on tamper-resistant hardware. eTRON chips are installed in T-Engine boards to prevent tapping and falsification; it also ensures that electronic information is safely delivered


The watch-style version of the Ubiquitous Communicator reads tags and retrieves relevant data from the database server.

NEWS

A few Japanese cities have embedded hundreds of electronic tags and road sensors in their pavement, sidewalks, and street furniture to help both tourists and the handicapped get around.

through insecure network channels, including the Internet. eTRON has a flexible cryptographic architecture and an ID protection protocol to prevent third parties from tracking the tag owner's activities.

Development of T-Engine products accelerated last year. Numerous companies introduced T-Engine boards, eTRON cards and readers, and network adapters. Japan's two printing giants Dai Nippon and Toppan are producing ultrasmall tags that can be used in anything from books to doormats. Last year, Dai Nippon developed a T-Engine-based compact camera board that can distribute real-time video over networks. Also proliferating is T-Engine software, including a Bluetooth protocol stack from Hitachi and a location-based-service framework from Oracle.

## MULLTILINGUAL ENVIRONMENT

One of the beneficiaries of growing support for T-Engine is Personal Media Corp., producer of T-Engine development kits and a long-time developer of TRON products. In the 1990s, PMC developed Cho Kanji, a multilingual environment that supports Japanese, Chinese, Korean, and about 40 other languages. Cho Kanji is an alternative for Unicode. The latter uses four-byte encoding for pictographic characters. Cho Kanji uses two-byte encoding, a considerable advantage in network environments and when using devices with limited memory. Cho Kanji currently supports approximately 170,000 characters, which can be used inside the application and in file names.

PMC claims demand for its products is increasing rapidly. "Several thousand companies are using our T-Engine development kit," says PMC's sales manager Nobuyuki Kashiwa. "T-Engine is becoming [the] de facto standard of developing tools for ubiquitous computing devices in Japan." Kashiwa believes T-Engine's open architecture and the security offered by eTRON are key factors in the platform's growing popularity.

T-Engine also enjoys growing support in other East Asian countries. For instance, Renesas Technology Corp., Nanyang Technological University, and the Singapore government cofounded Singapore's T-Engine Application Development Center (TEADEC), which provides English and Chinese tutorials for T-Engine development. TEADEC also supplies low-cost training material to training centers in Thailand, Malaysia, and Vietnam.

"The T-Engine platform is very easy to use, and application [development] can be done very quickly using standard tools," says TEADEC's Kwek Chu-Lih. "As long as it can obtain the support of middleware developers it can become the international platform for embedded systems development, including ubiquitous computing."

China's Beijing University has established an embedded-systems course using T-Engine boards, and the Chinese Academy of Science has ported its video compression technology AVS (a rival of MPEG) to T-Engine. The Korea T-Engine Center conducts educational activities to diffuse the T-Engine architecture and UID technologies in Korea, and Korean programmers have developed a humanoid T-Engine robot.

## THE END OF AUTONOMY

T-Engine technologies are finding their way into a wide variety of environments, from homes to automobiles. Toyota Home, a subsidiary of the carmaker, built the Toyota Dream House PAPI, an intelligent house filled with T-Engine boards. It's part of the Nagoya Expo, which opened on 25 March of this year. In an emergency, Toyota's Prius hybrid automobile can supply the Toyota home with electricity. The house gives new meaning to Le Corbusier's famous exclamation that a dwelling is "a machine for living."

Japan's Ministry of Land, Infrastructure, and Transport is spearheading the testing of the UID Center's Autonomous Movement Support Project. Electronic tags embedded in pavement stones and street furniture will supply users with location-specific information "anytime, anywhere, to anyone." In the cities of Kobe and Tsuwano, hundreds of electronic tags and road sensors have been embedded in the pavement, sidewalks, and street furniture, providing information to tourists about historical sites and to wheelchair users about obstacles.

When entire cities are "tagged," robots can be equipped with ucode readers and make deliveries of food or medicine. The city of Fukuoka in southern Japan has created a "robot-friendly" zone in the city center. It has adjusted the streets and changed traffic rules to let robot engineers test robots, and the public's reactions, in public spaces.

Whether T-Engine becomes a global standard remains to be seen. Given the potential market for ubiquitous computing technology, the Japanese technology will no doubt meet with competition. But Ken Sakamura has already succeeded in giving the notion of ubiquitous computing a new dimension. He notes that an electronic tag embedded in a medicine container or in a pavement stone doesn't need to know what it is or where it is. Its "intelligence" is in the database and the rule sets it contains. The potential for possible applications is limited only by the imagination.

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