

Assistive Embedded Technologies

Priya Narasimhan
Carnegie Mellon University



Trinetra integrates embedded devices to let blind users enjoy cost-effective, independent shopping.

Embedded computing technologies are not only an integral part of traditional safety-critical applications such as jet engine and automotive brake control, they are also being used to improve people's quality of life. Cellphones, PDAs, and radio frequency identification (RFID) exemplify such commercial off-the-shelf embedded systems. Increasingly, developers have begun considering these COTS embedded systems for *assistive technologies*, an application domain that addresses the special needs of those who suffer from impairments such as blindness.

This domain has traditionally been cost-prohibitive because the resulting packaged solutions cater to only a small fraction of the market. For example, products that specifically target the blind are more expensive than their counterparts for the sighted population because of the additional effort and cost required to adapt and test technologies specifically for the sight impaired. Moreover, economies

of scale do not exist to keep manufacturing costs low. The cost, portability, and usability of these systems have been common obstacles to adopting assistive technologies.

If inexpensive COTS embedded devices can be integrated into the existing civilian infrastructure with minimal maintenance and investment, assistive technologies can be made more affordable. The Trinetra system developed at Carnegie Mellon University (CMU) aims to cost-effectively provide blind people with a greater degree of independence in their daily activities. Overall, we sought to improve the blind's quality of life by harnessing the collective capability of existing distributed, embedded COTS devices to support activities such as grocery shopping and transportation.

MOTIVATION

Consider this question, posed by a blind person: "Have you ever opened a can, hoping to add tomatoes to your spaghetti sauce, and then been faced with the dilemma of figuring out how

to incorporate green beans into the menu?"

The National Federation of the Blind provides various suggestions to make grocery shopping easier, most involving the assistance of a sighted guide—typically a friend, neighbor, or store clerk. Alternatively, using a Braille writer and labeling tape to affix custom labels onto grocery items would let a blind user identify various items, including not just groceries but appliances, to allow for faster and more accurate identification without requiring a sighted person to be present.

Unfortunately, a sighted person would still be required at the time of product-tagging to generate the correct Braille labels. Moreover, only 8 to 10 percent of the US's blind population is Braille literate. Finally, this approach would not be economically feasible: The US Council of Better Business Bureaus observes that, "for most grocery stores, putting all price labels in Braille could not be done without significant expense."

The day-to-day needs of a typical blind user greatly influenced our design and evaluation of the Trinetra system. From the beginning, the user of our system also proved instrumental in helping design and test the system. The motivating factors in our design included the following:

- A blind person considers independence in daily activities—defined as not requiring the assistance of a sighted person—to be of the utmost value.
- For it to be adopted, the resulting solution must be judged cost-effective not only by blind users, but also by the vendors who manufacture and maintain the solution or its components.

Our blind user also made the following interesting observations, based on his personal experience:

- Blind users rarely get the chance to be intrinsically involved in the design of assistive technologies,



Figure 1. Trinetra system. The combination of a barcode-scanning pencil and a smart cell phone lets a blind user distinguish between various grocery products without assistance from a sighted individual.

whose developers only bring them in for after-the-fact testing.

- Sighted people tend to insert assistive enhancements into inappropriate locations, such as a blind person's cane, which might prove unwise because the additional weight can adversely influence the cane's everyday use.

Armed with these motivating factors and insights, we made Trinetra's initial goal to provide blind people with an independent and cost-effective grocery-shopping experience. For our first deployment target we chose CMU's campus convenience store, Entropy.

THE TRINETRA SYSTEM

Product manufacturers already tag individual grocery store products with barcodes. Further, online databases such as www.upcdatabase.com freely provide the mapping of barcodes to human-interpretable strings.

Although the use of RFID tags for merchandise identification has been touted for various reasons—such as the tags' reprogrammability, their ability to hold more product infor-

mation, no line-of-sight tag reading requirement, and localization accuracy—privacy and cost concerns have kept these tags from becoming prevalent in grocery stores.

We focused on two kinds of solutions:

- A practical, achievable, barcode-based solution that can be deployed and used by blind shoppers today and that would require no investment on the store's part; and
- a futuristic, RFID-based solution that would not help blind shoppers with their immediate needs because of the investment required by the store.

The tradeoff here is cost versus degree of independence. The RFID-based solution provides complete independence to a blind shopper, but at a higher cost and accompanying reluctance on the store's part because of the additional investment. The barcode-based solution provides relatively less independence, requiring a store clerk to navigate the blind shopper to the right aisle and shelf, but at no addi-

tional cost or maintenance to the store because the existing infrastructure can be leveraged.

As another aspect of cost-effectiveness, we used COTS components not necessarily developed with blind people in mind. To this end, we chose off-the-shelf portable embedded devices, including a barcode scanner, a standard smart cell phone, and a Bluetooth headset. To integrate these devices, we exploited standard protocols such as TCP, Bluetooth, and HTTP. We also took advantage of communication media such as the Enhanced Data GSM Environment and General Packet and Radio System networks.

On the software side, we used standard operating systems such as Symbian and Windows. We used off-the-shelf text-to-speech software only to convert text displayed on the cell phone into speech output. The manufacturer did not develop this software solely for the blind—for example, sighted people can also use it to listen to incoming e-mail safely while driving.

To promote usability, we sought to ensure that the Trinetra user interface employed a common or at least intuitive format, that the resulting technology would be portable, and—by avoiding noises or awkward, bulky gadgets—that it would not attract undue attention.

The use of text-to-speech software on the cell phone satisfied our first goal: Our blind user was already familiar with speech output from his cell phone, so conveying the product information in speech form merely leveraged the device's capabilities.

We achieved portability through the use of the Bluetooth-enabled cell phone and a barcode-scanning pencil-like device, both of which fit easily into the user's pocket and did not require any wires for communication. By providing our user with a small Bluetooth headset, we conveyed speech from the cell phone discreetly into the user's ear.

DEPLOYMENT

Figure 1 shows a blind user employing Trinetra at the CMU campus store

to distinguish among various packages of cookies without assistance from a sighted individual. In his left hand he holds a barcode-scanning pencil and in his right hand he holds a smart cell phone. A Bluetooth headset (in his right ear, not shown) provides the user with audible notifications from Trinetra.

As the user scans various grocery items of interest, the device communicates the barcode data, via Bluetooth, to the smart phone. The phone then communicates over the Internet to the public UPC database, which converts the barcode into a human-interpretable product name and relays this back to the cell phone. The onboard text-to-speech software converts the displayed text into speech output that the phone relays, unobtrusively, to the user's headset. As Figure 1 shows, our user could distinguish between various packages of cookies to select the one he preferred, without assistance from a sighted individual.

We are often asked how a blind user locates the barcode on a grocery item, since the scanner requires physical contact with the barcode to provide any output. Our experience has led us to appreciate how well developed a blind person's tactile senses and capabilities

can be. Within minutes of handling a new grocery item, our user located the barcode through various lengthwise and breadthwise surface scans, then subsequently recalled this experience to locate the barcode on other packages of the same type, such as a different kind of cookie from the same vendor.

Additional details of Trinetra's design, implementation, and evaluation, including a video of the system in action, are available at CMU's Web site (www.ece.cmu.edu/~trinetra/). We improved the system's performance, in the face of intermittent connectivity, by using an onboard cache to store the barcodes of frequently purchased items on the cell phone. The user can additionally exploit this capability to generate a shopping list before making a trip to the grocery store. Other features under consideration include optical character recognition integrated with the camera commonly found in cell phones. This can let the user scan and identify items not found in the publicly available UPC database.

Assistive technologies for the blind have been traditionally more expensive than, and not as well supported as, products for sighted

people. Embedded systems' low cost, portability, support for standards, and ease of integration afford new opportunities for developing assistive technologies that provide a higher quality of life and more independence for the impaired user.

Trinetra provides one example of a system that integrates embedded devices with existing infrastructure in grocery stores to let blind users enjoy a cost-effective, independent shopping experience. Beyond shopping needs, Trinetra can be applied to other daily activities such as cooking and transportation. We are currently exploring security and privacy issues in the usage and integration of these embedded devices. ■

Priya Narasimhan is an assistant professor at Carnegie Mellon University's Electrical and Computer Engineering Department. Contact her at priya@cs.cmu.edu.

Editor: Wayne Wolf, Dept. of Electrical Engineering, Princeton University, Princeton NJ; wolf@princeton.edu