Imperceptible Sensory Channels

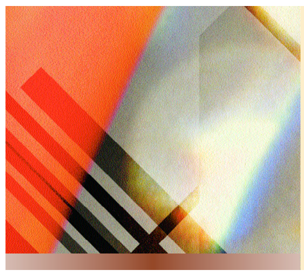
Joshua R. Smith, Tiax LLC

In 1965, MIT's Marvin Minsky described hardware for connecting a closed-circuit television camera to a PDP-6 computer (ftp://publications.ai.mit.edu/ai-publications/pdf/AIM-075.pdf). The next year, his colleague Seymour Papert outlined a plan to create, during the course of the summer, software that would allow this system to recognize objects (ftp://publications.ai.mit.edu/ai-publications/pdf/AIM-100.pdf).

Almost 40 summers and countless PhDs later, researchers worldwide are still hard at work on machine vision problems, including object recognition. Considering the enormous scale of this and other efforts to replicate human perceptual capabilities, it's surprising that little attention has been devoted to giving machines the ability to sense the world in ways that humans do not.

Providing machines with their own senses, via channels that may not be accessible to humans, can enable new approaches to creating smarter, safer, and more secure environments—goals in common with machine vision. Interaction designers can use these channels to create new types of interfaces that don't distract or annoy human users.

In the realm of machine-to-machine communication, embedding invisible digital data in ubiquitous human-to-human channels can be more cost-effective than establishing new, machine-only channels. In yet another class of applications, special-purpose perceptual systems can make use of imperceptible signals to track or authenticate apparently identical items, without requiring any modifications such as special identification circuits or materials.



System designers can use imperceptible sensory channels to create smarter, safer, and more secure environments.

UNOBTRUSIVE INTERFACES

For many computer applications, it's desirable that the interface not be a distraction or annoyance to the user. For example, in a car, too many blinking lights or sounding horns can compromise safety by taking the driver's attention away from the road or interfering with the display of data.

Instead of using visible light, several species of fish use low-frequency electric fields to "see" their environment. Based on this *electric field imaging*, Neil Gershenfeld and I invented a smart car seat sensor that Elesys North America (www.elesys-na.com) used as the basis for its SeatSentry Occupant Sensing System, a version of which Honda offers in select motor vehicles.

Flexible conductive fabric electrodes are embedded in the seat foam, and the passenger's body affects the capacitive loading of each of these electrodes. SeatSentry makes low-frequency electrical measurements of the passenger's body, infers size and pose information, and suppresses airbag firing in the rare situations in which it might be harmful—such as when an infant seat is attached to the front passenger seat.

SeatSentry doesn't compete for the passenger's attention, as a physical switch would; rather, it lets the user control airbag deployment implicitly, without the need for conscious action. A vision-based solution would require a line-of-sight between a dashboard camera and the passenger, which might be aesthetically objectionable as well as have to fight for space with important dials and displays. In contrast, the car seat bottom and seat back are irrelevant from the standpoint of explicit human-computer interaction, which relies on human senses.

SENSORY CHANNEL SHARING

Even signals that humans usually can sense can be coded in a way that makes them effectively imperceptible. These signals are typically low in amplitude, but they may nevertheless represent a large amount of signal energy spread through time, space, frequency, or spatial frequency. Such signals can share a channel—and associated infrastructure—with signals designed for human communication.

For example, in digital watermarking, small amounts of digital data are embedded in an analog image, audio stream, or video stream for copyright protection or digital rights management. Postal services around the world now authorize new forms of postage that likewise use digital signatures to improve security by making postal forgery cryptographically difficult.

Unfortunately, these information-based *indicia* usually require large bar codes, which occupy space that could otherwise be used for a stamp-type image or other meaningful message. My colleagues and I at the Escher Group (www.escher-group.com) worked with Singapore Post to create a new form of postage that embeds security data in a traditional stamp-type image.

Humans and machines can share other types of communication channels, such as the public address systems commonly found at airports and train stations. It would be possible to embed within broadcast PA announcements imperceptible machine-readable versions of the audio content. Rather than attempting to perform natural-language translation of the announcement, a traveler's PDA could listen to the machine-readable form, add appropriate information to its local calendar, and provide relevant alerts—for example, by vibrating if the traveler appears to be bound for the wrong gate.

HIDDEN IDENTIFICATION

Another application of invisible signals, similar to sensory channel sharing, is in tracking physical objects using a hidden identifier that already exists in the object.

While working on the problem of postage security, I discovered that every square centimeter of a piece of paper has a unique pattern of "hills" and "valleys" that can serve as an identifier, much like the whorls, arches, and loops in a fingerprint. As in digital watermarking, the amplitude of the signal in any one pixel is small, but a decoder—essentially a special-purpose perceptual system—can collect large amounts of signal energy by coherently summing the weak signals from a large number of pixels.

The Escher Group's FiberFingerprint is a copy-detecting indicium that manufacturers can conceal on personal checks, clothing tags, brand labels, and other easily counterfeited paper items. A scanning device samples the paper surface, forms a compact description of its unique characteristics, and prints this description on the item using some form of bar code.

The data in the bar code can be copied, but not the paper fibers. To verify authenticity, the scanner device reads the bar code data, reexamines the paper surface, and compares the two. If they match, the item is genuine; if someone copied the bar code onto a new piece of paper, the paper fibers in the copy will not correlate with the printed description, indicating that the item is a counterfeit.

Many other physical objects have unique surface characteristics that can function as an identifier. For example, in a proof-of-concept demonstration for a major watch manufacturer, my colleagues and I at Escher Labs showed that watch faces could be uniquely identified using intrinsic surface irregularities in the logo undetectable by the human eye. Figure 1 shows a sample FiberFingerprint image of one such watch logo.

This capability could be an important new tool for combating *product diverters,* who illegally or improperly exploit geographic price differentials—for example, by purchasing AIDS vaccines at low cost in Africa and reselling them for a huge profit in developed countries. In the case of watches, diverters deliberately remove the unique serial numbers engraved on the back of the watches to avoid being caught.

The advantage of using an imperceptible, intrinsic identifier is that it isn't necessary to add anything to the product, and the identifier can't be destroyed without destroying the product's key characteristic, such as its logo. Like radio-frequency identification, this technique allows objects to be uniquely identified. However, it doesn't require a separate chip; instead, the object's intrinsic properties form the basis of the ID. There is a cost, however: Identifying objects by their intrinsic properties requires a database search, which RFID does not.

Figure 1. FiberFingerprint scan of watch logo. Unique surface irregularities can function as an identifier in physical objects to prevent forgery and product diversion. Image courtesy of Escher Group, Ltd.

Beyond their diverse applications, imperceptible sensory channels suggest a new approach to the problem of machine perception. In adapting a video camera—a device designed to capture human-readable images—for use by the PDP-6, Minsky and Papert had to match perceptual algorithms to the sensor's capabilities. In contrast, for sensory channels such as electric field imaging that have no human analog, the sensor hardware can be designed to support perceptual algorithms.

I view this as an opportunity rather than a limitation: Just as fixed wings proved to be a better match to twentieth-century technological capabilities in aeronautical design than the flapping wings observed in nature, sensor systems that are not defined by human perceptual capabilities may be easier to realize with present-day technology. ■

Joshua R. Smith *is a senior technologist at Tiax LLC, a collaborative research and development company based in Cambridge, Mass. Contact him at jrs@media.mit.edu.*

Editor: Bill Schilit, Intel Research, Seattle; bill.schilit@intel.com