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ISTech Corporation's Safebath Project

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Intelligent Bathroom Fixtures and Systems: EXISTech Corporation's Safebath Project

Steve Mann

ABSTRACT

EXISTech Corporation's computer networks, control systems and image-sensor technology facilitate hygienic touchless control of plumbing fixtures. Two of EXISTech's sensors are described here in detail: an active infrared faucet sensor and a passive infrared autoflush sensor. These devices allow internetworked plumbing systems to help facility managers and law-enforcement personnel remotely monitor the operation of bathroom fixtures. Intelligent fixtures and systems based on quantimetric sensing technology enhance the privacy of law-abiding users by eliminating the need for invasive policing of restrooms. New computer-vision algorithms also automatically detect accidents, as well as vandalism and contraband disposal, to assist remote monitoring by law enforcement.

This paper describes new approaches to the design of automatic bathroom fixtures, as well as their control and management through the use of new computer-vision and image-processing technologies. The networked plumbing systems described here can help facility managers monitor the operation of various bathroom complexes from a central remote location.

Smart Bathrooms with Video-Based Motion Detection

By using video-based sensors, the intelligent bathroom provides a safe, hygienic environment that responds automatically to the needs of the user. Concomitant functions, such as security, drowning prevention and other safety features, are feasible in the intelligent bathroom. It is expected that the benefits of the automation of fixtures will cause sensors to be installed in virtually all bathrooms of the future.

It is also expected that the most economical sensors will be mass-produced single-chip video cameras, which currently cost only $10 U.S. in bulk quantities. Once these cameras are installed in most bathrooms, new uses, such as the automation of lighting, bathroom-door openers, distress calls in case of slip-and-fall injuries, and detection of vandalism, will become possible.

Sensor systems used in many of EXISTech Corporation's research prototype bathroom facilities employ standard video cameras with their infrared blocking filters removed to make them sensitive to infrared light. Because they are mass-produced, these cameras cost much less than the specialized sensors commonly used for automatically flushing toilets and urinals. Additional cost savings are introduced by the fact that a single video camera can monitor a number of fixtures. For example, one video camera can monitor a whole row of urinals to ensure that they flush only if they have been used. Intelligent computer-vision systems can monitor optical traffic flow patterns, so that a weak flush is used when others are standing in line to use a urinal, whereas a stronger flush is provided after the last of a group of users has finished.

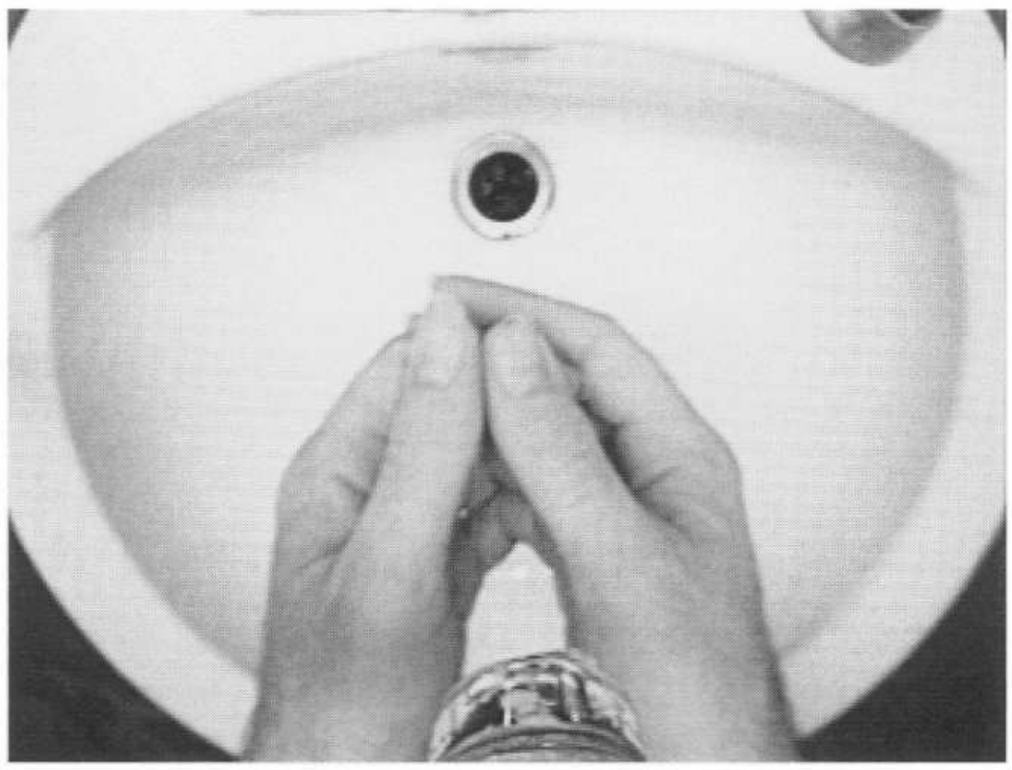
Intelligent video-based sensor technology will reduce initial installation costs as well as operating costs compared with those of other sensor technologies.

Camera-based sensors can provide a much more intricate and sophisticated form of control because they can detect user behavior, usage patterns, traffic flow patterns, and other attributes not trackable using traditional bathroom sensors.

Various optical elements are being used in EXISTech Corporation's experimental bathrooms [1]. For example, ceiling domes that provide the sensor with a wide field of view are being used for controlling a large number of bathroom fixtures with a single sensor. Many of the least expensive cameras have wide-angle lenses. A camera with a fish-eye lens can be placed on the ceiling of a shower room so that it can monitor the entire room, and thus automate many showers. Such a single sensor could be placed beyond the risk of vandalism, soap-scum buildup or other problems that could arise if sensors were distributed along the walls of the shower room, one sensor per showerhead.

Users of the intelligent bathroom will enjoy a nice hot shower without having to adjust the temperature or even touch anything at all. Users will simply step into the viewing area,

Fig. 1. Data output from sensor-operated gooseneck faucet, with an infrared emitter and infrared detector inside the spout. (© S. Mann) The infrared detector returns a byte array having 240 rows and 320 columns. Representing the numerical values in the array as shades of grey allows a view of the detection zone, including the hands of a user. A small part of the spout (visible at the bottom of the array), as well as most of the sink, is visible to the infrared sensor. Note also the specular highlights from the infrared source that is built into the sensor.



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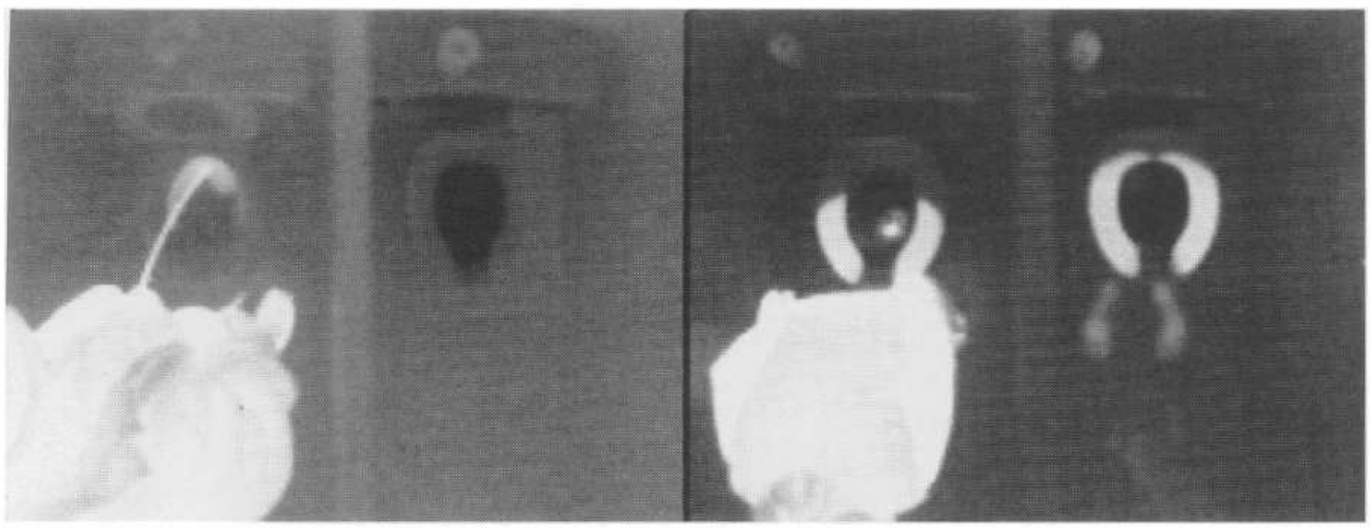


Fig. 2. Classification of waste type and detection of negligence. (© S. Mann) Passive infrared heat sensors are used for automatic flushing where fixtures are connected to cold water only. The computer vision system can detect waste products based on their thermal signature.

composed of several detection zones, and the shower will activate. Instantly, out comes water at the perfect temperature! When a user steps away to lather up with soap, the water turns off. When the user steps toward the spray head for a rinse, the water turns on again.

Moreover, maintenance and installation are simplified by having one image sensor controlling many shower spray heads. The one image sensor may provide other features such as automatic warnings to building staff if a person has slipped and fallen, automatic recognition of users' faces and water tempered to the preference of each user. The video-based motion-detection sensor will also act as a deterrent to crime and vandalism in the shower room. In addition, multiple spray heads at each station can spray a user with water in such a way that very little is wasted. A beam pattern of spray can adapt to the position and orientation of the user's body.

EXISTech's intelligent bathroom-control systems can be reprogrammed to respond to users in slightly different ways, and therefore user behavior can be modified slightly. Through slight modifications in user behavior, efficiency and restroom throughput (through-traffic-flow management) can be increased to make the facility run more efficiently. For example, the system might detect that, in a row of hand faucets, one, perhaps somewhat hidden from view, is used excessively during certain times of day. It might be determined that a homeless person is using it for hair-washing purposes. The system can detect this pattern of deviant use and correct it by adjusting the timing on that particular fixture so that it will time out sooner than the others. This would effectively move that user to another faucet. Thus slight changes in system parameters can be used to effect slight changes in user behavior.

Data output from an infrared sensor-operated faucet is shown in Fig. 1. The numerical values are represented in the array as shades of grey to allow us viewing of the detection zone.

The sensor produces its own source of light, so that it operates irrespective of ambient light (or any light—it will also work in a completely dark room). The faucet's processor runs GNU Linux and is connected to the Internet for remote maintenance and monitoring.

A central computing facility at an undisclosed branch of EXISTech's headquarters monitors a worldwide network of bathroom facilities. However, each fixture or group of fixtures has its own processor, so that the systems will continue to run during network outages. Statistical information is logged locally and files are updated using the UNIX rsynch feature when the network comes back online.

Smart Toilets

In addition to the automation of water flow to sinks, showers, bathtubs, etc., EXISTech sensors may be used to automatically flush toilets and urinals. A single sensor can control a row of fixtures. For toilets in stalls, one sensor is needed for every two toilets.

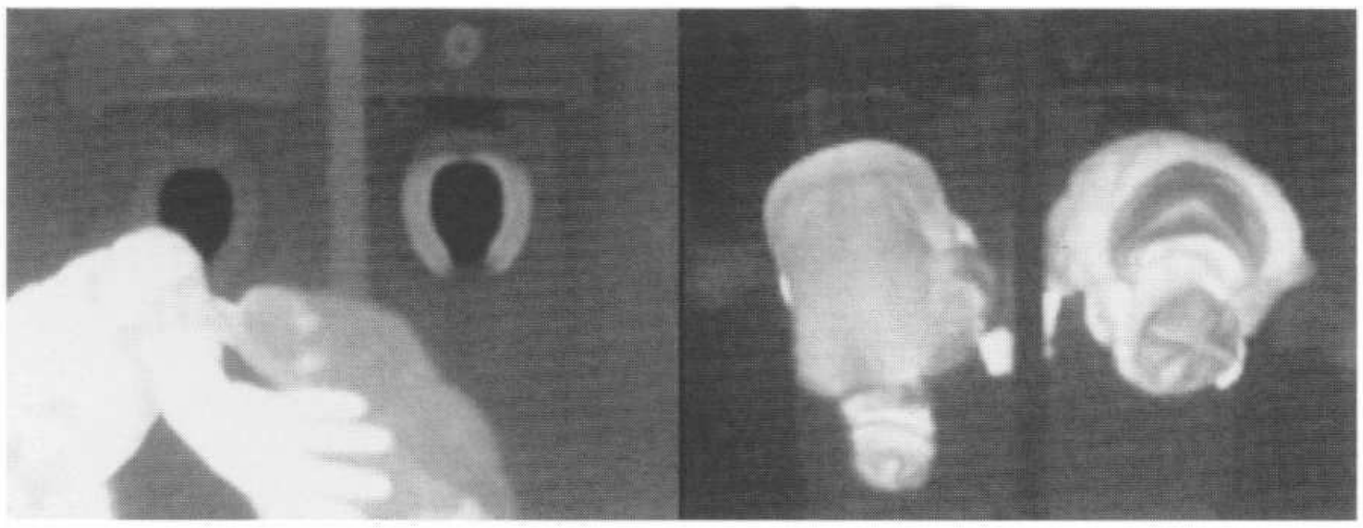
Typically, a passive infrared sensor is used for automatic flushing, because such sensors have the capacity to detect recently deposited waste products (owing to heat from the body, which causes waste products to be warmer than their environment). Since toilets and urinals are supplied with cold-only plumbing, the passive thermal sensor is the best choice for triggering automatic flush. However, in situations where hot-water plumbing is involved, such as showers and sinks, it is better to use an active infrared sensor, i.e. one that produces its own source of illumination. Since the illumination is still in the infrared, it is invisible to bathroom users.

Computer vision systems with sensor arrays save water by distinguishing between urination and defecation, as illustrated in Fig. 2. Urination, as in Stall 1, where the stream of warm urine as well as the urine in the bowl is visible, can be automatically distinguished from the defecation taking place in Stall 3, where solid waste matter is detected through the thermal contrast between warm bodily waste and the colder surrounding water. In Stall 4, note the visible thermal butt print on the toilet seat and two thermal footprints where the cement floor is still warm. This heat signature indicates recent use of the toilet in Stall 4. When urination is detected a smaller quantity of water is used, whereas more water is used to clear solid waste matter from the bowl after defecation is detected.

Sloppy aim, forgetting to flush and other acts of negligence can also be automatically detected and appropriate action taken (e.g. notification of staff, automatic flushing of toilets, automatic release of perfume or pepper spray, etc.).

Ceiling-mounted infrared sensors can also be used to automatically categorize inter-stall activity, for example distinguishing the changing of clothes from

Fig. 3. A person in Stall 1 (left) undresses and temporarily places clothes upon the stall divider. (© S. Mann) The computer can recognize that all of the articles of clothing are eventually retrieved by the user of Stall 1. However, when articles are passed from one stall to another (right), the computer vision algorithms track their passing as in Stalls 3 and 4, where contraband is being passed underneath the stall divider.



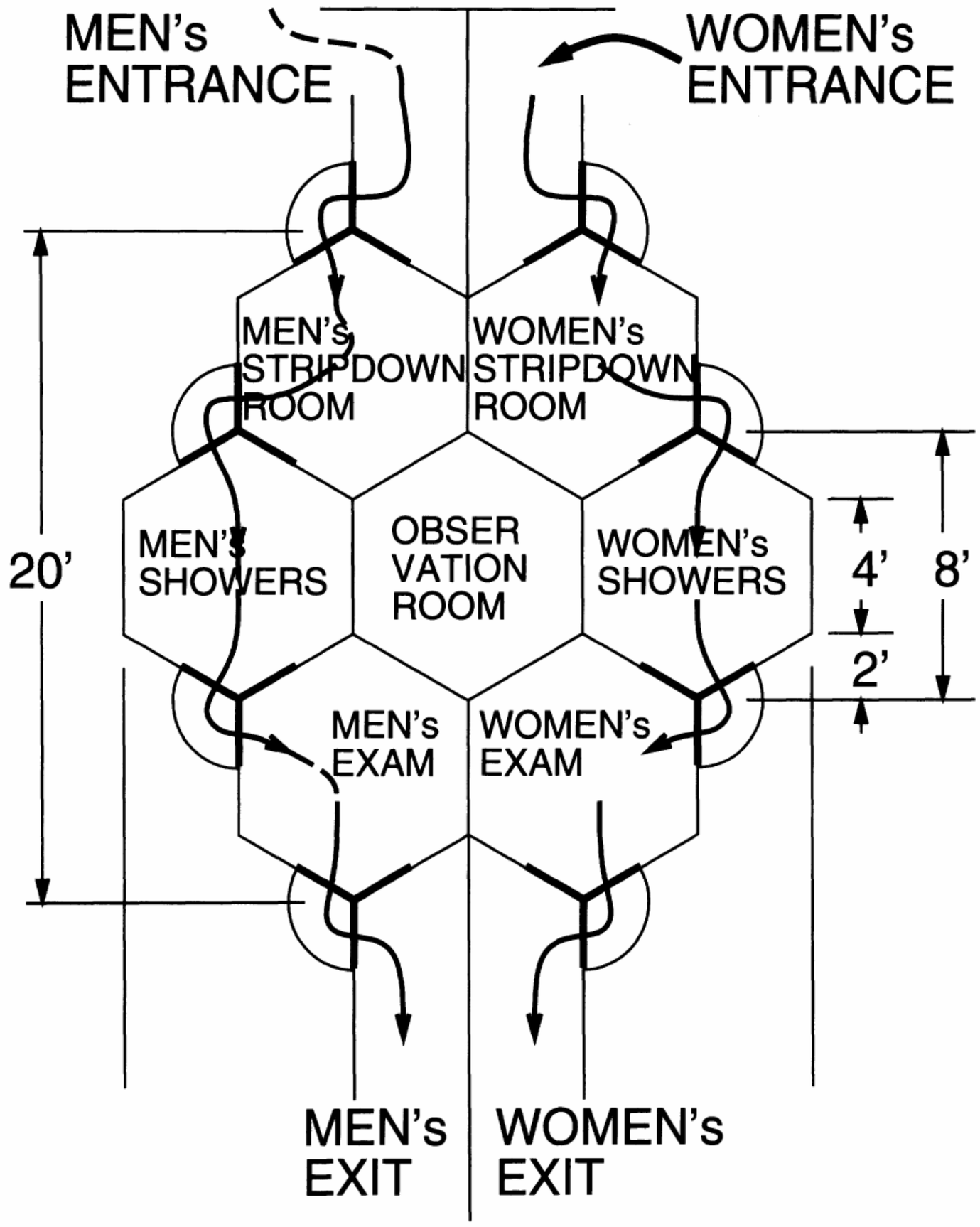


Fig. 4. Hexagonal architecture increases bathroom throughput and efficiency for mass casualty bioterror response preparedness. (© S. Mann) High-security Rotogate™ turnstiles lead into gender-specific undressing areas, then to shower rooms unlocked by a guard in the central control room. After showering, subjects are then allowed to enter the examination rooms. Telemedicine facilitated by high-resolution videocameras allows remote triage staff to perform medical exams and permit healthy persons to leave.

the passing of contraband, as illustrated in Fig. 3. An alert is then sent to the authorities, together with live video of only Stalls 3 and 4, while masking out the information in Stall 1, to protect the privacy of the person who is changing clothes.

Smart Showers

Additional features of image-based motion detection can also be applied to shower rooms to provide user safety and security through visual monitoring to make sure that the user is attended to when encountering danger such as tripping and falling.

High-quality pictures assist facility managers in monitoring usage patterns, to help reduce or eliminate deviant behavior such as excessively long showering, use by vagrants, shaving or washing clothes in the shower room. Using the appropriate artificially intelligent software, management can be sure of maximizing user satisfaction by making certain that one inconsiderate user does not decrease the user-satisfaction of others.

In addition to deterring crime and vandalism, intelligent plumbing fixtures can also be used to respond to acts of terrorism. A regular shower facility in a typical locker-room setting can double as a mass decontamination (decon) facility in times of emergency. In this case, having full-color video feeds will assist remote decon officers in determining, for example, if a powder on a subject's body is grey, like powdered anthrax, or some other color. A unique hexagonal architecture, shown in Fig. 4, speeds throughput when used with a six-person sensor-operated column shower installed in each shower room.

A six-person column shower having six nozzles around a hexagonal/round column is used to match this hexagonal architecture. The optics are composed of a single sheet of smoked polycarbonate inserted inside the column after six viewing holes have been drilled. A typical installation of this invention will use optics that allow color cameras to be concealed within the column, out of sight of vandals.

Hexagonal architecture increases bathroom throughput and efficiency for mass casualty bioterror response preparedness, such as in response to spilled salt or other mysterious powder. High-security Rotogate™ turnstiles lead into gender-specific undressing areas. There up to six men and six women strip completely and are then allowed to pass into the shower rooms through turnstiles unlocked via the central control room. Another six men and six women are then herded into the undressing rooms while the first group is showering. To protect the privacy of those undergoing decon, the central guard tower walls are made of smoked glass or polycarbonate, and there are black cloth baffles inside the control room. Thus men cannot see through to the women's side, or vice versa. After showering, victims are then allowed to enter the examination rooms through another remotely unlocked turnstile. Telemedicine facilitated by high-resolution videocameras allows remote triage staff to perform medical exams and permit healthy persons to leave.

An adhesive sealant makes the inside of the column watertight. Six video cameras are installed in the column with a 45° mirror on each one. Three cameras point up from below, while three point down from above. An embedded computer includes video capture devices in the column that are used to locally control six separate solenoid valve actuators while also providing remote connectivity.

Appropriate software detects the presence of users and turns on the appropriate showerheads where flesh is detected. In this way no water is wasted.

The six-person column shower works within the context of what I call a hexagraphic architecture, in which rooms are linked together in a honeycomb-shaped lattice guarded by turnstiles where walls meet at 120° angles [2]. Six cameras in each shower room and six cameras in the central triage room would comprise a total of 18 cameras. The captured images can be displayed on two television sets,

each showing a 3-by-3 mosaic of images (a 9-up image on each TV). A typical screen shot of the sensor-operated column shower in actual use is shown in Color Plate A No. 4 [3], which shows the output from the central triage room, which appears as the top row of the 3-by-3-image mosaic on the Men's Decon Officer control console.

CONCLUSION

Infrared sensor-operated plumbing fixtures can incorporate recent advances in computer vision. Passive infrared sensor arrays are optimal for computer control of toilets and urinals, whereas active infrared sensor arrays are most suited to the control of sinks and showers. However, for emergency preparedness, where telemedicine and remote triage are essential, showers should be equipped with full-color sensing capability, especially helpful in the identification of perpetrators who may be among the victims of a bioterror attack, especially in the case of suicide attackers, who would likely become victims, or in the case of accomplices, who might try to hide themselves among the casualty population.

Acknowledgment

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References and Notes

1. See <http://existech.com> and <http://wearcam.org/safebath/index.htm>.

2. See Canadian Patent 02303611, filed 1 April 2000 and URL from a July 2001 exhibit at Gallery TPW, <http://wearcam.org/tpw.htm>, and the curatorial essay at <http://www.existech.com/tpw/index.html>.

3. See the press release, "Mailroom Begins Operations June 30th; Public Tours July 5, 2001, at 7:00 pm" and the call for volunteers for a mass casualty anthrax decontamination drill at <http://www.existech.com/press_release_deliverify.htm>.

Manuscript received 18 October 2001.

S. Mann was born in Canada and spent much of his childhood inventing various kinds of smart clothing and wearable computers. He went to the United States to study at the Massachusetts Institute of Technology, receiving his Ph.D. in 1997, prior to returning to Canada as an Assistant Filing Clerk Trainee for EXISTech Corp. He is also a faculty member at the University of Toronto.

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