In "The Lighthouse Handbook on
Vision Impairment and Vision
Rehabilitation, Volume One,
Vision Impairment"
Oxford University Press, 2000

Signage and Wayfinding

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One of the profound adaptations that may be required of the individual with a vision impairment is learning (or in the case of newly acquired impairment, relearning) to travel independently and coping with architectural and other barriers unwittingly imposed by a nearly universally sighted society. Since people with spinal or lower limb injuries and disorders also encounter barriers that limit travel independence, people with vision impairments have found common political strength in advocating for environmental *accessibility* as a civil right. In the United States, laws supporting this right have been increasingly passed at both the state and federal levels since the 1970s, culminating in the Americans with Disabilities Act (ADA) of 1990 (see Chapter 30), which mandates architectural and other changes in the interest of increasing accessibility in businesses and facilities open to the general public and in employment equality.

Contrary to common opinion, the law does not guarantee accessibility to people who are disabled; it only requires that public entities, and private businesses and services that accommodate the public, remove architectural and communications barriers to access if doing so is "readily achievable." The Americans with Disabilities Act Accessibility Guidelines (ADAAG) (Architectural and Transportation Barriers Compliance Board, 1992), published by the Architectural and Transportation Barriers Compliance Board (ATBCB or Access Board), constitute the bulk of the interpretation for what constitutes "readily achievable" and provide guidance on how mandated changes are to be implemented for compliance with the law. All the required changes intended to increase access for people with vision impairments relate to signs, presumably on the theory that since signs generally provide sufficient wayfinding aid for sighted people, they must be sufficient for people who are visually impaired as well. However, given the difficulties faced by those with limited vision in finding signs, there is little evidence that signs using Braille or raised letters significantly increase the ability of people with severe vision impairments to travel independently. Better signs, however, are likely to increase accessibility for those with less severe vision impairments.

The ADAAG and its likely next revision as detailed in proposed guidelines under consideration as of this writing (ADAAG Review Federal Advisory Committee, 1996) mandate and recommend the location and format of signs (e.g., Braille, raised letter, high contrast). However, they do not address the realities of how persons with vision impairments will use such signs to find their way in unfamiliar public spaces. People who are blind have a good chance of identifying a room from a hallway if a mandated tactile sign is situated at the mandated (and consistent) location next to the door, but this does little to help them actively find the way to a desired location. Thus, while the ADA stipulates the removal of barriers to access, there has historically been no "readily achievable" and available technology that could provide that access to those with visual disability in the same way that ramps can remove barriers to access via wheelchairs. What is needed to make public spaces truly accessible for people with vision impairments is a wayfinding system that allows users to plan and follow a route to a desired location.

People who are visually impaired and those who use wheelchairs face very different obstacles, of course, to obtaining access to the environment. Architectural barriers are primarily physical for users of wheelchairs but are informational for those with vision loss. In terms of remediating reduced access, aids to wayfinding such as special signs and maps are of help to people with vision impairments, whereas structural architectural features such as ramps and wide doorways accommodate users of wheelchairs. Note that not all accessibility remediations are environmental, since people with vision impairments, like users of wheelchairs, may utilize personal accessibility aids (e.g., telescopes) that meet their individual needs. This chapter, however, is concerned with only environmental modifications that are intended to provide access to buildings and facilities used by the general public.

Universal Design

In recent years, the notion of *universal design* has gained wide acceptance as an ideal in the planning and implementation of environmental modifications to increase accessibility for people with disabilities. This principle seeks design parsimony and cost savings by utilizing, wherever possible, features that will serve all users. For example, a raised-letter large-print sign with high visual contrast might help both able-sighted people and those with vision impairments who can read raised lettering tactually. It is economical to manufacture and install one such sign rather than separate raised-letter and visual signs, and it is more parsimonious in terms of design as well. Proponents of universal design agree on a number of guidelines:

1. Signs should have adequate size, contrast, and typography (see below) to be readable by the maximum possible proportion of travelers. Not incidentally, these design features also make signs more easily readable even for people with able sight.
2. Placement of such features as door handles and elevator controls should be consistent so that a person who is blind knows where to expect them. The current law mandates signs to be 60 inches above the floor.
3. Simple environmental measures, such as ensuring that steps and curbs have contrasting edges and that indoor workspaces are well lighted and are decorated in contrasting colors, make viewing and functioning easier for those with normal or impaired vision.
4. Care must be taken when combining universal design features intended for different population subsets. For example, curb cuts designed to benefit users of wheelchairs, shopping carts, and strollers have to be placed (e.g., on the diagonal axes of intersections) so they do not remove the curb-edge cues normally used by pedestrians who are blind to avoid wandering into the street and to orient themselves perpendicular to the roadway before crossing. Sometimes compromises must be made. The proposed new ADAAG (ADAAG Review Federal Advisory Committee, 1996) may mandate placement of signs at a range of 48 to 60 inches above the floor, which will make them more difficult for a person who is blind to locate, but more accessible to shorter people and those in wheelchairs.
5. Developments in orientation and wayfinding technology originally intended to benefit one group can often benefit others or the entire population. Thus, in the case of curb cuts, the advantages extend to all wheeled vehicles, including strollers. Those who cannot read regular print signs—for example, the entire population with print handicaps, including those who cannot read for reasons other than visual problems, and foreign travelers who can hear the signs in their own language—benefit from auditory remote signage. Navigation aids based on satellite global positioning system technology (discussed below) may also have similar benefits for the general population. And tactile maps can

be designed to make map reading more attractive and fun for children and, indeed, all sighted users.

Universal design has generally had a positive impact on accessibility and has at the very least provided a useful conceptual framework for envisioning environmental designs that follow an inclusive philosophy. As we shall see, however, there are situations in which its principles may encourage compromises that result in less accessibility than can otherwise be achieved.

Human Factors in Wayfinding

Because vision impairment exists in many forms and degrees, ranging from total blindness to moderate visual difficulties that are often considered normal in older people, it is not surprising that difficulties in wayfinding are correspondingly diverse. An individual with a moderate acuity loss may function adequately with thoughtfully positioned large-print signs, while a person with tunnel vision may have little difficulty reading signs, but may not easily find them. These differences may be explained at the level of the functional description of the vision loss (see Chapters 14 and 15). Conversely, there is a great deal of diversity in geographic and navigational facility among individuals who are congenitally totally blind, and it cannot be easily explained by sensory experience. Indeed, specific mechanisms that would explain how visual experience during development affects general spatial competence are by and large unknown, although it has been shown that subjects who were sighted but blindfolded and subjects who were adventitiously blind performed better on a number of tasks than did subjects who were congenitally blind (Brambring, 1976; Casey, 1978; Dodds, Howarth, & Carter, 1982; Heller & Kennedy, 1990; Hollins, 1986; Kerr, 1983; Lederman, Klatzky, & Barber, 1985; Millar, 1981; Rieser, Guth, & Hill, 1986).

Finally, it is worth noting that there are likely many component capabilities of practical geographic ability that may or may not be related, including route planning, route memory, navigation, obstacle avoidance, and landmark (or sign) recognition, each of which is increasingly difficult to accomplish with increasingly diminished vision.

Signage

A single universal technology for successful wayfinding by all user groups has not yet been developed, but advancing the technology of sign accessibility is important for several reasons. First, society, through the ADA, has recognized signs as an architectural element whose accessibility to people with vision impairments must be increased. Second, since the largest segment of the population that is visually impaired has partial sight due to adventitious vision loss late in life (Rubin et al., 1997), improving the accessibility of signs can help a relatively large number of people with vision impairments. Third, making signs more accessible is less expensive than developing and manufacturing wayfinding aids, many of which are described in this chapter. Finally, the large existing sign industry can implement large-scale changes in signs by adopting modified industry standards for accessibility.

Placement

Visual signage is traditionally used to indicate or label either significant environmental information that is otherwise not visually obvious (e.g., the occupant or function of a room hidden from view by its door) or the route to a particular destination. Some signs serve both purposes. For example, signs with room numbers serve both to label the rooms and to signal the progression and hence direction of a desired route.

In either case, the traditional positioning of a sign is usually selected for convenience and likelihood of its being visually viewed by a specific group of people. At an airport, signs giving directions to the baggage claim area are generally positioned so that arriving passengers can easily see them, whereas signs giving directions to the ticket counter are mostly positioned so that departing passengers can easily see them.

While sign salience may be the best principle to follow for visual signage, it is probably not the best rule for tactile (Braille and raised letter) signs, whose location is difficult to determine nonvisually. Such signs must instead be placed in consistent spots that are easy to locate by touch. The current ADAAG guidelines mandate (ATBCB, 1992), for example, that interior signs indicating room number or function be placed at a height of 60 inches on the latch side of a door. It is likely that the next revision of the ADAAG will expand the range of sign heights to between 48 and 60 inches. The intention is to accommodate shorter individuals and those in wheelchairs, but this placement would increase the area that an individual must search by touch for a tactile sign. Furthermore, unfortunately, there are no standards for the consistent and specific location of Braille and raised letter directional signs, and it is difficult to imagine how they could be found or noticed nonvisually without additional cues such as auditory beacons.

Increasing Accessibility by Visual Means

For the most part, increasing the accessibility of signs through visual means involves simply making the text more legible. This is usually accomplished by increasing the text size, but manipulating other typographical features can affect legibility and accessibility as well (Arditi, 1996). If the size of the sign is limited by spatial or economic constraints, typography is especially important. Obviously, manipulation of visual attributes can increase accessibility for only the population with low vision. Factors found to have a significant impact on legibility are letter spacing (Bouma, 1970; Flom, Weymouth, & Kahneman, 1963), proportionality of spacing (Arditi, 1996; Mansfield, Legge, & Bane, 1996; Morris, 1988), stroke width (Arditi, Cagenello, & Jacobs, 1995b), letter aspect ratio (Arditi, Cagenello, & Jacobs, 1995a), and interior "ink" within strokes (Arditi, Liu, & Lynn, 1997). Also italics, slanted fonts, and decorative and ornate styles are all thought to be less legible than standard styles (Arditi, 1997b; Tinker, 1963), but this may have as much to do with readers' relative unfamiliarity with the letter forms as with their physical characteristics.

Several studies of reading legibility have focused on the role of contrast (Legge, Pelli, Rubin, & Schleske, 1985; Legge, Rubin, & Luebker, 1987; Legge, Rubin, Pelli, & Schleske, 1985). All the findings are consistent with the idea that increasing contrast never decreases legibility and, indeed, generally increases legibility for individuals with effective contrast reductions due to pathology and for normally sighted individuals viewing text under low-contrast viewing conditions. In addition, there is some evidence that for patients who report significant problems with glare, white text on a black background is more legible than the reverse, presumably because the amount of light entering the eye in the region of the text is lower with a dark than with a light background. Thus, maximum legibility for the largest proportion of populations that are normally sighted and visually impaired seems to be achieved with the highest feasible contrasts, using white letters on a dark background. For further discussions of the visual requirements for reading by individuals with low vision, see Chapter 15 of the handbook.

What color combinations result in the highest text readability? The few studies that have addressed this issue (Knoblauch, Arditi, & Szlyk, 1991; Legge, Parish, Luebker, & Wurm, 1990) have in general found that the most important chromatic determinant of readability is the luminosity contrast component of the color combination made up of the letters and background of the text display. In other words, for the standard observer (with a standard spectral luminosity function), hue and saturation per se are irrelevant; the luminance contrast between the colors chosen for letters and for background alone determines the readability. Of course, relative to the standard observer, most people with low vision have some color defect that is either congenital or acquired through aging or disorders that lead to producing spectrally nonuniform ocular media opacities (i.e., tinting of the ocular media) or cone losses differentially affecting short, medium, and long wavelength-sensitive cone photoreceptors. These color defects often result in luminosity functions that differ markedly from those of the standard observer, and, as a result, some color combinations have higher effective contrasts and hence are easier for these people to read.

Three guidelines are especially important to keep in mind when designing displays, environments, and documents for people who might have either a congenital or an acquired color deficit (Arditi, 1997a; Knoblauch & Arditi, 1994):

1. Optimize differences in lightness between foreground and background colors, and avoid using colors of similar lightness against one another, even if they differ in saturation or hue (Figure 35.1). Although a designer cannot be confident that the lightnesses she perceives will correspond to the lightnesses perceived by

sentation of geographic spaces of arbitrary size by exploiting the exquisite human ability to apply certain geometric transformations like scaling, rotation, and translation to mental images of visual scenes (Kosslyn, 1980; Shepard & Metzler, 1971). Most maps are essentially scaled and rotated representations of ground space—scaled down to the available map space, and rotated to present a top, or bird's-eye, view. The extent to which people who are congenitally blind share this ability for mental transformation of spatial information is a controversial topic, but it is clear that even those with no visual experience whatsoever can make good use of map information in orientation, mobility, and route planning given some familiarity with simple map concepts (Andrews, 1983; Bentzen, 1972; Blasch & Brouwer, 1983; Casey, 1978; Golledge, 1991; Holmes & Arditi, 1998). Because spatial resolution of the touch sense is much poorer than that of the visual sense (Loomis, 1990), less information can be put on tactile maps than on visual maps. Thus, much of the applied work in this area has focused on what types of map information are essential or most useful in such maps (Edman, 1992).

A problem with the design of tactile map elements is that there are few well-accepted conventions for the tactile representation of objects. Even a simple symbol such as a visual arrow has little meaning in raised form, except to people who can remember its shape from vision they once may have had. Similarly, many visual symbols are mnemonic, minimalist representations of visual images of objects from which map users develop a vocabulary. Translated directly to raised form, however, such symbols have little meaning to people who are blind.

Supplemented by computer-generated verbal information, talking maps can provide much richer information to users, both because they can train the traveler to use the system and because they can provide information that is customized to the particular needs of the user (Arditi, Holmes, Reedijk, & Whitehouse, 1999).

Infrared Remote Signage

The first system of remotely readable signs to be developed was the Talking Signs system. The concept was to provide coded infrared transmitters at any location where a sign or label is desirable, so that a pedestrian who is blind and who is carrying a suitable receiver could read signs at a distance in the same manner as sighted travelers use printed signs.

Talking Signs transmitters continuously broadcast signage information from infrared light-emitting diodes placed at the position of each sign or labeled location. The infrared signal is decoded by the individual's handheld receiver, to produce a directionally selective voice message. The direction selectivity is a characteristic of the infrared message beam, so that the intensity and clarity of the message increase as the sign is "pointed at" or approached. Thus, the individual can get feedback about his location relative to his destination as he moves toward the device. The signs are light and small, are easy to install, consume very little power, operate indoors and outdoors, and are easy to program with human voice or synthesized voice messages. Because different signs have different functions, the range and angle of coverage of each sign are adjustable.

In recent years, the Talking Signs system has become commercially available through Talking Signs, Inc., of Baton Rouge, Louisiana. A similar and compatible system called the Marco Audible Sign System is available through the Telesensory Corporation of Mountain View, California. Other companies are now entering or about to enter this field. Demonstration installations of the Talking Signs system are in the Carroll Center for the Blind in Boston; the Manhattan headquarters of Lighthouse International in New York; the Texas School for the Blind in Austin; the Glasgow Blind Resource Center in Scotland; the underground railway system in Venice, California; the Metro system in Washington, D.C.; and many facilities in San Francisco, including the new public library, the office building at 30 Van Ness Street, and the Powell Street Muni/Bay Area Rapid Transit (BART) station, as well as the five-way street intersection above it. Many other installations are being explored, are being planned, or are under construction in San Francisco, including the Yerba Buena Gardens project, Muni bus shelters, the ferry terminal, and the entire BART system.

The Talking Signs system has been evaluated in a number of psychophysical studies (Bentzen & Mitchell, 1993; Brabyn, 1983; Brabyn & Brabyn, a Braille sign is quite difficult. The user must search a much larger area, and there is less predictability about environmental structure.

Braille

Braille is the standard medium of literacy for persons who are blind, although a relatively small percentage of this population actually reads Braille. "Low-tech" Braille signs can be produced inexpensively by a variety of methods, including the use of a Braille Dymo Writer, and placed in locations chosen to be as convenient and easy to find as possible.

Thus, in the earlier example of the airport, doorways leading to the ticket counter and the baggage area may be labeled with Braille signs, but where should a traveler who is blind look for directions when getting off the plane? He generally emerges into a large open space with relatively little predictable structure, except for check-in counters placed at adjacent gates. There is no obvious place where he can try searching for Braille signs.

A possible solution may involve the determination of a standard that specifies the placement of Braille signs in the narrow entryways leading into such large open spaces. In an airport, a standard Braille sign (for giving directions to likely destinations such as the baggage claim area) could be placed on the wall of the tunnel where it emerges into the open space of the boarding area.

Raised Letter

Since few people who are congenitally blind have strong familiarity with visual letter forms, the primary users of signs with raised letters are presumably individuals who lose visual function late in life and whose impairment is extreme enough to make visual sign reading infeasible. Such people will generally rely on memory for shapes of letter forms, but have little experience with tactile letters. Although the current ADAAG mandate raised-letter signs, the benefit of providing access to this population by using tactile signage has not been clearly established. The original intention seems to have been to make visual signs accessible by touch by simply combining visual and tactile formats in the same signs. Although mixed upper- and lowercase text is thought to be more legible for visual reading (McLean, 1980), uppercase letters are more legible by touch than are mixed-case letters, and the currently mandated signs are hence required to be all uppercase. This requirement likely sacrifices some visual legibility for the sake of tactile accessibility, but the new ADAAG being considered (ADAAG Review Federal Advisory Committee, 1996) will allow separate visual and tactile signs, each of whose legibility may be optimized within sense modality.

Even within tactile signs, some compromises are inevitable. Braille dot height is standardized (Library of Congress Specification #800) for best legibility, but this may not be the optimal height for best legibility of raised letters. In addition, sign-manufacturing techniques may further limit tactile legibility by constraining height or profile of the raised element.

Remote Signage Systems

As mentioned earlier, Braille signs must be found before they can be read, thus negating much of the function of visual signage. The ability to read signs and to recognize environmental objects, facilities, and landmarks from a distance are clearly two keys to efficient orientation and wayfinding. This can be dramatically demonstrated to a sighted individual traveling in an area where all the signs are missing or are in a foreign script—as for a European traveling in China.

To achieve the same ease and independence of travel to which most persons with sight are accustomed, individuals who are blind would clearly benefit from any equivalent system of signs that can be read remotely and/or from remotely read labels for landmarks and other key objects that sighted people utilize for orientation. A number of proposals have been made for such remotely readable signage or environmental labeling systems. Whatever technology is used, it is clear that the ability to read signs at a distance—an ability taken for granted by people who are sighted—can greatly improve orientation and wayfinding skill, safety, and speed.

Wayfinding Systems

Tactile Maps

The use of maps for wayfinding has a long and rich cultural tradition dating back to the earliest times in recorded history. Map technology allows the repre-

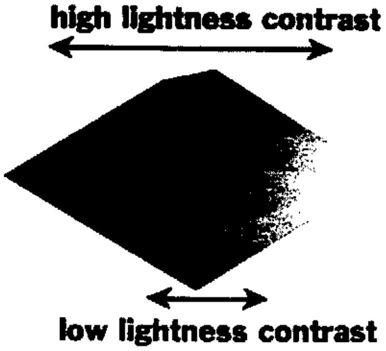

Figure 35.1. Effective contrasts for people with color deficits generally require using colors with very different lightnesses. (*See color insert.*)

people with color deficits, she can generally assume that they will see less contrast between colors of different lightness than she will. If lighter light colors and darker dark colors are chosen than would be chosen for people with normal color vision, the visual accessibility of the design to people with color deficits will generally be increased.

2. Choose dark colors with hues taken from the bottom half of the hue circle shown in Figure 35.2 (or black) against light colors from the top half of the circle (or white), and avoid contrasting light colors from the bottom half against dark colors on the top half (or black). Most people with partial sight and/or congenital color deficiency tend to suffer losses in visual efficiency for colors in the bottom of this circle. This guideline helps to minimize the deleterious effects of such losses on effective contrast.
3. Avoid contrasting hues from adjacent parts of the hue circle (Figure 35.3), especially if the colors do not contrast sharply in lightness. People with color deficiencies associated with partial sight (as well as those with congenital deficiencies) have more difficulty discriminating colors of similar hue than do those with normal vision.

Increasing Accessibility by Tactile Means

As mentioned earlier, a principal problem in the use of tactile signs is the user's difficulty in locating them. The ADAAG mandate that sign location be somewhat more uniform, making the problem of finding them a little easier. Thus, in corridors and other confined spaces, it is relatively easy to locate a Braille sign mounted on or near a doorway. Directional signage is more difficult to implement successfully with tactile signs than identifying signage, and few attempts have been made to apply or standardize the use of Braille directional signs. In open areas such as large rooms or public spaces, finding

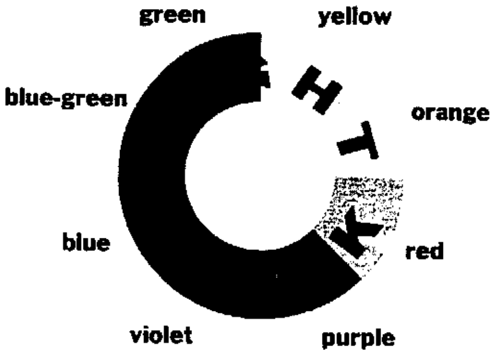

Figure 35.2. This hue circle is arranged with colors on its bottom half that tend to appear darker to people with color deficits than they do to people with normal color vision. To ensure that this effect does not reduce effective contrast for these people, select the dark colors in a contrast from the bottom half of the circle and the light colors from the top half. (*See color insert.*)

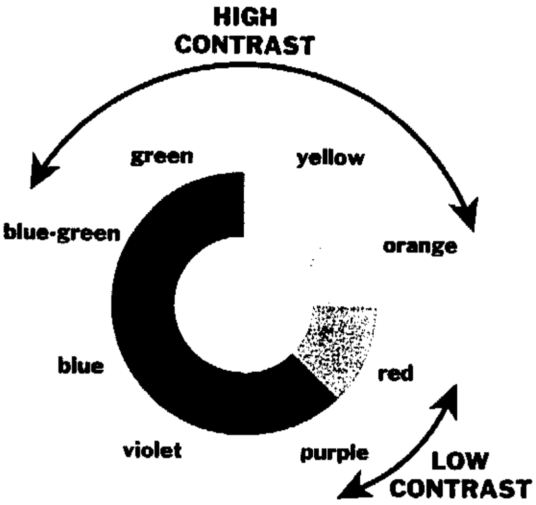

Figure 35.3. Since people with color deficits always have more difficulty distinguishing neighboring hues, contrast colors from distant, rather than adjacent, locations on the hue circle. (*See color insert.*)

1982; Schenkman, 1986). They have included an evaluation of Talking Signs in a university campus setting at San Francisco State University—evaluating travel within buildings and between buildings (i.e., open areas). Two indoor and four outdoor routes were utilized, each outfitted with Talking Signs transmitters. Data included both objective performance ratings and subjective questionnaires administered to the sixteen subjects (Crandall, Bentzen, Mitchell, & Rosen, 1994). Another study involved the outfitting of the BART and Muni subway stations and surrounding areas at Powell and Market Streets in San Francisco with ninety-five Talking Signs transmitters (Bentzen, Crandall, & Myers, 1997; Crandall, Bentzen, Myers, & Mitchell, 1995). Special transmitters for locations such as crosswalks—to incorporate information on the status of signal lights and lateral position in the crosswalk—have been tested.

The evaluation studies to date have generally been positive, and the reception by users who are blind has been enthusiastic. Evaluation results have uniformly shown improvements in performance for users of remote signage in terms of finding desired locations with fewer mistakes than would have occurred without remote signage. In most cases, speed is also increased. Clearly, remote signage technology can provide unique advantages to travelers who are visually impaired in allowing them to locate and recognize signs and landmarks from a distance both indoors and outdoors.

During the course of the studies, much was also learned about the problems and solutions involved in adapting remote signage for different environmental settings. Installing remote signage is not just a matter of securing transmitters to the wall and applying power. Just as size, font, positioning, etc., of regular print signs need to be varied to suit a particular location, equivalent parameters such as power output, transmitted beam shape, and sign position need to be adjusted for different physical situations, if optimal usefulness of remote signage is to be achieved.

Other infrared-based remote signage systems have now been proposed, including the OPEN project in Great Britain. This project utilizes principles similar to those used in Talking Signs and the Marco Audible Sign System and envisages a head-worn receiver and a computer-coordinated network of transmitters throughout London Underground stations.

Radio Frequency-Based Remote Signage

Remote signage and "interactive environment" systems using various forms of radio transmission as a medium have also been proposed and developed. The first system was developed by Kelly (1981) utilizing garage-door-opener technology. The idea was to place receivers at the locations of the signs or desired landmarks and have the transmitters, held by users who were blind, interrogate them. A keypad on the hand-held transmitter was used to select the type of sign one was looking for. If the user selected the code, for example, for the restroom, any restroom receiver in the vicinity would announce its presence via a sound emission that could be followed by the traveler to localize the facility.

A radio frequency orientation system was proposed by NYNEX (Urband & Stuart, 1992) involving a network or grid of radio transmitters located on tall structures and on street corners. The user would wear headphones to which a directionally selective receiver would be attached for orienting to these beacons.

Several innovative proposals for labeling the environment with relatively inexpensive devices that can be interrogated by radio transmissions have been explored. Examples include the REACT system developed by the Royal National Institute for the Blind, and systems proposed by Main (1991) and Fanmark Technology Corporation. Using such techniques, the idea that the environment may be responsive to the user's needs has been investigated with passive credit card–size tags that can absorb and retransmit appropriately coded radio signals from a suitable computerized transmitter (Jaffe, 1992). Proximity-triggered talking signs have also been tested (Jones, 1991). Related, although somewhat outside the definition of signage, are remotely readable SmartCards that are being tested in Europe and allow machines such as ATMs to determine that the user is visually impaired and may therefore desire larger print on the screen or synthetic speech via an earphone.

A commercial remote signage system utilizing radio transmission, known as Verbal Landmarks, appeared in 1992. It uses radio frequency transmissions from loops embedded in the jambs of doorways to identify entrances and other waypoints. A user's receiver within range of the Verbal Landmark transmitter announces the location as a verbal message.

In 1993, the Access Board of the American Council of the Blind determined that there was sufficient interest and promise in remote audible signage as a supplement to tactile signage to warrant a formal evaluation of the infrared- and radio frequency-based technologies. The resulting report (Bentzen & Mitchell, 1993), describing experiments in a hotel setting, showed a preference for the infrared-based technology in terms of objective travel measures (time to travel and travel distance) and subjective user opinion. This difference appears to be due largely to the ease of localization and beam-pattern control of the infrared-based technology.

Orientation Systems Using Global Positioning System Technology

Early military navigation systems such as Loran were explored for their application to the problems of orientation of people who are visually impaired, but the systems were found to be inadequate. The advent of the highly accurate satellite-based Global Positioning System (GPS) has opened up new possibilities.

GPS, also originally developed for military purposes, utilizes a network of satellites in very precise orbits around the earth, transmitting precisely timed microwave signals. Suitable receivers on the earth's surface, receiving information from three or more satellites, can use the signals to give an estimate of longitude, latitude, and altitude. Codes made available for civilian use allow positioning accuracy to within approximately 300 feet with "selective availability" and 50 feet without. Greater accuracy (3 to 50 feet) can be obtained with "differential" GPS, utilizing an additional transmitter placed nearby on the ground.

To make this raw position information usable by all individuals, whether sighted or visually impaired, it can be combined with specially developed maps or Geographic Information Systems (GISs). These are, in effect, computerized maps and databases containing whatever information about the local area is desired by particular users. For example, such computerized maps containing the locations and descriptions of freeway exits and restaurants might be useful to motorists, while information about bus stops and street addresses might be useful to travelers who are blind.

Experimental and developmental work on applying these technologies to assist people who are blind has been begun by several researchers and companies, including Loomis, Golledge, and Klatzky (1993), Bornschein, Balachandran, Frank, Arkenstone Inc., and others. In the approach taken by Loomis, Golledge, and Klatzky, the GPS receiver is used to locate the user in space, and through localizable auditory information delivered through headphones worn by travelers, known objects (stored in a computer also worn by the traveler) emit sounds, creating a "virtual auditory space" corresponding to real space. That is, travelers hear sounds during travel that inform them of landmarks they are passing.

Thus, in conjunction with suitable stored map information, computing power, and a carefully designed information display interface, GPS technology offers many possibilities for providing a wide variety of orientation and navigation information to a traveler who is blind. In the Arkenstone Atlas Strider system (Fruchterman, 1995), a computer-based talking map (Atlas Speaks) is combined with the GPS receiver to allow sophisticated interaction with the user, who not only can interrogate the system to find his or her present position but also can ask for and receive directions to a chosen destination. Using the computerized talking map separately before even beginning the trip, the traveler can "explore" possible routes in the same way as a person with sight would browse a printed map.

GPS technology is ideal for providing estimates of approximate position in open areas. But because the microwave signals used by the system can be occluded by objects intervening between transmitter and receiver, accuracy and operation may be compromised in many areas of interest to the traveler who is blind, such as narrow streets lined with tall buildings; indoor areas like hotels, office buildings, and shopping malls; and underground mass-transit stations. GPS cannot by itself provide location of objects with the accuracy available to pedestrians with sight. For example, a GPS-based system would be able to give the general location of a street address, but would not allow the user to find the building entrance without additional searching or referring to some other form of information. Precise location of vital areas in public spaces such as restroom doorways, ticket machines, public telephones, and subway entrances may require, for travelers who are blind, the combination of GPS with other technologies. These limitations on the underlying sensor technology suggest the desirability of integrating GPS with other technologies in any comprehensive navigation system.

Thus, in the MoBIC project being developed by a consortium of research and commercial entities in Europe (The MoBIC Consortium: Strothotte et al., 1996), it is envisaged that GPS sensors and a computerized talking map may be integrated with various other inputs to give the traveler who is blind a comprehensive menu of information. For example, cellular phone capability may be provided for "on-call" directions, and dead-reckoning sensors may be included to overcome the problems caused by the loss of satellite signals (e.g., when close to tall buildings).

Other Approaches

Another approach to orientation and navigation that has occasionally been proposed is the use of dead reckoning in navigation. Dead reckoning utilizes knowledge of a starting point, coupled with input from sensors such as a compass and pedometer or another form of distance-measuring device, to establish a person's present location. Once the person's position is determined, reference can be made to computer-stored maps or route descriptions to give a large amount of information about the surroundings and desired route.

Components of this type of system have long been in existence; for example, the adaptation of compasses for use by people who are blind has a long history. The advent of electronic compasses and other sensors, along with miniaturized computing power, has made the synthesis of complete dead reckoning–based navigation systems technically feasible. They have been incorporated into certain vehicle-based navigation systems, and potential exists for their application to orientation and wayfinding for pedestrians.

A test of the potential of this approach was carried out in 1988 (Jampolsky, Brabyn, & Gilden, 1989; Milner & Gilden, 1988). The sensor system evaluated consisted of a K-band Doppler radar to measure distance traveled, in combination with a flux-gate compass for directional information. While it could ultimately be integrated with computerized maps, in the initial, simplest embodiment of the system, route information would be prerecorded on a cassette tape rather than on a computer. To record a cassette for a given route, a person who is sighted would accompany the traveler who is blind, pushing a button to put a code on the tape as each landmark is reached. The guide would also record a verbal description of the "landmark" (bus stop, corner), as well as a running commentary on the points of interest between landmarks as the route is traversed.

The basic technology for this type of system was determined to be feasible in 1988, during which the Doppler radar distance-measuring device was found capable of operation even while aboard a bus when aimed out the window. To evaluate users' acceptance of the concept while obviating the expense of manufacturing and synthesizing all the components, the complete system was simulated using an experimenter to announce the desired messages and commentaries as the subjects who were blind traversed a typical travel route. The subjects wore a "control box" with push buttons to elicit or mute various aspects of the verbal commentary. Results from tests with a dozen subjects were extremely positive (Jampolsky et al., 1989); at the time, however, the collaborating manufacturer did not feel the commercial aspects of the project would warrant further expenditure. Contemporaneously, a dead-reckoning system was briefly explored by researchers at the Hines Veterans Administration Medical Center, but also was not developed into a commercial product.

When these early explorations were made, the technology for position sensing, electronic map storage, and high-power portable computing was considerably less advanced than is now the case; it would now be possible to apply many of these concepts while achieving greater positioning accuracy and lower cost.

Orientation and wayfinding technology utilizing forms of image processing or artificial recognition of environmental features has been explored by several investigators following the pioneering work of Collins (1985) on tactile vision substitution. Systems of this nature could conceivably be sophisticated enough to locate and read print signs and to recognize objects such as public telephones and many other features of the environment. Variations on satellite navigation systems have been proposed that eliminate some of the restrictions on GPS operation. A number of electronic map-reading technologies have been or are being explored, and these can be interfaced with locating and positioning systems. Various inertial navigation systems have been investigated and may provide an adjunct to other sensors in increasing accuracy and directional information. It can be expected that developments in technology well beyond the field of sensory aids will provide yet more possibilities for enhancing the existing approaches or providing new alternatives.

Considerations for Future Systems

Each of the major systems for providing useful orientation and navigation information to the traveler with impaired vision has its advantages and disadvantages, which may be overcome by developing new technologies or combining existing ones.

Cost

An obvious obstacle to be overcome for any technology is cost. All the major technological systems explored to date have a significant installation or infrastructure component. In the case of remote signage or environmental labeling systems, there are the costs for manufacturing and installing the signs. In the case of "stand-alone" dead-reckoning or GPS-based navigation systems, costs are less obvious but very real. Aside from the expense of the satellite system itself (which is currently but may not always be taxpayer supported), there is the cost of generating or obtaining the necessary detailed electronic maps of every area a pedestrian with impaired vision may wish to visit. Basic maps are becoming available commercially, but for use as navigation systems for people who are blind, they will need to be heavily customized with descriptive notes, commentaries, and landmark information relevant to the user. The cost of generating and regularly updating this information must be considered in weighing the advantages of different approaches. Even the use of conventional electronic travel aids (and even canes) is much more costly than the devices themselves, if the expense of appropriate training is included.

Against these cost considerations must be weighed the enormous benefits to be gained from increased orientation and wayfinding capabilities. These include substantial economic benefits flowing from the ability to travel to a workplace and thus to enter the workforce, as well as the human benefits of enhanced independence.

Human Input

Leaving cost aside, the optimization of the human component of any navigation system is perhaps the single most important aspect of future developments. Travelers should be provided with the information they want and need, in a convenient, easily understood manner. The option of *not* receiving the information (receiving it only when it is wanted) is one major factor in these considerations. Ideally, users should have available enough information to allow an effortless flow of travel with direct location (without the need to search the vicinity tactually) of the key points of interest (whether they are doorways, drinking fountains, telephones, or ticket machines). And, of course, the ideal system would have universal coverage of all areas to which the users may wish to go.

Combining Different Technologies

Since no available wayfinding or signage system currently meets all these requirements, the advantages of combining different approaches should be explored. The pinpoint accuracy, user convenience, and directionality of remote signage systems, for example, could be integrated with the approximate vicinity locations and verbal commentaries obtainable from suitable computer-interfaced GPS and dead-reckoning-based technologies, also giving coverage of those areas where remote signage is not installed. In the age of telecommunications, summoning instant assistance from a remote operator is another feasible backup component. Many permutations and combinations are possible, and the continuing trends toward miniaturization and cost reduction in electronic systems make consideration of such combinations feasible.

Serving the Needs of the Visually Impaired Population as a Whole

It is important to recognize that even though providing access to people who are totally blind is more technically challenging, providing access to the population with low vision is at least as pressing, given the greater number of those with some residual sight. In most cases of moderate vision impairment, vision can be used very effectively for detecting landmarks, especially those of sufficient visual size and contrast. The primary difficulties for the traveler with low vision are in reading directional and informational signs and maps, especially in high or low lighting, and resolving distant visual details; these in turn limit ability to plan complex routes.

Those who are totally blind or have little vision that is useful for navigating or detecting obstacles, on the other hand, generally rely on touch (alone or via a long cane) in combination with environmental sounds to create a cognitive picture of their surroundings. For this reason, they have a spatially smaller area that they can immediately apprehend for navigation, making unfamiliar spaces particularly difficult to plan movements. (Dog guides aid the traveler who is visually impaired in navigating a chosen path, but are of little help in planning movements, except in obstacle and hazard avoidance.) Thus, to serve the needs of the entire population in any single wayfinding system poses a significant challenge, especially taking into consideration the ideal of universal design.

For travelers who are blind or only partially sighted, planning and executing a route to somewhere or something that is not immediately visible or tangible are obstacles that fully sighted people cannot appreciate, since society tends to design things for users with sight rather than for those who are visually impaired. But Architectural provisions of the Americans with Disabilities Act of 1990 mandate that public access be provided with the disabled community in mind. The survey presented in this chapter suggests that although design of a wayfinding aid that can significantly reduce barriers to access for persons who are visually disabled is technically challenging, it is within our reach.

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