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Safer Transit Travel for the Blind Using an Infrared Warning System

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A collaborative team involving the Milton S. Eisenhower Research and Technology Development Center, the Technical Services Department, and the Business and Information Services Department of the Applied Physics Laboratory has designed, developed, and implemented an infrared hazard warning system for subway stations. The Infrared Integrated Indicating System (IRIIS) serves an equivalent function to strips of truncated domes, currently installed at some stations, which give an underfoot warning to blind and visually impaired travelers that they are approaching a platform edge. IRIIS is inconspicuous, easy to use, and strictly voluntary. It also contains an innovative feature: the ability to distinguish an open train car door from spaces between, in front of, or behind a train car. This article describes the design of the IRIIS and presents results of demonstrations and evaluations by blind and visually impaired users. The IRIIS Team received a 1996 APL Team Excellence Award for this collaborative effort.

(Keywords: Blindness, Infrared, Rehabilitation, Transportation.)

INTRODUCTION

In the spring of 1995, U.S. Congressman Norman Y. Mineta of the Committee on Transportation and Infrastructure and a principal author of the Americans with Disabilities Act (ADA) wrote to Lawrence Roffe, Executive Director of the Architectural and Transportation Barriers Compliance Board of the Federal Transit Administration (FTA), stating his concerns about certain ADA enforcement policies. Mineta explained that some of those policies dealing with transit system platform edge warnings were “overly rigid” and not in the best interests of persons with disabilities, transit operators, or the general public.

Specifically, Mineta was referring to a platform edge detection and warning system for blind and visually impaired travelers. This system, which is used in the Baltimore subways, consists of 2-ft-wide strips of “truncated domes” placed along subway or rail transit system platforms. The domes provide an underfoot “signal” indicating that the traveler is too close to the edge. The FTA policy explicitly mandates the strip width, dimensions, spacing, color (bright yellow), material, etc., for the truncated dome system.

The concerns expressed by Congressman Mineta and by transit system users and operators include aesthetics, convenience, and effectiveness of the domes as a warning system. In support of Mineta's views, a recent Battelle Corporation[1] study concluded that the truncated dome strips are no more effective as an underfoot warning system than a platform edge having warning lights embedded in concrete, such as the system installed in the Washington, DC, subway system, or any of a number of other designs for platform edges. In fact, the study indicated that a 2-ft warning zone may not allow the traveler enough time to react to an impending edge.

In the spring of 1995, the Washington Metropolitan Area Transit Authority (WMATA) was slated for a limited trial of truncated domes. However, because of concerns such as those already noted and others regarding cost and installation, the agency filed a petition before the Architectural and Transportation Barriers Compliance Board to rescind the truncated domes requirement. Joining the WMATA, which operates the subway system in the District of Columbia and the Maryland and Virginia suburbs, was the Baltimore-based National Federation of the Blind (NFB), the largest consumer organization of blind people in the United States with over 50,000 members.

As represented by the NFB, blind and visually impaired subway users do not want a warning system that is conspicuous and potentially inconvenient to the general public. They are sensitive to those who may perceive the truncated domes as a nuisance created by yet another special interest group. Unlike more inconspicuous accommodations (e.g., Braille markings on elevators and automated teller machines), the domed strips are obvious and become unsightly with wear and tear. To most blind users, the "edge is the edge"; it is quite detectable with the trained use of guidance aids (canes or guide dogs). Only the unskilled visually impaired traveler needs an auxiliary warning system such as the truncated domes.

In May 1995, the FTA agreed to permit the WMATA to demonstrate technology to achieve "equivalent facilitation" for platform edge warning as a potential alternative to truncated domes. The two parties established a timeline before any specific technology or system concept had been identified or developed: working installation in 10 WMATA Metrorail stations by 30 April 1996, and installation in all 74 WMATA stations by 30 April 1997. The earlier request to rescind the truncated dome requirement made by the WMATA was therefore deferred until after this equivalent facilitation could be demonstrated to the ADA Accessibility Guidelines Review Advisory Committee.

Principals of the NFB, acting on behalf of the WMATA, consulted Robert Massof of The Johns Hopkins University School of Medicine Wilmer Eye Institute. The basic problem was to define, develop, and implement a technology-based prototype system to show the feasibility of something equivalent to the underfoot warnings and demonstrate its voluntary use by the blind and visually impaired by November 1995. Massof, in turn, contacted John Sadowsky, co-director of the University's Sensory Engineering Program, to collaborate in addressing the NFB inquiry. This article describes the prototype system developed by the Infrared Integrated Indication System (IRIIS) Team and presents the results of an IRIIS demonstration at the L'Enfant Plaza Metro station in Washington, DC.

SYSTEM CONSIDERATIONS AND REQUIREMENTS

To satisfy the needs of the NFB, WMATA, and FTA, a solution to the platform edge detection system had to meet a minimum set of technical performance and user requirements. The primary function of any such system is to provide a sharply defined boundary to a warning zone that begins 3 ft back from the platform edge. System users should automatically know they are within the 3-ft warning zone (i.e., the warning should occur naturally and definitively, a goal achieved by truncated domes). The system should be reliable, inconspicuous, strictly voluntary, and acceptable to the majority of a cross section of blind users.

Meeting this last requirement is challenging, as the blind community is polarized on the issue of platform edge detection. A vocal constituency lacks confidence in technological aides for edge warnings and favors the perceived simplicity and reliability of truncated domes over other alternatives.[2] Thus, it was imperative to involve a focus group of blind and visually impaired subway travelers in the testing and functional design of the system.

Figure 1 illustrates an initial conceptual design. It was thought that any approach should be based on a "broadcast" signal. In addition to meeting the minimum requirements, such a signal offers greater flexibility than other "passive" alternatives, which cannot, for example, distinguish open car doors from spaces between cars.

In the 20-year history of the Washington Metrorail system, 120 fatalities due to travelers going over the platform edge have occurred; of these, 2 involved the blind or visually impaired. The first was a blind person who was accompanied by a guide dog that was not trained to use the subway system. The man apparently

Figure 1. Conceptual design illustrating the infrared emitters projecting a sharply defined warning zone along the platform edge.

tripped over his dog onto the tracks and into the path of an approaching train. The other rider was a partially sighted person using a cane. In this case the traveler mistook the opening between two train cars for an open door and fell between the two cars. Truncated domes would not have prevented either fatality; however, in the latter case, a signal-based indicator could have transmitted a distinctive signal to confirm that the opening was a hazardous space and not an open door.

Signal-broadcast systems are also extendable to more complex forms of information, such as identifying train destinations (e.g., yellow line vs. green line), guidance toward escalators and elevators, instructional use of fare card machines, and so forth. These extensions, however, were considered beyond the scope of immediate budgetary and scheduling constraints of this effort.

Early in the development phase, the system was envisioned to have two components: one or more “broadcast emitters” of a warning or confirmation signal that would emanate from the platform area and train cars, and a “receiver detector” that would be carried or worn by the user. This type of system was considered natural to use and easy to learn. The receiver detectors would be freely lent at all station kiosks and returned when the traveler departed the station. Training in the effective use of the system would only require a few minutes of orientation and explanation.

Most blind and visually impaired users rely on their other senses, especially hearing, to navigate complicated environments, so it was also important to design a platform edge warning system that would not interfere with or add noise to the auditory environment. The IRIIS Team, therefore, selected a technological solution that would present tactile rather than auditory cues to the user. Many travelers whose blindness is associated with diabetes, however, often experience an accompanying peripheral neuropathy, which causes a loss of sensitivity to tactile stimuli in the fingers and hands. Thus, the tactile signal for the warning system would also have to be detectable to those with low to moderate loss of sensitivity due to neuropathy.

The success of any system to verify safe subway access depends on how well a blind person can conceptualize and process spatial information. This cognitive ability is often influenced by the age at which a person loses useful sight. Thus, our goal in developing this aid was to gain acceptance from a reasonable majority of both congenitally blind persons and those who were adventitiously blind.

From the WMATA’s point of view, any implementation had to be architecturally consistent and cost-effective. They estimated the cost of installing truncated dome strips to be between $20 and $40 million. The existing granite edges and light fixtures would have to be removed to install the dome strips at the platform level. The WMATA felt that a $10 million alternative technology to the truncated domes would therefore be attractive, cost-effective, and unintrusive to routine Metro operations. In addition, implementation could not interfere with routine Metro operations. For example, because train rails are used to transmit electronic signals at certain frequencies, any broadcast signals introduced into the environment could not create interference at those frequencies.

Many other factors had to be considered for this development effort, including indoor and outdoor platforms, long and short platforms, four-season weather conditions, and human traffic. The system had to be robust and support some level of fault tolerance. The IRIIS Team recognized, however, that some weather conditions (e.g., snow and ice buildup) could render the strips of domes inoperable and could stop or delay subway operations; such extreme conditions were therefore also outside the performance requirements of any technological system. Moreover, consistent performance levels would require routine maintenance as an extension of that performed for normal operation. System materials would have to be able to tolerate the cleaning agents and techniques already in use on existing platform areas and railcars.

A final consideration in this effort was our understanding that no single auxiliary aid for the blind traveler is intended to be used alone. Rather, each guidance aid augments others (e.g., canes and platform-trained guide dogs) and integrates with other sensory stimuli to provide environmental awareness. This recognition also implies that the IRIIS was not designed as a wayfinding system, although the technology and system concept developed could evolve into a more comprehensive travelers' aid.

IRIIS DESIGN

The technological solution developed by the IRIIS Team was to use an array of signal transmitters to illuminate an area defining a spatial zone, in conjunction with a user-carried or -worn detector/receiver device that would produce vibration/tactile (vibro-tactile) stimuli when the traveler entered that zone. Two separate zones were defined, easily distinguished by different vibro-tactile responses: one zone defined a region between the platform edge and a parallel line 3 ft back from the edge, and the other formed distinctive "lanes" indicating the position of open doors once a train had stopped and its doors were opened.

Several possible signal sources were considered for the transmitter array, including radio frequency, microwave, sonic, and infrared. On the basis of many factors, such as the subway station environment (especially echoes), human safety, complexity, beam shaping, costs, available technology, and technology maturity, the IRIIS Team selected infrared signaling for the system prototype. Our initial concern about infrared signaling was potential interference by light sources, particularly at sunlit, outdoor stations. Another approach would be for the user to carry a pocket detector (or one worn on an item of clothing) that would generate a vibro-tactile response upon entering a hazardous zone. Infrared links would not be appropriate for this scheme. In our design, however, because sighted travelers detect the platform edge with a direct line-of-sight visual path, we felt we could design an inconspicuous and natural-to-use detector that would be acceptable to the target population.

We decided to employ a low-duty-cycle pulsed vibration and a continuous vibration as the two clearly distinguishable vibro-tactile stimuli. Mechanical vibrations are created using a vibrating motor, as is found in pagers. To conserve energy, the pulsed response would be used as the platform edge indicator and would remain, whereas the continuous wave response would confirm an open door and operate only after a train had stopped.

The emitters were grouped in an array and mounted on the platform's face, between the platform and a train, about 1 in. below the top (pedestrian) surface of the platform (Fig. 2). This system had to meet interactive, mechanical, optical, electrical, reliability, and environmental requirements for packaging and materials integration from system to elemental component level. Emitters were mounted on optically aligned brackets at an angle that could be adjusted but was set to achieve a 3- to 4-ft warning zone (Fig. 3). A linear array of emitters was spaced at intervals of 1 ft for redundant overlap of beams in the event of single point failures. The beamwidth of each emitter and adjacent emitter overlap to provide a uniform region of illumination and allow for angles of approach to the platform

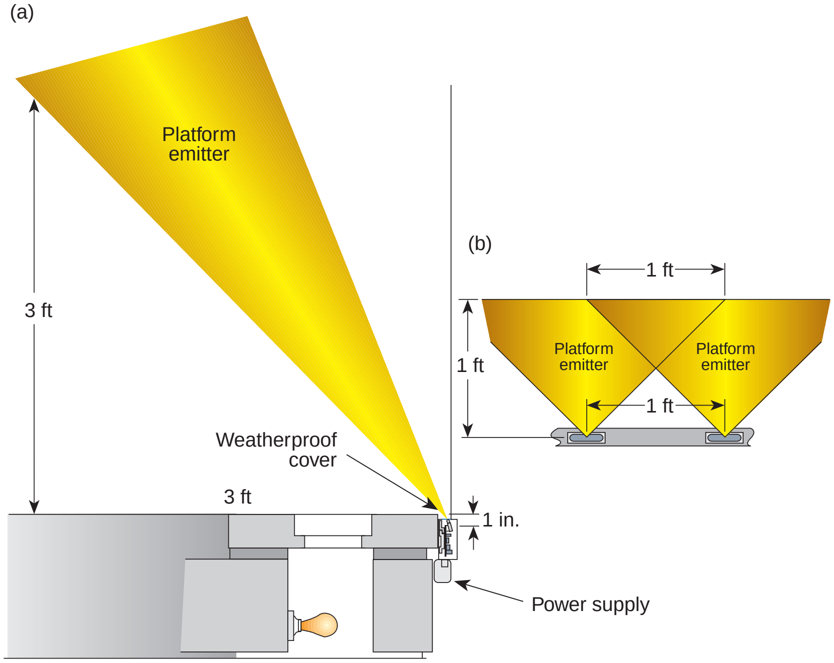

Figure 2. View of the beam from the infrared emitters mounted on the vertical rise of the platform edge. (a) A cross section of the platform (infrared light-emitting diode angle = 20–30°). (b) A view from above, looking down onto the platform. Emitter opening is shown with sealed infrared transparent cover.

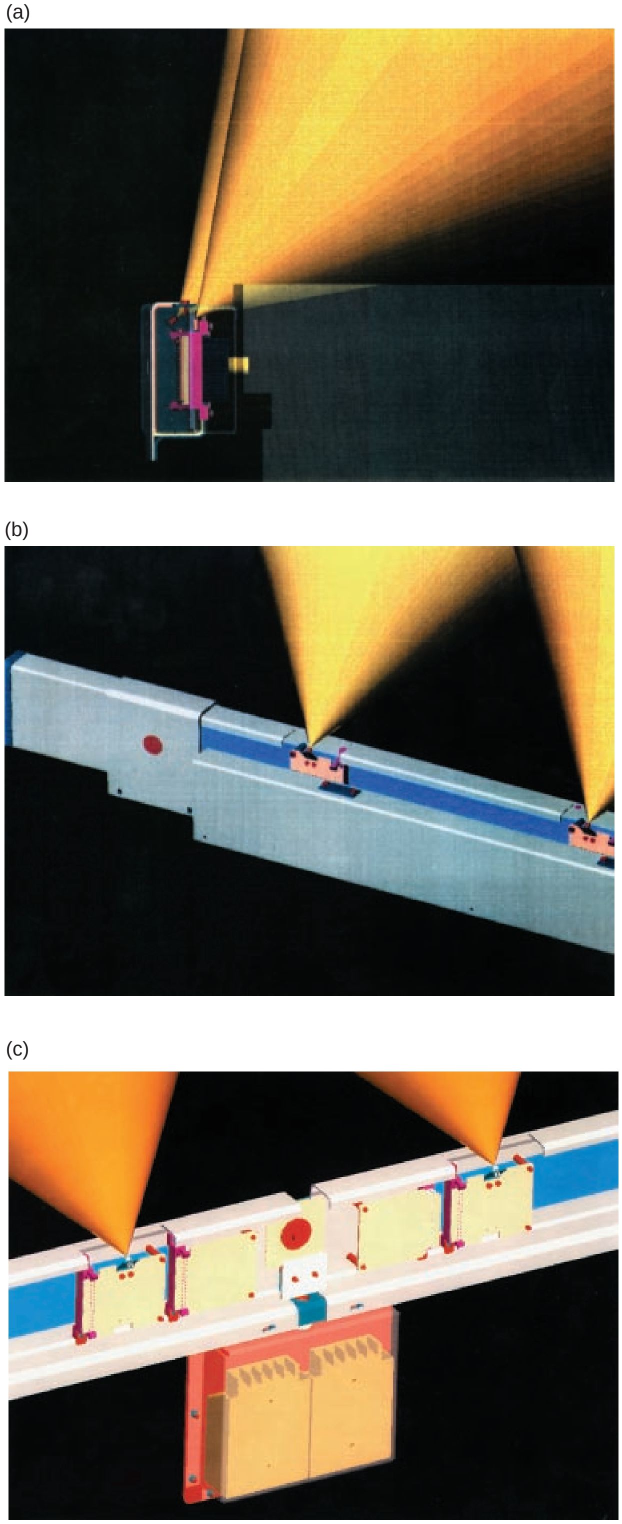

Figure 3. The platform edge emitter creates a sharply demarcated conical infrared beam that defines a clear line at a distance from the platform edge of approximately 3 to 4 ft, depending on the height above the platform at which the detector is held. This design is effective at both indoor and outdoor stations. (a) Side view over the platform edge showing angle of emitted beam. (b) View of infrared emitters from train side of platform showing beam overlap. (c) Cutaway view of emitter strip showing circuitry and power supply.

edge of up to almost 90°. The overlap design also ensures that even if one signal is blocked, another can be received. Of course, a sufficiently dense crowd of obstacles between the user and the edge could block detector reception, but in such a case, a "people barrier" would prevent someone from walking directly to the platform edge.

Indicating the location of open car doors was less straightforward than indicating the approach of a platform edge. Ideally, the platform edge emitters in front of the train car doors would send out an infrared signal modulation frequency that would cause a different tactile stimulus in a detector; however, the location of doors is not fixed in relation to a platform. In fact, the front location of a stopped train can vary by several feet, and train lengths may vary between four to eight cars. Since we therefore could not preset the locations of the train doors, we needed a door locating capability that could determine which subsets of platform edge emitters to activate.

Our solution was to place a signal emitter above each train door to provide a door-open confirmation output at a modulation frequency distinct from that of the platform emitters. WMATA trains have red indicating lights that are activated when the doors of a particular car are supposedly open. They are mounted above the middle door (each train car has six doors, three on a side, with only one side's doors open at a time) and can be clearly seen by the operator when looking back along the length of the train to check that all doors are closed, i.e., all the red lights are off. Figure 4 illustrates the overlapping regions of the infrared beams from the platform-mounted and train-mounted emitters.

The on/off state of each above-the-door red light was photodetected to activate a door-open signal. This was accomplished by on/off switching the power to the open-door signal electronics according to the state of the sensing photodetector. Thus, if a red light is not lit, none of the three open-door signal emitters on the respective side of the train can receive power, and therefore remain off. As a fail-safe measure, if a door does not open under power, a second sensor is used to verify the open-door state. This sensor is located in the door jamb such that a partially open door would prevent the door's signal from turning on. The door-open confirmation signal is therefore activated only if a door is fully opened and the door's red light is on.

Of course, the emitter signal may fail, even if the red light is on and the door opens. But a blind traveler who does not receive a door-open signal would know not to proceed. In passing, the traveler would not receive any signal at an opening that is not a door. This setup offers protection against entering a space between train cars or in front of or behind a train.

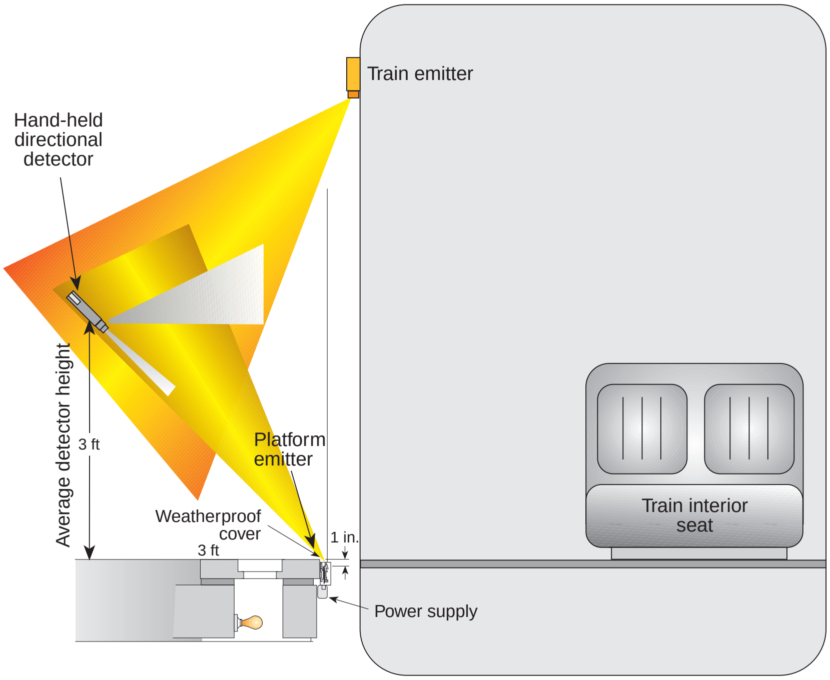

Figure 4. Cutaway view of train showing infrared beams from the platform-mounted and train-mounted emitters.

The infrared emitters used for the door-open confirmation and platform edge area detection were designed so that the same basic electronic board layout could be used for both, which allowed for a volume manufacturing and repair advantage. Separate components for clock circuitry to provide a coherent source for the infrared frequency and modulation, as well as power-source conditioning and distribution, were designed to ensure the generality of the emitter board design.

A fault indication circuit was also designed to detect any failures in the emitter. A warning light on an annunciator panel within the station's control center would alert the operator of the location of a circuit failure so that the particular emitter could be replaced with the aid of a diagnostic detector.

TOTAL QUALITY PROJECT AND WORK MANAGEMENT

Since a 100-ft-long IRIIS prototype had to be designed, fabricated, installed, and demonstrated at the L'Enfant Plaza Metrorail station within a 4-month period, we had no room for schedule slippage and very little tolerance for design error. Key to the success of this undertaking was APL's team-based work management system,[3] the APL Improvement Initiative (AIi), which is routinely practiced in the delivery of technical support services and other APL projects. The AIi is based on five guiding principles: customer focus, process improvement, measurement/benchmarking, teamwork/empowerment, and leadership. Its objectives are to increase awareness of the importance of improving work processes and systems through staff participation and to encourage all APL departments to continue efforts to empower staff to enhance quality, minimize costs, and reduce schedule time in meeting customer needs. Emphasis on Total Quality Management within the AIi[4] encourages and guides teams through processes and procedures as a routine way of doing business; the results speak to the accomplishment of the challenging objectives of IRIIS.

The IRIIS Team of 14 included APL staff from the Milton S. Eisenhower Research and Technology Development Center, the Technical Services Department, and the Business and Information Services Department. Thus, customer focus, engineering, fabrication, assembly, and acquisition were in concurrent development. This cross-departmental team with shared technical responsibility and the singular goal of meeting customer needs proved to be a productive, efficient, unifying, and synergistic structure for achieving success.

IRIIS PERFORMANCE

To assess the quality and usability of the IRIIS, the NFB organized a focus group of 20 volunteers (Fig. 5), representing a reasonable cross section of blind and visually impaired men and women. Both congenitally and adventitiously blind people were included. Some participants were young adults and others were older. Also represented were cane users, guide dog users, and those relying only on human assistance (in one instance, a person using a sign language interpreter); minorities; people with low but usable vision; people with diabetes-related blindness and associated peripheral neuropathy; members of the NFB and the American Council of the Blind as well as blind persons not affiliated with any advocacy group; and those with other sensory handicaps.

A full-scale mock-up of a subway station, called "IRIIS Junction," was built at APL. It consisted of a 30 × 10 ft platform, 3 ft above the ground (track level),

Figure 5. Participants in the focus group included cane users and guide dog users.

with a simulated granite edge and embedded lights similar to the construction of a WMATA station platform (Fig. 6). The lights were made to blink as if a train were approaching the station. A movable "train" could be boarded from the platform through a door that could open or close. The prototype IRIIS emitter strip was installed on the model platform edge, and the open-door warning emitter was installed on the model train.

The focus group participated in a three-phase plan. First, the group met and was given a detailed description of the problem and the proposed IRIIS solution. The meeting served to orient the volunteers, explain the rules for evaluation, and enable the IRIIS Team to get some immediate feedback. For the second phase, participants gathered a few weeks later at the APL mock-up station (Fig. 7). All group members were trained in the mock-up and were then observed interacting with the APL prototype as they got a feel for the system; their immediate feedback on potential performance and functional problems was noted for improvements and revisions. Finally, the focus group was assembled at the L'Enfant Plaza Metrorail station to experience the field prototype in the actual subway environment to assess its performance and utility. All three meetings were recorded on audio and video tape.

Opinions expressed during the orientation meeting varied. Some who advocated the truncated domes solution expressed skepticism and concern for the effectiveness and reliability of technological warnings. Others were very enthused about such a technological aid. In general, the basic idea of a voluntary system with

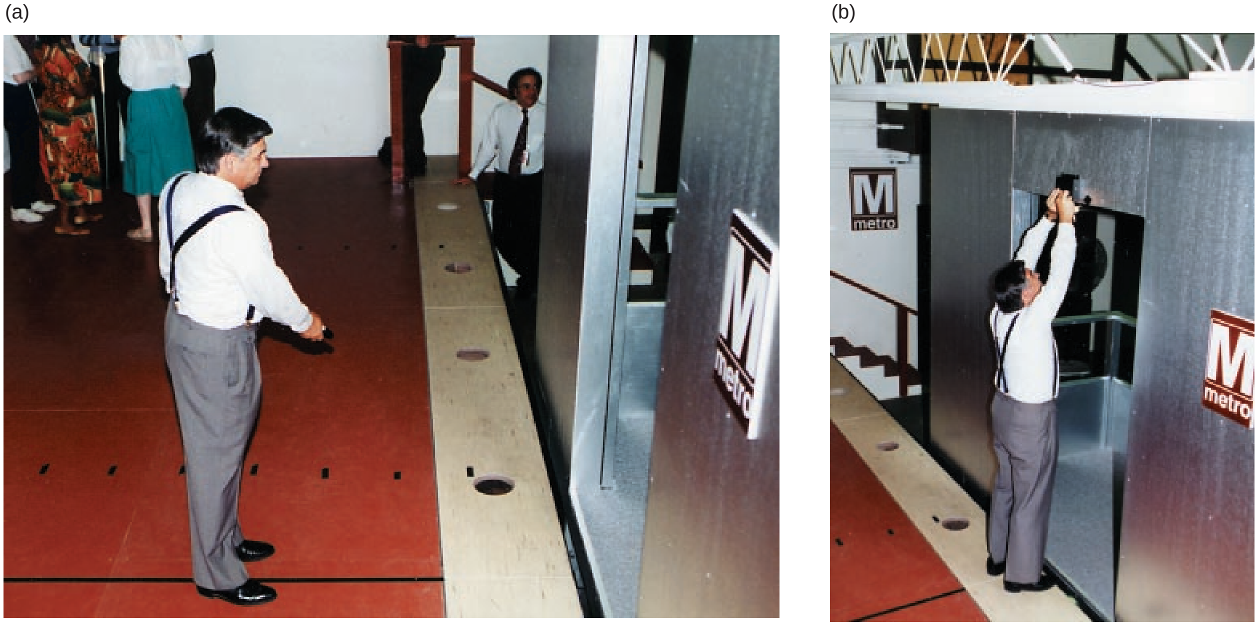

Figure 6. Joe Abita at IRIIS Junction, APL: (a) using the platform edge detector and (b) adjusting the emitter assembly for the open-door detector.

Figure 7. Focus group at IRIIS Junction, APL: (a) orientation to the system ; (b) participant using the system in conjunction with a cane.

tactile feedback was one that the focus group was willing to try and potentially support.

Subsequently, we interviewed all the volunteers regarding their experience in using the mock-up station outfitted with the IRIIS. Massof and associates from the Lions Vision Center of the Johns Hopkins Wilmer Eye Institute conducted tactile sensitivity testing over a range of vibrational amplitudes and pulse rates using a test system built at APL for that purpose. The experiment was designed to determine a lower-bound threshold over which most or all users would sense a detector's stimuli. In addition, a qualitative survey was conducted to determine user preferences for the detector options (e.g., worn on clothing or wrist, hand-carried, attached to cane or dog harness).

The focus group's consensus was that the system had high potential as an effective aid to blind travelers; for some who had expressed concerns about subway travel, the meetings served as a "confidence builder." Many participants suggested that the detector be attached to a cane rather than held in the hand; such ideas were recorded for subsequent consideration. Certain system problems were identified, and design modifications were made for the prototype installed for the L'Enfant Plaza demonstration. Results of tactile sensitivity measurements indicated that the prototype detector provided above-threshold stimuli that were readily discernible. In addition, the different stimuli for platform hazard zones and door-open states were easily distinguishable.

Many visitors and APL staff tried the APL IRIIS; a curious side note was that blindfolded, sighted users were significantly more anxious about trusting the system than the focus group volunteers. The necessity of involving blind users in the design of the IRIIS was reinforced by this observation.

As a result of the experience with the APL mock-up, the installation and demonstration at L'Enfant Plaza went very well. Small differences in train car and platform characteristics were handled by on-site adjustments to achieve desired optical and electronic performance. The overwhelming reaction of the focus group was very positive; this was a system that could benefit not only current users of the Metrorail but also the many blind people who have not yet traveled alone on the subway. The latter cohort expressed a new-found confidence level in the IRIIS.

SUMMARY

The IRIIS prototype was successfully demonstrated in the L'Enfant Plaza Metrorail station on three occasions: in November and December 1995, and again in January 1996. The first two occasions involved representatives from several organizations of the blind, including the NFB and the American Council of the Blind, and the third occasion included representatives from the U.S. Department of Transportation, the FTA, and the Architectural and Transportation Barriers Compliance Board. All of the demonstrations were well received. The WMATA decided to proceed with a second phase of the project: installation of the IRIIS, manufactured according to the APL design, along the entire Metro yellow line.

Before the design is finalized, it must undergo further extensive testing and evaluation. For example, it appeared that the car door prototype withstood the severe winter of 1996 with no problems, but this evidence of weather resistance is anecdotal and not quantified. Failure rates, mean time to failure, weather tolerance, operation of the platform edge detection system in outside stations (the L'Enfant Plaza station is underground) under normal and adverse conditions, and manufacturing tolerances are all to be determined. From the prototype demonstration, however, APL has shown that technology can meet the requirements of the ADA and address the concerns of relevant advocacy groups.

The name of our system, the Infrared Integrated Indicating System, reflects the potential extension of the concept to more general invisible information delivery and way-finding systems. The basic system concept and specific circuit designs have already resulted in the generation of three patent applications. Future versions could integrate infrared signals to produce a consistent, dynamic, tactile (and auditory, for more complex sets of information) response to provide a variety of important information. The ability to locate an edge and confirm that an opening is a doorway has already been incorporated in the prototype, but future versions could locate fare card machines and escalators, identify trains of specific lines, and convey important information to travelers with other handicaps and to foreign visitors.

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THE IRIIS TEAM

The IRIIS Team, recipients of a 1996 APL Team Excellence Award, are assembled at APL's "IRIIS Junction." (From left to right, John Sadowsky, Bliss G. Carkhuff, Ronald L. Stanford, Emily B. Morris, James F. Rider, Joseph L. Abita, Karen L. Josephson, Stephen J. Mobley, Raymond P. Aylor, Barbara A. Klem, and Samuel F. Wilderson. George A. Barney, Joseph Bohandy, and Wolfger Schneider are not shown.)