Field Testing of a Simple Adult/Child Differentiation System

June 2006

Directorate for Engineering Sciences

Randy Butturini, PE
Electrical Engineer

Jonathan Midgett, Ph.D.
Engineering Psychologist

Executive Summary

Every home contains areas or items that can pose hazards to young children. Despite the existence of both passive and active safety systems, many children die or are treated in emergency rooms each year for injuries occurring in and around the home.

A reduction in the number of incidents may be possible with additional systems that identify unaccompanied young children in areas with potential hazards and sound an alarm. Such a safety system could be designed to be always active, non-intrusive, sensitive, and flexible. These features would help alleviate problems associated with common consumer behaviors such as forgetting to enable the system or ignoring alarms from systems with a high false alarm rate. Fewer nuisance alarms may be possible if the system identifies and classifies persons as children or adults.

This report describes the field testing of one type of adult/child differentiator. A two-sensor system was designed, constructed, and installed at five sites: a daycare center, a bookstore, an indoor pool, an outdoor pool, and an outdoor water park.

Data from each field site were analyzed individually and collectively. Over 4700 detection events were recorded in more than 30 hours of field testing. The data showed that even for a simple system, no child was ever classified as an adult. Strengths and limitations for this prototype system are discussed. The potential to overcome the limitations is discussed.

TABLE OF CONTENTS

FIGURES

TABLES

1. Introduction

Unintentional injuries, such as falls, poisoning, burns, and drowning, continue to constitute a major public health problem in the United States. For people between the ages of 1 and 34, unintentional injuries (this excludes homicide, suicide, and assault) are the leading cause of death (Runyan & Casteel, 2004). Many of these injuries occur ed in the home. Part of the solution to this problem may be found in innovative applications of "smart home" technologies. *Smart homes* contain electronic layers of protection that integrate remote sensors, computers, networks, monitors, and alarms to provide homeowners with safety systems that alert them to hazardous situations forming inside their home environment. Among the many applications for smart home systems, monitoring the presence of children is especially important for potentially hazardous areas of the home. Garages, sheds, medicine cabinets and storage areas containing hazardous cleaning chemicals or building maintenance supplies, power tools or other hazards for children, could be monitored more effectively with applications of sensor technology. Swimming pools and spas especially require consistent vigilance to protect children living in the home and the child neighbors who sometimes stray into pool areas.

One of the main objections to smart home monitoring systems is that they often require regular attention from the homeowner, and because of this, can be subject to the failures associated with the normal limits of human memory and distraction. Effective safety system designs account for common human attributes, like distraction, impatience or forgetfulness (Norris & Wilson, 2003). Automatic systems that remain turned on are preferred because they work without significantly decreasing the homeowner's time and are not affected by forgetting to activate them. Effective monitoring systems also have as few false alarms as possible, better commanding the attention of the homeowner who must respond if the alarm is to be of any use at all. If a monitoring system activates easily and eliminates some false alarms, consumers may find it more attractive than cumbersome and false alarm-prone systems. All of the potential uses for and parameters of home monitoring systems are worthy of exploration. However, we present one easily-employed feature that could improve smart home monitoring systems' efficiency and attractiveness to consumers, namely, *adult/child differentiation*. A safety monitoring system that can differentiate children from adults can potentially reduce nuisance alarms and remain activated, thereby making it easier to use and less frustrating than regular intruder detectors.

One important application of a child monitoring alarm system is protecting pools and spas. Recent statistics show that an average of 280 U.S. children under 5-years old drown in swimming pools each year and in 2005, 2,100 children under 5 visited a hospital emergency room because of a submersion incident (Greene, 2006). Most submersion incidents occur in residential pools. The CPSC recommends home pools have multiple layers of protection (CPSC, 2004). The primary layer should be a barrier, such as a fence, with self-closing and self-latching gates, completely surrounding the pool. If the house forms the fourth side of the barrier, then doors leading directly to the pool area should have an alarm, or the pool should have a power safety cover.

Smart home technologies could provide additional layers of protection.

This report demonstrates a simple, prototype monitoring system that can accurately differentiate children under 5 years old from adults (17.5 years old and older) using a simple, inexpensive configuration of sensors that detect height.

We chose children younger than 5 years old because they have the highest risk for injury in unsupervised areas. Several methods of differentiating them from adults were considered in a prior study (Butturini & Midgett, 2004). A number of anthropometric and cognitive differences could serve this purpose, but height presents a large difference between adults and young children that readily available sensors can easily exploit.

The prototype adult/child differentiation system differentiated the heights of people walking through an area using off-the-shelf components: two photoelectric emitter-detector pairs set at different vertical heights, and a passive-infrared motion detector. If the lower photoelectric sensor detected someone without the upper one detecting that person, the system signaled detection of a short person, i.e. a child. If both sensors detected someone, i.e. a tall person, the system remained quiet. The main goal of the demonstration was to evaluate the ease of use and robustness of the components with real people in real environments that could potentially use such a system. We tested the prototype apparatus in a daycare center, a bookstore, and several swimming pools, both indoors and outdoors.

2. System Features

An evaluation system should contain many of the features that a fully implemented adult/child differentiator would possess in order to represent a reasonable model that is better able to predict the performance of a full differentiator system. Some full-system features, such as service life, parts reliability, system health checks, and maintenance costs were not considered during this evaluation. The important features that a field-tested adult/child differentiator should include are:

- Accuracy: The system must be capable of distinguishing adults from children. To that end, the system requires a minimum measurement accuracy. For adults and children, a 26-cm gap exists between the shortest adult and the tallest child. All of the errors associated with installation, calibration, sensor positioning, and repeatability must not result in excessive positioning uncertainty for a system to be workable.
- Portability: For field testing, the system requires portability. In practice, implemented adult/child differentiators may include permanently-installed components. For this evaluation, all the hardware needed to be portable.
- Set-up Ease: Fully developed adult/child differentiators may require professional installation (e.g., electricians). This evaluation involved temporary installation at sites where proprietors granted permission. Practical data collection over a short time at the site required a simple, quick set-up procedure.
- Non-obtrusiveness: Both the field-test system and full adult/child differentiators need to be non-obtrusive during use. Upsetting or annoying persons entering the monitored area would indicate a device that the public may have difficulty accepting.

- Walking speed: The evaluation system must be adaptable to a variety of human gaits. The speed at which a person moves through the monitored area is not indicative of their age. The system should respond correctly for speeds from slow walking to running.
- Closely spaced persons: The system should not require an excessive amount of time between events to cycle from detection processing to monitoring for the next event.
- Weather-resistance: The evaluation system should be insensitive to sunlight, stray reflections or glints, temperature, humidity, wind, water (if used near a pool or in areas with rain), or vibration, within reason.
- Continuous operation: The adult/child differentiator must be capable of monitoring an area continuously. Gaps in the coverage time of an area increase the possibility of not detecting an unaccompanied child.

Using the above criteria as a guide, a working model of an adult/child differentiator was designed and constructed to assess the ability to detect and distinguish adults from children, identify confounding factors, and evaluate the effects of unusual conditions.

3. Methods

3.1. Hardware

We chose the simplest hardware arrangement to evaluate how an easy-to-use, potentially inexpensive system would meet the performance requirements of an adult/child differentiator. Photoelectric (PE) sensors were selected because of their small size, insensitivity to external perturbations, ease of use, and rapid response. Figure 1 shows a picture of the sensor type used. The photoelectric sensors chosen consisted of separate emitters and detectors, using visible red light. This application could have used infrared sensors. However, visible emitters made aligning the sensors simpler. An installer stood at the detector location and, just by looking, determined if the emitter had power and whether the light beam reached the detector location.

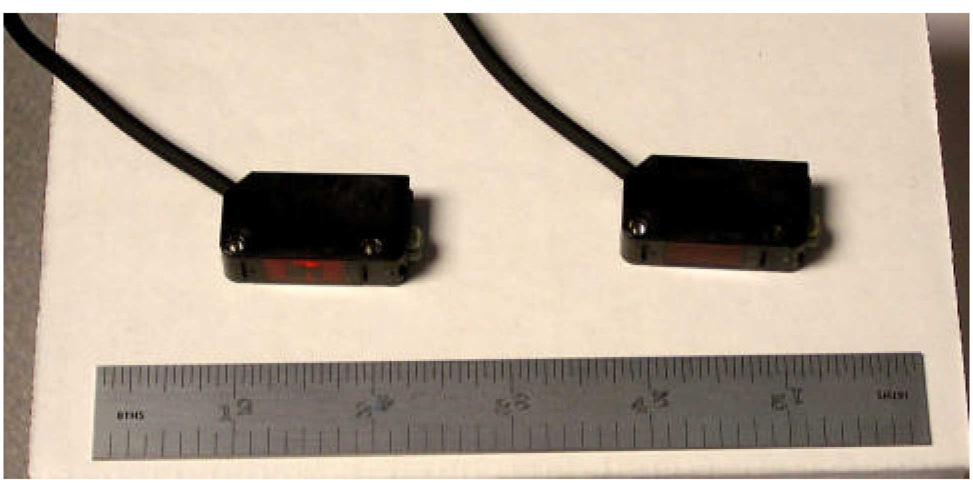

Figure 1: Photoelectric Emitter and Detector

The system differentiated adults and children by placing the photoelectric sensors at controlled heights. The upper sensor pair was positioned above the height of the tallest 5-year-old. The lower sensor pair was positioned low enough to have its beam obstructed by all passers by. The upper photoelectric sensor was installed at a height of 137 cm (54 inches). This height is higher than the maximum height of a 5 year-old (124 cm) and lower than the minimum height of a 17.5 year-old (169 cm) (Snyder, Schneider, Owings, Reynolds, Golomb & Schork, 1977). The lower photoelectric emitter sensor pair was mounted 30 cm (11.8 inches) above the ground. At this height, every person passing through broke the emitter's beam. The detector responded within 1.5 milliseconds of breaking the emitter beam. For this sensor, this corresponds to a maximum 667 Hz sampling rate.

A single passive infrared (PIR) sensor was added to assess how its detection sensitivity and nuisance alarm avoidance would compare to the photoelectric sensors. Figure 2 shows a picture of the PIR sensor with its field of view constrained (to approximately ± 5° horizontally) by black tape. The PIR sensor was not used to detect the presence of a person or object in the monitored area or to determine if the person was an adult or a child. Once the photoelectric sensors had detected the presence of a person, the PIR sensor output (triggered, not triggered) was read and recorded. The response time of the PIR sensor, at its fastest setting, was still greater than 3 seconds per detection. That value was too long for a practical adult/child differentiator. It is technologically possible to use PIR sensors instead of photoelectric sensors for a beam-breaking type of adult/child differentiator. Customization of the PIR sensor electronics and optics could quicken the sensor's response time and control its field of view. That effort exceeded the scope of this project.

Figure 2: Passive Infrared Sensor

In keeping with a simple system design, a portable mounting system was built using plastic pipe and foldable flagstand bases. The photoelectric sensors were affixed to the pipes at the aforementioned heights: both emitters on one pole and both detectors on the other pole. The separation of the two photoelectric sensors was large enough that over the length of sensor operation (specified to be at least 10 meters, or about 33 feet), the emitter's beam spread was too low to affect a detector other than the one directly across from it. The PIR sensor has a specified range of 12.2 meters (40 feet). Figure 3 shows the emitter pole (left) and the detector pole (right) with the PIR sensor at the bottom.

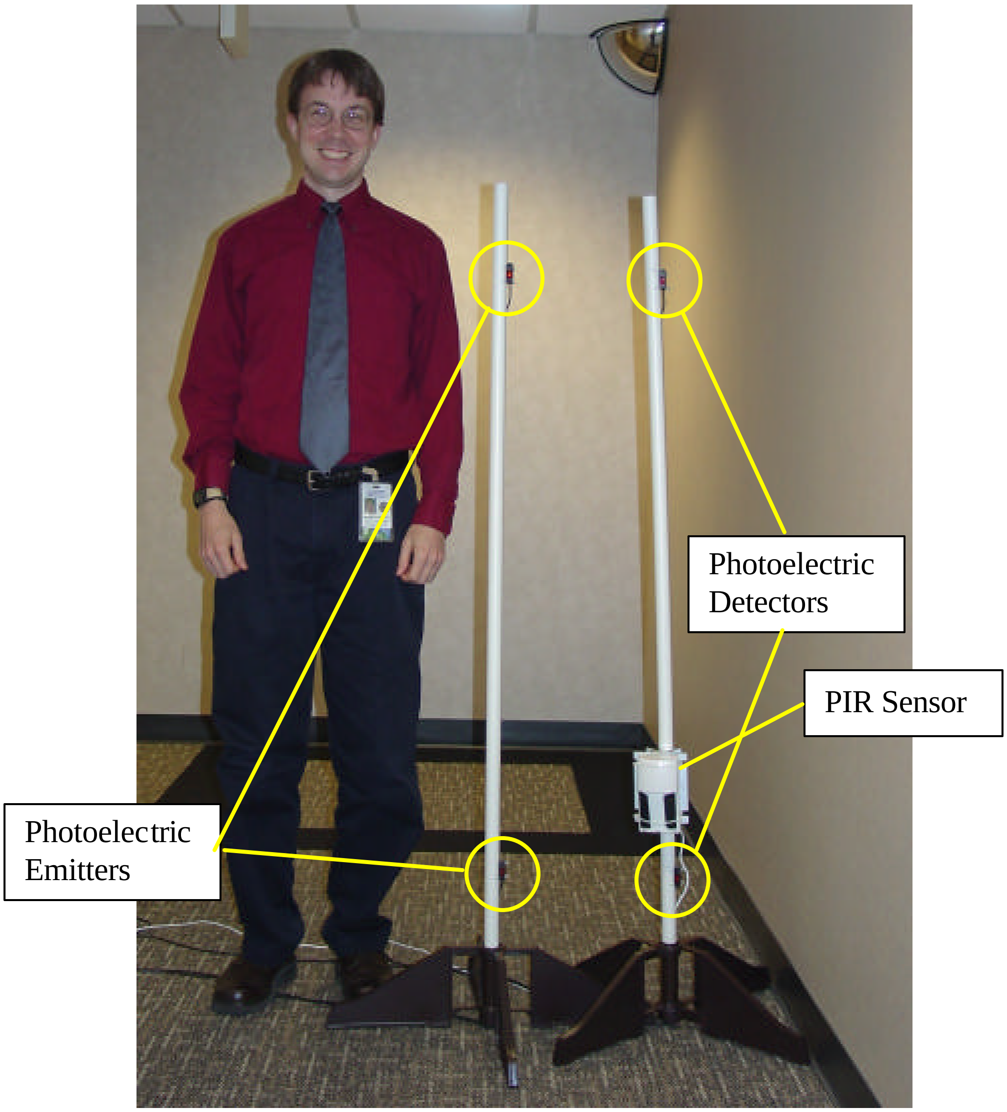

Figure 3: Emitter Pole (left) & Detector Pole with PIR Sensor (right)

The sensors used 12-volt DC power. A portable power supply and wiring supplied the power to each sensor. As a result, wires were routed across the space between the sensor poles. The wiring had two layers of electrical insulation and was covered with a wide tape to avoid a tripping hazard. A retroreflector photoelectric sensor could have been used instead of the discrete emitter/detector pair. In that design, an opposing passive retroreflector and integrated emitter/detector pair would have eliminated the need for wiring across the monitored area. We did not attempt to design a wireless system. Low-power photoelectric and passive infrared components are readily available for incorporation in such designs.

3.2. Algorithm

A personal laptop computer (PC, or laptop) running data acquisition software monitored the sensors, interpreted the sensors' outputs, and recorded the results of each observed event. An event began when the photoelectric sensor pair detected a blockage of the beam from the emitter to the detector.

During operation, the PC repeatedly polled the photoelectric sensors within a software loop. When one photoelectric sensor's output indicated that an emitter was blocked, a user-selectable sampling time began. During that sampling time, the PC continued to poll the other photoelectric sensor to determine if its emitter beam was blocked. Any sample of a sensor during the sampling time that indicated a beam blockage set the final sensor state as blocked for this event. At the end of the sampling time, the system read the PIR sensor output, and decoded the states of the two photoelectric sensors plus the PIR sensor. The possible output states are listed in Table 1.

Table 1: Adult/Child Differentiator Outputs

UPPER PE SENSOR	LOWER PE SENSOR	PIR SENSOR	OUTPUT
0	0	x	none
0	1	0	child
0	1	1	CHILD
1	0	0	'bird'
1	0	1	'balloon'
1	1	0	adult
1	1	1	ADULT

(0 = no detection, 1 = emitter beam blockage, x = don't care output)

The output of the data interpretation displayed on the PC screen in real time so that observations could be matched with the program's output. Thus, 'CHILD' represented the case where the Lower PE and PIR sensors detected a person; whereas 'child' was the case where only the lower PE sensor detected a person (this technique enabled the data collection PC and software to detect closely-spaced objects by minimizing processing resources dedicated to the display). 'Bird' and 'balloon' are the arbitrary names given to the events where the upper photoelectric sensor is blocked, but the lower photoelectric sensor never signaled a beam blockage during the sampling time.

The three sensors' outputs, the interpretation, and a time stamp were recorded for each event. The data collection program continued to monitor the photoelectric sensor outputs until both photoelectric sensors were unblocked. This signaled the end of the event. The data collection program then looped back to monitoring the photoelectric sensors for a new event. At the end of the test period, the data collection program recorded the total number of adults, children, and 'other' events.

Figure 4 shows a picture of the screen of the data collection PC with the test program operating.

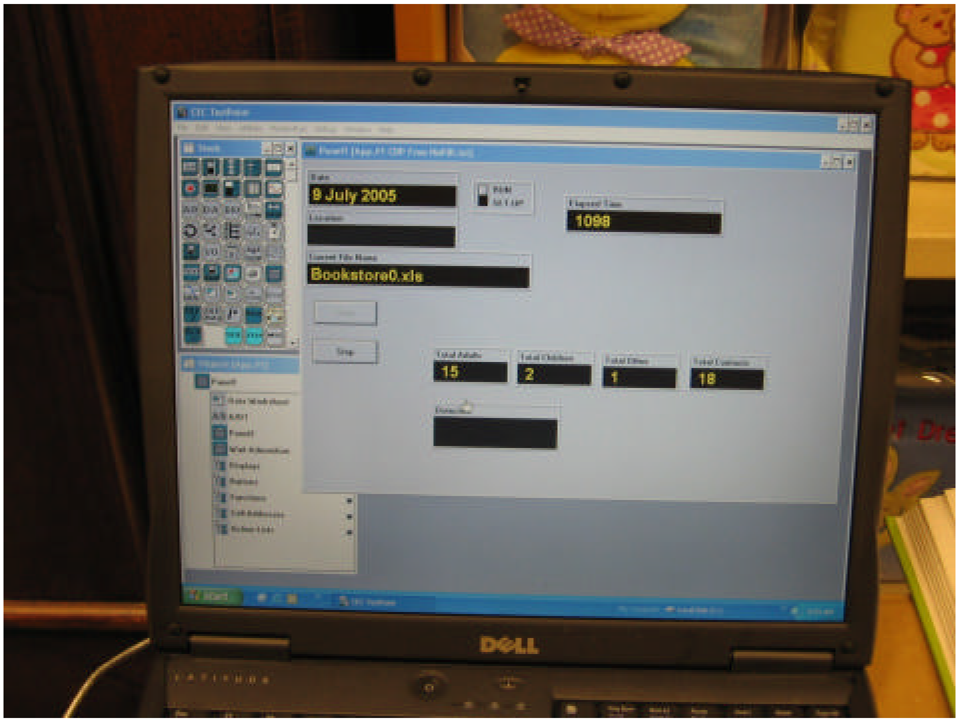

Figure 4: Data Collection Program User Screen

4. Site Selection

We searched for field sites to test the adult/child differentiator, taking into consideration several factors:

1. The site must have children 5 years-old and under present. Adults are assumed at every site.
2. The site must have a controlled access area for installation of the adult/child differentiator.
3. The site should have a reasonable number of adults and children present. Analysis of the effectiveness of a system with a very small number of observations is difficult.
4. Potential sites should include indoor and outdoor locations. This allows assessment of the operation of the system under different environmental conditions.
5. Electric power must be available to operate the sensors' power supply and the personal computer.
6. Permission of the proprietors is required before the site can be tested. No remuneration or other compensation was provided.

We chose five locations for field testing of the adult/child differentiator system. The sites selected do not represent a random sample of all the potential locations. Details about each site follow:

4.1. Daycare Center

A hallway just inside the entrance to a daycare center was selected for testing. The site consisted of a carpeted, well-lit indoor area through which all persons entering the children's areas passed. The emitter and detector poles were positioned about 2.41 meters (7.9 feet) apart. The data collection PC was installed in a room entering into the hallway. Daycare center staff, parents, children, and supply vendors with hand trucks passed through the adult/child differentiator. Figures 6 through 9 show the arrangement at the daycare center.

Figure 6: Entrance to Daycare Center from Outside

Figure 7: Entrance to Daycare Center from Inside

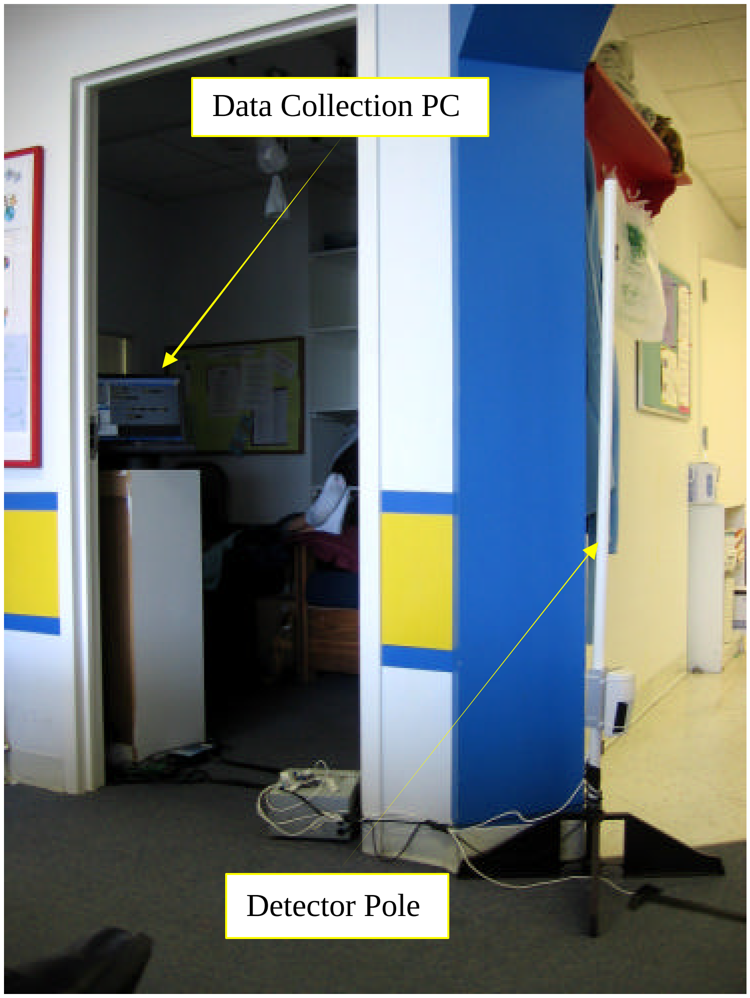

Figure 8: Data Collection PC and Emitter Pole

Figure 9: Daycare Center Hallway with the Adult/Child Differentiator

4.2. Bookstore Children's Section

A local bookstore's children's section was chosen to test the adult/child differentiator. Access to the section was restricted to one entrance at the top of an escalator. This was an environmentally-controlled indoor environment with a hard floor and fluorescent lighting. Adult shoppers with children were the only people in the area during the testing. The PC was positioned to the side of the entrance, and could not be seen until after passing between the poles. The emitter and detector poles were positioned about 5.36 meters (17.6 feet) apart. Figures 10 to 14 show the bookstore site and the positioning of the adult/child differentiator equipment.

Figure 10: Entrance to Children's Book Area

Figure 11: Emitter Pole from Ingress Side of Children's Book Area

Figure 12: Detector Pole (with PIR Sensor) Position

Figure 13: View Across Children's Book Area Entrance

Figure 14: View Across Entrance from Detectors to Emitters

4.3. Indoor Pool

The access area to a shallow pool in a large indoor public swimming area was selected for adult/child differentiator testing. Moderately low lighting was provided by fluorescent lamps situated on the ceiling of a three-story high interior. Humidity was at saturation levels and water was routinely splashed from the pools onto the walkways. The floor consisted of tiles that sloped towards several drains. The adult/child differentiator was situated between the edge of a pool in which exercise classes are held and a stairway to the upper level. The emitter and detector poles were positioned about

5.49 meters (18 feet) apart. One pole on a sloped surface had to be leveled during installation. Beyond the adult/child differentiator was a shallow pool in which swimming classes for small children were held. Figures 15 through 19 show the adult/child differentiator system at the indoor pool site.

Figure 15: Shallow Pool Access & Emitter Pole

Figure 16: Emitter & Detector Poles in Position

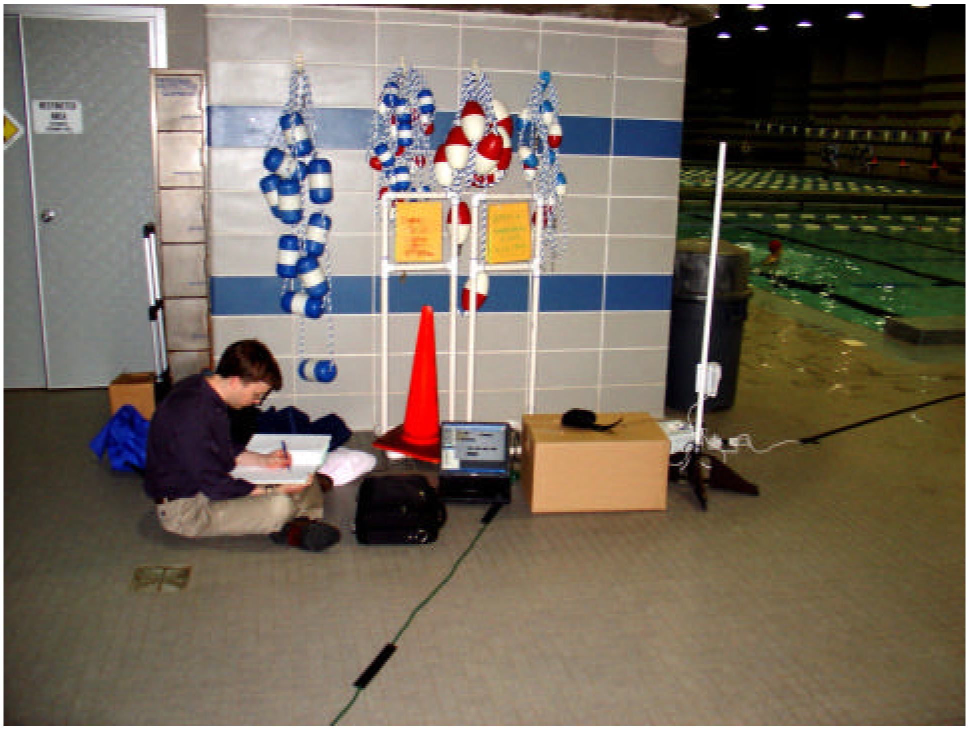

Figure 17: Data Collection PC Setup

Figure 18: View from Emitter Pole to Detector Pole

4.4. Outdoor Pool

The adult/child differentiator was installed between the clubhouse and the water at a private outdoor pool. All persons accessing the main pool or the baby pool had to pass between the emitter and detector poles. The typical patrons of the pool consisted of pool members enrolled in swimming classes or using the pool for general recreation. On the day of testing, the sky was clear and temperatures reached the low 90s Fahrenheit. The sun shone at the emitter pole front. The detector pole was positioned in direct sunlight with the back of the pole illuminated. The adult/child differentiator was installed on a concrete surface that sloped slightly, requiring a small leveling adjustment of one of the poles. The emitter and detector poles were positioned about 8.14 meters (26.7 feet) apart. Figures 19 through 22 show the adult/child differentiator system at the outdoor pool site.

Figure 19: View from Clubhouse to Baby Pool Entrance & Main Pool (in background)

Figure 20: Clubhouse Exit and Adult/Child Differentiator

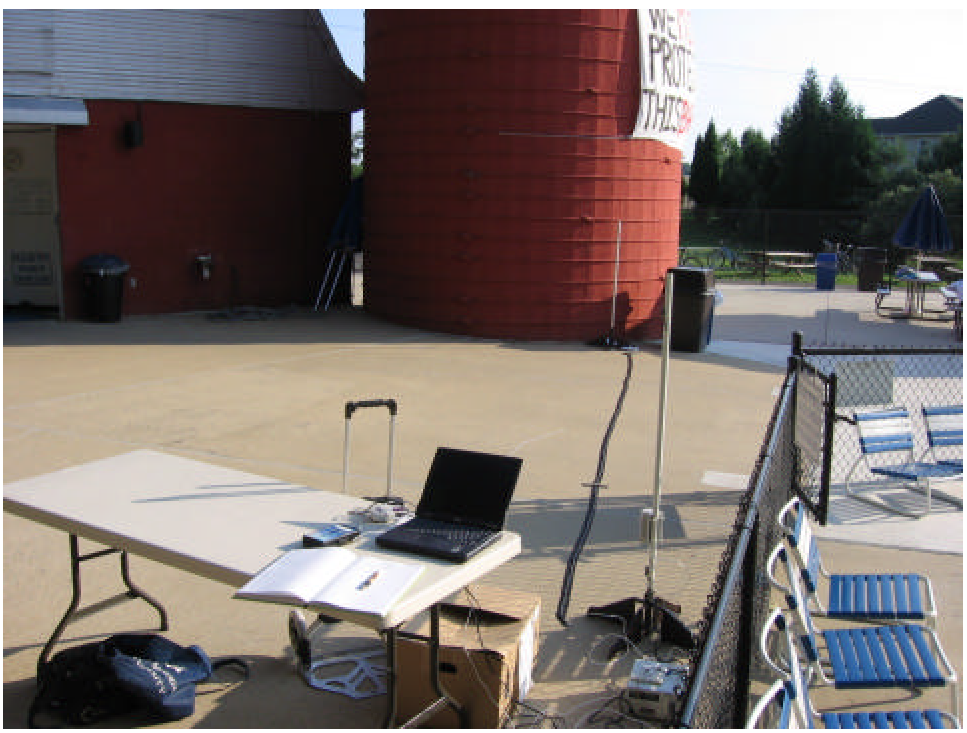

Figure 21: Emitter Pole & Detector Pole

Figure 22: Clubhouse Exit & Adult/Child Differentiator

4.5. Outdoor Water Park

A large, county-operated water recreation area was chosen for adult/child differentiator testing. This facility consists of an artificial "river," in which pumps create a current in a meandering loop, various water slides, wading pools, and multiple fountains. Families, groups, and day camp participants frequent the multi-acre facility. The adult/child differentiator was installed at the access to the two shallowest pools, including a one-foot deep "tenderfoot" pool. During the test period, the sky was partly cloudy (a brief shower occurred once), with temperatures in the middle 80s Fahrenheit. The emitter and detector poles were installed on a mostly flat concrete surface. The poles were separated by about 14.6 meters (47.8 feet). Figures 24 through 28 show the adult/child differentiator system at the outdoor water recreation site.

Figure 23: Entrance to Shallow Pool Area

Figure 24: View from Pool Area toward the Entrance

Figure 25: Adult/Child Differentiator Installation

Figure 26: View from Emitter Pole toward Detector Pole

Figure 27: Day Camp Participants at the Water Recreation Site

Figure 28: One-foot Deep Pool Area (Accessed only by passing through the Adult/Child Differentiator)

5. Results

5.1. Frequencies

The data from the five field sites were examined individually and in the aggregate. The potential performance of the PIR sensor was assessed by substituting its response for the lower photoelectric sensor (the PIR sensor was positioned near the lower photoelectric sensor). The percentage of 'other' events relative to the total number of events was calculated. Table 2 shows the results of the field tests for each site.

Table 2: Field Site Results

EVENT	DAYCARE CENTER	BOOKSTORE	INDOOR POOL	OUTDOOR POOL	WATER PARK	ALL SITES
ADULT	746	170	435	233	1534	3118
adult	65	0	6	10	219	300
CHILD	87	61	79	32	774	1033
child	5	0	5	0	201	211
Other	22	4	3	4	46	79
Site Total	925	235	528	279	2774	4741
PIR Performance	92%	100%	98%	96%	85%	89%
'Other' Percentage	2%	2%	0.6%	1%	2%	1.6%
Test Time (Hrs.)	13.8	2.3	4.4	4.9	4.7	30.1

If the lower photoelectric sensor was blocked, the event was recorded as a type of adult or child, regardless of the actual occurrence. If a crowd of people (or even two side-by-side) passed between the poles, only one event was recorded. The algorithm required that the beams from the emitters to the detectors be unblocked to avoid having a slow-moving person interpreted as a multiple of people.

5.2. Bird/Balloon Observations

At every site, some events were recorded as an 'other' condition ('bird' or 'balloon'). These events represented a blockage of the upper photoelectric emitter beam without blocking the lower photoelectric sensor within the sensing period. Typically, these events represented 2% or less of the total number. When a 'bird' or 'balloon' was recorded, the observed event (if discernable) was noted. The actions that resulted in a 'bird' or 'balloon' event included:

- One of the poles was knocked out of position. Typically, the upper photoelectric sensor lost alignment first and was sensed as being blocked. If the lower photoelectric sensor did not lose alignment within the sensing period, the event was interpreted as 'other.'
- An adult reached across or handed an object across the monitored area without crossing and blocked only the upper photoelectric sensor.
- An adult stood in the monitored area. Their legs straddled the lower photoelectric sensor while their torso blocked the upper photoelectric sensor.
- An elderly adult with a walker noticed the tape on the floor and stepped very slowly across the monitored area.

- A running adult's stride cleared the lower photoelectric sensor with both legs.
- A bird at an outdoor site appears to have flown through the upper photoelectric sensor beam.
- In several cases, no unusual incident was noticed during the passage of a person that was interpreted by the algorithm as 'other.'
- One occasion was noticed where the system registered 'other' when no persons passed through the monitored area.

5.3. System Performance

The combination of two photoelectric sensors with a simple decoding algorithm functioned reliably at each field site. Detection of single persons, whether adults or children, was accurate and repeatable. During the test periods, the following observations were made regarding system performance.

Unaccompanied children never registered as an adult in any setting. If a child preceded an adult through the monitored area, the combination of their separation and the selected sampling time determined if the event was recorded as a child or an adult. Several children together or several adults together were interpreted as one child or adult, respectively. An adult pushing a stroller or a deliveryman pushing a hand truck was interpreted as a child. This was the case where the lower photoelectric sensor beam was interrupted, and the sampling time expired before the upper photoelectric beam was broken. The algorithm waited until both photoelectric sensors were unblocked before monitoring for the next event.

If alignment was lost between the emitters and detectors for any reason, a single event was recorded, and the system would not monitor for any other events until alignment was restored.

The PIR sensor did not detect persons in the monitored area with the same frequency as the photoelectric sensors. With the PIR sensor mounted close to the ground, the sensor's field of view was limited to the legs if the person was close. Wet towels wrapped around the waist, or skirts sometimes prevented detection by the PIR sensor when the person passed through. In some instances, the PIR sensor did not activate when a fast-moving adult or child entered the monitored area. Wet persons who had just exited a pool were sometimes ignored by the PIR sensor. For some events in which the PIR did not activate when a person passed by, no apparent reason could be discerned. In contrast, every blockage of a photoelectric sensor resulted in an event being recorded.

The choice of the sampling time affected the performance of the system. At 0.1 seconds sampling time, an adult with a long stride registered as "child" then "balloon." Several other sampling errors were observed with short sampling times.

The lightweight, portable system to position the emitters and detectors made them susceptible to becoming misaligned if they were accidentally hit. A light breeze caused the poles to sway slightly, although the wind never caused a loss of alignment during the tests. Temperatures in the 90s Fahrenheit and very high humidity (at the indoor pool site) did not cause any performance diminution. The separation between the emitter and detector poles during one test was 4.6 meters (15.1 feet) greater than the maximum specified by the sensor manufacturer, again without performance loss.

5.4. Sensor Location

The system performed equally well indoors or out, in low or high humidity, in direct sunlight or shade. If something attracted persons to the line-of-sight between the emitters and the detectors, their presence often resulted in an 'other' determination. In the daycare center, the system straddled a hallway next to two doorways. As objects were handed across the monitored area, 'bird' and 'balloon' events were recorded. The wiring and tape on the floor were noticed by many persons in this setting. Placing the sensor poles in a throughway with no interesting items nearby usually resulted in more accurate determinations of adults and children. With no reason to slow down, stand in the beam, or pass an object across the monitored area without passing through, the algorithm made more accurate height assessments.

For example, the layout of the bookstore required the detector pole to be placed right next to a bookcase. As adults reached for books, the upper photoelectric emitter beam was blocked without having a person pass through. The wiring and tape were ignored by most persons entering the monitored area.

At the water park, even though the emitter pole was positioned next to a fence and a lifeguard's chair, occasionally the pole would be bumped and knocked out of alignment. At the indoor and outdoor pools, the poles were positioned well away from the paths people took to and from the water. The wiring and tape were mostly ignored by persons passing through.

5.5. Human Behavior

In the daycare center, most of the child traffic through the monitored area was during drop-off and pick-up. Many adults dropping off children appeared rushed and passed between the emitter and detector beams quickly. Sometimes, an adult carried the child into the daycare center.

In all the sites, people traveling side-by-side were common. Adult-child, child-child, and adult-adult pairs were observed. The single-dimensional differentiator system was only able to discern one person. An adult and child traveling through the monitored area were side-by-side more often than one following the other.

People could not move fast enough to be undetected by the photoelectric sensors. Even though visible light emitters were used, the beams could not be detected by people walking by unless they stopped in the line of sight from the emitter to the detector and faced the emitter pole. Occasionally, a curious adult stopped by and asked about the system. The only child to inquire about the adult/child differentiator was at the water park, and might have been prompted by an adult.

6. Discussion

With data and observations from 5 field sites, the model adult/child differentiator recorded almost 5000 events over more than 30 hours of test time. The hardware performed without malfunctioning during the testing. System set-up and initialization was quick and uncomplicated, usually taking less than 30 minutes from arrival to testing. Based on the measurements and observations taken, certain aspects of an adult/child differentiator can be addressed.

6.1. Strengths

The hardware required to construct the adult/child differentiator was inexpensive. Plastic poles with a noticeable bend were used to hold the emitters and detectors. Alignment was achieved without tools, usually in less than one minute. If a pole was knocked out of position, repositioning was simple. If the ground wasn't flat, any item placed under the low foot to raise it to approximately level, was sufficient to achieve alignment. Using a retroreflector system would have eliminated the wiring across the monitored area and could have resulted in eliminating one pole.

The system was resistant to some weather conditions. The photoelectric sensors were insensitive to sunlight and reflections. The plastic poles, flagstands, and sensors were repeatedly splashed at one pool site with no loss of operability. At another site, the wiring between the poles was accidentally doused with a bucket of water with no malfunction.

The testing showed that a portable system can achieve very high levels of operability. Lightweight, non-rigid structures were used to hold the sensors that differentiate children from adults. Accuracy to a few inches was required for the placement of the upper sensor. The lower sensor only needed to be close enough to the ground to detect all persons passing through.

The algorithm used to read the sensors and differentiate adults from children was simple and adaptable. If additional sensors or interpretation rules (such as using the length of time a sensor was blocked) were desired, they could be incorporated into the algorithm.

This system could provide a warning of an unaccompanied child in a hazardous area before the child encounters the hazard. Current perimeter pool alarms are typically installed right next to the water. Splash detector, pressure-wave alarms only respond after someone has already entered the water. This adult/child differentiator is capable of detecting a child far from the water, providing critical extra time for a caregiver to respond.

6.2. Limitations

The two photoelectric sensor system had limitations, some due to the simplicity of the design, and some due to the nature of the sensor and the algorithm. Because the algorithm waited until both photoelectric sensors were clear before terminating the processing of one event and resetting for the next event, groups were seen as one person, moving slowly. The algorithm required a minimum time where both detectors were unblocked between events. Another type of crowd (mostly observed at the daycare center) was an adult carrying a child. The model system interpreted that circumstance as a single adult.

The photoelectric sensors responded to every blockage of the beam from the emitter to the detector, regardless of whether the blockage was caused by a person. Any inanimate object, including strollers, hand trucks, laundry baskets, etc., were interpreted as adult, child, and so on (in one outdoor setting, the system responded ‘bird’ to a real bird that flew between the sensors).

The lightweight, portable system was susceptible to losing alignment between the emitters and detectors if the system was bumped. A loss of alignment was interpreted as an object blocking the beam and not moving away.

The PIR sensor required transverse motion of warm bodies to be triggered. If an inanimate object that is warmer than the background moves in the sensor’s field of view (e.g., the wind blew sun-warmed tree branches), the PIR sensor may be activated. If the motion is toward or away from the sensor, detection is more difficult.

Using PIR sensors had the potential to avoid false alarms caused by detection of inanimate, cool objects. However, an analysis of the PIR sensor compared to the photoelectric sensor showed that overall performance would have decreased if the PIR sensor output were used instead of the lower photoelectric sensor. The site with the lowest PIR performance was the water park. This was also the site at which the poles were the farthest apart. The PIR sensor specifications state that it detects warm objects up to 40 feet away. The 47.5-foot separation of the poles and the intentional constraining of the PIR field of view may have combined to limit its ability to detect persons far away.

The distance between the emitter and the detector was limited by the design of the parts. While at one site, the system functioned with the elements separated by almost 15 meters, it was apparent during setup that marginal performance conditions were being approached. For a system to operate to several tens of meters, alternate technologies may need to be used.

Similarly, the personal computer and data acquisition software were not optimized for adult/child differentiation. The test program was not fast enough to sense all persons who were very close together as they passed between the emitter and detector poles.

The presence of wiring on the ground covered by black tape affected the behavior of some of the people entering the monitored area. While most people simply ignored or shuffled their gait so as to step over the wiring, a few people stopped and examined the environment before proceeding. At one site, a few people stopped, waited, and then carefully stepped high over the wiring. One of these behaviors resulted in a ‘balloon’ detection event.

An event that was not observed but could have led to a misinterpretation of the sensor outputs would have been a child carrying a tall object. If the child passed through the lower photoelectric sensor beam, and the object broke the upper beam, that event would have interpreted a child as an adult (the hazard scenario of an unaccompanied child not triggering a response from the safety system).

No pets were encountered during the testing. If a medium-sized dog passed between the emitter and detector poles, it would probably be sensed as a child. This response would have increased the false alarm rate.

The adult/child differentiator system did not consider several design features that a commercially-available product should possess. Reliability, cost, maintenance, failure detection, backup power, anti-tampering features, etc., are some of the aspects that should be considered.

6.3. Potential to Address Limitations

Not distinguishing children in groups is not a limitation per se, unless it is important to count the number of adults and children that entered an area with the potential hazard. Similarly, an adult carrying a child is a type of group, and may not be important if the intent is for the system to detect unaccompanied children.

Photoelectric sensors could be combined with PIR sensors to lessen the sensitivity of the photoelectric sensor to every opaque object that blocks the beam from the emitter to the detector. Decoding software could require that the photoelectric sensor beam be blocked for a minimum amount of time before declaring that an object is in the monitored area. More than the minimum two sensors may be used in an adult/child differentiator system. The extra sensors could be used to verify other readings or to determine a person's direction of travel (toward or away from the potential hazard).

If the emitters and detectors of an adult/child differentiator system are positioned to the sides of the normal traffic areas, unintentional contact should be minimized. Non-portable systems could be securely fastened to a rigid support.

The ability of the PIR sensor to detect people in the monitored area could be increased by repositioning the sensor vertically so that a person's torso must pass through the sensor field of view, not just their legs. Establishing a minimum distance from a person to the PIR sensor would put a larger portion of a person's body in the sensor field of view.

Using software and digital hardware customized to adult/child differentiation would address most of the limitations observed with system response times. Real-time data collection systems and digital components that are application-specific are readily available.

The use of wireless, low-power components could conceivably eliminate the need for wires to stretch between the emitters and the detectors.

If an adult/child differentiator system needed to distinguish a child with a tall object, the system must be able to tell the difference between a tall object and an adult. PIR sensing devices with a field of view coincident with the upper emitter/detector sensor pair may be used to determine if the object blocking the beam is a warm body. This would address some of the possible scenarios regarding children carrying objects.

To photoelectric and PIR sensors, pets appear similar to small children. If pet access to a monitored area was allowable, perhaps an electronic tag could be attached to the pet's collar that would inform the adult/child differentiator of its presence.

6.4. Additional Features

Two photoelectric sensors with a 10-meter range were capable of differentiating adults from children under certain conditions. Additional features for an adult child differentiator may include the means to:

- Determine the direction the person in the monitored area is moving. Is the person moving toward or away from the potential hazard?
- Count the number of people in a monitored area to assure that all children are accompanied by at least one adult. This would assist in detecting the presence of an unaccompanied child near a potential hazard.
- Detect and ignore pets to decrease the potential nuisance alarm rate.
- Use wireless components to simplify installation and avoid the use of wires across the walking path.
- Expand one-dimensional adult/child differentiator to include differentiation on a perimeter basis. For example, a differentiator could be expanded to include all sides of a pool.
- Screen more precisely between children 5 years-old and younger, and older persons so that adolescents are not sensed as children. This would tend to reduce the nuisance alarm rate
- Screen out objects, such as strollers, hand trucks, and other inanimate articles before triggering a false alarm.

With the addition of improved algorithms and hardware, many of these features could be implemented.

6.5. Alternate Locations

The two-sensor adult/child differentiator was tested in the entrance to a daycare center, at a bookstore, and at three swimming pools. The concept of adult/child differentiation could be applied to any location where adults are normally permitted, and young children are not allowed. Adult/child differentiators could find uses at these places where potential hazards exist for unaccompanied children:

- Fireplaces while a fire is burning
- Storage cabinets for hazardous chemicals
- Workshops with power tools
- Kitchen ovens and cooktops, while in use

It is conceivable that a portable adult/child differentiator could temporarily monitor an area (such as an oven) while the hazard (hot surfaces) is present. Once the potential hazard is removed, the monitoring system could be turned off and stored until next time. The utility of such a system would depend on many factors, including ease of use, cost, flexibility, and reliability.

7. Conclusions

A simple adult/child differentiator has been shown to effectively discriminate young children from adults under certain conditions. Several possible ways to improve the system's performance have been identified. The field test data in this report demonstrated the concept of an electronic layer of protection that could, at a simple level, decide if the person entering the monitored area faced a potential hazard that required sounding an alarm.

Physical barriers (fences, locked doors, etc.) remain the most effective layers of protection around a potential hazard. However, electronic layers of protection can add additional safeguards that help protect people from injury or death. Ultimately, the added safety value perceived by the user must compare favorably with the added cost and complexity of an electronic layer of protection to result in its effective use.

8. References

Butturini, R. & Midgett, J. D. (2004). Designing Sensor Systems Capable of Differentiating Children from Adults. Washington, D.C.: U. S. Consumer Product Safety Commission.

CPSC (2004) *Safety Barrier Guidelines for Home Pools.* Washington, DC: U. S. Consumer Product Safety Commission, Publication 362.

Greene, M. (2006). *2006 Annual Drowning Memorandum*, Washington, DC: U.S. Consumer Product Safety Commission, May 5.

Norris, B. & Wilson, J. R. (2003). Preventing drowning through design – the contribution of human factors. *Injury Control and Safety Promotion*, 10, 4, 217-226.

Runyan, C. W. & Casteel, C. (Eds.)(2004). The state of home safety in America: Facts about unintentional injuries in the home. 2nd Edition. Washington, D.C.: Home Safety Council.

Snyder, R. G., Schneider, L. W., Owings, C. L., Reynolds, H. M., Golomb, D. H. & Schork, M. P. (1977). *Anthropometry of infants, children, and youths to age 18 for product safety design*. Report prepared by the Highway Safety Research Institute. Washington, DC: U.S. Consumer Product Safety Commission.