Discrimination of Children from Adults In Safety Systems

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Executive Summary

Every home contains areas or items that can pose hazards to children 5 years old and younger. Despite the existence of both passive and active safety systems, thousands of children die or are treated in emergency rooms each year for injuries associated with window falls, swimming pool submersions, and exposure to hazardous substances.

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. Fewer nuisance alarms may be possible if the system identifies and classifies persons as children or adults. Such a safety system could be designed to be always on, non-intrusive, sensitive, and flexible. These features would help alleviate problems associated with common consumer behaviors such as forgetting to arm the system or ignoring alarms from systems with a high false alarm rate.

This report describes some characteristics of a system that discriminates between children and adults. An anthropometric analysis identifies factors amenable to adult/child identification. Differences in height, foot length, and cognition (literacy in this study) were evaluated as means of determining whether a person entering an area is an adult or a child. The testing showed that simple sensor systems are capable of acquiring data adequate for such discrimination.

A discussion of the requirements of a discriminator system and different sensor combinations' effects on overall performance is included.

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1. Introduction

Every home contains areas or items that can pose hazards to children. Medicine cabinets or cabinets containing strong cleaning fluids, workshops with power tools, windows, fireplaces; all of these sites can contain chemical, trauma, burning or other dangers to children who may be unaware of the potential hazards. In 2002, over 1.2 million reports of exposure to hazardous substances in children 6 years old and under were recorded[1]. In 1999, over 3000 children 5 years old and younger were treated in U.S. hospital emergency departments for injuries associated with window falls[2].

Outside the home, swimming pools are an obvious example where unattended children face a risk of injury or death. From 1999 through 2001, swimming pools in the United States were associated with an annual average of 242 drownings of children under 5 years old[3]. In addition, approximately 1800 children under 5 were treated in U.S. hospital emergency rooms following swimming pool submersion incidents in 2003, primarily in residential settings.

Various techniques have been employed to prevent unsupervised access by young children to areas where potential hazards exist. Locked doors, self-closing and self-latching gates, fences, and cabinet latches are examples of such safety systems. In each, a physical barrier is imposed between the potential hazard and unauthorized persons. Other systems can include motion detectors, pool alarms (e.g., perimeter alarms and water disturbance alarms), or door alarms. However, some of these systems require manual activation and are susceptible to false alarms when inadvertently activated by adults. Failing to remember to activate a safety system, or activating a limited system may lead to a false sense of security on the part of a child's caregiver. In addition, a high nuisance alarm rate may lead to frustrated adults disabling the system for extended periods.

The persistence of deaths and injuries to unaccompanied children in areas with potential hazards (often with installed safety systems) highlights the need for additional safety efforts. For the circumstances listed above, the hazard scenario is the presence of a child in an area with no adult supervision in the same area. A safety system that responds only to the unsupervised presence of a young child has the potential to avoid the problems associated with manual activation and high false alarm rates. Several technologies have been developed to detect people. The techniques range from detection of infrared emissions from warm moving bodies to acoustic sonar to pressure switches that respond to a footstep. However, discrimination of children from adults (or the presence of children when no adults are also present) has not been widely implemented. This report

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[1] Watson, William A., Litovitz, Toby L., Rodgers, George C., *et al*, *2002 Annual Report of the American Association of Poison Control Centers Toxic Exposure Surveillance System*, The American Journal of Emergency Medicine, Volume 21, Number 5, September, 2003.
[2] Adler, Prowpit, *Window Fall Related Incidents*, U.S. Consumer Product Safety Commission, April 5, 2000.
[3] Sweet, Debra, *2004 Annual Drowning Memorandum*, U.S. Consumer Product Safety Commission, May 6, 2004.

details a study into some of the characteristics of a child discrimination system. Implementation of child discrimination into a safety system may help reduce the number of injuries and deaths associated with areas in the home that pose a hazard to unaccompanied children.

2. Project Description

In 2004, U.S. Consumer Product Safety Commission (CPSC) staff initiated a project to study the differences, in quantitative terms, between children and adults, and identify some of the system requirements for potential monitors capable of discriminating children from adults. For this study, effectively identifying children 5 years old and younger is the most important goal, because children this young are the most vulnerable. Detecting their presence and discriminating them from older children, teenagers and adults is the challenge. Determining that adults are present is necessary for systems monitoring areas where adult supervision is a requirement.

Anthropometric features such as height, weight, body proportions, foot size, etc., are parameters that were considered for sensing and determining if a person within a system's monitoring area is a child or an adult. The characteristics that are the most robust, and how many may be required for an acceptably low error rate, are addressed.

Based on the factors identified by the anthropometric evaluation, a search was made for sensor technologies capable of measuring those factors. A variety of sensor types were examined with the intent of identifying multiple ways to discriminate children from adults. Readily-available products were selected to show that existing components are capable of being used in novel applications. New sensor types or refinements to easily-obtainable designs could improve the performance of a system but are not necessary to demonstrate the fundamental concepts of the techniques.

System-level considerations to use in developing a working monitor/discriminator are discussed. Various combinations of sensor monitors are presented.

3. Anthropometric Differences Between Children and Adults

While sensors are commonly used to provide information about the presence or absence of a person in an area, such as in burglar alarms, discriminating one type of person from another adds considerable complexity to a detection system. Discriminating children from adults requires a system to screen information and select appropriate factors, either singly or in combinations, which results in an adult/child determination. A number of possible human factors were considered (see the Appendix) to discriminate children from adults. Physical, neurological, and cognitive factors exist that could serve for this differentiation. However, because humans vary so much, some large children could pass for small adults when only a single factor is considered. This might lead to a child fooling the discriminator and entering a hazardous area unsupervised, or it could lead to nuisance alarms. Parameters with large differences between adults and children are most likely to effectively discriminate between children and adults. Thus, from the possible anthropometric features that may be sensed by a discriminator system, the factors selected for further testing with current sensor technologies (see Table 1 below) represent relatively large differences between children and adults; but they are not the only factors that system designers may choose. For this evaluation, adults are considered to be 17.5 years old or older.

Table 1: Child Discrimination Parameters

FACTOR	MEAN 4.5-5.5 YEAR OLD	MAXIMUM 5.5 YEAR OLD	MEAN 16.5-17.5 YEAR OLD	MINIMUM 17.5 YEAR OLD
Height	108 cm	124 cm	169 cm	150 cm
Foot Length	17.0 cm	20.2 cm	25.0 cm	20.8 cm
Literacy	Rudimentary	Beginning literacy	Literate	Literate

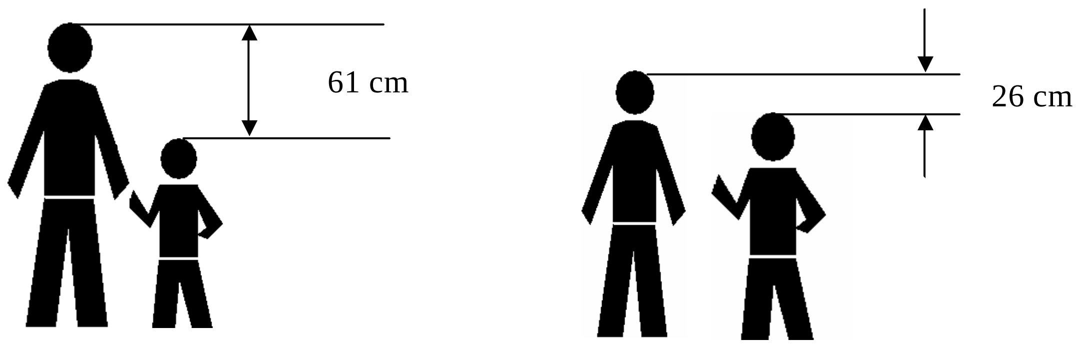
FACTOR	DIFFERENCE BETWEEN AVERAGE CHILD AND AVERAGE ADULT	DIFFERENCE BETWEEN LARGE CHILD AND SMALL ADULT
Height	~61 cm	~26 cm
Foot Length	~8 cm	~1 cm
Literacy	Multi-syllabic words/fluency	n/a

Height shows the largest difference between average children and average adults. Extremely short adults and extremely tall children may show some overlap, but this factor seems to present a low likelihood of giving a false alarm. Foot length requires a finer sensor reading. However, foot length differences seem large enough between average children and average adults for straightforward sensing. Additionally, the cognitive factor of reading ability was selected. While literacy itself is not sensed by an electronic system and so may not seem like a "sensor system," a system that uses literacy as a discriminator requires a sensor to detect the presence of an intruder. It fulfills the objective of a child discrimination system and requires very little hardware sophistication. Children under the age of 5 may be able to decode small words and letters, but advanced literacy is very unlikely during early childhood.

These three maturational differences between children and adults – height, foot length, and literacy – were selected to demonstrate the use of current sensor technologies for protecting children from hazardous environments.

4. Height Detection

Heights of adults and children have a substantive range where they do not overlap. The anthropometry tables (see Appendix) report a maximum height of a 5.5-year old at 124 cm (49 inches), while the minimum height of a 17.5-year old is 150 cm (59 inches). A height-measuring system can exploit this gap to determine if the person entering a monitored area is a young child or an adult. Figure 1 below illustrates the adult-child height differences.



Average Adult and Average Child **Minimum Adult and Maximum Child**

Figure 1: Height Differences Between Adults and Children

There are numerous ways to measure the height of a person. Three non-intrusive sensing techniques were chosen to illustrate this form of child discrimination: acoustic, photoelectric, and passive infrared.

4.1. Acoustic Sensing

Acoustic sensing involves using an ultrasonic transducer to emit sound waves in pulses, then timing the echoes from the pulses to determine the distance from the sensor to the target. With a known speed of sound in air, the distance from the transducer to the target is linearly proportional to the time delay between the outgoing and returning sound waves.

Using sonar in air to measure height holds promise as a child discriminator technology due to its precision, its non-invasive nature, and (for some designs) its range of operation. Height is measured by mounting the sensor in a downward-facing orientation. As persons walk underneath, the sensor output changes in response to the distance from the first echo with an amplitude above a preset magnitude. Presumably, the highest measured height (the shortest distance from the sensor to the target) is the top of the person's head.

Since the speed of sound in air is a function of temperature (and density, thus humidity to a lesser degree), monitors in areas with large temperature changes may need to correct the sensor readings after calibration to maintain the desired accuracy of the system.

4.1.1. Sensor Setup

A standard industrial sensor was chosen to demonstrate the ability to use acoustic sensing to measure height. Figure 2 shows a picture of the acoustic sensor as mounted.

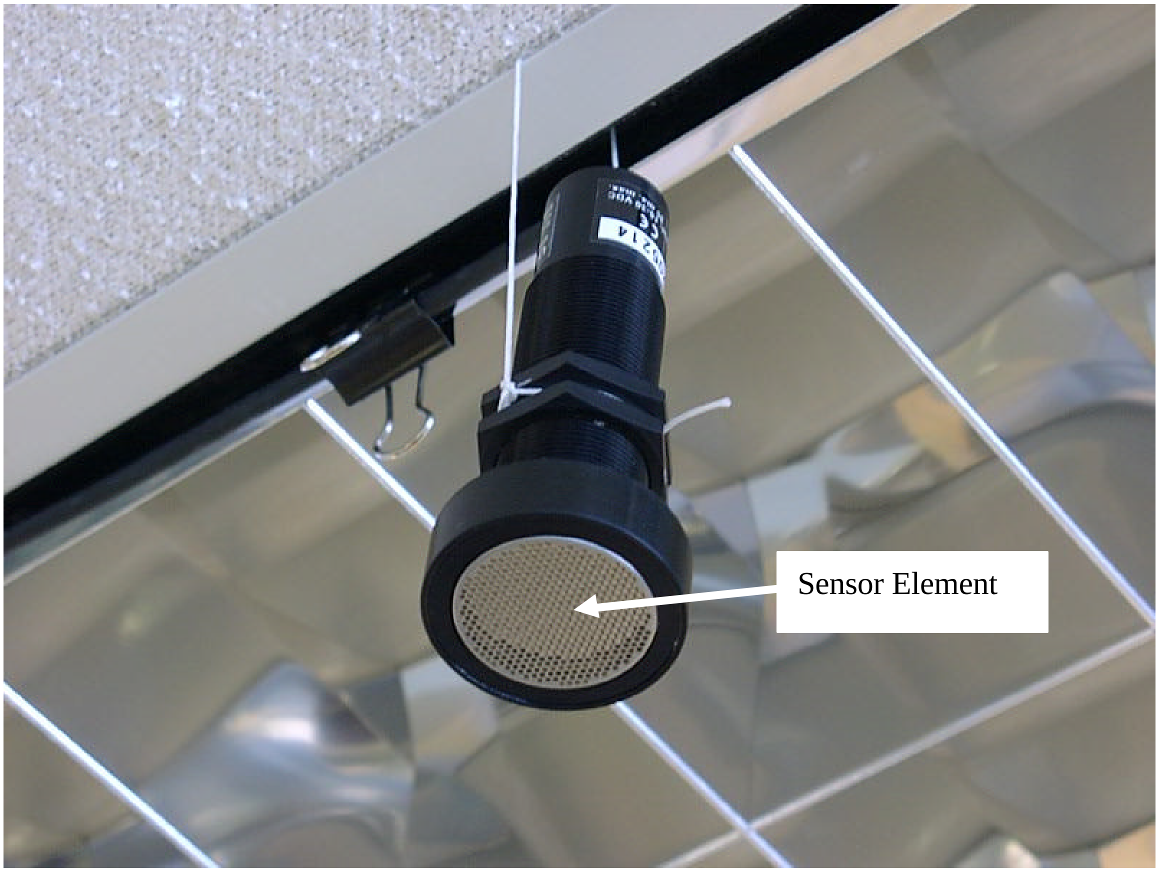


Figure 2: Acoustic Sensor

The sensor emits 20 pulses/second at a 50 kHz frequency and is insensitive to receiving sounds at frequencies other than the emitted value. The pulsed pressure waves diverge at about a 15º angle (± 7.5º from the perpendicular) from the face of the sensor. Thus, echoes from an expanding cone are capable of being detected. Figure 3 illustrates the monitored area underneath the sensor. The vertical resolution of this sensor is specified as 2 mm (0.078 inches). With a maximum range of 4.57 meters (15 feet), this device is capable of being mounted well above the head of anyone passing underneath.

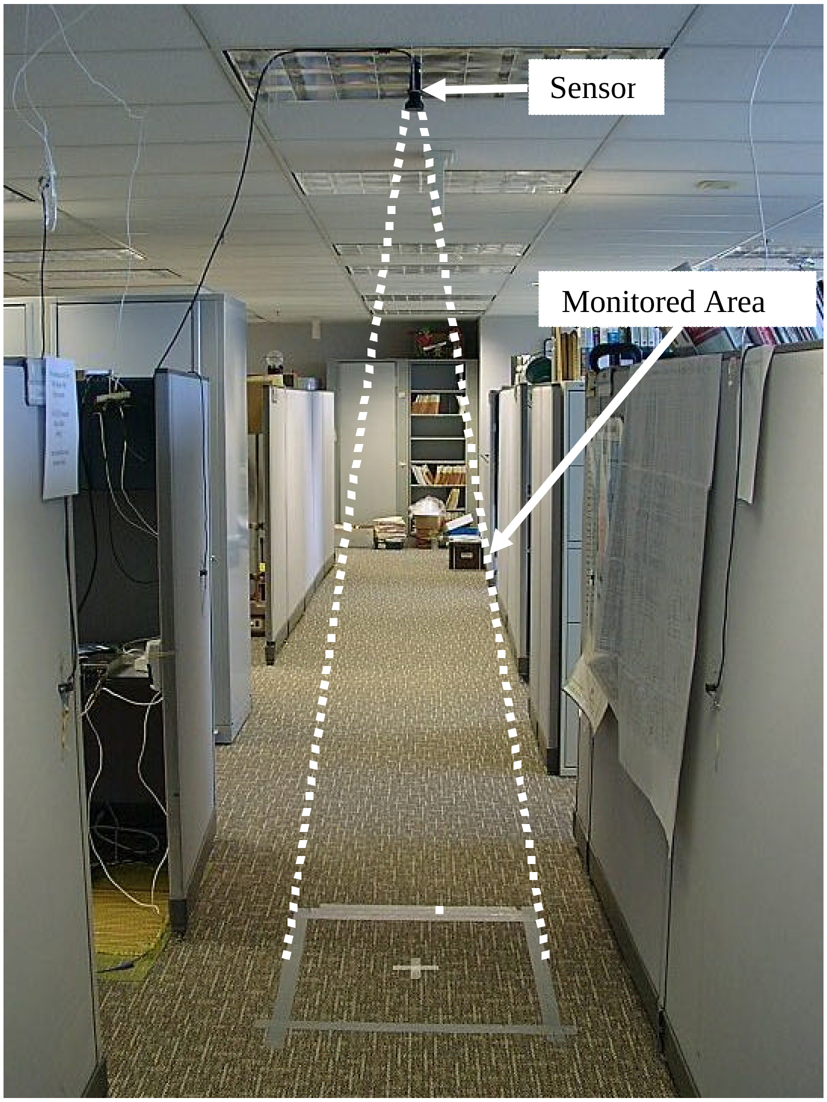


Figure 3: Acoustic Sensor Detection Area

Once the sensor was installed, a simple calibration procedure established the sensor output corresponding to the ground and a maximum height (238 cm, or about 94 inches) for this installation. Subsequent readings were linearly scaled to determine the height of the target object. A personal computer with data collection software was used to collect the sensor readings and calculate the height.

4.1.2. Sensor Operation

Sets of measurements were collected to establish the operability of the acoustic sensor. Once the function of the sensor was established, walking tests were conducted to determine sensor performance with moving persons.

A target with a flat, hard surface was placed perpendicular to the axis of the sensor at various heights. Forty readings were collected at each height and analyzed statistically. Table 2 below contains the results of the static height testing. The nominal height of the target was established with a tape measure. The measured height was calculated from the sensor readings. The accuracy and precision of the acoustic sensor were consistent except for a slightly greater variation at the very lowest heights (closest to the floor). A close examination of the 69-cm data showed a slight offset in the readings that was attributed to the data collection hardware.

Table 2: Static Height Measurements
All measurements are in cm (inches)

NOMINAL HEIGHT	MEASURED HEIGHT	STANDARD DEVIATION	RANGE (MAX-MIN)
3.2 (1.25)	2.5 (1.0)	0.14 (0.06)	0.52 (0.20)
31 (12.25)	31 (12.1)	0.015 (0.006)	0.074 (0.029)
69 (27)	68 (27)	0.36 (0.014)	0.15 (0.059)
91 (36)	91 (36)	0.18 (0.007)	0.09 (0.035)
122 (48)	121 (48)	0.18 (0.007)	0.10 (0.038)
152 (60)	152 (60)	0.025 (0.01)	010 (0.044)
183 (72)	182 (72)	0.023 (0.009)	0.11 (0.041)

(Note: Some values may be different due to rounding)

To assess the edge detection ability of the sensor, two cardboard boxes were pulled through the monitored area. A 32-cm and a 70-cm tall box were passed underneath the sensor at about 1 inch per second. As seen in Figure 4, the leading and trailing edges were quickly detected. Interestingly, the sensor reported a slightly lower reading at the edges than the actual box height.

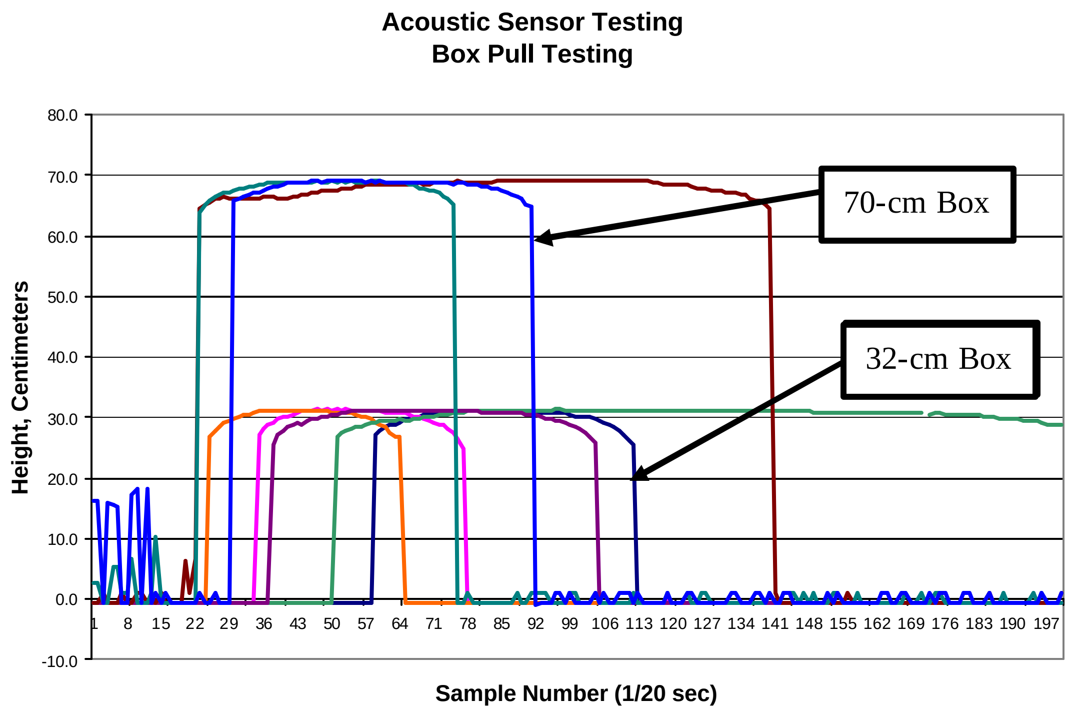


Figure 4: Edge Detection Performance

Performance with different materials at varying tilt angles was evaluated to determine the sensor's ability to detect a target that is not perpendicular to the sensor. Since an echo is required for detection, a material that reflects the sound pulses away from the sensor would not be perceived. Figure 5 is a picture of the testing apparatus with the tilt angle depicted. Table 3 lists the maximum tilt angle at which a target could be detected for Plexiglas, closed-cell foam rubber, cotton duck cloth, terrycloth, and polyester batting (a material commonly used in plush toys). The hard, flat Plexiglas and the foam rubber were detectable at tilt angles up to 12 degrees. The cotton duck could be detected at angles up to 23 degrees. The terrycloth was detected at angles up to 45 degrees. The polyester batting was acoustically transparent, regardless of its thickness or angle of incidence to the sensor.

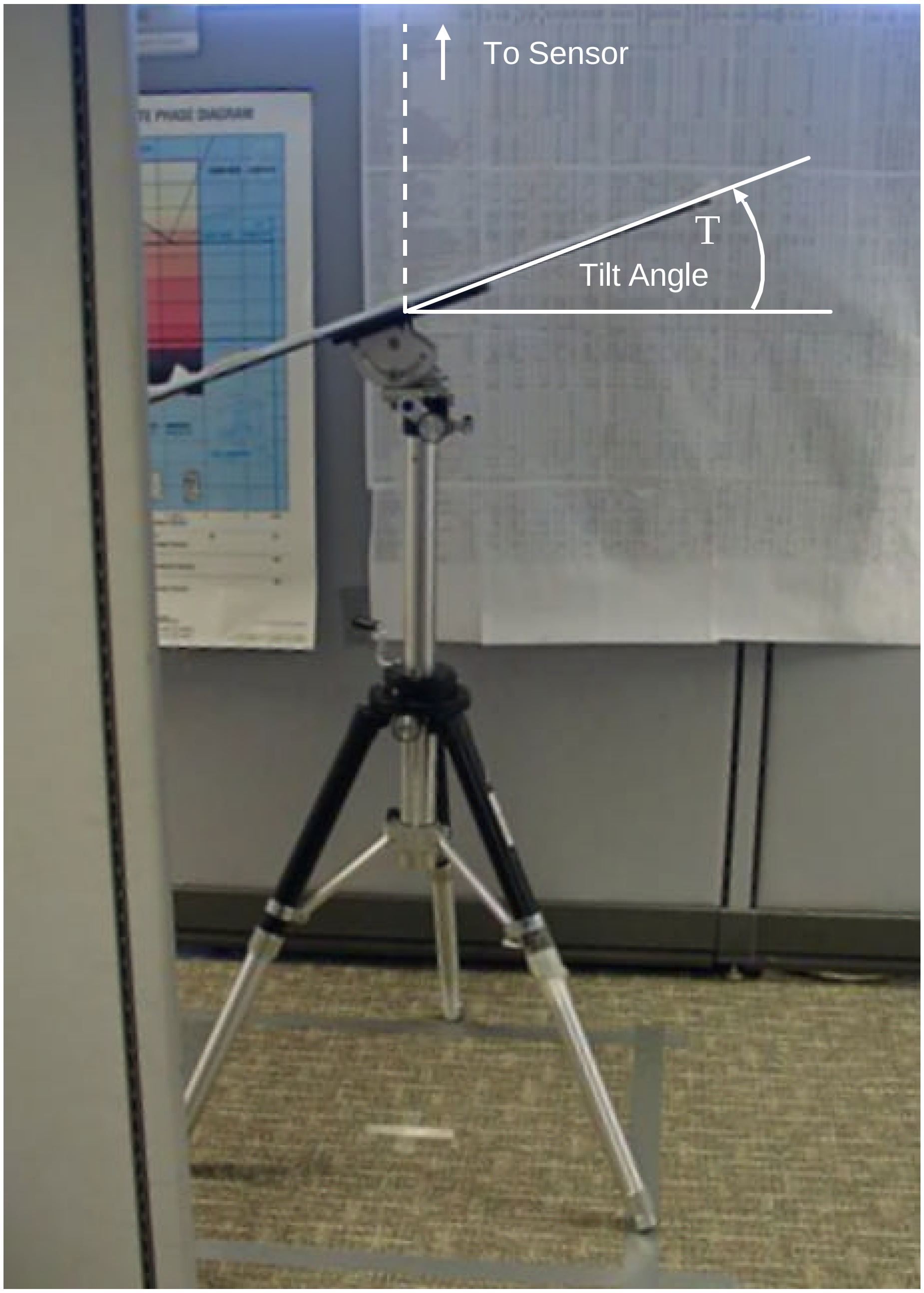


Figure 5: Tilt Testing Setup

Table 3: Acoustic Sensor Tilt Response
All measurements are in degrees

Material Tested	Maximum Angle
Plexiglas	12
Terrycloth	45
Cotton Duck	23
Foam Rubber	12
Polyester Batting	0

The pulses emitted from the sensor expand in a conical pattern with decreasing intensity as the off-axis angle increases. Targets close to the sensor vertically can only be detected in a small horizontal zone. At distances further from the sensor, the detection zone is wider. Figure 6 shows the ability of the sensor to sense an edge at different heights. The limit of each height's off-axis displacement represents the position at which a returning echo exceeded the sensor's threshold for target detection.

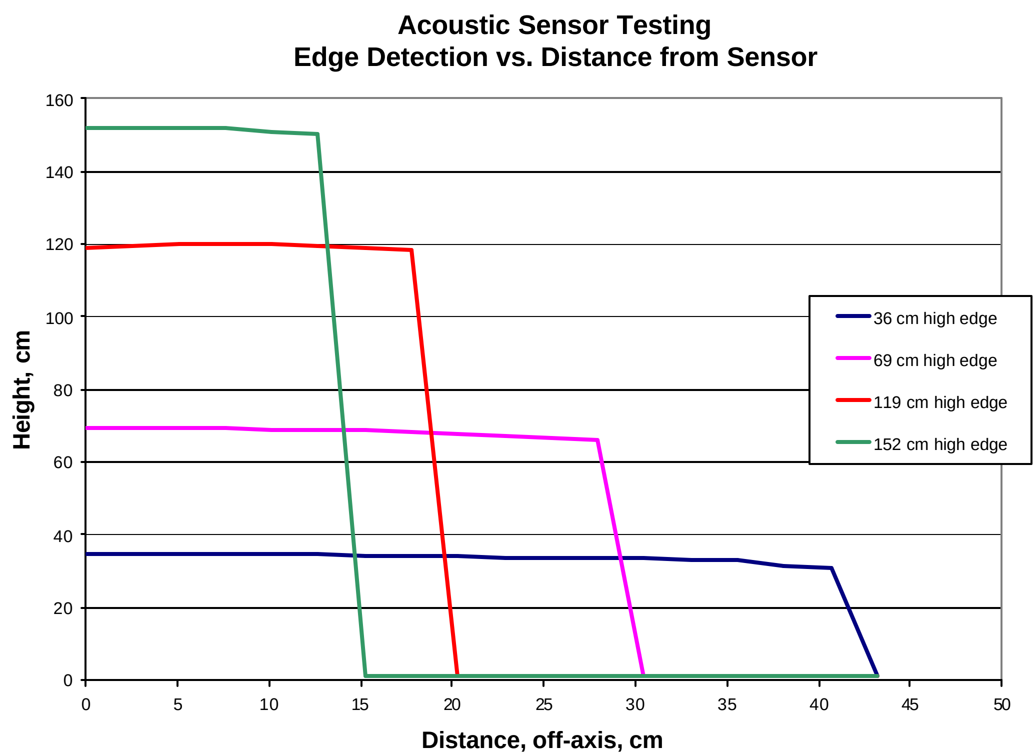


Figure 6: Edge Detection as a Function of Horizontal Offset and Vertical Height

4.1.3. Height Detection of Walking Persons

The data collection system was programmed to record 2 seconds of data at 20 samples per second once triggered by a person walking underneath the sensor (modeled in Figure 7). The system automatically analyzed the raw data and calculated a height from the maximum recorded value. The maximum value is closest to the normal standing height of a person and correlates best to the data in the Appendix.

Figure 7: Height Measurement During Walking

Two sets of ten repetitions each were collected for each of seven persons walking underneath the acoustic sensor. The walkers included both males and females, with the females wearing low- and high-heeled shoes. Table 4 lists the maximum measured height and the range (maximum minus minimum) for each person.

There was no significant correlation between the height of the walker and the range calculated.

Table 4: Walking Height Measurements
All measurements are in cm (inches)

WALKER	DATA SET	MAXIMUM HEIGHT	RANGE (MAX-MIN)
A	1	185 (72.8)	5.6 (2.2)
	2	184 (72.6)	4.9 (1.9)
B	1	178 (70.2)	4.3 (1.7)
	2	178 (70.0)	2.7 (1.1)
C	1	174 (68.5)	3.8 (1.5)
	2	174 (68.4)	3.3 (1.3)
D	1	172 (67.9)	4.3 (1.7)
	2	172 (67.9)	4.9 (1.9)
E	1	172 (67.6)	3.7 (1.5)
	2	171 (67.1)	3.0 (1.2)
F	1	168 (66.2)	4.5 (1.8)
	2	168 (66.0)	2.5 (1.0)
G	1	163 (64.3)	2.6 (1.0)
	2	163 (64.2)	2.7 (1.1)

(Note: Some values may be different due to rounding)

Figure 8 shows a representative set of data collected from one of the walkers. The maximum height (most probably the top of the head) is reasonably consistent even though no efforts were made to have the walker maintain a consistent stride as he/she passed underneath the sensor. As people walk, they tend to bob up and down slightly. Thus, the instantaneous walking height is often lower than the static standing height. The sensor readings before and after the peak values represent other body parts such as feet, knees, arms, and shoulders, entering the monitored area before and after the head passed through.

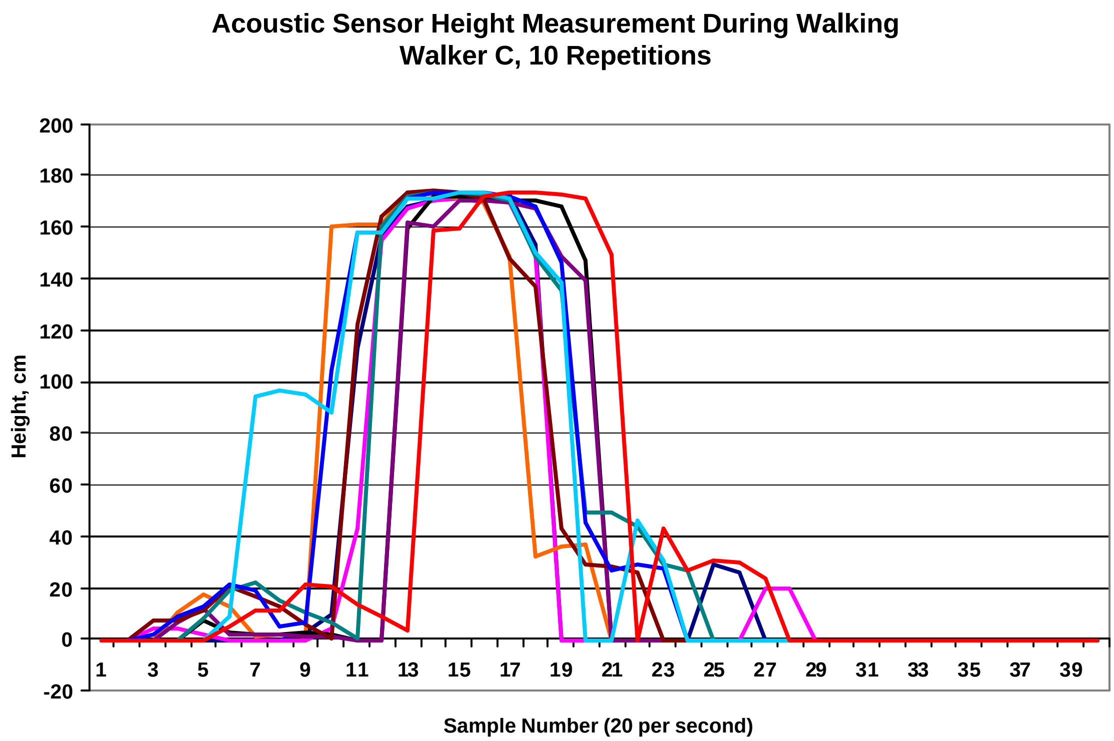


Figure 8: Typical Walking Profiles

The walking tests show that the sensor and data collection system consistently measure the height of a subject with small sample-to-sample variations. The height difference between adults and children is on the order of 26 cm, much greater than the maximum within-person variation of 5.6 cm. The bobbing motion of the head during walking should affect both adults and children similarly, and should tend to maintain the adult-child height gap.

4.2. Photoelectric Sensing

Photoelectric sensing involves a transmitter (emitter) sending a light beam to a receiver (detector). When the beam is interrupted by an opaque object, the receiver's output changes to signal that event. Photoelectric sensors can use either visible or infrared light; and they can be constructed in a throughbeam configuration (the emitter and detector are at opposite ends of the light beam's path) or in a retroreflective design (the emitter and detector are both at one end of the light beam's path, with a mirror positioned at the other end).

The height of a person passing through a photoelectric sensor's monitoring area is determined by positioning the sensors to emit horizontal light beams at specific heights. If a beam is interrupted, an object at least as tall as the height of the sensor has passed through. For adult/child discrimination, at least two sensors are required. One sensor would be positioned at the minimum height of an adult (150 cm, or 59 inches), and a second sensor would be located at a height that would detect small children passing underneath the higher sensor. One choice for the height of the second sensor would be the minimum height of a 2- to 3.5-year old child, or 81.3 cm (32 inches), which is listed in the Appendix. The sensor could be set to a lower height without failing to detect a child.

4.2.1. Sensor Features

Photoelectric sensors have attractive features as a detection technology. Among the attributes that are amenable to a sensing system are:

- The sensors are insensitive to dust, smoke, and vibration (within reason).
- The use of infrared emitters makes the sensors an invisible (non-disturbing) element of a monitoring system.
- Typically, the transmitted light beam is pulsed and the receiver is sensitive to light only at the modulation frequency. Detection of stray light, reflections, and other light sources is suppressed by the electronic filtering in the receiver.
- Installation is generally uncomplicated. Setting the proper height can be achieved in a variety of ways.
- Long range sensors are available. Throughbeam photoelectric sensors can span a distance of several meters. Infrared laser optic sensors are available that can detect an interrupted beam over a 50 meter (164 foot) distance.
- Photoelectric sensors can be small and relatively inexpensive.

4.2.2. Sensor Evaluation

Commercially-available visible-light throughbeam and retroreflector sensors were examined. Figure 9 shows a picture of the emitter and detector of the throughbeam sensor set. Figure 10 shows a picture of the plastic retroreflector.

Both sensors reliably signaled an interrupted light beam when an opaque object was inserted between the emitter and the receiver (or between the emitter/receiver and the retroreflector). To assess whether light sources other than the emitter could be sensed by the detector (or whether reflective surfaces other than the retroreflector could be detected by the emitter/detector's detection circuitry), other light sources were tested. For the throughbeam system, fluorescent light, sunlight, and incandescent light failed to be sensed by the detector. A variety of materials, including glass, plastic, and metal mirrors, and a diffuse reflector like white paper could effectively reflect off-axis emitter light into the detector over short distances.

For the retroreflector sensor, no reflective surface with the exception of a bicycle reflector (which is a type of retroreflector) was capable of triggering the detector.

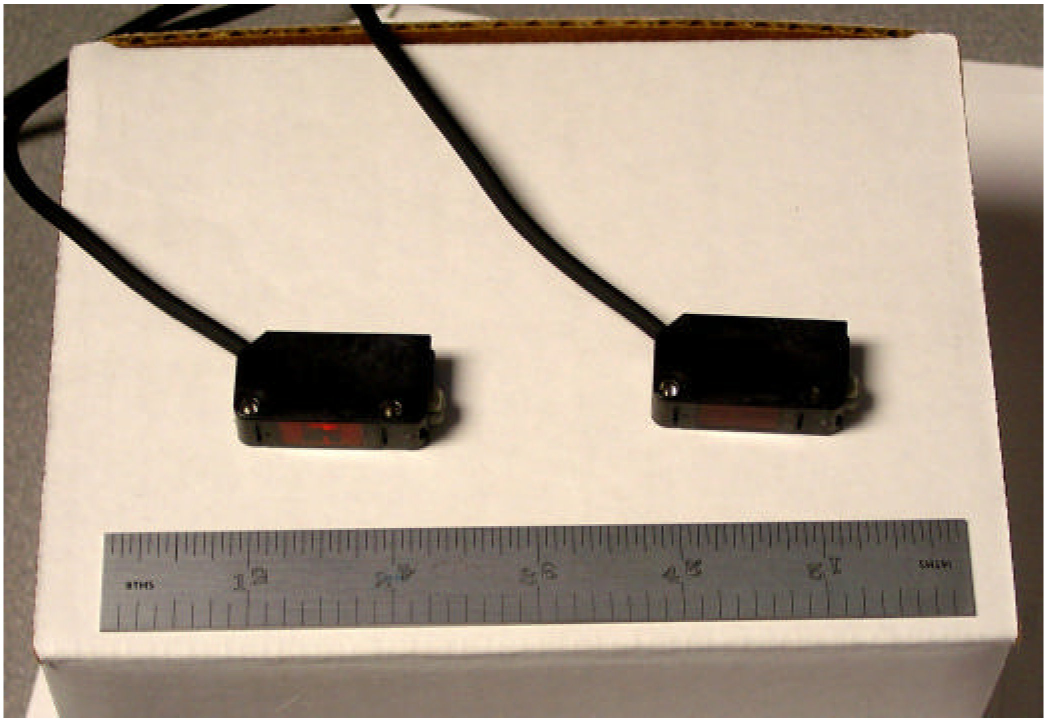


Figure 9: Photoelectric Emitter and Detector

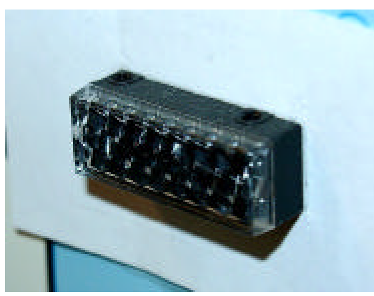


Figure 10: Retroreflector Mirror

Readily-available photoelectric technology is available for use as a sensing element in a height-detection system. The sensors possess a long range, insensitivity to unwanted light, dust, and smoke, and can use invisible beams to monitor an area of interest.

4.3. Passive Infrared Sensing

Another light-sensitive technology that could be employed to measure height is the use of pyroelectric elements (passive infrared detectors) to detect warm, moving bodies. This is the electronic device typically used in motion detectors. For photoelectric sensors, any opaque object, including balloons, balls, leaves (if outside), and other inanimate articles, is capable of triggering the detector. For pyroelectric elements, the long-wavelength infrared energy from a warm object serves as the emitter. The radiation reaching the element is converted into an electrical signal. Height detection with a pyroelectric sensor would be achieved in a manner similar to that of the photoelectric system; sensors would be installed at various heights to detect the presence or absence of a person moving through the monitored area. A two-sensor system would discriminate children from adults based on whether one or both of the height-positioned sensors were triggered.

While false triggers from inanimate objects can be reduced through the use of pyroelectric sensors, the technology has features that must be considered in any system design. Pyroelectric elements generate signals in response to any temperature changes. Such a change can be either the motion of a warm body, or a heating or cooling of an object in the sensor's field of view. In order to reduce the unwanted signals generated by emissions from the environment, vignetting optics (a faceted lens) and a dual-detector configuration are employed. This configuration minimizes the ambient sensitivity but results in the necessity for the warm object to move across the sensor's field of view, rather than towards or away from the sensor. These features might limit the applicability of passive infrared sensing as an adult/child discriminator.

5. Foot Length Discrimination

Another anthropometric characteristic of adults and children with the potential to serve as a discriminating factor is foot length. Adults' and children's foot lengths have a non-overlapping space that might be exploited by a monitoring system. The Appendix reports a maximum foot length of a young child at 20.2 cm (7.95 inches), with a minimum adult foot length of 20.8 cm (8.19 inches). The maximum-minimum difference of 0.6 cm (about one-quarter of an inch) is a small number and would require a precise measuring system to reliably discriminate minimum-sized adults from maximum-sized children. However, the Appendix also reports that the 95th percentile foot length of a young child is 18.4 cm (7.24 inches), while a 5th percentile adult's foot length is 22.2 cm (8.74 inches), resulting in a gap of 3.8 cm, or about 1.5 inches. Thus, for most persons, a wider range is available for discriminating adults from children.

The most obvious means by which the length of a foot can be determined is to have a person step on a large sensing object that determines where contact between the foot and the sensor occurs. With contact information, a length calculation can be made, and a determination of whether the foot length is that of a child or an adult can be attempted.

5.1. Sensor Description

A series of contact switches from a commercially-available safety mat were reconfigured into two arrays of sensors (the H Mat and the V Mat). The H Mat contained 30 elements. The V Mat contained 20 elements. The number of elements was chosen to create a sensor with a large surface area upon which to step. The element-to-element resolution (the width of each individual contact switch element) of each mat was measured at 1.5 cm (0.59 inches), which was a function of the contact switch element used.

Normal walking will usually result in the entire foot stepping on the sensing surface. When pressed with eight ounces of force or greater, a switch will connect two electrical conductors and change the switch's output voltage. Figure 11 shows a single contact switch. Figure 12 shows the two contact switch mats individually. As a foot length sensor, the two mats are stacked such that one mat can sense contact along one axis and the other mat senses contact in a perpendicular axis. Figure 13 shows the two mats as stacked. The H Mat is arranged to sense contact primarily in the direction of motion. The V Mat senses contact primarily in the direction perpendicular to the motion of the walker.

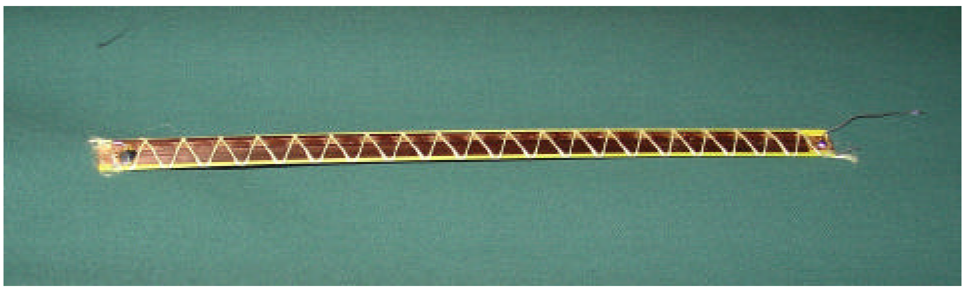


Figure 11: Individual Contact Switch Element

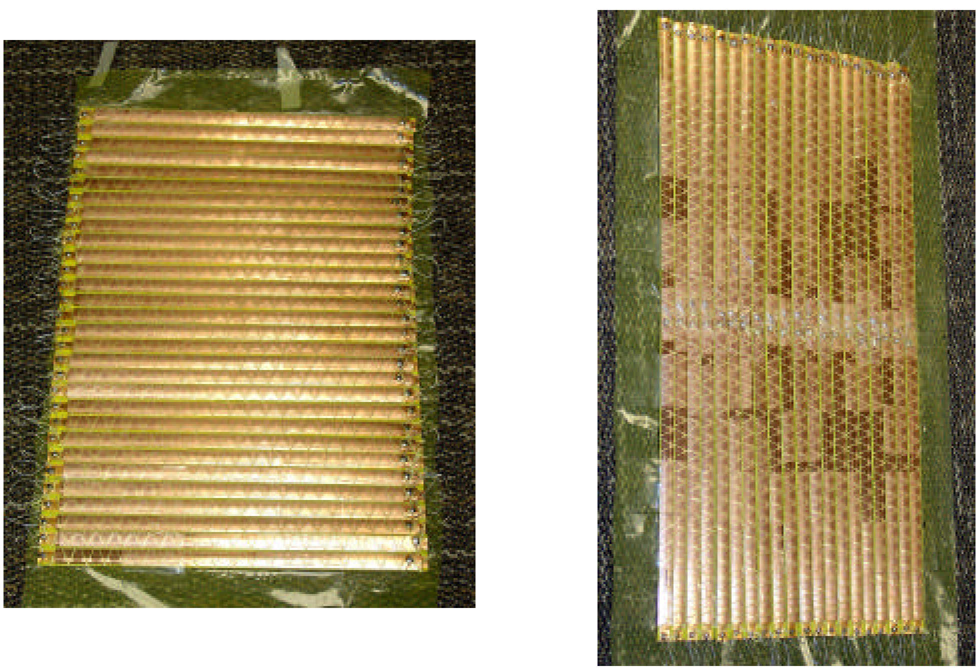


Figure 12: The H and V Mat Sensor Arrays
(Walking is generally from the bottom to the top in these views)

Figure 13: Stacked Contact Switch Arrays

5.2. Data Collection and Length Determination

Walkers stepped on the sensor mats at a normal gait. Footwear from barefoot to high- and low-heeled shoes to flat-soled shoes was tested. Some walkers stepped several times to assess the within-person variation of the sensor system.

A data collection system, reading all of the switches at a 10 Hz rate, recorded which switches were pressed for each data cycle. A footstep on the sensor resulted in an array of H Mat and V Mat contacts that were closed for each 0.1 second sampling period. Figures 14 and 15 show a graphical output of the sensor for a single footstep.

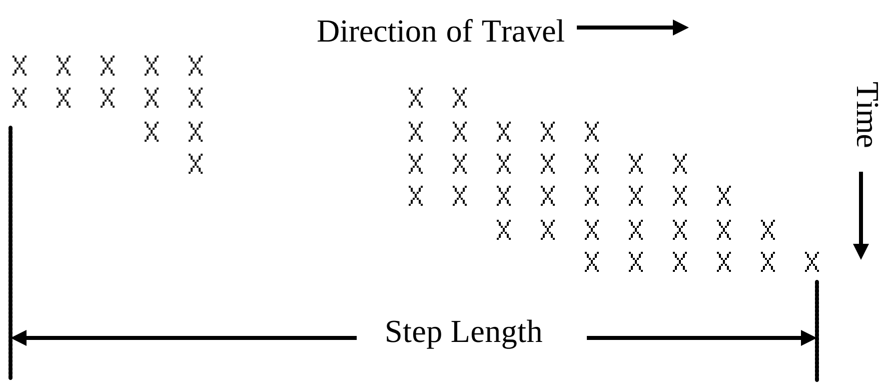


Figure 14: H Mat Data for a Single Step

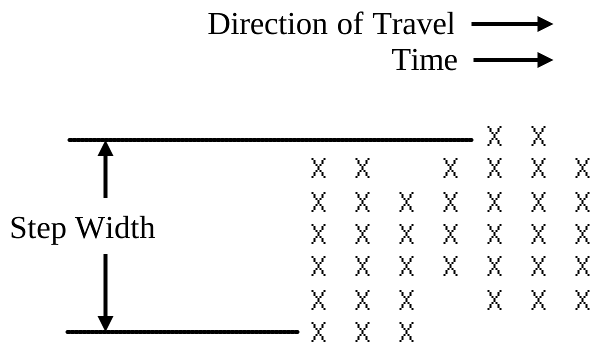


Figure 15: V Mat Data for a Single Step

The H Mat data show the length of the footstep (in this instance, a low-heeled shoe was worn). The V Mat shows the width of the step at each sampling instance. Data from both mats were combined to calculate the foot length. The length value from the H Mat was determined by noting the number of elements that were pressed. The width value of the V Mat is the distance from the midpoint of the first set of elements contacted to the midpoint of the last elements contacted. This is a correction factor that is made to account for steps on the sensor that are not perpendicular to the sensing elements. Figure 16 shows a pictorial representation of the calculation of the V Mat width value. The foot length is calculated as the root-sum-square of the H Mat and V Mat length and width values. These calculated values were compared to the measured foot/shoe lengths of the walkers. Table 5 summarizes the calculated values and their comparisons to the measured lengths. The last two entries in the table refer to deliberate footsteps at large angles relative to the axes of the sensors. In these cases, the V Mat values are a significant portion of the total foot length calculation.

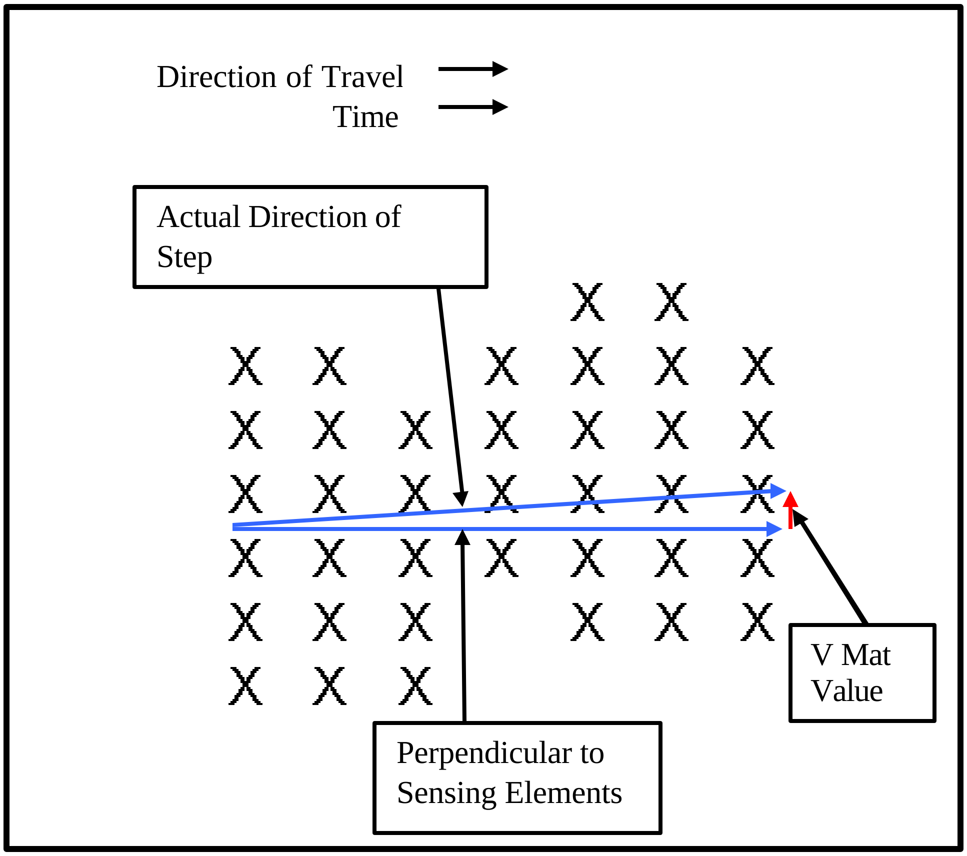


Figure 16: Determination of V Mat Value

Table 5: Foot Length Determinations
(All dimensions in cm)

WALKER	CONDITIONS	FOOT LENGTH		DIFFERENCE
		Calculated	Measured	Calculated minus Measured
A	Low heels	30.3	31.1	-0.9
	Low heels	27.2		-4.0
		30.2		-0.9
		31.7		0.6
		31.7		0.6
B	Low heels	31.8	32.4	-0.6
		30.2		-2.2
		28.7		-3.7
		31.7		-0.7
C	Low heels	25.7	28.6	-2.9
		27.3		-1.3
		27.2		-1.4
		27.2		-1.4
D	Low heels	28.7	30.5	-1.8
		28.7		-1.8
		25.8		-4.7
		30.3		-0.2
E	Flat soles	24.2	28.6	-4.4
F	High heels	22.7	26.7	-4.0
G	Low heels	25.7	26.0	-0.3
G	Barefoot	22.6	24.1	-1.5
		24.2		0.1
B, 30 degrees off-axis		26.7	31.8	-5.0
		28.6	30.5	-1.9
B, 45 degrees off-axis		27.7	31.8	-4.1
		31.8	30.5	1.4

Just over half of the calculated foot lengths are within one sensing element's width from the measured value, with seventy percent of the readings within two times the resolution of the sensor arrays. Almost every error is negative; that is, the calculated length is less than the measured length. This may be due to the fact that one-half pound of force is necessary to close the contacts on a sensor element. At the end of a step, when the foot is lifting off the array, the toe may not press down hard enough to close the contacts on the last element.

With a foot length difference of 3.8 cm between children and adults (at the 95th percentile level for children and the 5th percentile level for adults), this foot length sensor array would have difficulty consistently distinguishing adults from children. Thinner elements and a lower force required to close an element's contacts could improve the system's performance. Algorithms and threshold lengths for adult/child discrimination would have to account for whether the person walking on the sensor array had shoes (which would make the foot appear longer) or was barefoot.

6. Cognitive Ability Determination

The ability to reason is another way to distinguish adults from children. One approach to exploiting this ability is to employ a warning system that only works with proper supervisors who can respond to the alarm. First, the warning system detects the presence of a person by using a sensor. The sensor activates an alarm system that begins a countdown. Without the appropriate response keyed into the system, an alarm will sound. The appropriate response is a relatively simple question for literate people but incomprehensible to a child. Many different kinds of questions are possible (as discussed in the Appendix).

6.1. System Description

In this demonstration, activation of a passive infrared motion detector was used to start the countdown to an alarm. Any person-detector technology would work in this system. Figure 17 shows an example of a warning sign at the entrance to the guarded area to alert participants of the need to participate in the child screening system.

Figure 17: Example Warning Sign

A personal computer running a data collection software program was used as the human interface to the monitoring system. The computer monitor was clearly visible in the area and easily accessed with a mouse, but any input device would serve the same purpose. Figure 18 shows the message seen by anyone entering the monitored area.

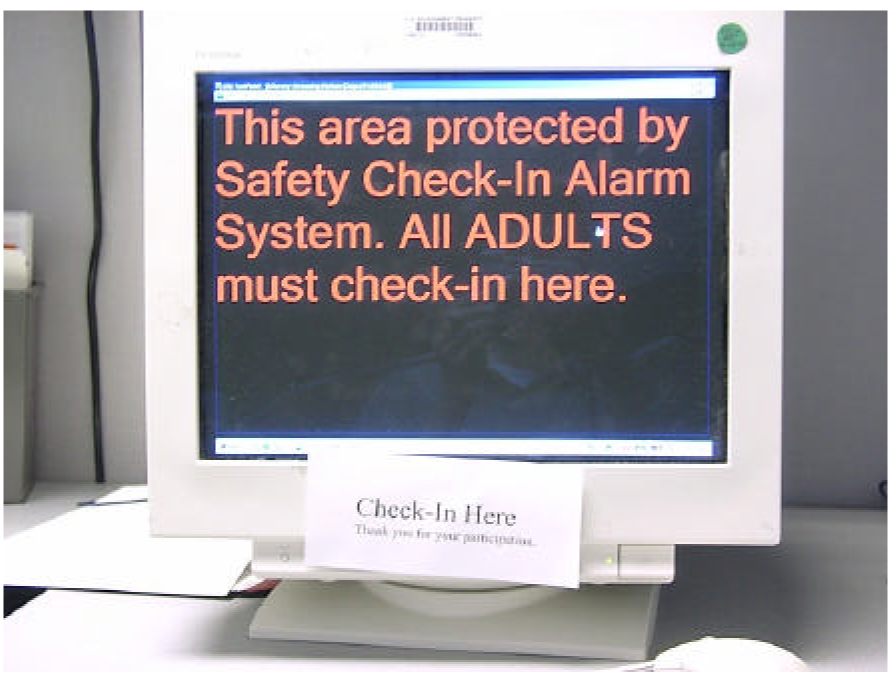


Figure 18: Initial Monitoring System Message Screen

Appropriate instructions were immediately apparent on the monitor. Users were to read instructions to answer a literacy-challenging question on the same screen (which was a number written in text for this demonstration), and then key the numerical value into the system to deactivate the alarm. Figure 19 shows the question-input screen with the time remaining to answer before an alarm was activated.

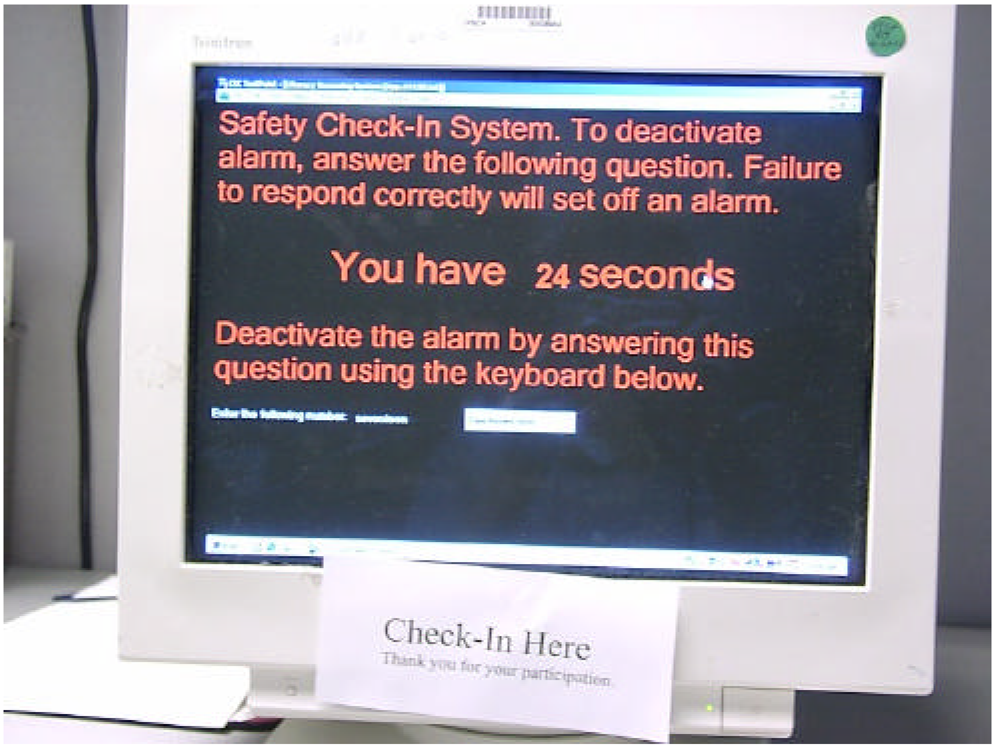


Figure 19: Literacy Test Input Screen

Users were given a 30 second time period to key in the correct responses to the literacy challenge. The remaining time was clearly counting down on the monitor. Less or more time to respond to the question could be programmed into the system, depending on the circumstances. No aversive sounds were presented in this demonstration; however, large entryways where the input device might be overlooked would require a flashing light or an audible alert to compel entrants to notice and visit the input device. Such an aversive stimulus might occasionally provide the added benefit of deterring children if they entered the area unsupervised. This system also requires responsible supervisors with clear duties and motivation to check every alarm when it sounds. Further refinements could include the options to either manually reset the system or automatically enable alarming after a set time.

6.2. System Operation

The adults interacting with this demonstration project were capable of understanding and performing the task as expected, but no children were tested. It is unlikely that a child under the age of 5 could meet the literacy challenge, but the user of any system should evaluate the literacy tests with the intended populations before use. Harder questions or even passwords can be used if needed. Overall, this type of warning system could be used to develop an inexpensive, simple, flexible, easily installed, and effective child detector that requires minimal user training and time commitment.

7. System Design Considerations

7.1. Population Characteristics

Sensor systems must successfully contend with normal human behaviors in order to be effective. Consumers tend to be more willing to buy and operate safety equipment, of any kind, if it does not require too much investment from them, either in money, time, skill, memory, concentration, or dedication.

System designs with a minimum of complexity in installation and fewer steps required to operate are more likely to be used properly. More complicated and time-consuming devices with required maintenance will be more likely to be deactivated or misused. Designers need to anticipate the effects of distractions, failing memories, and hurried lifestyles. Desirable attributes such as being unobtrusive, quiet, and aesthetically pleasing will encourage the system's use. Designers need to account for a homeowner's guests who may be uninformed about their operation and accommodate foreseeable special circumstances that might require a manual override of the system. Monitors need to be effective with few false alarms. In short, consumers prefer simplicity, attractiveness, flexibility, customizability, utility, saving time and money, and conserving their mental and physical energy for leisure activities instead of chores.

These attributes may seem obvious, but they have extra importance with a safety device because the benefits of owning and operating one are invisible. The rewards of safety equipment reside in the event that didn't happen. This can be hard to envision, so safety equipment needs to motivate users. Keeping these characteristics in mind will help designers invent more desirable systems.

7.2. Sensor Sensitivity, Selectivity, Reliability

A safety system used to discriminate adults from children should include considerations of many design attributes. Proper protection of unaccompanied children will be dependent on the combination of system components and the human interaction with that system. Among the global design factors to take into account on a child detector system are:

- Acceptable cost: The purchase and operating costs must be low enough to be affordable. Systems that are too expensive will not be used frequently enough to make a significant difference in the hazards to which children may be exposed.

- Ease of installation: Whether set up by the purchaser or a professional, the system should install without requiring major modifications to the monitored area. The use of wireless communication technology could simplify the installation. Of course, systems involving components installed outdoors need to take weather conditions such as temperature extremes, precipitation, and sun position into consideration.

- Ease of operation: Minimal training should be required to properly operate the system. Actions to take in the event of an alarm situation should be understood without difficulty or confusion. All of the potential caregivers in the home should be familiar with the actions to take in the event of an alarm.

- Continuous operation: The discrimination system should be capable of continuous monitoring without requiring frequent manual activation. Avoiding the circumstance of forgetting to enable the monitor is highly desirable in a safety system. The use of battery back-up is one consideration for powered systems that may experience temporary outages.

- Non-intrusive operation: A safety system that does not continuously impose its presence on consumers is more likely to be considered acceptable.

- Low nuisance alarm (or annoyance) rate: To minimize the possibility of having the safety system turned off (and then unintentionally not re-activated), a monitoring system should not pose an unwarranted irritation to persons. Minimizing the false alarm rate is an important consideration in any safety system design.

- High Sensitivity: The discriminator should repeatedly be capable of distinguishing children from adults. Multiple sensors and complex data processing may ultimately be required to achieve the desired level of discrimination without an accompanying high false alarm rate.

- Low maintenance: Frequent adjustment, calibration, or parts replacement could result in monitors with extensive periods of suboptimal operation. Systems that function well without "tweaking" are more likely to be in proper operating condition when a potentially hazardous situation arises.

- High selectivity: The discriminator system should not respond to environmental perturbations not associated with child detection and discrimination. Factors such as vibration, reflection, the presence of pets, and weather changes should not result in a false alarm signal.

- Reliability: Since the costs of a failure in a safety system could be very high, reliable operation during the monitoring period is necessary. Techniques such as automatic health checks, self-purging redundancy, and standby sparing (replacing a unit in which a fault has been detected with a ready spare) are options that can be incorporated into monitor designs.

- Life: The operational life of a child discriminator is a function of the aforementioned continuous operation, low maintenance, and reliability components. Depending on the application, a discriminator system may be in use seasonally (in the case of some swimming pool monitors), or year-round (for monitored areas inside the home).

A child discriminator system is likely to involve sensing, data processing, and alarm features. Additionally, consideration must be given to achieving a high degree of desirable functions (sensitivity, selectivity, reliability) while simultaneously avoiding undesirable attributes (costliness, false alarms, difficult operation). No system will function without adults who are capable of responding properly in the event of an alarm situation.

7.3. Multiple Sensor Systems

Instead of depending upon a single sensing element to provide sufficiently accurate, precise, and reliable data for a monitoring system, several sensor inputs can be combined to determine if a person has entered an area and if the person is a child or adult. The intent of multiple sensor use is to increase desirable system features (e.g., sensitivity, selectivity, reliability), and decrease undesirable features (nuisance alarms). The use of multiple inexpensive sensing elements instead of a single expensive sensor may result in a lower overall cost while maintaining the necessary performance.

How the sensor inputs are combined has an impact on overall system performance. Requiring a positive detection from all the inputs may create a system with a low annoyance rate but an unacceptably high failure rate (e.g., a child entering a monitored area is either not detected or is classified as an adult). Conversely, a system that responds to any of a number of sensors may detect children with a high degree of confidence but with a nuisance alarm rate so large as to make the system impractical to use.

As examples of multiple-sensor systems, a statistical analysis was performed on a hypothetical 3-sensor system. Three configurations were considered:

1. An AND system, where all sensor inputs must respond positively in order for the system to detect a child.

2. An OR system, where one or more positive detections are required for the system to detect a child.

3. An N-of-M system, where at least N out of M sensors must respond positively in order for the system to detect a child. In our example, a 2-of-3 system is used.

The four possible outcomes of an individual sensor are:
1. The sensor detects a child and a child is present.
2. The sensor detects a child and no child is present.
3. The sensor does not detect a child and a child is present.
4. The sensor does not detect a child and no child is present.

Cases 1 and 4 represent proper operation. Case 2 is a nuisance, or false alarm. Case 3 is the hazard scenario that a monitoring system must minimize.

For a given sensor, the probabilities of cases 1 and 3, and the probabilities of cases 2 and 4 must add to 1. To simplify the analysis, the probabilities of cases 1 and 4 (proper operation) were set equal. This has the effect of setting the probability of cases 2 and 3 (improper operation) also equal. The three independent sensors were arbitrarily assigned probabilities of accurate child detection at values between 0.9 and 0.7. Eight combination sets of sensor detection probabilities were assigned. Table 6 lists the probabilities of proper operation that were assigned for each set of sensors. Improper operation is equal to 1 minus the proper operation value.

Table 6: Sensor Probability Combinations

SENSOR	SET 1	SET 2	SET 3	SET 4	SET 5	SET 6	SET 7	SET 8
A	0.9	0.9	0.9	0.8	0.9	0.8	0.8	0.7
B	0.9	0.8	0.8	0.8	0.7	0.8	0.7	0.7
C	0.9	0.8	0.7	0.8	0.7	0.7	0.7	0.7

7.3.1. AND System Operation

In this configuration, all three sensors must simultaneously detect a child for the system to generate an alarm signal. Figure 20 shows the results of the statistical combination of the sensors with their assigned probabilities of proper operation.

As an example, the Set 3 working, nuisance, and hazard probabilities are calculated as shown below.

P(working) = Probability of detection given a child is present
= P(A)*P(B)*P(C) = 0.9*0.8*0.7 = 0.504
P(nuisance) = Probability of detection given that a child is not present
= (1-P(A))*(1-P(B))*(1-P(C)) = 0.1*0.2*0.3 = 0.006
P(hazard) = Probability of no detection given a child is present
= 1-(P(A)*P(B)*P(C)) = 1-0.9*0.8*0.7 = 0.496

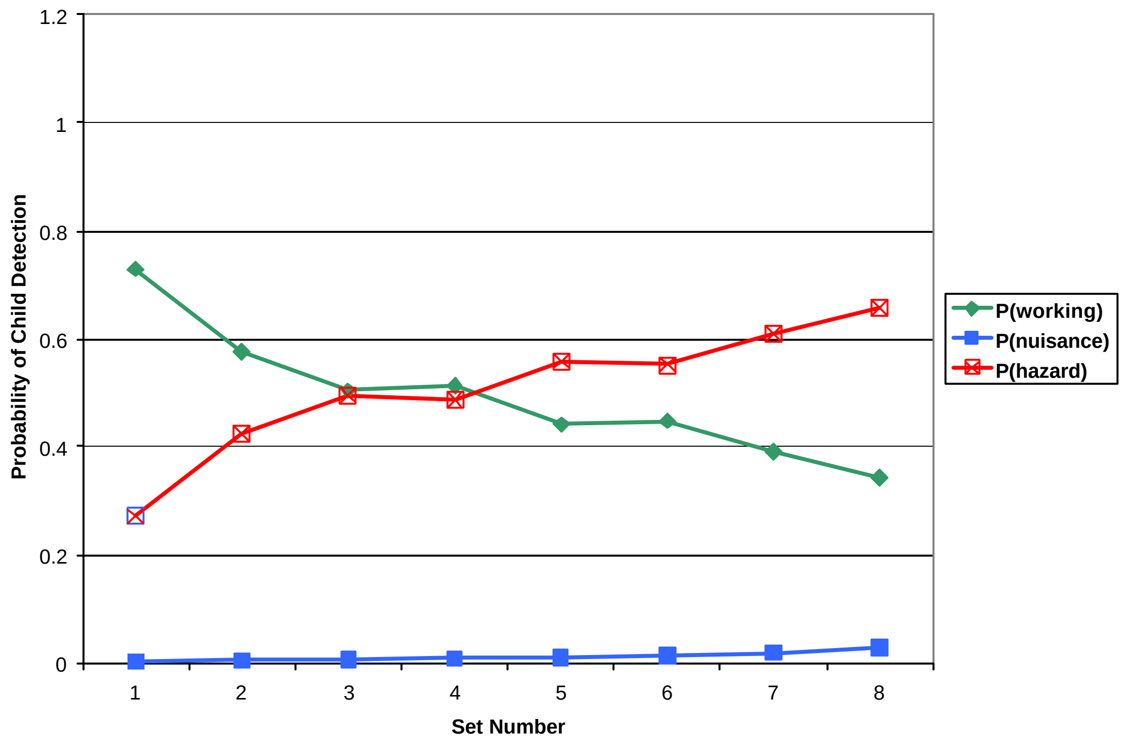


Figure 20: AND System Configuration System Design

The AND configuration results in a very low nuisance rate for all the set probabilities. However, the probability of proper operation is never better than 0.73 (3 sensors, each at a 0.9 probability of correct operation); and as the probability of sensor operation decreases, the system response drops quickly.

7.3.2. OR System Operation

In this configuration, the system generates an alarm signal if any of three sensors detects a child. Figure 21 shows the results of the statistical combination of the sensors with their assigned probabilities of proper operation. The probabilities of proper and improper functioning are calculated in a manner similar to the example given for the AND system, with appropriate changes to reflect the logical OR operation.

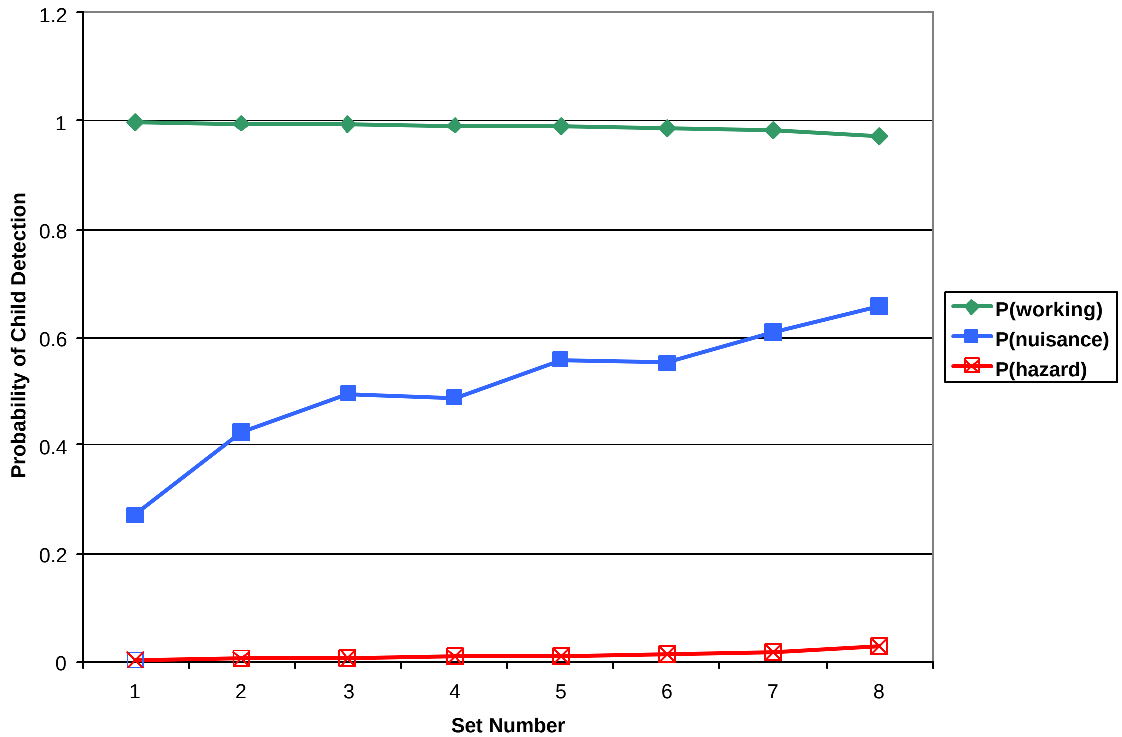


Figure 21: OR System Configuration System Design

The OR configuration results in a very high proper operation rate and a low hazard rate for the set probabilities. The nuisance rate rises quickly as any sensor's probability of proper operation decreases.

7.3.3. 2-of-3 System Operation

In this configuration, two or three of the three sensors must simultaneously detect a child for the system to generate an alarm signal. Figure 22 shows the results of the statistical combination of the sensors with their assigned probabilities of proper operation.

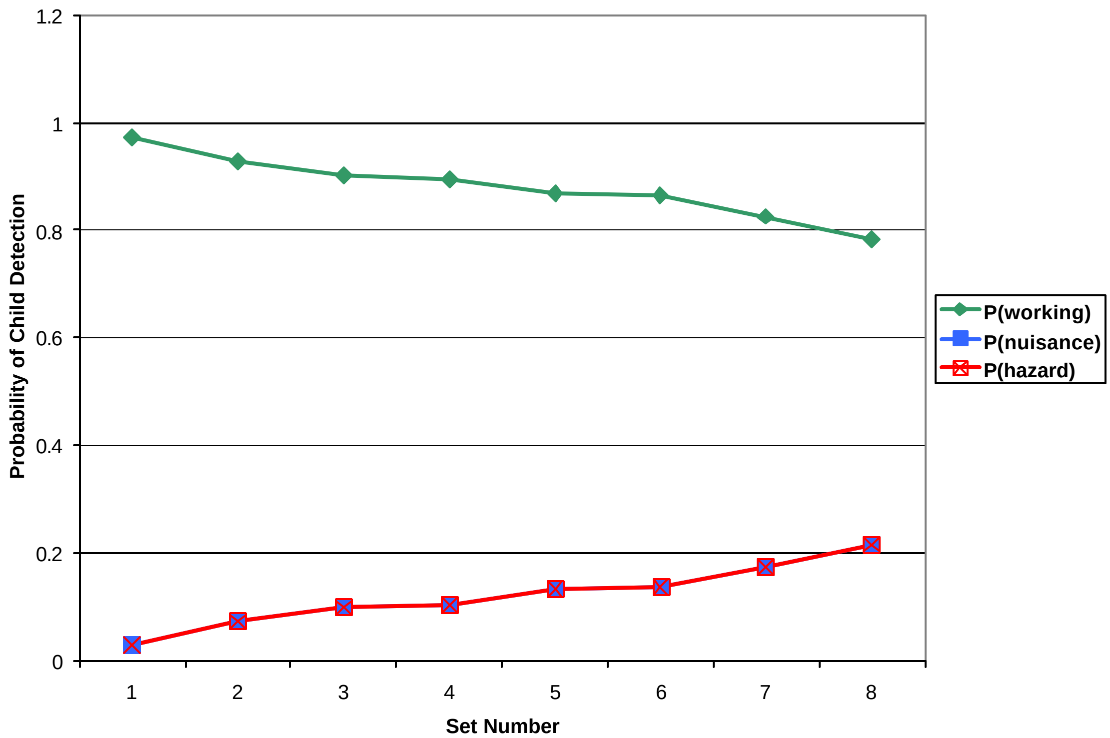


Figure 22: 2-of-3 System Configuration System Design

This style of system design results in a relatively high proper operation rate with relatively low rates of annoying false alarms and failures to detect a child. The superposition of the nuisance and hazard rates are a function of the assumptions regarding the assignment of probabilities discussed in Section 7.3.

7.3.4. Alternate System Designs

The three potential systems discussed above are not the only choices available for combining multiple sensors. The N-of-M design can be configured to any combination of sensors (4-of-5, 3-of 5, etc.). Alternatively, some sensor inputs may be weighted more than others. Hybrid configurations that treat separate sensors differently could be designed. For example, one hybrid system could require Sensor A to detect a person, then poll Sensors B-D on whether the person is an adult or a child. Multiple sensors of the same type could be clustered into one detector. The detector's output to the remainder of the monitoring system could be an algorithmic combination of the cluster of sensors. Other configurations could be conceived.

If the desired application of a safety system is for an always-on, non-intrusive adult/child discriminator, and the potential hazard is unaccompanied young children, then a person-counting feature may be necessary. As people enter and leave a monitored area with a potential hazard, the safety system would keep a tally of the number of adults and the number of children. When the count of adults reached zero and the count of children was above zero, the system would activate an alarm. The counting system would detect and respond to a child entering a monitored area in which no other people were present, and would also alert adults when the last adult left an area that still contained children.

8. Conclusions

A study of how to exploit the physical and cognitive differences between adults and children for safety system designs was undertaken. Three factors (height, foot length, and literacy) were investigated as to the ability of a sensing system to discriminate adults from children. Simple sensor-based systems were constructed to evaluate some of the factors involved with collecting data for subsequent adult/child discrimination. In addition, a statistical evaluation of the effect of various sensor combinations on system performance was performed.

Height differences of adults and children have a relatively wide gap and can be measured in a variety of ways. The use of acoustic, photoelectric, or passive infrared sensors can be non-intrusive and accurate for the area monitored. Foot length determination can be accomplished with simple sensing devices but requires additional data processing in order to calculate foot length. Literacy testing is a straightforward but more intrusive form of discriminating adults from children.

The use of AND, OR, or N-of-M systems has the potential to improve a system's ability to detect a child without an unacceptably high false alarm rate. Data from multiple inputs can be combined many ways to increase adult/child discrimination accuracy.

Discrimination of children from adults can be done with current technology. Active safety systems can provide information regarding the proximity of unaccompanied children to potential hazards. These systems are capable of extending the time for an adult to act before an incident occurs. However, every system requires adults to be capable of acting when an alarm is activated.

APPENDIX

Discriminating Children from Adults

I. Introduction

As part of a continuing goal to promote the safety of children, the CPSC staff conducted an evaluation to illustrate the utility of existing technologies for detecting the presence of people in potentially hazardous areas, such as close to swimming pools. Such technologies could also have applications in other hazardous locations, such as workshops, or chemical storage areas. Such systems require high detection rates, reasonable costs, low false alarm rates, and intuitive, uncomplicated installation and operation. The particular challenge of discriminating children from adults has been proposed for this phase of the research. If possible, discriminating humans from pets is also desirable to further limit false alarms.

The following human factors analysis describes the relevant differences between children and adults that might be useful to designers of child discrimination systems. This discussion highlights some key factors for the purposes of illustrating the concepts involved in discriminating children from adults; however, other factors given short mention below may also aid future designers. Obviously, no single solution will fit all of the variations needed to safeguard all possible situations. Designers and prevention experts are urged to create innovative approaches to safety however and whenever possible.

II. Large Variability in Humans

Given the large range of size variations within the human population, selecting a single variable to discriminate a child from an adult is difficult. By around age 10, some children are approaching adult-like statures. Some very short adults are smaller than very large children. Concomitantly, the accuracy of many child discriminator systems will decrease around this age. The most critical ages that need monitoring around hazards, however, are those of younger children. Most swimming pool drownings, for instance, involve children under the age of 5 years. So the real problem is finding features of children younger then 5 that differ significantly enough from adults to enable systems to reliably discriminate them from adults. Because of this difficulty, safety systems are likely to have some false alarm rates, i.e., some adults will be mistaken for children. This is probably acceptable as long as the accuracy of detecting the youngest, highest-risk children is high, i.e., no children are mistaken for adults.

Many factors that could discriminate children from adults exist; however, not all of them are significant differences, due to the large and normal physical variations within the human population. Designers of safety systems may want to consider the following factors singly or in combination when seeking ways to discriminate children from adults.

III. Human Factors Considered

A. Physical Factors

Height (stature or reach) – The stature of a person changes drastically over the first few years of life. This measurement and the associated dimensions, like a person's reach or leg length, are good choices for discrimination. The tallest 5.5 year old child is 124.4 cm (s.d.= 4.7 cm), which would be a reasonable target threshold to distinguish young children from adults. If this height were used as a threshold in a discrimination system, it would sound its alarm for children up to about age 10 years. A 5th percentile 8.5 to 9.5 year old is 124.1 cm (s.d.= 6.0 cm) (see Attachment A for anthropometric tables from Snyder, et al (1977)). Consumers can have gate "safety" latches installed that are mounted higher than a short person can reach[4]. Of course, children can defeat these kinds of latches with enough time, motivation, and accessible ladder-like toys or hand-held implements that extend their reach.

Foot size – The maximum foot length of a 5.5 year old is 20.2 cm (s.d.= 0.9 cm), which is a reasonable target threshold for distinguishing children from adults. This foot length is equal to the 5th percentile 10.5-11.5 year old. If this foot length were used as a threshold in a discrimination system, it would sound its alarm for children up to about age 12 years. The range of foot breadths in children actually overlaps the range of adult foot breadths. The maximum foot breadth of a 5.5 year old is 7.9 cm (s.d.= 0.4 cm). A 5th percentile 11.5 –12.5 year old is 7.8 cm (s.d.= 0.7 cm)(see Attachment A for anthropometric tables). Despite some overlap in this dimension, foot size may be useful for discriminating the majority of children from the majority of adults.

Weight – This factor has a larger variability than height across the population and so is less discriminating. Extremely overweight children could be identified as adults if the target threshold of the sensor system were set too low. Also, multiple children might activate the system simultaneously and produce a heavier reading that could be identified as an adult. The maximum weight of a 5.5 year old is 36 kg (s.d.= 2.5 kg), which might serve as a reasonable target threshold to distinguish children from adults. If this weight were used as a threshold in a discrimination system, it would sound its alarm for children up to about age 15 years. A 5th percentile 13.5 to 14.5 year old is 37.7 kg (s.d.= 9.0 kg).

Head-to-body-size ratio – This ratio is noticeable when observing young children and would require measuring both head size and height. Head height of an average 4.5 - 5.5 year old is 17.8 cm with an average stature of 108.5 cm, which yields a ratio of 0.164. An average 11.5 – 12.5 year old's head height is 19.9 cm with an average stature of 142.7 cm, which yields a ratio of 0.139. The oldest

[4] *Safety Barrier Guidelines for Home Pools*, U.S. Consumer Product Safety Commission publication number 362., http://www.cpsc.gov/cpscpub/pubs/pool.pdf

adolescents, virtually full-grown, have a ratio of 0.124. The variation within this factor is unknown, so its use is not recommended without further research.

Strength – Children are usually weaker than adults; however, strength also has a huge amount of variability within the population especially if older adults are included. Sensing strength also would require a test, not a passive sensor. However, strength is a relevant difference between children and adults in a discussion of physiology, so we include it here.

Other Factors – The following physiological factors may show average differences between children and adults, but they show such a great variability during daily activity and across the population that they lose any utility for differentiation: pitch of voice, heart rate, breathing rate, temperature, and skin conductivity, luminance, and reflectance.

B. Neurological Factors

Children's nervous systems are immature, resulting in slower reaction times and coordination attempts relative to adults. This is obvious when watching children learning to walk and run, playing Simon-Says, and rubbing their bellies while patting their heads. These activities are challenges to children because they require integration of sensory and intentional muscle control. Children's nerves are not fully myelinated. ("Myelin" is a protein sheath that grows over human nerve fibers and speeds electro-chemical impulses.) Balance, gait, reaction time, sensory acuity, general coordination and dexterity are all visibly affected by slower nerve fibers, although quantification of the differences is task-specific. These kinds of factors may be used in discriminating children from adults. They are listed here to promote ideas and further research.

C. Cognitive Factors

The most pronounced differences between adults and children are found within their reasoning and understanding of the world. While such factors may not seem like obvious mechanical solutions for designing a child discrimination system, existing types of alarm systems regularly employ mental factors to discriminate between different people. For instance, combination locks or password-deactivated alarm systems discriminate between people who know the numbers and people who don't know them. Because children have limited knowledge about how things work and limited literacy skills, such factors can be used to discriminate children from adults with very little technological fabrication.

For example, if a system were designed to detect an intruder and then pose a written question requiring a response, illiterate intruders would be unable to avoid setting off an alarm while literate intruders would be free to enter. This system is a discrimination system and would be effective for discerning children and pets from adults. Alternatives are possible without literacy features, including puzzles, mechanical devices with trick or hidden closures, or those requiring feats of coordination or memory. Children and pets can be screened using many cognitive challenges, literacy, vocabulary, mechanical knowledge or knowledge of physics. An added advantage is that different levels of difficulty can be used with the same system to screen out older children who may know how to read (see Attachment B for examples).

IV. A Literacy Screening System

For this type of system to work, it must detect the presence of an intruder and then activate some device that compels an age-determining response. The system must compel a response or people will just ignore it and false alarms will be too common for the system to be useful. An aversive stimulus of some kind, such as a loud noise that can only be turned off by a correct response to the system's cognitive challenge, may be annoying enough to command participation by virtually everyone. This kind of system should use the following components:

1. A warning sign at the entrance to the guarded area that alerts adults of impending participation in a child screening system
2. A clearly visible, easily accessed input device with appropriate instructions
3. A presence detector of some type (pressure mat, photoelectric eye, sonic sensor, etc.)
4. A brief period of time preceding the aversive stimulus for experienced users to key their responses (perhaps 3 to 5 seconds)
5. An aversive signal to compel users to make themselves known by using the input device or face the consequences of enduring the aversive stimulus or setting off the alarm
6. An input device to present questions and take responses, detect correct and incorrect answers, and sound an alarm after a few seconds elapse without a correct response
7. An alarm system of some type that is appropriate for the hazard and monitoring capabilities available on the site that will effectively alert supervisors that no response or an incorrect response was keyed into the input device
8. Responsible supervisors with clear duties and motivation to check every alarm
9. If the device is not manually reset, it should automatically arm after a fixed time period.

V. A Decoy System

Finally, another mental factor that will discriminate children from adults is children's innocence and their gullible lack of foresight. Although not foolproof, children can be detected by tricking them into giving themselves away by providing an attractive object within easy reach, such as a decoy. If the object is prominently located and designed to trigger an alarm when touched, young children will actually sound the alarm themselves.

The advantage of this type of system is that pets and adults will not give any false alarms and it does not require a barrier system, like a gate or an approach pathway like some other optical, pressure sensor, or motion-activated systems. Many protective systems require doors, fences, and gates to be effective, and these features are not preferred in some situations because of their restrictiveness and aesthetics. A decoy system can take up a very small space in an area, will have almost no false alarms, and may even be aesthetically pleasing. The main drawback is that it may not be as effective as other systems because it depends on the attractiveness of the decoy and in getting children's attention, which is never completely assured no matter how attractive the decoy. It is also likely to work only a few times with the same child before it loses its appeal and/or the child becomes conditioned to avoid it. If the decoy is too attractive and can be seen from outside the hazardous area, it might provide motivation for a child to enter the area, quite contrary to the intended purpose of the system.

Despite these difficulties, such a system may be an effective portion of a larger, layered defense for some hazardous environments. The decoy will have to be kept hidden during regular, supervised exposures to the protected areas so that children have no chance to habituate to it. The decoy will have to be sufficiently versatile to attract a wide range of children from many different backgrounds. It will be more effective if it is highly visible and must compel an action from the child to touch it or something near it so that the alarm will sound. The possibilities for effective decoys are endless; children are easily attracted to some novel talisman that is colorful, soft, calming, textured, smooth, bright, powerful, exotic, etc. Some possibilities are replicas of baby animals (puppies, kittens), flashy gems with lights, favorite foods, or familiar characters from popular media. Proper placement is essential to the effectiveness of the decoy. It should be placed at child height, in plain view, in comfortable reach, without anything alarming or distracting nearby. The more decoys that are present, the more likely the system will be to lure a child into activating it by touch or proximity.

While such a system will never be the most effective child discrimination system, it could have a low false alarm rate and be one of the simplest to create, install, and operate, even as a portable system. For protecting minimally hazardous areas, this may be a preferable type of system.

VI. Conclusions

No child discrimination system will be ideal for every situation; however, some human factors seem to be more likely candidates for differentiating children from adults than others. Among these, stature variables like height and foot size seem feasible for detecting children under the age of 5 years because of their significant differences between adults and children. In addition to physical factors, certain cognitive differences may be useful, like literacy and innocence, if appropriately paired with adult-aversive or child-attractive stimuli.

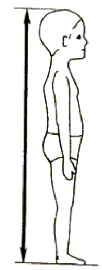
Designers of safety systems may find these thresholds (Table 1) useful for discriminating children from adults: a 5.5-year old child is less than 125 cm tall, with a foot imprint less than 20 cm long and 8 cm wide. Finally, children's limited reading skills can provide significant benefits to a discrimination system.

TABLE 1: Child Discrimination Parameters

Factor	Mean 4.5- 5.5 year old	Standard Deviation	Maximum 5.5 year old	Mean 16.5-17.5 year old	Standard Deviation	Minimum 17.5 year old
Height	108 cm	4.7 cm	**124 cm**	169 cm	8.9 cm	150 cm
Foot Length	17.0 cm	0.9 cm	**20.2 cm**	25.0 cm	1.9 cm	20.8 cm
Foot Breadth	6.8 cm	0.4 cm	**7.9 cm**	9.7 cm	0.9 cm	7.8 cm

Factor	Difference between average child and average adult	Difference between large child and small adult
Height	~61 cm	~26 cm
Foot Length	~8 cm	~1 cm
Foot Breadth	~2.9 cm	~ -0.1 cm

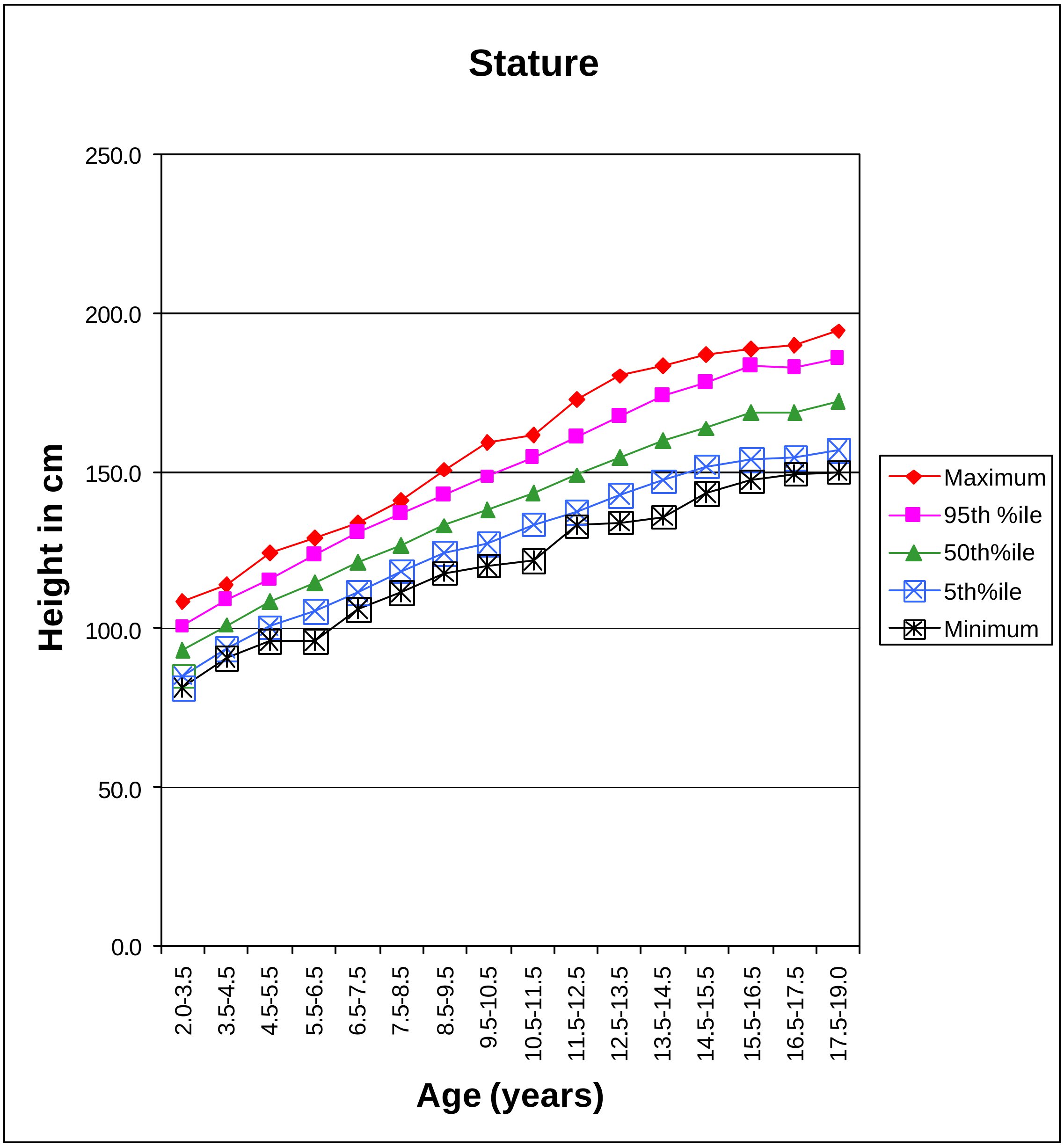
Attachment A: Anthropometric Tables



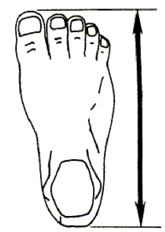
STATURE CM. - (MALES AND FEMALES)

AGE/YRS	N	MEAN	S.D.	MIN	5TH	50TH	95TH	MAX
2.0-3.5	213	93.4	5.0	81.3	85.7	93.4	100.8	108.5
3.5-4.5	228	101.4	4.5	90.9	93.9	101.4	109.1	114.1
4.5-5.5	271	108.3	4.7	96.5	100.6	108.5	115.8	124.4
5.5-6.5	242	114.6	5.1	96.5	105.8	114.5	123.7	128.7
6.5-7.5	227	121.2	5.5	106.3	111.8	121.2	130.5	133.8
7.5-8.5	198	126.9	5.6	111.5	118.2	126.4	136.9	140.6
8.5-9.5	257	133.0	6.0	117.8	124.1	132.6	142.3	150.3
9.5-10.5	258	137.7	6.3	120.1	127.1	137.6	148.3	159.0
10.5-11.5	282	143.3	6.6	122.0	133.1	142.7	154.6	161.1
11.5-12.5	287	148.8	7.2	132.8	137.5	148.6	160.4	172.4
12.5-13.5	315	154.6	7.7	134.1	142.1	154.5	167.6	179.8
13.5-14.5	271	160.1	8.2	135.4	147.0	159.4	173.6	183.2
14.5-15.5	264	164.2	8.0	143.2	151.5	163.6	177.6	186.7
15.5-16.5	198	168.4	9.3	147.1	153.5	168.5	183.4	188.3
16.5-17.5	221	168.8	8.9	149.1	154.6	168.3	182.9	189.6
17.5-19.0	156	170.9	9.5	149.9	156.4	171.8	185.7	194.4

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.



Stature
Height in cm
250.0
200.0
150.0
100.0
50.0
0.0
2.0-3.5
3.5-4.5
4.5-5.5
5.5-6.5
6.5-7.5
7.5-8.5
8.5-9.5
9.5-10.5
10.5-11.5
11.5-12.5
12.5-13.5
13.5-14.5
14.5-15.5
15.5-16.5
16.5-17.5
17.5-19.0
Age (years)
Maximum
95th %ile
50th%ile
5th%ile
Minimum



FOOT LENGTH CM. - (MALES AND FEMALES)

AGE/YRS	N	MEAN	S.D.	MIN	5TH	50TH	95TH	MAX
2.0-3.5	212	14.7	1.1	11.6	13.0	14.7	16.4	17.8
3.5-4.5	227	16.1	1.0	13.6	14.6	16.0	17.7	20.2
4.5-5.5	263	17.0	0.9	14.7	15.5	17.0	18.4	20.2
5.5-6.5	219	17.9	1.1	14.8	16.2	17.8	19.8	21.5
6.5-7.5	225	18.9	1.2	15.6	16.9	18.8	20.8	22.7
7.5-8.5	191	19.8	1.1	16.8	17.9	19.7	21.5	23.0
8.5-9.5	251	20.8	1.3	17.9	19.0	20.6	23.1	25.4
9.5-10.5	253	21.6	1.3	17.9	19.6	21.6	23.6	25.3
10.5-11.5	282	22.4	1.3	18.2	20.2	22.3	24.8	25.9
11.5-12.5	287	23.2	1.3	19.8	21.1	23.2	25.3	27.2
12.5-13.5	315	23.9	1.5	20.7	21.5	23.7	26.5	28.8
13.5-14.5	270	24.6	1.7	20.6	22.0	24.4	27.7	29.5
14.5-15.5	264	24.8	1.7	20.3	22.4	24.7	27.5	29.2
15.5-16.5	197	25.1	1.9	21.2	22.2	24.9	27.8	29.3
16.5-17.5	221	25.0	1.9	21.5	22.1	24.7	28.1	30.0
17.5-19.0	155	25.5	2.1	20.8	22.2	25.2	28.7	31.1

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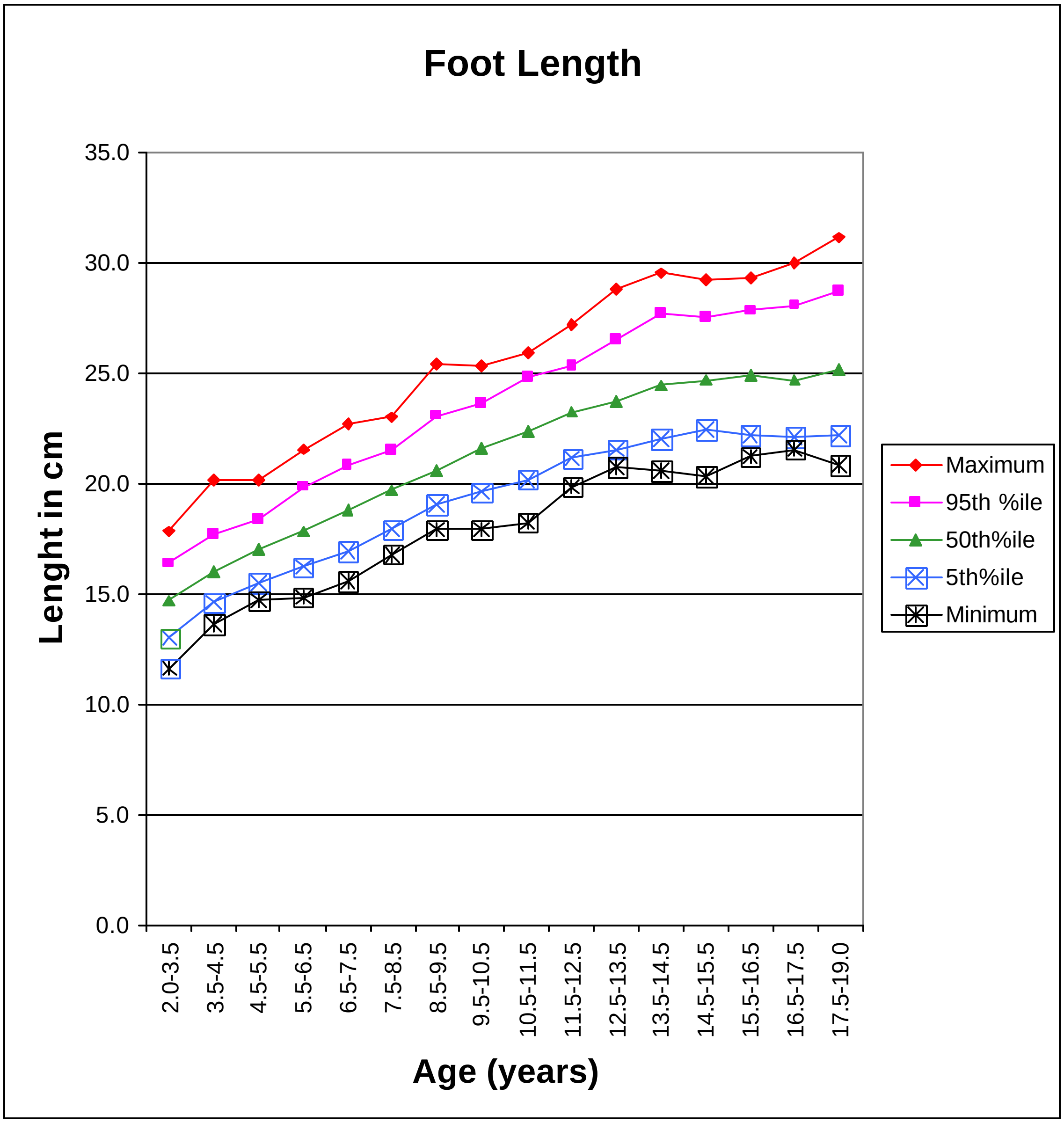
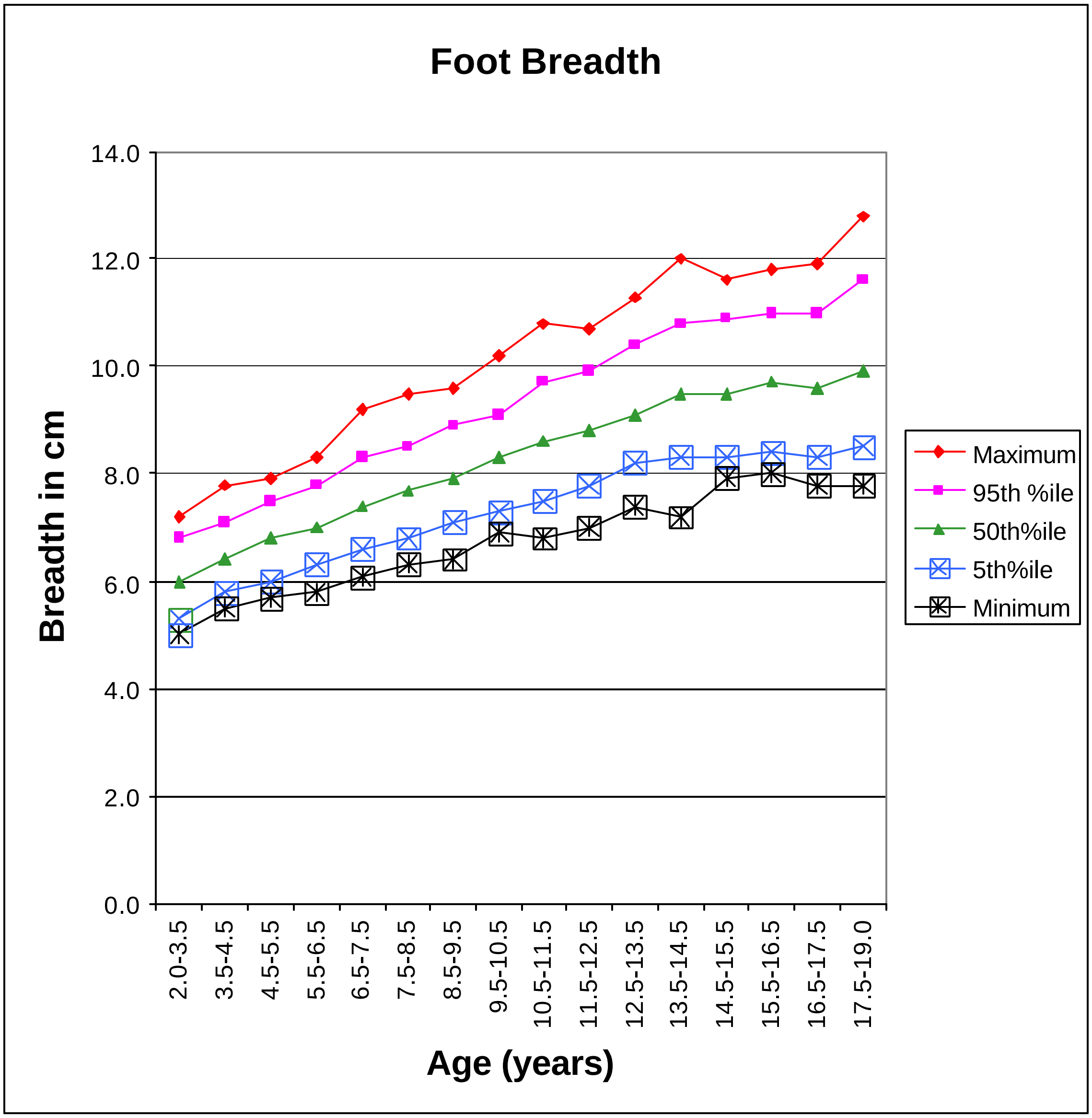

Foot Length
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Lenght in cm
2.0-3.5
3.5-4.5
4.5-5.5
5.5-6.5
6.5-7.5
7.5-8.5
8.5-9.5
9.5-10.5
10.5-11.5
11.5-12.5
12.5-13.5
13.5-14.5
14.5-15.5
15.5-16.5
16.5-17.5
17.5-19.0
Age (years)
Maximum
95th %ile
50th%ile
5th%ile
Minimum

FOOT BREADTH CM. - (MALES AND FEMALES)

AGE/YRS	N	MEAN	S.D.	MIN	5TH	50TH	95TH	MAX
2.0-3.5	212	6.1	0.5	5.0	5.3	6.0	6.8	7.2
3.5-4.5	226	6.5	0.4	5.5	5.8	6.4	7.1	7.8
4.5-5.5	263	6.8	0.4	5.7	6.0	6.8	7.5	7.9
5.5-6.5	219	7.1	0.5	5.8	6.3	7.0	7.8	8.3
6.5-7.5	226	7.5	0.5	6.1	6.6	7.4	8.3	9.2
7.5-8.5	191	7.7	0.5	6.3	6.8	7.7	8.5	9.5
8.5-9.5	251	8.0	0.5	6.4	7.1	7.9	8.9	9.6
9.5-10.5	252	8.3	0.6	6.9	7.3	8.3	9.1	10.2
10.5-11.5	281	8.6	0.6	6.8	7.5	8.6	9.7	10.8
11.5-12.5	287	8.9	0.7	7.0	7.8	8.8	9.9	10.7
12.5-13.5	315	9.2	0.7	7.4	8.2	9.1	10.4	11.3
13.5-14.5	269	9.5	0.8	7.2	8.3	9.5	10.8	12.0
14.5-15.5	264	9.6	0.8	7.9	8.3	9.5	10.9	11.6
15.5-16.5	198	9.8	0.8	8.0	8.4	9.7	11.0	11.8
16.5-17.5	221	9.7	0.9	7.8	8.3	9.6	11.0	11.9
17.5-19.0	155	9.9	0.9	7.8	8.5	9.9	11.6	12.8

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.


Foot Breadth
Breadth in cm
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
2.0-3.5
3.5-4.5
4.5-5.5
5.5-6.5
6.5-7.5
7.5-8.5
8.5-9.5
9.5-10.5
10.5-11.5
11.5-12.5
12.5-13.5
13.5-14.5
14.5-15.5
15.5-16.5
16.5-17.5
17.5-19.0
Age (years)
Maximum
95th %ile
50th%ile
5th%ile
Minimum

Attachment B: Examples of Items for a Cognitive Child Discriminator System

Enter the number two-hundred seventeen.

Enter the following word: Sunday.

Enter the following digits: twenty-four, thirty-seven, forty-eight.

Enter the first 6 letters of the alphabet.

Enter the solution to this equation: eighteen divided by three equals __.

Enter the capitals of the following letters: b a t f q r

Enter the total number of days in one year.

Enter your ATM pass code below.