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Applying State-of-the-Art Technologies to Reduce Escape Times from Fires Using Environmental Sensing, Improved Occupant Egress Guidance, and Multiple Communication Protocols

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14. ABSTRACT

In 2006, under contract to the Consumer Product Safety Commission (CPSC), the Naval Research Laboratory (NRL) was tasked with investigating various technology and concepts — such as visual signals and unique audible sounds — that have the potential to improve residential occupant escape in the event of fire. The investigation included an evaluation of the feasibility of incorporating new technologies or concepts to aid escape capabilities and that may improve egress times in residential homes by implementing and demonstrating a prototype automated egress control system. This report presents the results of that investigation.

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1.0 INTRODUCTION

In the early 1970s, in excess of 8000 Americans were dying in fires annually, 80% of them in residential fires. In 1974, the report of the presidential commission on fire, *America Burning*, recommended that Americans protect themselves from fire at home by installing smoke alarms. According to estimates by the National Fire Protection Association (NFPA) and the U. S. Fire Administration (USFA), U.S. home usage of smoke alarms rose from less than 10% in 1975 to at least 95% in 2000, while the number of home fire deaths was cut nearly in half. The home smoke alarm has been credited as one of the greatest success stories in fire safety in the last part of the 20th century.

The U.S. Consumer Product Safety Commission (CPSC) staff has previously demonstrated technological innovations [1],[2],[3] in fire research and is continuing to search for advances that will provide earlier warning to consumers that may provide additional escape times. In 2006, under contract to CPSC, the Naval Research Laboratory (NRL) was tasked with investigating various technologies and concepts – such as visual signals and unique audible sounds – that have the potential to improve residential occupant escape in the event of fire. The investigation included an evaluation of the feasibility of incorporating new technologies or concepts to aid escape capabilities and that may improve egress times in residential homes by implementing and demonstrating a prototype automated egress control system. This report presents the results of that investigation.

2.0 DESIRABLE AUTOMATED EGRESS SYSTEM ATTRIBUTES

Many people perish in residential fires trying to get to exits. Toxic smoke and heat between them and an exit can cause people to become disoriented, even in buildings in which they are familiar. The use of alarm horns and strobe lights located at exits for directional assistance may provide some benefits, but new and smarter technologies may increase the effectiveness of assisted escape devices. Sound bouncing off interior walls and arriving from multiple paths, or multipaths, may make sounds from alarm horns appear to be originating from multiple directions and thus cause confusion for escaping occupants. Strobe lights may also be ineffective at guiding evacuees to exits in heavily smoky environments due to light absorption and light reflections obscuring the exit location and strobe light source.

The objective of this effort was to study the use of sight and sound techniques that have the potential to enhance occupant escape capabilities when adverse environmental conditions caused by a fire or other life threatening condition are detected and to automate an escape response based on conditions at or near exits. In this investigation, data from sensors (heat, smoke obscuration, and carbon monoxide (CO)), motion detectors, and microphones were analyzed and compared to preset thresholds to determine whether preprogrammed combinations of visual, sound, and speech responses could improve occupant escape from a fire or other life threatening environmental condition. In addition, properly selected sound sources, such as white noise, which may provide good multipath sound rejection or minimize reflected sound waves, were

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investigated as a potential means to improve an occupant's ability to locate exits, even in dense smoke.

A prototype of a smart escape system was constructed to automate an escape response to a detected fire or environmental condition by adapting an off-the-shelf micro-controller to monitor environmental sensors and to activate sight and sound responses to detected threats. The prototype was used to demonstrate an automated response to data from multiple sensors that could provide evacuation guidance to occupants in the event of fire or detected hazardous environmental conditions. Evacuees could be made aware of a number of environmental conditions at the exit including:

1) Direction to safe exit
2) Temperature
3) CO levels
4) Smoke obscuration

Communication between multiple automated exit monitors could direct evacuees to the best available exit. Automating the evacuation of occupants of a burning structure must rely on knowledge of the environmental conditions present in the structure and those conditions present between the occupant and possible escape routes - using that knowledge to guide evacuees to safety. Large structures, such as office buildings and smaller structures, such as a house, both would benefit from an automated system that provides information on the environmental conditions near the exits. Environmental conditions to be monitored at an exit include:

1) Smoke density or obscuration
2) Temperature or heat
3) CO levels
4) Motion
5) Detected and analyzed sound

Collecting and analyzing these conditions at locations around the exits and along egress paths within a building could provide data to help guide occupants to safety. Use of directional sound sources, voice prompts of environmental conditions between evacuees and exits, strobe lights and alarm buzzers could aid in the evacuation process, if used properly.

Evaluation and use of collected environmental data must be studied to determine how this information can best be used to direct occupants to a safe exit. In this prototype, monitoring and evaluation of environmental sensor data were accomplished using a micro-controller that initiates directional white noise sound sources, voice prompts, voice data indicating environmental conditions, strobe lights, alarm horns, and other data derived from and in response to the environmental sensor data. A set of different response outputs could be programmed and designed into the prototype if desired or intended for specific scenarios. For the prototype device described in this report, the responses generated by the prototype were dictated by the environmental conditions sensed by the input sensors on the prototype. The initial responses or inputs programmed into the prototype could be adjusted if future in-depth testing reveals the need to detect and respond differently.

3.0 IDENTIFICATION OF SYSTEM REQUIREMENTS

This effort was focused on the development of an integrated exit control scheme to evaluate environmental sensor data and to control various sound sources, voice prompts, and visual and auditory aids to automate exit strategies from burning structures. Figure 1 is a simple block diagram of the components used in the prototype to monitor and evaluate environmental conditions, initiate sound and voice prompts, control visual alerting equipment, and monitor movement in the exit area.

In the prototype system developed by NRL, smoke density, carbon monoxide levels, temperature, and rate of temperature rise were monitored as inputs. The prototype system evaluated available data to determine if an exit area was safe, and it output commands to direct occupants toward or away from the exit. The prototype system also continued to monitor and evaluate the environment to provide automatic responses of directional sound, visual aids, and auditory prompts to aid an evacuee's escape progress and/or determine the viability of certain escape routes to safely escape a smoke-filled, burning structure.

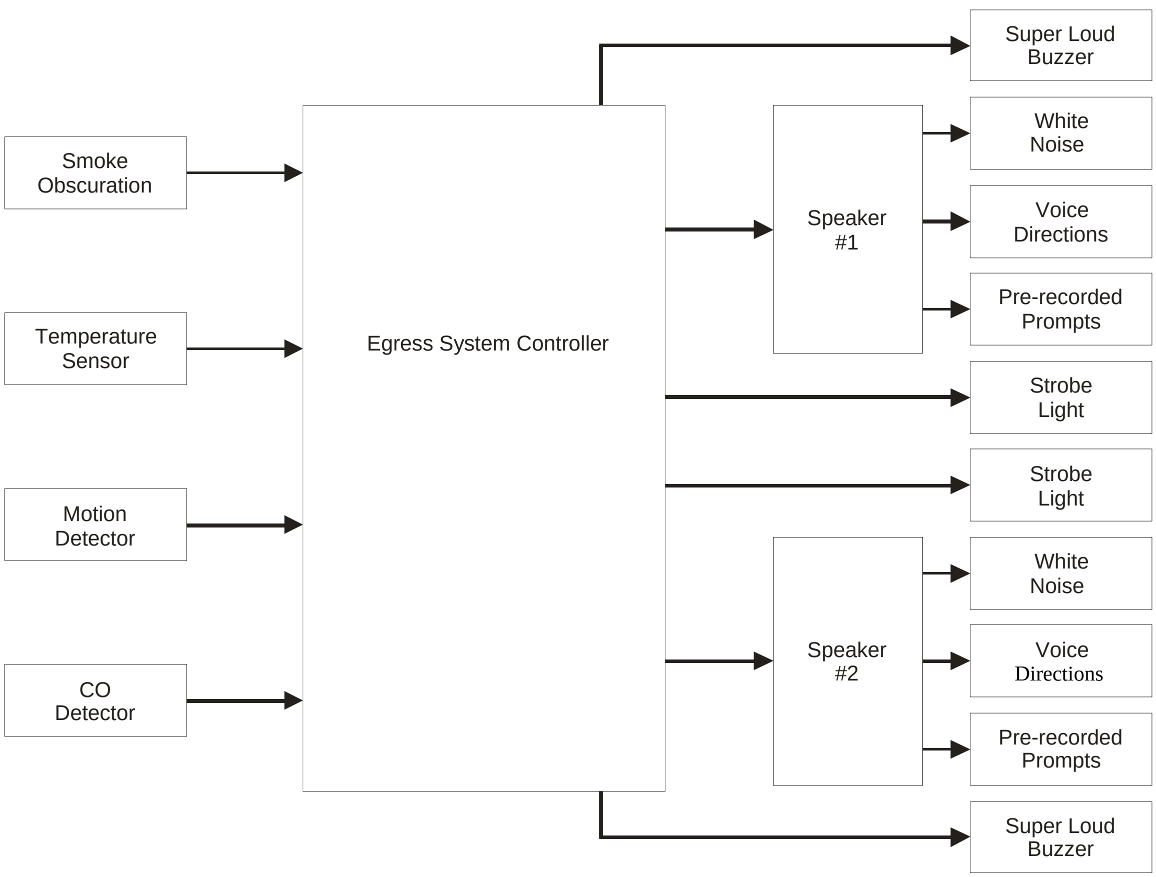


Figure 1. Automated Egress Controller

Future development and testing would be required to determine the optimum response by the system during actual fires to assure that sound and logical responses to data conditions are made. A systematic evaluation of sensor data during actual fires could yield information that would reinforce the use of some predetermined responses to sensor data outputs. In future work, predetermined responses to data could be supplemented by sensor data from other systems at different exit locations and the use of smart smoke alarms that are capable of relaying environmental information to the exit systems. This would provide complete coverage and monitoring of multiple locations throughout a structure [4].

3.1 Environmental Sensors

The prototype automated exit control developed for this project used sensory input data to compute preprogrammed responses that could direct or guide evacuees to safety in the event of a fire. The input sensory data included:

- Smoke obscuration sensor with 0 to 100% obscuration capability
- Temperature sensor with -55°C to 125ºC (-67ºF to 257ºF) temperature range
- Carbon monoxide sensor with a range from 30 ppm to 1,000 ppm
- Motion detector with a range between 20 to 35 feet

3.2 Audio Output Sources

Once the prototype system evaluated the sensory input data and determined that it met the preset thresholds, the system output preprogrammed audio responses could direct or guide evacuees to safety in the event of a fire. The audio outputs included:

- White noise
- Voice prompts, message dependent on the input sensory data
- Pre-recorded voice instructions
- Alarm horn
- Super loud piezo sounder

3.3 Visual Sources

In addition to audio outputs, the prototype system used visual output responses that could direct or guide evacuees to safety in the event of a fire. The visual outputs included:

- White strobe light
- Colored strobe light
- Low voltage spot light
- Luminescent light source

4.0 HARDWARE IMPLEMENTATION

In this project, off-the-shelf components and products were used for the detectors, sensors, controllers, and notification devices. Since the objective was to examine feasibility and not packaging, minimizing the size of the unit was not a priority. A search for off-the-shelf controller products that could monitor sensors, evaluate environmental conditions, and control visual and sound devices was conducted. The home automation products used to monitor and control home security and fire detection systems offered a wide selection of the latest technologies that could be adapted for use in the prototype system. Use of off-the-shelf home automation products allowed the implementation of an egress control prototype suitable for test and evaluation while minimizing development costs. Figure 2 shows the finished prototype unit. A key requirement in selecting an off-the-shelf hardware controller was its ability to interface with individual sensors, evaluate the conditions, and then output the appropriate preprogrammed responses using the various output devices. Ease of sensor interface, suitable operational capabilities, and ease of software development were the primary requirements for product selection. Further development to reduce size and consider packaging, mass manufacturing, and logistics would add additional costs and development time.

Figure 2. Automated Egress Control Prototype

After selecting the off-the-shelf components, such as the controller boards, sensors, and output devices, the individual components were interfaced together. A plug-in, switching, 12 VDC, power supply providing 1.6 amps was used to power all of the electronic circuit boards in the prototype. In future development, a battery back-up system could provide power to the unit in case power was lost during an event. If a battery back-up system was to be used, closer attention to power management would be required during the design phase. The length of time the unit would be required to remain operational would determine the capacity of the battery back-up that would be needed.

It was desirable to limit the size of the enclosure to resemble a typical commercial exit sign, which is approximately 12 ¼" H x 9" D x 5" W (31.1 cm x 22.9 cm x 12.7 cm). This enclosure size allowed more than adequate space for mounting all the required electronics as shown in Figure 3. Hinged doors on each side of the enclosure allowed easy access to the electronics for adjusting and troubleshooting the various circuit boards. The hinged sides also provided access to a programming port to download and modify software. For this prototype, the enclosure was designed with mounting flanges to allow the unit to be installed similarly to a typical commercial exit sign. Residential application would require future development to reduce the size of the unit to the size of a typical smoke alarm. In this application, the unit could be mounted above an exit sign to provide guidance to evacuees in exiting a building. A smaller design would be mounted above the doors in a residential home.

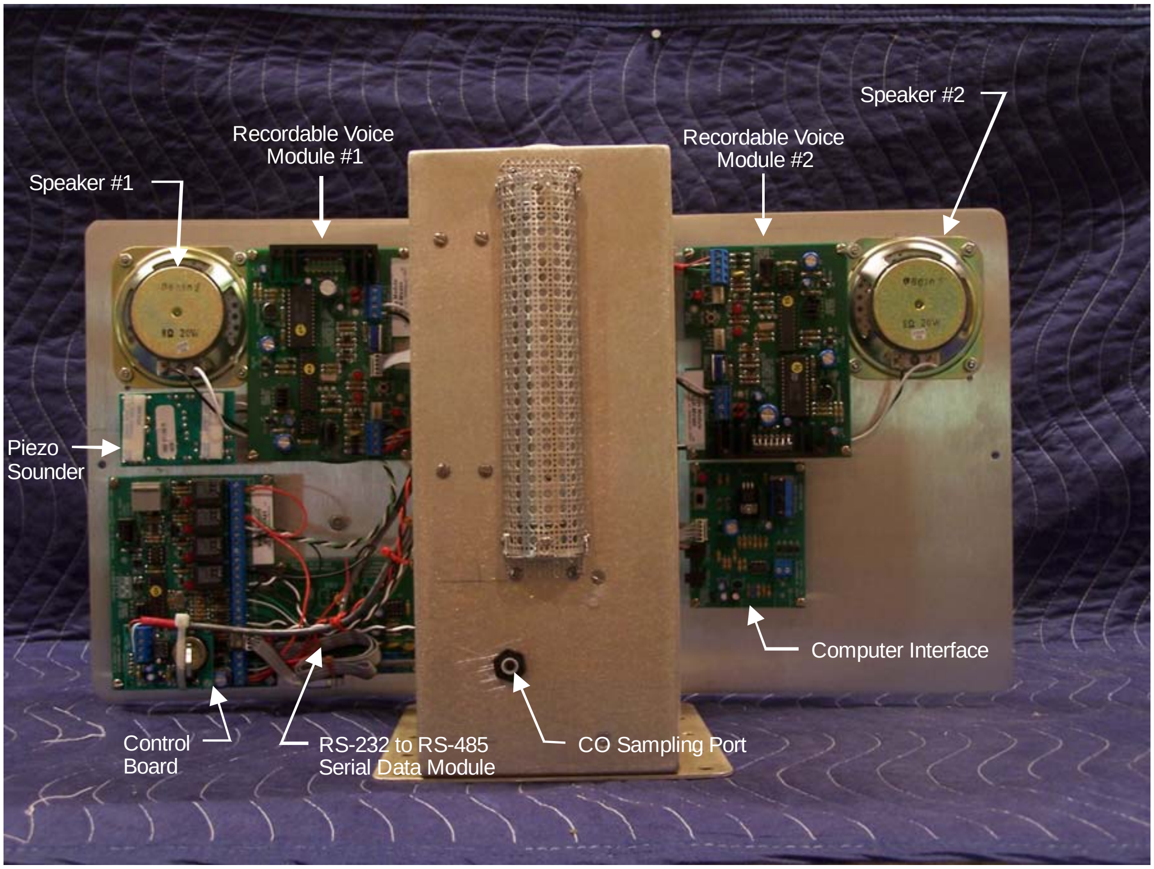


Figure 3. Automated Egress Control Prototype Layout

4.1 Circuit Boards

Electronic boards and controllers were used to operate the various sensors and output devices. The following are the electronic circuit boards used in the prototype, the number used in this application, and a brief description of their capabilities.

- **ELK-MM443 Programmable Controller (1)**

  The MM443 Programmable Controller, Figure 4, is a four analog or digital input, four relay controlled output programmable logic controller (PLC) that can be programmed using a personal computer (PC) in SIMPLE programming language.

The program is stored in an Electrically Erasable Programmable Read Only Memory (EEPROM). For this application, the controller was used as a stand alone field programmable controller. A software program was designed and downloaded into the MM443's EEPROM to implement the prototype automated egress control functions.

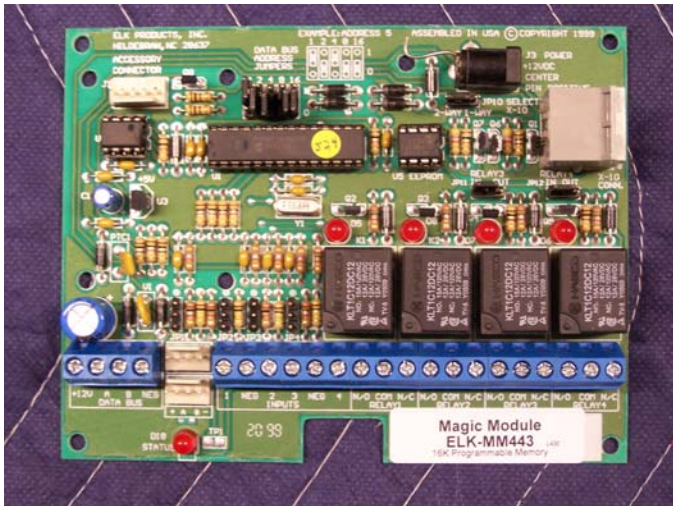


Figure 4. MM443 Programmable Controller

- **ELK-MV480 Recordable Voice Module (2)**

The MV480 Recordable Voice Module, Figure 5, is arranged in 400 pre-recorded and/or custom-recordable segments of 1.2 seconds each. Some segments are pre-recorded by the manufacturer but may be custom recorded utilizing the on-board microphone or downloadable .WAV files. For this application, two recordable voice modules were used to reduce the time it takes to download and transmit messages. The ELK-129 computer interface was used to download recorded sounds (.WAV files) from a PC into the 400 channels of the voice module. Playback command strings (messages) were generated with the manufacturer software program. The messages can be output from the board to any device with an RS-232 or RS-485 port, including a PC.

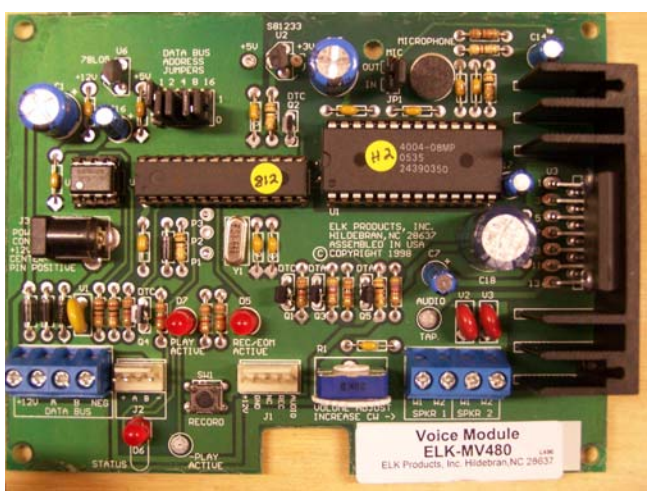
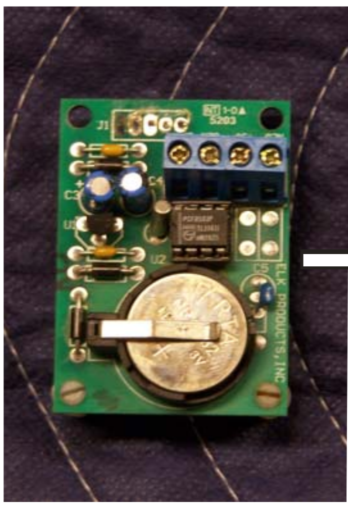


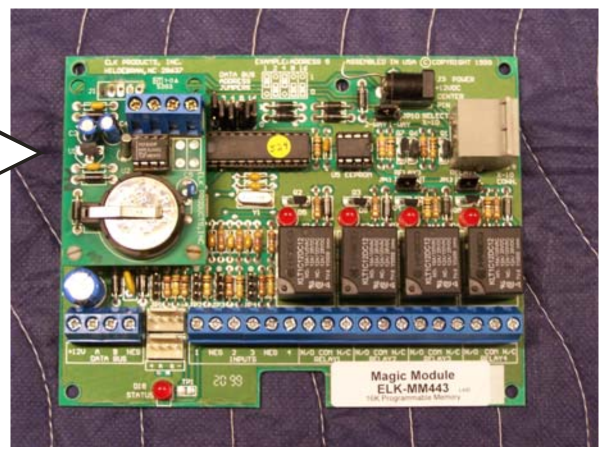
Figure 5. MV480 Recordable Voice Module

- **ELK-MC100 Clock/Calendar (1)**

The MC100, Figure 6, added clock/calendar functions to the MM443 controller. The MC100 has an on-board connection for the MT100 temperature sensor and supports a vast array of clock and calendar and timing functions requiring time-of-day and timed settings. The clock/calendar was piggy-backed on the MM443 Programmable Controller. For this application, the MC100 clock/calendar was used to relieve the MM443 from generating some timing functions that would otherwise slow the real-time execution of the prototype's software program. An on-board battery was used to guarantee that MC100 functions were stored even when the prototype was turned off. The battery life of the MC100 was not an issue in this application, since this was a prototype to determine concept feasibility and because future designs could be implemented without the need for a backup battery requirement.



MC100 Clock/Calendar



MC100 Clock/Calendar Piggy-Backed on the MM443 Programmable Controller

Figure 6. MC100 Clock/Calendar

- **ELK-MB485 Serial Data Converter (1)**

The MB485 Serial Data Converter, Figure 7, was used to communicate software programs and commands between a PC and the MM443 Programmable Controller and to convert RS-232 serial data to RS-485 data used by the MM443. It allowed programs that were generated, modified, and stored on a PC to be downloaded into the MM443.

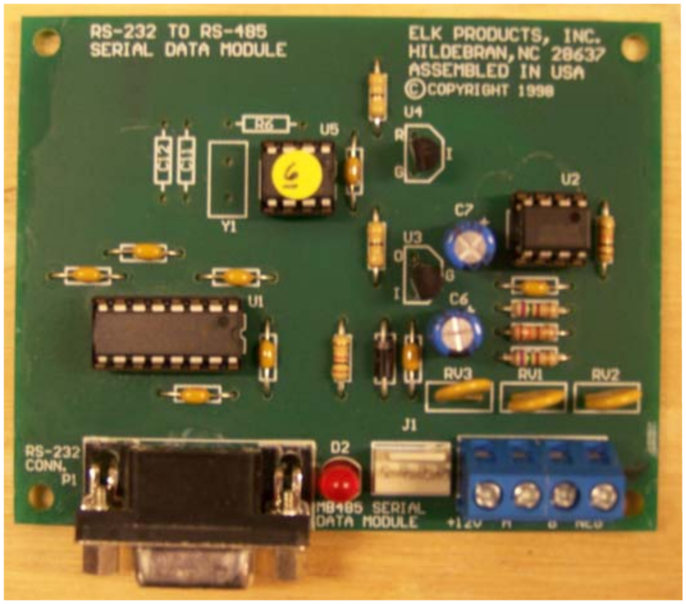


Figure 7. MB485 Serial Data Converter

- **ELK-129 Computer Audio Interface (1)**

  The ELK-129 Computer Audio Interface, Figure 8, allowed a PC's speaker output to be used as one of the tools for programming sounds into the MV480. It includes software to control downloading a PC's audio files (.WAV) to the MV480.

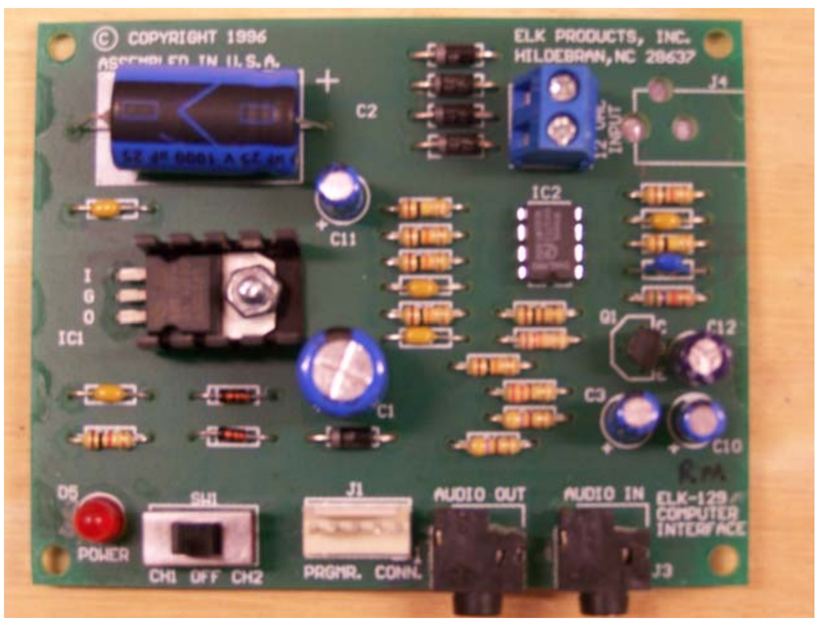


Figure 8. ELK-129 Computer Audio Interface

4.2 Sensors

Various sensors were used to monitor the environment. Sensor data was sent to the internal electrical boards for processing. The following are the sensors used in the prototype, the number used in this application, and a brief description of their capabilities.

- **GE AP100PI Motion Sensor (1)**

The AP100PI Motion Sensor, Figure 9, was a programmable sensitivity, adjustable range passive infrared motion detector. The AP100PI was modified to deliver 7 VDC to the Programmable Controller when motion was detected near the prototype (the detected motion indicated that the exit was in use for this exercise).

Figure 9. GE AP100PI Infrared Motion Detector

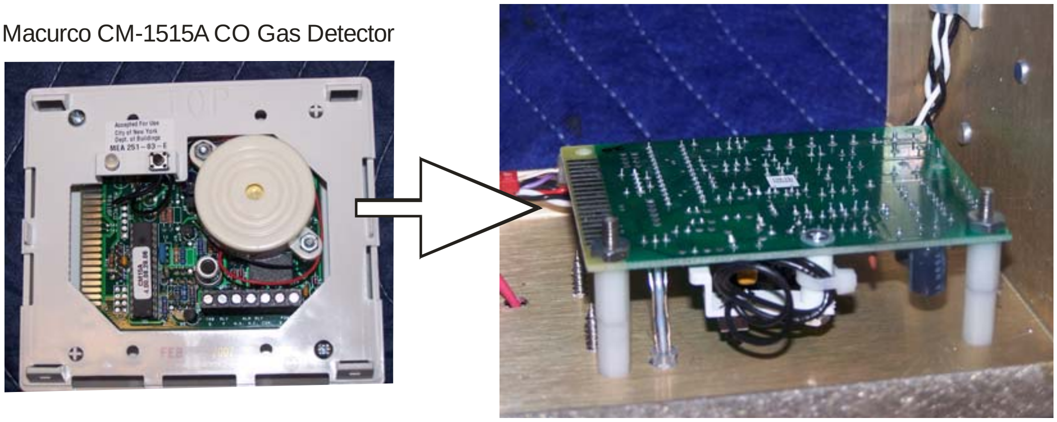
- **ELK-MT100 Temperature Sensor**

The MT100 Temperature Sensor, Figure 10, has a temperature range from -55ºC to +125°C (-67ºF to 257ºF). The sensor allowed the MM443 Programmable Controller to monitor ambient temperatures and control functions. The MT100 was connected to the clock/calendar module on the MM443 controller and was mounted behind a perforated cover on the Egress Control's chassis to allow temperature convection to the temperature module, without the need of a fan.

Figure 10. ELK-MT100 Temperature Sensor

- **Macurco CM-15/15A CO Gas Detector**

The CM-15/15A CO Gas Detector, Figure 11, was factory programmed to alarm if the danger levels of carbon monoxide were exceeded, which were time and concentration-related. The alarm points were: 70 ppm of CO after 60 to 240 minutes, 150 ppm of CO after 10 to 50 minutes, and 400 ppm of CO after 4 to 15 minutes, in accordance with the provisions of the voluntary standard *. The CO detector was modified by removing the alarm horn because the alarm signals were input directly to the Programmable Controller which could output various visual and audible devices within the prototype unit.



Macurco CM-1515A CO Gas Detector

CO Gas Detector Board Installed in Prototype

Figure 11. Macurco CO Gas Detector

- **NRL-Developed Smoke Obscuration Detector and Electronic Interface**

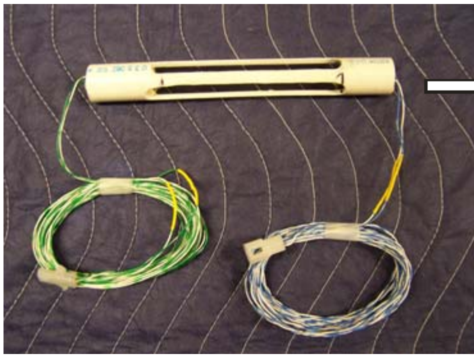
NRL previously developed an optical obscuration detector to measure obscuration due to water drops, which was modified for this application [5]. The detector was incorporated into the prototype unit to measure smoke obscuration as shown in Figure 12. The output voltage levels from the detector were calibrated to correspond to the percent of smoke obscuration detected.

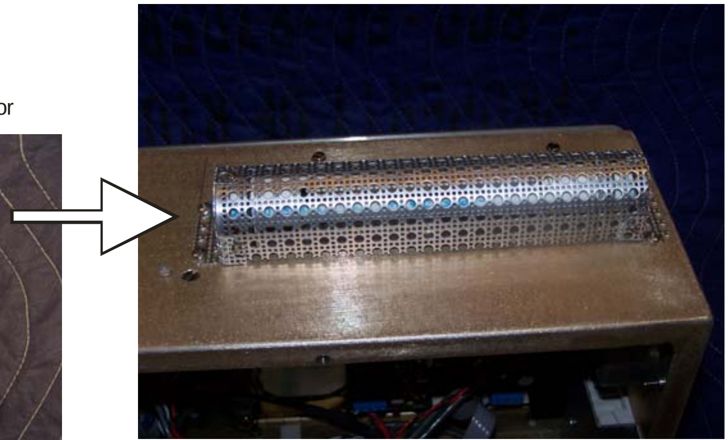
A red diode laser taken from an inexpensive laser pointer was used to supply a concentrated light source in the 645 nm wavelength at approximately 2 mW power and was mounted in one end of a ⅞" (2.2 cm) diameter PVC tube. A photodiode, model S1133-01, having a spectral response of 320 nm to 1100 nm was mounted approximately 4" (10.2 cm) away from the diode laser in the PVC tube. The PVC tube was approximately 6⅝" long x ⅞" (17.5 cm x 2.2 cm) in diameter. The diode laser transmitter and receiver were mounted inside of the PVC tube approximately 4" (10.2 cm) apart.

Four slots approximately 4" (10.2 cm) in length between the transmitter and receiver were cut in the PVC tube every 90° to allow air circulation from the surrounding environment to be analyzed for smoke obscuration. A single supply, inverting operational amplifier (op amp) using a Texas Instruments TLC27 was fabricated for this application, Figure 13. The amplifier was configured as an inverting amplifier with offset adjustment to null out the +4 VDC offset, invert the signal, and set the amplifier gain. The output of the op amp was adjusted to deliver a voltage level between 0 VDC to +4 VDC corresponding to the obscuration level. Zero VDC corresponded to 0% obscuration and +4 VDC corresponded to 100% obscuration. The obscuration output was equal to 40 mV/1% obscuration between 0 VDC and +4 VDC.

* Underwriters Laboratories (UL) 2034, Standard for Single and Multiple Station Carbon Monoxide Alarms

NRL Developed Smoke Obscuration Detector





Smoke Obscuration Detector Installed under Shield on Prototype

Figure 12. NRL Developed Smoke Obscuration Detector

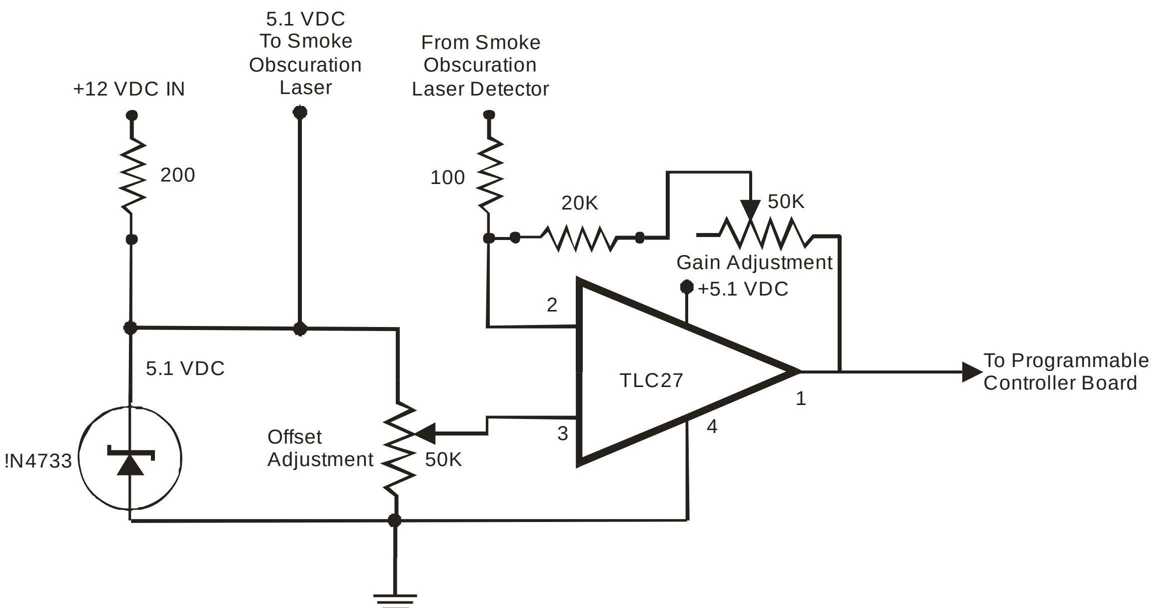


Figure 13. Inverting Amplifier Interface for Smoke Obscuration Detector

4.3 Enunciators

Various audible output devices were used as alerting devices to assist occupants in a fire. The following are the audible output devices used in the prototype, the number used in this application, and a brief description of their capabilities.

- **ELK-73 Speaker (2)**

Two ELK-73 3½", 8 ohm, 20 watt speakers were used, Figure 14. The speakers are weather resistant and used for the transmission of white noise, voice prompts, and voice directions. For this application, the speakers were configured to operate independently to reduce the time for downloading and transmitting messages.

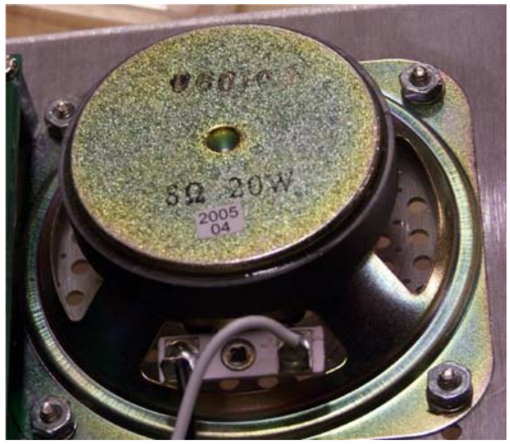


Figure 14. Weather Resistant Speaker

- **Moose MA-2 Piezo Resonator (1)**

The MA-2, Figure 15, is a dual tone, super loud (100 decibels @ 10 feet) Piezo resonator or sounder.

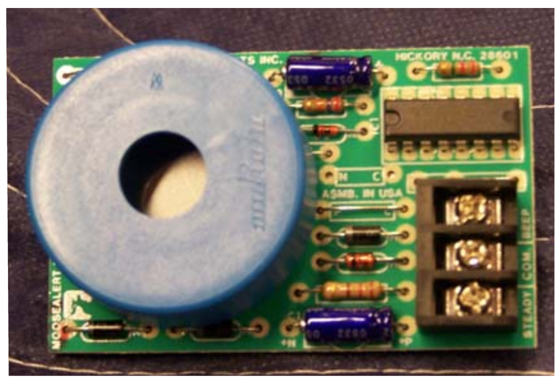


Figure 15. MA-2 Super Loud 100 dB Piezo Resonator

4.4 Visual Devices

In this application, only one visual device was used as a signaling device to assist occupants in a fire. In future development, a visual text board could be implemented to display real time information. The following is the strobe device used in the prototype unit and a brief description of its capabilities.

- **ELK-SL1 Strobe Light**

The ELK-SL1, Figure 16, is a weatherproof strobe light. The strobe light operates on 12 volts DC and draws 210 mA. The flash rate is approximately 1 flash every second. The manufacturer specification sheet did not specify the candela output; but in an actual production unit, it would require sufficient candela output to meet the requirement of building codes and standards.

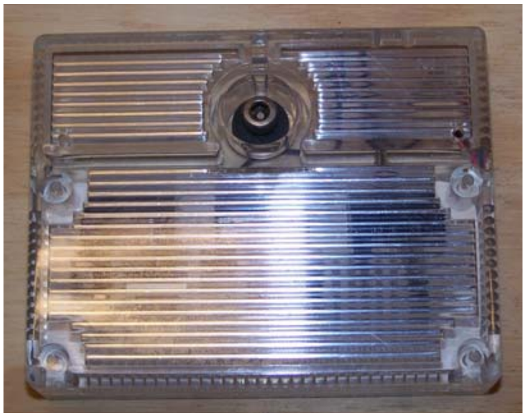


Figure 16. ELK-SL1 Strobe Light

5.0 SOFTWARE IMPLEMENTATION

The MM-443 is a field programmable controller that can be connected to a personal computer (PC) using a RS-485 data bus. A software program was developed, debugged and compiled on a PC using SIMPLE programming language. A built-in code editor and pseudo compiler, simulator, program wizard, code writer and application writer were provided on a compact disc (CD) with the purchase of the Programmable Controller. The software tools provide the programmer with a convenient way to write a software program on a PC and download it to the electrically erasable programmable read-only memory or EEPROM on the MM-443.

5.1 Software Development

Using the available software tools, a program was developed to monitor the various sensors, evaluate the incoming data, and output the appropriate prerecorded audible and/or visual devices. This program routine is intended to aid in the safe evacuation of occupants of a structure in case of fire or environmental hazard. Temperature, smoke obscuration, and carbon monoxide levels were monitored in the vicinity of an exit and evaluated to determine the proper audio/visual response to aid evacuees. Verbal audio response segments, such as *high temperature, warning: smoke, high carbon monoxide level, motion detected at exit,* and *exit immediately*, were prerecorded and could be used depending on the environmental conditions. White noise segments could also be played to help assist occupants as an audible direction signal. Two strobe lights mounted on each side of the unit provided a visual response at the exit area. Sensor threshold levels for temperature, smoke obscuration, and carbon monoxide were evaluated to determine “normal,” “elevated,” and “extreme” ranges for software programming purposes. Future development and research would be required to determine the optimum settings and combinations of audible and visual signals needed to achieve the objective of assisting occupants in exiting the structure.

5.2 Software Operation

The software code developed for the Automated Egress Control prototype is provided in Appendix A. The program was designed with three operational alarm modes labeled as follows: (a) normal, (b) elevated, and (c) extreme, as shown in Figure 17.

(a) The normal mode is a software loop that constantly evaluates the various sensor inputs to determine if increased levels of temperature, smoke, or carbon monoxide are present.

- When the system mode changes from normal to an elevated alarm mode, a one-second audible tone occurs.
- Once in an elevated alarm state, the system will reset to normal alarm mode if all sensors remain below elevated alarm levels for approximately 24 seconds. A two-second steady tone indicates when the system has returned to the normal alarm mode.

(b) The system will achieve an elevated alarm mode status if the temperature reaches 46°C (115ºF) or the obscuration level reaches 10%.

- The system will then respond with a voice prompt stating either ‘High Temperature’ or ‘Warning Smoke.’
- If motion is detected, the system will respond with ‘Motion at Exit.’
- Strobe lights on each side of the prototype will activate.
- Elevated levels of CO will default to the extreme mode.

(c) The system will go into extreme alarm mode if any of the following occur: detected temperature above 60°C (140ºF), detected obscuration above 25%, or detected temperature above 49°C (120.2ºF) with a detected 10% obscuration level, or carbon monoxide is detected.

- Strobe lights will activate.
- Voice prompts will activate based on the activated alarm mode level: ‘High Temperature,’ ‘Warning Smoke,’ or ‘High Carbon Monoxide Level.’
- There will be an additional voice prompt of ‘Exit Immediately,’ followed by ‘Motion Detected at Exit’ if the motion detector is triggered.
- Voice prompts will alternate with white noise to facilitate evacuee’s determination of exit direction, as it is assumed that the environment is smoke-filled and determining exit direction may be difficult.

More study and operational testing are required before a “hazardous exit” designation is made that would re-direct an evacuee to an alternate exit – possibly sending him into a more hazardous area. Environmental sensor data from smoke alarms throughout the building and other automated egress controllers at all exits would provide data to determine when/if to re-direct evacuees to an alternate exit. The prototype is designed to evaluate the feasibility of automating the egress of people from hazardous environments based on environmental sensor data and is one leg in that process.

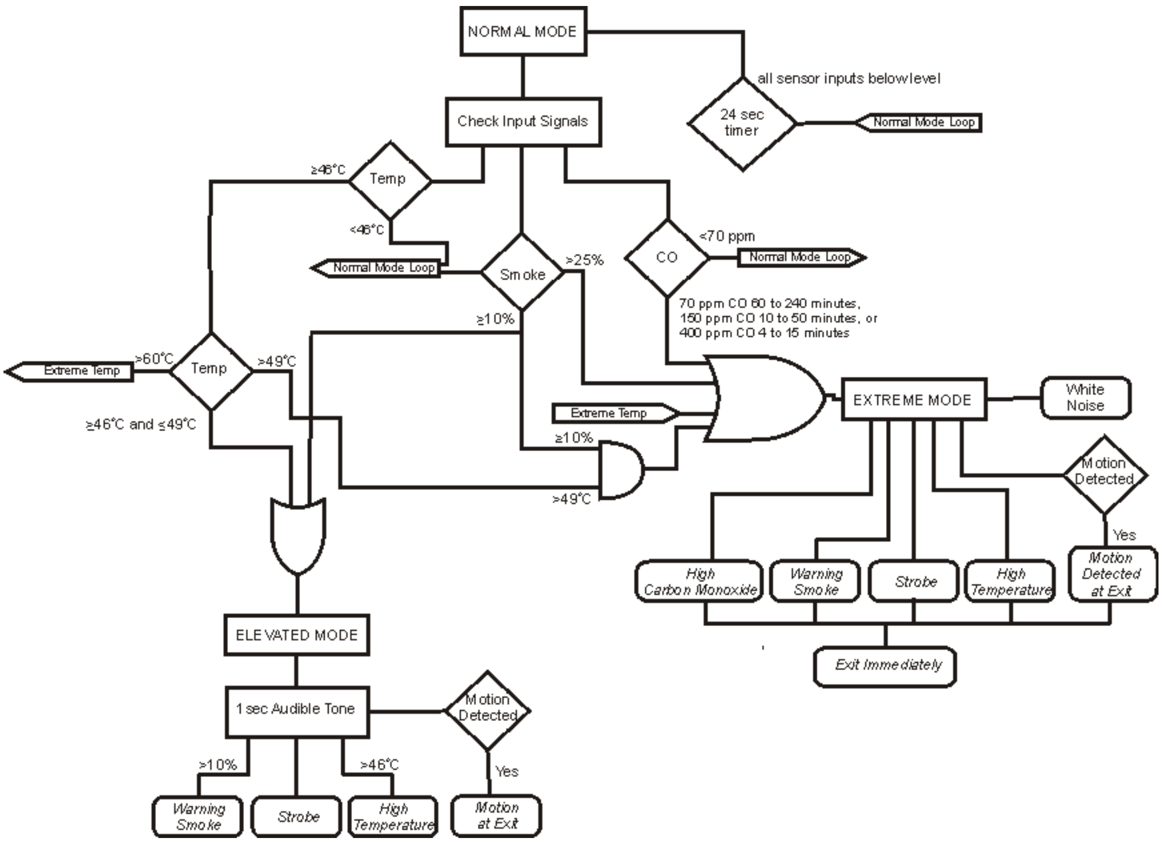


Figure 17. Block Diagram of Software Routine

Sensor inputs to the processor system included temperature, smoke obscuration, carbon monoxide, and motion detection.

- Temperature was measured by a built in temperature sensor that was piggy-backed on the MM443 Programmable Controller and output in degrees Celsius.
- The NRL-developed smoke obscuration detector was calibrated to a 0 to 4 VDC signal level corresponding to 0 to 100% obscuration.
- The carbon monoxide detector output 12 VDC when alarm points of 70 ppm of CO for 60 to 240 minutes or 150 ppm of CO for 10 to 50 minutes or 400 ppm of CO for 4 to 15 minutes were detected.
- The motion detector output was 8 VDC when motion was detected. Both inputs were set 1 VDC lower than their alarm levels. The controller converted the analog input voltages from these sensors using an 8 bit (8 bits = 255 levels) digitizer and used the digital values in the Controller

program. The digitizer range of the signal was 0 to 15.8 VDC, resulting in a resolution of 0.062 VDC (15.8 VDC / 255 levels = 0.062 VDC per level).

Therefore the program was set to accept the following inputs:

- Smoke Obscuration
  - 0.4 V (10% obscuration) = 7 (.04 VDC / 0.062 VDC = 6.45 or 7 levels)
  - 1 VDC (25% obscuration) = 17 (1 VDC / 0.062 = 16.22 or 17 levels)
- Carbon Monoxide
  - 11 V = 177 (11 VDC / 0.062 VDC = 177 levels)
- Motion Detector
  - 7 V (detected motion) = 113 (7 VDC / 0.062 VDC = 112.9 or 113 levels).

6.0 CONCLUSIONS AND RECOMMENDATIONS

Off-the-shelf components were used to build a prototype automated egress controller. Initial testing revealed that the unit functioned as planned.

Using off-the-shelf hardware generated limitations on how the software, which was part of the unit, could be implemented. All design requirements were met, but modifications to the software functions, although possible, will not be as easy to implement as originally intended.

A rigorous testing program of this prototype would be needed to uncover any areas where the operational characteristics designed into the prototype can be thoroughly exercised to determine if there are areas not conforming to reliable and safe operation, including correct responses to sensor data in all situations. In the future, a microcontroller-based system could be implemented with much less hardware and a more robust and more easily modifiable software suite. However, initial implementation would be more costly.

This prototype is a first step in automating the safe egress of occupants from a hazardous environment. It shows promise in its ability to direct the egress of occupants based on an analysis of environmental sensor data. Future automated egress systems could collect data from other automated egress system locations, wireless smoke alarms, and sensors throughout a structure for decision making and have the ability to communicate information to firefighters and rescue personnel.

This new approach could easily be adapted to individual recognition and warning of chemical or biological contamination, via automated environmental sensing using new sensors such as the volume sensor [4].

6.1 Further Work

Future studies to determine the best combination of sensory inputs and visual and audio outputs would be required to determine the parameters for the most effective evacuation and guidance system. Future automated egress systems may employ different combinations of environmental sensors and audio and visual alerting devices for improved detection and guidance. For instance, lights of different colors may be more effective in dense smoke or reduced light. Technologies such as volume sensor, data fusion, and pattern recognition could be evaluated to determine if their use would raise the situational awareness of environmental conditions and reduce the use of point sensors for this application [4]. Increased use of wireless RF links between smoke alarms [2] and other devices [3] with sensors could provide easier access to environmental data measured throughout a structure.

New sensor approaches, such as the use of chemical or biological sensor systems, could be incorporated. The incorporation of a more advanced sensor system could result in an earlier warning of fire hazards and provide real time situational awareness, and may provide a high immunity to nuisance sources (false alarms) [4]. Using sensors that monitor spaces is termed "Volume Sensor" because of its ability to detect event signatures within the volume of a space rather than relying on point sensors. One type of volume sensor is a data-fusion-based detection system utilizing standard video, near infrared (IR) video, ultra-violet (UV) and mid-IR sensors and a microphone. The system uses algorithms incorporating decision rules, pattern recognition, and Bayesian evaluation to analyze the data to determine if the situation is threatening.

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9.0 APPENDIX A

The following is a list of the software program's explanation of labels.

Timer Events
Tmr1Evt – Main system loop
Tmr3Evt – Pulse tone timer
Tmr4Evt – Steady tone timer

Inputs
TEMP – Temperature
IN1 – Smoke obscuration
IN3 – Motion sensor
IN4 – Carbon monoxide

Outputs
OUT1 – Strobe light
OUT3 – Pulse tone
OUT4 – Steady tone

Counters
CNTR1 – White noise check
CNTR2 – First time check
CNTR3 – Full alert check
CNTR4 – Normal mode check

Voice Events
TXdata1 – 'High'
TXdata2 – 'Smoke'
TXdata3 – 'Temperature'
TXdata5 – 'Warning'
TXdata6 – 'and'
TXdata7 – 'Carbon Monoxide'
TXdata8 – 'Level'

TXdata9 – ‘Exit’
TXdata10 – ‘Building’
TXdata11 – ‘Immediately’
TXdata13 – ‘Motion’
TXdata14 – ‘At’
TXdata15 – White Noise
TXdata17 – 200 ms Silence

EGRESS CONTROL SOFTWARE PROGRAM LISTING

```
ELK Magic Module Compiler - white - C:\Program Files\MagicModuleExt\FullProg.src
     Label   Command     Directive     cmp/=to     Goto    Comment
------------------------------------------------------------------------
             ;                             ;FullProg
             ;                             ;ELK Magic Module File Version C
             ;                             ;Compiler Version 5. 1. 17
             title titleend                ;Goto end of Title Data
             data     70                   ;F
             data     117                  ;u
             data     108                  ;l
             data     108                  ;l
             data     80                   ;P
             data     114                  ;r
             data     111                  ;o
             data     103                  ;g
     titleendnull                          ;End of Title
             ;                             ;
             ;                             ;Description Area
             ;                             ;*Timer4 = Timer 4
             ;                             ;
             ;                             ;*Timer3 = Timer 3
             ;                             ;
             ;                             ;*Timer1 = Timer 1
             ;                             ;
             ;                             ;--Put Code Description here--
             ;                             ;end of Description Area
             ;                             ;
             ;                             ;Setup Area
             set      EvtTMR4     Tmr4Evt              ;Timer 4 - Timer4 Event
             set      T4SEC0                ;set seconds value
```

```
        ;                                   ;
        set     EvtTMR3     Tmr3Evt                 ;Timer 3 - Timer3 Event
        set     T3SEC0                  ;set seconds value
        ;                                   ;
        set     EvtTMR1     Tmr1Evt                 ;Timer 1 - Timer1 Event
```

EGRESS CONTROL SOFTWARE PROGRAM LISTING

```
        set     T1SEC8                  ;set seconds value
        set     CNTR1       0                   ;
        ;                                   ;
        set     ElkCode                         ;Special Elk Magic Module Functions
        ;                               ;--Put Initialization here--
        ;                               ;end of Setup Area
        ;                               ;
main    null                            ;Main Program
        ;                               ;--Put main program here--
        goto    main                    ;end of Main Program
        ;                               ;
        ;                               ;Subroutine Area
Tmr4Evt         null                            ;Timer 4 - Timer4 Event
        set     T4SEC0                  ;set seconds value
        ;                               ;--Insert Timer4 Event Program
        set     OUT4  Off               ;
        return                  ;return from timer 4 event
        ;                               ;
Tmr3Evt         null                            ;Timer 3 - Timer3 Event
        set     T3SEC0                  ;set seconds value
        ;                               ;--Insert Timer3 Event Program
        set     OUT3  Off               ;
        return                  ;return from timer 3 event
        ;                               ;
```

```
Tmr1Evt     null                    ;Timer 1 - Timer1 Event
      set   T1SEC8          ;set seconds value
      ;                     ;
      ;                     ;--Insert Timer1 Event Program
      set   CNTR3     0             ;
chkhighTmp  if    TEMP <    60      chkhighObs    ;check for 60C (140F)
      set   CNTR3     3             ;
      set   CNTR4     0             ;
      if    CNTR1 <   2     chkhighObs    ;
      csub  TXBUS     TXdata1             ;Transmit Data Bus – High
```

EGRESS CONTROL SOFTWARE PROGRAM LISTING

```
      csub  TXBUS     TXdata3             ;Transmit Data Bus - Temperature
      set   T1SEC2          ;set seconds value
      if    IN1 <=7   chkhighObs    ;check for 10% obs
      csub  TXBUS     TXdata17            ;Transmit Data Bus - 200 ms Silence
      csub  TXBUS     TXdata6             ;Transmit Data Bus - And
      csub  TXBUS     TXdata5             ;Transmit Data Bus - Warning
      csub  TXBUS     TXdata2             ;Transmit Data Bus – Smoke
      set   T1SEC3          ;set seconds value
      goto  chkCO           ;
chkhighObs  if    IN1 <=    17      chkCO ;check for 25% obs
      set   CNTR3     3             ;
      set   CNTR4     0             ;
      if    CNTR1 <   2     chkCO ;
      csub  TXBUS     TXdata17            ;Transmit Data Bus - 200 ms Silence
      csub  TXBUS     TXdata5             ;Transmit Data Bus - Warning
      csub  TXBUS     TXdata2             ;Transmit Data Bus - Smoke
      set   T1SEC2          ;set seconds value
      if    TEMP <    49    chkCO ;check for 49C (120F)
      csub  TXBUS     TXdata17            ;Transmit Data Bus - 200 ms Silence
```

```
        csub    TXBUS       TXdata6             ;Transmit Data Bus - And
        csub    TXBUS       TXdata1             ;Transmit Data Bus - High
        csub    TXBUS       TXdata3             ;Transmit Data Bus - Temperature
        set     T1SEC3              ;set seconds value
chkCO   if      IN4 <=177   chkCombo    ;check for CO alarm
        set     CNTR3       3           ;
        set     CNTR4       0           ;
        if      CNTR1 <     2       chkCombo    ;
        csub    TXBUS       TXdata17            ;Transmit Data Bus - 200 ms Silence
        csub    TXBUS       TXdata1             ;Transmit Data Bus - High
        csub    TXBUS       TXdata7             ;Transmit Data Bus - Carbon Monoxide
        csub    TXBUS       TXdata8             ;Transmit Data Bus - Level
        set     T1SEC4              ;set seconds value
chkCombo        if      CNTR3 >=    3       FullAlert       ;
        if      TEMP <      49      chklowObs   ;check for 49C (120F)
        inc     CNTR3                   ;
        set     CNTR4       0           ;
chklowObs       if      IN1 <=7     chkStatus   ;check for 10% obs
```

EGRESS CONTROL SOFTWARE PROGRAM LISTING

```
        inc     CNTR3                   ;
chkStatus       if      CNTR3 <     2       chkTemp     ;
        set     CNTR4       0           ;
        if      CNTR1 <     2       FullAlert   ;
        csub    TXBUS       TXdata1             ;Transmit Data Bus - High
        csub    TXBUS       TXdata3             ;Transmit Data Bus - Temperature
        csub    TXBUS       TXdata17            ;Transmit Data Bus - 200 ms Silence
        csub    TXBUS       TXdata6             ;Transmit Data Bus – and
        csub    TXBUS       TXdata17            ;Transmit Data Bus - 200 ms Silence
        csub    TXBUS       TXdata5             ;Transmit Data Bus - Warning
        csub    TXBUS       TXdata2             ;Transmit Data Bus - Smoke
```

```
        set     T1SEC4              ;set seconds value
FullAlert       if      CNTR2 =     4       notFirst        ;
        set     T4SEC1              ;
        set     OUT4  On            ;Pulse tone
        set     CNTR2       4               ;
        csub    TXBUS       TXdata17                ;Transmit Data Bus - 200 ms Silence
        csub    TXBUS       TXdata17                ;Transmit Data Bus - 200 ms Silence
notFirst        set     CNTR3       0               ;
        set     OUT1  On            ;Strobe Lights
        if      CNTR1 <     2       whtnoise        ;
        set     CNTR1       0               ;
        csub    TXBUS       TXdata17                ;Transmit Data Bus - 200 ms Silence
        csub    TXBUS       TXdata17                ;Transmit Data Bus - 200 ms Silence
        csub    TXBUS       TXdata9                 ;Transmit Data Bus - Exit
        csub    TXBUS       TXdata11                ;Transmit Data Bus - Immediately
        set     T1SEC2              ;set seconds value
        if      IN3 <=113   normal  ;check for Motion
        csub    TXBUS       TXdata17                ;Transmit Data Bus - 200 ms Silence
        csub    TXBUS       TXdata17                ;Transmit Data Bus - 200 ms Silence
        csub    TXBUS       TXdata13                ;Transmit Data Bus - Motion
        csub    TXBUS       TXdata14                ;Transmit Data Bus - At
        csub    TXBUS       TXdata9                 ;Transmit Data Bus - Exit
        set     T1SEC4              ;set seconds value
```



```
        goto    normal              ;
whtnoise        csub    TXBUS       TXdata15                ;Transmit Data Bus - White Noise
        goto    normal              ;
chkTemp         if      TEMP <      46      chkObs          ;check for 46C (115F)
        if      CNTR2 >=    2       notFirst2       ;
        set     T4SEC1              ;
```

```
        set     EvtTMR      Tmr4Evt             ;
        set     OUT4  On            ;Pulse Tone
        set     CNTR2       2               ;
notFirst2       set     CNTR4       0               ;
        set     OUT1  On            ;Strobe Lights ON
        csub    TXBUS       TXdata1             ;Transmit Data Bus – High
        csub    TXBUS       TXdata3             ;Transmit Data Bus - Temperature
        set     T1SEC2              ;set seconds value
        if      IN3 <=113   normal ;check for Motion
        csub    TXBUS       TXdata13            ;Transmit Data Bus - Motion
        csub    TXBUS       TXdata14            ;Transmit Data Bus - At
        csub    TXBUS       TXdata9             ;Transmit Data Bus - Exit
        set     T1SEC3              ;set seconds value
chkObs          if      IN1 <=7     normal ;check for 10% obs
        if      CNTR2 >=    2       notFirst3       ;
        set     T4SEC1              ;
        set     OUT4  On            ;Pulse tone
        set     CNTR2       2               ;
notFirst3       set     CNTR4       0               ;
        set     OUT1  On            ;Strobe Lights ON
        csub    TXBUS       TXdata5             ;Transmit Data Bus - Warning
        csub    TXBUS       TXdata2             ;Transmit Data Bus - Smoke
        set     T1SEC2              ;set seconds value
        if      IN3 <=113   normal ;check for Motion
        csub    TXBUS       TXdata13            ;Transmit Data Bus - Motion
        csub    TXBUS       TXdata14            ;Transmit Data Bus - At
        csub    TXBUS       TXdata9             ;Transmit Data Bus - Exit
        set     T1SEC3              ;set seconds value
        ;                   ;
normal  if      CNTR4 <     3       end     ;
```

```
            set     CNTR4       3                   ;
            if      CNTR2 =     0       Nrelayskip  ;
            set     EvtTMR3     Tmr3Evt             ;
            set     T3SEC2              ;
            set     OUT3  On            ;steady tone
Nrelayskip  set     CNTR1       0                   ;
            set     CNTR2       0                   ;
            set     CNTR3       0                   ;
            set     OUT1  Off           ;Strobe Light OFF
end         inc     CNTR4                           ;
            inc     CNTR1                           ;
ret         return              ;return from timer 1 event
            ;                   ;
            ;                   ;--Put subroutines here—-
            ;                   ;end of Subroutine Area
            ;                   ;
            ;                   ;No Program Below Here, Only Data!
            ;                   ;
            ;                   ;Data Area
            ;                   ;200 ms Silence
TXdata17    data    4                   ;TXBUS Data, Type To (Voice Module)
            data    2           ;TXBUS Data, Address To (1 to 31)
            data    32          ;Say Voice Message
            data    30          ;Voice Lo Start Address
            data    0           ;0= oneshot, 1= repeat phrase
            data    0           ;Voice Hi Start Address
            data    0           ;dummy
            ;                   ;
            ;                   ;White Noise
TXdata15    data    4                   ;TXBUS Data, Type To (Voice Module)
```

```
        data    3                        ;TXBUS Data, Address To (1 to 31)
        data    32                       ;Say Voice Message
        data    134                      ;Voice Lo Start Address
        data    0                        ;0= oneshot, 1= repeat phrase
        data    1                        ;Voice Hi Start Address
```

EGRESS CONTROL SOFTWARE PROGRAM LISTING

```
        data    0                        ;dummy
        ;                                ;
        ;                                ;At
TXdata14        data    4                        ;TXBUS Data, Type To (Voice Module)
        data    2                        ;TXBUS Data, Address To (1 to 31)
        data    32                       ;Say Voice Message
        data    53                       ;Voice Lo Start Address
        data    0                        ;0= oneshot, 1= repeat phrase
        data    0                        ;Voice Hi Start Address
        data    0                        ;dummy
        ;                                ;
        ;                                ;Motion
TXdata13        data    4                        ;TXBUS Data, Type To (Voice Module)
        data    2                        ;TXBUS Data, Address To (1 to 31)
        data    32                       ;Say Voice Message
        data    201                      ;Voice Lo Start Address
        data    0                        ;0= oneshot, 1= repeat phrase
        data    0                        ;Voice Hi Start Address
        data    0                        ;dummy
        ;                                ;
        ;                                ;Immediately
TXdata11        data    4                        ;TXBUS Data, Type To (Voice Module)
        data    2                        ;TXBUS Data, Address To (1 to 31)
        data    32                       ;Say Voice Message
```

```
        data    155                     ;Voice Lo Start Address
        data    0                       ;0= oneshot, 1= repeat phrase
        data    0                       ;Voice Hi Start Address
        data    0                       ;dummy
        ;                               ;
        ;                               ;Building
TXdata10        data    4                       ;TXBUS Data, Type To (Voice Module)
        data    2                       ;TXBUS Data, Address To (1 to 31)
        data    32                      ;Say Voice Message
        data    67                      ;Voice Lo Start Address
        data    0                       ;0= oneshot, 1= repeat phrase
```

EGRESS CONTROL SOFTWARE PROGRAM LISTING

```
        data    0                       ;Voice Hi Start Address
        data    0                       ;dummy
        ;                               ;
        ;                               ;Exit
TXdata9         data    4                       ;TXBUS Data, Type To (Voice Module)
        data    2                       ;TXBUS Data, Address To (1 to 31)
        data    32                      ;Say Voice Message
        data    118                     ;Voice Lo Start Address
        data    0                       ;0= oneshot, 1= repeat phrase
        data    0                       ;Voice Hi Start Address
        data    0                       ;dummy
        ;                               ;
        ;                               ;Level
TXdata8         data    4                       ;TXBUS Data, Type To (Voice Module)
        data    2                       ;TXBUS Data, Address To (1 to 31)
        data    32                      ;Say Voice Message
        data    174                     ;Voice Lo Start Address
        data    0                       ;0= oneshot, 1= repeat phrase
```

```
        data    0               ;Voice Hi Start Address
        data    0               ;dummy
        ;                       ;
        ;                       ;Carbon Monoxide
TXdata7 data    4                       ;TXBUS Data, Type To (Voice Module)
        data    2               ;TXBUS Data, Address To (1 to 31)
        data    32              ;Say Voice Message
        data    71              ;Voice Lo Start Address
        data    0               ;0= oneshot, 1= repeat phrase
        data    0               ;Voice Hi Start Address
        data    0               ;dummy
        ;                       ;
        ;                       ;and
TXdata6 data    4                       ;TXBUS Data, Type To (Voice Module)
        data    2               ;TXBUS Data, Address To (1 to 31)
        data    32              ;Say Voice Message
        data    46              ;Voice Lo Start Address
        data    0               ;0= oneshot, 1= repeat phrase
        data    0               ;Voice Hi Start Address
        data    0               ;dummy
        ;                       ;
        ;                       ;Warning
TXdata5 data    4                       ;TXBUS Data, Type To (Voice Module)
        data    2               ;TXBUS Data, Address To (1 to 31)
        data    32              ;Say Voice Message
        data    56              ;Voice Lo Start Address
        data    0               ;0= oneshot, 1= repeat phrase
        data    1               ;Voice Hi Start Address
        data    0               ;dummy
        ;                       ;
        ;                       ;Temperature
TXdata3 data    4                       ;TXBUS Data, Type To (Voice Module)
```

```
        data    2                           ;TXBUS Data, Address To (1 to 31)
        data    32                          ;Say Voice Message
        data    30                          ;Voice Lo Start Address
        data    0                           ;0= oneshot, 1= repeat phrase
        data    1                           ;Voice Hi Start Address
        data    0                           ;dummy
        ;                                   ;
        ;                                   ;Smoke
```

EGRESS CONTROL SOFTWARE PROGRAM LISTING

```
TXdata2         data    4                       ;TXBUS Data, Type To (Voice Module)
        data    2                           ;TXBUS Data, Address To (1 to 31)
        data    32                          ;Say Voice Message
        data    13                          ;Voice Lo Start Address
        data    0                           ;0= oneshot, 1= repeat phrase
        data    1                           ;Voice Hi Start Address
        data    0                           ;dummy
        ;                                   ;
        ;                                   ;High
TXdata1         data    4                       ;TXBUS Data, Type To (Voice Module)
        data    2                           ;TXBUS Data, Address To (1 to 31)
        data    32                          ;Say Voice Message
        data    148                         ;Voice Lo Start Address
        data    0                           ;0= oneshot, 1= repeat phrase
        data    0                           ;Voice Hi Start Address
        data    0                           ;dummy
        ;                                   ;
```