Alternative Calibration Process for Optical Smoke Detectors

A Major Qualifying Project
submitted to the faculty of
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

By:
Maura Killeen and Lauren Giacobbe

In Partnership with:
Jikang (Tony) Cui and Chengliang (Carl) Ye
of Shanghai Jiao Tong University

Date:
August 23, 2012

Advised by:
Professor Yiming (Kevin) Rong

Abstract

Optical smoke detectors must be calibrated in order to accurately determine obscurity levels. Engineers from Tyco International identified several disadvantages with previously utilized methods of calibration. This project investigated several potential improvements to the existing techniques, and developed alternative methods of calibrating optical smoke detectors. After conducting extensive research and systematically comparing multiple processes, the method of inserting a reflective surface with a variable angle of refraction was identified as the most appropriate. This paper provides justification for that selection.

Acknowledgements

Numerous people provided abundant support and assistance over the course of this project. In addition to employees of Tyco in Westminster, Massachusetts; Wizmart in Ningbo, China; and Flextronics in Suzhou, China; the team would like to thank:

Yiming (Kevin) Rong, Professor of Mechanical Engineering at Worcester Polytechnic Institute

Lei Zhang, Professor of Mechanical Engineering at Shanghai Jiao Tong University

A.J. Capowski, Chief Engineer, Tyco Fire Protection Products

Bob Lin, Engineering Manager, Tyco International

Justin Tu, Mechanical Engineer, Tyco Fire Protection Products

Authorship

Maura Killeen and Lauren Giacobbe contributed equally to this project.

Table of Contents

List of Figures

List of Tables

1.0: Introduction

The functionality of optical smoke detectors is vital for public safety (Baker & Adams, 1993). Normally, these devices utilize photodiodes housed in dark chambers. Ventilation through the casing allows the surrounding air to enter. An infrared light-emitting diode (IRLED) projects a beam parallel to the photodiode. Under clean air conditions, the refraction from the IRLED onto the photodiode is minimized. However, an increase in refracted light will raise the output from the photodiode, which can indicate the presence of obscuring particles. Therefore, an alarm is generated if there is a prolonged increase in photodiode output (Wizmart engineers, personal communication, 25 June 2012). Determining the value at which an alarm should be generated is crucial. False alarms resulting from overly sensitive devices can result in decreased significance and inconvenience; delayed alarms in actual emergencies can prevent responsive action and result in property damage, injuries, and death (Dubivsky & Bukowski, 1989).

In order to ensure that the alarm is initiated at an appropriate level of obscuration, optical smoke detectors must be calibrated (United Nations Industrial Development Organization, 2006). The most common method of accomplishing this is to determine what value the assembled smoke detector will output at a specific obscurity. This value can be identified by placing the device in a chamber with a simulated obscurity; the output can then be recorded (A.J. Capowski, personal communication, February 9, 2012). This value can then be compared to the output in clean air, and the resulting offset can be used to adjust the sensor (Mi & Rattman, 2009).

Tyco Fire and Security, a major producer of smoke detection instruments, has requested an improved calibration method. Details can be seen in Appendix A. While their “smoke boxes” accurately simulate obscurity, this process requires extensive control systems including ventilation. The company has developed electronic calibration stations, which temporarily replace the external cover of an assembled sensor and simulate refraction using additional IRLEDs. These devices have worked well, but are aging and will soon have to be replaced. Tyco International would like to use this opportunity to explore areas for improvement in the calibration process, including lowering expenses, increasing accuracy, reducing number of control systems, decreasing completion time, and increasing throughput during manufacturing, as noted in the project description in Appendix A.

The overarching goal of this product is to aid Tyco International in the development of a calibration process that addresses these requests. We hope to accomplish this by researching and investigating currently utilized calibration techniques, analyzing these processes, comparing these to any potentially feasible new methods, and selecting one or more processes for further development. After defining the most appropriate calibration technique(s), we will present our findings and recommendations to Tyco to facilitate their design processes.

2.0: Background & Literature Review

In this chapter, relevant information concerning optical smoke detectors and their calibration is discussed. The first section details optical smoke detectors and their functionality. In section two, the importance of ensuring accurate calibration of optical smoke detectors is addressed. Section three summarizes calibration techniques that are currently utilized in industry. In section four, the methods utilized by the company are identified. Finally, section five discusses the Tyco International specifications for an improved calibration method.

2.1: Optical Smoke Detectors

For this project, the focus will be on photoelectric light scattering smoke detectors, which utilize a light source in order to detect obscuration (System Sensor, n.d.). In Appendix B it is stated that photoelectric smoke detectors, also known as optical smoke detectors, primarily detect slow-burning fires such as overheating cables; ion chambers are more appropriate for rapidly spreading fires ("Smoke Alarm Roundup", 2008).

All photoelectric smoke sensors require a chamber, a photodiode, and an IRLED (infrared light-emitting diode). The chamber is the space inside the smoke detector that is not exposed to any light, but ventilation allows obscuring particles from the air to enter, as seen in Figure 1 (Wizmart engineers, personal communication, 25 June 2012).

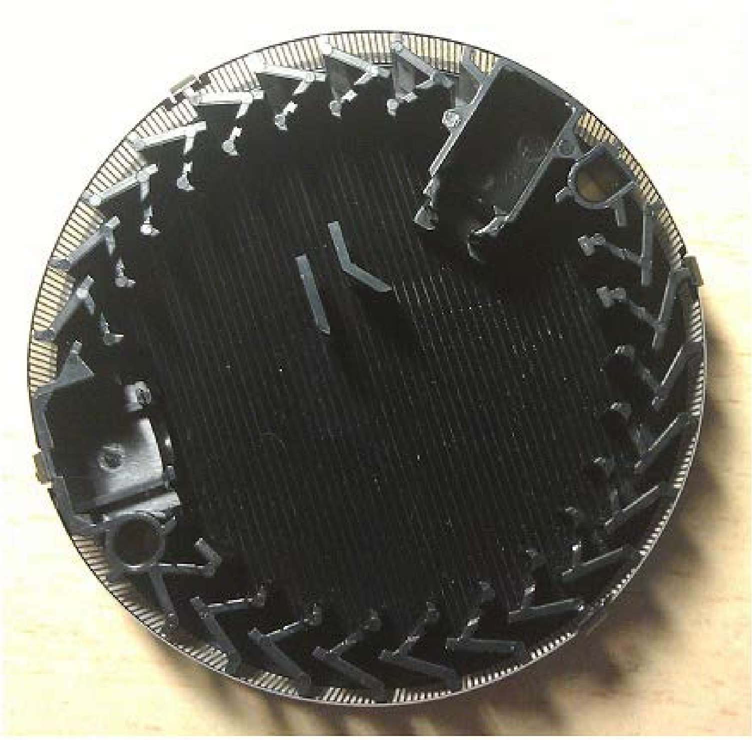


Figure 1. Exposed chamber of an optical smoke detector.

The photodiode produces a current or voltage when it is exposed to its specified trigger value for light (Hamamatsu, n.d.). The IRLED is a light source that projects a beam of infrared light parallel to the photodiode; light then triggers the sensor when a predetermined level of obscuring particles crosses the path of the IRLED beam and reflects light (Baker & Adams, 1993).

The alarm for the smoke sensor is activated when the photodiode detects the specified level of obscuration. As smoke, dust, and other obscuring particles reflect light from the IRLED, the photodiode detects these changes. When the particle density is at the specified percent obscuration per foot, the alarm is then triggered (Kadwell & Pattok, 2005). There are two distinct types of photoelectric smoke detectors: light obscuring and light scattering. The obscuring sensor triggers an alarm by an absence of light due to a specified level of obscuration. The light scattering photoelectric smoke detector triggers an alarm when smoke particles reflect light from the IRLED onto the photodiode; this is the model for which Tyco has requested a new calibration method.

A large range of percent obscuration per foot values are used for optical smoke sensors. As the National Institute of Standards and Technology (NIST) notes, manufacturers often design smoke sensors to detect as wide a range as possible in order to facilitate calibration (Dubivsky & Bukowski, 1989). However, the devices are most frequently set to values ranging from 1 to 3% obscuration per foot. Additionally, most public and private organizations do not set sensitivity any lower than 0.6% obscuration per foot, so as to avoid excessive false alarms (Duke University, 2006). The National Institute of Standards and Technology lists approximately 1.01% obscuration per foot, 2.01% obscuration per foot, and 2.99% obscuration per foot as the high, middle, and low sensitivity settings, respectively (Cleary, 2009). For this project, Tyco has suggested 3% obscuration per foot as the target number (see Appendix A). A random sampling of smoke detectors yields a dominant result of approximately 2.6-3.6% obscuration per foot, which confirms the company standard as a relatively common choice (Shapiro, 1994).

2.2: Importance of Calibration

A proper calibration method is vital to ensure that each smoke detector is accurate and reliable (United Nations Industrial Development Organization, 2006). Additionally, initial calibration in the factory is required by the UL 268 regulation, a publication by the nonprofit safety organization UL (Gentex, 1998; UL LCC, n.d.). This rule is enforced by UL representatives testing random samples from the company on an annual basis (Dungan, 2007). According to the United Nations Industrial Development Organization, calibration is defined as a set of operations that establish the relationship between values indicated by the instrument, a separate measuring system, and the corresponding known values. This process is necessary in order to guarantee traceability, or that all smoke detectors will output consistently corresponding values which meet reference standards.

The National Fire Protection Association, a nonprofit organization dedicated to outlining safe practices for fire safety, outlines the importance of smoke sensor calibration in their NFPA 72 publication. Manufacturing differences and other variables such as dust or dirt can alter the sensitivity of the sensor (System Sensor, 2010). Common manufacturing variations include photodiode sensitivity, IRLED strength, and imperfections in the sensor chamber (Wizmart engineers, personal communication, 25 June 2012). Failing to properly calibrate the sensor can result in either lack of functionality (less sensitivity) or excessive false alarms (more sensitivity). Therefore, it is imperative that each smoke detector is calibrated according to each respective manufacturer.

It is also important to use a viable calibration technique. For example, canned smoke or an aerosol chemical spray may be arbitrarily sprayed to test the functionality of the smoke detector. However, utilizing an unmeasured concentration can produce random or inconsistent results, as the NFPA notes (National Fire Protection Association, 2010).

2.3: Existing Calibration Methods

Several alternative calibration techniques for photoelectric sensors exist that are currently employed by numerous organizations. While most of the methods implement similar concepts, some steps and equipment are distinctly different.

The smoke box method makes use of an enclosed chamber that contains a consistent level of smoke. The assembled smoke detector is placed in this compartment, where fire conditions are simulated by producing a specific percentage of obscuration. This is often accomplished using an aerosol generator, as the behavioral differences of aerosol and smoke particles are negligible (Weiner, Cleary, Mulholland, & Beever, 2003). Readings are then taken in the unaltered air outside the apparatus, which serves as a control value, and inside the smoke box. The difference in values is measured and the potentiometer within the detector is adjusted accordingly. Finally, a reading is taken in the air outside the apparatus again to confirm that the values are within an accepted tolerance. As described in Appendix A, if the calibration was unsuccessful, then the process is reiterated until the difference in values is within range.

The Gemini 501A Smoke Detector Analyzer is a variation of the traditional smoke box apparatus, which Tyco currently employs instead (Gemini Scientific Corporation, 1996). A nebulizer first sprays an FDA grade mineral oil into the closed environment; all particles larger than the acceptable size for simulating smoke are removed by means of an impactor. After the particles are within a consistent range of approximately 0.2 to 0.45 micrometers, the concentration of smoke is adjusted. A vacuum pump removes excess smoke and a blower propels room air into the box in order to reduce the level of obscuration. This design is preferential due to the harmless nature of the particulates; a common concern with smoke box calibration is the hazard of exposing the surrounding environment to smoke. Many smaller organizations and laboratories choose this product for individual calibration needs (Brown & Vickers, 1995). For example, Meridian photoelectric smoke detectors are calibration with the Gemini 501A in order to ensure accuracy and prove safety before distributing their products to the public (Digital Security Controls, 1996).

Another similar product is the AW Technology 1900 optical detector calibration tunnel (AW Technology, 2010). This calibration instrument utilizes aerosol in a contained environment that is easily controlled by means of a computer. After the tunnel stabilizes at the desired percent obscuration, the calibration may be completed for each batch of smoke detectors in approximately three minutes with an optical scatter smoke sensor. As a result, this adaption of the smoke box apparatus facilitates calibration and improves efficiency.

2.4: Calibration Methods for Photoelectric Smoke Sensors Utilized by the Company

Due to manufactured differences, a calibration process is necessary for each photoelectric smoke sensor in order to ensure that obscuration levels are consistently detected and that industry standards are met (United Nations Industrial Development Organization, 2006; Dungan, 2007). Tyco currently utilizes two techniques for calibrating sensors: the smoke box method and the electronic calibration method (A.J. Capowski, personal communication, February 9, 2012).

2.4.1: Calibration by Means of a Smoke Box Apparatus

Multiple smoke box calibration stations are currently utilized at Wizmart, an important manufacturer for Tyco located in Ningbo, China. Initially, one basic station is utilized for calibration of every manufactured product that passes through the factory. Afterward, two more accurate testing stations, the UL Smoke Testing Box ESD C01 and the Lorenz Test-tunnel EN54-5/7, verify if random samples pass American and European standards, respectively. The UL Smoke Testing Box is more accurate than the generic smoke box, but can take up to three hours to complete one test. The Lorenz Test-tunnel is the most accurate apparatus in the factory, but it is a multimillion-dollar machine that is costly to maintain and replace. Therefore, only the less accurate smoke box is employed on a regular basis in order to control cost and time consumption (Wizmart engineers, personal communication, 25 June 2012).

For accurate and consistent calibration of smoke detectors, the environment inside the box must be maintained at a known obscuration. Six different materials are consecutively burned inside the box to simulate 3 percent obscuration per foot. During these six trials, the software pauses until there is an appropriate amount of smoke and clean air is introduced if the obscuration becomes too elevated. After a stable environment is produced, a densitometer, or a calibrated smoke detector, is inserted into the smoke box in order to determine the obscuration and whether a calibration is appropriate at that level (Wizmart engineers, personal communication, 25 June 2012).

WizMart engineers follow a systematic method for the smoke box calibration station. First, a clean air value (CAV) is defined as the photodiode output for the uncalibrated product before it enters the controlled environment. After the environment inside the box has been adjusted to represent 3% obscuration per foot, the output value of the photodiode inside of the box is recorded (3SV). A delta value (DV), or the difference between the CAV and the 3SV, is then calculated. If the values are not in range, a potentiometer is adjusted in order to alter the outputs (Wizmart engineers, personal communication, 25 June 2012). The basic layout of a smoke box may be seen in Figure 2.

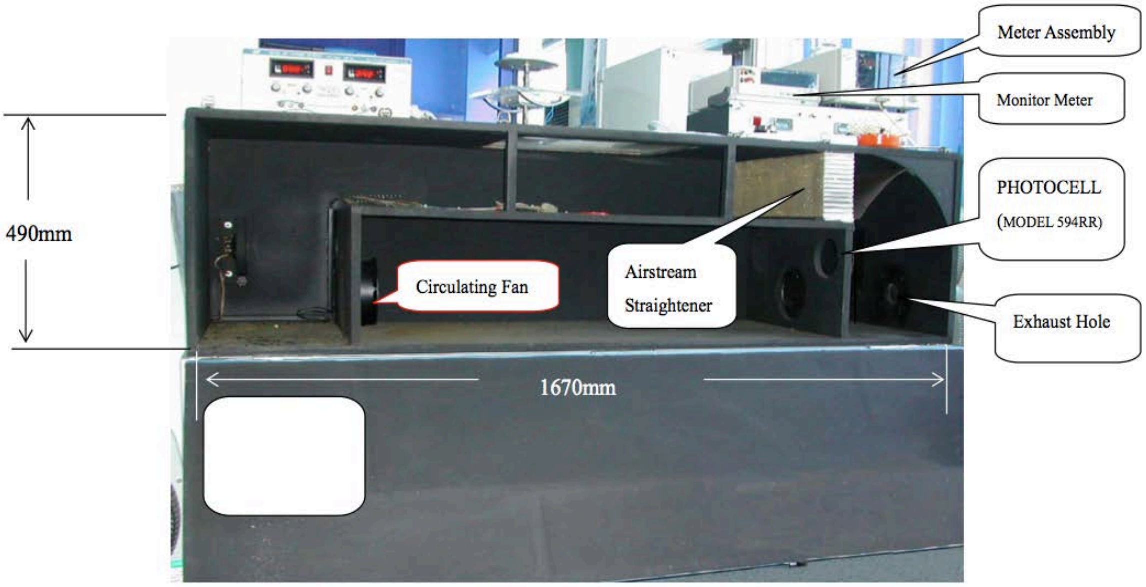


Figure 2. Layout of a traditional smoke box.

While the smoke box method of calibration is an accurate standby for most fire protection companies such as Tyco, there are several drawbacks. The process of physically simulating an accurate level of obscuration and completing the calibration requires a much longer period of time than electronic calibration. Additionally, the obscuring agent inside the apparatus must be consistently maintained at 3%

obscuration per foot. A ventilation pipe and other bulky equipment are also necessary in order to effectively clear obscuring agents from the box. One of the most evident flaws with this method is the sample smoke detector. The accuracy of the calibrated smoke detector is a result of the accuracy of the sample product; however, extended exposure to high obscuration levels produces unwanted buildup within the sample. This decreases the overall accuracy of both the sample and calibrated smoke detectors.

2.4.2: The Electronic Calibration Process

Tyco also employs an electronic calibration method for smoke sensors that is utilized by Flextronics in Suzhou, China. In this method, the top of the product chamber is replaced with the calibration device, which includes an additional LED light source and an optical fiber light sensor. The bottom of the product connects to a power source on the calibration station, therefore enabling the machine to adjust the potentiometer and monitor the photodiode (Flextronics engineers, personal communication, 29 June 2012).

The electronic calibration is a two-step process that requires approximately ten seconds to complete one smoke detector. In the first step, the smoke detector IRLED is not lit but the additional calibration light source is illuminated. This information is received by the optical fiber cable and then quantified by a CPU, resulting in clean air and delta value outputs on an adjacent monitor. The power of the calibration light source is then modified until it accurately simulates the desired value. Additionally, the potentiometer is adjusted so that an appropriate delta value may be obtained. For the second step, electronic calibration station is detached from the smoke detector, and the product is reassembled. After this process is complete, a clean air value is measured and the operator may determine whether or not the smoke detector is acceptably calibrated (Flextronics engineers, personal communication, 29 June 2012).

Conversely, the electronic process is less accurate than the smoke box method. Of the electronically calibrated products that are randomly tested in a UL certified smoke box, approximately 1% fail to function correctly. This error is commonly attributed to faulty photodiodes in the products (Flextronics engineers, personal communication, 29 June 2012). As a result, some organizations do not recommend electronic calibration as a sufficient calibration method (Washington State Patrol Fire Protection Bureau Inspection Station, n.d.). While the electronic calibration technique is faster, the project description conveys that it is also significantly more expensive and replacing or updating the aging equipment is costly.

2.5: Specifications for New Calibration Method

The existing methods of calibration for photoelectric smoke detectors may be inadequate regarding certain aspects (Magallanes, 2010). For ionic smoke sensors, the limited amount of controlled variables facilitates the calibration process. Contrarily, photoelectric sensor calibration requires the monitoring of multiple variables such as intensity of the photocurrent and the concentration of smoke.

As a result of the assorted limitations for the current methods of photoelectric calibration, representatives of Tyco have outlined several criteria that are important considerations for an improved calibration method (see Appendix A). These include:

- Affordable cost
- Accuracy
- Fewer control systems
- Shorter timeframe
- Higher throughput during manufacturing

This new technique will combine the strongest aspects of the various existing calibration methods. For example, smoke box calibration is accurate but slower than other methods; similarly, electronic calibration requires fewer control systems but is more expensive. There is a need for a calibration technique that will integrate all of the positive aspects and minimize the current limitations.

3.0: Methodology

In this chapter, a discussion of the methods utilized to achieve the stated project objectives is presented. In section one, the tasks that the team completed to sufficiently investigate existing calibration techniques are discussed. The process for brainstorming alternative calibration methods is then detailed in the second section. In the third section, a discussion of the methods used to brainstorm alternative techniques is presented. Actions completed to develop the selected method are also reviewed in section four. In the fifth section, the process utilized to present these results and recommendations to Tyco International is discussed.

3.1: Exploration of Previously Utilized Calibration Techniques

Before the team considered alternative techniques for the company, it was necessary to gain a thorough understanding of the existing calibration methods. The team completed extensive preliminary research concerning the basic functionality of optical smoke detectors and common methods of calibration. The team also reviewed several calibration patents regarding optical smoke detectors from both Tyco International and similar organizations. The Tyco subsidiary SimplexGrinnell, located in Westminster, Massachusetts, was visited and engineers were interviewed in order to better understand the equipment and processes employed in the smoke box calibration technique. The companies Wizmart Technology Inc. in Ningbo, PRC and Flextronics International Ltd. in Suzhou, PRC were also visited and interviewed were conducted in order to gather information about the smoke box and electronic calibration methods, respectively.

3.2: Brainstorming of Alternative Calibration Methods

The team implemented a systematic approach for devising potential calibration methods. As a group, the team collectively brainstormed several options for addressing current disadvantages and improving detector calibration. The scope of the alternative techniques was then narrowed down to account for idea feasibility, project timeframe, and available resources. Each team member then individually formulated a solution that incorporated one or more of the elements discussed in the group brainstorming process, and the team examined these new methods.

3.3: Selection of the Most Appropriate Calibration Technique

After the team obtained a thorough understanding of all existing calibration techniques and possible alternatives, the evaluation process was initiated. A side-by-side comparison of benefits and disadvantages of existing and alternative calibration methods was generated. The criteria provided by the company and additional factors generated by the group were also documented and compared. Each criterion was assigned a weighted factor in order of company priorities, and each technique was quantified in a design matrix. The calibration method with the highest value was then selected as the most appropriate option to fulfill the criteria specified by Tyco International.

3.4: Development of the Selected Calibration Method

Multiple processes were utilized in the development process of the chosen calibration technique. These fundamental procedures included the employment of CAD models and simulation software in order to refine and improve the design.

3.4.1: Utilizing CAD Models to Aid in Design Selection

Initially, the team produced preliminary sketches after discussion of the rudimentary apparatus. These designs were then detailed in CAD models and modified as the team identified flaws or areas for improvement. Among other considerations, stability and minimalism were notable aspects when the most appropriate design for the calibration device was being selected. After multiple iterations and several modifications, a final design was unanimously chosen.

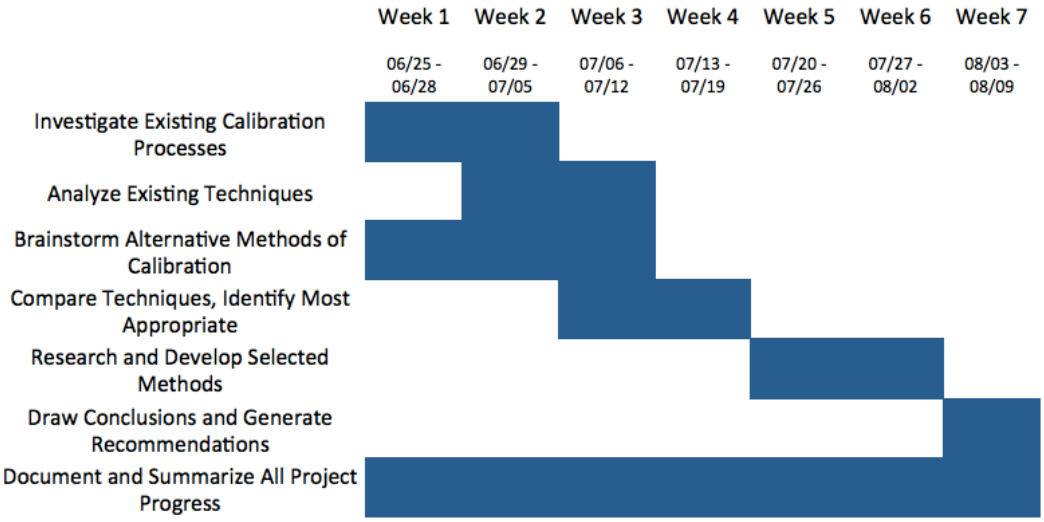
3.4.2: Employing Simulation Software for Angle Selection

For the selected variable angle mirror method, optical simulation software was utilized to determine the mirror positioning that most accurately simulated 3 percent per foot obscuration. Assuming that the light received by the photodiode was proportional to the voltage output, an LED was inserted into the simulated chamber and optical parameters were set. The resulting number was used as the zero value. For simulating the 3 percent per foot obscuration, the team inserted one fixed and one variable angle mirror into the chamber. When the mirrors were parallel, the angle was adjusted to zero. When the mirror rotated clockwise, the angles were determined to be negative. Correspondingly, angles were determined to be positive when the mirror rotated counterclockwise. The simulation was then completed with the given parameters and the angles best replicating the specified obscuration were identified.

3.5: Generation of a Succinct Summary and Recommendations

Throughout the course of the project, the team concurrently documented all pertinent progress, as seen in Table 1. A final report including a detailed summary of all research, results, conclusions, and recommendations was generated and provided to Tyco International. This material was then succinctly summarized in a Powerpoint presentation that was delivered to the Tyco CEO Mr. George Oliver and other concerned parties. The team also conducted a presentation, consisting of an overview of this content, to an audience containing engineers and Tyco representatives.

Table 1. Distribution of tasks and progress concerning documentation.



	Week 1 06/25 - 06/28	Week 2 06/29 - 07/05	Week 3 07/06 - 07/12	Week 4 07/13 - 07/19	Week 5 07/20 - 07/26	Week 6 07/27 - 08/02	Week 7 08/03 - 08/09
Investigate Existing Calibration Processes	■	■					
Analyze Existing Techniques		■	■				
Brainstorm Alternative Methods of Calibration	■	■	■				
Compare Techniques, Identify Most Appropriate			■	■			
Research and Develop Selected Methods					■	■	
Draw Conclusions and Generate Recommendations							■
Document and Summarize All Project Progress	■	■	■	■	■	■	■

4.0: Results

In this chapter, a detailed summary of the development of an alternative calibration process for optical smoke detectors is presented. Justification for decisions made during the brainstorming process will be provided in section one. Section two contains brief descriptions of several proposed calibration methods. The third section outlines the comparison process used to select the most appropriate technique. In section four, the final design for the chosen calibration technique is detailed. Section five reviews the outcomes of the simulations utilized in order to select optimal mirror positioning.

4.1: Brainstorming Process

4.1.1: Problem Definition

The first efforts from the project team's brainstorming process were devoted to narrowing the focus of the stated problem. While the request for an alternative method of calibration is extremely broad, the team hoped to collaborate on the improvement of a specific section of the existing process.

Limiting factors such as project resources and timeframe, as well as abilities of project team members, were considered. During brainstorming, there was a lack of detailed information on certain portions of the calibration processes, such as the functionality of the electronic calibration stations, or voltage outputs from the photodiode at various stages of calibration. Because of the limited timeframe during which the project was completed, team members agreed to proceed as if this information was not available. The project team comprised mechanical engineering students, so potential improvements focusing on electronic or software components were disregarded.

The project team concluded that the alternative calibration technique should redirect a reduced portion of the output from the IRLED into the photodiode in order to simulate the desired level of obscuration. By simulating a known obscurity without the use of ventilation, a new calibration technique could achieve many of the advantages of the electronic calibration process. The alternative method could potentially utilize many of the components from the existing process, such as the software for photodiode measurement and the potentiometer adjustment system. However, the project team could reduce the cost and number of control systems by calibrating with light from each detector's installed IRLED, instead of inserting a new light source. This approach also enables the new calibration process to account for minor differences between various detectors' IRLEDs, which only the smoke box method currently does.

4.1.2: Methods of Redirecting and Reducing Infrared Light

The team brainstormed several potential methods of redirecting and/or reducing the light from the IRLED. Prior to organizing these approaches into formal calibration techniques, research was conducted on each topic in order to explore potential applications.

- Semi-Opaque Materials

- Polarizers
- Apertures
- Mirrors
- Lenses
- Fiber Optical Cables

Each of these potential methods of light reduction and redirection were considered and discussed. Team members then spent a brief period of time working independently to develop separate, complete methods of reducing IRLED output by a desired amount, and then directing that reduced light into the photodiode.

4.1.2.1: Semi-Opaque Materials

One explored technique of simulating obscuration was the insertion of a semi-opaque material. The material would be attached to a calibration cover, which would have the piece positioned such that the IRLED would be obscured by a specific opacity. For this method, the team investigated numerous materials in search of an affordable material that could be manufactured at various opacities. Polycarbonate was identified as an inexpensive, durable semi-opaque material for insertion into the chamber.

4.1.2.2: Polarizers

The team also researched the use of polarizers for obscuration purposes. Specifically, a set of two linear polarizers could be adjusted to simulate different levels of obscuration. If one polarizer remained in a static position while another was rotated, the amount of light being transmitted would be altered. The level of obstructed light could be adjusted to represent 3% obscuration per foot; unlike the constant obscuration of a semi-opaque material, multiple trials of different opacities would not be required.

4.1.2.3: Apertures

The team investigated the use of apertures as an alternate method of controlling the amount of transmitted light. The aperture could be easily widened or narrowed to expose the photodiode to either an increased or decreased amount of IRLED light, respectively. A disadvantage of this option included acquisition of an appropriate device for insertion into the chamber; with limited time and resources, this obscuration method was not the most feasible option.

4.1.2.4: Mirrors

A system of mirrors was explored as an alternative to the currently utilized methods of redirecting and reducing light from the IRLED. Similar to the insertion of polarizers, one mirror would remain motionless while the other mirror was adjusted in increments. As the mechanical system altered the angle of the adjustable mirror, the amount of light being redirected to the photodiode could be controlled to simulate the desired 3% obscuration per foot.

4.1.2.5: Lenses

When exploring numerous options for adjusting the amount of light being received by the photodiode, the team considered the implementation of lenses. By utilizing the level of curvature for the manufactured lens, a specific amount of light from the smoke detector IRLED could be redirected. However, the team observed that a potential disadvantage was the necessity to manufacture several lenses in order to select a curvature that accurately simulated light redirection at 3% obscuration per foot.

4.1.2.6: Fiber Optical Cables

Fiber optical cables were also investigated as a method of controlling the amount of light being transmitted to the photodiode. These cables were employed in the previously utilized electronic calibration technique in order to detect the amount of light that was transmitted from the calibration station light source. An improved method would incorporate fiber optic cables to facilitate the sustainment of known obscurity; using the cables, the amount of light being redirected in the chamber could be maintained at a level simulating 3% obscuration per foot.

4.2: Brainstormed Methods of Simulating Obscuration

4.2.1: Insertion of a Semi-Opaque Material

One possibility that the project team discussed was the design of a calibration system that utilized a semi-opaque material to simulate a known obscurity. As suggested in one of the Tyco project descriptions (see Appendix A), a sample of material that refracted light in a manner similar to smoke could be inserted into the sensor chamber during calibration.

Before the calibration cover is attached to the smoke detector, the untested product would be attached to the electronic base identical to the one used in the current electronic calibration method. Voltage outputs from the photodiode would then be converted to quantitative values representing the amount of obscuration in clean air; this clean air value would then be recorded. Next, the cover of the smoke detector would be replaced with a calibration cover. The calibration apparatus would resemble a normal cover, with the exception being a polycarbonate lens would be strategically attached to partially obscure the light traveling from the IRLED to the photodiode. This arrangement can be seen in Figure 3.

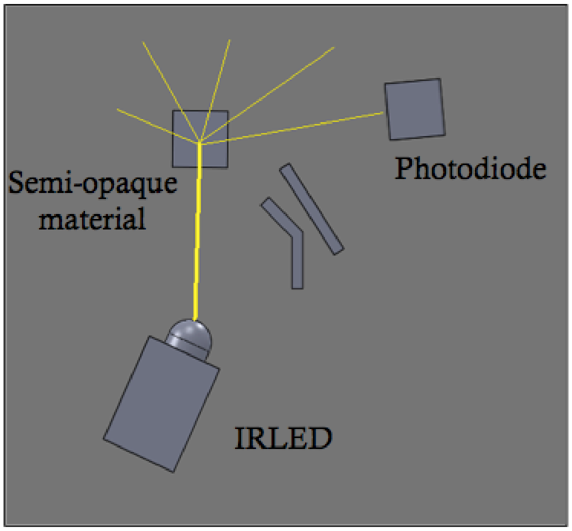


Figure 3. Insertion of a semi-opaque material for simulation obscuration.

Another voltage reading is recorded and converted to a quantitative output that represents the amount of light received from the photodiode at 3% obscuration per foot. The difference between the 3% and clean air values, also known as the delta value, could then be observed. The potentiometer would be automatically adjusted depending on where the delta value is in relation to the acceptable range. Afterward, the smoke detector would be tested once more in order to confirm that the calibration was accurate. Once this process has been completed, the smoke detector would be removed from the base and the original cover would replace the calibration lid.

4.2.2: Adjustable Mirror Apparatus

Another viable method that was proposed would be the application of an adjustable mirror apparatus in order to redirect an appropriate amount of infrared light. This process would be similar to the current electronic calibration station, except that an additional IRLED that must be mechanically readjusted is replaced with a set of mirrors that redirects light from the smoke detector IRLED.

In the first step, the smoke detector would be connected to the electronic base, which could then record all voltage outputs from the photodiode. Output values would then be converted and quantified by utilizing the accompanying software, and the results would be displayed on a nearby computer. With this initial setup, a clean air value would be recorded. Seen in Figure 4, the original smoke detector cover would then be removed, and the calibration cover containing the mirror apparatus would replace it.

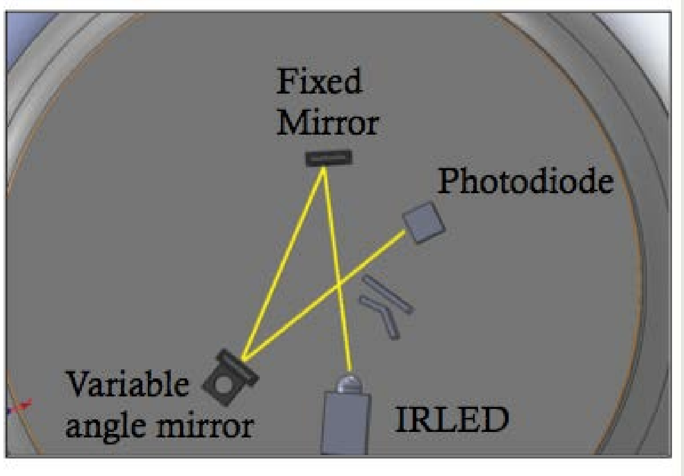


Figure 4. Variable angle mirror apparatus.

Operating a mechanical system containing a servo device, the mirror would be rotated until the angle simulating 3% obscuration per foot was achieved, and the output from the photodiode would be recorded. A delta value could be obtained utilizing the difference between the 3% and clean air values; using this value, an automatic potentiometer adjustment may be implemented. The original cover would then be reattached to the product. To confirm accuracy, the smoke detector would be tested one final time. After determining whether the calibration had passed or failed, the smoke detector would then be removed from the base and reassembled.

4.2.3: Insertion of Polarized Lenses

Additionally, insertion of polarized lenses was propositioned as an accurate method of calibrating the photoelectric smoke detectors. For this method, a pair of linear polarizers is utilized in order to obscure an appropriate amount of IRLED light from the photodiode. Similarly to other potential calibration methods, the process would require an electronic base that could read the voltage output from the photodiode and deliver this information to the appropriate software.

The polarized lens method would consist of multiple stages. Initially, a clean air value would be recorded with the uncalibrated smoke detector. The calibration cover with containing the polarized lens apparatus would then be attached after the original cover was removed, as seen in Figure 5.

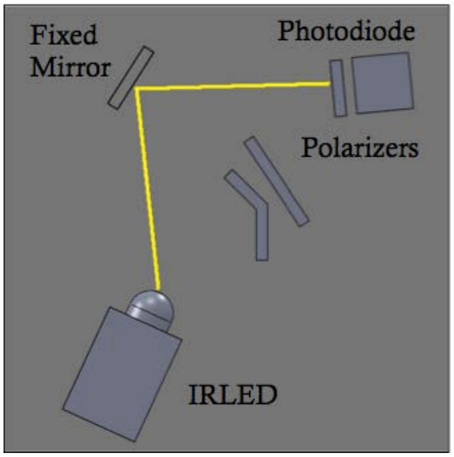


Figure 5. Positioning of polarized lenses.

One of the lenses would remain static, while the other would be rotated until the target level of obscuration was observed via the voltage output. From these two values, a delta value could be obtained and the potentiometer could be automatically adjusted depending on whether the resulting figures were in an acceptably safe range. After the adjustments, the product would be tested once more to ensure that the process was successful. The calibration cover would then be removed and the smoke detector would be detached from the base. The original product cover would then be replaced.

4.3: Selection of Most Appropriate Method

Multiple approaches were included in the decision-making process for the most suitable calibration technique. First, the team narrowed the scope of the project; a group discussion yielded the conclusion that options involving extensive programming would not be feasible given the limited timeframe. Additionally, the team established that each brainstormed method should involve a mechanical system.

In the next phase, the team discussed all potential methods and produced a list of unexplored options. With these proposals and the established conditions in mind, each team member brainstormed a unique calibration technique and presented their results to the collective. A consensus on the most appropriate method for Tyco International was then reached after quantifying and comparing several factors for each technique. These categories, outlined by the company in their original project description, include: cost to build a station, time for one calibration, level of accuracy, number of control systems, and throughput during manufacturing. Additional factors that the team included were feasibility of the method and incorporation of the current calibration stations. The brainstormed technique that fulfilled these categories most fully was then universally selected as the method to develop further.

4.3.1: Assumptions for All Proposed Techniques

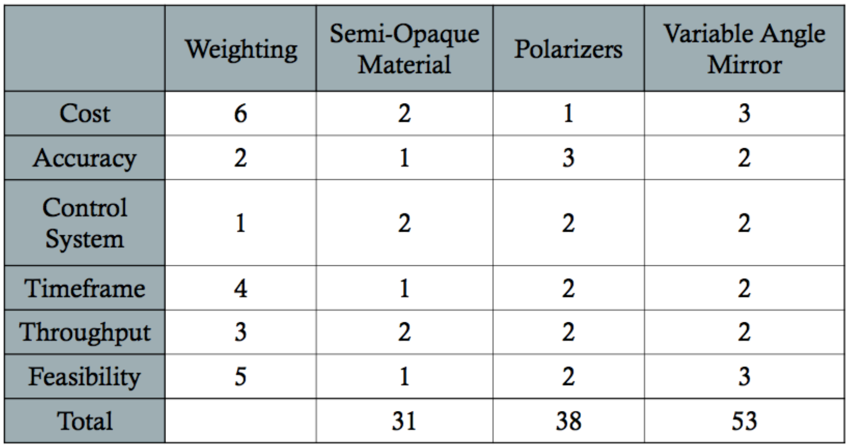
Every technique selected for consideration included several common assumptions. One of these expectations was the incorporation of components from the current electronic calibration station. All proposed methods required the currently used electronic base. This component served as a power source to the smoke detector and as a connection to the computer setup that displayed the obscuration level; both of these functions were necessary for each new method of calibration. Another shared assumption was the necessity of the software utilized in Tyco's existing calibration methods. After the voltage values from the photodiode were received by the system, the software was critical for converting these outputs to quantified obscuration levels.

Logistical assumptions were also established before executing the project. The team brainstormed these methods under the impression that detailed information concerning the relationship between the LED and photodiode output would be provided by the company. An additional supposition was that all the necessary materials that were ordered would be delivered in under a week. Following this assumption for each proposed technique, a universal schedule was generated to reflect this allotted period of time for shipping.

4.3.2: Comparison of Proposed Techniques with Previously Utilized Techniques

Another step in the selection procedure was the comparison of techniques implemented by Tyco International and the proposed alternatives. Similar to the assessment of brainstormed techniques, the several criteria specified by the company were compared for each method, as seen in Table 2.

Table 2. Weighed factors utilized to select calibration method.



	Weighting	Semi-Opaque Material	Polarizers	Variable Angle Mirror
Cost	6	2	1	3
Accuracy	2	1	3	2
Control System	1	2	2	2
Timeframe	4	1	2	2
Throughput	3	2	2	2
Feasibility	5	1	2	3
Total		31	38	53

These five categories were the cost to build a station, level of accuracy, number of control systems, in the time for one calibration, and throughput during manufacturing. Feasibility, specifically regarding the major benefits and disadvantages of utilizing each technique, was also determined for each method. Each criterion was given a weighted factor according to the necessity for improvement with the existing techniques. While cost and timeframe were significant concerns with the smoke box method, variables such as the control systems were given lower precedence. Since improving the software aspects of the electronic calibration station would have required an implausible amount of time and resources, feasibility was given a high weighted factor of five. A complete, quantified assessment of all calibration options was then completed and the variable angle mirror method was identified as the most appropriate technique according to the specified criteria.

4.4: Final Design for Calibration Apparatus

4.4.1: Housing

After several possibilities were considered for the variable angle mirror device, the team generated a final design. The apparatus was designed to replace the original smoke detector cover with both a static mirror and a mechanically adjustable mirror. A solid, exterior superstructure was selected to support all of the components, as seen in Figure 6. The housing also facilitated an efficient transfer from the original detector cover to the calibration system. Unlike the previously utilized electronic calibration system, this design was much simpler and did not require unwieldy additions such as the fiber optic cable extension.

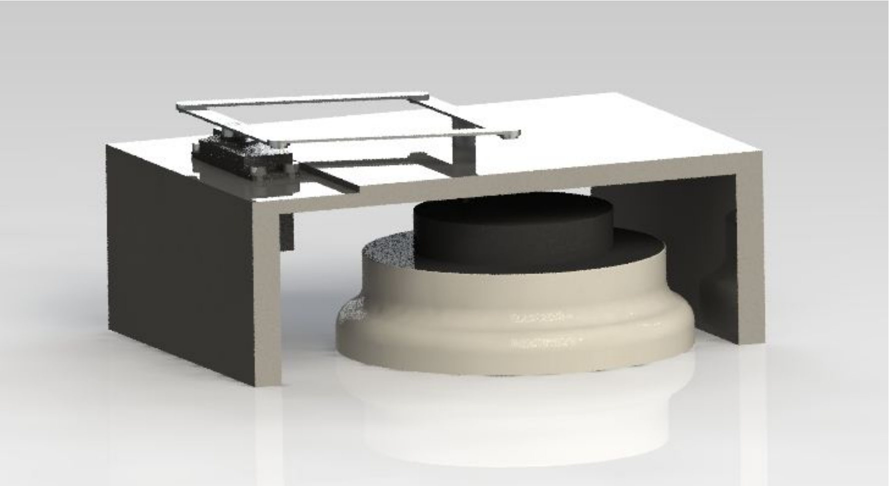


Figure 6. Superstructure of the calibration device.

4.4.2: Servomechanism

The team also utilized a servomechanism in order to adjust one of the mirrors to an appropriate position. This setup may be seen in Figure 7. A benefit of this option included the ability to alter the mirror angle in intervals of approximately 0.1 degrees; this feature could increase the accuracy of the calibration system.

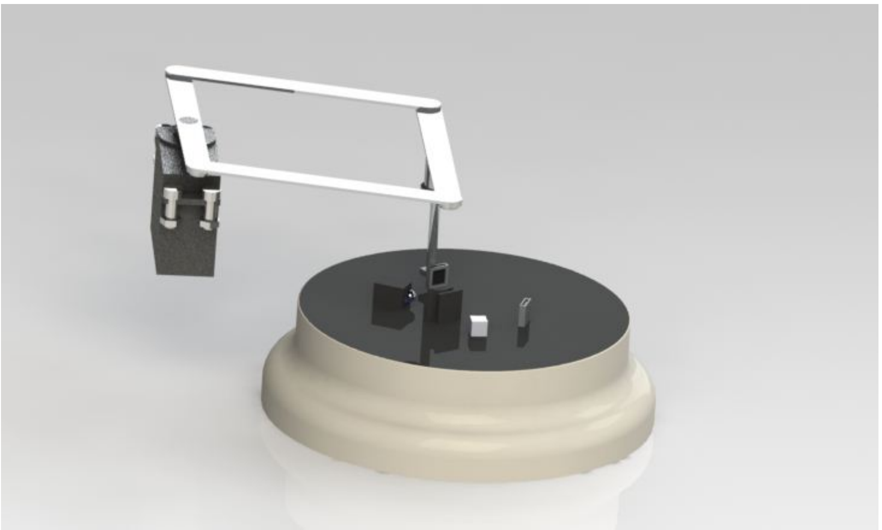


Figure 7. Servomechanism component of the apparatus.

4.4.3: Four-bar Linkage

An additional feature that the team incorporated was a four-bar linkage, seen in Figure 8. After multiple options such a gear or chain and sprocket system were considered, the four-bar linkage was selected due to the stability and efficiency of the setup. As the servomechanism altered the position, the linkage was adjusted proportionally.

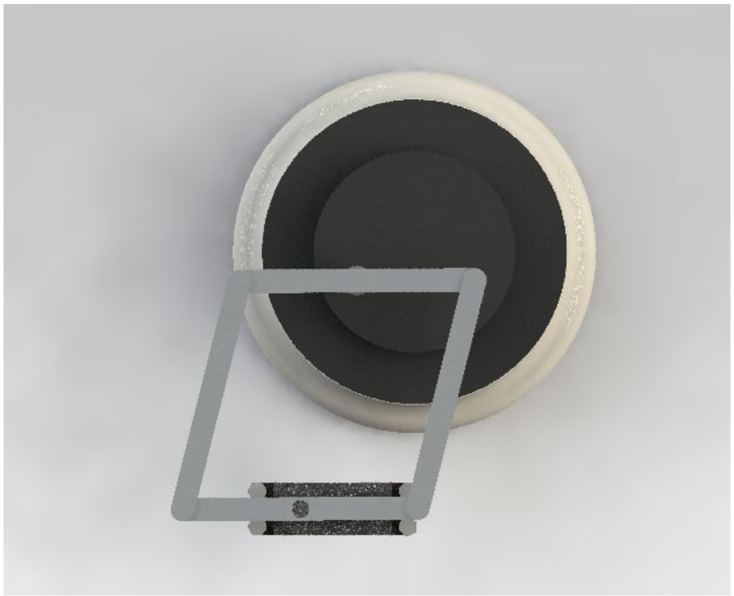


Figure 8. Aerial view of the four-bar linkage.

4.4.4: Shaft Component

The final piece included in the variable angle mirror apparatus was the shaft component, seen in Figure 9. The shaft connected the four-bar linkage and the adjustable mirror. As the four-bar linkage was altered a specific amount by the servomechanism, the shaft equivalently adjusted the mirror. In this manner, the smoke detector may be calibrated by means of a simple and effective mechanical device.

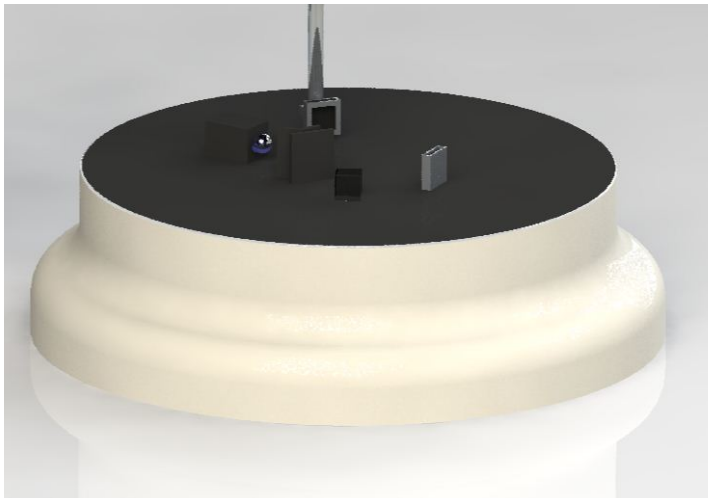


Figure 9. Shaft component of the variable angle mirror apparatus.

4.5: Selection of Mirror Positioning for Simulating Obscuration

After the variable angle mirror method was selected as the most appropriate calibration technique, it was necessary to determine the mirror angles that emulated 3% obscuration per foot. These positions were necessary for simulating obscuration as accurately as possible; therefore, the team utilized optical simulation software in order to determine which values should be employed during calibration. This process required simulation at the clean air value and at the smoke value, 3% obscuration per foot.

4.5.1: Simulation at the Clean Air Value

Before measurements were recorded at a specific level of obscuration, a clean air value was required. Seen in Figure 10, an IRLED was inserted into the detector chamber. Optical parameters were then established and the simulation was initiated.

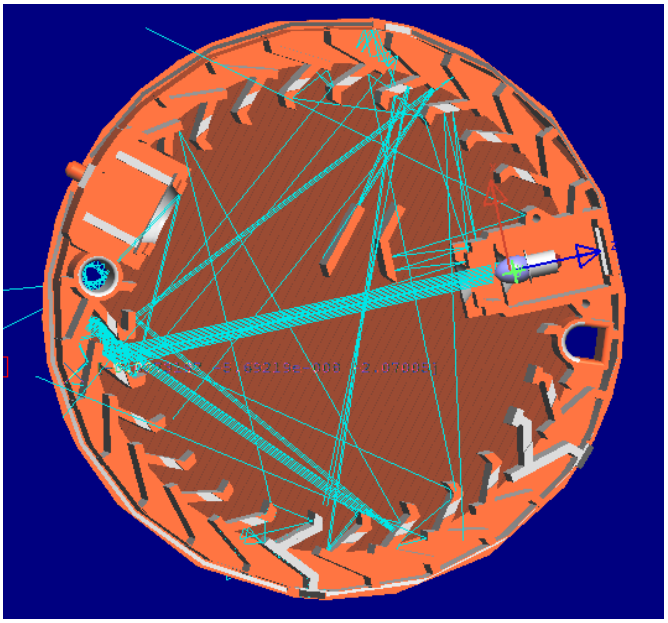


Figure 10. Optical simulation for the detector.

The simulation yielded a value of approximately 4.306 µW as the amount of light being received by the photodiode. By assuming that the quantity of light that was received by the photodiode was proportional to the voltage output, calculations to aid in the simulation processes could be incorporated. Utilizing quantified output values provided by the company (seen in Appendix C), the team calculated:

$$\frac{Illuminance\ for\ Clean\ Air\ Value}{Illuminance\ for\ Smoke\ Value} = \frac{80}{80+82}$$

Because the given ratio and the output at the clean air value were known, the amount at the smoke value was computed to be approximately 8.16 µW.

4.5.2: Simulation at the Smoke Value

After the output value was obtained, parameters were inserted for the simulation at 3% obscuration per foot. In addition to the basic chamber, a fixed mirror and an adjustable mirror were included in the chamber, as seen in Figure 11.

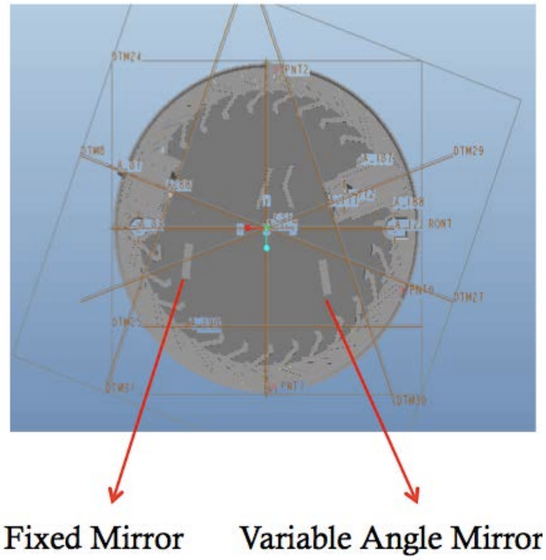


Figure 11. Setup used in the optical simulation.

Specifications were also established for each mirror position. Parallel positioning for the mirrors resulted in an angle of zero. The angle was a negative value when the mirror was rotated counterclockwise. Likewise, the angle was positive if the mirror was adjusted in a counterclockwise direction. Power outputs, measured in Watts, rapidly increased from approximately 0 to 10 degrees. These results can be seen in Figure 12.

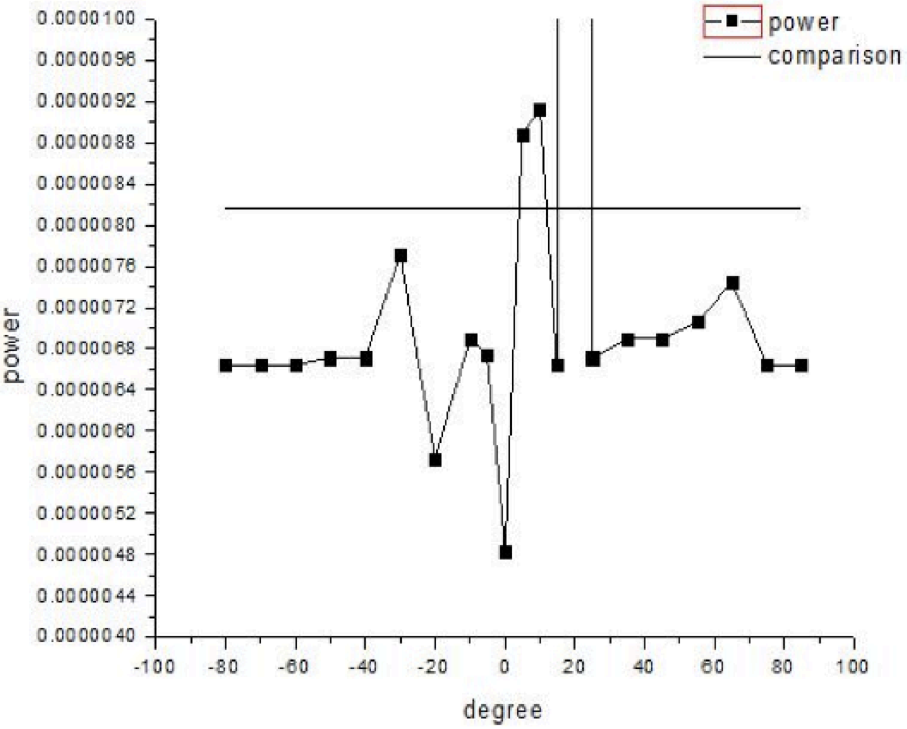


Figure 12. Results of the simulation.

The 10 to 15 degree yielded significantly more stable values; therefore, these data points were determined to be the most accurate values for simulating 3% obscuration per foot. The team identified 4.04 degrees and 11.86 degrees as acceptably accurate angles for usage by the company in future investigations concerning the variable angle mirror method.

5.0: Conclusions & Recommendations

In this chapter, closing statements concerning the outcomes of the project are discussed. The weaknesses and areas for improvement of the previously utilized calibration methods are detailed. As an alternative, a less expensive method that is still accurate and rapid is recommended. Additionally, maintaining thorough records of each calibration technique is advocated. The possibilities of improving electrical or software components of the calibration process are also considered.

5.1: Areas of Improvement for Previously Utilized Calibration Techniques

Currently employed calibration methods, while fully functional, have several disadvantages. For example, the smoke box technique requires excessive control systems due to bulky ventilation systems and the necessity to maintain a constant obscuration in the chamber. Additionally, as the day progresses and variables change with each trial, accuracy may be decreased depending on the condition of the sample smoke detector. Physically simulating a fire with various smoke and aerosol substances also requires a significantly higher amount of time to complete than the electronic calibration process. Another time concern is the CAV; if the product does not have a value within range, the process must be repeated. The electronic calibration technique also has multiple areas for improvement. When the station equipment becomes outdated or in need of repair, an expensive setup is required due to the necessary charging base and software components. Additionally, control systems including the additional light source and fiber optic cable attachments are another limiting factor for electronic calibration.

5.2: Alternative Calibration Method for Reducing Company Expenditures

Implementing a new method could reduce cost without compromising accuracy, timeframe, or throughput. The variable angle mirror apparatus would cost less than 1000 RMB, or less than $150 USD, to build. In addition, the time to calibration one device would be approximately ten to fifteen seconds, similar to the currently implemented electronic calibration method. The accuracy and throughput would also be comparable to previously utilized techniques. A further benefit of the variable anger mirror method includes the capability of integration into the existing software and electronic components, which would save the company time and money if the new technique were selected.

5.3: Importance of Documentation for Calibration Methods

Detailed documentation of calibration techniques is crucial for future development. While researching previously utilized calibration techniques, the team was unable to obtain any information regarding the electronic calibration method. Thorough descriptions of each calibration technique could facilitate improvements and updates to the systems. Therefore, the team recommends that the company record and maintain documentation detailing each process, and provide this to future brainstorming teams.

5.4: Identification of Areas for Future Investigation

Due to a limited timeframe and resources, the team was unable to investigate several options for development. One possibility would be improving the variable angle mirror apparatus. Basic simulations generated estimates for ideal mirror positions, but future investigations regarding the most effective positioning could increase the accuracy of the system. Future exploration for the company could include improvement of the electronic and software aspects of calibration. Altering facets such as the current program used to analyze the data or the electronic base setup could potentially improve the overall time or accuracy of the calibration system.

Works Cited

AW Technology (2010). 1900 calibration tunnel. Retrieved from http://www.awtechnology.com/Products/1900Tunnel.htm

Baker, D. & Adams, P. (1993). Residential fire detection. Retrieved from http://extension.missouri.edu/p/G1907

Brown, R.H. & Vickers, R.N. (1995). Smoke detector operability and reliability in military family housing. Retrieved from http://handle.dtic.mil/100.2/ADA307087

Cable Organizer Learning Center (2008). Smoke alarm roundup: The difference between ionization and photoelectric smoke detectors. Retrieved from http://cableorganizer.com/articles/smoke-alarm-roundup.html

Cleary, T. (2009). Proceedings from the SUPDET 2009: *Fire Protection Research Foundation's 13th Annual Suppression and Detection Research & Applications Symposium*. Orlando, FL: Cleary.

Digital Security Controls (1996). Meridian photoelectric smoke detectors & alarms. Retrieved from http://www.hsasecurity.com/meridian.pdf

Dubivsky, P.M. & Bukowski, R.W. (1989). False alarm study of smoke detectors in Department of Veterans Affairs Medical Centers (VAMCS). Retrieved from http://fire.nist.gov/bfrlpubs/fire89/PDF/f89012.pdf

Duke University (2006). Smoke detector standards. Durham, N.C.: Facilities Management Department.

Dungan, K.W. (2007). Reliability of fire alarm systems. *Fire Protection Engineering, Winter 2007 (33).*

Gentex (1994). Gentex technical bulletin number 003. Retrieved from http://www.gentex.com/sites/default/files/fire_docs/TB003.pdf

Gemini Scientific Corporation (1996). The Gemini 501A smoke detector analyzer technical data. Retrieved from http://firesafetytech.com/images/pdf/Gem%20501A-Bat%20brochure.pdf?PHPSESSID=9e0cdcc8c28f81b97d7828a58f446bb9

Hamamatsu (n.d.). Photodiode technical information. Retrieved from http://sales.hamamatsu.com/assets/applications/SSD/photodiode_technical_information.pdf

Kadwell, B.J. & Pattok, G.R., Gentex Corporation (2005) *Compact particle sensor*, U.S. Pat. 6,876,305 B2.

Magallanes, S.S. (2010). On the calibration of photoelectric smoke detector technology. Retrieved from http://calibration.ezinemark.com/on-the-calibration-of-photoelectric-smoke-detector-technology-168f00cdc69.html

Mi, Z. & Rattman, W.S., Tyco Safety Products (2009) *Smoke detector calibration*, U.S. Pat. 7,474,226 B2.

National Fire Protection Association (2010). NFPA 72: National fire alarm and signaling code. Retrieved from http://www.nfpa.org/

Shapiro, J. (1994). Smoke detector operability survey: Engineering laboratory analysis. Retrieved from http://www.cpsc.gov/library/foia/foia01/os/operable.pt2.pdf

System Sensor (2010). Applications guide: system smoke detectors. Retrieved from http://www.systemsensor.com/pdf/A05-1003.pdf

System Sensor (n.d.). Guide for the proper use of intrinsically safe fire protection devices. Retrieved from http://www.systemsensor.ca/guides/I56-1257.pdf

United Nations Industrial Development Organization (2006). Role of measurement and calibration in the manufacture of products for the global market. Retrieved from http://www.unido.org/fileadmin/media/documents/pdf/tcb_role_measurement_calibaration.pdf

UL LCC (n.d.). Smoke detectors for fire alarm systems: UL 268. Retrieved from http://ulstandardsinfonet.ul.com/scopes/scopes.asp?fn=0268.html

Washington State Patrol Fire Protection Bureau Inspection Station (n.d.). Smoke detector sensitivity testing and smoke entry/alarm respond testing. Retrieved from http://www.wsp.wa.gov/fire/docs/inspections/smoke_det_sensitivity_testing.pdf

Weiner, D.W., Cleary, T.G., Mulholland, G.W., & Beever, P.F. (2003). Light scattering characteristics and size distribution of smoke and nuisance aerosols. Retrieved from http://fire.nist.gov/bfrlpubs/fire03/PDF/f03058.pdf

Appendix A: Project Descriptions

Sensor Calibration Project

Background: A photo sensor consists of a chamber, which keeps out light, but allows smoke particles to enter. The chamber consists of a bottom, in which the electronics are mounted, and the top, which provides a cover and creates the smoke chamber. Within the chamber there is an Infrared LED that is pulsed on every few seconds. Located off at an angle away from the IRLED is a prism which will direct light down to a photo diode that is connected to a photo amplifier circuit. Because the LED is shooting light at an angle, the light from the LED does not normally hit the prism. When smoke enters the chamber the light is reflected off the smoke particles and some of the reflected light hits the prism and illuminates the photo diode, creating a signal. The level of this signal is dependent on the characteristics of the smoke particles entering the chamber, for example, particle size, color, and density.

One of the problems with designing photo sensors was monitoring the LED to make sure it was functional. This problem was solved by allowing for a little reflection in the chamber to hit the photo diode, so there is a small background signal present when the LED flashes and there is no smoke. The amount of signal depends on the characteristics of the IR LED and the background scatter of light within the chamber area. This background signal is called the “zero value” or the long term average value. Alarms are then generated when the signal rises to a certain level above the background signal.

When manufacturing a smoke sensor, one major issue is the need to calibrate the sensor. Calibration insures that the sensor puts out a signal that is properly correlated to the smoke level. Variation in the IR LED, photo diode, and electronics mean that there are a broad range of values that can come out of different detectors for the same amount of smoke. These variations need to be calibrated out.

Calibration methods:

Two methods of calibrating Tyco smoke sensors have been developed and used over the years. Each is described below:

One approach utilizes an electronic calibration station. In this approach, the Sensor is loaded onto the station with the sensor chamber top removed. A special calibration head is lowered onto the sensor housing; this simulates the chamber cover, and has electronics to measure the IR LED's spectral emissions, dispersion, and intensity characteristics; as well as a source (smoke LED) that is directed at the prism, which is used to provide the simulated smoke obscuration signal.

Based on the IRLED's characteristics, the smoke LED signal strength is determined to represent the calibration signal which represents 3%/ft obscuration. There are two calibration parameters to validate: a proper zero value, and a proper delta value (additional signal) at 3% obscuration. A potentiometer is provided on the Photo Sensor PCA that is used to adjust the signal gain of the photo amplifier circuit. Based on the zero value, and the delta value read once the smoke LED is activated, the potentiometer is adjusted to get a valid delta value while the smoke LED is active; the zero value is then again measured; if it is within range, calibration is complete; if not, then the procedure is repeated. Note, adjusting the potentiometer varies both the zero value and delta value. Once calibration is complete, the Photo sensor is removed from the fixture, a chamber top is snapped on, and the zero value is validated.

Another approach is to us a "smoke box" to generate the 3%/ft obscuration. With this approach, wick can be used to provide the smoke obscuration, or an aerosol generator using mineral oil can be used to provide the 3%/ft obscuration. The Sensor is mounted to a door of the smoke box; a zero value is read; then the sensor is put into the smoke box with 3% obscuration. The new signal is read from the sensor; the delta is calculated, and then based on the zero value, and the new value at 3% obscuration, the potentiometer is adjusted to give the new calculated 3% value. The sensor is removed from the 3% obscuration; then the zero value is read; if the zero value and delta value are in range, the calibration is complete; otherwise the procedure is repeated.

The Project:

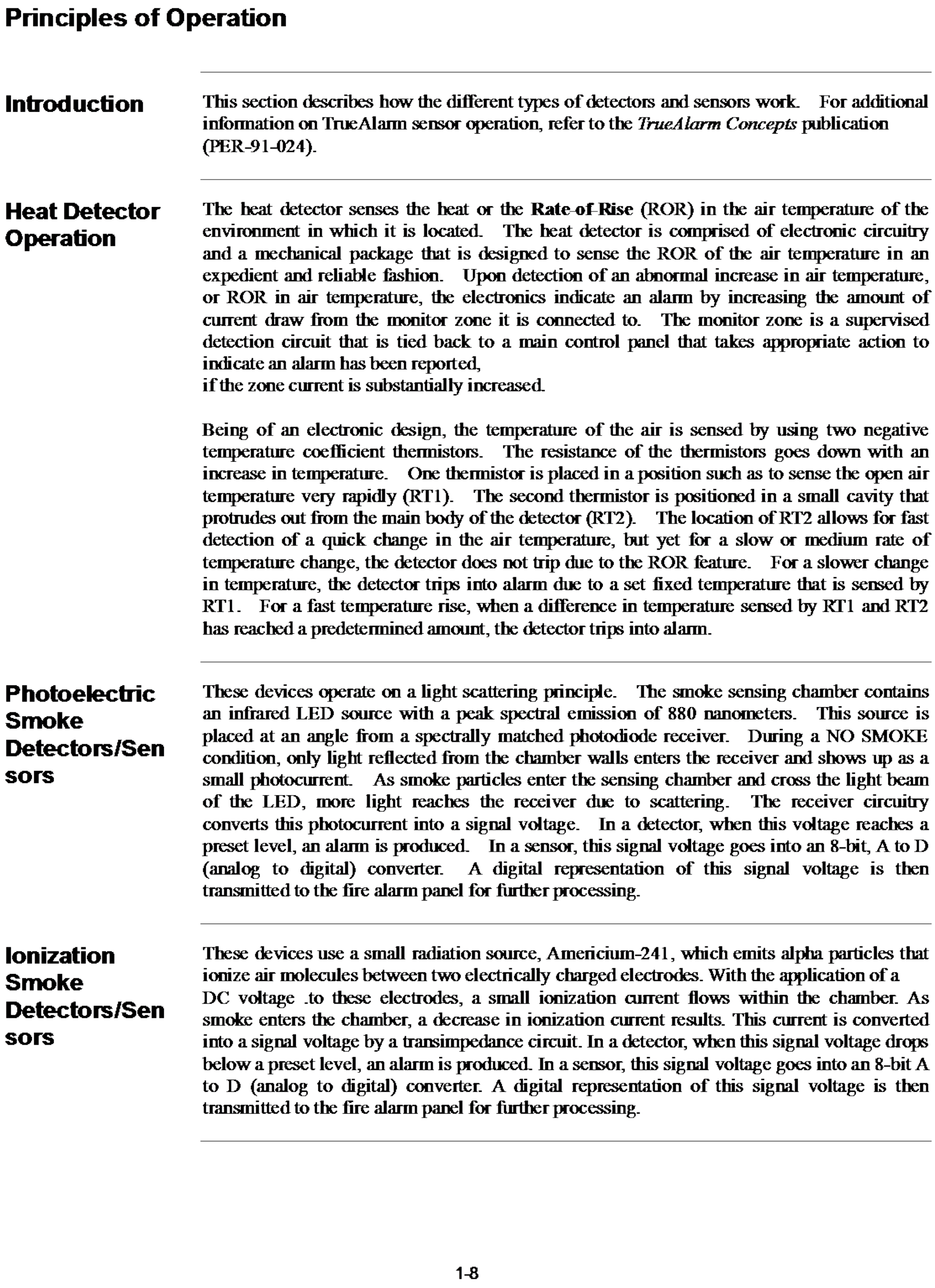
The above approaches have their own limitations. The electronic calibration stations are costly; they are getting old and difficult to maintain; and are not as accurate at setting the proper delta values as is possible with the smoke box process. The smoke box process requires an exhaust vent to the outside air to remove the smoke or aerosol from the box; requires a control system for maintaining the 3% obscuration; particle size of the smoke/aerosol is a factor can vary throughout the day; the speed of calibration is slower than the electronic calibration stations. Thus, it is desirable to develop an alternate calibration procedure.

This alternate calibration method would have to be less costly than the electronic calibration stations, provide more accurate calibration, require less control systems than the smoke box procedure, and calibrate the sensors in a short timeframe, have a higher throughput.

One method that has been discussed is to insert some physical element accurately into the path of the IRLED, which would then reflect a consistent amount of the IRLED light into the prism that would represent a known %/ft obscuration. This method would have to be validated. One issue to control would be whether, with the variations of the IRLED, and the mechanics involved, the tester could produce an accurate and repeatable process. The method would also have to provide a means to quickly go between reading the zero value and the obscuration value, so that the calibration process could be stepped through several times in a row quickly.

Project Statement: Develop an approach for calibrating smoke sensors that does not involve smoke, and can be implemented at reasonably low cost with high throughput on a manufacturing line.

Appendix B: Basic Specifications for the Given Smoke Detector Model



Principles of Operation

Introduction

This section describes how the different types of detectors and sensors work. For additional information on TrueAlarm sensor operation, refer to the *TrueAlarm Concepts* publication (PER-91-024).

Heat Detector Operation

The heat detector senses the heat or the **Rate-of-Rise** (ROR) in the air temperature of the environment in which it is located. The heat detector is comprised of electronic circuitry and a mechanical package that is designed to sense the ROR of the air temperature in an expedient and reliable fashion. Upon detection of an abnormal increase in air temperature, or ROR in air temperature, the electronics indicate an alarm by increasing the amount of current draw from the monitor zone it is connected to. The monitor zone is a supervised detection circuit that is tied back to a main control panel that takes appropriate action to indicate an alarm has been reported,
if the zone current is substantially increased.

Being of an electronic design, the temperature of the air is sensed by using two negative temperature coefficient thermistors. The resistance of the thermistors goes down with an increase in temperature. One thermistor is placed in a position such as to sense the open air temperature very rapidly (RT1). The second thermistor is positioned in a small cavity that protrudes out from the main body of the detector (RT2). The location of RT2 allows for fast detection of a quick change in the air temperature, but yet for a slow or medium rate of temperature change, the detector does not trip due to the ROR feature. For a slower change in temperature, the detector trips into alarm due to a set fixed temperature that is sensed by RT1. For a fast temperature rise, when a difference in temperature sensed by RT1 and RT2 has reached a predetermined amount, the detector trips into alarm.

Photoelectric Smoke Detectors/Sensors

These devices operate on a light scattering principle. The smoke sensing chamber contains an infrared LED source with a peak spectral emission of 880 nanometers. This source is placed at an angle from a spectrally matched photodiode receiver. During a NO SMOKE condition, only light reflected from the chamber walls enters the receiver and shows up as a small photocurrent. As smoke particles enter the sensing chamber and cross the light beam of the LED, more light reaches the receiver due to scattering. The receiver circuitry converts this photocurrent into a signal voltage. In a detector, when this voltage reaches a preset level, an alarm is produced. In a sensor, this signal voltage goes into an 8-bit, A to D (analog to digital) converter. A digital representation of this signal voltage is then transmitted to the fire alarm panel for further processing.

Ionization Smoke Detectors/Sensors

These devices use a small radiation source, Americium-241, which emits alpha particles that ionize air molecules between two electrically charged electrodes. With the application of a DC voltage .to these electrodes, a small ionization current flows within the chamber. As smoke enters the chamber, a decrease in ionization current results. This current is converted into a signal voltage by a transimpedance circuit. In a detector, when this signal voltage drops below a preset level, an alarm is produced. In a sensor, this signal voltage goes into an 8-bit A to D (analog to digital) converter. A digital representation of this signal voltage is then transmitted to the fire alarm panel for further processing.

4098 Smoke Detectors

Introduction

CAUTION: Install the detectors described in this publication in accordance with applicable NFPA standards, local codes, and the Authorities Having Jurisdiction (AHJs). Failure to follow these instructions may result in failure of the detector to initiate an alarm condition. The manufacturer is not responsible for detectors that have been improperly installed, tested, or maintained.

Smoke Detector Limitations

The smoke detectors used with these bases are designed to activate and initiate emergency action, but do so only when used in conjunction with other equipment. They are designed for installation in accordance with NFPA 72 National Fire Alarm Code.

- Smoke detectors do not work without power. AC or DC powered smoke detectors do not work if the power supply is cut off for any reason.
- Smoke detectors do not sense fires when smoke does not reach the detectors. Smoke from fires in chimneys, in walls, on roofs or on the other side of closed doors may not reach the smoke detector and alarm it.
- A detector may not detect a fire developing on another level of a building. For this reason, detectors should be located on every level of a building.
- Smoke detectors have sensing limitations. Ionization detectors are better at detecting fast, flaming fires than slow, smoldering fires. Photoelectric detectors sense smoldering fires better than flaming fires. Because fires develop in different ways, and are often unpredictable in their growth, neither type of detector is always best, and a given detector may not always provide warning of a fire. In general, detectors cannot be expected to provide warning for fires resulting from inadequate fire protection practices, violent explosions, escaping gases, improper storage of flammable liquids like cleaning solvents, other safety hazards, or arson.
- Smoke detectors cannot last forever. Smoke detectors contain electronic parts. Even though detectors are made to last for many years, any of these parts could fail at any time. Therefore, test your smoke detector system per NFPA 72 at least annually. Clean and take care of your smoke detectors regularly. (See Chapter 5 of this publication for cleaning instructions.)

Continued on next page

Specifications

Table 2-1. Smoke Detector Specifications

Specifications	Smoke Detector Data		
Detector PID (4098)	-9601, -9605	-9602	-9603
Type of Detector	Photoelectric	Photoelectric with Heat	Ionization
Working Voltage (2-wire)	8.5 – 33 VDC	8.5 – 33 VDC	8.5 – 33 VDC
Rated Voltage (4-wire)	15 – 32 VDC	15 – 32 VDC	15 – 32 VDC
Input Ripple Voltage	25% Max.	25% Max.	25% Max.
Max. Alarm Current	86 mA	86 mA	86 mA
Surge Current	<200 µA	<200 µA	<200 µA
Standby Current	<100 µA	<100 µA	<100 µA
Heat Element Rating	N/A	135° F	N/A
Humidity Range (Non-Condensing)	10-95% RH	10-95% RH	10-95% RH
Air Velocity Range	0-2000 FPM	0-2000 FPM	0-300 FPM

Continued on next page

4098 Smoke Detectors, *Continued*

Mounting Requirements

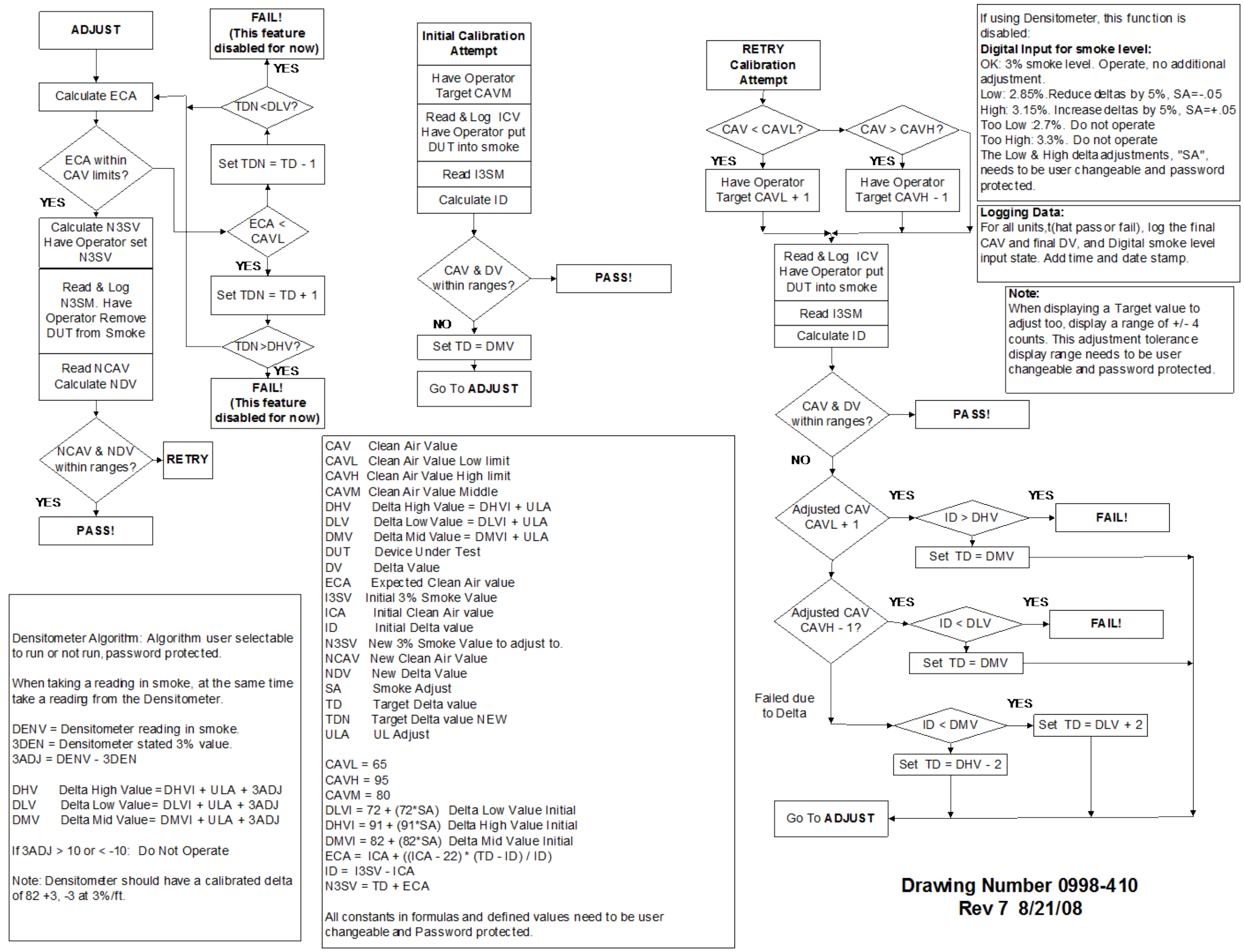
All smoke detectors identified in Table 2-1 mount to a detector base (refer to the “4098 Bases” section of this chapter for more information). Use the following considerations and Figure 2-1 when mounting smoke detectors.

IMPORTANT: Smoke must enter the chamber of the detector. Thus, air flow, air stratification, air velocity, air stagnation, and air migration affects detector efficiency.

Note: Where the possibility of positive airflow from the electrical conduit/junction box exists, seal the conduit openings with 3M Weatherban #606 (or equivalent), a non-flammable sealing compound.

- Do not install detectors in areas where temperatures are likely to exceed 100° F (38° C) or fall below 32° F (0° C).
- Because the 4098-9602 detector combines heat sensing, DO NOT install this detector in locations where the ambient temperatures exceed 100° F (38° C) or where temperature fluctuations above 6° F/min. occur.
- Do not install detectors on a ceiling within 4 inches (10 cm) of a wall.
- Do not install detectors where forced air ventilation may dilute the smoke before it reaches the detector.
- Do not install detectors in areas where smoke is normally present (kitchens, furnace rooms, laundry rooms, loading docks, rooms with fireplaces, rooms with candles, soldering rooms, etc.).
- Do not install detectors in areas where there is likely to be steam (in hospital patient rooms with vaporizers, near shower rooms, above large sinks, etc.).
- Do not install detectors above ashtrays in elevator lobbies.
- Wall-mounted detectors should be located 4 to 12 inches (10-30.5 cm) from the ceiling to detector head.
- Protect all detector heads during construction to avoid infiltration of construction debris. Remove any protective covers before activating the system.
- If using the adapter plate, tighten the mounting screws without warping the adapter plate.

Appendix C: Calibration Flowchart



If using Densitometer, this function is disabled:

Digital Input for smoke level:
OK: 3% smoke level. Operate, no additional adjustment.
Low: 2.85%.Reduce deltas by 5%, SA=-.05
High: 3.15%. Increase deltas by 5%, SA=+.05
Too Low :2.7%. Do not operate
Too High: 3.3%. Do not operate
The Low & High delta adjustments, "SA", needs to be user changeable and password protected.

Logging Data:
For all units,t(hat pass or fail), log the final CAV and final DV, and Digital smoke level input state. Add time and date stamp.

Note:
When displaying a Target value to adjust too, display a range of +/- 4 counts. This adjustment tolerance display range needs to be user changeable and password protected.

CAV	Clean Air Value
CAVL	Clean Air Value Low limit
CAVH	Clean Air Value High limit
CAVM	Clean Air Value Middle
DHV	Delta High Value = DHVI + ULA
DLV	Delta Low Value = DLVI + ULA
DMV	Delta Mid Value = DMVI + ULA
DUT	Device Under Test
DV	Delta Value
ECA	Expected Clean Air value
I3SV	Initial 3% Smoke Value
ICA	Initial Clean Air value
ID	Initial Delta value
N3SV	New 3% Smoke Value to adjust to.
NCAV	New Clean Air Value
NDV	New Delta Value
SA	Smoke Adjust
TD	Target Delta value
TDN	Target Delta value NEW
ULA	UL Adjust

CAVL = 65
CAVH = 95
CAVM = 80
DLVI = 72 + (72*SA) Delta Low Value Initial
DHVI = 91 + (91*SA) Delta High Value Initial
DMVI = 82 + (82*SA) Delta Mid Value Initial
ECA = ICA + ((ICA - 22) * (TD - ID) / ID)
ID = I3SV - ICA
N3SV = TD + ECA

All constants in formulas and defined values need to be user changeable and Password protected.

Densitometer Algorithm: Algorithm user selectable to run or not run, password protected.

When taking a reading in smoke, at the same time take a reading from the Densitometer.

DENV = Densitometer reading in smoke.
3DEN = Densitometer stated 3% value.
3ADJ = DENV - 3DEN

DHV	Delta High Value = DHVI + ULA + 3ADJ
DLV	Delta Low Value= DLVI + ULA + 3ADJ
DMV	Delta Mid Value= DMVI + ULA + 3ADJ

If 3ADJ > 10 or < -10: Do Not Operate

Note: Densitometer should have a calibrated delta of 82 +3, -3 at 3%/ft.

Drawing Number 0998-410
Rev 7 8/21/08