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Evaluations of Fiber Optic Sensors for Interior Applications

Martin W. Sandoval, Timothy P. Malone

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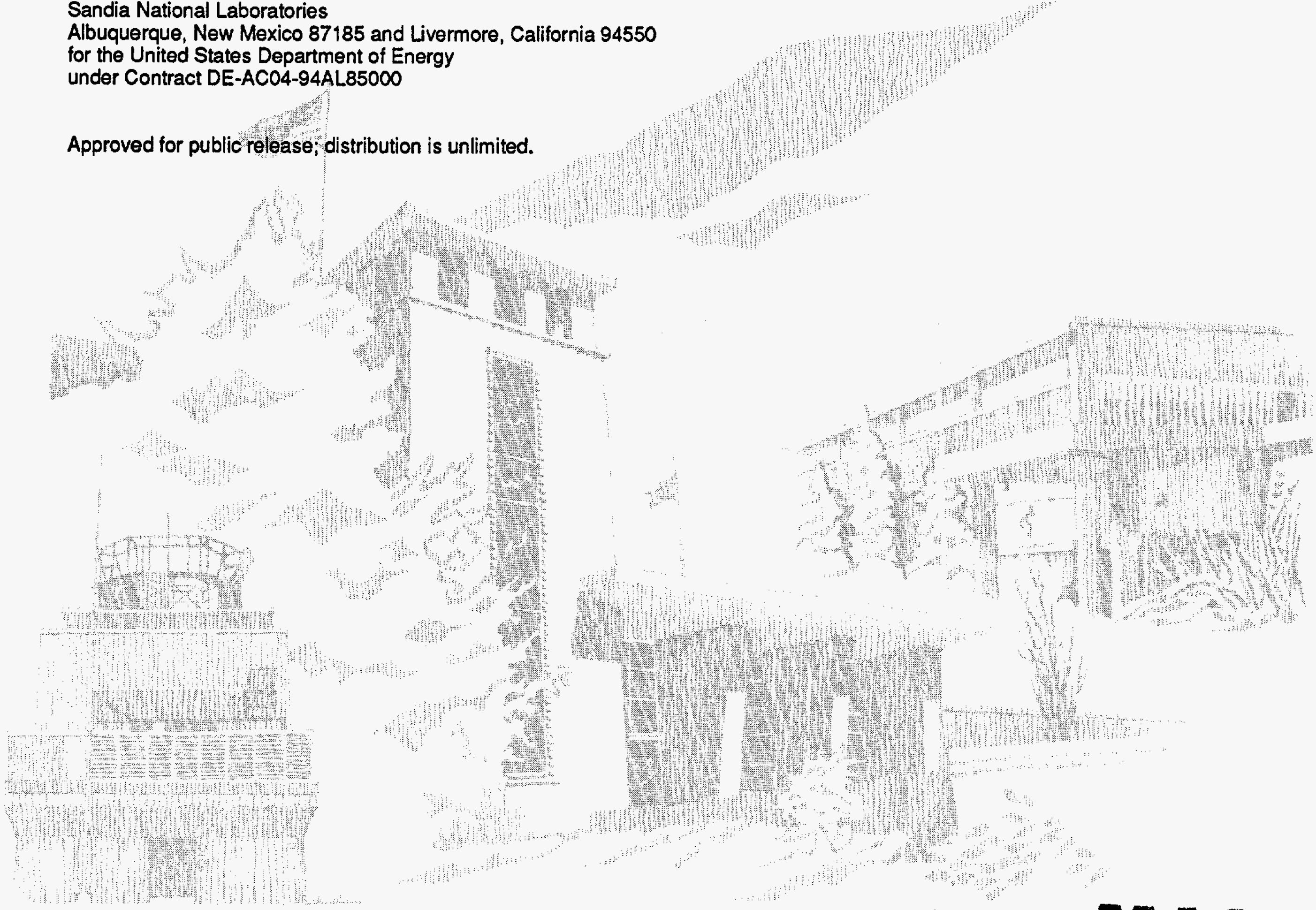

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Evaluations of Fiber Optic Sensors for Interior Applications

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ABSTRACT

This report addresses the testing and evaluation of commercial fiber optic intrusion detection systems in interior applications. The applications include laying optical fiber cable above suspended ceilings to detect removal of ceiling tiles, embedding optical fibers inside a tamper or item monitoring blanket that could be placed over an asset, and installing optical fibers on a door to detect movement or penetration. Detection capability of the fiber optic sensors as well as nuisance and false alarm information were focused on during the evaluation. Fiber optic sensor processing, system components, and system setup are described.

Acknowledgments

The authors would like to thank Basil J. Steele, Manager, Intrusion Detection Technology Department, Ron W Moya, Manager, Mary Woodruff and Theresa Bourne, DOE Security Programs Department for reviewing and editing this report.

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Introduction

Designing an effective physical protection system (PPS) is a complex process. In order to have an effective PPS design understanding the different technologies in the system is essential. Primary considerations of a sensor's performance include probability of detection (Pd), nuisance alarm rate, and vulnerability to defeat.

New sensor technology is always suspect to many of the typical problems that face existing sensors, thus characterizing any new sensor is critical. Fiber optic intrusion detection sensors have recently emerged as a new technology intended for use in the PPS environment. Fiber optic technology appears to be a promising and viable solution for certain applications.

This report discusses the results of additional evaluation and testing of fiber optic sensors in interior intrusion detection applications. In a previous report, SAND94-0020, *An Evaluation of Fiber Optic Intrusion Detection Systems in Interior Applications*, Jose T. Vigil, four commercially available fiber optic intrusion detection systems were evaluated and tested in a false ceiling application.

The testing documented here involved fiber optic sensors applied in above suspended ceilings to detect removal of ceiling tiles, embedding optical fiber inside a tamper or item monitoring blanket that could be placed over an asset, and installing optical fibers on a door to detect movement or penetration.

The scope of this testing and evaluation was limited to performance characterization. Blackhatting to identify inherent vulnerabilities of the technology was not performed. Thus, the potential exists that serious vulnerabilities may be identified in later evaluations. Two commercial fiber optic sensor systems were evaluated. One of these sensor systems was evaluated and tested in the previous work.

Fiber Optic Sensor Operation

Fiber Optic Sensor Systems Operation

Present commercial fiber optic sensors designed for intrusion detection applications typically consist of two major components: an alarm processing unit (APU) and a fiber optic sensor cable. Depending on the system, other components may include an APU programmer or programming software, weather resistant enclosures, an external power supply, and fiber optic beam splitters.

The APU contains a light emitting source which transmits light into a fiber optic cable, a detector for receiving light from the cable, and signal processing electronics. The fiber optic sensing cable is usually in a loop configuration with both ends connected to the APU.

Fiber optic sensors are sensitive to very small changes (known as microbending) in the fiber optic sensor cable. Microbending in the fiber optic cable can be caused by vibration, movement, or pressure applied to the cable. When a fiber optic cable is subjected to microbending, changes to the way that light travels through the cable occurs. These changes to the light path or paths are detected by the APU receiver and then processed.

Three techniques for detecting changes in fiber optic cable light path are called interferometry, speckle pattern, and intermodal interference.

Interferometry Technique

Interferometry technique uses single mode fiber optic cable. A beam splitter is used to divide the transmitted light into two different wavelengths, sending each wavelength through the cable in different directions. An interference pattern then occurs within the cable as a result of the different wavelengths. Microbending in the cable causes changes to the light path and hence changes to the interference pattern. The changes in the interference pattern are detected and then converted to an electrical signal by the APU detector.

Speckled Pattern Technique

The speckle pattern technique uses multimode fiber optic cable. When light is transmitted through multimode cable, the light travels along many different paths. If the light exiting the cable is focused on a plane, a pattern of light and dark patches (speckle pattern) appears due to the many light paths. When the cable is stationary, the pattern is stationary. When microbending occurs, the pattern changes. These changes in the speckle pattern are detected and then converted to an electrical signal.

Intermodal Interference Technique

Intermodal interference technique also uses multimode fiber optic cable. In this technique, the combination of a laser diode light source and the multimode cable results in many different wavelengths of light traveling through the fiber cable. Microbending causes changes to the relationship or interference of the different wavelengths to each other. The receiving detector generates an electrical signal which is proportional to changes in the distribution of optical spectral intensity.

Fiber Optic Sensor Systems Tested

Fiber SenSys, Inc., Models M105 and M110

Two fiber optic sensor models manufactured by Fiber SenSys, Inc., were tested. Model M105 units were tested in the false ceiling and monitoring/tampering applications. The M110 is a newer model which became available during the test period and was tested in the door sensor applications.

The M105 and M110 units are similar and both employ intermodal interference for detecting pressure, vibration, and movement applied to fiber optic cable. They have very similar APU units and the same setup controls and parameters.

The M105 model is intended for exterior applications such as fences and buried in gravel and for interior applications such as in walls or above drop ceilings. The maximum sensor cable length for the M105 is 2000 meters.

The M110 is primarily intended for exterior chain-link fence applications with faster and easier installation than the M105. Easier fence installation is a result of crimp-on connectors which do not require epoxying and polishing. The maximum M110 sensor cable length is 300 meters.

Both units require the use of a hand-held calibrator to setup or change parameters and to gain system information useful for trouble shooting. The calibrator consists of an alphanumeric keyboard with a two line liquid crystal display (LCD). (Figure 1.)

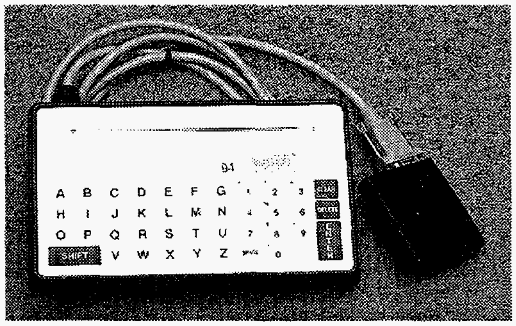

Figure 1.
Hand-Held Calibrator

M105/110 APU Setup Parameters

The calibrator uses a security device in line with the interface to the APU. This helps to prevent unauthorized access to the APU parameters. User-adjustable setup controls and parameters for both systems are:

Low-Frequency Cutoff and High-Frequency Cutoff: These two adjustments set the roll-off points for high and low pass filters. They allow for tuning out frequencies picked up by the sensor cable that are not useful for detection, but cause nuisance alarms.

Sensitivity: The sensitivity control adjusts the integration time of an integrator circuit which converts sensor signals to an equivalent average energy imparted to the sensor cable over time.

Threshold: The threshold is adjustable from 1% to 100% of the full output scale of the integrator circuit. When the signal level from the integrator reaches the threshold point or above, it is qualified as an event.

Event Count: This is the number of events that must be registered by the event counter before an alarm is generated by the system. When an alarm is generated, the alarm relays change state and an indicator is illuminated on the APU panel. The event counter is reset to zero after alarm activation.

Event Window: This is a window of time during which another event must occur in order to be counted by the event counter. It is initialized and the clock starts when an event occurs. If another event does not occur, the event counter is reset to zero after the time period. If another event does occur within the time period, the event counter is incremented. The time period can be adjusted from 1 to 100 seconds.

Event Mask Time: This is also a time period initialized by an event. It is adjustable from 0 to 9.99 seconds. During the time period that is selected, the event counter will not be incremented by events.

Alarm Relay Time: This parameter allows the user to set the time period during which the sensor remains in the alarm state. This period is selectable from 1 to 1800 seconds.

Datecode: Displays the date when the sensor unit was initialized or calibrated. A new date can be entered when recalibrated.

Comment Field: A message line where 30 characters can be stored for commenting purposes.

Allow Disable: A front panel switch can be set to disable the sensor. A 'YES' entered for this parameter will allow the switch to disable the sensor. A 'NO' will not allow the switch to disable the sensor.

Lock Unit: Allows the APU to be secured so that no setup parameters can be changed without the password.

Table 1 shows the M105 and M110 user setup parameters and the range for each parameter.

Parameter	Range
Low Frequency Cutoff	1 to 500 Hz.
High Frequency Cutoff	50 to 2000 Hz.
Sensitivity	1% to 100%
Threshold	1% to 100%
Event Counter	1 to 250 Events
Event Window	1 to 100 Seconds
Event Mask Time	0 to 9.99 Seconds
Alarm Relay Output	1 to 1800 Seconds

Table 1.
M105 and M110 Setup Parameters

Test Setup and Equipment

Test Areas

Evaluation and testing of the fiber optic sensors was conducted in a mobile office-type building and in a concrete, earth-burmed storage bunker. False ceiling application testing was conducted in the mobile office building. Item monitoring/tampering tests were conducted in the storage bunker. Door sensor application tests were conducted in both areas.

Alarm Data Collection

Computer-based alarm data collection systems located in both areas were used to monitor and record alarms from the fiber optic sensors. These systems operate unmanned, record time and date for each alarm, and control video recording equipment for later assessment of causes for alarms. This provided automatic storage of nuisance and false alarm information from the sensors. Periodically, the alarm data and video recordings were reviewed for assessment of alarm causes. Figure 2 shows the major components of an alarm data acquisition system used to collect nuisance and false alarm sensor data.

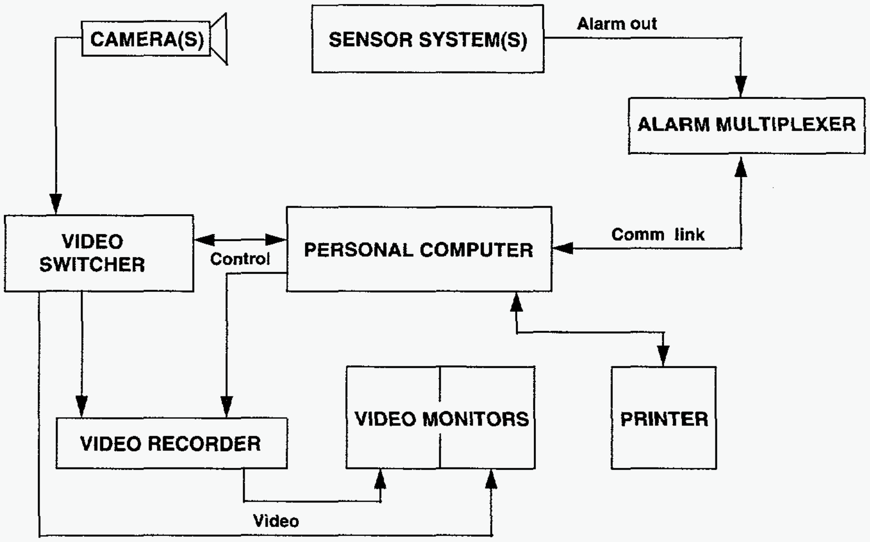

Figure 2.
Alarm Data Acquisition System

Suspended Ceiling Application

Model M105 Installation

A suspended ceiling in a mobile office was used to conduct testing for applications in restricted passage areas. The objective of the testing was to provide an evaluation of fiber optic sensors to detect ceiling tiles being moved. Detection of attempted entry into a restricted area and objects being removed or placed into a restricted area via a false ceiling are primary considerations for restricted passage-type areas. The fiber optic sensor cable was installed on the top side of the suspended ceiling and arranged so that two strands of the cable lay across individual ceiling tiles. The alarm processing unit was mounted on the wall six inches beneath the false ceiling for easy access. Figure 3 is a photo of the area above the ceiling and Figure 4 shows the processor unit mounted on the wall.

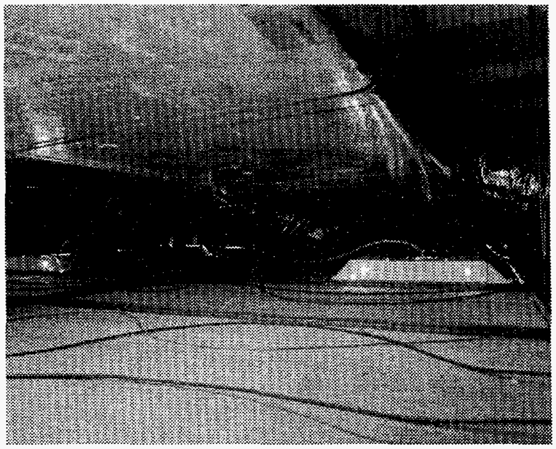

Figure 3.
Area Above the Suspended Ceiling

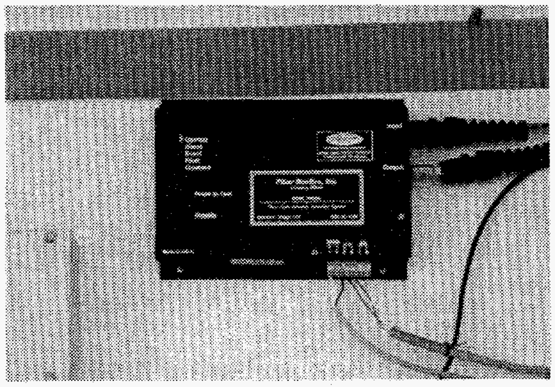

Figure 4. Processor Unit

Testing Procedures

Initial testing involved adjusting the sensor's parameter for acceptable performance. The ultimate goal in sensor performance would be to have 100% detection with never any nuisance or false alarms. Unfortunately, as with any sensor, these performance characteristics do not exist. Thus an acceptable setting must be determined that provides the best detection possible with the least number of nuisance alarms.

The initial testing, along with previous evaluation and testing of the M105, gave an indication as to the proper setting of all of the parameters. Fine tuning of these parameters was necessary to achieve the best detection with the least nuisance alarms. Final system parameters are listed in Table 2.

Parameter	Setting	Range
Low Freq. Cutoff	1 Hz.	1 to 500 Hz.
High Freq. Cutoff	50 Hz.	50 to 2000 Hz.
Sensitivity	71%	1% to 100%
Threshold	40%	1% to 100%
Event Counter	2 Events	1 to 250 Events
Event Window	10 Second	1 to 100 Seconds
Event Mask Time	0.99 Seconds	0 to 9.99 Seconds
Alarm Relay Output	2 Seconds	1 to 1800 Seconds

Table 2.
Fiber Optic Sensor Settings for Ceiling Application

Detection Testing

Detection tests consisted of slowly lifting each corner and side of individual tiles six inches, at a rate of approximately two inches per minute. Six inches was chosen based on requirements concerning detection of a six-inch object being removed from a protected area and placed above the ceiling or an object being placed in the area from above.

Ceiling Layout and Test Points

Figure 5 shows the suspended ceiling layout, fiber optic cable placement, and the tiles used for detection tests. The numbers indicate the tiles tested for detection. These tiles were arbitrarily chosen and represent a sample of all tiles. The tests were conducted in such a manner that the experience of the perpetrator varied from inexperienced with no technical background to a technically capable intruder with detailed knowledge about the fiber optic sensor and how it was installed.

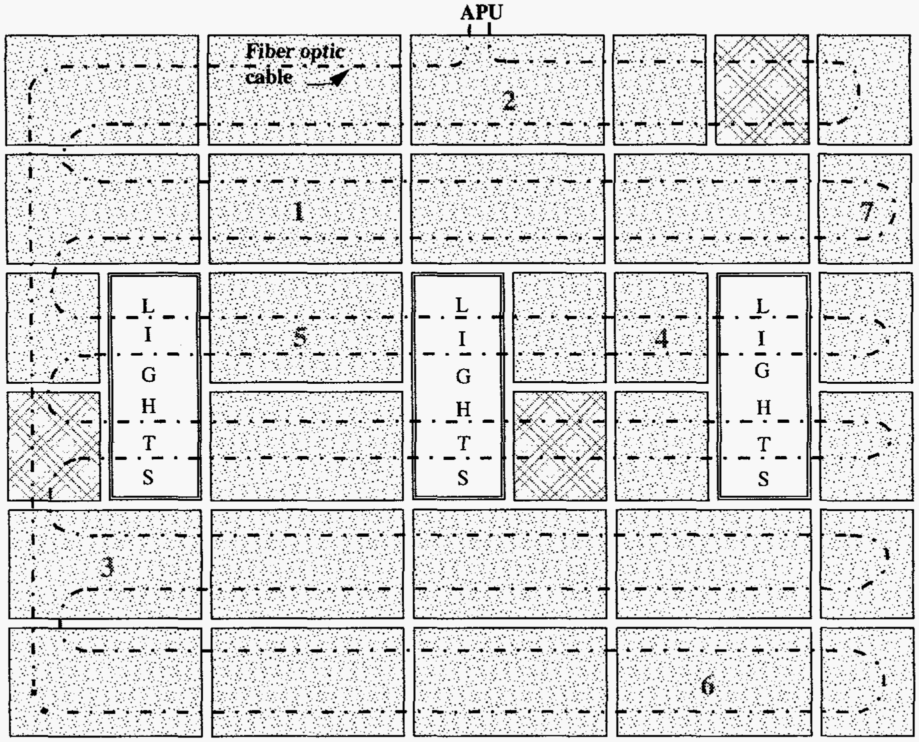

Figure 5.
Suspended Ceiling Tile Layout and Test Points

Detection Testing Results

The following tables and graphs are representative of the data gathered. Table 3 indicates the results of performance testing conducted to obtain a probability of detection (Pd) with at least a 95% confidence level. Figures 6 and 7 show these results graphically.

Tile No.	Attempts	Detections	Pd
1	75	73	92%
2	75	62	76%
3	75	72	90%
4	75	74	94%
5	75	72	90%
6	75	75	96%
7	75	30	<35%

Table 3.
Suspended Ceiling Detection Testing Results

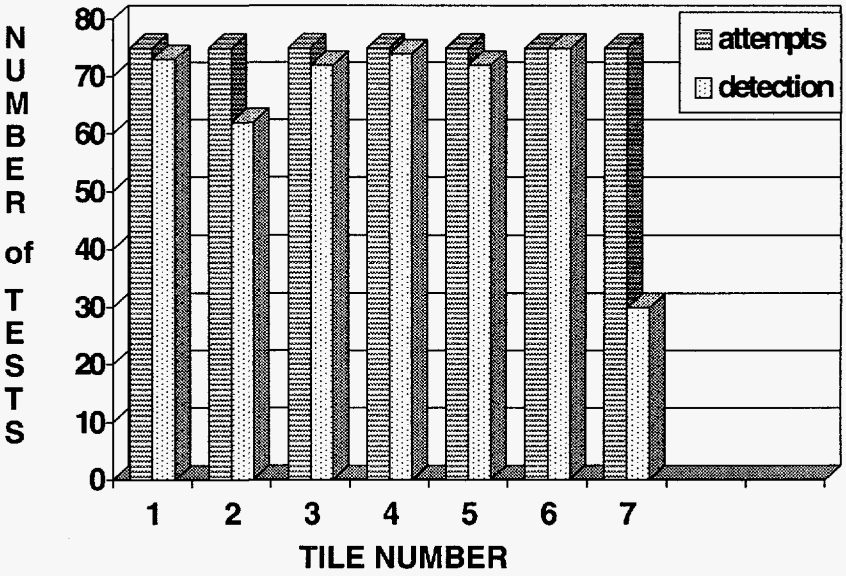

Figure 6.
Detection Test Results per Ceiling Tile

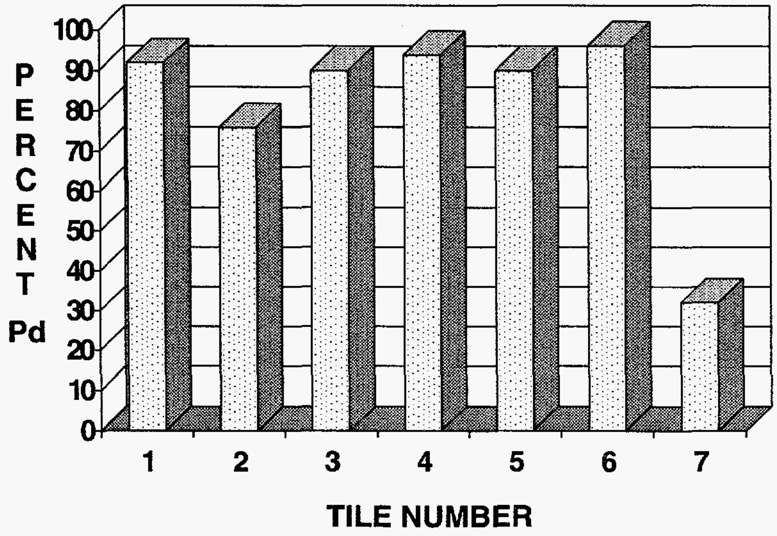

Figure 7.
Pd with a Confidence Level of 95%
for each Individual Tile Tested

Alarm Data Collection Results

Testing of the ceiling application concluded with 2324 hours logged for the parameters set to final specifications. Most of the data collected occurred during evening and night time hours as well as 24-hour monitoring during weekends.

Nuisance Alarms

The only known nuisance alarms were caused by doors near the room where the testing was being conducted. An exterior door, closed by an automatic door closer, caused vibrations within the mobile office when the door hit the closed position resulting in nuisance alarms. Interior doors near the test room also caused some nuisance alarms when they were closed.

Unknown Alarms

Unknown alarms are described as alarms that cannot be identified by video tape assessments. Vibrations within the mobile office structure caused by high winds, thunder, and aircraft are possible sources for these types of alarms.

Figure 8 shows the number of nuisance and unknown alarms with respect to time periods during alarm data collection.

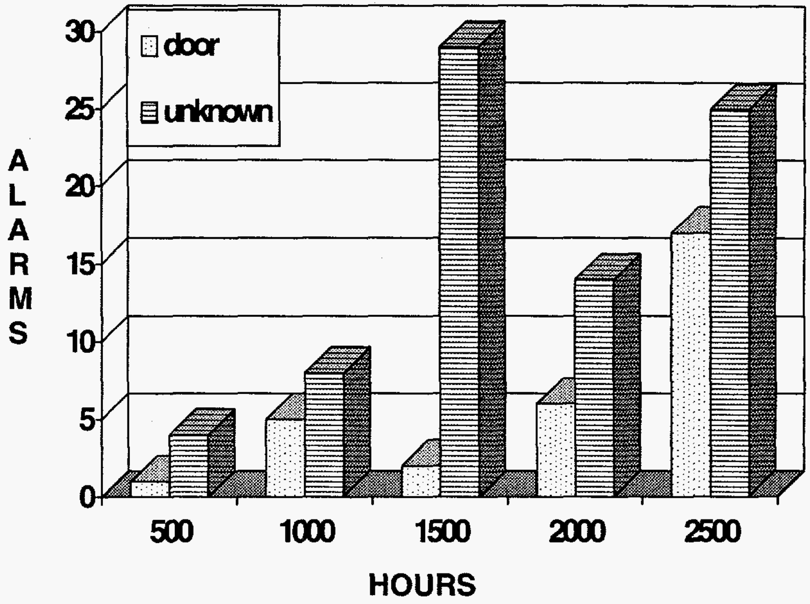

Figure 8.
Nuisance Alarms versus Periods of Data Collection

Item Monitoring and Tampering Application

Installation and Setup

A sensor blanket for placing over an item to detect movement or tampering of that item was constructed using the Fiber SenSys M105 sensor. The blanket is a prototype built to demonstrate a fiber optic blanket concept. Construction of the prototype blanket consists of fiber optic sensor cable attached to a sheet of plastic construction fence material which is sandwiched between canvas material. Plastic bubble pack material is also placed between the fence material and canvas on one side. The fence and bubble pack materials serve to help prevent the fiber optic cable from being bent to less than the minimum bend radius and to prevent the fiber from moving within blanket. Dimensions of the prototype blanket were 110 inches long, 82 inches wide, and approximately 3/8 inches thick. Approximately 4 feet of the sensor cable exited the blanket and connected to the M105 processor.

For demonstration and evaluation, the blanket was placed over a weapon mockup as shown in Figures 9 and 10. It was placed so that the side with the bubble pack was against the mockup. Initial testing showed that the fiber optic blanket is very sensitive to slight blanket and mockup movement as well as slight pressure to the blanket surface such as hand movement across surface. During initial testing the sensor system parameters were set for good detection performance while keeping minimal nuisance alarms in mind.

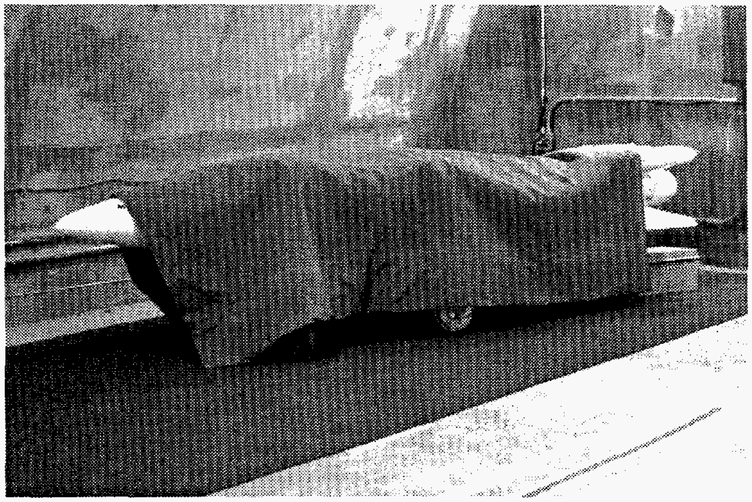

Figure 9.
Prototype Sensor Blanket Over Weapon Mockup

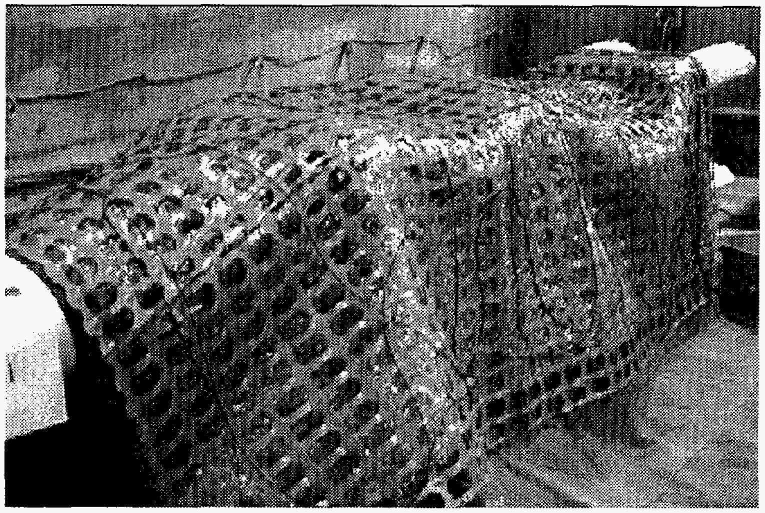

Figure 10.
Inside of Prototype Fiber Optic Sensor Blanket

Detection Testing

Detection testing and nuisance alarm data gathering were performed with the weapon mockup and blanket inside a storage bunker. The bunker is a concrete structure with 2-3 feet of earth burm. It has one large metal access door in the front. Because of the bunker construction and that personnel do not routinely work inside, it is a very quiet area.

Initial testing determined where the fiber optic sensor parameters should be set for best performance with regards to detection and nuisance alarms. The settings are listed in Table 4.

Parameters	Setting	Range
Low Freq. Cutoff	1 Hz.	1 to 500 Hertz.
High Freq. Cutoff	75 Hz.	50 to 2000 Hertz.
Sensitivity	40%	1% to 100%
Threshold	50%	1% to 100%
Event Counter	2 Events	1 to 250 Events
Event Window	15 Seconds	1 to 100 Seconds
Event Mask Time	1.485 Seconds	0 to 9.99 Seconds
Alarm Relay Output	4 Seconds	1 to 1800 Seconds

Table 4.
Parameter Settings for Blanket Application

Detection of Blanket Movement

Detection testing of the blanket consisted of lifting the blanket at different locations, one location at a time. The blanket was grasped at the bottom edge at each corner and mid-way between the corners and was moved outward and up. When an alarm occurred, the approximate distance of movement outward from the starting position of the bottom edge of the blanket was recorded. Six trials of lifting the blanket were performed at each location. The blanket was also pulled straight up at both ends along the top and the alarm point recorded.

Detection Testing Results

The detection tests show quite a range of blanket movement for each test location and different sensitivities depending on location. The blanket is more sensitive towards the right rear corner because this is the area where the fiber optic sensor cable enters and exists the blanket. The 0 inches of movement are due to an alarm being generated when the blanket was grasped, but not moved outward. Figure 11 shows the results of these detection tests with the amount of blanket movement for each trial at the various locations.

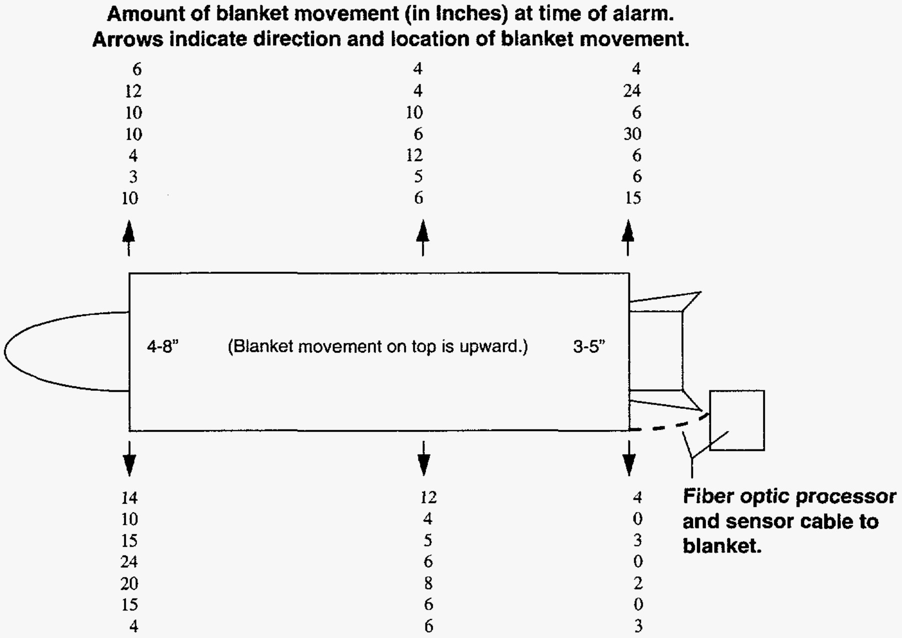

Figure 11.
Blanket Detection Tests

The variations in the sensitivity at each test point of the blanket are believed to be due to a number of factors including variations in the way the blanket flexed as it is moved and slight variations in the speed of movement. During detection testing, it was also discovered that the blanket is fairly sensitive to hand movement across the blanket surface.

Alarm Monitoring

The blanket was continuously monitored for alarms for approximately 4 months. The alarm relay output of the sensor was connected to an alarm data collection system. An overhead video camera, which viewed the mockup assembly and blanket, provided video for recording and alarm assessment.

Alarm Monitoring Results

Alarms that occurred during the monitoring period were categorized into three areas: testing and demonstrations, wildlife, and unknown.

Testing and demonstration alarms occurred when the blanket was being touched or disturbed and when the mockup item was being moved. The wildlife and unknown alarms are shown in Figure 12.

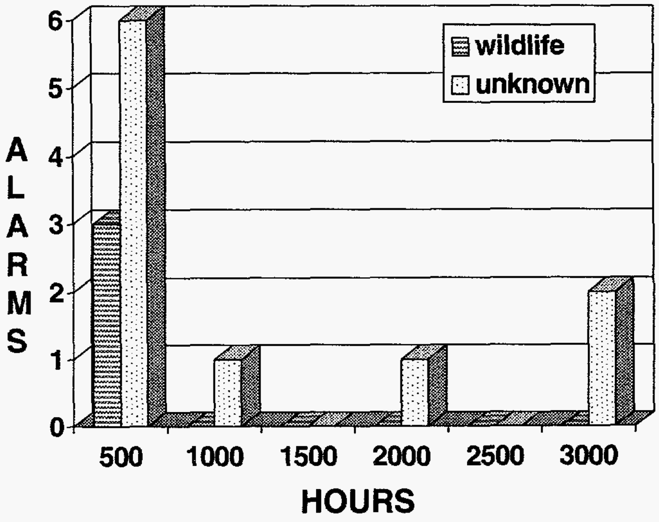

Figure 12.
Sensor Blanket Nuisance and Unknown Alarms

The only alarms classified as wildlife were assumed to be due to a large spider or small rodent. During the first 500 hours of nuisance alarm monitoring, a tarantula as well as a small rodent was seen on the video in the area of the mockup weapon. They caused alarms on a video motion detector covering an area near the mockup weapon. Although these creatures were not seen directly on the blanket, they may have disturbed the sensor cables between the blanket and processor or may have disturbed the underside of the blanket.

The unknown alarms were ones for which a cause could not be seen on the recorded video. The 6 unknown alarms within in the first 500 hours of data collection occurred within 48 hours of the three wildlife alarms. These may have also been caused by the spider or rodent, but were not seen on anywhere within the recorded video scene.

Door Sensor Application - Interior Office Door

Installation and Setup

A wooden interior door within a mobile office trailer complex was used to evaluate fiber optic sensor technology for use as a door sensor. The door leads to a lab area from a hallway. Detection of opening the door and penetrating the door by cutting, drilling, or sawing was desired. Current sensor technology such as a balanced magnetic switch can detect a door opening within the first inch of movement, but it cannot detect cutting through the door.

The Fiber SenSys model M110 was installed so that a horizontal serpentine pattern covered the entire door. Approximately 30 feet of fiber optic cable was attached to the inside of the door with six-inch horizontal spacing between cables and no turns exceeding a one-inch radius. The sensor processor unit was mounted off the door. A loop was formed in the fiber optic cables on the hinged side of the door to allow enough flexibility to compensate for the door being opened.

Initial Test Results

Initial setup and testing of the door-mounted fiber optic sensor resulted with nuisance alarms being a major problem. The mobile office environment was a major contributing factor to the nuisance alarms. Vibrations caused by other nearby doors opening and closing, personnel traffic moving in the hallway, and a small amount of play in the door latch caused most of the nuisance alarms. An unsuccessful attempt was made to adjust sensor parameters to filter out nuisance alarms. Even with minimal sensitivity and maximum frequency filtering, excessive nuisance alarms occurred.

Detection of activity such as light knocking or tapping on the outside of the door was very good which would make detection of cutting or sawing through the door highly probable. This detection capability, however, could also be a detriment in the office environment. Personnel walking by the closed and secured door could unintentionally or intentionally bump, scrape, or rap on the door causing nuisance alarms.

Detection of door movement within the first inch of opening was poor, especially with slow door movement. With this installation configuration, the only place where sensor cable movement occurs when the door moves is at the loop on the hinged side of the door. Moving the door 1 or 2 inches results with very little changes in the cable loop. To improve door movement detection increased sensor cable movement or vibration is needed.

Due to the high susceptibility to nuisance sources in the mobile trailer office, further testing of the fiber cable on a door in this environment was discontinued.

Door Sensor Application - Storage Bunker

Installation of Fiber Sensor

A Fiber SenSys, Inc., Model M110 fiber optic sensor system was installed using two different methods on the door of the storage bunker area where the item monitoring blanket testing was performed. One installation method involved attaching the fiber optic cable directly to the door. The other method used flexible conduit attached to the door with the fiber cable inside the conduit. Evaluation and testing were performed for both methods of installation.

Door dimensions were 101 inches tall, 78 inches wide, and 1.75 inches thick. The door was comprised of 5/8 inch plate steel on the exterior side and 1/4 inch plate steel on the interior side. These outer and inner door skin plates were separated by, and welded to, 7/8 inch-wide spacer plates along the edges. The inside of the door had filler material between the plates. There was a 18 inch by 22 inch ventilation opening located in the lower middle of the door. This opening was covered by a 1/2 inch diameter rod mesh on the inside and a box shaped plate steel cover on the outside that protruded out 6 inches. The cover was open on the bottom and had a metal screen mesh to allow air movement. The door was locked by means of two hinged latches on the outside that accommodate standard or high security padlocks.

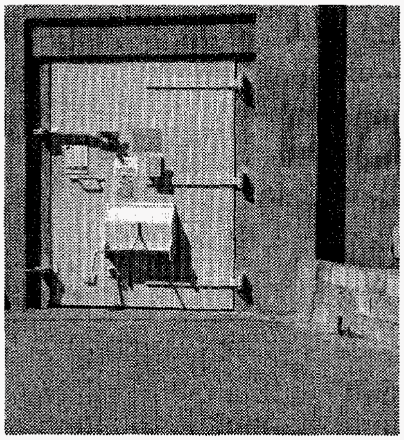

Figure 13. Storage Bunker Door

Sensor Cable Installed Directly on Door

The first method of installation involved a quick and simple method using tape so that the fiber optic cable was in direct contact with the door inside surface. The fiber optic sensor processor was installed in an enclosure and mounted on the bunker wall adjacent to the hinged side of the door. A short section of flex conduit was used for cable protection for the transition from the door to the processor enclosure. (See Figure 14.)

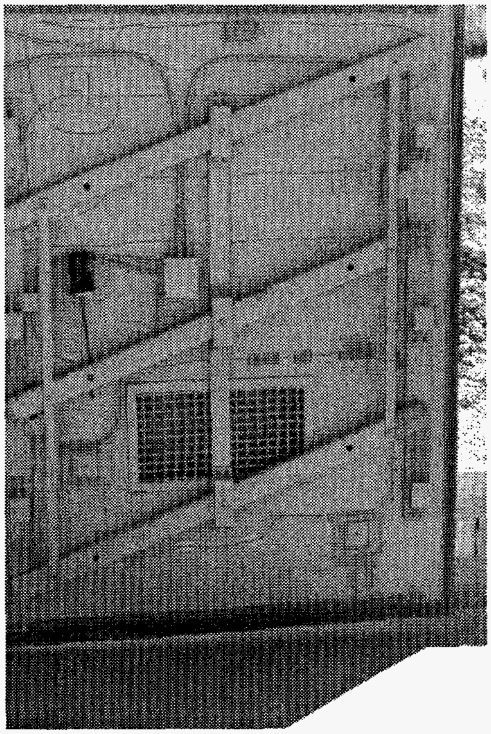

Figure 14. Inside of Bunker Door With Fiber Optic Cable Attached

Sensor Cable Installed in Flexible Conduit

The second method of installation used flexible metal conduit attached to the inside door surface with the fiber sensing cable running inside the flex conduit. The processor remained in the same place – on the bunker wall. The flex conduit was continuous for the entire sensor cable loop with both ends terminating at the processor enclosure. (See Figures 15 and 16.)

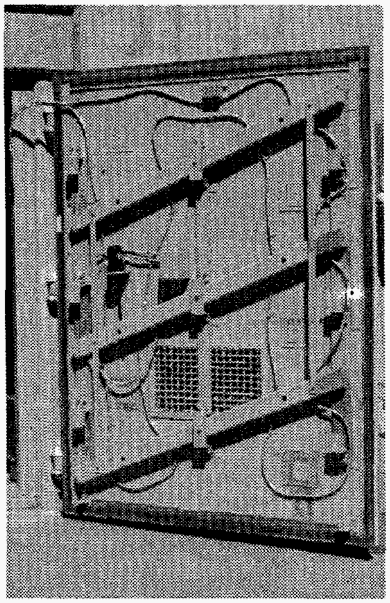

Figure 15. Bunker Door with Sensor Cable Inside Flexible Conduit

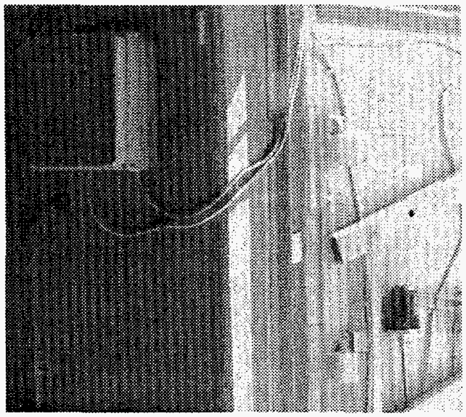

Figure 16. Conduit Transition from Door to Sensor Processor Enclosure

Sensor Setup

Initial detection tests and nuisance alarm monitoring were performed so that the sensor parameters could be set. In the first installation method (with the cable in direct contact with the door surface), the cable was installed across the vent opening in the door. This resulted in numerous nuisance alarms when the wind caused air movement through the vent. To reduce nuisance alarms, the cable was rerouted so it did not cross the vent. Detection of door movement depended on the movement of the cable and flex conduit at the off-door transition as the door moved. Initially, detection of door movement was poor. The flex conduit was repositioned so that more movement and vibration would occur.

With the second installation method (sensor cable installed in flexible conduit), improved detection of door movement along with protection of the sensor cable were goals. For improved door movement detection, additional mechanical means for inducing sensor cable vibration and movement was implemented. A simple method was employed to evaluate this concept. Two spring-type wires were attached to the inside of the door so that they would momentarily catch on the door frame lip as the door was opened. The flex conduit was attached to the spring wires. The sudden return of the spring when it let go from the lip caused sudden cable movement and vibration to the cable. (See Figure 17).

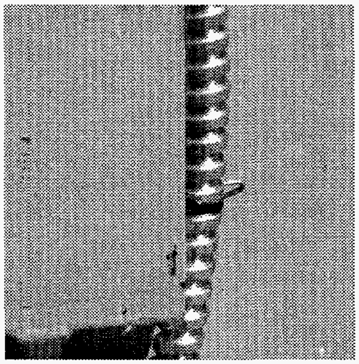

Figure 17. Spring Tab Attached to Conduit

Sensor parameters chosen for testing both of the installation methods were aimed at acceptable overall performance between detection and nuisance alarms. These parameters are listed in Table 5.

Parameter	**Settings**	
	Cable Contacting Door Surface	**Cable in Flex Conduit**
Low Frequency Cutoff	25 Hz.	15 Hz.
High Frequency Cutoff	200 Hz.	200 Hz.
Sensitivity	25%	25%
Threshold	35%	35%
Event Count	2 Events	2 Events
Event Window	10 Seconds	10 Seconds
Event Mask Time	0.990 Seconds	0.792 Seconds

Table 5.
Sensor Parameter Settings for Bunker Door Application

Detection Testing

Detection capability of door movement as well as detection of activity on the outside of the door were tested. Testing for activities outside the door were limited to nondestructive tests. These included removing the lock and moving the door latch, tapping on the door and hinges with a hammer, and drilling and sawing on test plates attached to the door.

Detection Test Results

Detection tests were performed both during the initial setup when sensor settings were being determined and at later times. Tables 6 and 7 reflect the results of the detection testing. The data in the tables represent detection tests after initial sensor setup.

Test	Attempts	Detections	Notes
Door Movement:			
Door opening. Movement at 1″ per second.	20	20	Door had to move 4″ to 11″ before alarm occurred.
Door opening. Movement at 1/2″ per second.	20	20	Door had to move 4″ to 20″ before alarm occurred.
Door opening. Movement less than 1/2″ per second.	3	0	No detection out to 20″ of door movement.
Outside Activities:			
Tapping on outside surface hammer.	20	20	2-3 taps on door surface required for alarm.
Removing lock and latch.	5	0	Careful handling of lock and latch not detected.
Hacksaw. Each attempt consisted of sawing for 30 seconds.	5	1	No detection of saw teeth cutting into metal. One alarm when saw frame rapped against door.
Drilling. Each attempt consisted of drilling into metal plate on door surface for 30 seconds.	5	0	No detection of drilling on outside of door.

Table 6. Detection Test Results -
Sensor Cable Installed Directly on Door

With exception of hammer taps, detection was poor for the direct cable installation on the door. Although movement of the door was detected 100% of the time, the amount the door could move before an alarm was generated was excessive. No detection occurred with careful removal of the lock and slow steady movement of the latch arm. When the lock and latch components were allowed to rap against the door during removal, then detection usually occurred. Drilling and hacksawing did not impart enough vibration energy through the door and into the cable. Since the hacksawing and drilling were nondestructive tests, holes were not made in the door. It is possible that actual drilling through the door would be detected because of the door thickness and the time required to completely drill through the door.

Test	Attempts	Detections	Notes
Door Movement:			
Door opening. Movement at 1″ per second.	20	20	Consistently alarmed by the time the door moved 2″.
Door opening. Movement at 1/2″ per second.	0	–	No tests performed at this rate.
Door opening. Movement less than 1/2″ per second.	20	20	Consistently alarmed by the time the door moved 2″.
Outside Activities:			
Hammer taps on door outside surface.	20	20	2-3 taps required for alarm.
Hammer taps on door hinge and latch bolts.	10	10	3-5 taps required for alarm.
Removing lock and latch.	5	1	Lock and latch carefully removed.
Hacksaw. Each attempt consisted of sawing for 30 seconds.	5	0	No detection of saw teeth cutting into metal.
Drilling. Each attempt consisted of drilling for 30 seconds.	5	0	No detection of drilling on outside of door.

Table 7. Detection Test Results -
Sensor Cable Installed in Flex Conduit

In the flex conduit configuration, detection of door movement was greatly improved. This improved detection was a result of the additional mechanical means which allowed increased movement and vibration to be imparted to the sensor cable. The flex conduit offered protection for the fiber optic cable and made implementing the mechanical spring devices easier. Detection of activities outside the door remained essentially the same as with the cable installed directly on the door surface.

Alarm Monitoring Results

Both installation methods had very low nuisance alarm rates. With the sensor cable installed directly on the door, the system was monitored for false and nuisance alarms for

30 days. During this period, no nuisance or false alarms occurred. The only alarms recorded were when personnel opened and closed the door.

The flex conduit installation was monitored for 30 days also. Eight unknown alarms occurred during this period. Nothing was seen on the video recording for these alarms. Possible sources for these alarms include low flying aircraft that had just taken off from a nearby airport or settling of the flex conduit at the off-door transition after the door was closed.

Summary and Conclusions

The fiber optic sensor systems performed best in a non-occupied stable structure (storage bunker with almost no pedestrian and very little vehicle traffic) as compared to a less stable structure such as the mobile office building.

To use fiber optic sensors in an interior environment careful considerations need to be given to the characteristics of the building or structure nuisance alarm sources. Nuisance alarm sources for fiber optic sensors include building vibrations from doors slamming, extreme weather conditions, heating and cooling systems, and equipment and machinery located either inside or outside.

Detection can be enhanced by devices that will increase movement and vibration into the fiber optic sensor cable. A fairly simple mechanical method for enhancing detection was explored in this evaluation for a door sensor application. Vulnerabilities of this method were not part of this evaluation. However, weaknesses of any method for enhancing detection must be considered in actual applications.

Summary and Conclusions <u>Suspended Ceiling Application</u>

A fiber optic intrusion detection sensor system was installed above a suspended ceiling in a mobile office type building. The purpose was to conduct an evaluation of fiber optic sensors for applications in secured area intrusion detection via a restricted passage area such as a suspended ceiling. Fiber optic sensor cable was installed on the top side of a suspended ceiling within a room and arranged so that two strands of the cable lay across individual ceiling tiles. The sensor was setup to detect movement of ceiling tiles during attempted entry into the area and also to detect attempts at removing objects from, or placing objects into, the area.

Out of 31 ceiling tiles, 7 were tested for detection of movement. These were randomly located throughout the room. The system detected movement of five of the tiles with a probability of detection (Pd) of 90% or greater at a 95% confidence level. Two tiles, both located next to a wall, ended up with less sensitivity. For these two tiles, the sides of the tiles adjoining the wall had the least sensitivity. The cable laying loose on the tiles, combined with where the cable was positioned on the tile, resulted with minimal sensor cable disturbance and therefore less sensitivity.

For all the tiles, detection sensitivity deteriorated slightly as more tests were conducted. After repetitious testing, tiles could be moved slightly further before causing the fiber optic sensor to alarm. This was due to the shifting of the fiber optic cable away from the side of the tile that was being repeatedly lifted. Although this slight reduction in sensitivity did occur, the five tiles with 90% Pd stayed within the desired detection – at or before six inches of lift.

Slightly more than 2300 hours of alarm data was collected. Thirty known nuisance alarms and 79 unknown alarms occurred. For the overall test period these alarms averaged 4.7 alarms per 100 hours. The known nuisance alarms were caused by vibrations within the mobile office structure due to doors closing. Possible sources for the unknown alarms include personnel activity not within view of data collection video camera, high winds, thunder and aircraft, all of which cause vibrations in the structure. During the testing period, the nuisance and unknown alarm rates generally increased as time progressed. Reasons for the increase are not known. Possibilities include increased personnel activity, changes to the environment or changes to the sensor itself.

A major factor in the nuisance and unknown alarms appears to be construction of the mobile office. Doors closing and external events caused vibrations within the structure. These could not be filtered out with the sensor frequency filtering parameters without degrading detection of tile movement. Installation in a more permanent type structure should improve nuisance alarm performance.

Improvement of detection capability for the two tiles near the wall is needed. More disturbance to the sensor cable as a tile is lifted would help. A fairly simple method may be the installation of ceiling tile clips that help secure the tiles into the framework. The ceiling tested did not have clips. When clips are used, they are meant to be removed before a tile is lifted. If a tile is pushed up from the bottom when the clips are in place, the possibility of sudden movement or damage to a tile is greater, which would improve detection. Clips designed to hold the sensor cable as well as the tile might improve detection performance even further. Such a clip would improve cable disturbance during tile or clip movement and also keep the cable from being displaced during testing or maintenance.

Summary and Conclusions

Item Monitoring and Tampering Application

A prototype sensor blanket for placing over an item to detect movement or tampering of that item was constructed using a fiber optic sensor. Construction of the prototype blanket consisted of the sensor cable attached to a combination of plastic construction fence and bubble pack material. The outer covering of the blanket was a canvas material. Testing and evaluation was performed in a bunker storage area, which is not normally occupied. For demonstration and evaluation, the blanket was draped over a weapon mockup.

Tests that involved movement of the blanket showed that detection occurred within a range of 0 to 24 inches of blanket corner or edge movement. Detection at 0 inches of movement occurred at the point where the fiber cable exited the blanket, enroute to the sensor processor.

Over the period of 4 months, six alarms believed to be due to a rodent or insect and seven unknown alarms occurred. Some of these unknown alarms might also have been due to the rodent or insect crawling across the exposed sensor cables that ran between the blanket and the processor.

As an initial, prototype sensor blanket, detection and nuisance alarm performance were good. Nuisance alarm performance was aided by the storage vault type environment. To further improve detection of blanket removal, a production blanket should be designed to be tied around an object or tied down to the floor. The blanket and fastening gear should be designed so that vibration and noise are generated and transferred to the sensor cable when the blanket is untied or moved. A good quality Velcro material might be one solution for securing a blanket around an object. A semi-stiff material within the blanket that will crackle when it is being moved could also further improve detection performance. Placing more material between the outer surface of the blanket and the fiber cable, as well as placing the sensor processor inside the blanket could reduce nuisance alarms. Another consideration for a production blanket is settling. Small amounts of movement after the blanket is installed or maintained could be a source of nuisance alarms.

Summary and Conclusions <u>Door Sensor Application-Interior Office Door</u>

An interior door within a mobile office trailer complex was used to evaluate fiber optic sensor technology for use as a door sensor. The Fiber SenSys model M110 was installed so that a horizontal serpentine pattern covered the entire door. Detection of opening the door, along with penetrating the door by cutting, drilling or sawing was desired.

Detection of door movement was poor, especially with slow door movement. Opening the door 1 or 2 inches resulted with very little sensor cable movement. Detection of activity such as light knocking or tapping on the outside of the door was very good. Destructive tests such as cutting or drilling through the door were not performed.

This installation had many nuisance alarms from the start. Slight play in the door latch caused many of these alarms. Construction of the mobile offices also contributed to nuisance alarms. Vibrations within the office area due to other doors being closed, nearby pedestrian traffic and external events all produced vibrations that were transmitted to the cable. An attempt was made to adjust sensor parameters to filter out nuisance alarms. This was unsuccessful. Even with minimal sensitivity and maximum frequency filtering, excessive nuisance alarms occurred.

Due to the high susceptibility to nuisance sources in the mobile trailer office, further testing of the fiber cable on a door in this environment was discontinued.

Summary and Conclusions <u>Door Sensor Application-Storage Bunker</u>

A fiber optic sensor was installed on the interior side of a large metal door leading into a normally unoccupied concrete storage bunker. The objective was to evaluate fiber optic sensors for use as a door sensor on a more stable door (than the mobile office door) and in a quiet environment. As a door sensor, detection of door movement as well as detection of intrusion activity outside the door was desired. Two installation configurations of the fiber optic sensor cable were evaluated.

The first installation was configured with the sensor cable in direct contact with the door surface. A short section of flexible conduit was used to transition the sensor cable from the door to the processor which was mounted on an adjacent wall. In this configuration, detection of door movement depended on disturbance and movement of the sensor cable within the section of flexible conduit transitioning off the door.

Detection testing of door movement resulted with required door movement varying from 4 to 20 inches before an alarm was generated. This amount of door movement before an alarm is considered excessive, therefore detection of door movement was poor. Results of detection testing of outside activities included very good for 2-3 light hammer taps on the door surface, and poor for drilling and hacksawing on a metal test plate attached to the outside of the door. (The drilling and sawing tests were nondestructive so a metal test plate was used for drilling and sawing.)

In the second configuration, the fiber optic sensor cable was installed inside flexible metal conduit for the entire sensor cable run with the flexible conduit attached to and contacting the door surface. In this installation, improved detection of door movement was a goal. A mechanical method for inducing sensor cable vibration and movement was implemented Two spring wires were attached to the door and flexible conduit. These wires momentarily contacted the door frame lip as the door was opened. This induced additional motion into the sensor cable with the return motion of the spring wire.

Door opening movement detection was greatly improved. Alarms were generated consistently during testing before the door reached 2 inches of movement from a closed position. Detection of outside activities remained about the same. Two to three light hammer taps on the outside door surface were required for an alarm. In addition, 3-5 five taps on the door and latch hinge bolts (located off the door on the outside wall surface) resulted in alarms. Drilling and sawing on the test plate was not detected.

Although detection of drilling and sawing on a test plate was not detected, it may be that actual drilling through the door would be detected because as the drilling progresses into the inner door skin, transmission of vibration to the sensor cable would be increased. Detection of actual sawing through a door hinge or latch using a standard hacksaw may not be detected due to the small amount of vibration generated. Using a hacksaw to cut a hinge or latch, however, would take a while to complete. Use of power saws would provide much more vibration which increases the likelihood of detection.

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