The Helios System and Border Security

An independent evaluation of the Helios System as applied to Border Security monitoring in Southern Arizona

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Executive Summary

This report describes the outcome of an independent investigation of the Helios Distributed Acoustic Sensor, manufactured by FOtech Solutions of UK, conducted by the Lowell Institute for Mineral Resources and the National Center for Border Security and Immigration at the University of Arizona. The investigation was commissioned by Zonge International of Tucson, Arizona. Zonge intends to market and deploy the Helios system for border security applications in the United States.

The study consisted of a review of the technology behind the Helios system and its performance in the Arizona border security environment. Evaluating this product in the desert is of crucial importance as the Helios system was developed and tested in the UK, where the ground is made of hard clay material - ideal for carrying acoustic waves with little loss of energy. In contrast, the soil in southern Arizona and the area surrounding the US-Mexico border consists mainly of alluvium sand, a loose material that transmits sound much less efficiently.

Fiber optic sensors in general and distributed acoustic sensors in particular have been used in the civil, petroleum and other industries over the past decade. Optical fibers are extremely sensitive to changes in pressure waves or acoustic disturbances. As sound hits the cable, the wave energy is transferred to the fiber, creating a tension proportional to the incident energy which in turn influences the light traveling inside the fiber. This influence is detected by an analyzer, de-modulated off the fiber line, and translated to a high-fidelity representation of actual events occurring along the length of the fiber. In contrast to current technologies, the innovative features of the Helios system include:

- No need for specially packaged fiber optic cables; a standard fiber optic cable can be used
- The system can interrogate the cable over large distances up to 50 km with an accuracy of 1 m
- No need for external power sources or additional electronics
- Accurate event location along the entire length of the cable comparable to GPS
- Potential for building advanced discrimination capability to differentiate and identify the source of disturbances along the cable.

These features could make the Helios system an attractive option for perimeter security monitoring where the major expenditure associated with the installation and operation of the system would be the cost of trenching to bury the fiber.

Continuous monitoring of the border is a particularly difficult problem in Southern Arizona. Some of the reasons for this are:

- Size of the area to cover
- Lack of manpower and proven technology
- Traffickers’ ability to adapt and counteract new surveillance measures in a short time

The Helios system could help fill some of the gaps in the border surveillance. The fact that it is 'invisible' (once installed below ground, it leaves no 'footprint' on the ground) could make it less likely to be detected, and because it can be deployed over large areas, it is conceivable that by linking relatively few Helios boxes, the entire US-Mexico border could be watched continuously.

For the purposes of this investigation, one Helios system and three types of standard fiber optic cables were deployed over a distance of 100 m at the test site. The cables' response to standardized tests was analyzed to identify the one that provides the highest quality data in the southern Arizona desert environment. Next, a series of experiments simulating typical and stealth border crossers, ranchers, wild life movement, and vehicle traffic were conducted to measure and analyze the system's discrimination capabilities.

The results show that with sufficient training, an observer could reasonably differentiate between events triggered by a group of people, cattle, horses, digging tunnels, cars or even 'stealthy' border crossers. The system is easy to use and the hardware performed reliably during the test period without any breakdowns. If successfully integrated into the current border security system, the software would need to be improved as it currently lacks automatic and unassisted event recognition capability. Helios has the potential to be deployed and integrated with an SBI-net type system. In a typical implementation, the distributed acoustic sensor would be used to detect events in real-time along the entire length of the border with GPS accuracy. The events' spatial coordinates would then be fed into an SBI-net type system to direct stationary or mobile cameras to interrogate the scene in the vicinity of the events. If necessary, field agents could be summoned to the location to further investigate.

It is the opinion of the authors that the Helios system should now be tested over a two to five kilometer stretch near the US-Mexico border for a period of three to six months, both to get a better understanding of its strengths and weaknesses and to demonstrate its potential as an integral part of the larger border monitoring system. In addition, event recognition algorithms should be developed and tested prior to a full scale deployment. These are important steps, as they will provide additional data currently lacking with respect to signal degradation, equipment durability, likelihood of detecting false positives, and potential threats in the Arizona border security environment.

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1. Introduction

In the summer of 2010, Zonge International, located in Tucson, AZ signed an exclusive agreement with FOtech Solutions of UK, to market and distribute the Helios Distributed Acoustic Sensor for border security monitoring applications in the United States. As part of its marketing efforts, Zonge commissioned an independent investigation of the Helios' suitability for deployment in the Arizona border security environment. The services of experts at the University of Arizona were retained in August of 2010 and a comprehensive study was planned with the assistance from the technical staff at Zonge International and FOtech Solutions. This report presents the results of the investigation conducted in November 2010 at the University of Arizona's Avra Valley Experimental Test Site.

2. Background

Illegal immigration from Mexico to the United States has been an ongoing problem for decades, but the issue reached new prominence after the World Trade Center and Pentagon attacks on 9/11. Concerned that terrorists might infiltrate the border to attack Americans with conventional weapons, or weapons of mass destruction, border security became a top priority for the U.S. government. Since 9/11, the Department of Homeland Security and U.S. Customs and Border Protection (CBP) were formed to better protect US borders.

According to CBP's website, cbp.gov (11/30/10), "CBP is one of the Department of Homeland Security's largest and most complex components, with a priority mission of keeping terrorists and their weapons out of the U.S. It also has a responsibility for securing and facilitating trade and travel while enforcing hundreds of U.S. regulations, including immigration and drug laws." CBP combined all the previous border law enforcement agencies under one administrative umbrella. This involved absorbing employees from the Immigration and Naturalization Service (INS), the Border Patrol, the Customs Service, and the Department of Agriculture. CBP's mission is to prevent terrorists and terrorist weapons from entering the country, provide security at U.S. borders and ports of entry, apprehend illegal immigrants, stem the flow of illegal drugs, and protect American agricultural and economic interests from harmful pests and diseases (Arrayano 2009). CBP maintains two overarching and sometimes conflicting goals: increasing security while facilitating legitimate trade and travel. In 2008, CBP's net budget totaled $9.42 billion and manpower totaled 50,417 personnel (Nunez-Nito 2008).

At official ports of entry, CBP officers are responsible for conducting immigrations, customs, and agricultural inspections. CBP inspectors routinely examine and verify travel documents of incoming international travelers to ensure they have a legal right to enter the country. On the customs side, CBP inspectors ensure that all imports and exports comply with U.S. laws and regulations, collect and protect U.S. revenues, and guard against the smuggling of contraband. Additionally, CBP is responsible for conducting agricultural inspections at ports of entry in order to enforce a wide array of animal and plant protection laws. In order to carry out these varied functions, CBP inspectors have broad powers to inspect persons, vehicles, conveyances, merchandise, and baggage entering the country from a foreign country.

Between official ports of entry, the U.S. Border Patrol (USBP) enforces U.S. immigration law and other federal laws along the border. USBP is the uniformed law enforcement arm of the Department of Homeland security. Its primary mission is to detect and prevent the entry of terrorists, weapons of mass destruction, and unauthorized aliens into the country, and to interdict drug smugglers and other criminals. The USBP patrols over 8,000 miles of our international borders with Mexico and Canada and the coastal waters around Florida and Puerto Rico (Nunez-Nito 2008).

The US-Mexico border is 1,969 miles long. It is the most frequently crossed border in the world. The following excerpt from Wikipedia (from 11/30/10) gives a brief description of the border:

> The U.S.–Mexico border has the second highest number of both legal and illegal crossings of any land border in the world, behind the Canada – United States border. The border is guarded by more than twenty thousand border patrol agents, more than any time in its history. However they only have "effective control" of less than 700 miles of the 1,969 miles of total border. The border is paralleled by United States Border Patrol Interior Checkpoints at major roads generally between 25 and 75 miles to the U.S. side of the border.
>
> There are an estimated half a million illegal entries into the United States each year. Border Patrol activity is concentrated around big border cities such as San Diego and El Paso which do have extensive border fencing. This means that the flow of illegal immigrants is diverted into rural mountainous and desert areas.
>
> For a period of time in the 1990s, United States Army personnel were stationed along the U.S.-Mexico border to help stem the flow of illegal immigrants and drug smugglers. These military units brought their specialized equipment such as FLIR (forward looking infrared) devices and helicopters. In conjunction with the United States Border Patrol, they would deploy along the border and, for a brief time, there would be no traffic across that border which was actively watched by "coyotes" paid to assist border crossers. The smugglers and the alien traffickers simply ceased operations over the one hundred mile sections of the border sealed at a time. It was very effective but temporary as the illegal traffic resumed as soon as the military withdrew.

The article highlights the current problem of illegal traffic across the border. To counter this problem, CBP has bolstered Border Patrol agent numbers and invested in new technologies. Even so, the problems persist as smugglers and traffickers quickly adapt to each new technique and technology meant to thwart their activities.

2.1 Current Border Security Measures

Today more than 20,000 Border Patrol agents are employed to guard the U.S.-Mexico border. Border Patrol agents are federal law enforcement officers whose principal duty is to prevent the smuggling of goods and contraband and the unlawful entry of undocumented aliens into the United States. In addition, Border Patrol agents apprehend people found to be in violation of US immigration law, process those people for deportation, and run permanent and temporary vehicular checkpoints.

Border Patrol agents apprehend undocumented aliens by conducting the line-watch which involves the detection and apprehension of undocumented aliens and their smugglers by maintaining surveillance from a covert position, pursuing leads, responding to electronic sensor alarms, utilizing infrared scopes during night operations, using low-light level television systems, sighting aircraft, and interpreting and following tracks, marks, and other physical evidence. In some sectors, agents flying fixed-wing aircraft and helicopters are able to track persons and direct ground forces to their locations.

Traffic checkpoints are used to deter terrorism, illegal immigration, and smuggling into the United States. At checkpoints Border Patrol agents have the authority to stop and question vehicle occupants even if there is no reason to believe that illegal activities are taking place. There must be probable cause for searching a vehicle. Tactical checkpoints support permanent checkpoints by screening vehicles that may be bypassing permanent checkpoints on secondary roads. Tactical checkpoints are temporary and lack permanent infrastructure.

2.2 Employed Technologies

To increase their effectiveness and efficiency, Border Patrol agents employ Enhanced Sensor Technologies as “force multipliers”. The technologies used include, but are not limited to, sensors, light towers, mobile night vision scopes, remote video surveillance systems, directional listening devices, various database systems, and more recently unmanned aerial vehicles (UAVs) (Bolkcom 2008). Additional high-tech equipment such as X-rays are used for “noninvasive detection of contraband goods and to curtailing illegal activities at the borders” (Arunachalam, Udpa et al. 2005).

The Border Patrol operates an extensive network of sensor devices comprised of motion, thermal, video and seismic equipment. Information from these devices is fed back to station command centers where agents monitor the systems 24/7. When a sensor is tripped, the agents focus resources on the area to determine the cause. In the border environment it is not uncommon for animals, including cattle, to cause the alarms to go off. If the agent in the command center is unable to determine the cause, he or she will direct agents to the location.

The Border Patrol recently began employing Mobile Surveillance Systems (MSS). The MSS is a truck-based platform armed with thermal imaging, ground radar, laser range finder, and high-resolution video cameras. Data from the MSS is not easily transmitted to the nearest stations. As a result, these systems must be manned full time and nearby Border Agent activities directed by the MSS crew. Additionally, data from the MSS is not stored for future analysis. Despite these shortcomings, the MSS is a valuable tool and accounts for a significant portion of all illegals apprehended miles away from the border.

One well-known system for remote surveillance is the Secure Border Initiative Network, or SBInet. The following description of SBInet is taken from CBP.gov (11/30/10):

> SBInet is a major technology effort focused on the areas between the ports-of-entry on the Southwest Border. The goal of the SBInet program is to integrate new and existing border technology into a networked system that will enable CBP personnel to more effectively detect, identify, classify, and respond to incursions at the border.
>
> SBInet is responsible for acquisition, development, and integration of technology solutions to provide:
>
> - Surveillance and detection tools such as unattended ground sensors, radar, and cameras for comprehensive awareness of the border situation(s) and to give agents the information they need to make deployment and interdiction decisions in their area of responsibility;
> - Command, control, and intelligence tools to help CBP operators manage the large volume of information through a common operating picture (COP), to facilitate tactical decision making, and to coordinate law enforcement responses; and,
> - A communications infrastructure needed to transport sensor information from operational field elements to headquarters.
>
> The initial deployment of SBInet capabilities is referred to as SBInet Block 1, which includes deployment of towers with a suite of integrated day and night cameras, radars, unattended ground sensors, and a communications relay. Block 1 also includes a COP, which links towers and sensors within an area of operations, and feeds information to a display in a Border Patrol command center, providing situational awareness of what is happening at the border. The Block 1 system completed Systems Qualification Testing in January 2009 at the Field Test Lab in Playas, N.M., and the first of three testing milestones in the SBInet development process.

One of the greatest technological issues facing border security that must be taken into consideration whenever a new technology is deployed is how to manage new databases. Every organization within Homeland Security develops and maintains their own set of databases for tracking information relevant to their organization. Each organization is also very protective of who can access their information. Unfortunately the information maintained in one database could be of use to another agency, if only it could be shared. Worse still, when one database is updated, related information in another database is not automatically updated. When dealing with illegal immigration, this often creates significant amount of extra work to determine which information is accurate. Also, when a database is shared, it is not integrated, thus forcing agents to use multiple login/password combinations and hindering efficient information sharing. Home-made database systems are pervasive throughout the Border Security environment. Agents have developed databases (primarily Microsoft Access-based) to track everything from prosecution documents to forfeiture/vehicle seizure assets. These databases are not linked or distributed and may or may not contain updated information. Adoption of any new technology should include an approach that would not add to the database management issues faced by CBP and Border Patrol.

3. Proposed Technology: Helios Distributed Acoustic Sensor

The Helios system is manufactured by FOtech Solutions (www.fotechsolutions.com) located in Church Crookham, Hants, UK. This is an improved version of existing distributed acoustic fiber optic sensors in that it can use standard communications fibers selected based upon the ground condition in which the fiber is used. Another enhancement is that Helios can accommodate a maximum fiber length in excess of 50 km. The entire system consists of only two parts: a standard single mode communications fiber buried approximately 18” in the ground in the vicinity of the object to be analyzed and the analyzer that is connected to one end of the fiber as shown in the figure below (provided by FOtech Solutions).

3.1 Basic Operation of Distributed Acoustic Sensors

Optical fibers are extremely sensitive to changes in pressure waves or acoustic disturbances. They consist of a center glass core surrounded by several layers of protective materials. They transmit light rather than electronic signals, eliminating the problem of electrical interference. Fiber optic cabling has the ability to transmit signals over much longer distances than coaxial and twisted pair. It also has the capability to carry information at vastly greater speeds. As sound (pressure wave) hits the shield, the wave energy is transferred to the fiber, creating a tension proportional to the incident energy which influences the light traveling inside the fiber. This influence is detected by the analyzer, de-modulated off the fiber line, and translated to a high fidelity representation of the actual acoustic event(s) occurring along the length of the fiber.

Distributed acoustic sensors are typically used in extreme applications such as submarine sonar and fighter jet gyroscopes. They have many advantages over analog sensors - commonly used in many applications such as monitoring the condition of infrastructure and vibration in mechanical parts for measuring elusive problems in machinery (shaft misalignment, rotor imbalance, etc.) - some of which include:

- Extremely high fidelity
- Fiber is the sensor itself – no need for additional circuitry
- Fiber is a simple, low cost sensor
- Large bandwidth

- Complete protection against electromagnetic and system noise
- Modulation performed at source contributing to high-fidelity

Conventional analog sensors offer a signal-to-noise ratio (SNR) of in the range of 4:1 with a frequency range of 20 to 3000 Hz. Typical fiber optic sensors have an SNR of 100:1 or better and the frequency range is slightly higher.

3.2 Characteristics of the Helios System

The technology developed by FOtech Solutions allows events to be simultaneously detected, located and recorded with an accuracy of less than one meter and at one meter intervals along the length of the cable. FOtech Solutions reports that a newer version due in 2011 will extend the detection range to 125km using a single analyzer. Longer distances are covered by installing additional equipment in series. The Helios system can be programmed to send light pulses of variable wavelength (typical values used are 50ns and 100ns). The light pulses reflected inside the cable as a result of changes in its physical properties in response to an incident mechanical energy (for example people walking/running near the cable) are recorded at a sampling rate of 10 kHz to allow a spatial resolution of 1m along the fiber optic length. The Helios System properties are summarized below:

- Fiber Length: can be used with fiber of 50 km (new version in excess of 125 km)
- Detection Accuracy: detect and position sudden and sustained events to within 1m
- System Resolution: can distinguish separate events if more than 2m apart
- Temporal Resolution: 0.01 second
- Sensitivity: 0.1 μ-strain / m in conventional fiber cable
- Distributed Monitoring: possible to record data at each 1m interval along fiber
- Signal Bandwidth: up to 50 kHz bandwidth along fiber (new version more than 100 kHz)
- Pattern Recognition: event detection and classification
- Communication: two way communications, full diagnostics and health monitoring
- Remote Management: system parameters can be changed locally or remotely

3.3 Field Evaluation of Helios System

To determine the suitability of FOtech Solution's technology as an integral component of an effective border security monitoring system, extensive field trials were conducted at the University of Arizona's Avra Valley Experimental Test Site. This property is used by the Faculty and researchers in the College of Engineering, Department of Geosciences and local engineering consulting firms to conduct subsurface sensing and imaging experiments. The test site is situated about 20 miles southwest of Tucson, AZ. Because of its proximity to the US-Mexico border, the ground condition at this location is similar to that found at the points of entry used by the illegal immigrants and traffickers.

3.3.1 Fiber Optics Layout

The figure below illustrates the cable layout used in these experiments. The configuration builds redundancy in the measurements and more importantly allows the operator to determine the direction of travel based on the order in which points along the cable light up. The total path length is 100m.

3.3.2 Experiment Setup

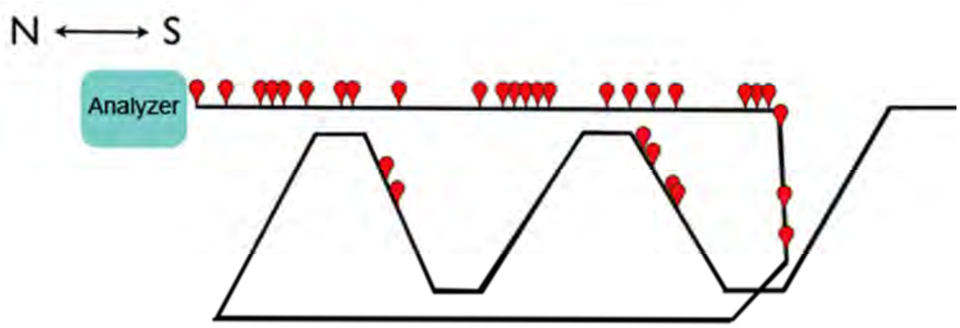

Figure 1:

Layout of the fiber optic cable used in the tests. Balloons represent the location of events along the cable length.

Three cable types were laid approximately 18” in the ground following the above configuration. The cables were selected to evaluate the influence of hardness and size on signal quality:

- Blue Cable - Excel CST armored
- Large Diameter (LD) Black Cable - Excel
- Small Diameter (SD) Black Cable – Fibrefab

To determine the sensitivity of the coupled Helios-cable system in the US-Mexico border environment, standardized drop tests were performed. A pick with a head weighing 5 kg was dropped at the same location from the east length of cable. The pick was dropped three times at about 1 second intervals from distances of 6, 12, and 24 feet from the cable. Signals were captured at a pulse repetition frequency of 10 kHz with pulse widths of 50 and 100ns for each cable. The data were then analyzed and a signal-to-noise ratio was calculated for each scenario.

Additional tests were conducted to evaluate the discriminatory power of the system simulating common border crossing activities such as:

1. A person weighing about 200 lb walking and running
2. Digging a tunnel
3. A group of people crossing the border in close formation
4. A group of people crossing the border in single file
5. A small animal (for example a dog) wandering near the border
6. A large animal (for example a horse) moving across the border
7. People running in the cover of a dust cloud from a car (border patrol) driving by
8. ‘Stealth’ crossers wearing socks or carpets over their shoes to avoid footprints on the ground

3.3.3 Test Results

3.3.3.1 Drop Tests

Figure 2 shows results from dropping a 5 kg pick at different distances from the blue and the large diameter black cables. The data is presented in 'watershed' format where earlier events are at the bottom of the screen and the most recent events are near the top. The blue cable (stiffer than the black) did not necessarily produce the highest amplitude signal, however, the noise field around it was smaller than for the black cables (shown by a more uniform blue color compared to a grainy display for the black cable). The individual impacts of the pick are easier to discern over the background noise with the blue cable.

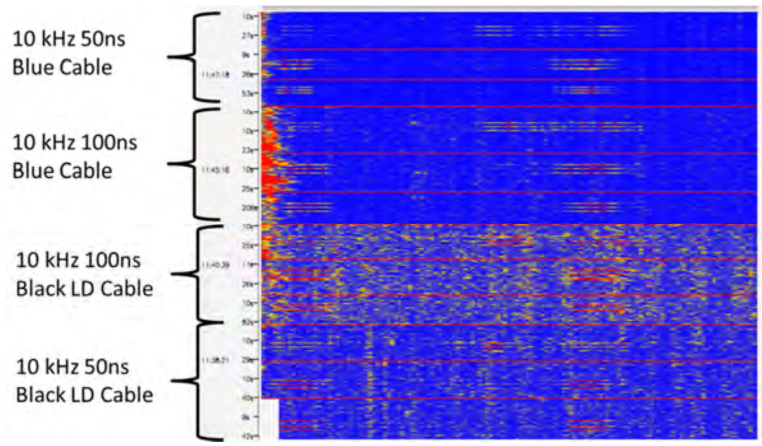

Figure 2:

Results of the drop tests used to calibrate the Helios system.

The table below presents the results of all the drop tests performed over the three cable types.

Cable Type	Pulse Width	Distance from Fibre	SNR
Blue	50ns	6ft	51.70
Blue	50ns	12ft	69.07
Blue	50ns	24ft	64.60
Blue	100ns	6ft	17.93
Blue	100ns	12ft	5.4
Blue	100ns	24ft	23.69
LD Black	50ns	6ft	46.46
LD Black	50ns	12ft	43.66
LD Black	50ns	24ft	54.14
SD Black	50ns	6ft	42.45
SD Black	50ns	12ft	50.64
SD Black	50ns	24ft	42.29

3.3.3.2 Person Walking/Running

In this test a person weighing about 200 lb first walked along the east line of the array (top line in the cable layout diagram shown in section 3.3.2) in the south direction (lower thin red trace), then he turned to walk about 2/3 of the path in the north direction (upper thin trace), followed by intense running for the remainder of the distance shown by the thick red trace. The balloons at the top of the 'watershed' plot are events registered by the Helios system along east line. The horizontal axis represents the entire cable including the bends and turns as shown in the cable layout diagram in section 3.3.2.

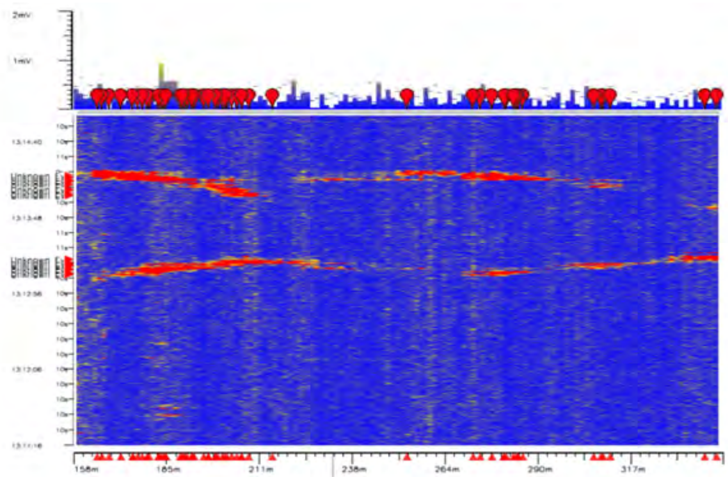

Figure 3:

Plot showing a person walking (lower red line) and running (upper left corner).

3.3.3.3 Tunnel Digging

To simulate tunnel digging activity, an 18" hole was dug over the east line (top line in the cable layout diagram) in the array using a shovel. Digging was stopped once the fiber optic cable was exposed.

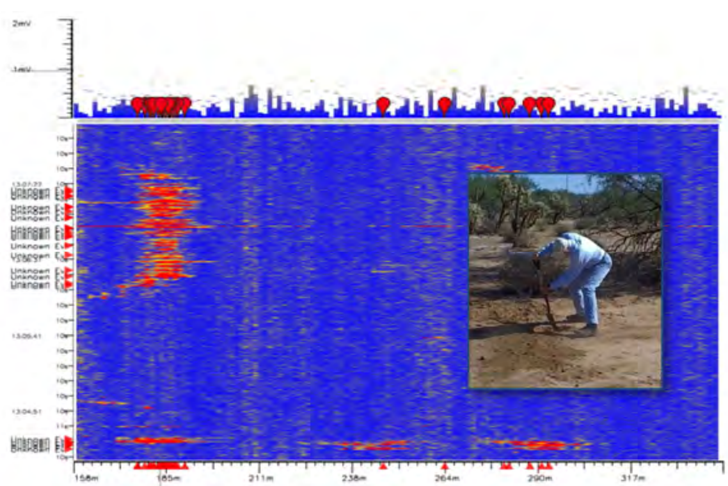

Figure 4:

Simulation of tunnel digging activity using a shovel by one person over the east line of the array.

3.3.3.4 People Walking in Close Formation

A group of five men walked at normal pace parallel to the east line of the array, first in the south direction and then in the north direction. The slope of the line provides information as to the speed of the traveller(s). Although it is difficult to determine the number of people on the ground walking close to each other, it may be possible to estimate their combined weight, through careful analysis of these signals in conjunction with calibration data such as those obtained from the drop tests presented in section 3.3.3.1. This type of analysis was not performed because the authors did not have access to the raw data from the experiments.

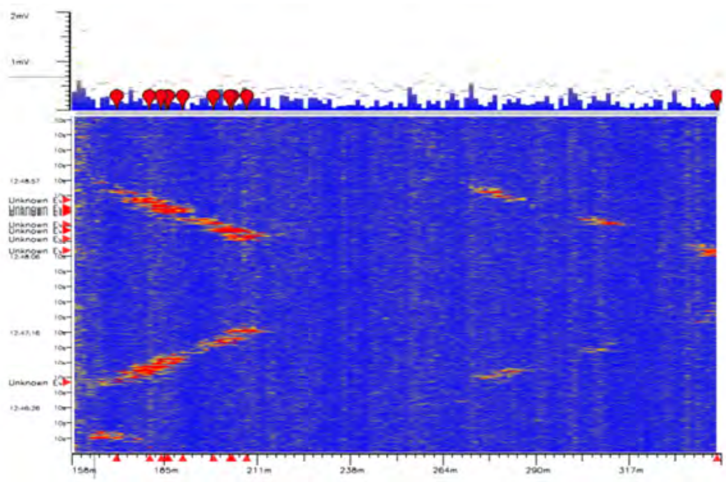

Figure 5:

Plot showing five men walking together parallel to and over the east line in the array.

3.3.3.5 People Running in Single File

In this experiment, the same five men ran across the array in single file and about 2m away from each other. If one looks closely in the plot below, at the 185m mark, one can observe three distinct and relatively strong events, appearing as horizontal red bands. This could represent the fact that one or more individuals followed others at a distance larger than 2m. At the 290m mark, however, the event is larger in size and appears to be one single dot. Here, the distance between the five individuals was less than 2m. By conducting a more detailed quantitative analysis, one may be able to correlate the relative size of the event (red dot on the display) to the relative size of the source (in this case, the combined weight of the individuals).

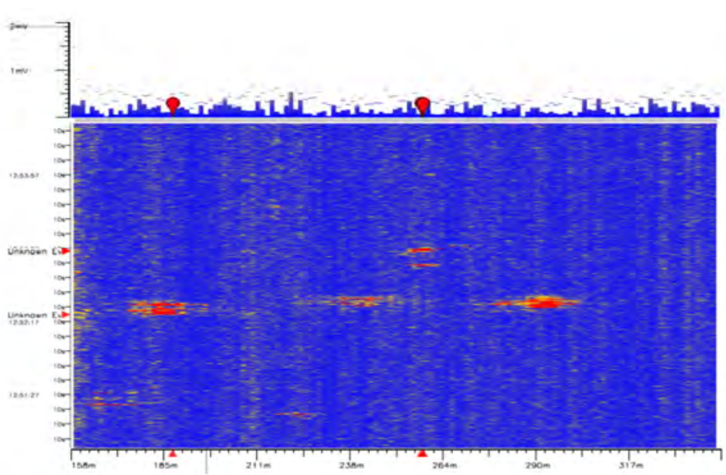

Figure 6:

Plot showing five men running in single file across the array.

3.3.3.6 Signature from Small Animals

The Helios system was setup to monitor the movements of a 35 lb dog in the vicinity of the cable. Two plots are shown. In the first case, the dog was moving at a slow pace through the array. The lack of strong motion and impact on the ground is reflected by the fact that the system did not register any signal: the plot displays what might appear as background noise caused by the blowing wind and other cultural noise due to the proximity of the test site to a major road. In the second plot, the dog was instructed to run across the array. The dog started his run on the left hand side of the plot and ending it on the right side over a distance of about 50m. The circles on the plot highlight the events triggered by the dog at the points where he picked up more speed and moved across over the cable.

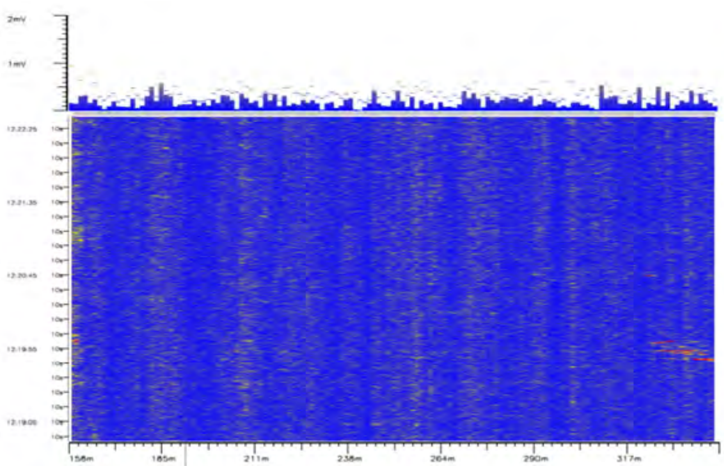

Figure 7:

System output from a 35 lb dog strolling at slow pace through the array. No significant event was detected.

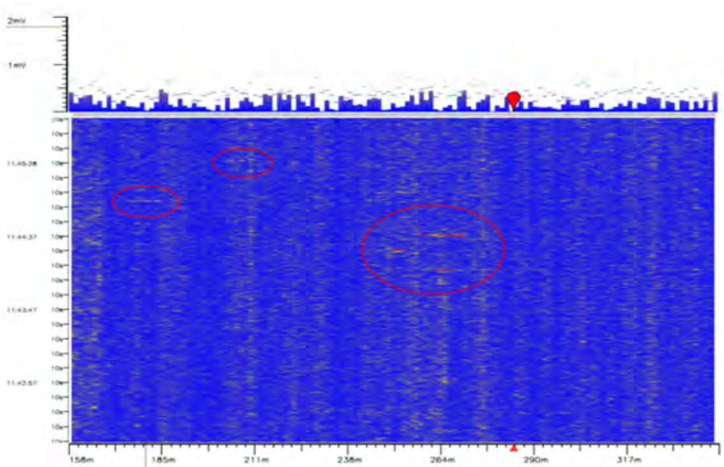

Figure 8:

System output from a 35 lb dog running across the array in the east-west direction. Weak events were registered when the dog picked more speed and passed over the cable

3.3.3.7 Signature from Large Animals

To investigate the signature from large animals roaming in the southwest desert, two horses were brought to the site and trotted through the array. The larger was a 1300-lb mare. The mustang weighed about 900 lbs. The following figures show three scenarios where the horses walked and trotted parallel and across the array in single file. The events from this experiment are noticeably larger – they cover wider areas in the display – and stronger – more red pixels in the plot – compared with the previous tests. Again, there is a correlation between event size and the size of source (in this case the weight of the animal and the force of impact on the ground by the horses) that triggered the events.

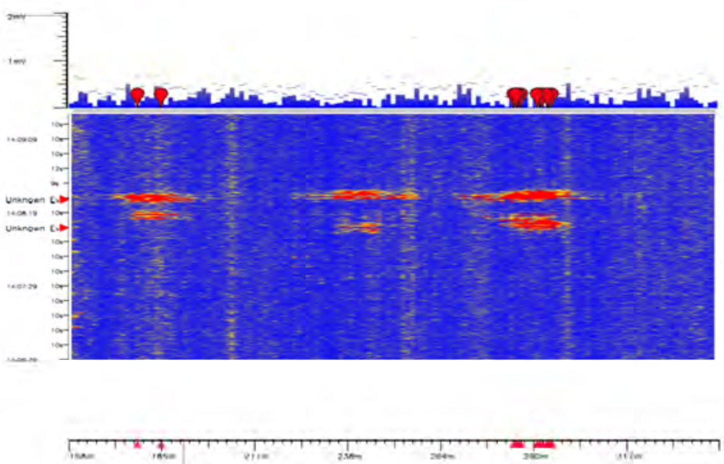

Figure 9:

Plot of two horses walking across the array in single file. The larger horse is in front followed by the smaller horse by few meters. The larger events on the far right are the results of both horses picking up speed and trotting.

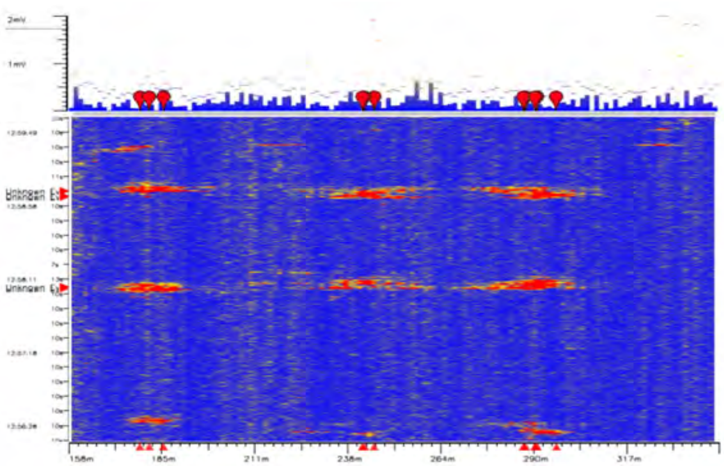

Figure 10:

Plot of two horses running 10m apart across the array.

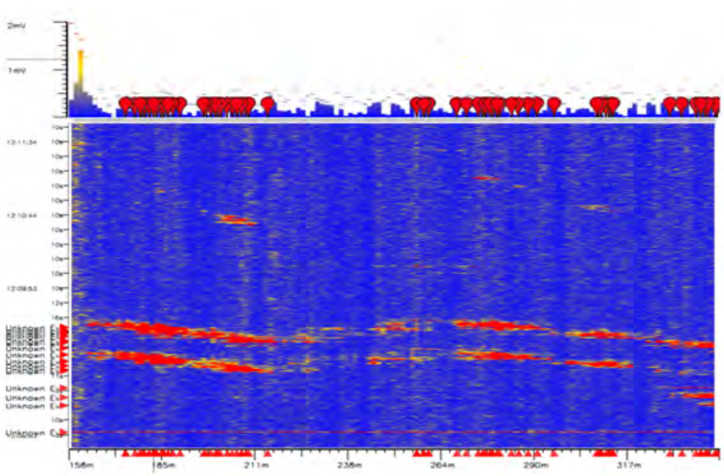

Figure 11:

Plot of two horses running parallel to the east line in the south direction. The smaller horse follows behind the large one by one minute.

3.3.3.8 Differentiating Between Cars and Human Beings

It is common that for border crossers to take cover in the dust cloud created by the passing patrol car to move between the US and Mexico. To evaluate the discrimination power of the Helios system, a series of tests were conducted in which the movement of an individual running behind a small pickup truck was monitored. The figures below show the signature of the pickup truck approaching the sensor array and idling, followed by driving at slow speed along the east line of the array and gradually speeding, and finally a 200 lb person running behind a speeding truck. It is possible for an observer to differentiate between a car driving and idling rather easily. To recognize a person running behind the vehicle requires an experienced operator, however, it is likely that existing classifiers and pattern recognition algorithms would be able to discriminate between a car and a person.

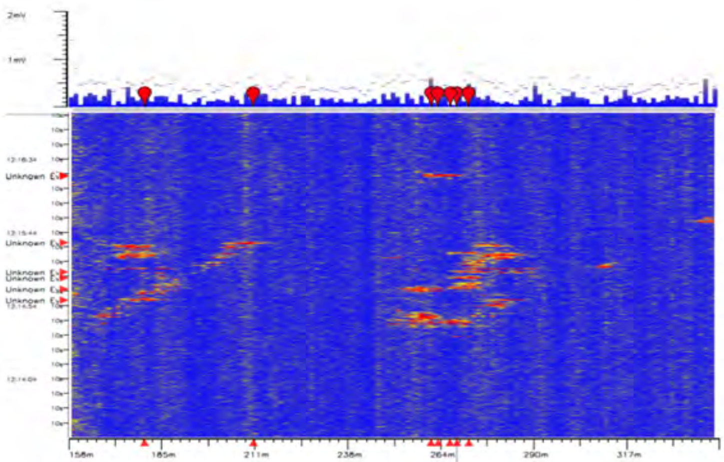

Figure 12:

Plot of a pickup truck approaching the array (slope of the line in the left of the figure can be used to determine the speed of the vehicle) and the signature of the idling vehicle (cluster in the middle of the figure).

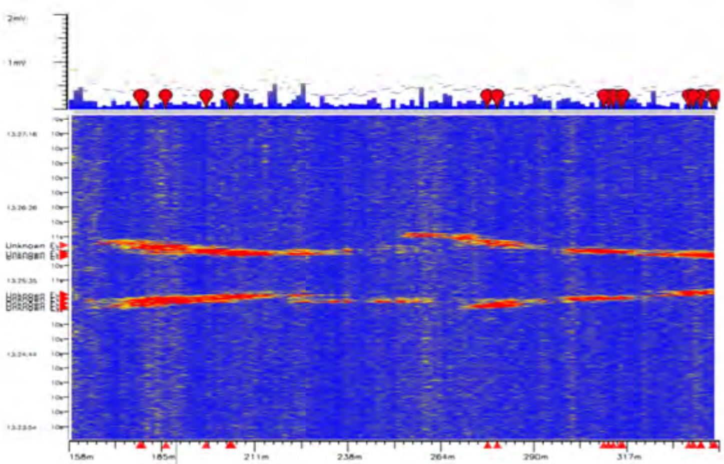

Figure 13:

Plot shows the pickup truck driving at constant speed in the south direction (bottom horizontal line in the left of the figure), then accelerating slightly (bottom line in the right). Next the car turns north and speeds up (top line in the right), and then slows down again in the top left of the figure.

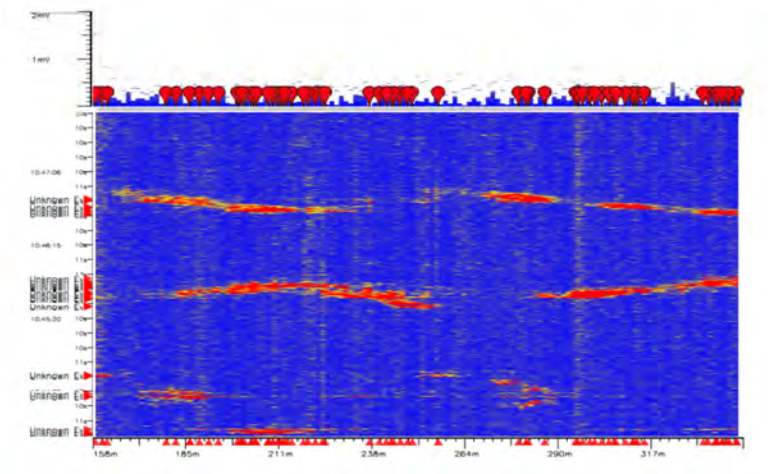

Figure 14:

This plot has the same features as the one in Figure 13 above. Similar to the previous test, the car drives first south and then to the north, followed by an individual running behind the vehicle. In this case, visual discrimination of the person running is more of a challenge.

3.3.3.8 'Stealth' Crosser

Border crossers often wear thick socks or segments of carpet or fabric around their shoes to avoid being tracked by the border patrol. A slim person weighing 125 lbs with a carpet tied around the shoes walked slowly across the array to simulate a 'stealth' crosser. To improve the chances of detection, a mechanical amplifier was used. It was made of a 4" diameter PVC pipe cut in half along a 3' section and buried – with the inside wall facing up – beneath a segment of the cable. This arrangement allowed the Helios system to register a weak signal from crosser stepping over the cable. A screenshot of the results is shown below.

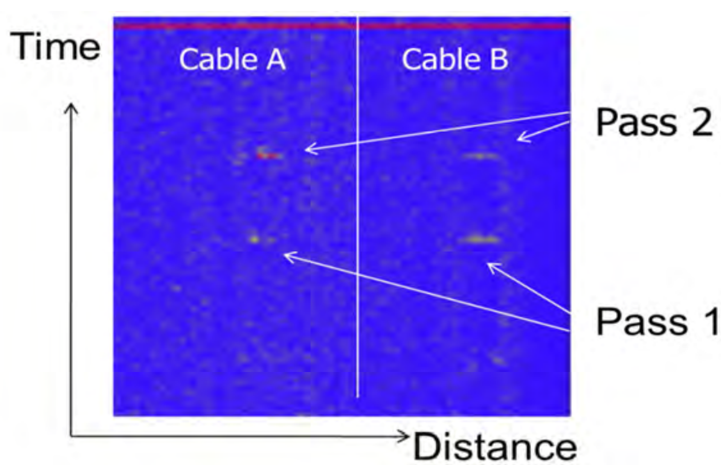

Figure 15:

'Stealth' crosser walking slowly over the cable wearing a carpet around the shoes.

3.3.4 Discussion

The overall performance of the Helios system in the Arizona border security environment was very good. The opinion is based on personal observations of the authors of this report, limited quantitative analysis of the data and direct qualitative examination of the results. Test results presented in this report were conducted over a three-day period in the presence of the authors. The analyzer ran continuously and flawlessly between six to eight hours a day while the experiments were performed. The system software froze on several occasions requiring a warm reboot of the computer. The following discussion presents an evaluation of the overall system performance.

The main advantage of the Helios is its ease of installation, speed and high degree of accuracy in locating events. It can use existing fiber optic cables, or a standard fiber optic cable can be substituted. It requires no additional power source or equipment over a 50 km stretch. FOtech Solutions claims that the new version of the Helios to be released in 2011 will extend the range of the system to over 125 km.

The system software has a simple interface and provides options to setup a test in terms of programming the monitoring parameters into the data logger and analyzer. The software allows a layout of the cable mapped using a GPS or other surveying technique to be created for the purpose of displaying the events on the computer screen similar to the diagram shown in Figure 1. Helios System uses a 'watershed' type plot (shown in section 3) to continuously display the acquired data. Screenshots provide a fast way to store a visual record of the events. Time series – one dimensional record of individual vertical lines in the watershed plot – displayed as time versus signal amplitude are stored in PDF format and can be opened using the Adobe Reader or Acrobat. The software has the option to save raw data locally which can be retrieved for viewing at a later date. Time and distance stamps are automatically assigned to each event which makes the task of event location easy. However, no option was available on the system used to convert the data from FOtech Solutions' proprietary format into other formats (for example '.mat' used by Matlab) for further analysis on an independent platform such as Matlab.

Helios has been employed in detecting leaks and damage in oil wells and pipelines, and perimeter surveillance by tracking footsteps and vehicles. Although these capabilities have been shown to work well in areas where little traffic is expected, the system lacks ***automated*** pattern recognition needed in a border security environment typically found in the southwestern United States, where the number of false positives related to the movements of cattle, ranchers, wild species, and patrol officers would be comparatively high. The lack of classifier can be amended using existing and off-the-shelf toolboxes.

The experiments conducted at the University of Arizona's Avra Valley test site suggest that in its current configuration, the Helios system has the potential to be immediately deployed over any stretch of the US-Mexico border. The lack of unassisted recognition and identification capability can be overcome in the short run by training operators to identify runners, normal pace walkers, stealthy slow pace crossers, large animals and vehicles in the vicinity of the fiber.

Additional points related to the deployment of the Helios system are discussed in the following section.

4. Integration with Current Border Security Monitoring System

The goal of Border Patrol is to achieve operational control of the United States border. Their objectives can be broken down into the following five categories: 1) Apprehend terrorists and terrorist weapons illegally entering the United States, 2) Deter illegal entries through improved enforcement, 3) Detect, apprehend and deter smugglers of humans, drugs, and other contraband, 4) Use "Smart Border" technology, and 5) Reduce crime in border communities, and improving the quality of life.

To meet these objectives, the Border Patrol is implementing the following strategy: 1) Have the right combination of personnel, technology, and infrastructure, 2) Have increased mobility for rapid deployment of people and resources, 3) Employ defense-in-depth using interior checkpoints and coordinated enforcement operations, 4) Partner with other law enforcement agencies, 5) Increase border awareness and intelligence, and 6) Centralize the chain of command.

The Helios system has two important distinctions from other ground sensors: 1) the sensor is continuous from its point of origin to its point of termination, and 2) the sensor is powered at its point of origin and extends to 50 km away. Because of these unique qualities, if the implementation of the FOtech system is successful it would help fulfill the objectives of Border Patrol by improving strategies 1, 3, and 5. The sensor would boost the technological capabilities of Border Patrol and would allow better allocation of resources by increasing border awareness and intelligence. Defense-in-depth strategies would be augmented as Helios could be paired with checkpoints or placed anywhere a permanent building exists.

It appears that the Helios system would be economical to maintain as the major expenditure is the trenching operation - fiber optics cost is insignificant. Repairing the cable (resplicing) if dug up and severed is fast and inexpensive. However, integrating a new device / sensor into existing monitoring systems represents one of the greatest hurdles for adoption. Helios must rely on a permanent structure in order to be operational. From this structure, the fiber optic line can ostensibly stretch for 50 km, though the demonstration at the University of Arizona's test site was over a distance of 100 m.

The Helios system is manufactured to be installed in a server rack. The installation and integration of the system is limited by the number of permanent, powered structures along the US border. These structures could be owned by the US government or leased from private property owners. However, without a permanent structure this device cannot be utilized. MSS's could not house the Helios analyzer.

It seems plausible that the Helios system could be integrated into SBInet by housing it in SBInet towers, or the infrastructure around the towers. The data could be sent over the same wireless infrastructure used by other SBInet sensors for remote monitoring. However, it is not known if the towers could provide the Helios system with protection from environmental factors such as heat, cold, wind, dust, and rain.

Permanent checkpoints are another location where the Helios' analyzers could be housed. The analyzer could potentially become part of the checkpoint infrastructure, increasing the detection capabilities in adjacent areas. Since checkpoints are often used to divert traffic from major traffic corridors, this technology could be used to detect those skirting the checkpoints on foot.

Official ports of entry would also be a likely site for housing the Helios equipment. In this case, the fiber optic line would run parallel to and near the border fences. The technology could provide early warning in the event that someone crossed the fence.

4.1 Potential Impact

A successful deployment of the Helios system could be characterized by improved detection capabilities which would lead to an increase in apprehensions in the system deployment zone. Increased apprehensions in this area could have the effect of funneling traffic to other areas where Border Patrol could focus additional human resources.

Helios could potentially be used in conjunction with SBInet cameras and would help identify the source of ground vibrations. This system may also be able to detect tunnel traffic though it was not tested / demonstrated for this purpose.

Algorithms are still being developed and evaluated in order to distinguish between human and animal footsteps. A successfully deployed system would discriminate between animals and humans, groups and individuals, and illicit and legal traffic. With reliable algorithms, agents intercepting the source of triggers would have more assurance they were tracking humans.

Since Helios distributed acoustic sensor provides continuous monitoring over long distances, it acts essentially as a virtual fence. It is expected that the cost of the system would be substantially less than a permanent fence infrastructure that already exists. Since the sensor is below ground and “invisible”, wild life traffic would not be hindered and the environmental and aesthetic impact would be minimal.

4.2 Keys for Success

A successful implementation of the Helios distributed acoustic sensors would require:

- Reliable performance over the entire length of the fiber
- Rapid integration into existing border security systems such as SBI-net
- Automated and unassisted events identification
- Use of existing infrastructure to deploy the system

4.3 Countermeasures

A well designed and hidden fiber layout would be difficult to circumvent. In the eventual breach of the perimeter where traffickers unearth and cut the cable, the system would immediately identify the location(s) where the cable has been severed. Because of its continuous monitoring capability, the system would function between the point of origin and newly terminated point. Border security patrol can resplice the fiber within minutes. One could rule out multiple simultaneous attacks as they would draw immediate attention and would make it less likely for the traffickers to escape.

5. Proposed Next Steps

The authors would like to suggest that the Helios system be tested over a two to five kilometer stretch near the US-Mexico border for a period of at least 90 days, possibly longer (up to six months would be ideal) to get a better understanding of its strengths / weaknesses and demonstrate its potential as an integral part of a border monitoring infrastructure. This is an important step before a full scale deployment as it will provide additional data currently lacking with respect to signal degradation, equipment durability, and potential threats in the Arizona border security environment.

6. Conclusions

The Helios distributed acoustic sensor detects ground vibrations along the entire length of the perimeter where it is deployed. It can pinpoint events with the accuracy of a GPS. A trained Helios operator can differentiate between events triggered by a person walking, running, and the movement of cattle, horses, and vehicles. Despite the lack of automated discrimination capability at the time of this writing, the Helios system can provide:

- Reduced cost
- Better use of agents' time
- Improved security
- More apprehensions
- Reduced human and drug traffic
- Tunnel digging detection (though this was not fully investigated in this study)

7. Referenced Publications

Nunez-Nito, B. (2008). Border Security: Key Agencies and Their Missions. Report to Congress.

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8. Investigating Team

Moe Momayez is associate professor in the Department of Mining and Geological Engineering, and geosensing team leader at the Lowell Institute for Mineral Resources at the University of Arizona. Professor Momayez's expertise is in applied geophysics, geomechanics, and rock physics, and has 15 years of experience developing technologies for assessing the integrity of infrastructures. He holds four patents and two patent applications related to instrumentation and geomaterials characterization. His expertise in non-invasive methods led to the development of techniques to estimate paleo-stresses in rocks, and to measure the quality of concrete, and shotcrete used as support system in underground excavations.

Kevin Moffitt is a research scientist and PhD Candidate at BORDERS, the DHS Center of Excellence for Border Security and Immigration. His research interests revolve around evaluating new real-time credibility assessment and screening technologies for deception detection. His software SPLICE allows for real-time analysis of text including transcriptions from interviews. He also investigates eye tracking as a guilty knowledge test for integration into an AVATAR agent for use in border screening scenarios.