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Development of a Low-Cost Passive Infrared Profiling Sensor

by Ron Frankel

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by Ron Frankel

Sensors and Electron Devices Directorate, ARL

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Contents

List of Figures	iv
Acknowledgments	v
1. Introduction	1
2. Fundamentals of Operation	1
3. Sensor Element and First Passive Profile Sensor	5
4. First Tactical Configuration	7
5. Reconfigurable Laboratory Array	8
6. Second Tactical Configuration	9
7. Graphical User Interface (GUI)	11
8. Culvert-Emplaced Version	12
9. Sensor Atom Concept	13
10. Power, Control, Communications, and Displays	14
11. Conditions Adversely Affecting Performance	14
12. Summary	15
13. Future Developments	15
14. Conclusions	15
15. References	16
List of Symbols, Abbreviations, and Acronyms	17
Distribution List	18

List of Figures

Fig. 1	Profile generation.....	2
Fig. 2	Typical deployment of a passive profile sensor.....	3
Fig. 3	Beam-breaker (active) profile sensor.....	4
Fig. 4	Melexis 90614 sensor	5
Fig. 5	Parallel-beam passive profile sensor.....	6
Fig. 6	First demonstration unit. The sensor unit is outlined in yellow—the individual sensor elements are not visible. The poster is for size comparison.....	7
Fig. 7	Divergent-beam passive profile sensor.....	8
Fig. 8	Fifteen-element divergent array.....	8
Fig. 9	Reconfigurable research unit	9
Fig. 10	Nine-element profile sensor.....	10
Fig. 11	Sensor deployed for desert environment field demonstration. Placing the sensor where it is shielded from the sun is desirable.....	10
Fig. 12	GUI imagery from first demonstration unit.....	11
Fig. 13	Douglas, Arizona, data showing 3 people (left) and 1 person on horseback (a second horse is appearing on the right).....	12
Fig. 14	Primal Innovation culvert-emplaced profile sensor.....	13

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1. Introduction

Many technologies exist to monitor potential threats and areas of interest, which, it seems, are everywhere these days. Cameras of all sorts provide massive amounts of data requiring extensive amounts of processing (automated and human). Other sensor technologies, including acoustic, magnetic, seismic, and infrared (IR), are used to track people and vehicles for surveillance purposes. Lately, other non-sensor-specific monitoring has included social media and other web-based traffic. All available data may be utilized in making the decisions about measures to be taken to address potential threats. This is the data-to-decision process, and it involves an overwhelming flow of information derived from many sources. New sensors or other sources of data are routinely evaluated to assess their efficacy and their potential for use as a new source of actionable intelligence.

This report addresses a new type of sensor called a profile sensor, which offers several benefits over cameras. These benefits include lower cost, lower power, and lower bandwidth. What is unique about profile sensors is that they take a minimalist approach to providing a target image, starting with the least number of pixels required to assess a target, thereby minimizing cost, computational power, and bandwidth required. Camera systems tend to move in the direction of an increasing number of pixels for better resolution, then relying on compression algorithms to minimize the required bandwidth. The simplest of profile sensors, on the other hand, would be a single-element system (the “sensor atom” concept) and can provide an economical means for migrant foot route monitoring, for example, with a mere 2 bytes of data required per detection event to convey the location and number of people in a group. Small power requirements mean a unit could remain in the field for months (or even years, using solar recharging) before requiring servicing.

2. Fundamentals of Operation

Figure 1 is a depiction of profile generation. The sensors are mounted as a linear array in a vertically oriented housing. They produce a varying voltage as the subject passes in front. This is shown as a time-dependent “rolling strip” image on any available computer or device screen. The image processing requirements for data produced in this fashion are minimal.

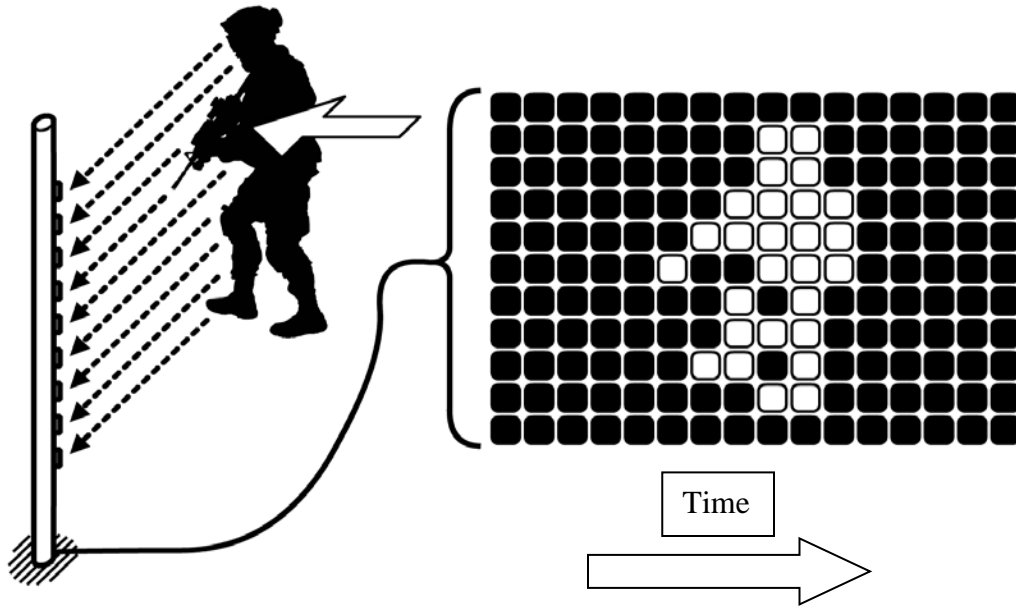


Fig. 1 Profile generation

Presented in this report are the results of research conducted on various configurations of profile sensors based upon a common IR element. Linear arrays were designed and built to evaluate performance against people, vehicles, and animals.

Profile sensors have been developed as a means to classify targets of interest using low-cost, low-bandwidth technologies. A profile of the target is developed using optoelectronic (OE) elements. This profile, usually just tens of pixels in height, is a side-view silhouette of a moving target and is easily processed by computer algorithms called classifiers. They are potentially useful as perimeter protection for forward operating bases (FOBs) or squad overnight camps, or for border/trail monitoring.

Figure 2 depicts a profiling system used for trail monitoring. The sensor itself is the somewhat-hidden, tan-colored vertical stick in the lower right. Each of the red beams shown emanating from the profile sensor represents the field of view (FOV) of a passive (non-radiating) IR detector. Combined together, the detections recorded when a subject passes in front of the sensor produce a 2-dimensional image referred to as the profile. In Fig. 2, the subject's profile may be seen on the (inset) Soldier's tablet computer. Note the depiction of the gun and the backpack. A simple height-to-width measurement has been shown to be very effective in determining whether it was a person or a vehicle passing in front of the sensor. This requires much simpler processing than that needed for a conventional camera image.



Fig. 2 Typical deployment of a passive profile sensor

Please note that the beam pattern depicted in Fig. 2 represents the FOVs of passive sensors and is not meant to show light beams. Although the first profile sensors developed were “beam-breakers,” with an active beam of light, the focus of this effort is on single-sided, passive sensor systems.

The first beam-breaker profile sensors (Fig. 3) required the target (vehicle, person, or animal) to pass between 2 columns, one containing transmit elements (visible or IR light sources) and the other receiver elements (photodiodes). This requirement to pass between 2 portions of the sensor system, usually separated by just a few feet, severely limits the tactical scenarios in which this sensor could be used.

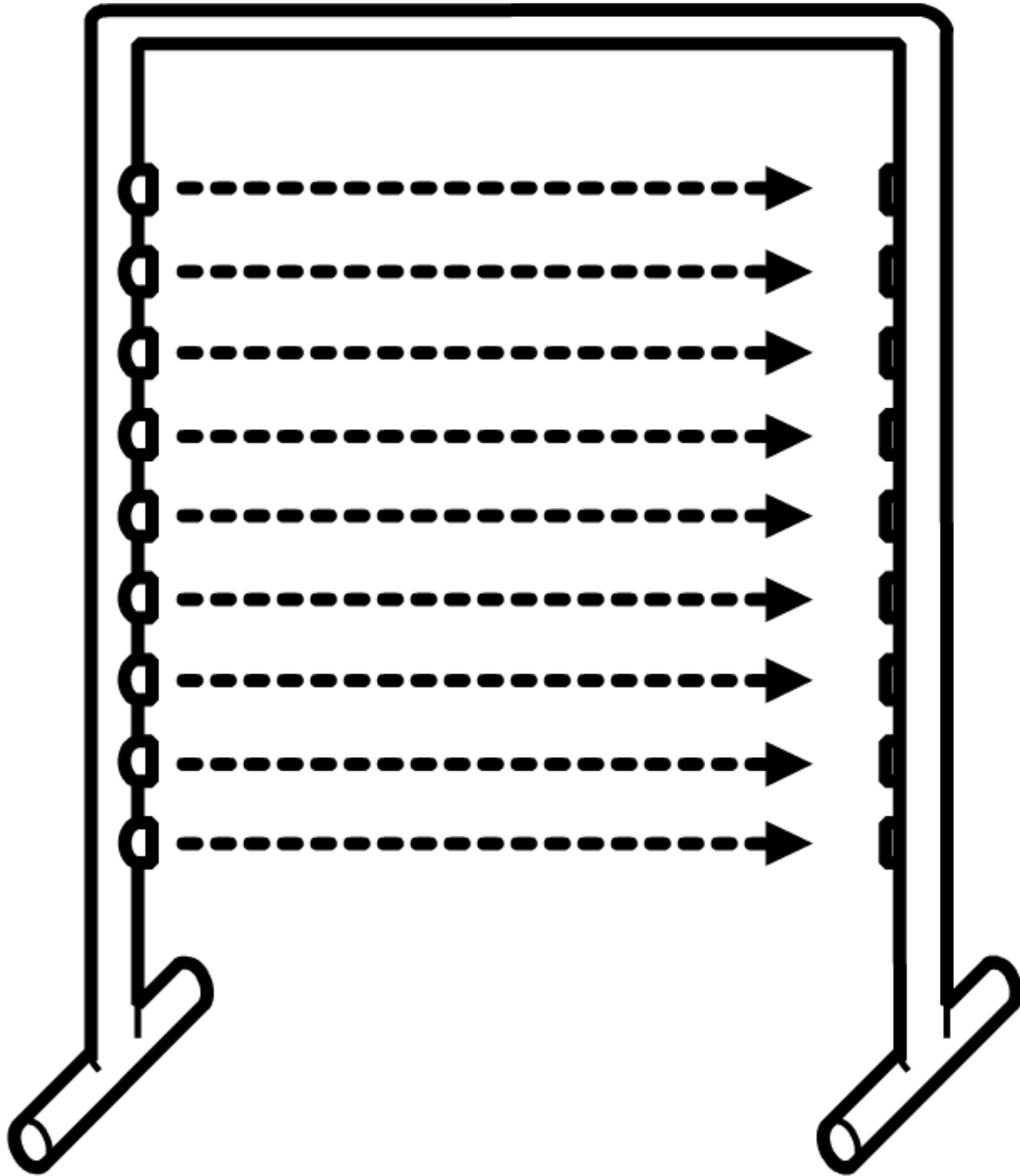


Fig. 3 Beam-breaker (active) profile sensor

To eliminate this shortcoming and at the same time eliminate the non-stealthy active component, the US Army Research Laboratory (ARL) developed a series of single-sided profile sensors using thermopile IR sensor elements. This sensor requires no OE transmit element but instead senses target temperature directly.

3. Sensor Element and First Passive Profile Sensor

After evaluation of several different manufacturers' sensors, the Melexis 90614 series of thermopile sensors was chosen (Fig. 4). It was chosen over the others because of superior performance with regard to sensitivity, in addition to the ease of interfacing with a data-collection system enabled by the onboard electronics. The 90614 is a very sensitive sensor, which detects IR radiation in the 5.5 to 14.5 micron region. It comes in a package containing all of the necessary circuitry for analog-to-digital (A/D) processing, filtering, signal conditioning, and communication over a 2-wire serial bus (National Instruments SMBus). This greatly facilitated development of software using the LabView programming language. Furthermore, the TO-39 package is available with several different built-in lens configurations producing different FOVs.

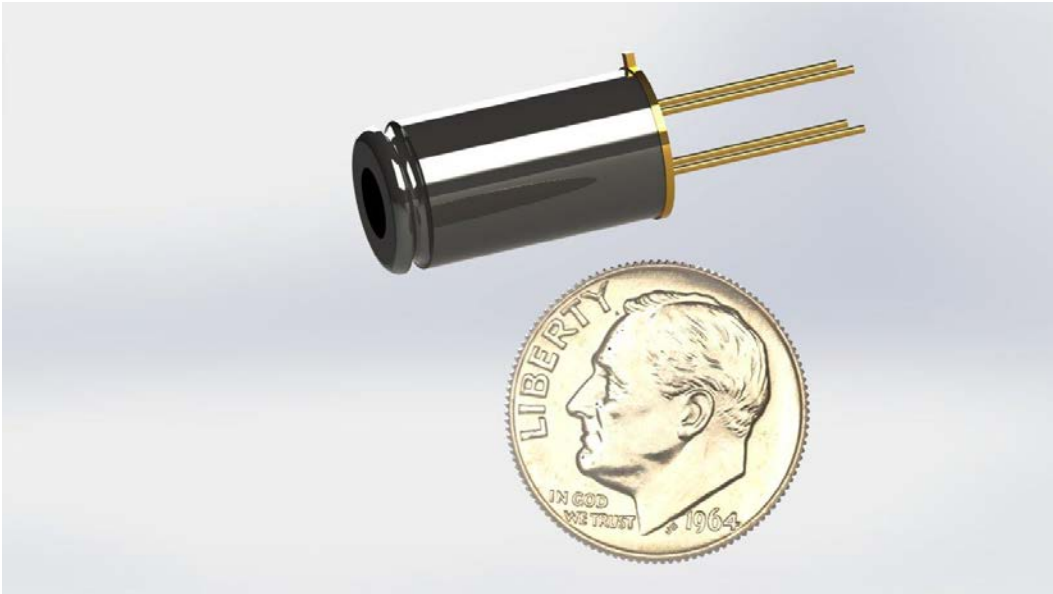


Fig. 4 Melexis 90614 sensor

The first unit produced was a 27-element, 7-ft-tall, parallel beam configuration (Fig. 5). The actual unit is shown in Fig. 6. The Melexis 90614 sensors used had a 10° FOV, the narrowest available at the time. Experiments were conducted with individual sensors to reduce the FOV and increase the range using either external germanium or plastic Fresnel lenses. While the experiments were successful, the use of external lenses would have greatly increased the cost, complexity, and time to develop these first profile sensor units and hence were not used. The tradeoff in not using external lenses was a limited effective range of the profile sensor. The first unit had an effective range of only about 12 ft, but it did produce imagery good enough to show proof of principle and lead to further development. Later

versions showed effective ranges out to about 40 ft. Future improvements such as more sensitive detector elements or the addition of lenses may extend the effective range to several hundred feet.

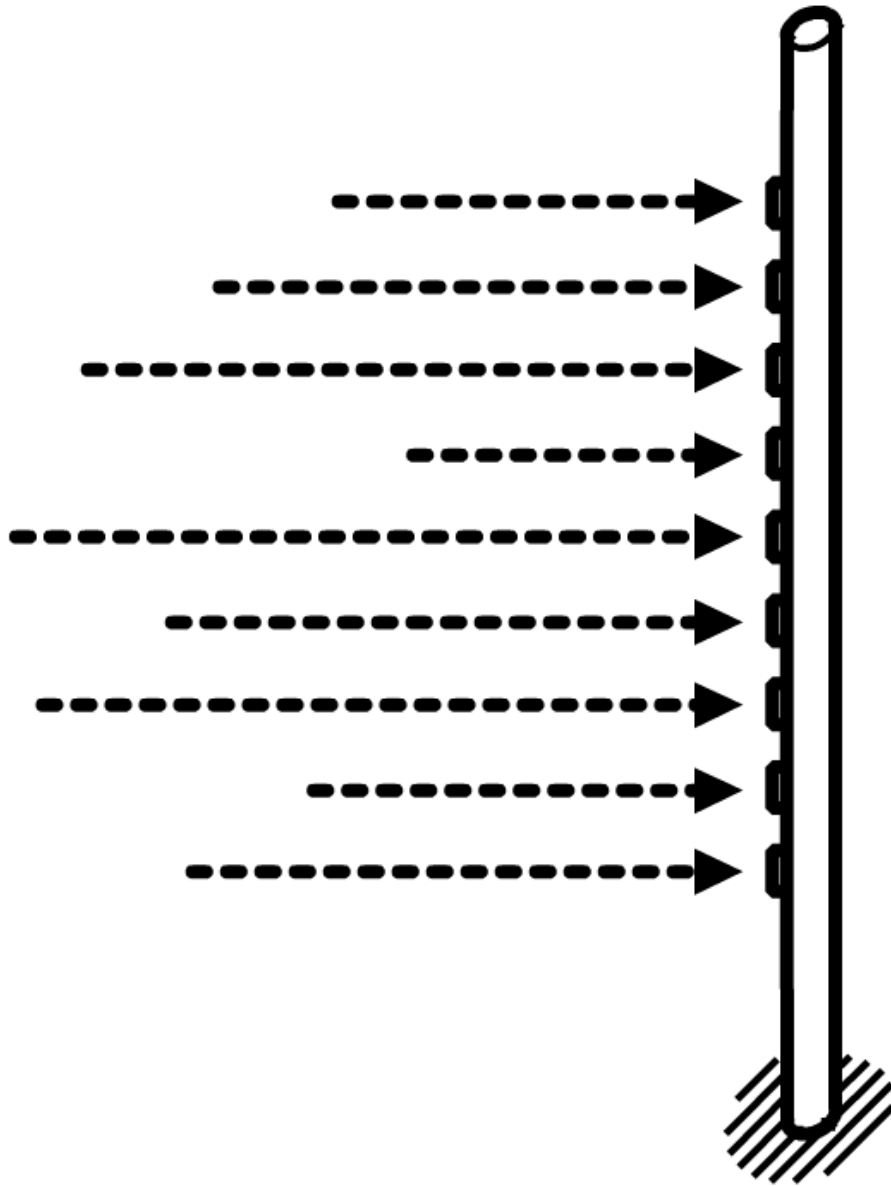


Fig. 5 Parallel-beam passive profile sensor

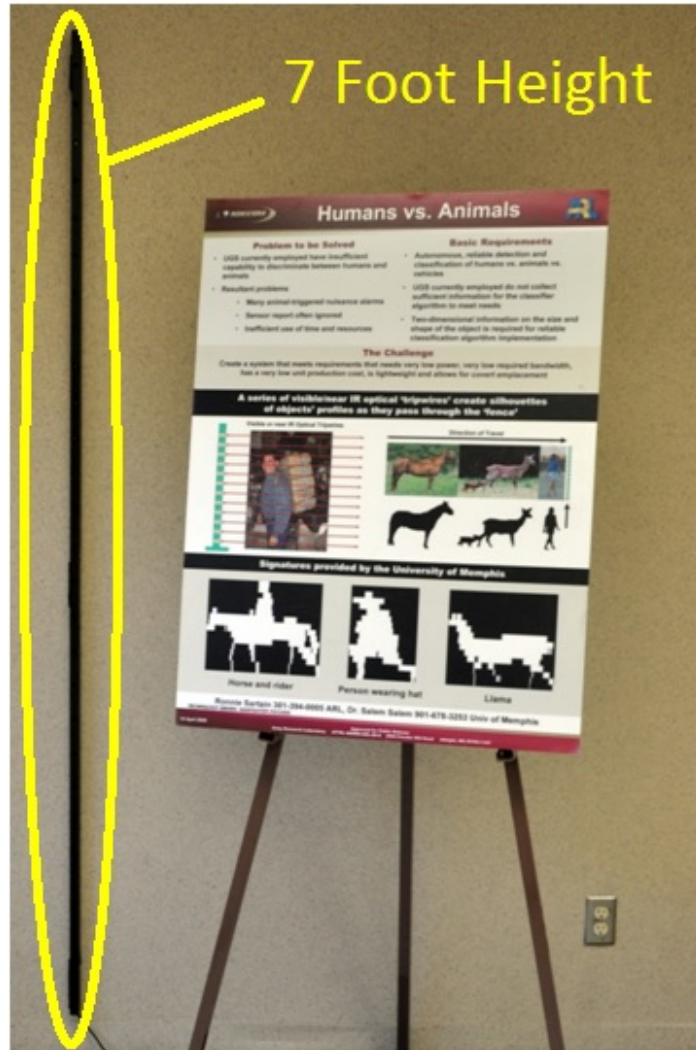


Fig. 6 First demonstration unit. The sensor unit is outlined in yellow—the individual sensor elements are not visible. The poster is for size comparison.

4. First Tactical Configuration

The second unit produced was a 15-element, 9-inch-high diverging (non-parallel) beam configuration (Fig. 7). The actual unit is shown in Fig. 8. A 3/4-inch-square aluminum bar was drilled and reamed with holes for the sensors. The bottom hole is parallel to the ground. The next hole up points the sensor at approximately 2° above the first. Each successive hole is at an increasing angle, so (roughly) 4°, 6°, etc. A compass on the top allows for vertical alignment and spikes on the bottom allow for easy emplacement in soft ground. (The spikes proved impractical to use on harder surfaces and were replaced by a fixed metal plate.) This unit demonstrated the utility of a low-profile sensor, but again, the 10° FOV sensors (the narrower FOV sensors were not yet available) limited the range.

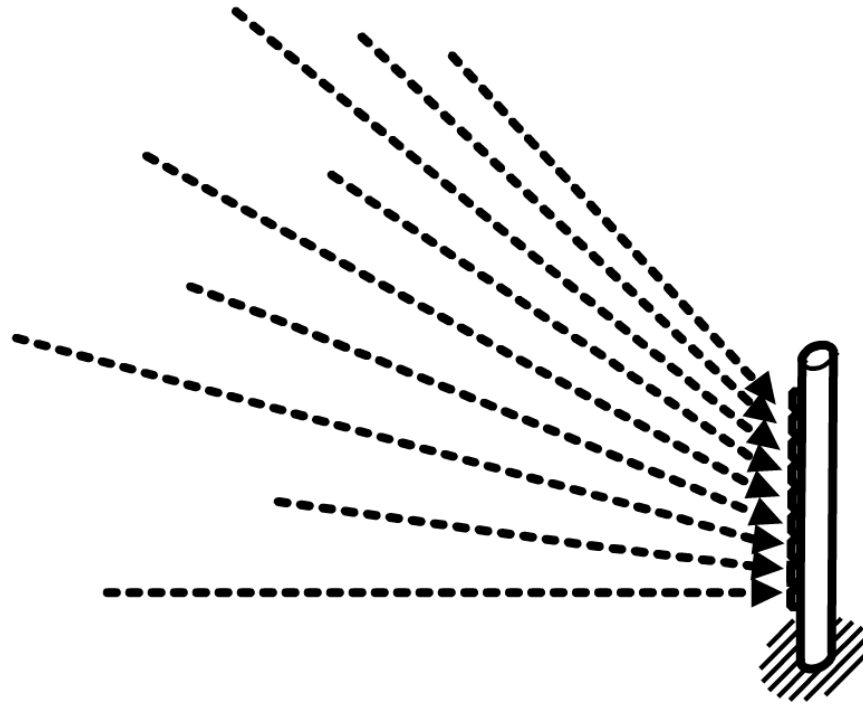


Fig. 7 Divergent-beam passive profile sensor

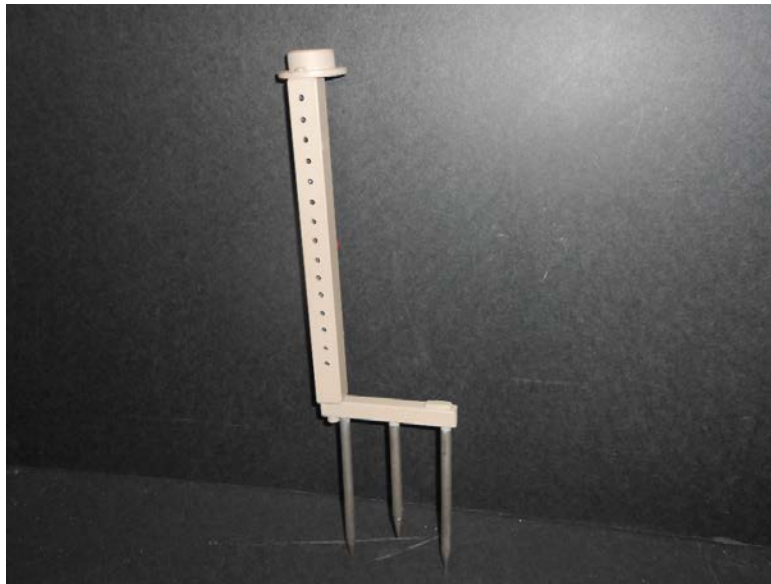


Fig. 8 Fifteen-element divergent array

5. Reconfigurable Laboratory Array

Shortly after completion of the 15-element array, 5° FOV sensors became available and were procured. These were Melexis 90614-AAI sensors. A 21-element, 21-inch-high laboratory research unit was produced (Fig. 9). This

unit has each sensor mounted in its own aluminum block, which could be rotated in the vertical axis so as to reconfigure the entire sensor for an unlimited range of sensor alignment arrangements. A tiny eye-safe laser mounted on each aluminum block allows for precise angular setting of the individual sensors. This sensor system was extremely useful in evaluating numerous sensor configurations in a short period of time.

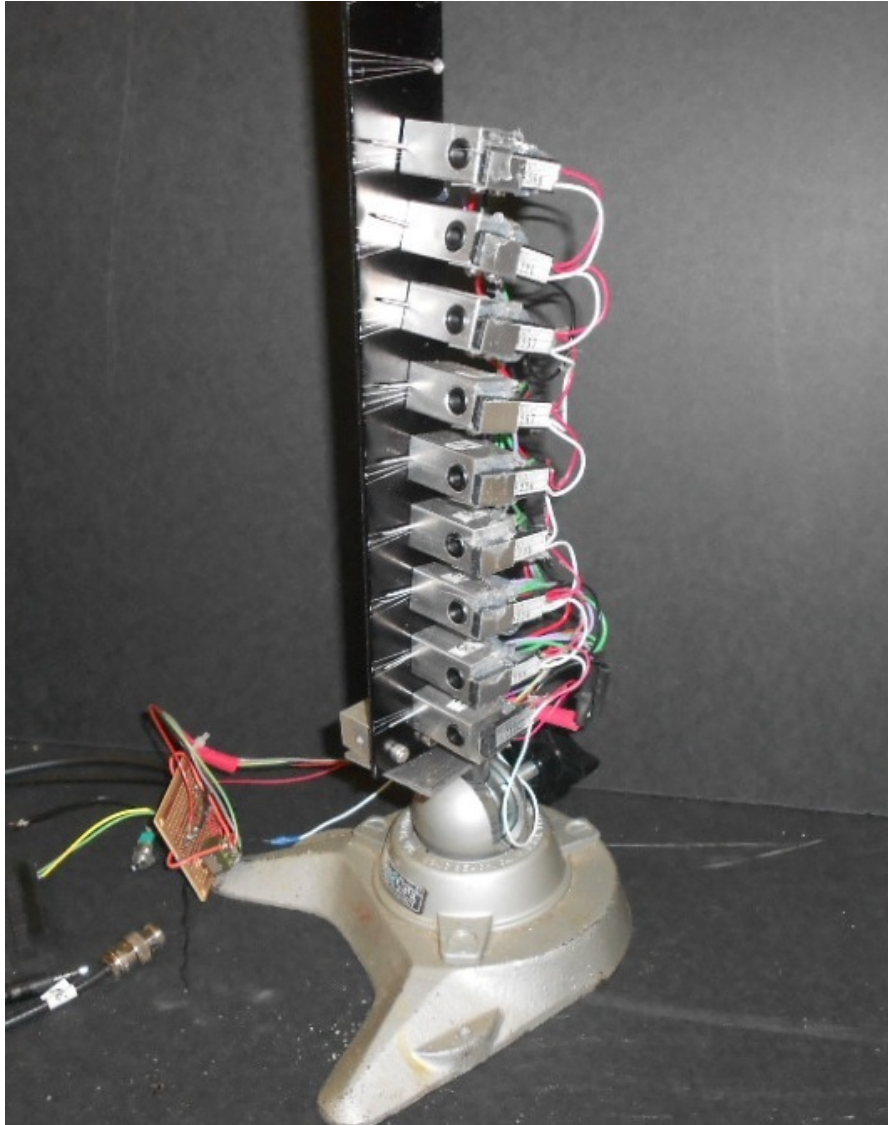


Fig. 9 Reconfigurable research unit

6. Second Tactical Configuration

Based on evaluations of several different possible configurations using the laboratory research instrument, a low-profile, 9-element unit was produced (Fig. 10). A flat base was used instead of spikes for easier evaluation both in the

lab and outdoors. This unit was taken to Douglas, Arizona, for participation in a field evaluation of border- and trail-monitoring sensor systems (deployed sensor, Fig. 11). Effective detection and classification ranges out to about 35 ft were demonstrated.

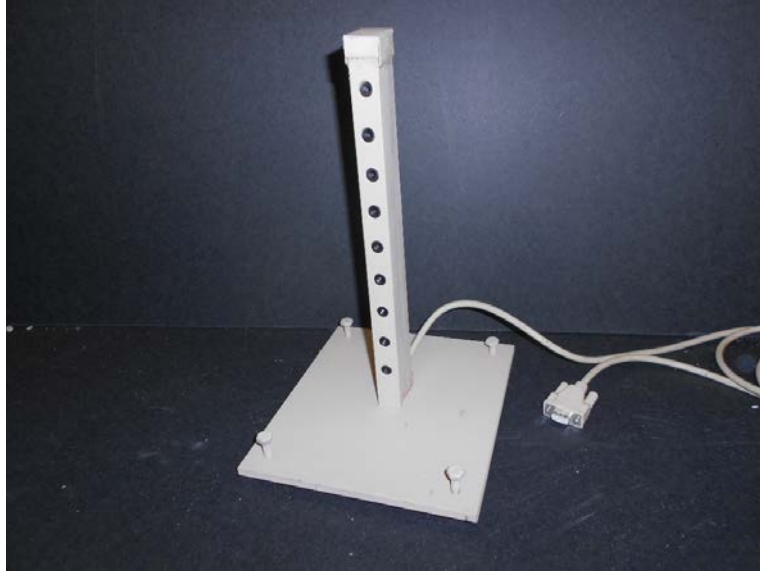


Fig. 10 Nine-element profile sensor



Fig. 11 Sensor deployed for desert environment field demonstration. Placing the sensor where it is shielded from the sun is desirable.

7. Graphical User Interface (GUI)

The graphical user interface (GUI) was designed for ease of use while still providing easily interpreted visual representations of the data collected. Referring to Fig. 12, the dot-matrix display with the green figures represents a time-sequenced display of the individual sensor outputs (i.e., an x - y plot showing sensor output vs. time). Each vertical column represents the sensor outputs at any given moment in time. The horizontal axis is the time progression of the sensor outputs, so any profile figure displayed moves from left to right. The figures shown here are of a person moving past the sensor sideways with arms outstretched. The number of sensors in use and the acquisition speed are both user-settable.

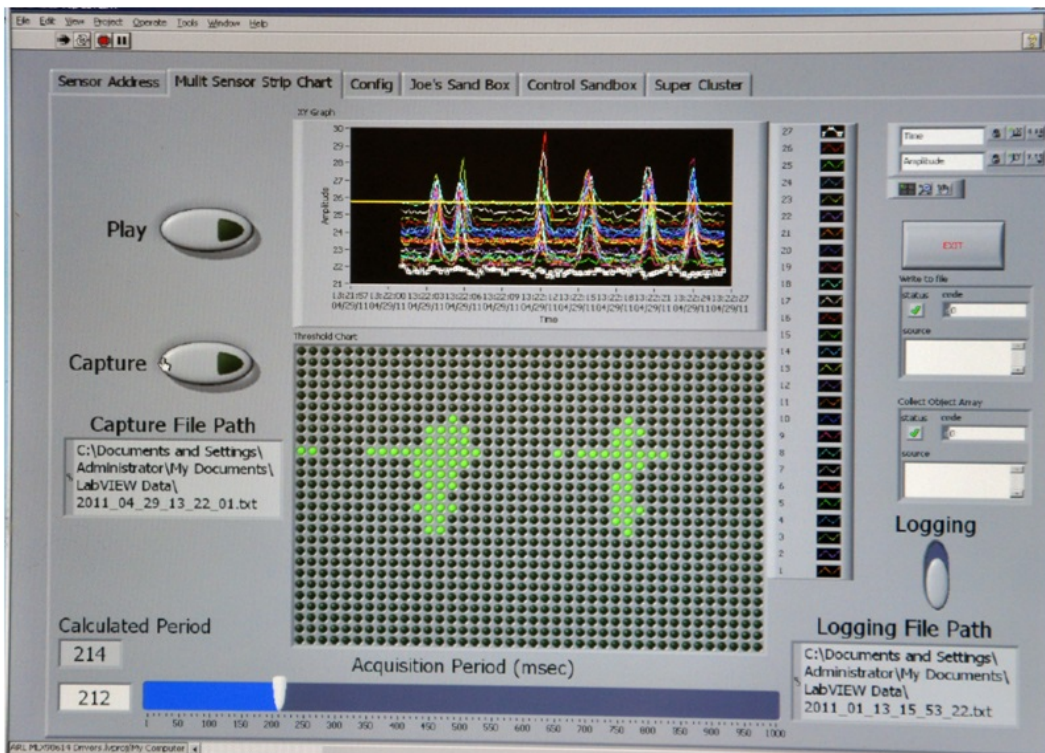


Fig. 12 GUI imagery from first demonstration unit.

Ground-truth data in the form of camera or video images were not recorded for reasons of expediency.

Above the dot-matrix display is a graphical display of the spectral outputs of every sensor in use. The yellow line is the user-settable threshold above which a given dot will be illuminated on the dot-matrix display. There is now a second line (not shown), which may be set below the average for a negative spectral line,

representing a cooler target on a warmer background, such as a person walking in front of a rock cliff.

Available options allow for data logging and playback, array configuration, and setting of run-time parameters.

A screenshot of the LabVIEW display showing profiles of people and people on horseback is shown in Fig. 13. At the top of the screenshot is shown the spectral display of each individual sensor. These spectral data may be used for more advanced signal processing algorithms.

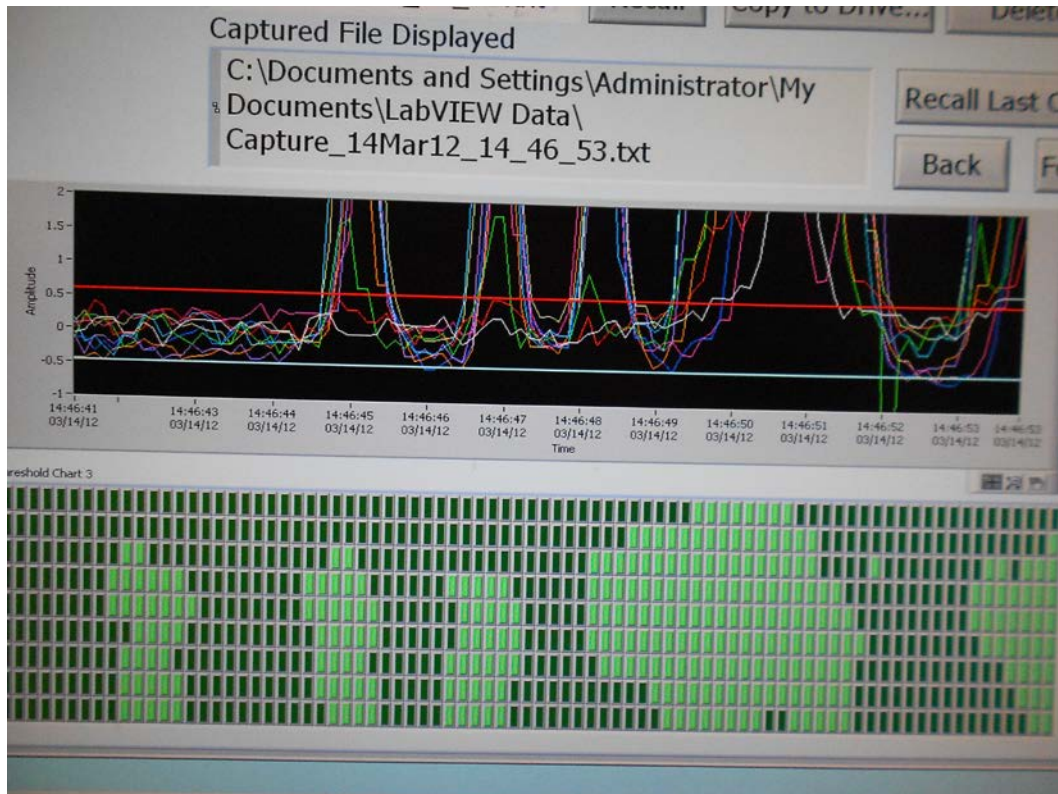


Fig. 13 Douglas, Arizona, data showing 3 people (left) and 1 person on horseback (a second horse is appearing on the right)

8. Culvert-Emplaced Version

Based on the units developed by ARL, Primal Innovation of Sanford, Florida, developed a unit to be placed in a culvert (Fig. 14).

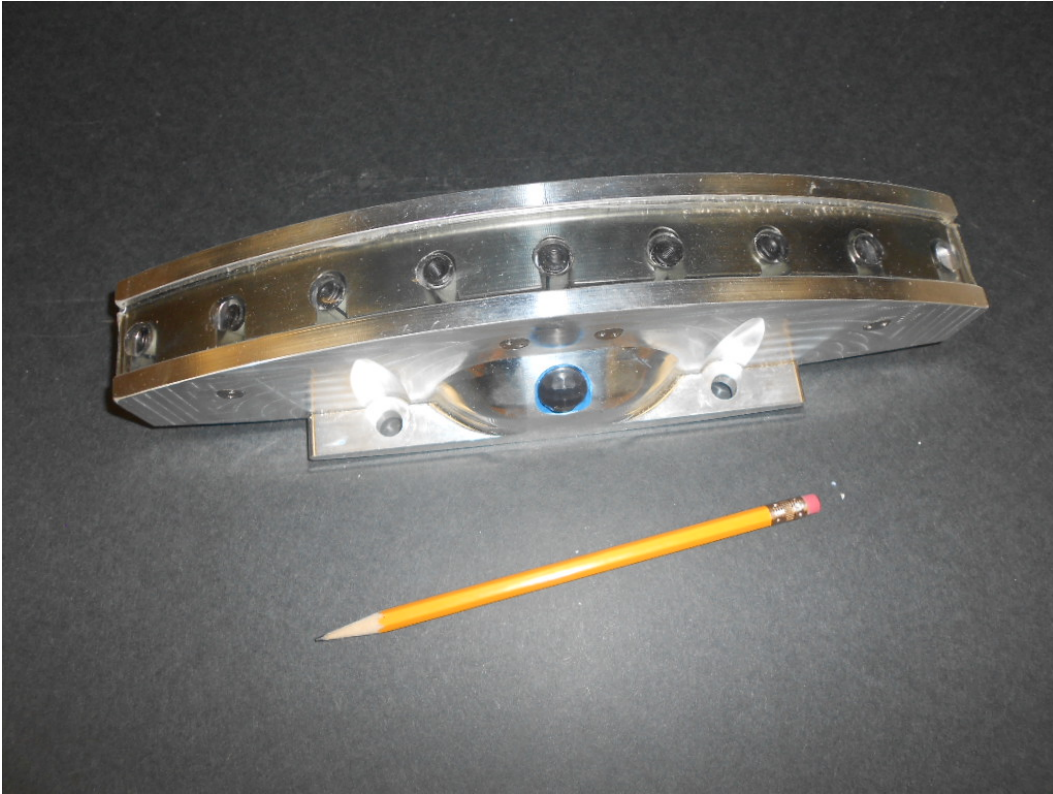


Fig. 14 Primal Innovation culvert-emplaced profile sensor

This unit has 9 sensor elements mounted orthogonally on a curved surface to achieve the desired beam spread. Additionally, the back surface is curved to match the radius of a 5-ft-diameter culvert. Two additional sensors on either side of the array (1 visible toward pencil) add a “sentry” feature, alerting the processor to awake from low-power sleep mode. These sentry sensors also allow monitoring of the speed of passage of the target of interest. This unit has not yet undergone field evaluations.

9. Sensor Atom Concept

The passive IR sensor used here would be an ideal candidate to demonstrate the sensor atom, or single-element sensor as a system, concept. A single sensor with a collimating lens and a basic microprocessor could be deployed along a known trail and serve as a simple counter when a group of individuals pass by. A series of these sensors could be deployed to monitor an area on the southwest border, for instance. If a trail of humans were to pass by, just 2 bytes of data would need to be sent via radio link: the sensor identification and the number counted. This would indicate where and how many people were traversing the area of interest.

10. Power, Control, Communications, and Displays

For the demonstration units developed and deployed during this research effort, the usual items that need to be addressed for fielded units were of secondary interest and were not implemented.

Power for a fielded unit would most likely be a solar-recharged BA-5590 battery, which would give a virtually unlimited lifetime.

Control of the sensors would first be realized with a Compact RIO controller unit for ease of transition, with a final configuration utilizing a microprocessor for size and cost savings.

Communications for remote units would be implemented in a spread-spectrum burst communications mode to minimize the potential for interception. Fixed units could have wired or optical links if the infrastructure is available.

The GUI display would depend on the recipient of the data and could be any fixed or mobile display device, including common smart phones, tablets, or pads.

11. Conditions Adversely Affecting Performance

Certain conditions are known to degrade the performance of any IR device, and steps must be taken to minimize exposure to them. Among them are solar glare (direct or reflections), background interference (known as “clutter”), target conditions, and viewing angles.

Solar glare is the exposure of the detector element(s) to sunlight, either directly or from a reflection off of any shiny object such as vehicle or aircraft windshields. It causes unwanted current to flow in the detector and will greatly deteriorate the performance of the unit. All possible actions must be performed to point the detector or array in directions that will minimize exposure to solar glare during use.

Clutter signals may be caused by any foliage (trees, bushes, grass, etc.) moving in the wind; any animal, human, or vehicle traffic; heating and cooling of rocks, cliffs, etc., as the day progresses; or any other objects within the FOV of the detector(s) that is a different temperature from the (no-target) ambient. Proper placement of the sensor unit to minimize clutter effects is essential and dictated by knowledge of the sensor characteristics.

Profile sensors are designed with an orthogonal passage of the target as the optimal situation. The sensor must be placed where targets are most likely to pass at as close to a 90° orientation as possible. The effect of other angles is to degrade

the quality of the profile, although a usable height-to-width ratio is often still obtainable. A systematic evaluation of potential “off-axis” profiles has yet to be undertaken.

Meaningful performance statistics for certain profile sensors, including detection, classification, false-classification, and false-alarm rates, have been compiled in separate reports.^{1,2}

12. Summary

In summary, profile sensors have been shown to offer a capable, low-cost, low-bandwidth means of detecting and classifying people, vehicles, and animals. Such sensors may find use in monitoring military bases including FOBs, small platoon-sized outposts, or larger facilities such as naval ports or airport hangars. Further uses may include the remote monitoring of border areas or human or drug trafficking routes.

13. Future Developments

Further development of profile sensors is planned and includes the incorporation of more advanced thermopile sensors utilizing vanadium-gold technologies offering increased sensitivity and range. Also planned are improved signal processing and development of a number of different sensor configurations for use in a variety of the aforementioned scenarios.

14. Conclusions

Continued development of profile sensor technology is recommended. Low-cost modules of varying configurations should be developed and demonstrated to potential users. Possible users include the following:

- platoon-level troops establishing FOBs that are in need of perimeter security;
- security personnel in charge of facilities such as aircraft hangers, petroleum, oil, and lubricants (POL) stores, munitions bunkers, etc;
- airport managers requiring perimeter monitoring;
- port facilities and dockyards; and
- electrical, gas, and water utilities monitoring essential equipment.

15. References

1. Haskovic EY, Walsh III S, Cloud G, Winkelman R, Jia Y, Vishnyakov S, Jin F. (Brimrose Corp.) Application of inexpensive, low-cost, low-bandwidth silhouette profiling UGS systems to current remote sensing operations. Proceedings of SPIE. 2013;8742:87420.
2. Kothari CR, Russomanno DJ, Frankel R. Towards data-to-decision sensing environments to assess human intent from responses to stimuli, Purdue School of Engineering and Technology, Proc. SPIE 8389, Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR III, 838904 (8 May 2012); doi: 10.1117/12.918598.

List of Symbols, Abbreviations, and Acronyms

A/D	analog-to-digital
ARL	US Army Research Laboratory
FOBs	forward operating bases
FOV	field of view
GUI	graphical user interface
IR	infrared
OE	optoelectronic
POL	petroleum, oil, and lubricants

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