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The Portable Sensor System: Addressing the Recognition Gap in Modern Surveillance Systems

Brandon C. Sanders
James Madison University

pp. 320-327

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Introduction: Surveillance

Ranges Of Surveillance

Surveillance systems are composed of two components: an asset (i.e., platform) and the equipment (i.e., sensors) installed on it.[1] The combination of the two determines how capable a system is at providing surveillance. There are many ways to measure the surveillance capability of a system, some of which are: the ability of a system to detect items of interests (IOI) in lowlight; the maximum range at which an IOI can be detected; and how well an IOI can be detected when it is masked by thick foliage. This paper focuses on the ranges of surveillance, one of which is the aforementioned maximum range of detection. The other two ranges are the range of recognition and the tracking range. The range of recognition is the maximum range at which a system can recognize an IOI, and, in most cases, the range at which that system can classify an IOI (e.g, a vehicle vs. a person). For the sake of this paper, recognition is defined as surveillance that is capable of determining the intent of a specific IOI (e.g., smuggler vs. an illegal immigrant). The final range, tracking, describes how far a system can track an IOI once it has been detected. These ranges not only quantify the capabilities of a system, they also describe exactly what range-specific capabilities a surveillance system possesses.

The Surveillance Envelope

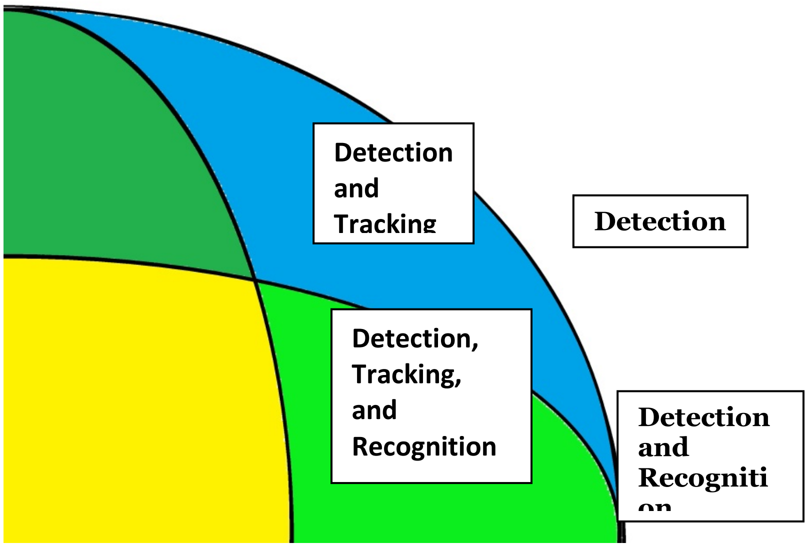
Describing the range-specific capabilities of a system is nothing more than a fancy way of discerning whether or not a surveillance system is capable of detection, recognition, and/or tracking. For example, ground radars like ICx's STS-1400 are capable of detecting and tracking IOIs while pressure plates (or any other type of unattended ground sensor or [UGS]) are only capable of detecting them. The range-specific capabilities of a system are broken down into a surveillance envelope. This envelope, shown in Figure 1, describes every possible combination of range-specific capabilities a system can possess and their relationship to one another (e.g., if a system can track IOIs then it is also by definition capable of detecting them). As shown in Figure 1, a system can possess one, two, or all three range-specific capabilities.

The notion of range-specific capabilities as they apply to surveillance systems can be applied to the broader notion of surveillance networks. A surveillance network is one or more systems working within a single domain to maximize the surveillance capability of the systems within that domain. In some cases there are multiple systems with identical range-specific capabilities (e.g., long-range radars augmented with short-range radars) while in other cases the network in place is layered with a variety of different systems (laser trip sensors that, when activated, tell

[1] This classification was based in part on contract between ICx and the General Services Administration. Some organizations use asset and equipment, others platform and sensors:
General Services Administration Federal Supply Service Authorized Federal Supply Schedule Price List, Contract Number:GS-07F-0117U, U.S. General Services Administration, 2005.

camera to take a photo thereby providing detection and recognition of the IOI). The greater the variety of range-specific capabilities a network (or system) possesses the more effective (and efficient) the organization employing that network can complete its mission.

Figure 1: Range-specific surveillance envelope by Brandon Sanders.



The Deficit of an Incomplete Network

Ideally, a surveillance network is composed of systems that provide all three range-specific capabilities. Unfortunately, most networks are far from ideal. In the certain cases where funds are available to implement a layered network those funds are often used instead to increase the range of one or both of the other range-specific capabilities that network already possesses. In some scenarios this is an acceptable and wise decision[2]. In other scenarios the decision to do so does not result in a noticeable return on investment. These resources would have been better spent on the acquisition of a different surveillance system or that of additional enforcement assets (the acquisition of either would assist in the completion of the overall mission). However, there are instances in which one or two of the range-specific capabilities are unavailable, an unfortunate fact that has predictable consequences.

If a surveillance network lacks the range-specific detection capability appropriate for that scenario, that network will first detect an IOI at a range that requires enforcement assets to scramble in response. The act of scrambling will result in ill prepared and informed enforcement assets that will most likely not know the number, vector, velocity, or details (recognize) of the IOI they are intercepting. Doing so wastes both time and money. Insufficient tracking results in a similar outcome. If an IOI is detected at long-range the enforcement assets dispatched to intercept it will have to do so based solely on the last known position of that IOI. The failure to recognize an IOI has consequences not unlike those above.

[2] An example of this would be expanding a manned radar network from 350m to 1400m. At 350m it is borderline possible to recognize an IOI with handheld optics, increasing the recognition capability would make no sense.

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Exploring the Role and Importance of Recognition

The Importance of Recognition

The failure to provide adequate range-specific recognition has consequences similar to those described in the previous section (detection and tracking). First, if recognition is lacking the enforcement assets responsible for enforcing the region under surveillance will be unaware of the intent or number of IOIs detected. Since the operators of surveillance networks often send enforcement assets that are capable of overwhelming the IOI encountered, the number and capability of those assets may be inappropriate for the given scenario. Doing so costs the operators time and money. Second and even more important, it ties down enforcement assets that could otherwise be used to intercept additional IOI, IOI that were discovered only after detection of the first. There is however a consequence unique to recognition, one that is unlike those from the previous chapter – the ability to discern whether or not an IOI is a false positive. Scenarios in which an IOI is inaccurately classified as a threat is an event commonly referred to as a false positive. It is one thing to send too many enforcement assets in response to the detection of an IOI; it is something else entirely to dispatch those assets when the IOI detected is of no consequence whatsoever. Doing so not only waste time and money, it leaves the operators extremely vulnerable to the use of decoys. With this in mind, the capability to provide range-specific recognition is the only way to determine with absolute certainty whether or not an IOI is a false positive.

Surveillance Systems Incapable of Recognizing IOIs

Despite the importance of recognition it is the most lacking of the three range-specific capabilities provided by modern surveillance networks. This isn't surprising given the fact that most large scale surveillance networks primary purpose is to track the IOIs they detect. As is described by Figure 1, tracking requires detection but not recognition. The most common systems used to detect and track IOIs are radars, thermal imagers, UAVs, and manned aircraft. Although some of these systems can be fitted with equipment that enables them to recognize IOIs, those systems outfitted to do so are the exception, not the rule. One of the primary reasons existing networks lack the capability to recognize IOIs is the cost associated with doing so. Quite simply, it is less expensive to engage IOIs with overwhelming force that may or may not be necessary than it is to acquire and deploy systems capable of providing range-specific recognition.

Resolving the Recognition Gap – The Portable Sensor System (PSS)

Template of the PSS

The PSS was designed to be a cost-effective system that fills the need for recognition that is endemic to many of the surveillance networks in use today. The original concept of the PSS required that it meet the following criteria:

- Portable
- Mobile
- Modular (and thereby upgradable)
- Inexpensive

- Extensive use off the shelf parts (or slightly modified versions of them) and/or technology

In addition to these criteria, the original concept called for the creation of a surveillance system which design was 'entirely original'. Entirely original means that both the operation (e.g., the way the system functions or works) and combination of components that make up the PSS had to be unique with respect to existing surveillance systems (e.g., the PSS could not provide recognition via the use of a spotlight and high-quality optics since systems like it already exists,). Originality also happened to be the most difficult criteria satisfy. Whenever research uncovered a surveillance system whose design was similar to the PSS, the design of it had to be modified or altogether rethought.

Final Design of the PSS

The final design of the PSS uses a thermal camera for detection and tracking, a range finder to determine the range between the system and the IOI, a traditional still frame camera for imaging, a modified version of commercial flashlights to enable imaging at night, commercially available narrow band Wi-Fi for intra-system communications, and a commercial pan/tilt mechanism that enables horizontal and vertical rotation of the upper assembly (see Figure 2). The mount on which this equipment rests contains the battery and a fully adjustable support system. Fully assembled, the specifications of the PSS are (all dimensions are visible in Figures 2, 3, and 4):

- Tall (dimension 1)
- Diameter (dimension 2)
- 13.5cm (5.3") tall (dimension 3)
- 19cm (7.5") wide (dimension 4)
- 27.9cm (11") long/depth (dimension 5) (length does not include stakes which are removable)

Figure 2: Mount

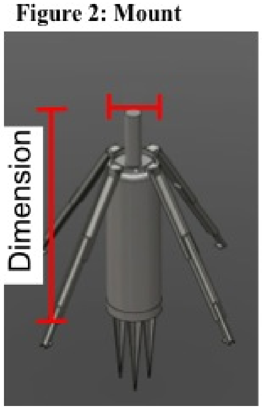

Figure 3

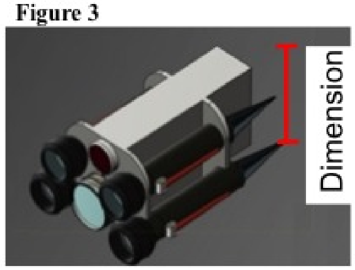

Figure 4

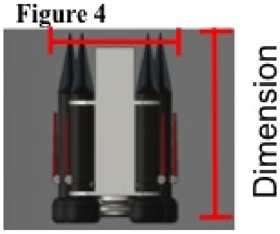

Figure 5: Complete System

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The need for intra-system communication is a byproduct of the PSS's design. The specific implementation of this system is discussed in the next section. For now the important thing to know is that the upper assembly is equipped with a narrow band transmitter while all of the flashlights are equipped with generic, off the shelf Wi-Fi receivers. The thermal camera used in this design is an extremely low-end version of ones that are marketed to everyday citizens (e.g., FLIR First Mate II). The final two components of the PSS are the battery and solar panels. The specific type and size of battery used can vary depending on the operator's needs. The only restriction placed on the selection of a battery is that the battery must be capable of fitting in the main body of the lower assembly (the mount). Solar panels are an option that extends the uninterrupted operation of the system; a capability that would likely appeal to those operators interested in surveillance systems capable of enduring long-term deployments.

Deployment of the PSS

When it is used as a standalone system the PSS is capable of detecting, tracking, and recognizing IOIs. However, when it is used in conjunction with other systems only one or two (depending the capabilities possessed by other systems in the network) of those capabilities are actually utilized. When operating as a standalone system, the engagement of IOIs is as follows:

1. The thermal camera detects the heat signature indicative of an IOI
2. The thermal camera tracks the IOI, using the pan and tilt mechanist to keep the IOI in the very center of the thermal cameras display
3. As soon as the thermal camera begins to track the IOI, the laser rangefinder starts measuring the distance between the IOI and the PSS (the rangefinder is fixed to the upper assembly, directly below the thermal camera)
4. The focus of the camera, which is located directly below the rangefinder, is adjusted so that it is constantly in focus. This is accomplished by linking the focus of the camera to the distance measured by the range finder
   Steps 5 and 6 when the PSS is operating during the day:
5. At a predetermined, user defined distance the camera takes a series of digital photographs (still frames, not video)
6. These photographs are relayed to a local or regional command and control center (the type of communication equipment used depends on the needs of the operator)
   Steps 5 through 7 when the PSS is operating at night:
7. At a predetermined, user defined distance the upper assembly broadcast a signal via narrowband Wi-Fi to all flashlights (both those on the PSS itself and those in the field) connected to that specific system telling them to turn on for a short period of time (usually between 1/5th and 1 second).
8. The camera takes a series of digital photos a fraction of a second after the upper assembly tells the flashlights to turn on
9. These photographs are relayed to a local or regional command and control center

The PSS is capable of being deployed in three different configurations that vary depending on the location and number of flashlights deployed. The three different configurations are:

- Two or four flashlights mounted on the upper assembly, none in the field

- Two or four flashlights mounted on the upper assembly and any number of them deployed in the field
- No flashlights mounted on the upper assembly, any number (at least two) of them deployed in the field

The only time these configurations alter the surveillance capability of the PSS is at night, the daytime operation of the PSS is one dimensional regardless of the configuration or environment. Flashlights in the field are those that are staked to the ground, have their heads rotated 90^{o}, and their Wi-Fi receiver extended (Figure 6). The only drawback to this configuration is that it doesn't guarantee that the light provided is focused on the IOI. The amount of light that does reach the IOI depends on the location (relative to the flashlights) and vector of the IOI, the number of flashlights deployed, and the size of the region being lit up (the larger the region, the more difficult it is to illuminate).

Each of the three configurations (Figure 7) has its benefits and drawbacks. The first configuration has the shortest range but is also the most accurate. Because the flashlights are fixed to the upper assembly they will always be pointed in the exact same direction as the camera, thermal camera, and rangefinder. The only major drawback to using this configuration is that, because all the flash comes from a single source, it is easy to detect and more likely to be vandalized.

The second configuration increases the range of the PSS and flashes the IOI from multiple directions. This makes it harder for the IOI to detect the PSS all the while ensuring that at least some of the flash (that which comes from the flashlights mounted on the upper assembly) is directed towards the IOI. The only downside to using this configuration is that the PSS is still vulnerable to detection, albeit less vulnerable than in the first configuration. The capability of this configuration to recognize IOIs is improved significantly if four flashlights are mounted on the PSS. The survivability of systems using this configuration are improved if all flashlights deployed in the field are done so in pairs. Pairing two flashlights produces a greater flash (from a single point), making it more difficult to discern between the flash of the flashlights and that of the PSS.

The third and final configuration has no flashlights mounted on the PSS. This configuration makes it virtually impossible to locate the PSS at night and maximizes the range at which it can recognize IOIs (when using a preset number of flashlights). The two downsides to using this configuration are: it is the least likely of the three to guarantee light is directed at the IOI and it requires more flashlights than the other two configurations combine (since it there is no flash on the PSS itself the light provided by the flashlights must be exceptional).

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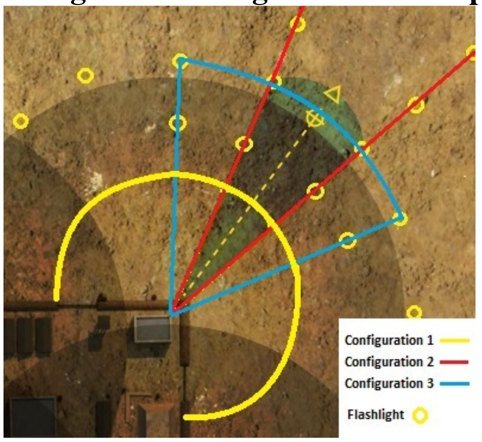
Figure 6: Flashlight

Figure 7: Configuration and deployment of the PSS



Shortcomings of the PSS

The PSS was design to fulfill a very specific need, the need for recognition. However, it is far from perfect. The desire to build a low-cost system from off the shelf parts has consequences. The most obvious shortcoming is the vulnerability of the system to vandalism, particularly when it is deployed for an extended period in a remote location. PSS networks that are not augmented with long-range detection equipment are only capable of tracking IOIs that are relatively close to the individual systems (400-450m). If any of these IOIs spot one or more of the PSS systems they may choose to vandalize or destroy those systems. Unfortunately, the remote location of these sensors means that enforcement assets will take a while to respond, quite possibly longer than it takes the vandals to flee the scene.

PSS are also vulnerable to threats that attack from behind, even if the systems that make up that network are used in conjunction with long-range detection assets. Fortunately the only scenario in which this vulnerability can be exploited is along border. If the PSS is used in the defense of a perimeter (e.g., a military base, critical infrastructure, etc.) the only objects and personnel behind it are friendly.

The second significant shortcoming of the PSS is that it is unable to recognize well in harsh atmospheric environments. These environments include both inclement weather and atmospheric phenomena unrelated to the weather (e.g., sandstorms). This is a serious weakness that well-informed threats can expose. However, the PSS is not rendered entirely useless. The

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thermal camera and range finder enable the PSS to both detect and range IOI, useful capabilities when the PSS is deployed as a stand-alone system. These capabilities are also useful if the PSS is used as a detection system that augments the detection capability of a larger, more system. In this scenario the PSS is used to detect IOIs in terrain that cannot be monitored by the primary system, usually because that system is blinded by terrain that blocks its line of sight.

Conclusion

Work to be Done

Prior to presenting at the conference additional work will be performed. This work includes changes to existing chapters, research that has been left out so as to meet the length requirements of this paper, and chapters/work that hasn't yet been perform. Some of the additional work and research presented at the conference includes:

- The effect recognition has on the tactics used by surveillance organizations
- Scenario-specific deployment of the PSS
- Use of the Scenario-Specific Optimization of Surveillance Assets (SOSA) tool
- Research into the resilience of the PSS when deployed in harsh environments
- Cost of the system[3]

Recognition is a significant range-specific capability integral to the proper functioning of any surveillance network, one that has been often been ignored by the operators of those networks. It would be impractical and in some cases impossible to replace existing systems with ones capable of providing surveillance networks with the range-specific capabilities required by the operators on a scenario-by-scenario basis. The PSS is a cost-effective system that has the potential, when used to augment existing systems, to meet these requirements.

[3] Early estimates suggest that a single system with four flashlights will cost between $7,000 and $12,000.

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