Novelty in Synergistic Radar technology, by adding Intrusion Location Capability

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Abstract - There is a new trend in the outdoor security market that demands more precision in identifying the crossing area of an intruder. Often called "intrusion location capability", this capability also presents inherent features such as; more accuracy in camera pre-set positioning, temporary disabling of sub-zone and individual sensitivity level per sub-zone. However, even though the market trend demands them, such features must have minimum impact to the overall system cost.

This paper presents how the Synergistic Radar technology can be modified to offer intruder location capability to a sub-zone area as precise as 10% of the total zone length. In other word, for a typical zone length of 100 meters, the zone is sub-divided in to up to ten equally spaced sub-zones of 10 meters each, giving an intrusion crossing point resolution of 10 meters.

The Synergistic Radar technology can be applied to buried, surface, wall and roof applications. This "intrusion location capability" also applies to each of these applications.

Introduction

This paper presents the most recent developments in Synergistic Radar[1], a new technology that was first introduced at the 1992 Carnahan in Atlanta, Georgia and later commercialized under the name ENCLO**SURE** in mid-95. Although ENCLO**SURE** was initially introduced as a passive perimeter intrusion detection system using the FM broadcast radio signals as a “transmitter of opportunity`”, this concept opens itself to a variety of new applications. Indeed, in most current applications, a stand-alone transmitter is used to replace the FM broadcast radio signals. In both cases, passive or active, the RF waves propagate in the air and offer a more stable and predictable field disturbance based sensor. The air is just more stable and more uniform than the soil surrounding the perimeter. In contrast to other buried line field disturbance sensor, the Synergistic Radar technology is based on an aboveground RF field, as opposed of an in-ground RF field.

This paper shows the progression of utilizing Synergistic Radar technology in an active way (aboveground RF field) for perimeter intrusion detection systems, more specifically by presenting the concept of intrusion location capability.

Even though the majority of intrusions sensor (with the exception of few of them, that will be described later in this paper) offer a maximum of two zones per electronic module, there is a growing need to provide a much higher number of zones per electronic module. Smaller zones increase considerably the resolution of the crossing points. Such increased resolution allows the user to have better pre-set camera accuracy that is crucial in video assessment. Naturally, such features must be achieved at no increase in system cost. This now permits taking advantage of the Synergistic Radar technology in a totally new direction.

In the majority of applications, line sensors are rarely installed in the middle of nowhere. In-fact, the line sensor is likely to be installed parallel to a physical barrier, i.e. a chain-link fence or brick wall. This reality offers an ideal support to mount the transmitting antennas. Like a string of Christmas lights, a set of miniature antennas is mounted up on the physical barrier[2]. This antenna configuration maintains a uniform RF signal strength all along the secured perimeter.

Crossing location is then obtained by simply activating only one antenna at a time by time multiplexing the antennas. Therefore, each individual antenna forms its own detection zone.

Recall: TDR (Time Domain Reflectometer)

TDR technology is widely used today in cable fault location equipment. Also called "range gating" TDR forms the basis of the radar principles. An intrusion sensor applying the TDR principles to leaky coaxial cable was first introduced in the 70's under the name of Guidar[3]. More recently, a fence sensor using a similar concept was also introduced[4]. In both cases, an RF pulse is launched into a cable, and TDR and range gating principles are used to sub-divide the cable into a series of sub-zones. Unlike the traditional radar, where the RF pulse is launched in the air, the sensor cable presents a much higher level of attenuation and dispersion. Thereby, the returned pulse is severely distorted by such cable attenuation and dispersion, which practically limits the maximum length of the overall sensor cable.

Exploiting the Synergistic Radar concept by adding the Intrusion Location Capability

The Synergistic Radar concept presents the best system to integrate the intrusion location capability. Patent pending. Indeed, it uses an above-ground RF field combined with a simple leaky coaxial cable forming the detection envelope. The use of multiple frequencies in a "quasi-spread spectrum" to reduce the effect of multi-path also contributes. Finally, the use of today's fast microprocessors and DSP's that are developed for multi-tasking purposes eases the integration of intrusion location capability. In other terms, today's technology facilitates high resolution location of the intruder crossing points, without increasing the overall system cost.

Working Principles

For ease of understanding, throughtout this paper, the antenna transmits and the sensor cable receives. However, antenna reciprocity does apply, meaning that the receiver and the transmitter are interchangeable.

A series of miniature flat antennas are mounted directly on the fence (spaced every 50ft typically) and only one antenna radiates at a specific time. The radiated field is received by a leaky coaxial cable forming a sub-zone of detection which corresponds to the area of the sensor cable that is radiated by the corresponding flat antenna. See Figure 1.

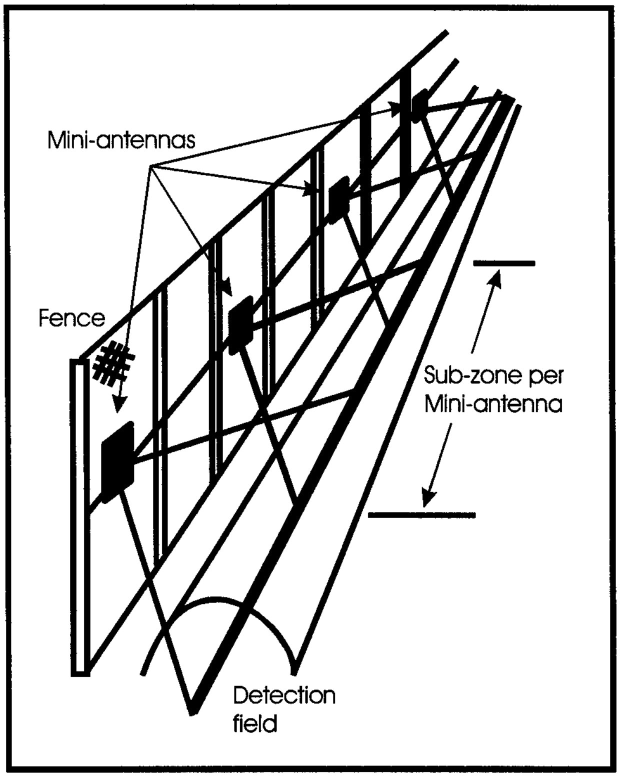

Figure 1
A typical system configuration is deployed parallel to a chain-link fence, with the mini-antennas mounted directly to the fence.
Each mini-antenna forms a perimeter sub-zone of 50 ft long typically. Each sub-zone is overlapped with its neighbouring sub-zone to obtain full coverage.

The antennas are electrically isolated from the sensor cable. This isolation maintains a mechanical continuity of the coaxial cable, a fundamental aspect in order to obtain a high level of reliability. As shown in Figure 2, each antenna has its own address. Only one antenna is connected at a specific time. The address data is sent via the coaxial cable interconnecting the antennas. Each antenna includes an address decoder and an RF switch.

However antenna reciprocity do apply.

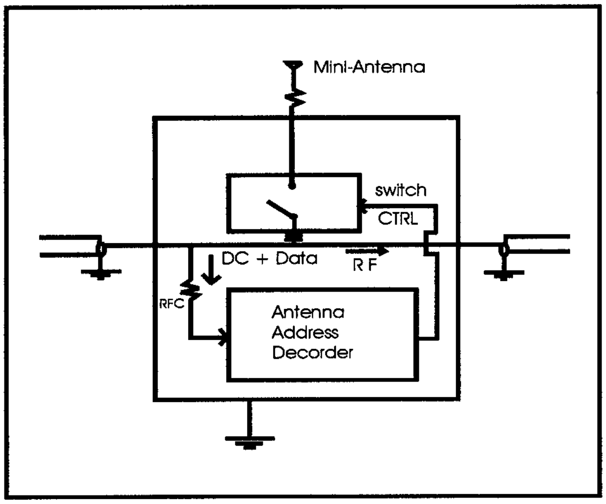

Figure 2
Each mini-antenna consists of three main components, one radiating element, one address decoder and one RF switch. Note that the coaxial cable integrity is maintained (not truncated) which is crucial to obtaining a high level of reliability.

The main processor rotates the activation of the antennas in a sequential manner, often known as time multiplexing.

The objective is to "time multiplex" as many antennas (sub-zones) as possible while maintaining a sampling rate per antenna high enough to obtain a reasonable resolution of the intrusion profile signature.

A typical time multiplexing analysis

To put into perspective the advantage of time multiplexing, let's make the following practical assumptions:

a) minimum electronic sampling rate:
2 milliseconds / sample.

b) typical sample per intrusion profile:
5 samples / intrusion.

For a minimum sampling rate per intrusion of:
2 X 5 = 10 milliseconds / intrusion, or 0.01 sec / int.

c) maximum intruder running speed:
8 meters / second (18 miles / hour).

d) typical width of the detection envelope:
2 meters (6 to 7 feet).

For a minimum intrusion time of:

2 / 8 = 0.25 second

Therefore, the over-sampling ratio for a running intrusion (worst case scenario) is:

0.25 / 0.01 = 25

which means that a maximum of 25 sub-zones can be time multiplexed without sacrifieing the probability of detection, even for a fast running intruder.

Example: A typical correctional perimeter has of a dual fence spaced by 20ft and 12ft high. In such an application, the mini-antennas are spaced apart by 50ft.

For a total perimeter of 1,250 ft (350m) maximum (25 antenna X 50 ft / antenna) per electronic module with sub-zone resolution of 50 ft.

Now, let's add the "Track-While-Scan" to the time multiplexing analysis

The concept is based upon a variable sampling rate. In the absence of intrusion (target), the sampling rate per antenna is reduced, which increases the over-sampling ratio, which typically increases the number of antennas to "time multiplex" per electronic module by a factor of ten (10). A pre-alarm threshold, (that is normally set midway between the alarm threshold and background noise) is used. Under quiet operation (i.e. in the absence of intrusion) each antenna is switched at a lower rate on an even basis. But when one antenna response exceeds the pre-alarm threshold, more time is spent sampling that antenna.

This track-while-scan technique presents a variable sampling rate condition for no intrusion, first intrusion, second intrusion, etc. This means that the probability of detecting a single intrusion is higher than detecting a double intrusion and so on. This is the compromise to increase the number of sub-zones per single electronic module. Such compromise depends on the threat level and the applications.

Preferably, the sampling rate is increased not only for the antenna that reaches a pre-alarm condition, but also for its 2 neighbouring adjacent antennas.

Example, follow-up: For a total perimeter of 12,500 ft (2.4 miles or 3.8 kilometers) max. (250 antenna X 50 ft / antenna) per electronic module with sub-zone resolution of 50 ft.

Finally, an even finer resolution for the intrusion location is obtained by comparing intrusion alarm conditions between adjacent sub-zones. See Figure 1. With this technique a resolution accuracy equal to the third of the antenna spacing, for a final location resolution of 50 ft / 3 = 17 ft (5 meters), can be obtained.

Other benefices associate to the sub-zone.

A secondary feature will allow setting of an individual threshold per mini-antenna (sub-zone). This way, the noise of a difficult sub-zone is not integrated to the entire perimeter noise.

Also any sub-zone can be temporarily disabled to allow authorized personnel to cross the perimeter without shutting down the entire perimeter.

Finally, the increased intrusion resolution allows the video camera to be pre-set to a finer resolution for more efficient video assessment.

The miniature antenna, a crucial part of the system

A wide range of miniature antennas can be used as long as the loaded impedance is high in reference to the coaxial cable impedance. A high impedance, like a test probe, extracts a very small portion of the RF signals that propagate within the coaxial cable in order to minimize the cable loss along the array of antennas.

A small antenna is characterized as an antenna with any physical dimension less than 1/10 of the wavelength. Such antennas include the well know mini-whip antenna. Mini-whip antennas are the easiest to mount.
The mini-whip antenna can be easily mounted directly to a tree. Mini flat antennas are also popular for applications that required minimal obstruction. Often found in aircraft, also called patch antenna[6], these antennas are conformed to the fuselage of the aircraft. Figure-3 shows a mini-flat antenna mounted on chain-link fence. Figure 4 shows a close view of a flat antenna. However, as the chain-link fence is not electrically stable, the flat antenna needs to be electrically decoupled from the unstable chain-link fence that acts as an unstable ground plane[7]. To do so, the antenna is spaced by a ½ inch thick PVC layer and connected to the center conductor of the coaxial cable by a series resistor (called here, decoupling resistor) typically of 220 ohms.

Figure 3
Shows a picture of a mini flat antenna mounted directly on the center and up section of a fence fabric. The antennas interconnect cables are run at the base of the fence.

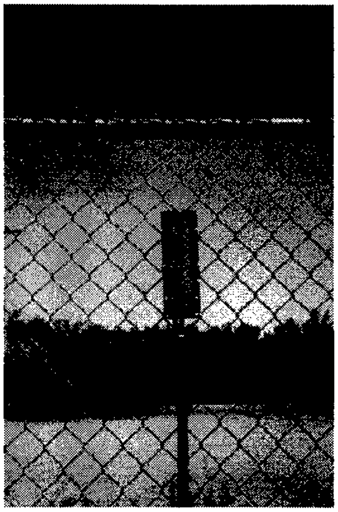

Figure 4
Shows a close view picture of an 8 inch by 2 inch mini-flat antenna mounted on the fence fabric of a chain-link fence via a ½ inch PVC spacer. Particular decoupling attention is given minimizing the impact of the electrical instability of the fence fabric.

Alpha Test (conducted at Auratek test-field)

Preliminary alpha testing was successfully conducted during the spring of 2000. The test included a total of 4 sub-zones due to the limitation imposed by the current 8 bit microprocessor. A first test was done with 10 inch long mini-whip antennas mounted on top of a chain link fence using 18 inch long PVC stands. As shown in Figure 5, a second test was done with miniature flat antennas (8 by 2 inches) mounted on a 6 feet chain link fence using a ½ inch PVC insulator.

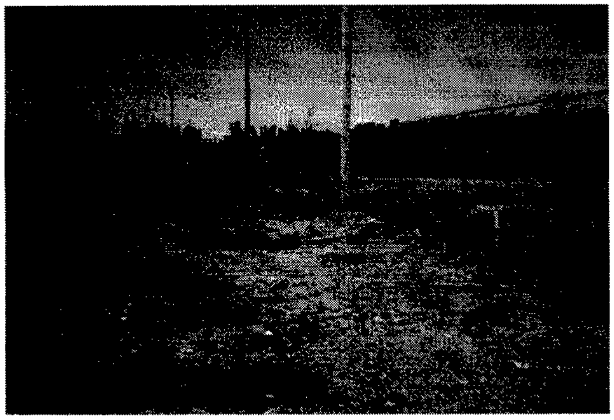

Figure 5

Shows a picture of a section of the 6 feets fence perimeter secured with flat antenna mounted on the fence fabric spaced by 50 feet apart.

A preliminary result showed that the detection envelope is uniform and very similar for both types of antenna. However as expected, the mini-whip configuration is less susceptible to fence noise. On the other hand, the flat antenna can be severely affected by the electrical instability of a chain link fence. This effect can be substantially reduced when proper decoupling material is used. An experimental trial and error approach was used to determine the parameters of the decoupling circuit in order to maximize the antenna efficiency and to minimize the effect of the fence instability.

The optimum decoupling circuit was achieved using a rectangular (8 by 2 inches) flat antenna, spaced by a ½ inch thick PVC plate, interconnected with a 220 Ω resistance. This antenna topology presented an antenna gain of -25dBd with noise immunity to tolerate lateral displacement of the fence fabric up to +/- 1/4 inches.

Extreme long perimeter in exchange of less resolution

When fine resolution is not required, the same technique is applied to time-multiplex longer sub-zones of 300 feet (100 meter) each. This is done by increasing the distance between the antennas and the sensor cable, where each antenna radiates a longer section of the sensor cable. For a detail explanation on antenna placement, refer to reference #2 "ENCLOS**URE** processor using Multiple Miniature Antennas". In such configuration, many miles (kilometers) of perimeter can be covered with only on electronic module, placed inside a control room.

Current state of development

Presently, the miniature flat antenna has been developed and tested on a variety of chain-link fences. A system with 4 sub-zones with flat antennas mounted on a fence was tested to prove the concept. The speed limitation of the out-dated 8 bit microprocessor does not allow "time multiplexing" of more than 4 sub-zones.

A revised 32 bit processor circuitry, including a built-in DSP, is currently under development. It is expected to time multiplex a total of 50 sub-zones without the track-while-scan feature and up to 500 sub-zone with the track-while-scan feature.

Conclusion

The Synergistic Radar concept takes advantage of its above ground RF field characteristic to introduce the concept of fast time multiplexing to time multiplex an array of miniature antennas. This concept presents a unique approach to integrate the intrusion location capability with a perimeter intrusion leaky coaxial system.

This fine crossing location resolution allows more accurate video assessment in order to improve the human response time and accuracy.

Indirectly, the cost per zone is substantially reduced since a single electronic module can now secure a perimeter of a few miles (few kilometers) with resolution as small as 50 feet (15 meters). Indeed, this single electronic module can be placed inside the control room, which eliminates exposing the electronics to outdoor environments and sabotage. In reality, only the antenna switching circuitry is mounted outdoors. On the same aspect, the detection field is formed by a single sensor cable, which minimizes the use of coaxial connectors. The complexity of zone overlapping is also eliminated. Therefore, the overall reliability (MTBF, Mean Time Before Failure) of such system is substantially improved.

References

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