F2-E: Detection of Electronically Initiated Explosive Devices

Abstract—Explosive devices are often triggered by electronic components like wireless receivers, timers, and microprocessors. When active, these electronics emit electromagnetic energy and are susceptible to damage from external electromagnetic fields. Our goal is to develop methods to remotely detect and neutralize electronics used in explosive devices by exploiting their electromagnetic characteristics. Our work with DHS has focused on detecting and locating radio receivers (used to remotely initiate a device) and on detecting electronic timers (e.g., like a stove timer or a watch). Algorithms have been developed to detect receivers using a low-power stimulation that modifies their emissions. This approach is able to detect these receivers from far greater distances or in far greater noise than traditional passive methods. In the last year we have perfected techniques to locate (not just detect) radio receivers using this “stimulated emissions” approach. Location is determined using a variant of radar ranging techniques. The approach has been implemented in a hand-held software-defined radio and its capability demonstrated on multiple receivers in a noisy urban environment. The receivers in our tests were located within an RMS error of less than 7 m at a range of up to 50 m or more. Over the course of the project, five journal papers have been submitted, one patent disclosure was made, and several presentations were given. Commercialization of the developed technology is being pursued with a small company. Work will continue into year 5 through a no-cost time extension.

I. PARTICIPANTS

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II. PROJECT OVERVIEW AND SIGNIFICANCE

Many improvised explosives are initiated with an electronic device, like an electronic timer, wireless receiver, or motion detector. Our goal is to develop methods to indirectly detect and locate explosives by detecting the electromagnetic emissions from these electronic initiators. This approach has the advantage that a device can potentially be detected from tens or even hundreds of meters away in a very short period of time using relatively small, inexpensive, low-power sensors. While detection of electronic devices common to initiators does not guarantee that an explosive device has been found, detecting suspicious electronics can indicate the possibility of an explosive device and, fused with other data, can help overcome the limitations of other detection technologies. For example, while Raman Spectroscopy can reliably detect trace levels of explosive...
compounds, it cannot be applied quickly to large areas of concern. Detection and location of suspicious electronic devices can help direct Raman sensors to specific areas with potential explosives. Also important is that detection of electronics can give the EOD (explosive ordnance disposal, i.e. bomb squad) technician additional information about potential threats that cannot be obtained through other sensors. For example, consider an EOD technician searching for a vehicle-born explosive in a parking garage who discovers a parked van with large amounts of material hidden under a tarp. Detecting the presence of a running timer under the tarp increases suspicion that may allow the technician to elevate the method used to deal with the threat. Detection of the timer remotely also gives the technician information about how the device might be initiated and, therefore, how it might be deactivated. The more the technician knows about the electronic initiator, the better he can deal with the explosive device.

III. RESEARCH AND EDUCATION ACTIVITY

A. State-of-the-Art and Technical Approach

Because of the close association between electronics and military/defense issues, the defense community has funded the development of a variety of methods for detecting, neutralizing, and disrupting electronics. Most existing detection approaches rely either on electromagnetic emissions from an intentional transmitter, like a cell phone during a call, or on stimulating a response from non-linear P-N junctions that are part of all electronics. While intentional transmitters may be detected very reliably from long distances, few explosive devices are built to intentionally emit an RF signal. Detection of non-linear P-N junctions can detect a large variety of electronics and can be performed even when the device is turned off, but it requires a very high-energy stimulation, is difficult to perform reliably (particularly if one is to determine what kind of electronics are present), and may typically only be performed at very close range if a safe level of stimulation is used.

Some work has been done previously to detect electronics based on their unintended emissions, but these approaches typically depend on simple detection of the energy present at a given frequency [1], which is highly susceptible to noise, or use an approach that depends on simple matched filters [2], which requires very precise knowledge of the device one is detecting and are made unreliable by common variations in emissions due to temperature, manufacturing tolerances, and other factors. Explosives are also often detected using chemical or similar signatures related to the explosive compound. While detection of chemical signatures can be very effective, they face several imposing challenges for use in the field, including a high false-alarm rate (depending on the approach), an inability to detect explosives at long range (or only very slowly), and possibly an inability to locate the explosives once a chemical signature is detected. Unfortunately, there is no silver bullet solution.

The overarching goal of our work is to develop a fundamental understanding of the physics that allow devices to generate radiated emissions and to be susceptible to electromagnetic energy, to develop a solid characterization of the radiation and susceptibility of existing electronic devices, and to develop algorithms or methods that exploit these mechanisms to create improved detection, neutralization, and interrogation approaches. Our work under Department of Homeland Security (DHS) funding focuses on the detection of electronic devices. Neutralization of electronic devices has been studied under another project with the Navy.

Our unique detection approach uses a weak stimulation to modify the unintended emissions from electronic devices. This method was developed in our laboratory and has the potential to improve the detection range, detection accuracy, and ability to locate certain electronic devices, particularly radio receivers [3], [4]. Our technique works, essentially, by creating a very weak radio signal that is received and modified by an electronic receiver. Some of the modified signal is unintentionally re-emitted by the receiver. The presence of the modified signal indicates the presence of the receiver. Each receiver class (e.g. superheterodyne or regenerative) modifies the signal in a unique way. Only these receivers, not other electronics, will generate the modified signal, so false alarms can be minimized. The technique can potentially detect devices relatively quickly.
from relatively long range using inexpensive, hand-held, battery-operated equipment.

Our work has focused on emissions that are likely to occur from the two main classes of electronic receivers: superheterodyne and regenerative receivers. Regenerative receivers are commonly used in remote-control applications like remote-controlled cars, wireless doorbells, and car alarms. These receivers are common to improvised explosives since very little modification is required to allow them to initiate an explosive device. Superheterodyne receivers are used in most radios transmitting analog or high-speed signals, like for voice or data communications. Cell phones and walkie-talkies are good examples. These receivers have a relatively long range and often include "passcodes" that control operation (like a phone number, or a squelch code), making them another favorite of terrorists.

The first step in our project was to survey existing methods of detecting very weak electromagnetic signals in significant noise and to assess the applicability of these detection methods to the stimulated emissions problem, where some control of emissions is possible. Once suitable methods were identified, we then explored ways to improve these methods for detection of radio receivers. Algorithms to determine the presence of these receivers were developed in the first part of the project. In the last year we have completed the development of methods that allow the determination of range to the receiver, using a modification of the traditional FMCW radar approach. Once the range is known, it is relatively straightforward to locate the receiver. While our project's official end date is June 30, we have received a 1-year no-cost extension to continue the work, since the project was started later than planned. During the 1-year extension, we plan to conduct a more thorough demonstration of the ability to accurately locate a radio receiver and to develop methods to generically detect emissions from digital electronic devices in the presence of significant noise. As our ability to detect devices has matured, we have pursued commercialization of the technology. We are currently working closely with a small company to produce a hand-held device for electronics detection.

B. **Major Contributions**

In summary, major contributions of the first four years of this project include:

- Explored existing signal processing methods for detecting weak signals in significant noise, particularly those methods for detecting stimulated emissions from regenerative and superheterodyne receivers;
- Characterized the unintended electromagnetic emissions from superheterodyne receivers both with and without the presence of an external stimulation (significant work had already been done previously on the emissions from regenerative receivers [4]);
  - Discovered that unintended emissions from superheterodyne receivers may be modified using a low-power stimulation.
- Developed techniques for enhancing the emissions from superheterodyne receivers to provide a stronger and more easily-detected signal.
- Developed methods to detect superheterodyne receivers using a low-power stimulation. These methods were tested against existing detection techniques that passively look only for emissions from the local oscillator. Our methods were shown to perform substantially better;
- Implemented detection algorithms on a software-defined radio to demonstrate that detection could be performed using man-portable hardware in real-time.
- Explored the possibility of modifying the emissions of digital oscillators using an external stimulation, for example the oscillators used to provide the clock signal in a digital circuit;
- Began development of methods to detect the very weak electromagnetic signals emitted by digital timers. Extremely sensitive receivers were explored for this purpose. Research into detection and location of digital timers was begun early at the urging of DHS bomb technicians who visited our lab.
- Modified the ESPRIT method of detecting the angle of arrival of an RF signal in order to use it to locate

- Demonstrated the inability of existing RF ranging techniques (interferometric SAR, near-field EM ranging, and Doppler techniques) to adequately determine the range to a receiver using the stimulated emissions approach.
- Developed modifications to traditional radar-ranging techniques to locate radio receivers based on the stimulated emissions from the receiver.
- Implemented radar-ranging methods in a software-defined radio. Used this implementation to demonstrate the sensitivity of the detection method in a realistic urban environment.
- Submitted 5 journal papers for review on the remote detection of regenerative and superheterodyne receivers, submitted one invention discloser on detection of superheterodyne receivers, and made multiple presentations over research results.
- Teamed with a small company that builds ruggedized hand-held electromagnetic emissions detection equipment to explore commercial products based around our algorithms.

Some examples of results over the past year are shown in Figures 1 and 2. A methodology was developed to determine the range to a radio receiver using its unintended RF emissions. This method of determining range is based on concepts from frequency-modulated continuous-wave (FMCW) radar, but differs from conventional radar in that it depends on the modification of the unintended emissions from the target device rather than on a passive reflection. For a superheterodyne receiver, the transmitted signal is shifted upwards to a much higher frequency before re-emission. This is an advantage, since the stimulated emission is not at the same frequency as the stimulation or its harmonics, so it can be detected more easily, and since superheterodyne receivers are the only electronic devices likely to show this response, so false alarms are minimized. To demonstrate the performance of the technique, the algorithm was implemented in a Universal Software Radio Peripheral (USRP) – a small, inexpensive, highly-flexible RF processing unit. This hardware implementation is illustrated in Fig. 1. Custom hardware modules, implemented in an FPGA in the USRP, were written to generate FMCW chirps transmitted from the USRP and to de-chirp the received emissions in real-time to determine range. Tests were performed on two different target devices: a low-cost, consumer GMRS/FRS receiver and a high-quality wideband radio scanner. Tests were performed in a noisy, multipath-rich ambient environment when the sensor (the USRP) and the target device were up to 50 m apart and while the device was moving. Results of these tests are shown in Fig. 2. The average range error is less than 4.7 m in all cases. Complete details of this study can be found in [1].

IV. FUTURE PLANS

![Fig. 1. Hardware implementation of the range-detection algorithms in a Universal Software Radio Peripheral.](image)
While this project was slated to end on June 30, 2012, we have received a 1-year no-cost extension to complete the proposed work, since our project started later than expected. Some work in the next year will be conducted to better polish the range detection approach and demonstrate its capabilities, but the majority of the effort will focus on the development of generic signal processing algorithms to detect digital timers and clocked digital devices with unknown operating frequency. The importance of detecting digital timers was emphasized by DHS bomb technicians who visited our lab. In their opinion, there were several scenarios where detecting digital timers could be useful to the bomb tech., including the case where bomb technicians were trying to locate vehicles of interest when looking for vehicle-borne improvised explosives. While emissions from timers can be detected, they are very weak. Detecting the emissions at a reasonable distance (several meters or more) will require development of specialized hardware and detection algorithms.

Detection of clocked digital devices is important since most all microprocessor-based circuits use a digital clock. These clocked devices generally show emissions at the clock frequency and its harmonics. Emissions from digital devices are readily recognized by eye, but a generic method to detect these devices is not available – particularly to perform detection in the presence of significant noise when the clock frequency is unknown. Signal processing methods for generically detecting digital devices will be explored. These methods can be applied to detect a broad range of devices (e.g. digital timers, microcontroller-based electronics like those in many motion detectors, digital cameras, even gas-powered vehicles). These specialized signal processing methods should yield better sensitivity and improved range over generic detection approaches.

V. RELEVANCE AND TRANSITION

Detection of electronics has an advantage over many other explosives detection techniques in that it can potentially be done relatively quickly from relatively long range and can be done with relatively inexpensive equipment. It gives the bomb technician one more point of information with which to make a decision about the presence of explosives and how to deal with the explosives once found. While detection of suspect electronics does not necessarily indicate the presence of an explosive device, this information can be combined...
with other information relatively easily to confirm or add information about a threat. The information is unique from other explosive sensors, so it is well primed for sensor fusion.

Our methods to detect radio receivers using our stimulated emissions technique are quickly approaching commercialization. Two patents and a provisional patent have been issued on the technique. The algorithms we developed have been implemented in a hand-held software defined radio and have been shown to detect the receivers at relatively long range in real-time. Radar-based ranging algorithms have similarly been implemented in the hand-held software defined radio and show good potential. This work is also ready for commercialization. We have teamed with a small company, Firestorm Emergency Services, to explore the development of a commercial product around our algorithms. Firestorm manufactures a small, inexpensive, hand-held device for detecting and locating the electromagnetic signatures from aircraft emergency beacons and from radio location beacons worn by Alzheimer's patients, so they already have hardware under development that is ideal for our approach. The fundamental detection methods developed here are also being extended with Firestorm to develop systems for locating vehicles at remote border crossings – another critical application to DHS. We are actively seeking funding to advance this effort.

VII. DOCUMENTATION

A. Publications

B. Technology Transfer

C. Seminars, Workshops and Short Courses
None to date.

VIII. REFERENCES

