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PROGRESS, STATUS, AND MANAGEMENT REPORT
Final Report

Summary

This final report has been prepared in support of contract N00014-04-M-0382. Work under the contract has been completed, with extremely promising results. In summary, the objectives of this contract were:

- To further characterize and understand the explosive chemical signature of improvised explosive devices (IEDs)
- Develop and adapt high volume sampling methods for use against IEDs and for incorporation into a robotic platform
- Modify and adapt the Fido sensor device to operation on a small robot
- Integrate the Fido and high volume sampling functions into a small footprint commensurate with operation of a small robot
- Test the integrated prototype in the laboratory and in the field

These objectives were achieved and were demonstrated in a proof-of-concept test at the US Army Yuma Proving Grounds (YPG) countermine test facility from December 13 – 17, 2004. During these tests, a Fido vapor sensor modified to include high-volume sampling capability was deployed on a Dragon Runner robotic platform. As will be described in this report, the combined system was able to detect a range of IEDs throughout the course of the test. Nomadics personnel were able to quickly train an EOD technician and a Marine Corps Captain to operate the sensor and detect targets deployed along a roadway. These targets were detected by the integrated platform while providing substantial standoff between the system operator and IED. Targets concealed in vehicles were also detected. In related work, trace-level contamination on personnel that had handled explosives (i.e., EOD technicians), and trace contamination spread by persons that had handled explosives was demonstrated with the sensor when operated in a hand-held mode. This related work will be presented in detail in an upcoming progress report being drafted for Navy SBIR contract number N00014-05-M-0010 (Field Collection and Analysis of Forensics and Biometric Evidence Associated with IEDs).

A discussion of work completed towards achieving each objective listed above follows, along with suggestions for future work to increase the functionality of the system to produce a system with enhanced capability for the warfighter. We believe that these enhanced capabilities can be developed and incorporated into the system rapidly, resulting in a more robust system that can be deployed for testing in-theatre in a matter of months.

Technical Basis for use of Chemical Vapor Detection to Detect IEDs

IEDs are particularly difficult to detect. They are often deployed in such a way that they are very difficult to discriminate visually. In addition, the wide variety of IED configurations makes it difficult to find a common property by which to detect them. The explosive charge contained in IEDs provides one of the very few common threads and may provide the most consistent method of detection. In this regard, the challenge of IED detection is very similar to landmine detection. Regarded by some as the gold standard in landmine detection, canines detect the chemical signature emanating from explosive charges in landmines and have successfully detected IEDs by the same mechanism. These facts support the notion that IEDs generate a distinct explosives chemical signature that stands out from the environment. It follows that an ultra-sensitive electronic sensor with detection thresholds rivaling canines could equally serve to detect IEDs.

There are two basic methods for detection of explosives. One is with a bulk-type detection method such as quadrupole resonance (QR) or some type of nuclear sensing method, while the other is to detect the trace chemical signature of the explosive material. Trace sensing offers a number of advantages over QR or nuclear bulk sensing methods including equipment size, weight, complexity, and cost. Speed of detection is another area where trace chemical sensing has potential advantages. In addition, trace vapor sensing offers the possibility of standoff detection and the possibility of deployment on small, remotely-operated robotic platforms.

It can be stated unequivocally that there is no silver bullet for solving the IED problem. However, the results obtained during Phase I of this effort strongly suggest that detection of IEDs via trace chemical signature sensing can and will play a strong role in the suite of technologies ultimately deployed against this threat. The following factors support this belief:

- Every IED contains explosives which produce a chemical signature.
- Dogs, which are in essence an extremely sensitive chemical sensor, can detect IEDs.
- The South African military has used chemical signature methods to detect landmines, IEDs, and weapons caches, providing a precedent for use of the method.
- Recent Nomadics field tests have yielded positive results against high fidelity simulated IEDs.

Based on experience with canines, and recent technological breakthroughs, it has become clear that the detection of chemical vapors emanating from IEDs provides significant advantages in detection. Further, added capability is offered by integration of chemical sensors with robotic platforms to greatly expand mission options while greatly reducing the risk to the warfighter during operations.

Related System Development Prior to Phase I Contract

Prior to this Phase I effort, interest in the sensor for detection of IEDs was expressed by the Marine Corps after a demonstration of an earlier prototype. At this time, feedback from the Corps suggested that the prototype sensor was too bulky and heavy (the earlier prototype weighed close to 18 pounds with battery pack) for deployment in certain critical missions. In addition, the user interface was too complex and not suitable for use in a combat environment. Hence, a rapid engineering effort, funded with internal Nomadics R&D funds, was undertaken to reduce the size, power consumption, and weight of the sensor. In addition, the head of the sensor was separated from the sensor user interface and was attached via a tether, greatly increasing the ease with which the sensor could be utilized in a hand-held mode. The user interface was greatly simplified, and the external computer required to operate the earlier prototype (a handheld PDA) was eliminated. The result of this six-week effort was the Fido XT sensor (Figure 2). The new sensor weighs approximately 2.6 pounds, is less than half the size of the earlier prototype, and is much easier to use.

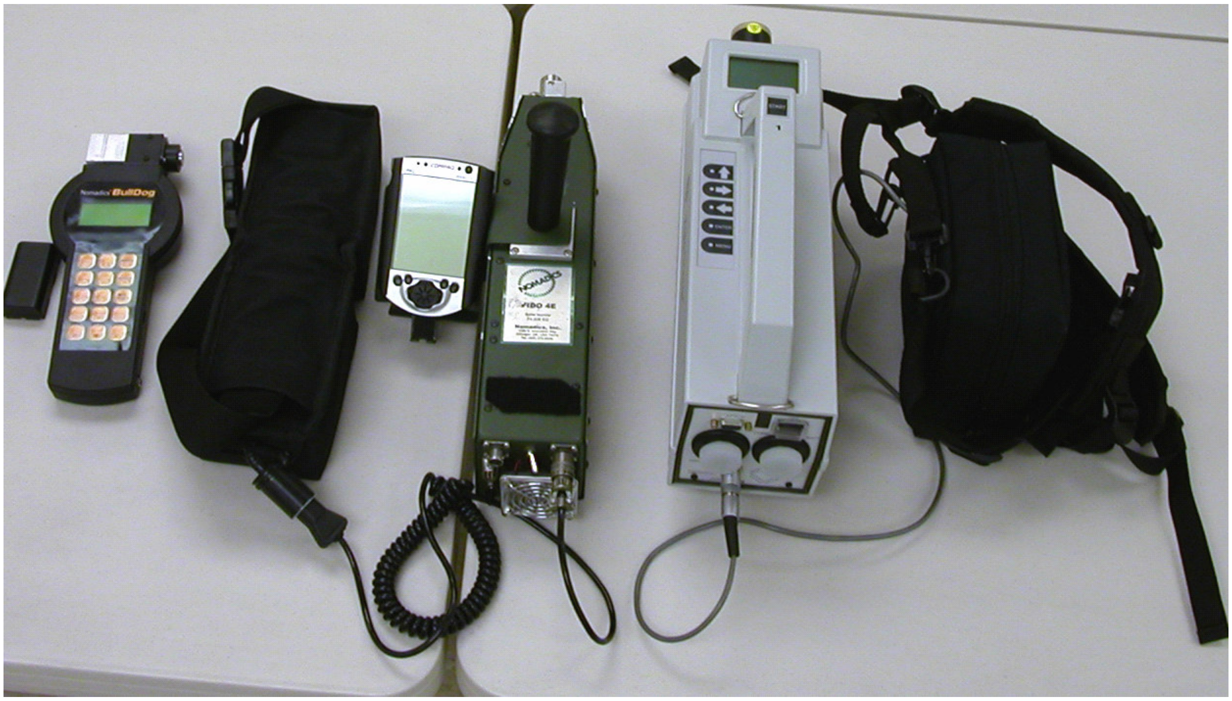

Figure 1. Comparison of trace chemical sensors and batteries. From left to right, the Fido X sensor (1.5 pounds), Fido 4EG sensor (previous Fido prototype, approximately 10 pounds), and commercial off-the-shelf ion mobility spectrometer (almost 20 pounds).

Figure 2. Fido XT operated in hand-held mode.

The new sensor was again demonstrated to the Marine Corps. Feedback was extremely favorable. At this time, an interest was expressed in the possibility of interfacing the sensor to a small Marine Corps robot (the Dragon Runner, shown deployed in Figure 3 with a Fido sensor). An interface between the robot and the sensor was quickly developed to facilitate communication between the sensor and robot, and the sensor and robot were integrated. Two of these integrated systems, adapted for deployment in under three months, are now deployed in Iraq and are undergoing testing in-country. While feedback has been limited, it has been encouraging.

Because the initial development was rapid, and because the systems were deployed to Iraq immediately after operators were trained by Nomadics personnel, Nomadics engineers and scientists had little opportunity to assess the performance of the system prior to deployment. However, as a result of this Phase I effort, Nomadics was able to borrow a Dragon Runner robot from the Marine Corps Warfighting Lab. This enabled Nomadics engineers and scientists to gain practical experience using the integrated system, and has led to improvements in the system that were demonstrated during testing at YPG earlier this month.

Figure 3. Fido XT deployed on the USMC Dragon Runner.

Objective 1: Further Characterize the Explosive Chemical Signature of IEDs

Because IEDs contain explosives, and because explosives generate a complex bouquet of chemical vapors that can escape from the IED, chemical vapor detection can be exploited as a means of detecting IEDs. Very little has been published regarding the explosive chemical signature of IEDs. Either this subject has not been studied extensively, or if this information exists it is likely classified for obvious reasons.

Information relating to the chemical composition of IED chemical signatures and concentrations of key chemical constituents is vital for sensor developers. For example, explosives are not pure chemicals, but usually contain many chemical constituents. Other than the explosive, these constituents (synthesis by-products, unreacted synthetic starting materials, or degradation by-products) are usually contained in the bulk explosive at low concentrations. However, some of these minor constituents are much more volatile than the parent explosive, and could be good targets for detection because they may be present in the chemical vapor signature of IEDs at higher concentration than vapors of the actual explosive. For example, military-grade TNT always contains some dinitrotoluenes (DNT), which have vapor pressures more than an order of magnitude greater than TNT. In addition, DNT is not a common substance, so it is not likely to be detected routinely in the chemical background when explosives are not present. Hence, DNT is a possible target analyte that could be exploited as a means of detecting IEDs containing TNT or Composition B (the two explosives most commonly encountered in IEDs). Composition B is a mixture of TNT and RDX, so DNT is commonly found in the chemical vapor signature of Composition B.

In addition to the composition of the chemical signature and concentrations of key compounds, environmental influences play a large role in trace chemical detection. For example, the vapor pressure of explosive increases with temperature. Hence, as the temperature of an IED rises, it is likely that the concentration of explosive vapor present for sensing will rise as well. How the explosive is concealed in an IED is also an important factor because this can influence the rate at which explosive vapor is generated by the IED. How the chemical vapor emanating from an IED is dispersed into the air around the IED is also important. Once target vapors are released from the IED into the air, they can be transported away from the target by wind currents, providing the possibility for standoff detection. Other factors also play a role in generation of the chemical signature of IEDs. This is obviously a very complex system, and because little is known about it, further study is warranted. An understanding of these parameters will greatly enhance the probability of successful development and deployment of chemical sensors for detection of IEDs.

During this contract, Nomadics had the opportunity to investigate certain aspects of the chemical signature of IEDs. While very limited in scope, our findings will now be presented. Nomadics collected data at Ft. AP Hill, and at two sites at YPG (the Countermine Test Facility at Kofa Range and the Joint Experimental Research Complex (aka 'Little Baghdad') at the North Cibola Range. At all three sites, the exterior surfaces of munitions were sampled for possible contamination by explosives. These munitions were of the types that are commonly used to construct IEDs (artillery shells, landmines, and mortars). Contamination of these munitions could have occurred during storage of the munitions in magazines, and some likely occurred during handling of the munitions by EOD personnel whose hands were contaminated with explosives. This is believed to be typical of the type of handling that IEDs would experience in-theatre.

Samples were collected from the surfaces of munitions by two methods. The first method was to dissolve surface contamination from the surface of munitions using filter paper soaked in a solvent (acetone). The explosive traces dissolve in the acetone-soaked paper, and when the solvent evaporates, the explosive residue remains on the paper. The samples, once collected, were transferred to clean, glass vials and were transported to the Nomadics laboratory for analysis using gas chromatography with either electron-capture detection or mass spectrometry. The second sampling method involves 'swiping' the surface of munitions with a strip of Teflon. Explosive traces are transferred from the surface of the munition to the Teflon strip during swiping. These strips are then analyzed in the field by presenting them to a Fido sensor. Explosive traces on the strips produce significant responses when analyzed by Fido. In addition to analyzing surfaces of muntions for contamination, personnel were also sampled using the Teflon strip method.

Figure 4 is an acetone-filter paper swipe of a 155 mm Howitzer shell filled with Comp B. The sample was analyzed using an HP 5890 gas chromatograph equipped with an electron capture detector. Peaks in the chromatogram due to TNT and RDX are clearly visible. These samples were collected at YPG during work on a related project. Numerous samples were collected from 155 rounds filled with TNT or Comp B. Analysis of all samples is not yet complete, but almost all samples analyzed have contained large quantities of explosives. In fact, the sample from which the chromatogram in Figure 4 was obtained contained less explosive than all other samples analyzed to date. Quantitative determination of the level of surface contamination is being completed, but is not available at the time of this report. Direct vapor sampling of these munitions with Fido also produced significant responses, suggesting that this level of contamination generates sufficient vapor to enable detection of these rounds. These rounds were lying on the ground with the shipping plug intact. They were not concealed in any way.

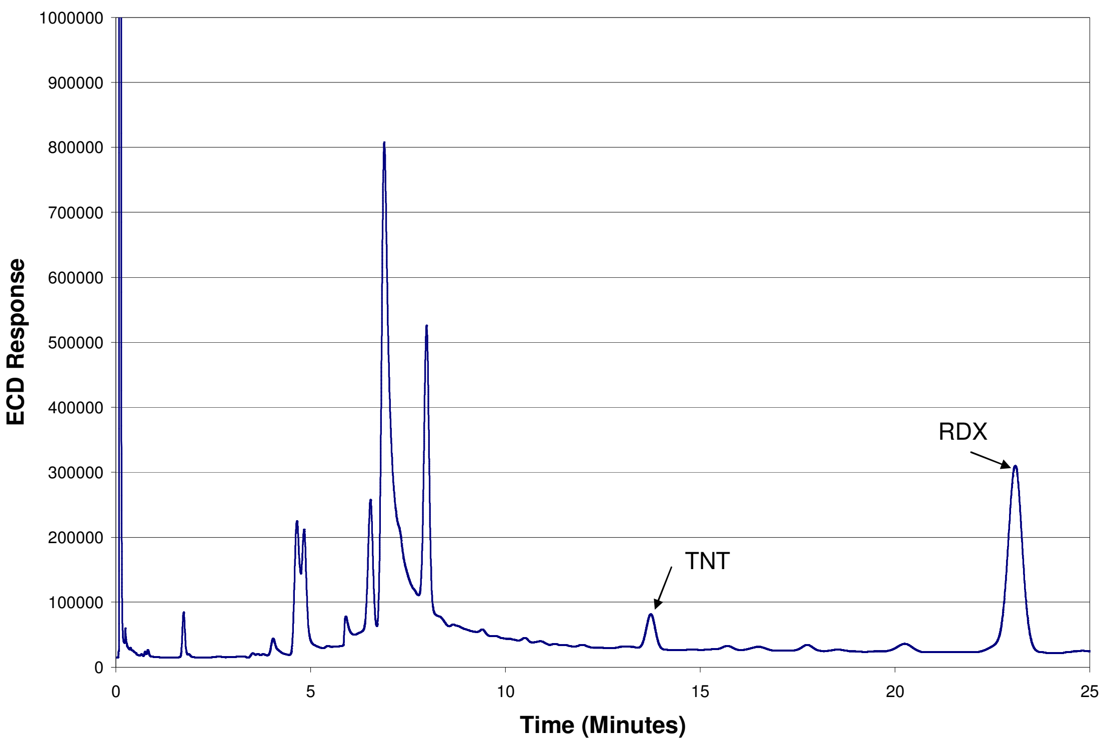

Figure 4. GC-ECD response to solvent extract of swipe taken from outer surface of a Comp B filled 155 mm Howitzer round.

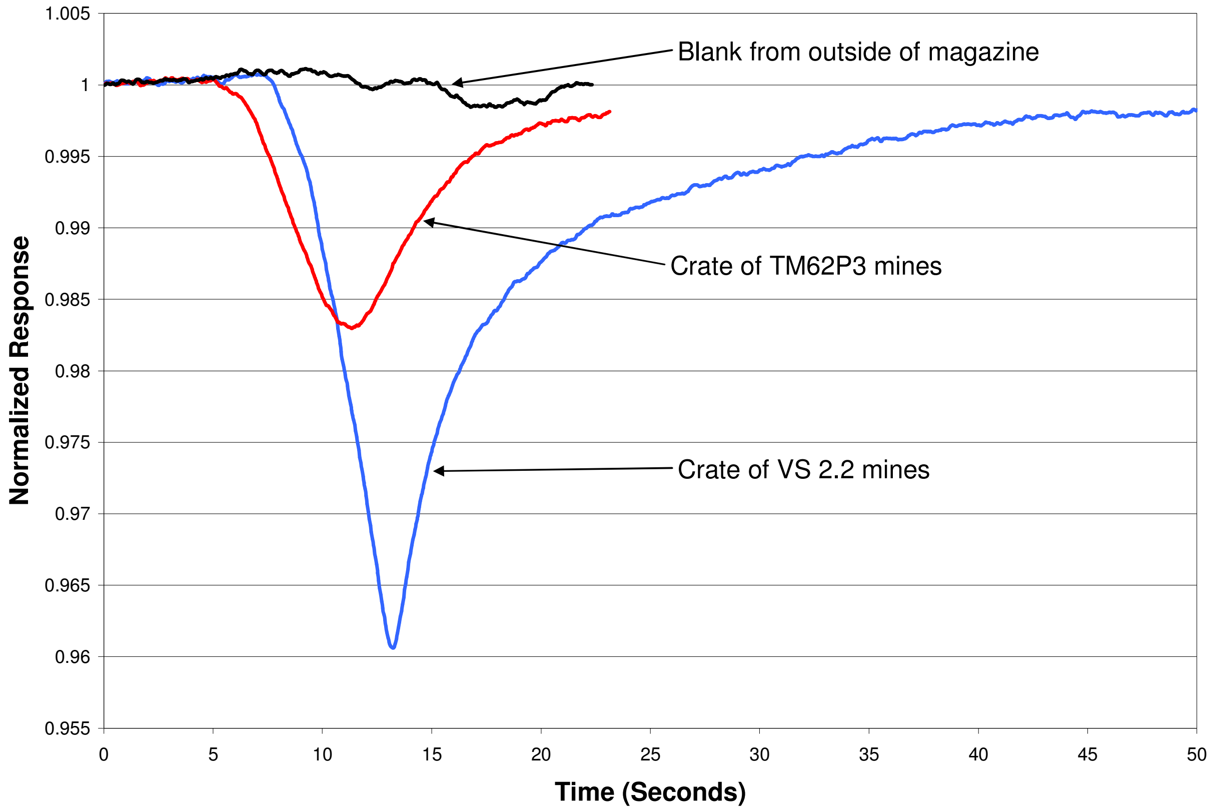

Figure 5. Evidence for surface contamination of targets, sampled with Teflon swipes that were then analyzed with Fido in-the-field.

Figure 5 illustrates results from representative Teflon swipe samples taken from Ft. AP Hill. Access was granted to explosives magazines at the site, and swipe samples were collected from items inside the magazines. The figure shows responses characteristic of nitroaromatic explosives contamination on wooden crates holding Italian VS 2.2 and Russian TM62P3 landmines. These crates had been stored in the magazine for several months, and had not been handled recently. For comparison, a response to a 'blank' sample taken from outside the magazine (from the hood of a vehicle) shows no response. Contamination was widespread within the magazine, which contained mostly landmines and artillery shells. This finding is not entirely surprising, but points out that objects within a magazine (arms cache) are likely to be heavily contaminated on their outer surfaces with explosives. An explosive device that is stored for a time in an arms cache and then removed for deployment will likely be heavily contaminated with explosives, which provides an avenue for generation of a vapor signature. How long this signature will persist once the munition is removed from the cache has not been investigated, but will likely persist long enough to provide a source of explosives for detection. Data to support this hypothesis will be presented later in the report. Further, if the IED structural material is permeable to explosives vapors (as is the case with most plastics), the surface contamination could be replenished for decades by diffusion of explosive through the structural materials to the outside. If the structural material is not permeable (as with metals), there are almost always cracks, seams, and seals that can allow escape of explosive vapor from the interior of the item.

The fact that surface contamination can generate sufficient vapor signature for detection is supported by the data presented in Figure 6. This data was collected from vehicles before and after exposure to explosives.

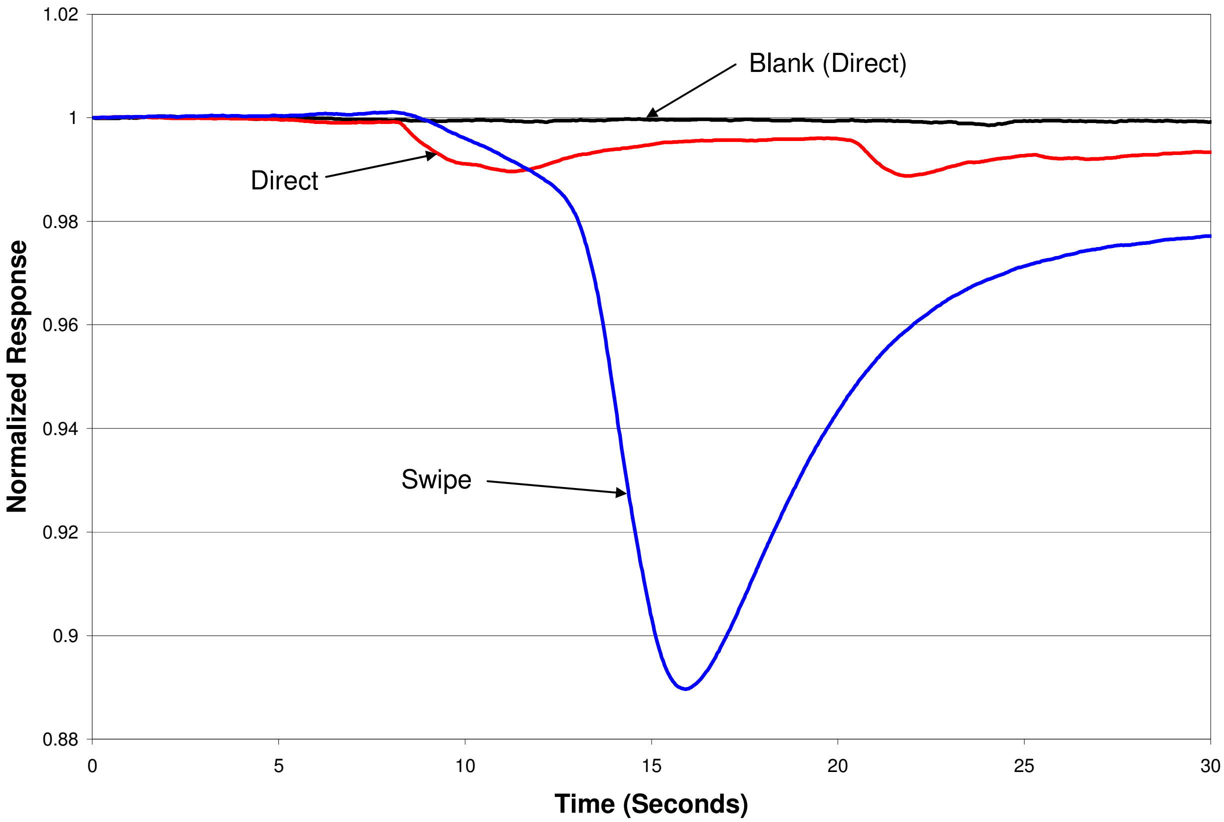

Figure 6. Detection of trace TNT contamination on a door lock.

The vehicle (a small trailer) was sampled via direct vapor sampling prior to being loaded with 50 pounds of TNT. Once blanks were collected, the trailer was loaded with the explosive. Personnel who had not handled explosives opened the door of the trailer, and an EOD tech placed the explosive inside the trailer without touching anything other than the crate holding the explosive. The door was then closed by the 'clean' assistant so that there was no accidental transfer of contamination to the outside of the trailer. Finally, the EOD tech with contaminated hands touched specific locations on the exterior of the trailer, contaminating these areas. One area touched was the lock on the trailer door. The blank trace in Figure 6 was collected from the lock prior to contamination. Direct vapor sampling of the lock after contamination, followed by a swipe of the lock are included in Figure 6. The simple act of closing a lock with contaminated hands transfers enough contamination to the surface to generate sufficient vapor to enable direct detection of the contamination. Note that in the 'direct' trace there are actually two responses. This is because after the sensor registered the first response, the sensor was moved away from the lock so that the sensor was sampling uncontaminated air. After the sensor recovered, the lock was again sampled, giving the second response to TNT. The response for the swipe sample was even larger than for the direct samples. Furthermore, there was no evidence of signature depletion after three days. It is not known how long the signature would have persisted due to the short duration of the test. It is expected that the signature would be depleted eventually as the explosive sublimes (evaporates) from the surface or degrades from environmental influences, and the rate at which this occurs will depend on a number of factors including the temperature and composition of the surface contaminated. The temperature during the test period reached a high of near 75 °F each day during the test. Earlier this year, similar tests were conducted at YPG when temperatures were near 110 °F. In this case, the signature appeared to deplete somewhat over the course of one to two days, but it could still be detected.

In summary, while much is unknown regarding IED chemical signatures, data that has been collected to date supports the hypothesis that detection of IEDs using chemical sensors is viable. Obviously, the explosive charge contained in the IED is a significant source of explosive vapor than can be exploited for detection. The data strongly suggests that items commonly used to construct IEDs are often contaminated with detectable levels of explosive, and this contamination can come through a variety of sources (during storage, assembly, transport, or deployment). Trace contamination of surfaces therefore provides a secondary means of detection. More work is warranted in this area.

Objective 2: Development of High Volume Sampler / Preconcentrator for Use on Robotic Platforms

Prior to this contract, Nomadics has developed promising high-volume vapor sampling for landmine and IED detection. These methods require large volumes of air to be drawn through disposable filters designed to trap vapors and particles of explosives. Once a sample is collected, the filter is analyzed using the Fido sensor. If traces of explosive are detected on the filter, the area or object sampled is regarded as suspect. Initial results using these methods have been promising. However, the filters are single-use, and as such are probably not the best solution for use in battlefield conditions. Recently, multiple-use preconcentrators have been developed as a means of eliminating the potential problems associated with the use of a consumable item. Prior to this work, several preconcentrator designs had been tested with encouraging results.

As reported in the progress report, the basic premise of the design is to draw a sample through a small tube coated on its inner surface with a material that has a high affinity for explosives and Explosives Related Compounds (ERCs). Hence, explosives are trapped on the inner walls of the tube, while compounds with lesser affinity for the coating pass directly through the preconcentrator without being trapped. The tube is then heated rapidly, and the sorbed explosive vapor is liberated from the coating. The liberated explosive vapor is then swept into the sensor for analysis.

Under the current project, the performance of the existing preconcentrator prototype was enhanced. The initial thought was to increase the throughput, which would allow an increase in flow rate, thereby increasing the sample volume and potentially trapping a larger mass of analyte. A prototype was designed and built based on the GC-5 design described in Progress Report 1. However, desorption (or presentation of the explosive vapor to the sensor), proved to be somewhat problematic for the GC-5 prototype. Although initial results were adequate and showed much improvement over direct detection, the Nomadics science and engineering team felt that the design could be improved.

For the new design, an optimal column length was chosen to provide the maximum analyte capture efficiency with the highest maintainable flow rate and the lowest overall power consumption. In a preliminary test at our facility, there appeared to be an optimal length for the collection column. If the column was shorter than the optimal length, it appeared that there was analyte bleed through; that is, the column did not appear to be able to retain all of the analyte that passed through it. If the column was too long, it was difficult to maintain an adequate flow rate because of increased backpressure. In addition, longer columns required more power to heat, increasing power consumption. Peak broadening was also observed on the longer columns, resulting in a decrease in response magnitude (refer to Figure 7).

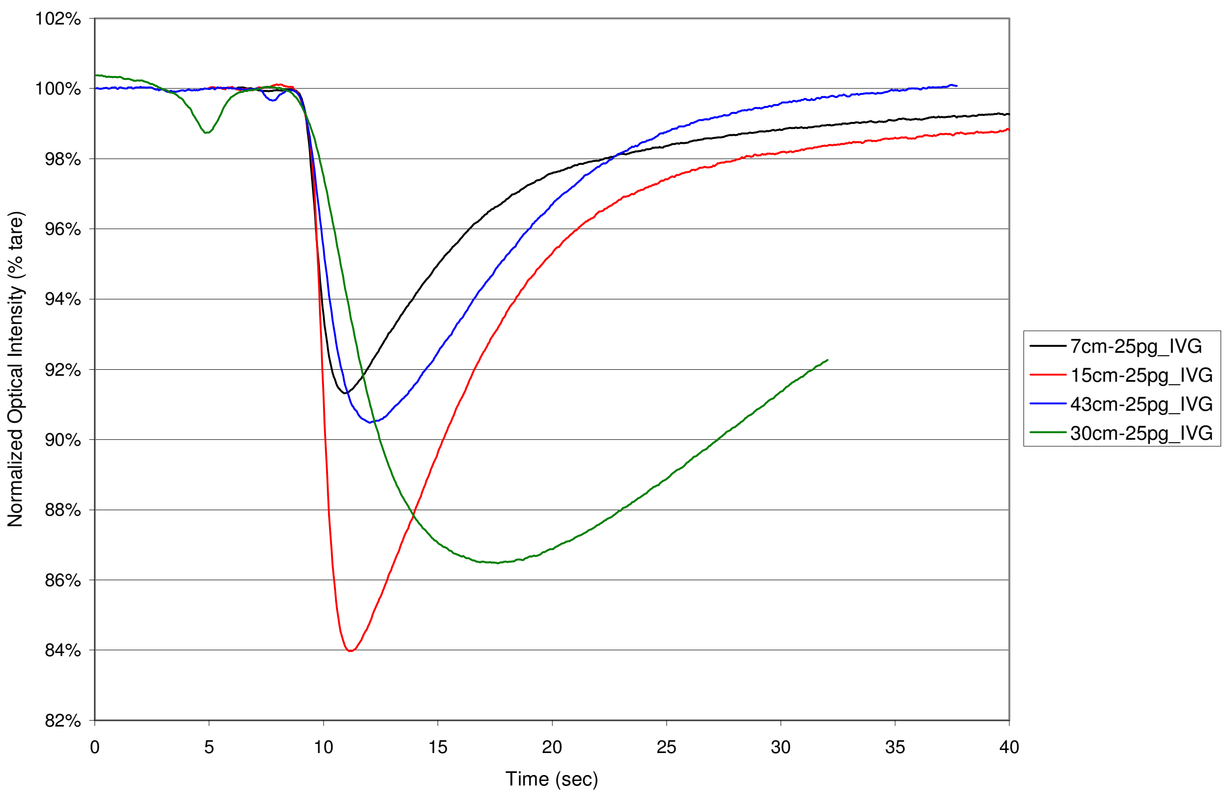

Figure 7: Effect of column length on preconcentration and sensitivity

Figure 7 compares the response of Fido using different preconcentrator lengths. 25 picograms of TNT was introduced into the preconcentrator using an INEEL vapor generator (IVG). The vapor generator delivers consistent, quantifiable masses of explosive vapor to the sensor, making it possible to compare the responses of different sensor hardware combinations. The response was determined to be optimal for a column that was 15 centimeters in length.

An additional test was performed using the optimized GC Precon head with a Fido 4TD sensor. A simulated IED vapor source was placed outdoors and was sampled using the GC Precon Fido 4TD, a standard Fido 4TD, and the new Fido X. All three sensors were tested and compared for standoff distance. The GC Precon was able to consistently detect the vapor source from approximately 24 inches away, while the Fido X sensor in direct sampling mode could detect at two inches standoff. The older Fido 4TD prototype in direct sampling mode could consistently detect the target at a distance of one inch. While standoff distances are not large with the GC Precon, they represent a significant improvement over direct sampling. These test results drove a decision to modify the GC Precon for modular use on the new Fido XT sensor and subsequent use on a robot.

The new precon prototype was developed to take advantage of the Fido XT's small form factor, light weight, and its robust, modular design. The column was initially to be wrapped around a spool to save space, but after preliminary testing it was determined that the stress placed on the column was too high to survive the heat cycle, and the column would eventually break. This problem was discovered three days before the December field test. This led to a complete redesign of the prototype. A new prototype using a linear column configuration was completed in under 48 hours, and was tested in the laboratory prior to deployment during the YPG field test.

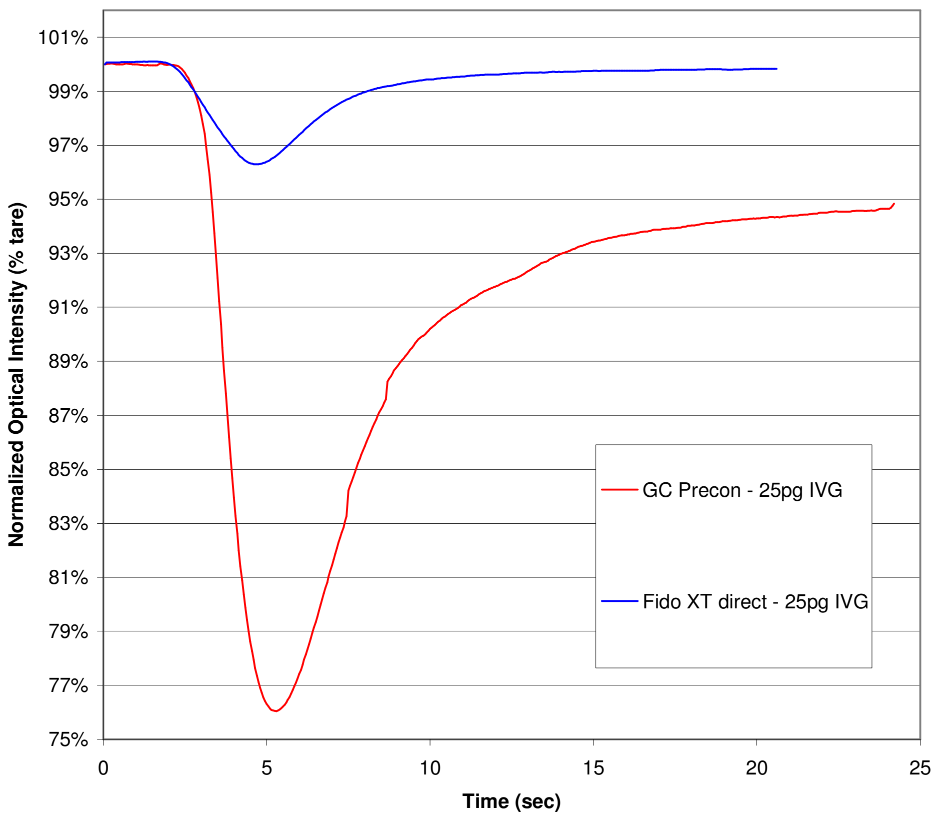

Figure 8: Comparison of the Fido XT GC Precon against the standard Fido XT

Figure 8 compares performance of the prototype preconcentrator relative to direct sample introduction into the sensor. The blue trace show the response to 25 picograms of TNT presented to a standard Fido XT sensor via the laboratory vapor generator. The red trace shows the response to 25 picograms of TNT presented to the Fido XT with the GC Precon installed. The sensor response with the preconcentrator installed is sharper and more intense than without the preconcentrator. In addition, the response is very reproducible. The GC Precon showed a six-fold improvement over the standard Fido XT. This enhancement is likely due to a combination of an improvement in sample volume processed (30 ml/min in direct sampling mode versus 150 ml/min in precon mode – a five-fold improvement), and a sharpening in the analyte pulse delivered to the sensor. Assuming the volumetric sampling rate can be increased without a significant loss in analyte capture efficiency, the preconcentration factor can likely be increased significantly.

Figure 9: Evolution of the Fido XT Preconcentrator (Left to Right: Standard Fido XT, Fido XT CG5, Coiled GC Precon, Linear GC Precon)

Figure 9 illustrates the evolution of the Fido XT Precon. At left is the standard Fido XT head as equipped for direct sample introduction. Next to the Fido XT is the Fido XT CG5, described in Progress Report 1. The coiled GC precon prototype is then shown, and finally the linear GC precon design tested at YPG. It is likely that the coiled design can be revisited. It functioned well with the exception of frequent column breakage. By increasing the radius of the coil slightly, it is likely that column breakage can be eliminated while reducing the overall dimensions of the linear precon / Fido XT unit. The cycle time for the precon / Fido XT system is currently under 30 seconds, which includes a ten second sample collection period, a seven second desorption / analysis period, and a ten second cool-down period. The cycle time can be shortened significantly with further development.

The lab and field test results for the linear precon / Fido XT unit demonstrate the advantages of increasing volumetric sample throughput for IED detection. It was shown that it is possible to enhance the response of the sensor while increasing standoff distance from the target during sampling. In addition, the unit was incorporated onto the Dragon Runner robot and tested during the YPG field tests with excellent results.

Objective 3: Modification and Adaptation of the Fido Sensor for Operation on a Small Robot

The Nomadics engineering team has successfully mated a Fido XT sensor with Carnegie Mellon's Dragon Runner robot vehicle. After procuring use of a Dragon Runner for testing, several new interfaces were designed. As stated in our proposal, the Fido XT had previously been placed on the USMC Dragon Runner robot (Figure 3). Since this initial integration, the capabilities of the system have been expanded to include audio and visual sensor output to the user through the Dragon Runner's integrated remote display. An interface was constructed that converts output from Fido into output compatible with the Dragon Runner communication protocols. This interface allows easy connection of the sensor to the robot and translates sensor data into the proper format for the Dragon Runner. The firmware in the original adapter was updated to interface automatically to the new Fido XT design. The Fido XT firmware was updated to allow for the detection of the new adapter, and was given an out signal formatted in Dragon Runner-format messaging. This same interface could be used to easily integrate additional sensors with the robot, provided that the data stream generated by the sensor is not of extremely high density. Laboratory tests were performed to ensure that all system components were communicating and operating as designed. Finally, the Dragon Runner/Fido system was successfully tested at YPG during the December 2004 tests.

Objective 4: Integrate the Fido with High Volume Sampling Capability Onto a Small Robot

This objective was easily met because the GC precon unit was a direct replacement for the Fido XT head assembly. Because the Fido XT direct sampling system had already been integrated onto the Dragon Runner, the precon/Fido XT integration was seamless. All that is required to switch between Fido XT configured for direct sampling mode and precon mode is to disconnect the direct sampling head assembly from the tether and replace it with the precon head assembly. The tether is equipped with quick disconnects on each end, making head changes extremely simple. No tools are required and it takes less than a minute to make the conversion. The precon head adds 1.2 pounds of weight to the package, bringing the total weight of the precon/ Fido XT to 3.8 pounds including batteries. Figure 10 illustrates the precon / Fido XT unit installed on the Dragon Runner during testing at YPG.

Figure 10: Fido XT GC Precon on the Dragon Runner at YPG Countermine Test Facility

Objective 5: Test the Integrated Prototype in the Laboratory and Field

A Field Test of the integrated GCPrecon / Fido XT/Dragon Runner was performed at YPG under the supervision of Jesús Estrada, Countermine Test Facility (CMTF) Manager. The system was tested against roadside IEDs and vehicle-borne IEDs (VBIEDs). The IED targets were constructed from several types of munitions including 155mm TNT-filled artillery shells, 155mm Comp B-filled artillery shells, C4 demolition blocks, TNT Demolition blocks, and M19 anti-tank mines.

Roadside IEDs were constructed by placing a single munition under a pile of rocks for concealment. Blank rock piles were also added to provide background samples. Two rock piles concealed 155 mm artillery shells filled with TNT, two rock piles concealed 155 mm artillery shells filled with Comp B, and two rock piles concealed M19 landmines. Six rock piles were provided for blanks. The artillery shells were configured with the shipping plug removed and C4 packed into the detonator well to simulate an improvised detonator.

Vehicles, free of explosives contamination prior to the tests, were loaded with munitions as described in Table 1 and illustrated in Figure 11. When the vehicles were loaded, an assistant whose hands were not contaminated with TNT opened either the door or trunk lid to allow an EOD tech to place the IED in the vehicle. The EOD tech, whose hands were contaminated with explosives, did not touch the vehicle while placing the IED. After the IED was in place, the EOD tech was instructed to touch the vehicle in specific locations (trunk lid, door handles, steering wheel, gear shift, etc.). In this way there were areas of the vehicle that were contaminated and areas that were not contaminated by transfer of explosive from the EOD technician. Care was taken to prevent spread of contamination to clean areas of the vehicle. Prior to placing explosives in the vehicles, the vehicles were screened for background contamination using Fido in direct-sniff mode and the Precon / Fido XT. No background contamination was detected.

Vehicle Make and Model	Type of IED
Chrysler 300	3- M14 Comp B AT mines
Pontiac Bonneville	3-TNT 155mm howitzer shells
Ford Taurus	3-Comp B 155mm howitzer shells
U-Haul 5' X 8' Trailer	50 -1lb Demolition Blocks
Chevrolet Impala	20 1 lb C-4 Demolition Blocks

Table 1: Summary of VBIED targets and explosives

TNT demolition blocks

AT mines

C-4

155 howitzer shells

Figure 11: Photos of VBIED targets

Prior to testing the precon / Fido XT on the Dragon Runner, vehicles were screened using the precon / Fido XT system. Samples were collected with the preconcentrator at selected locations on the vehicle by waving the preconcentrator over the surface of the vehicle at a given position for ten seconds. The sample was then analyzed. Figure 12 illustrates a representative sampling of the results. As can be seen from the data, responses were noted to areas contaminated with explosives, while areas not contaminated with explosives generally gave little to no response, as would be expected. In general, a response in excess of 0.25% quench would be regarded as positive. The system was able to differentiate clean from contaminated areas on the vehicles with a high degree of probability.

Next, the precon / Fido XT was mounted on the Dragon Runner and roadside IEDs were investigated. Only three of the rock piles were interrogated because it proved to be difficult to position the Dragon Runner near the targets. The mounting arm on the robot was not automated, so the sensor was mounted in a fixed position on the arm. Because the sensor could not be articulated with the arm, the robot had to approach a target carefully to position the sensor inlet

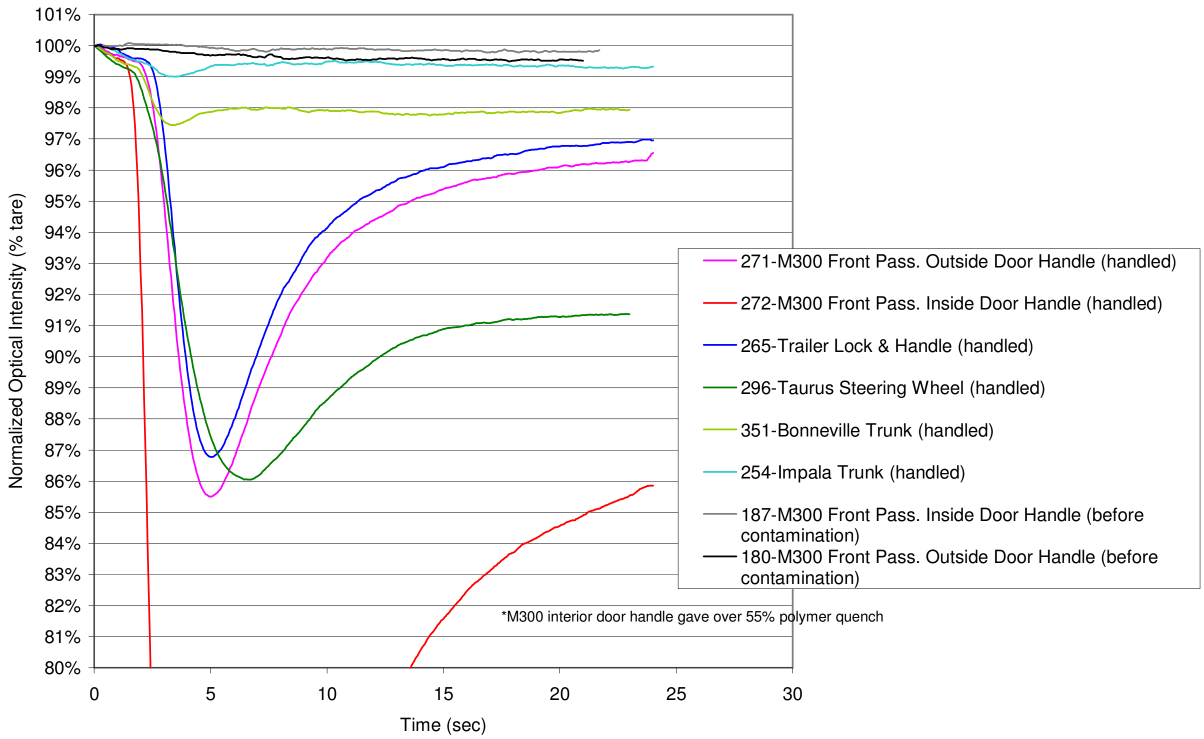

Figure 12: Selected GC Precon data for vehicle sampling

close to the desired location right to left. The distance of the sensor above the ground could not be adjusted during operation. It was difficult to approach a target carefully, as the Dragon Runner was difficult to move forward in small increments of distance. Hence, extreme care had to be taken to avoid running into a target. Otherwise, the Dragon Runner performed well. In spite of taking extreme care to not run into the IEDs, the sensor was rammed into the rock piles with considerable force on several approaches to the piles. The sensor received heavy cosmetic damage, but continued to function without a noticeable degradation in performance. Figure 13 illustrates the results for the three targets sampled. All targets were not interrogated because of the difficulties encountered in controlling the robot. The blank rock pile (#12) was sampled a total of three times, while rock piles #9 (an M19 mine) and #10 (a Comp B 155) were sampled twice. The blank rock pile gave no appreciable response, while the M19 and 155 mm IEDs were easily detected. The responses were quite reproducible. The same targets were sampled several times by direct vapor sampling with a Fido XT and the IEDs were difficult to detect, giving responses only slightly elevated over the blank rock pile response. Hence, the preconcentrator improved detection of these targets significantly. While all targets were not sampled, detection using high-volume sampling methods with a sensor mounted on a robot was demonstrated.

Detection of vehicle-borne IEDs with the precon / Fido XT on the Dragon Runner was not attempted because of concerns regarding damage to the vehicles. In addition, the arm on the robot would not reach high enough or far enough to sample contaminated locations on the vehicle.

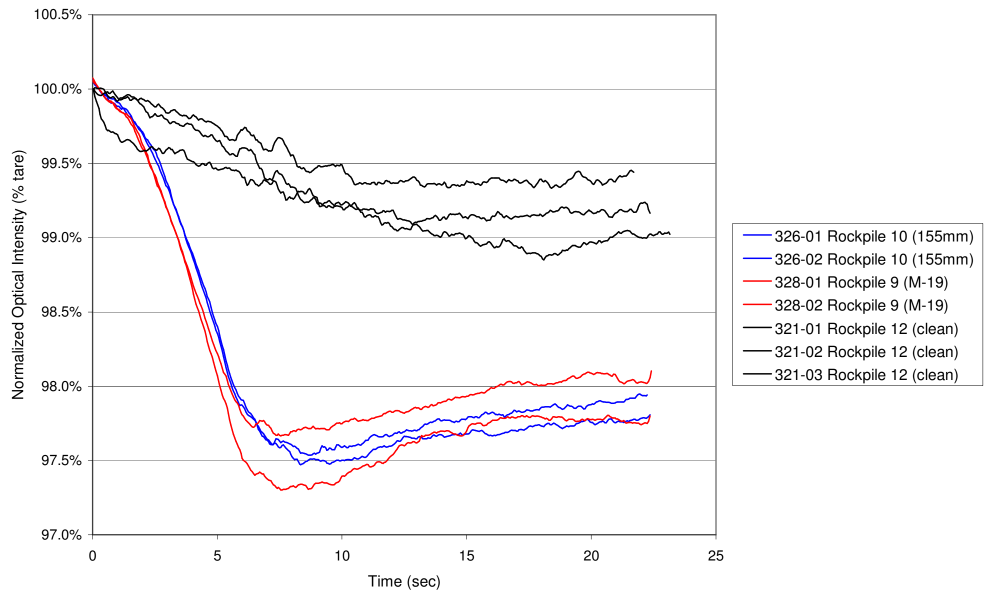

Figure 13: Roadside IED interrogation by robot-mounted Fido XT GC Precon

Captain Kyle Patton, Program Manager for Dragon Runner development at the Marine Corps Warfighting Lab, was present to witness the operation of the robot and sensor, and to receive training in operation of the combined system. Captain Patton is scheduled for deployment in Iraq to train operators of the Dragon Runner system. He was trained in use of the combined Dragon Runner / Fido system on Wednesday morning of the tests. On Wednesday afternoon, Captain Patton participated in a blind test to determine if he could detect two IEDs hidden in bushes along a roadway at the test site. The IEDs consisted of five one-pound demolition blocks of TNT hidden under two different sets of bushes along the roadway. Captain Patton maneuvered the system down the roadway, interrogating suspicious items along the path. The robot is also equipped with a video camera that transmits images back to the operator in near-real time so that the operator can have visual feedback as to the location of the system and what the sensor is interrogating. Approximately 20 bushes were along the path. Both bushes concealing IEDs were detected. Figure 13 shows the response of the system to a blank section of roadway (the blue trace), and the response obtained near the bush concealing the IED. The response to the IED was large and easily detected. This exercise further supports the utility of the Fido / Dragon Runner combination as a tool for detecting IEDs.

The only other alarm that was encountered by Captain Patton was near a bush that did not conceal an IED. Upon further inspection, a sheet of paper that had presumably been part of the packing in a box of landmines was found under the bush. The sensor responded strongly to the paper. The paper is being analyzed in the Nomadics laboratory for traces of explosives.

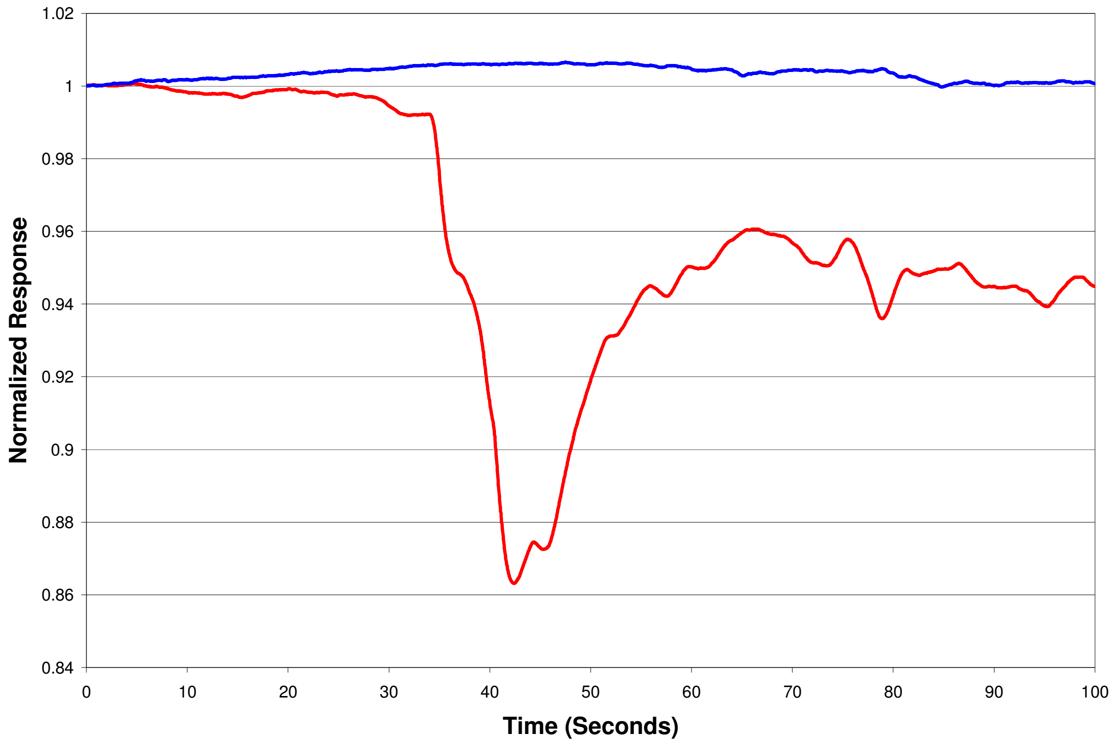

Figure 14. Detection of a roadside IED concealed under a bush, and the response to a blank section of roadway.

Conclusions

All project objectives were achieved. Although the chemical signature of IEDs is a complex issue that is not completely understood, data was collected that supports the assertion that sensitive chemical sensors can be used to detect IEDs. It was shown that high volume sampling methods can improve system performance in terms of sensitivity and increases in standoff distance. This conclusion was supported by laboratory tests and results from testing in the field. The high-volume sampling capability was integrated with the Fido sensor, which was in turn integrated to the Dragon Runner robot. The utility of the combined system was then demonstrated under field conditions against realistic, simulated IED targets. A newly-trained system operator was able to demonstrate detection of roadside IEDs in a blind test. Hence, the concept of detection of IEDs using a chemical vapor sensor on a robotic platform was clearly demonstrated.

Proposed Future Work

Several resolvable issues arose concerning the deployability of the system. First, the Dragon Runner / Fido combo would greatly benefit from addition of an articulated arm to help position the sensor near targets. Second, the Dragon Runner is difficult to position near a target, so the addition of finer control of the robot would be an advantage. There was also a two to three second time lag in transmission of video and audio signals to the operator, making it difficult to know the exact position of the robot in real-time. The range of remote operations needs to be extended, because the current range of remote operation places the operator within the kill-zone of a 155mm IED.

Issues related to the sensor include the need for an optional sensor algorithm that alerts the operator with a simple go-no go alarm, reducing the demands on the sensor operator to make detection decisions. This would not supersede the audio and graphical cues now available to the sensor operator. The sensor package should be made more robust, particularly the sensor head which will receive significant abuse while mounted on the sensor. A proper sensor mounting bracket should also be developed to facilitate secure attachment of the sensor to the robot while allowing rapid detachment. The preconcentrator could also benefit from increases in volumetric sampling capacity which should translate into enhanced sensitivity and standoff distance.

It is likely that the system at its current state of development has utility for IED detection. Feedback from operators already using systems in-theatre would drive and greatly accelerate further system development. The proposed system improvements could be implemented incrementally, resulting in significant improvements in system performance in the near-term, and sustainability and expanded capabilities over time. Many of the proposed improvements in the system can be achieved with only a few months of additional development, quickly expanding system capability for the warfighter.