SANDIA REPORT

SAND2005-5916
Unlimited Release
Printed September 2005

RoboHound^{TM}: Developing Sample Collection and Preconcentration Hardware for a Remote Trace Explosives Detection System

John A. Hunter, Mark J. Baumann, Dennis L. Carlson, Michael C. Lenz, David W. Hannum, Mary-Anne Mitchell, T. Scott Gladwell, Clinton G. Hobart, Robert J. Anderson, David J. Denning, David J. Peterson

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865)576-8401
Facsimile: (865)576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800)553-6847
Facsimile: (703)605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2005-5916
Unlimited Release
Printed November 2005

RoboHound^{TM}: Developing Sample Collection and Preconcentration Hardware for a Remote Trace Explosives Detection System

John A. Hunter, PMP, Mark J. Baumann, Dennis L. Carlson, Michael C. Lenz,
David W. Hannum, Mary-Anne Mitchell
David J. Peterson, New Mexico Tech, Student Intern
Entry Control & Contraband Detection
T. Scott Gladwell, Clinton G. Hobart, Robert J. Anderson
David J. Denning
Mobile Robotics Department

Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-0782

Abstract

The RoboHound^{TM} Project was a three-year, multiphase project at Sandia National Laboratories to build and refine a working prototype trace explosive detection system as a tool for a commercial robot. The RoboHound system was envisioned to be a tool for emergency responders to test suspicious items (i.e., packages or vehicles) for explosives while maintaining a safe distance. The project investigated combining Sandia's expertise in trace explosives detection with a wheeled robotic platform that could be programmed to interrogate suspicious items remotely for the presence of explosives. All of the RoboHound field tests were successful, especially with regards to the ability to collect and detect trace samples of RDX. The project has gone from remote sampling with human intervention to a fully automatic system that requires no human intervention until the robot returns from a sortie. A proposal is being made for additional work leading towards commercialization.

Acknowledgments

Basil J. Steele	6430, the Program Manager
Marcella Marie Madsen	6430, for providing the initial funding
David A. Zusi	6430, for providing the continuation funding
Dominic Ruiz	6421, for photographic and video support
Bart Chavez	14132, for the stereo lithography model fabrications
Charles A. Brusseau	6418, for the inlet nozzle and preconcentrator designs
W. Sue Williams	10265, for helping us acquire the van doors from the government van that was being parted out, and for keeping us all well fed.
Gary W. Shannon	6418, for wiring the first RoboHound™ prototypes
Lester H. Arakaki	6418, for providing the circuitry for the preconcentration heating

Note: RoboHound™ is a trademark of Sandia National Laboratories.

Contents

Figures

Nomenclature

μg	microgram(s), 1×10^{-6} g
μL	microliter(s), 1×10^{-6} L
C-4	military plastic explosive, 90% RDX, 10% plasticizer
CCD	charge coupled device, a video camera system
DC	direct current
DoD	Department of Defense
DOE	Department of Energy
EOD	Explosive Ordinance Disposal
FPM	feet per minute
GE	General Electric
g	gram(s)
HE	high explosive
HMX	cyclotetramethylenetetranitramine, an explosive
IED	Improvised Explosive Device
IMS	Ion Mobility Spectrometer
IR	Infrared
JAUS	Joint Architecture for Unmanned Systems
kg	kilogram(s), $1 \times 10^{3\ g}$
LB	pound
LED	light emitting diode
LLOD	lower limit of detection
LOD	limit of detection
mg	milligram(s), 1×10^{-3} g
ng	nanogram(s), 1×10^{-9} g
NG	nitroglycerin, an explosive
PETN	Pentaerythritol tetranitrate, one of the strongest known high explosives
pg	picogram(s), 1×10^{-12} g
RDX	Cyclotrimethylenetrinitramine, or hexogen, a military high explosive
RVR	Robotic Vehicle Range
SNL	Sandia National Laboratories
TNT	2,4,6-trinitrotoluene, an explosive
UMS	Unmanned Systems

1. Introduction

1.1 Overview

The RoboHound Project was a three-year, multiphase project that began in October 2002 and was completed in September 2005. It was initially a weapon security research and development effort. The project investigated combining Sandia's expertise in trace explosives detection with a wheeled robotic platform that could be programmed to interrogate suspicious items remotely for the presence of explosives. The RoboHound system was envisioned to be a tool for emergency responders to test suspicious items (i.e., packages or vehicles) for explosives while maintaining a safe distance. Two Sandia departments (the Entry Control and Contraband Detection Department and the Mobile Robotics Department) worked on the task. The RoboHound system was designed at Sandia National Laboratories (SNL) concurrently in Building 821 and in MO250 at the Robotic Vehicle Range (RVR). Annual field testing was performed at the RVR, where realistic outdoor testing environments exist.

Proven sampling and preconcentration hardware from the Hound Project [ref. 1] was used for the first proof of concept. From this foundation, each of the three years of development resulted in a unique version of the RoboHound system. Incremental improvements were implemented from the results of the previous year's field tests. Improvements were made using stereo-lithography for working components and noncontact sensors to maintain the distance of the air inlet nozzle from the suspicious package. Improvements were also made to the robot controls and interface to automatically create a search path based on the geometry of the package being interrogated.

1.2 Objective

The objective of the RoboHound Project was to develop a remote explosives detection system that could be used both at a critical facility's entry controlled points and in emergency response situations. Before the development of RoboHound, trace explosives detection equipment required an operator to stand within a few inches of a potential explosive device when obtaining a sample for chemical analysis. This project developed a prototype remote-controlled trace explosives detection system using a wheeled robot platform, a Sandia-developed sample collector and preconcentrator, and a commercial detector. An integrated software package was developed to allow an operator to easily maneuver the robotic platform into position while the operator remained in a "command" trailer up to one hundred feet away from a suspect vehicle, package, or other object. The robotic platform approached and imaged the object to create a three-dimensional scanning path. The air surrounding the object was sampled, and then a commercial detector performed an on-board analysis for explosives. The long-term goal was to develop a semi-automated system that performed searches and screening tasks with minimal operator involvement.

1.3 Statement of Work

The proposal was for a three-year, three-phase project. The primary goals of Phase I were to (1) determine system requirements and (2) develop a working proof-of-concept model that incorporated an existing Sandia-developed trace explosives detection system and a robotic platform (with programmed search pattern capabilities) for technical evaluation.

The goals of Phase II were to develop novel trace explosives sampling and detection concepts based on lessons learned from the proof-of-concept model and to produce a laboratory prototype for evaluation. The emphasis of the remote sampling technology development was the creation of a device that is capable of sampling several potential improvised explosive device (IED) container shapes. The detection system would have near-time remote explosives detection capability.

The goals of Phase III were to refine the prototype and perform a system evaluation in a semi-realistic environment.

2. Robotic Platform

The Turing robot (Figure 1) was chosen for this project because of its interchangeable tool set and its ability to approach suspicious packages using a tethered Ethernet cable. The Ethernet cable was chosen over radio-frequency communications to prevent the accidental triggering of a radio-frequency-activated detonator attached to the explosives being interrogated. The Turing robot was on loan from the British military to perform basic research. The Mobile Robotics Department staff at SNL added a stereoscopic charge-coupled device (CCD) vision system to the robot to enhance the ability to image and scan three-dimensional geometry.

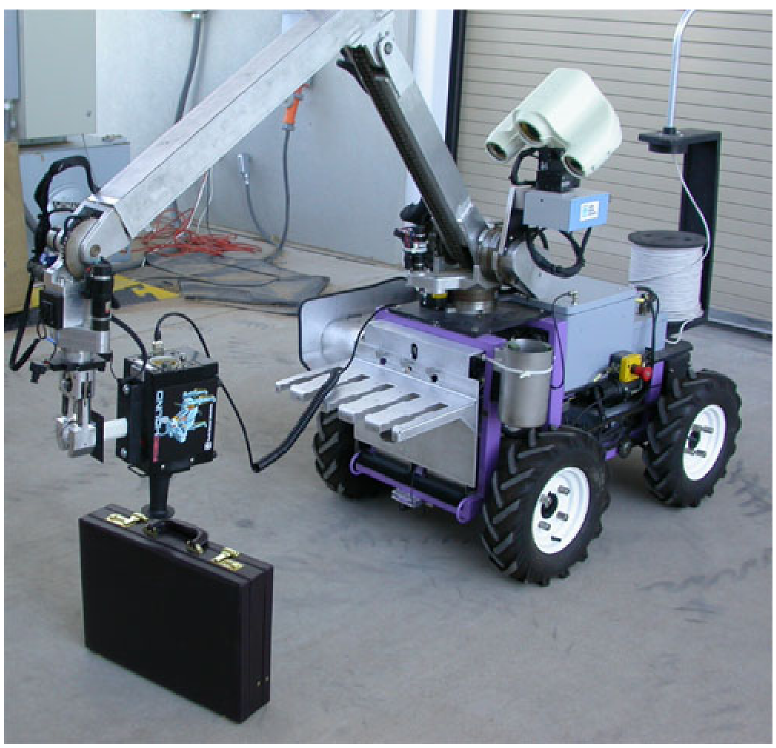

Figure 1. Turing Robot Platform at SNL's Robotic Vehicle Range and Version 1 of the RoboHound Interrogating a Briefcase for Explosives [ref. 2]

3. Preconcentration

Trace explosive residue is collected and concentrated on a steel mesh preconcentrator screen as shown in Figure 2.[1] The sample is then desorbed from the screen by a short, high-temperature heating cycle (around 200 °C in less than 2 seconds) and introduced into the commercial detection system. The use of a rapid desorption cycle to introduce the concentrated sample to the detector improves the ability to detect trace levels of explosive residue. For vapor sampling, the improvement is a result of the greatly increased volume of collected air sample and subsequent concentration of that sample into a much smaller volume than can be rapidly delivered to the detection system.

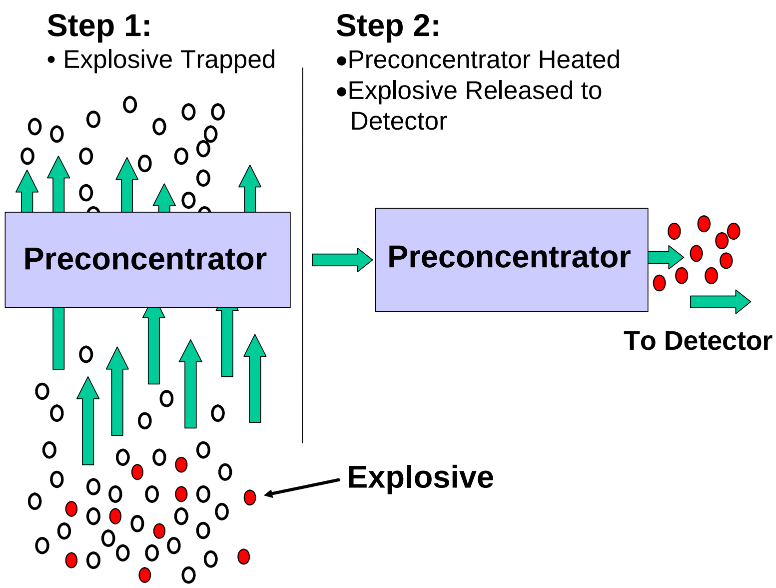

Figure 2. How Sandia's Preconcentrator Works

4. The Hound System

The Hound system (Figure 3) is a hand-held system that inspired RoboHound. The Hound front end is a portable sample collection and preconcentration system designed by SNL to enhance the detection abilities of commercial trace explosive detectors. For this project, the team used the General Electric (GE) VaporTracer2. The Hound can perform both vapor (contactless) and swipe (contact) sampling. Vapor sampling is performed by placing the vapor screen module in the slot of the vapor collection unit and pressing the switch to start the blower. The operator controls the length of time for vapor sampling, which typically lasts from 5 to 30 seconds. (Less than 5 seconds would not provide enough sample; longer than 30 seconds could "wash out" the explosives from the preconcentrator.)

[1] The SNL-patented preconcentrator technology is a miniaturized version of the technology developed for use in the explosive detection personnel portal for the Federal Aviation Administration (FAA), now the Transportation Security Administration, and licensed to Barringer (now owned by Smiths Detection) for commercialization.

The recovery time for the VaporTracer2 depends on the amount of explosive present. For example, for 10 ng of TNT desorbed from the vapor screen module, cleanup time is approximately 20 seconds. For significantly greater amounts of explosives, the cleanup time can reach tens of minutes and may require manual system cleaning.

An optional external laptop computer can be connected to the RS232C port on the VaporTracer2 to capture, display, and save the test results. The laptop allows easier access to VaporTracer2 information such as test spectra, detection algorithms, and settings.

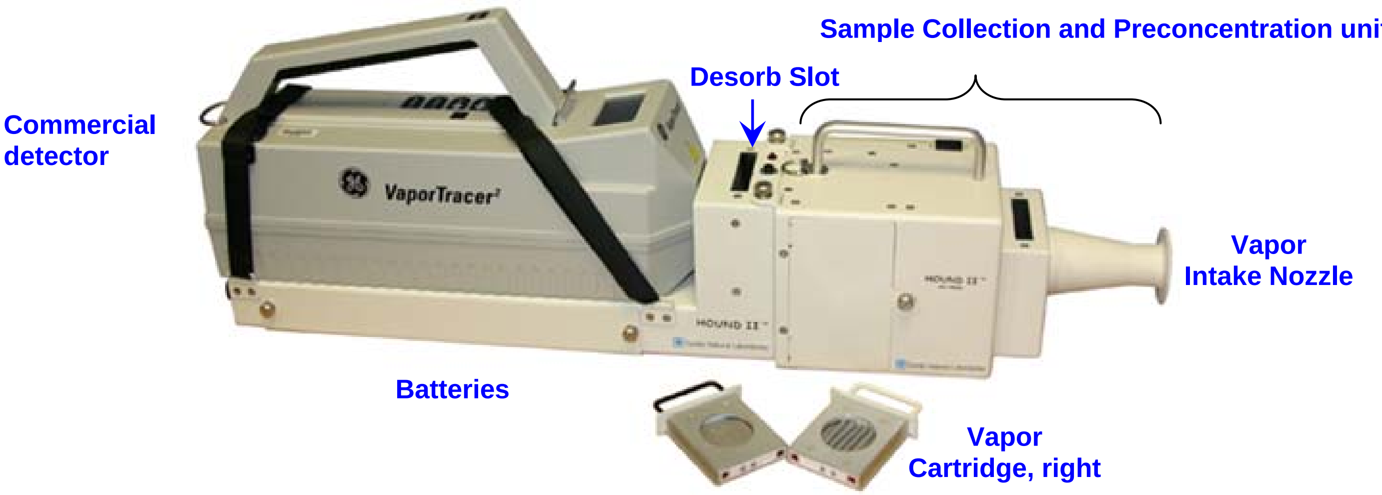

Figure 3. Hound Sample Collection and Preconcentrator with GE VaporTracer2 Commercial Detector

For the initial proof of concept, the Hound sample collector and preconcentrator were held by a robotic arm and used to sweep the air surrounding a suspicious package. The vapor module was moved to the desorb unit for heating and delivery to the delivery to the commercial detector (Figure 4).

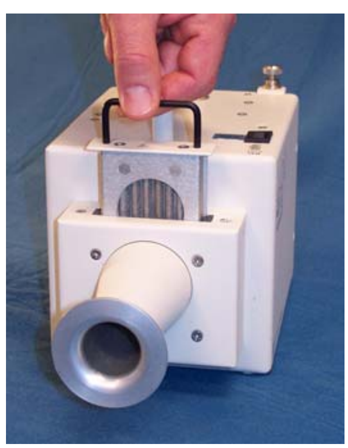

Figure 4. Hound Sample Collection and Preconcentration Unit with Vapor Module Removed

5. Phase I – Fiscal Year 2003

5.1 RoboHound, Version 1

Capitalizing on another sample collection project that was under way, the two teams shared designs such as the gripper interface, power and logic controls, and the air impeller and direct current (DC) motor assemblies.

The first RoboHound (Figure 5) was adapted from the Hound sample collector and preconcentrator, and from the MicroHound Project [ref. 3] including an inlet nozzle, an internal battery, a remote battery recharge connector, a thermally resetting circuit breaker, remote control plug, an on-off button at the back and on the top, and a light emitting diode (LED) indicator so that the operator could tell that the RoboHound was operating when viewed from a CCD camera on the robot. A three-pin Cannon connector was mounted on the rear surface to allow the robot operator to remotely operate RoboHound.

RoboHound carried an on-board 12 Volt DC rechargeable battery (manufactured by Frezzi), to minimize the power loading on the robot. A section view of the assembly is shown in Figure 6.

Air was drawn into the inlet nozzle by a 12 Volt DC motor and impeller assembly, manufactured by the Dewalt Corp. Air flow measurements performed in the laboratory showed that we recorded the highest air flow by using a 12 Volt motor and the impeller from a 7.6 Volt motor/impeller assembly. The 7.6 Volt assembly from Dewalt had a larger impeller than the 12 Volt assemblies. RoboHound operational measurements are shown in Figure 7.

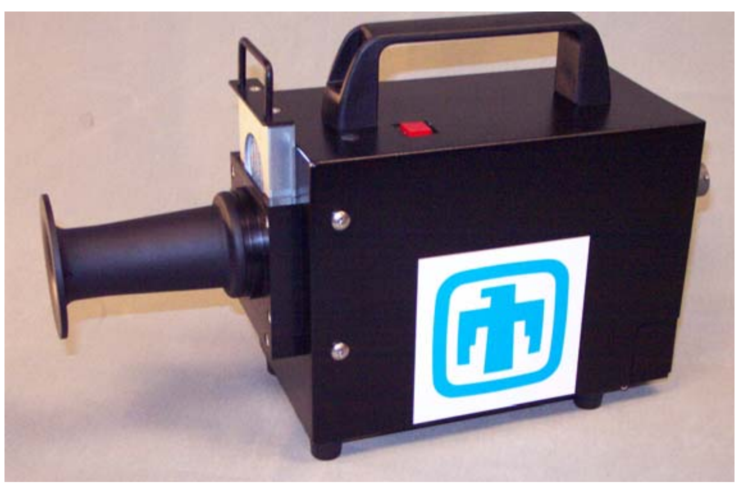

Figure 5. RoboHound, Version 1

During Phase I, the handle at the top of the RoboHound sample collector was eventually removed to install the tool changer pyramid grip.

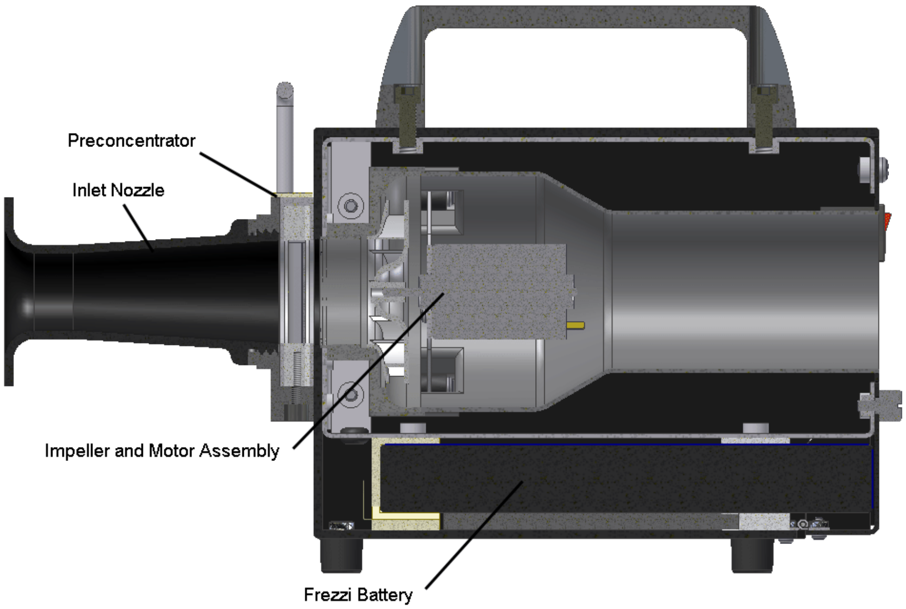

Figure 6. Section View of RoboHound Assembly, Version 1

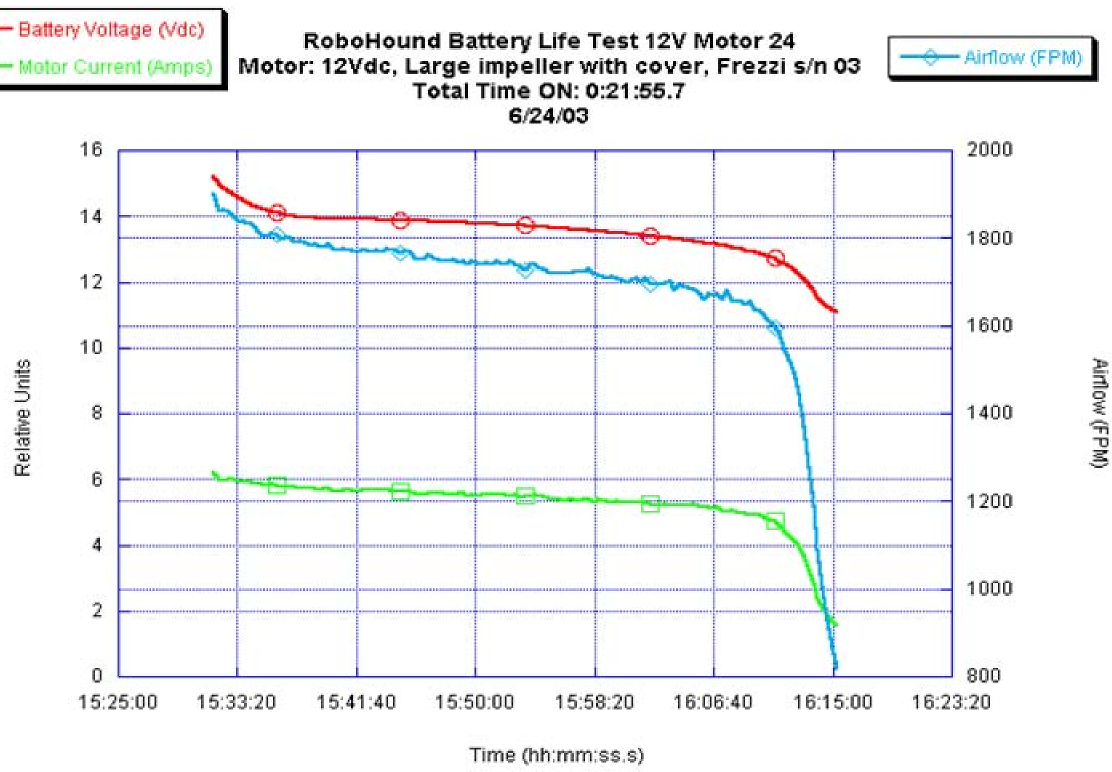

Figure 7. RoboHound Parameters during Battery Lifetime Tests

The team performed battery lifetime measurements to predict when the batteries had to be replaced for recharging during field experiments. Measurements of the 12 Volt motor and the impeller from the 7.2 Volt motor/impeller assemblies gave average air flows of 1750 feet per minute (FPM), an increase of 50 FPM from the 7.2 Volt motor/impeller assemblies. The average battery current (in green) was 6.0 Amps. The average battery voltage (in red), measured when the motor was off, was 13.8 Volts, and the average air flow (in blue) was approximately 1750 FPM. In the battery lifetime test, the battery had a total on-time of 21 minutes and 55 seconds. These tests were done with 10 seconds on time followed by 20 seconds off time.

A key item in Figure 8 is the initial "on" current in the upper left graph. The initial on current is saturated in this graph due to analog-digital scale settings. Further measurements showed that the initial on current peaked as high as 25 Amps. The current settled to its average value of 6 Amps in less than 1.5 seconds. This high initial current drain became important in the FY04 tests when the power supply was routed from the robot battery.

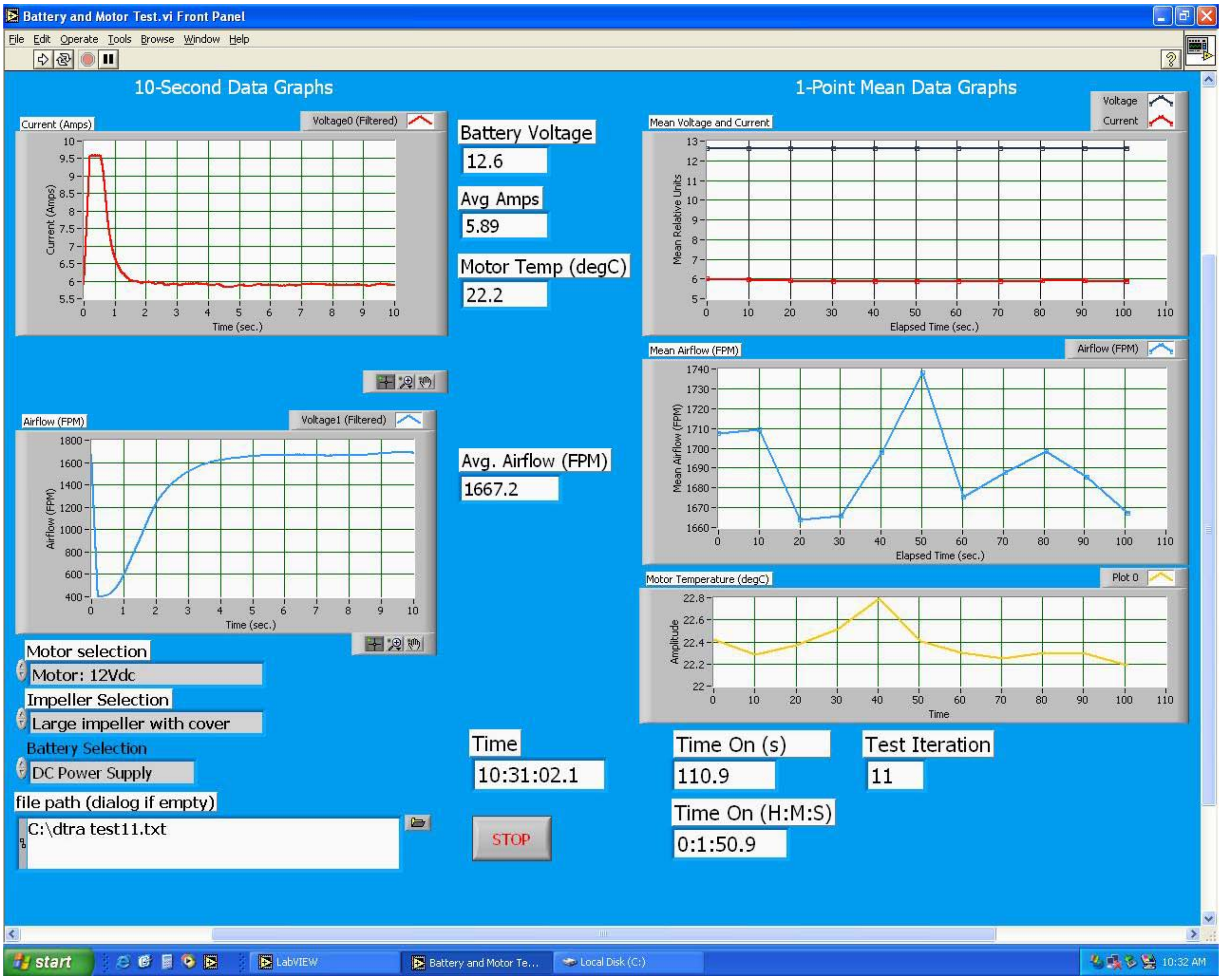

Figure 8. RoboHound Motor/Impeller Operational Parameters

5.2 Initial RoboHound Field Test

In Figure 9, the RoboHound is shown during the field test, sniffing for explosive residue on the door handle of a government van. When the 10 second air sample was accomplished, the robot was driven back to the operator area. The scanning of the RoboHound around the suspect packages was performed manually from the robot operator station (Figure 10). At this time, we limited the air sampling time to 10 seconds to minimize the amount of collected explosive particles lost through the preconcentrator metal mesh. The preconcentrator was removed manually and installed on the Hound, a front end preconcentrator heating assembly interfaced with a GE VaporTracer2 commercial explosives detector. The preconcentration and detection were started manually, and a laptop computer displayed the explosive compound detected. Single fingerprints of C4 and TNT, approximately 100 to 500 micrograms of explosive residue/ fingerprint, were successfully sampled and detected in the FY03 field test. Output spectra showed that approximately 5 to 10 nanograms of each substance were actually detected.

Figure 9. Version 1 of the RoboHound Sniffing for Explosive Residue on the Rear Door of a Government Van

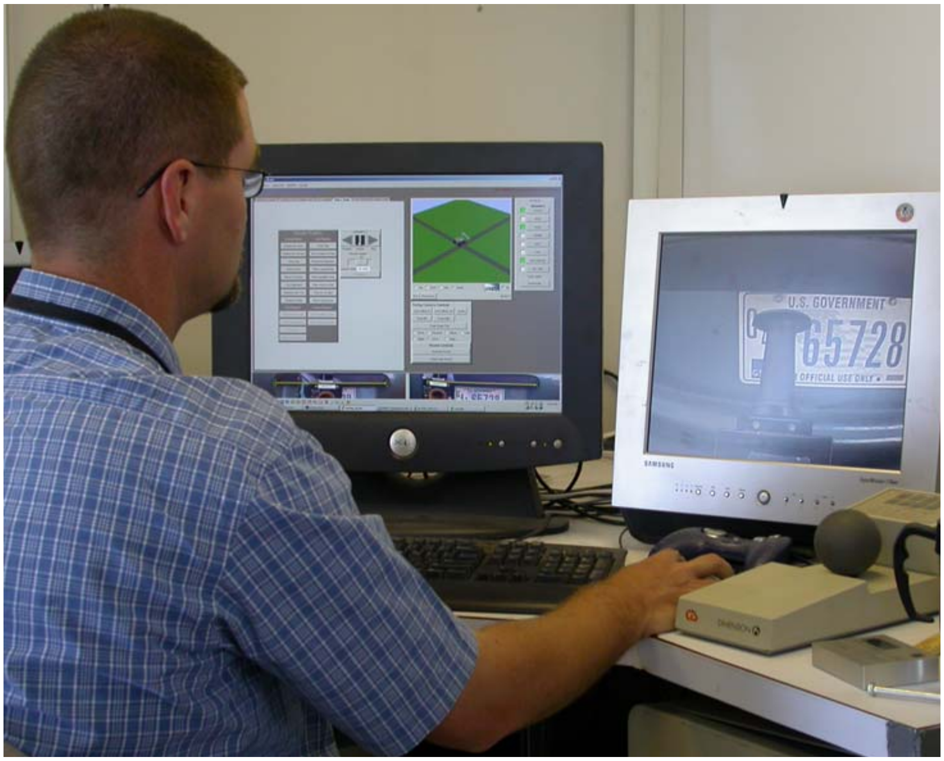

Figure 10. View of Remote Robot Operator's Computer Station

5.3 Post-Field-Test Improvements for FY04

The following list describes the improvements implemented for FY04:

- Because government vans were checked for explosives at the entrances to SNL Technical Areas, it was decided to stop using operational vans for explosive residue (single fingerprints of C4 residue) and to use van doors from a junk yard instead.
- Automated the manual scanning by RoboHound. Developed a software routine that mapped three-dimensional shapes for auto sample profiling: cardboard boxes, briefcases, and barrels.
- Removed the internal battery and ran the RoboHound from the Turing robot 24 Volt batteries using a voltage divider to obtain 12 Volts.
- Installed a dedicated GE VaporTracer2 detector aboard the robot platform.
- Integrated the RoboHound to the detector. Docking RoboHound to the detector provided automated preconcentrator heating at the time of docking.
- Added noncontact sensors to keep the nozzle the correct distance from suspicious containers. Tested it with a 200 mm laser noncontact sensor.
- Minimized cable lengths.
- Developed a tool changer gripper with electrical connections to provide power to the RoboHound and to the sensors. Added additional contacts to receive the signals from the noncontact sensors.
- Used a rechargeable battery to perform the preconcentration heating/desorption.

- Added a circuit board to the Dewalt motor/impeller assembly to allow easier installation of the thermal circuit breaker and associated motor and sensor wiring.

6. Phase II – Fiscal Year 2004

6.1 RoboHound, Version 2

With the elimination of the internal battery, the design for the next version of RoboHound was streamlined to only housing the motor and impeller assembly, nozzle, preconcentrator, and noncontact sensors. Several designs were considered for docking RoboHound to the detector. The primary problem was the front surface of the preconcentrator that contains any collected explosive particles is the same surface that is to be presented to the detector when the preconcentrator mesh is flash heated. Either the preconcentrator had to be rotated 90 or 180 degrees after sample collection, or the distance from the nozzle to the mesh had to be reduced after sample collection.

We decided to use stereo-lithography fabrication techniques to make a collapsible nozzle. The new nozzle was modeled from a collapsible outdoor drinking cup. An external spring was added to the nozzle to expand it while the air sample was collected and then the nozzle could collapse to less than 1 inch in length, allowing the preconcentrator mesh to be close to the detector at flash heating for accurate explosive detection.

A new gripper (Figure 11) was designed to allow ten separate electrical conduction lines from the robot to the RoboHound. The proper polarity was maintained if the black half of the gripper mated to the black half of the robot gripping fingers.

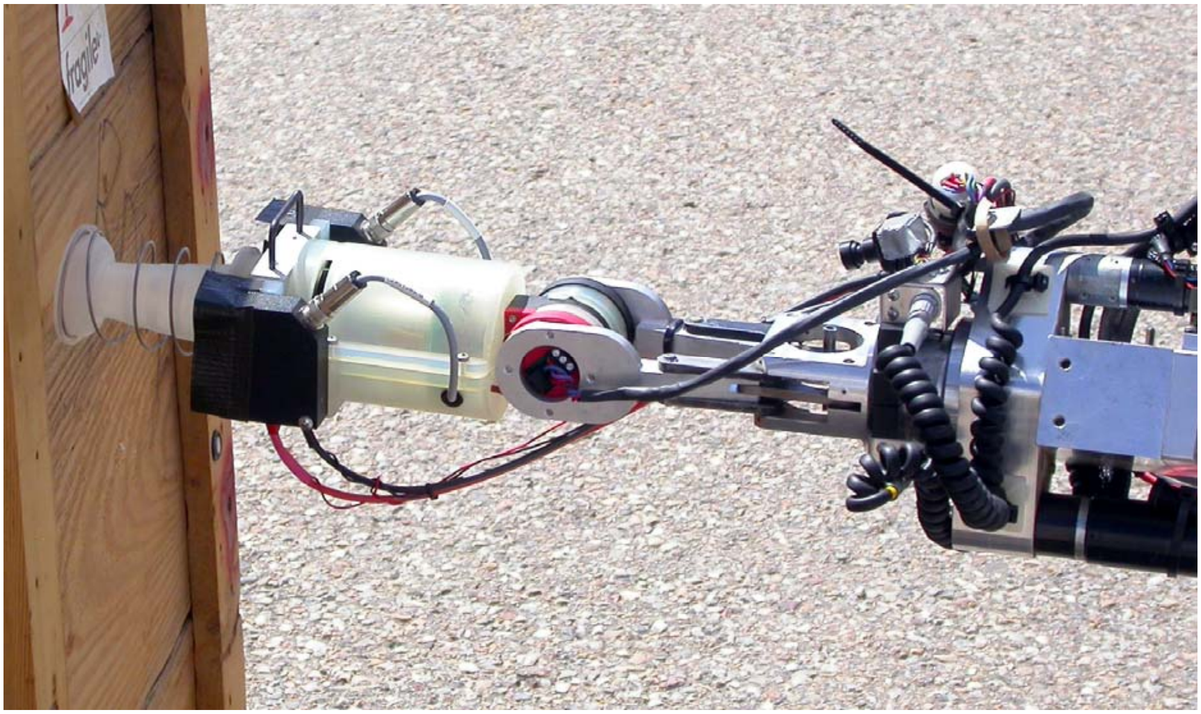

Figure 11. Version 2 of the RoboHound with a New Gripper, Noncontact Sensors, and a Collapsible Nozzle

The GE VaporTracer2 was mounted vertically on the Turing robot front end. To reduce shock to the detector from the movement of the robot, the detector was mounted on a spring-loaded Newport X-Y translation table that had the micrometer drives removed. This translation table had an added feature in that the detector assembly had about ½ inch of free travel and could self-align with the robot arm at docking.

The RoboHound docked with the detector, collapsing the nozzle to get the preconcentrator mesh to within 1 inch of the detector inlet (Figure 12). It was essential to get the mesh as close as possible to the detector inlet to facilitate efficient sample transfer to the VaporTracer2 during the desorption process.

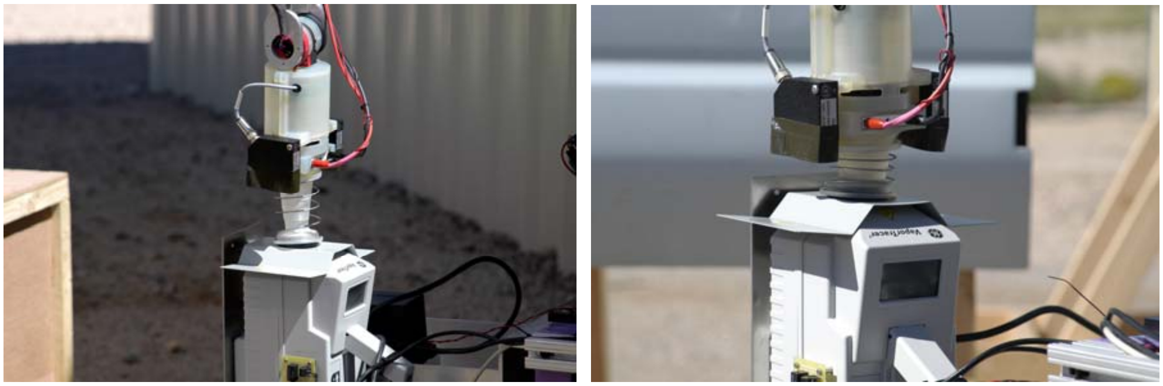

Figure 12. Version 2 of RoboHound's Collapsible Nozzle Docking with Detector, Left, and Fully Collapsed, Right

Two noncontact laser proximity sensors were added to RoboHound to send a measurement of the distance from the end of the nozzle to the suspicious object back to the remote operator. Two sensors were added so that the operator would get a signal of an upcoming obstruction from left or right direction scans. The feedback signal was included in the three-dimensional scanning of the paths, and it kept the nozzle less than 1.0 inch from the surface being tested. In the outdoor field tests, the detectors for the laser sensors often became saturated from the sunlight.

An overall view of the Version 2 RoboHound is shown in Figure 13, taken during the field test while testing a van door for explosive residue.

Figure 13. Version 2 RoboHound System Performing an Automated Detection of Explosives on a Van Door

A flash heating circuit was designed and built for desorbing explosives from the preconcentrator metal mesh. This circuit required the two on-board batteries, one to provide the logic power and the other to provide the high-Amperage direct heating of the mesh. The battery was basically shorted across the metal preconcentrator mesh for less than 1 second to achieve 200 °C.

It was mentioned earlier that the initial turn-on current for the air sampling motor was as high as 25 Amps. When the robot system was first turned on, RoboHound tripped the robot's circuit breakers. A circuit was designed and implemented to limit the motor turn-on to about 7 Amps. The motor took an extra second to turn on, but no longer tripped the circuit breakers.

For the FY04 field tests, the RoboHound system approached a suspicious object, mapped out a search path, collected the air sample, preconcentrated, docked to the detector, flash heated the preconcentrator, and started the detector automatically. This process was performed manually in the previous year. Single fingerprints of C4 and TNT, approximately 100–500 micrograms of explosive residue/fingerprint, were successfully sampled and detected in the FY04 field test. Data analyses showed low nanogram detections of each type of explosive.

6.2 Post-Field-Test Improvements for FY05

The FY04 field testing was deemed successful, but items were noted that needed to be improved:

- The laser noncontact sensor detectors were saturated by the direct sunlight during outdoor testing; ultrasonic noncontact sensors were investigated.
- The gripper was too complicated to use as a multitool gripper; the pyramid gripper required redesign to have power and infrared (IR) communication connections.
- Removed the preconcentration heating wires and made that electrical connection at the docking location so that the preconcentrator heated only when docked to the detector.
- The RoboHound body was susceptible to cracking during docking if too much force was used by the robot arm. The body and end plate of the RoboHound were strengthened.
- Made the collapsible nozzle thicker and stronger.
- Developed a way to automatically clean the preconcentrator after positive explosives detection. It was necessary to get a clean reading on the detector before proceeding to the next target.
- Redesigned the RoboHound body to mate with the gripper plate used in the sample collection project (a four-hole mount configuration).
- The Robotics team reconfigured the new gripper with an infrared RS-232 serial communications sensor and receiver to send operational signals from the RoboHound
- Performed laboratory testing of trace explosives to determine if the air sampling could be extended beyond 10 seconds

7. Phase III – Fiscal Year 2005

7.1 RoboHound, Version 3

In Phase III, the wall thickness of the RoboHound body was increased to prevent the body and end plate being crushed by the robot arm at docking. The collapsible nozzle was made with a thicker plastic, still using stereo lithography.

Laboratory experiments were performed on trace explosives to determine if the 10 second air sampling time could be increased so that the robot operator could scan more of the target surface between detections. The data from these experiments are given in Figure14.

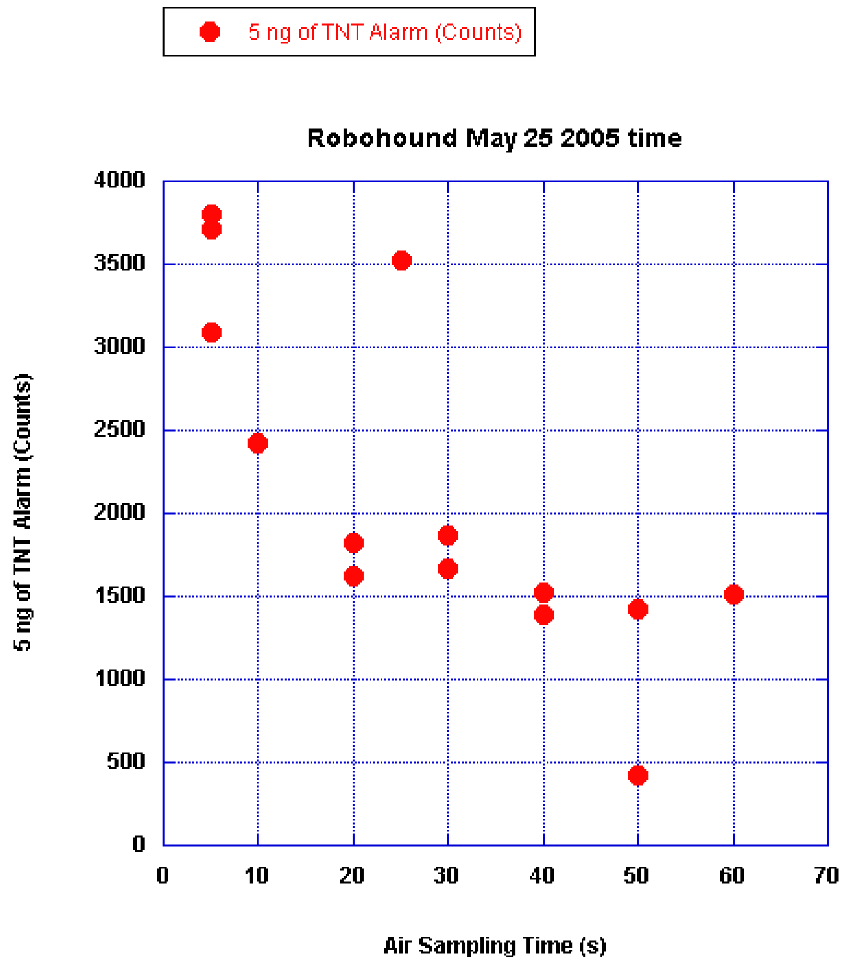

Figure 14. TNT Alarm Counts as a Function of Air Sampling Duration

The data from Figure 14 show that for trace detection of TNT, the peak air sampling duration was between 5 to 10 seconds. We did particle explosive detection at our field tests, not trace air samples, so a direct comparison may not be valid. The laboratory staff stated that once there are air-collected explosive particles (vs. trace air sampling), the particles were much more likely to stick to the preconcentrator mesh than was the case for vaporized trace samples. The data did not conclusively show that we could always detect explosives at longer air sampling durations; we decided to try it in the field experiments and record the results, so we extended the air sampling at the field experiments to 40 seconds and recorded the results.

The docking of the RoboHound to the GE VaporTracer2 made the electrical connections to the preconcentrator instead of the long cables that were used in FY04. The electrical connections were made at the inside on the new collapsible nozzle as seen in Figures 11 and 12. The reason for doing this was to reduce the resistance of the flash heating. To heat the preconcentrator metal mesh to 200 °C, a 12 Volt battery was shorted across the mesh for a portion of a second, controlled by integrated circuitry. Unnecessary cable lengths added resistance to the heating circuit.

At lower heating temperatures, not all explosive compounds are released from the preconcentrator. Higher heating temperatures, to an extent, improved the release of the explosive compounds and the probability of those explosive compounds being detected.

The pyramid-shaped gripper (Figure 15) was based on the Atlas robot gripper modified by the sample collection team. It replaced the 10-pin electrical gripper from FY04 and used infrared (IR) RS-232 communications. The aluminum gripping fingers were at a 12 Volt potential and supplied RoboHound with voltage. The signals from the ultrasonic sensors were sent to the robot operator's station through the IR RS-232 between the gripper and the RoboHound.

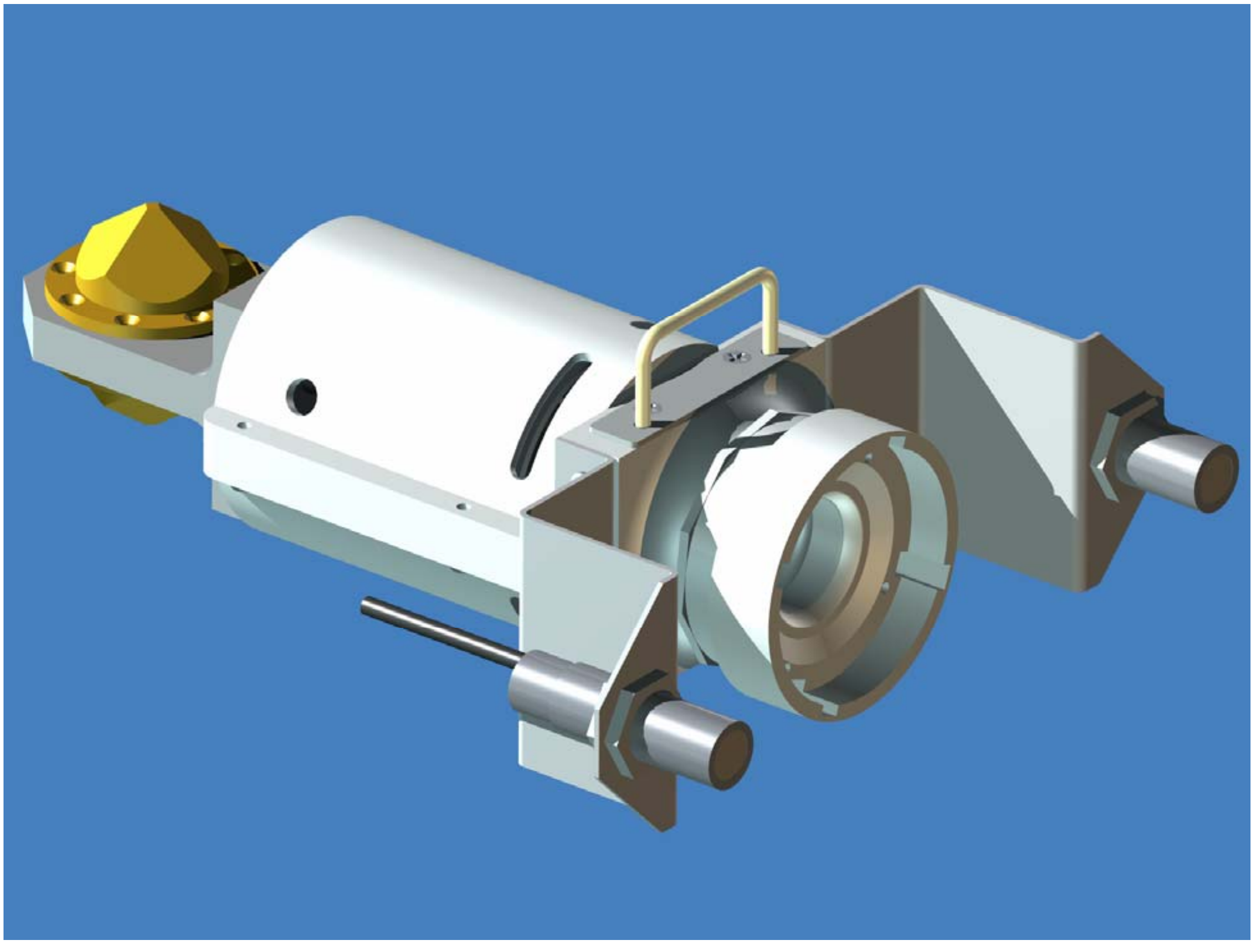

Figure 15. Version 3 RoboHound™ with the Pyramid Gripper

The final field test was set up for the RoboHound to test for the presence of a fingerprint of TNT and/or C4 on a cardboard box, a backpack, and a vehicle door handle. The test was conducted indoors on September 6, 2005. The test was performed indoors due to a rainstorm. Version 3 of the RoboHound system (Figures 16 and 17) was able to correctly differentiate TNT from C4. Several video movies were recorded along with still photographs.

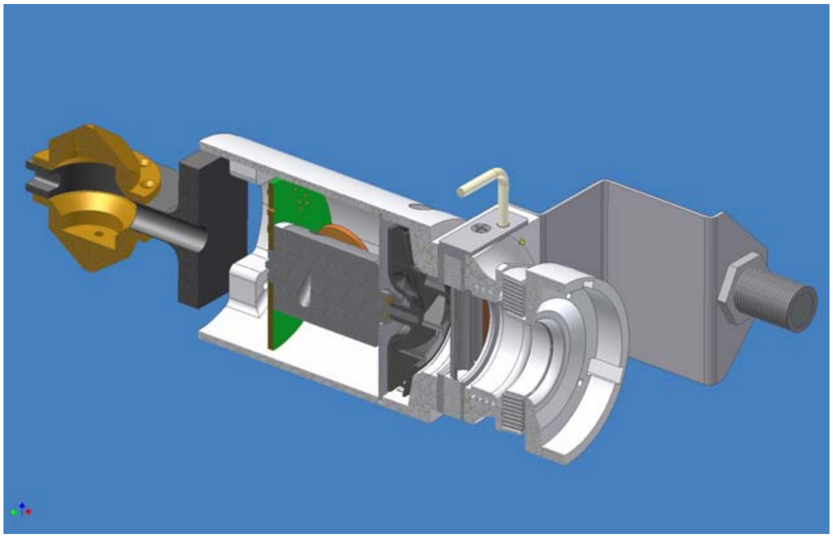

Figure 16. Section View of the Final RoboHound

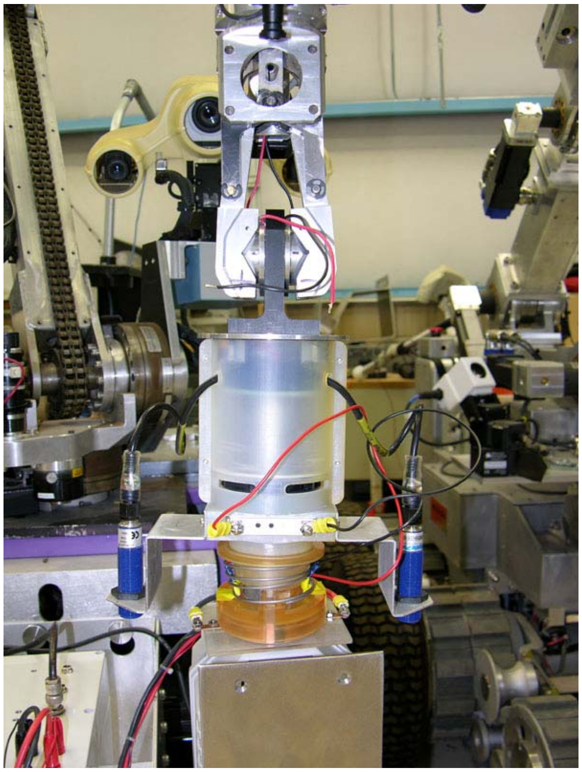

Figure 17. Final Version 3 of the RoboHound Docking with the Detector and Showing the Ultrasonic Noncontact Sensors (in Blue)

7.2 FY05 Field Test Results

The final field test occurred on September 6, 2005, at the RVR. The first sample tested was C4 on the rim of a metal 35 gallon drum. Although RDX from C4 was shown as an elevated ion mobility peak, the amplitude of the RDX was observed to be below the alarm threshold. An experienced operator would have seen the elevated RDX peak and considered the sample as suspicious and worthy of being reinspected. RoboHound was able to detect a fingerprint trace of TNT on the handle of a lunch bucket, and the RDX ion mobility peak was positively identified from a another sample of the explosive C4 on a vehicle door handle. RDX has a very low vapor pressure and is therefore difficult to detect in trace amounts.

The ability of RoboHound to detect RDX shows that the overall system is designed well and that the collapsible nozzle is close enough to the detector when the preconcentrator is flash heated and desorbed. The sample collection screen had to go through two automated cleaning cycles to remove all trace explosives from the preconcentrator. The cleaning cycle involved backing the RoboHound away from the detector about one foot, performing a 40 second air sample while the preconcentrator was flash heated. Then the RoboHound is docked to the detector and the detector is started with a flash heat of the preconcentrator to determine if the screen is clean and ready for the next sample.

8. Conclusions

All of the RoboHound field tests were successful, especially with regards to the ability to collect and detect trace samples of RDX. The RoboHound system was envisioned to be a tool for emergency responders to test suspicious items (i.e., packages or vehicles) for explosives while maintaining a safe distance, and it has proven itself in that application. The project has gone from remote sampling with human intervention to a fully automatic system that requires no human intervention until the robot returns from a sortie. An automated self-cleaning cycle routine has shown to be effective and keeps the user from having to change the preconcentrator between sorties. Appendix A describes the Lessons Learned, and Appendix B lists some the risks encountered.

Based on these promising results, we have submitted a proposal to SNL to fund the development of the RoboHound system for one final year to prepare it for commercialization. We will work with the Technology Commercialization and Partnerships Center (10100) to prepare RoboHound for commercialization.

We propose the following:

- Purchasing a smaller, commercial robot platform and using the RoboHound as a tool for that platform.
- Implementing the Joint Architecture for Unmanned Systems (JAUS) interface standard [ref. 4]. The JAUS is an architecture specified for use in research, development, and acquisition primarily for Unmanned Systems (UMS). The implementation of JAUS requirements provides for an interoperability capability for commanding and controlling all UMS platforms.
- Modifying RoboHound designs and fabrication methods as might be suggested for commercialization.

References

1. David W. Hannum and Mary-Anne Mitchell, *Performance Evaluation of the SNL Hound Explosives Detection System*, SAND2004-5555. Sandia National Laboratories, Albuquerque, NM (Unclassified Controlled Nuclear Information), November 2004.
2. Mark J. Baumann, *The RoboHound^{TM} Remote Explosives Detection,* SAND2004-1185P, Sandia National Laboratories, Albuquerque, NM.
3. Kevin L. Linker, Charles A. Brusseau, Mary-Anne Mitchell, Douglas R. Adkins, Kent B. Pfeifer, Arthur N. Rumpf, and Steven B. Rhode, *Portable Explosives Detection System: MicroHound ^{TM}*, SAND2003-2254C, Sandia National Laboratories, Albuquerque, NM.
4. *The Joint Architecture for Unmanned Systems,* http://www.jauswg.org/baseline/CS%20V%201.1%2010Mar05.doc

Appendix A: Lessons Learned

Lessons Learned Document

Project Name	Project Ref. No.	Prepared By (print)	Preparer's Initials
RoboHound 2005	10579 01.07	John A. Hunter	JAH
Customer	Contact	Contact's Phone	Date Prepared
DoD Projects	Dave Zusi	505-845-9008	May 24, 2005

SUMMARY

PROJECT BACKGROUND

The RoboHound is a teleoperated remotely controlled explosives vapor detector that can sniff the air around suspicious packages and dock to a commercial GE VaporTracer2 detector. All communications are serial to ethernet via a towed cable.

LEARNING HIGHLIGHTS

The laser proximity sensors are swamped by direct desert sunlight. Try ultrasonic non-contact proximity sensors. Hyde Park ultrasonic sensors: do not follow the wiring instructions, tie all grounds together. Y-axis is distance. Otherwise the analog output goes from 0-10 volts to 1.7 to 0.7. The Impeller, when running backwards, still inhale but not as much, so check the rotation. If you are going to build something, be able to test in the lab entirely, or make an extra to be used in the lab.

Think of the wiring paths before you build the unit.

STL can be metal plated

Build things knowing that they will be dis-assembled many times.

Patience, good communications, and timely meetings with firm agendas are necessary when working within and outside of your organization.

RECOMMENDATIONS SUMMARY

TECHNICAL REVIEW

PROJECT EXPERIENCE

RECOMMENDED PROCESS IMPROVEMENTS

PROPOSED TOOL MODIFICATIONS OR IMPROVEMENTS
Replace to Turing robot that no one is using. Try a smaller, commercial robot platform. Obtain a formalized JAUS standard. Adapt the RoboHound to a JAUS interface and work on commericialization.

Appendix B: Risk Assessment Questionnaire

Risk Interview Questions—25 Generic

Project Name	Project Ref. No.	Prepared By (print)	Preparer's Initials
RoboHound	10579 01.07	John Hunter	JAH
Customer	Contact	Contact's Phone	Date Prepared
DoD	David Zussi	505-845-9008	02/03/2005

1. What issues do you think could put this project in jeopardy? Why? SNL does not own the robot, it is on loan from the British government. We fight for time on the robot. Changes from laser to ultrasonic sensors.
2. Are there issues that might cause serious problems in terms of cost? Only if we loose access to the robot.
3. Are there issues that might cause serious problems in terms of schedule? Getting the robot and operators time.
4. Are there issues that might cause serious problems in terms of technical performance? no
5. Do you foresee any management concerns or conflicts? Lack of continuation of the project. Bring this issue up to Rebecca Horton for DHS development?
6. Do you foresee any concerns or conflicts associated with other parts of the organization? no
7. Do you anticipate any complaints or concerns from the customer? no
8. Do you foresee any concerns or conflicts with vendors or support teams? no
9. Do you foresee any human resource concerns? Dave Hannum and his explosives expertise.

10. Do you foresee any material resource concerns? Robot being available.
11. Are there potential issues associated with the movement of materials? Dave Hannum and his explosives expertise.
12. Are there potential issues associated with travel? no
13. Are there potential issues associated with personnel safety? The robot arm drops when deactivated. If a person is near when this happens, one could suffer serious injury.
14. Are there potential safety issues for the customer or end users? no
15. Does the project in any way put the organization's image in jeopardy? Only if someone gets hurt or if the system does not work. It does work, however.
16. Does the project in any way put any customer's image in jeopardy? Could enhance if the unit is commercialized properly.
17. Does the project in any way limit future opportunities? no
18. Do you foresee any conflicts with the existing organizational infrastructure? no
19. Could the project create problems with regulatory or supervisory agencies? Who? How? no
20. Could the project create any issues associated with data ownership or data rights? We should consider copyright and patents.
21. Are there environmental issues (physical, personal, or societal) that could negatively affect the project? The explosives detectors (commercial) have sealed radioactive sources (Ni63) that could spread contamination if it were explosed by an IED, or were to start leaking or flaking.
22. What is the worst external catastrophe that would directly impact this project? A vendor builds a similar product that replaces the RoboHound™.
23. Are there any *little* problems that could have a lasting negative impact on the organization, even though they do not create major conflict? no

24.	How would you rate the project's chances of success? Why? Outstanding
25.	If you could change one aspect of the project, what would it be? More money for continued development and to buy our own robot. It would be good to try this tool on other robot platforms. Adding the capability to do swipe samples.

Distribution:

1	MS0762	Billy W. Marshall, Jr.	06410
1	MS0762	Rebecca Darnell Horton	06420
1	MS0768	David A. Zusi	06430
1	MS0768	Basil J. Steele	06430
1	MS0768	Marcella Marie Madsen	06430
2	MS0780	John A. Hunter	06428
1	MS0780	Mark J. Baumann	06428
1	MS0780	Dale W. Murray	06428
1	MS0780	David J. Peterson	06428
1	MS0780	Dennis L. Carlson	06428
1	MS0782	David W. Hannum	06418
1	MS0782	Mary-Anne Mitchell	06418
1	MS0782	Michael C. Lenz	06418
1	MS0782	Kevin L. Linker	06418
1	MS1005	Russell D. Skocypec	06640
1	MS1063	David J. Denning	05714
1	MS1125	Phil C. Bennett	06644
1	MS1125	T. Scott Gladwell	06644
1	MS1125	Clinton G. Hobart	06644

1	MS0762	Steve G. Jordan	06411
1	MS0899	Central Technical Files	04535
2	MS0899	Technical Library	04535
1	MS0161	Patent and Licensing Office	11500