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DESIGN, DEVELOPMENT AND FIELD DEPLOYMENT OF A TELEOPERATED SAMPLING SYSTEM

Michael J. Dalmaso, Robert F. Fogle, R. Anthony Hicks, Larry J. Harpring, D. Mackenzie C. Odell

Savannah River National Laboratory, Bldg 723-A, Aiken, SC 29808, Michael.Dalmaso@srnl.doe.gov

Richard L. Nimmerrichter

Camber Corporation, DTRA/CSCF, MS6201, 8725 John J. Kingman Rd, Ft Belvoir, VA, 22060, Richard.Nimmerrichter_contractor@dtra.mil

Wilbur McCullough

URS Corporation, DTRA/CSCF, MS6201, John J. Kingman Rd, Ft Belvoir, VA, 22060, Wilbur.McCullough_contractor@dtra.mil

A teleoperated sampling system for the identification, collection and retrieval of samples following the detonation of an Improvised Nuclear Device (IND) or Radiological Dispersion Devise (RDD) has been developed and tested in numerous field exercises. The system has been developed as part of the Defense Threat Reduction Agency's (DTRA) National Technical Nuclear Forensic (NTNF) Program. The system is based on a Remotec ANDROS Mark V-A1 platform. Extensive modifications and additions have been incorporated into the platform to enable it to meet the mission requirements.

I. INTRODUCTION

The Defense Science Board Task Force on Unconventional Nuclear Warfare Defense, 2000 Summer Study Volume III report recommended the Department of Defense (DOD) improve nuclear forensics capabilities to achieve accurate and fast identification and attribution. One of the strongest elements of protection is deterrence through the threat of reprisal, but to accomplish this objective a more rapid and authoritative attribution system is needed. [1]

The NTNF program provides the capability for attribution. Early on in the NTNF program, it was recognized that there would be a desire to collect debris samples for analysis as soon as possible after a nuclear event. Based on nuclear test experience, it was recognized that mean radiation fields associated with even low yield events could be several thousand R/Hr near the detonation point for some time after the detonation. In anticipation of pressures to rapidly sample debris near the crater, considerable effort is being devoted to developing a remotely controlled vehicle that could enter the high radiation field area and collect one or more samples for subsequent analysis.

II. TELEOPERATED SAMPLING SYSTEM

In FY03, the Savannah River National Laboratory (SRNL) in conjunction with DTRA (Camber and URS) began to develop a system to provide a teleoperated vehicle capable of entering a high radiation field, locating and collecting sample(s). The retrieved samples are returned and remotely off-loaded from the vehicle. Retrieved samples are subsequently analyzed in the field and at fixed laboratories for attribution.

The use of a teleoperated vehicle permits sample collection from areas with dose rates that are too high for human entry, and also will serve to reduce personnel exposure to As Low As Reasonably Achievable (ALARA).

II.A. Remotec ANDROS Platform

The Remotec ANDROS Mark V-A1 platform was selected as base platform for the system. The ANDROS is a robust, reliable platform that is used by Explosive Ordinance Disposal (EOD), Law Enforcement/SWAT, HazMat and other first responders.

The platform is a tracked vehicle with optional wheels and is 46.5" high (72" with pan/tilt mast extended), 43" wide with wheels installed, and 48" long. Weight of the platform is 790 lbs. The platform can be operated on the tracks, or on a detachable wheel set. For the NTNF application the wheels are almost always used as they result in smoother, faster operation. Maximum speed with the wheels is on the order of 3-4 mph.

The ANDROS has a 6 degree of freedom manipulator arm. The manipulator arm has a capacity of 100 lbs at 18" extension and 60 lbs at full extension. Reach of the arm is 125" vertical and 67" horizontal. It also has three on-board cameras which are the drive camera mounted low on the vehicle between the tracks, an arm camera mounted on the arm looking at the gripper and a mast camera mounted on the extendable mast. The drive camera is a black and white, fixed iris and fixed focus camera. The arm and mast cameras are color with variable iris and focus. The mast camera is mounted on a pan and tilt unit. The mast camera is the primary camera used when manipulating the arm, as the arm has no feedback or position information and positioning it is done entirely by visual feedback. On board power is provided by two 12 VDC, 65 amp-hr, lead-acid (Pb-acid), batteries operated in series.

The vehicle is operated from a control unit that consists of a removable switchbox and a 15" LCD screen. The control unit is connected to the robot with either a fiber optic tether or a radio link.

Figure 1 is a picture of the ANDROS platform as received from Remotec.

Fig 1. Remotec MarkV-A1 ANDROS

Figure 2 shows the ANDROS with all of the modifications and additions to the system as part of this project.

Fig 2. Modified Mark V-A1 ANDROS

II.B. Radiation Detection Equipment

Identification of samples can be made visually for "traditional" type evidence, but the identification and selection of radioactive samples requires radiation detection equipment. Two radiation detectors were added to the Andros vehicle; one on the mast and one on the arm.

The camera and light from the original Andros mast were combined with a collimated radiation detection device and digital compass to provide an effective system in searching for radioactive samples over a wide range of dose rates. A Scionix cesium iodide detector is mounted co-axial with the camera so the radiation rate corresponds to the objects in the camera's field of view. Tungsten shielding (1 ¼") around the detector makes it forward looking. A unique aspect of this collimator is that in addition to the shielding on the sides and back of the detector a remotely controlled slide in front of the detector provides adjustable collimation. The moveable slide can be positioned in three distinct positions, which have three different size openings in the slide. The different size openings provide distinct levels of attenuation allowing the detector to function over a wide variety of dose rates. Because of this, the collimator can be used to scan large areas for radioactive items and be used to locate specific items of interest at very short ranges (very high dose rates).[2]

Figure 3 is an illustration of the shield and remotely controlled slide.

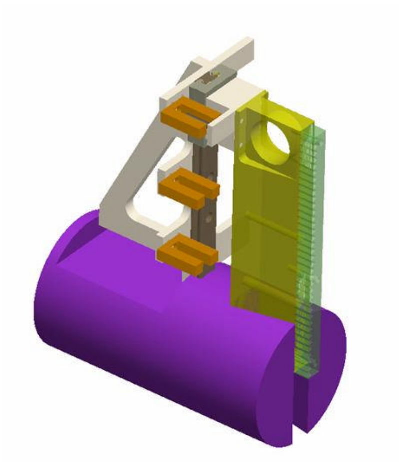

Figure 3 – Collimator Shield and Slide

The collimator assembly weighs approximately 37 lbs and severely taxed the capabilities of the pan and tilt unit that was supplied with the ANDROS platform. The original pan and tilt unit was subsequently replaced with a computer controlled pan and tilt capable of handling payloads of up to 100 lbs. The computer control feature has allowed for automated scans to search for radioactive sources.

Figure 4 is a photograph of the collimator and computer controlled pan and tilt.

Figure 4 – Collimator and Pan and Tilt Unit

A second radiation detector has been added to the platform on the manipulator arm just behind and coaxial with the arm camera, which is aimed at the manipulator arm gripper. This detector is a Ludlum G-M tube shielded on the sides and back by ½” of tungsten. The tungsten shielding makes the detector 90% forward looking.

The signals from each of the radiation detectors are processed by an on-board radiation instrumentation board before being relayed via radio to the operator control station.

II.C. Sampling System Equipment

The system is capable of collecting three distinct types of samples: particulate, debris or “chunk” and smear samples. Different types of samples will be collected depending on the type of event (IND or RDD) that is being responded to.

Two “wings” are mounted to the ANDROS chassis to carry all of the sampling equipment. These extend on both sides of the platform, and carry a total of five particulate samplers, five receptacles for debris samples and a smear sampler capable of collecting six smear samples. Figure 5 shows the left wing installed on the ANDROS. The left wing carries three of the particulate vacuums, two debris bins and the holder for the smear sampler. The right wing carries two particulate vacuums, three debris bins and the GPS unit for navigation.

Figure 5 – Left Wing installed on ANDROS platform.

A spacer was added between the ANDROS chassis and arm to allow the arm to reach the required points for picking up the particulate vacuums or to reach the debris bins for dropping off a debris sample. The spacer also freed up room on top of the chassis for a battery and the electronics enclosure.

II.C.1 Particulate Sampling

A particulate sample can loosely be described as material that is small and loose enough to be vacuumed up. Sandia National Laboratories developed a small 12 VDC vacuum shown in Figure 6 for this application.

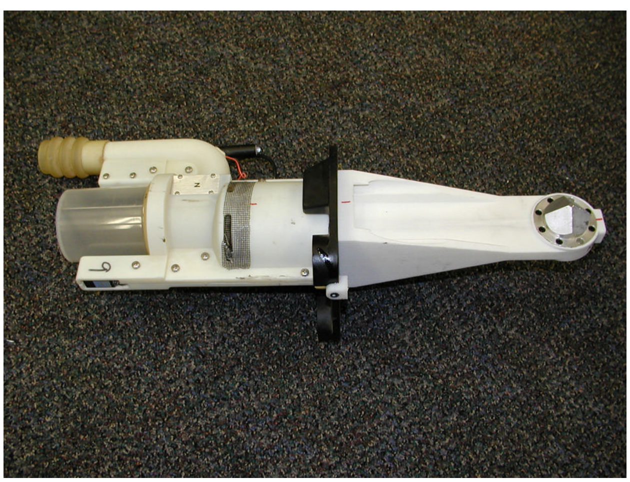

Figure 6 – Particulate Vacuum

Power for the vacuum is provided from the ANDROS through the pyramid shaped contacts on the top of the vacuum. These contacts also serve as a positive engagement point for picking up the vacuum and moving it with the ANDROS manipulator arm. Communication for turning the vacuum on/off and reading the vacuum sensors is achieved through an infra-red port on the top of the vacuum.

The ANDROS gripper fingers were replaced with new fingers that have the vacuum power contacts in the design. The contacts are the inverse of the pyramid contacts on the vacuum. An infra-red port for vacuum communications was also added to the gripper.

Vacuums are located and held on the wings with a pair of dowel pins. The dowel pins are mounted on a base that allows some compliance to assist in returning the vacuums after sampling. A switch detects when a particular vacuum has been removed from its storage location.

II.C.2 Debris or "Chunk" Sampling

A debris or chunk sample is a sample that is too large for the vacuum to collect and up to roughly the size of a 12 oz. soda can. These types of samples will be picked up with the ANDROS manipulator arm and placed in a bin located on the wings. The bins have lids that are opened and closed by pneumatic cylinders to lessen the potential for cross contamination. Each of the bins has a removable liner to ease sample offloading at the end of a mission. Figure 7 shows three of the debris bins in the closed position.

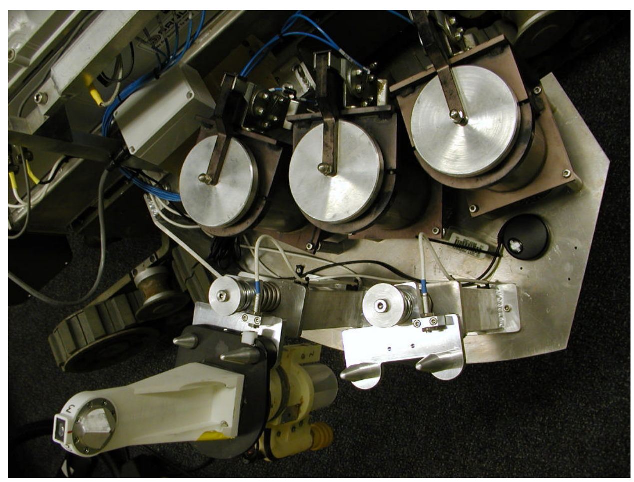

Figure 7 – Debris Bins

II.C.3 Smear Sampling

Smear sampling consists simply of taking a smear or swipe off of a surface to collect contaminants that may be present in much the same way Radiological Control personnel take swipe samples to check for transferable contamination.

Remotec makes a smear sampling device as an accessory for the ANDROS platform. The smear sampler is held by the ANDROS gripper and has six spring loaded fingers. Removable smear sample pads are affixed to each of the fingers. Figure 8 shows the smear sampler installed on the left wing in its holder.

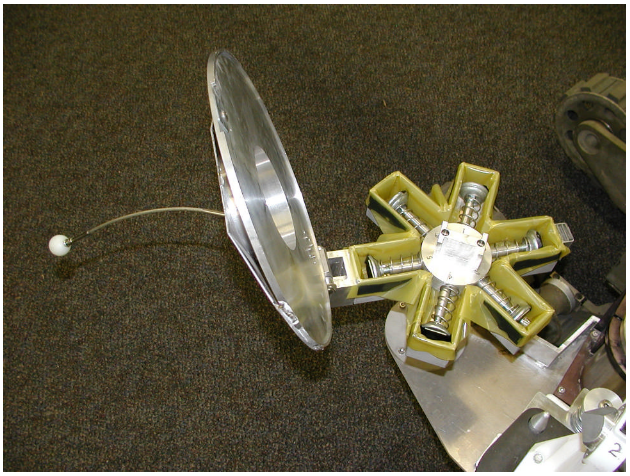

Figure 8 – Smear Sampler in its holder

II.D. ANDROS Range Extension

As delivered from Remotec, the ANDROS did not have the range needed to meet the NTNF mission requirements. The battery and radio/tether range are sufficient for typical EOD, SWAT and HazMat missions for which the ANDROS was designed. However, both needed upgrades to meet the NTNF mission requirements.

II.D.1 Battery Upgrades

A number of battery technologies were investigated. This included Pb-acid, Nickel Metal Hydride (NiMH), Nickel Cadmium (NiCad), Lithium Ion (Li-ion) and Lithium Polymer (Li-poly). Li-ion technology was selected primarily due to its very high volumetric density, high gravimetric energy density and commercial availability.

Valence Technology's K-charge battery was chosen because its form factor afforded the best fit with the ANDROS vehicle. The K-charge series was designed to provide back-up power for telecommunications equipment. They are packaged in a rack-mount design with dimensions 21.4" L x 11.9" W x 3.44" H and weigh approximately 67 lbs. Two K-charge units were integrated into the vehicle to provide the necessary capacity.

To keep the vehicle's center of gravity as low as possible, one of the K-charge batteries was repackaged and placed in the lower portion of the chassis in the location previously occupied by the Pb-acid batteries. The other K-charge battery was mounted on top of the chassis in a custom battery enclosure.

II.D.2 Radio Upgrades

As delivered from Remotec, the ANDROS can operate either with a fiber optic tether or radio link communications. The use of a fiber optic tether may not always be feasible primarily because of its potential to become entangled or get run over and break. Radio operation permits the most versatility, however, the range of the standard Remotec radio package is limited to about ¼ mile depending on the environment and terrain. To improve the communication range of the ANDROS, a new radio system was added which included a repeater. Depending on the terrain between the robot and its objective, the repeater can be ground-based or mounted to an aircraft. The new radios and repeater greatly extended the range of the ANDROS.

II.E. Control System and Graphical User Interface

In addition to the Remotec controls, the platform required additional controls to handle the radiation detection and sampling equipment. An operator control unit and graphical user interface was also developed for the operator to operate the sampling system and record data.

II.E.1 Control System

The control system for the sampling system controls the operation of the radiation detectors, the computer controlled pan and tilt, sampling tools (with the exception of the smear sampler), the GPS and the electronic compasses. An electronics enclosure was added to the vehicle to house the controls for the sampling system. It includes the embedded computer, control system radio, air compressor, accumulator, solenoid valves, radiation detection boards, power supplies, digital I/O, etc. Figure 9 shows the inside of the electronics enclosure.

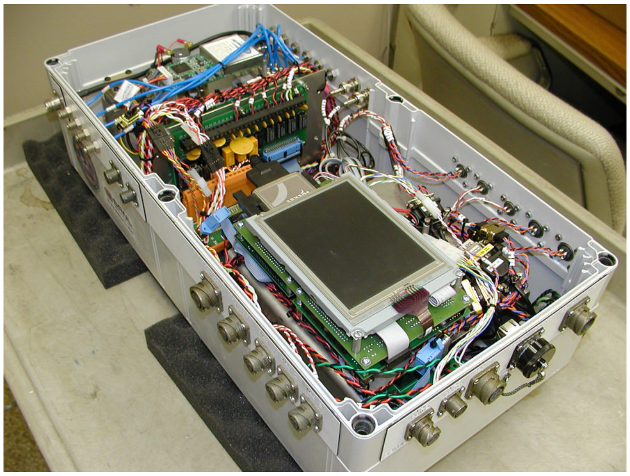

Figure 9 – Electronics Enclosure Interior

The electronics enclosure is located on top of the custom battery enclosure mounted on the ANDROS chassis.

II.E.2 Graphical User Interface (GUI)

The graphical user interface is a menu driven application operated on a laptop PC. The GUI along with the ANDROS controls are used to perform sampling mission. The GUI has numerous tabs within the application for performing initial equipment checkout, mapping, sampling, searching, pan and tilt control, and a tools tab. Figure 10 in an example of the mapping screen from the GUI and figure 11 is an example of the sampling screen.

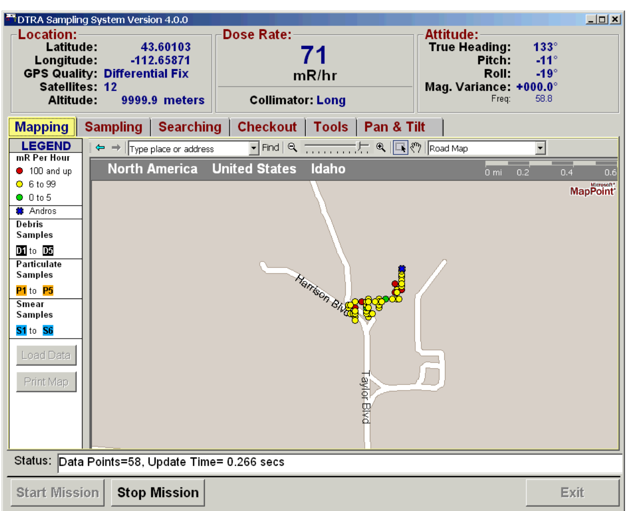

Figure 10 – GUI Mapping Screen

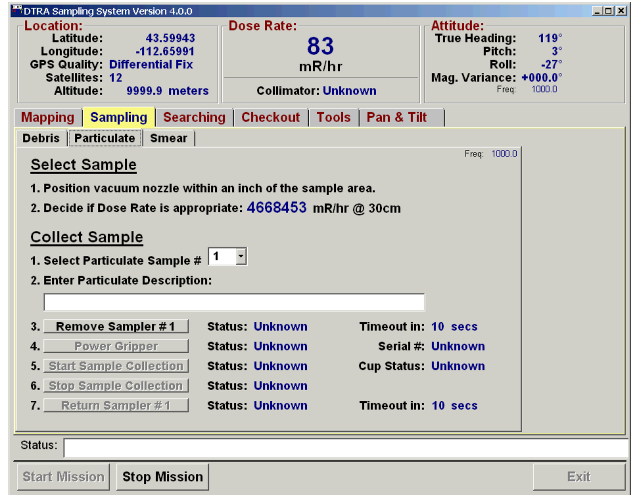

Figure 11 – GUI Particulate Sampling Screen

The application records information such as GPS locations, sample locations, dose rates where samples were collected and any operator's comments such as sample description. The application also notifies the operator if he/she tries to use one of the sampling devices for a second time in the same mission. After the mission is completed, this data is written to Microsoft Excel for mission report generation and archiving.

II. E. 3 Software Architecture

The sampling system software consists of Embedded Visual Basic code running on the embedded computer and the laptop GUI code written in Visual Basic 6.0. These two pieces of software communicate via an RS-232 radio link. The GUI sends one to three character commands that instruct the embedded code to communicate with RS-232 devices (GPS, digital compass, radiation detector, etc.) and control/read digital I/O (bin lids, collimator position, etc.)

III. FIELD EXERCISES

The NTNF program has participated in or held numerous exercises since the program's inception. Purposes of the exercises are to evaluate equipment, develop and evaluate procedures, train personnel, and test communications.

The teleoperated sampling system is one of many tools available to the NTNF program to complete its mission. The equipment is used to supplement personnel performing manual collections when the radiological conditions are too adverse for humans. Sampling missions are carefully planned based on information gathered regarding the expected ingress and egress routes and conditions at the point(s) of material collection.

Dependent on the sampling mission plan, the vehicle can be down range for extended periods of time. Upon return to the hot line, the vehicle will off-load its sample cargo in shielded containers for processing through triage, preliminary sample preparation and analysis. After off-loading samples, the vehicle is prepped for another mission. The preparation can consist of decontamination as needed, charging batteries and restocking particulate vacuums, smear samplers and sample bin liners as necessary.

Operating environments have ranged from a relatively open exercise area to simulate the post blast scene of a yield producing IND to the clutter of an urban landscape immediately following the detonation of a vehicle borne RDD. During one post blast RDD exercise, the vehicle was tasked to enter a building and climb stairways searching for radioactive materials.

During these exercises the equipment has been used to locate and identify radioactive sources, collect real and simulated radiological samples, and collect traditional evidentiary materials. Federal law enforcement personnel have utilized the video capabilities of the equipment to gather downrange intelligence (e.g., VIN numbers) that is then used to commence investigative activities while the robotic vehicle is still down range. Additionally, the vehicles has been used to located "hot spot" sources and move them away from areas of interest allowing law enforcement personnel to deploy down range to commence "on scene" investigative activities. Numerous enhancements to the equipment and operational techniques were identified as the result of participation in the exercises.

III. CONCLUSIONS

In the event of a domestic nuclear event, the United States Government has a nuclear forensics program to rapidly and accurately identify and attribute the nuclear materials used in the event. One portion of this mission is the identification and retrieval of samples needed for the identification and attribution.

A teleoperated sampling system based on a commercially available robotic platform that meets the needs of the NTNF mission has been developed and tested in a variety of field exercises. This system provides the NTNF program the capability to detect, collect and retrieve a variety of samples that can be further analyzed for attribution purposes.

ACKNOWLEDGEMENTS

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REFERENCES

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2. D. M. C. Odell, L. J. Harpring, F. S. Moore, P. J. French, J. R. Gordon, "Ultra-wide Range Gamma Detector System for Search and Locate Operations," WSRC-MS-2005-00643, October 26, 2005.