CONF-9607137--2

Applications of Low-Cost Radio-Controlled Airplanes to Environmental Restoration at Oak Ridge National Laboratory

Jonathan E. Nyquist
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, TN, 37831 (nyq@ornl.gov)

Abstract

The US Department of Energy is endeavoring to clean up contamination created by the disposal of chemical and nuclear waste on the Oak Ridge Reservation (ORR), Tennessee, with an emphasis on minimizing off-site migration of contaminated surface and ground water. The task is complicated by inadequate disposal records and by the complexity of the local geology. Remote sensing data, including aerial photography and geophysics, have played an important role in ORR site characterization. Are there advantages to collecting remote sensing data using Unmanned Aerial Vehicles (UAVs) ? In this paper, I will discuss the applications of UAVs being explored at Oak Ridge National Laboratory (ORNL) under the sponsorship of the Department of Energy's Office of Science and Technology. These applicaions are: aerial photography, magnetic mapping, and Very Low Frequency (VLF) electromagnetic mapping.

Introduction

Oak Ridge National Laboratory (ORNL) was created as part of the Manhattan Project during World War II. In what was a remote part of East Tennessee (Figure 1), the US government purchased over 35,000 acres of farmland to create the Oak Ridge Reservation (ORR). In the past 50 years, research in nuclear energy, nuclear medicine, and weapons production led to the creation of numerous Solid Waste Storage Areas (SWSAs), shallow burial grounds on the ORR for the disposal of nuclear waste and hazardous organic chemicals. From 1955-1963 ORNL was designated the Southern Regional Burial Ground by the Atomic Energy Commission, accepting waste generated at commercial nuclear power plants (Coobs and Gissel, 1986). By 1973 over 170,000 m^3 of hazardous waste had been disposed of in SWSAs 1 through 6.

The waste disposal practices of the 1950's and 1960's were inadequate by today's standards. Bulldozers were used to excavate trenches. Then workers placed the waste, usually contained in 55-gallon drums or large steel boxes, into the trenches and bulldozed the excavated soil over the top of the canisters (Figure 2). Eventually the buried canisters corroded and groundwater leached radionuclides and hazardous chemicals from the buried waste into the local streams and the nearby Clinch River. The Department of Energy (DOE) is currently cleaning up the burial grounds at Oak Ridge and other DOE facilities with the short-term goal of reducing off-site migration of hazardous wastes.

DISCLAIMER

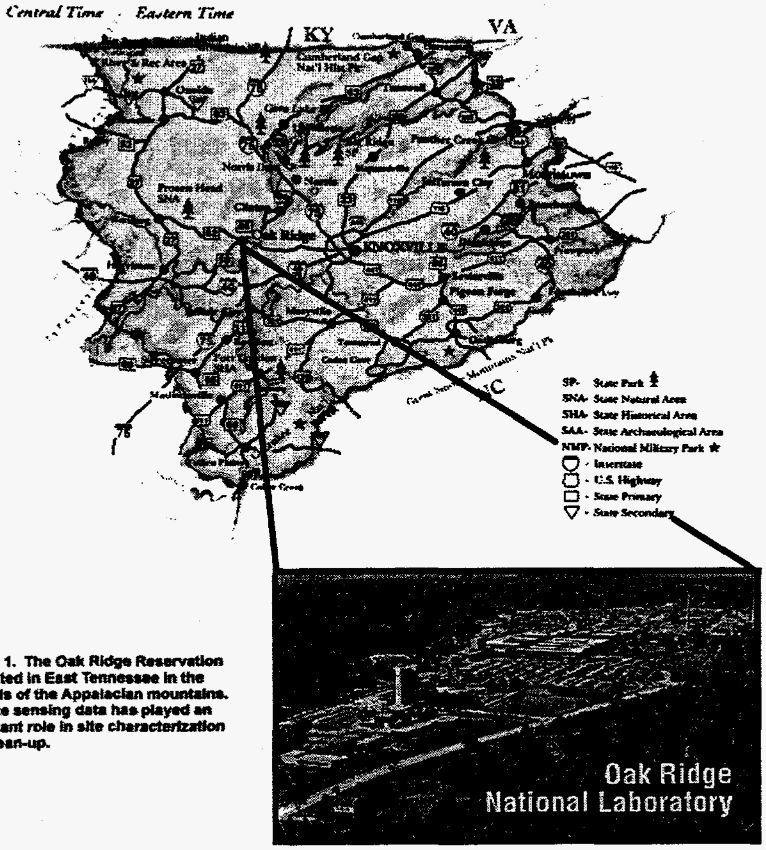

Figure 1. The Oak Ridge Reservation is located in East Tennessee in the foothills of the Appalacian mountains. Remote sensing data has played an important role in site characterization and clean-up.

Figure 2. Workers lowering waste canisters into a trench at SWSA 4.

The primary routes for contaminant migration on the ORR are surface and groundwater. To evaluate the risks to the public and the environment from off-site migration of contamination requires information about the locations and types of buried waste and the hydrogeology governing groundwater pathways. Unfortunately, in many cases the disposal records are inaccurate or incomplete; consequently, the sources of contamination are poorly known. Furthermore, because the ORR is located in the foothills of the Appalachian thrust and fold belt, the geology is extremely complex. Faults, fractures, sinkholes, and folded and tilted rock layers make modeling the migration of contaminated groundwater extremely difficult. Detailed site characterization information is essential.

Remote sensing data is an important component in site characterization and clean-up activities on the ORR. Remote sensing data collected by the Environmental Restoration Remote Sensing and Special Surveys Program includes: natural color and IR photography, multispectral and thermal imagery, and airborne radiation and geophysical data. The latter includes magnetic and electromagnetic induction measurements made by manned helicopter collected on a series of parallel flight lines spaced 150 ft spanning the entire ORR.

Collecting remote sensing data using manned aircraft is economical for large sites, such as the 35,000 acre ORR, but for smaller sites it is difficult to justify the cost of mobilization. For these smaller sites it may be more economical to use UAVs to collect remote sensing data (McCown, 1996). This paper describes recent work at ORNL developing UAV systems to collect aerial photography, magnetic, and electromagnetic data for environmental site characterization and facility management. A series of examples is used to illustrate applications of UAV technology to Environmental Restoration Problems.

Aerial Photography

The simplest and most developed application of UAVs is aerial photography. Aerial photographs have long been used to document waste site conditions. Historical aerial photographs are available for the ORR starting with US army overflights in 1943, before the land was purchased by the government, and continuing at roughly five to ten year intervals up to the most recent complete flyover in 1993.

Aerial photographs are especially useful once they have been rectified. A rectified photograph is a scanned image that has been translated, rotated, and scaled, to conform to a given coordinate system, which can then be displayed along with other spatial information using a Geographic Information System Display (GIS). GIS systems have proved extremely useful for managing and displaying the data collected as part of hazardous waste site investigations because site characterization data are best organized in a spatial database where spatial patterns can be recognized and interpreted. GIS software can be used to organize spatial data such as roads, steams, utilities, buildings, land-use classifications, and proposed construction activities into layers that can be superimposed in any order. Rectified aerial photographs are often used as the base layer. Photographs contain more information than a map and are more intuitive to interpret.

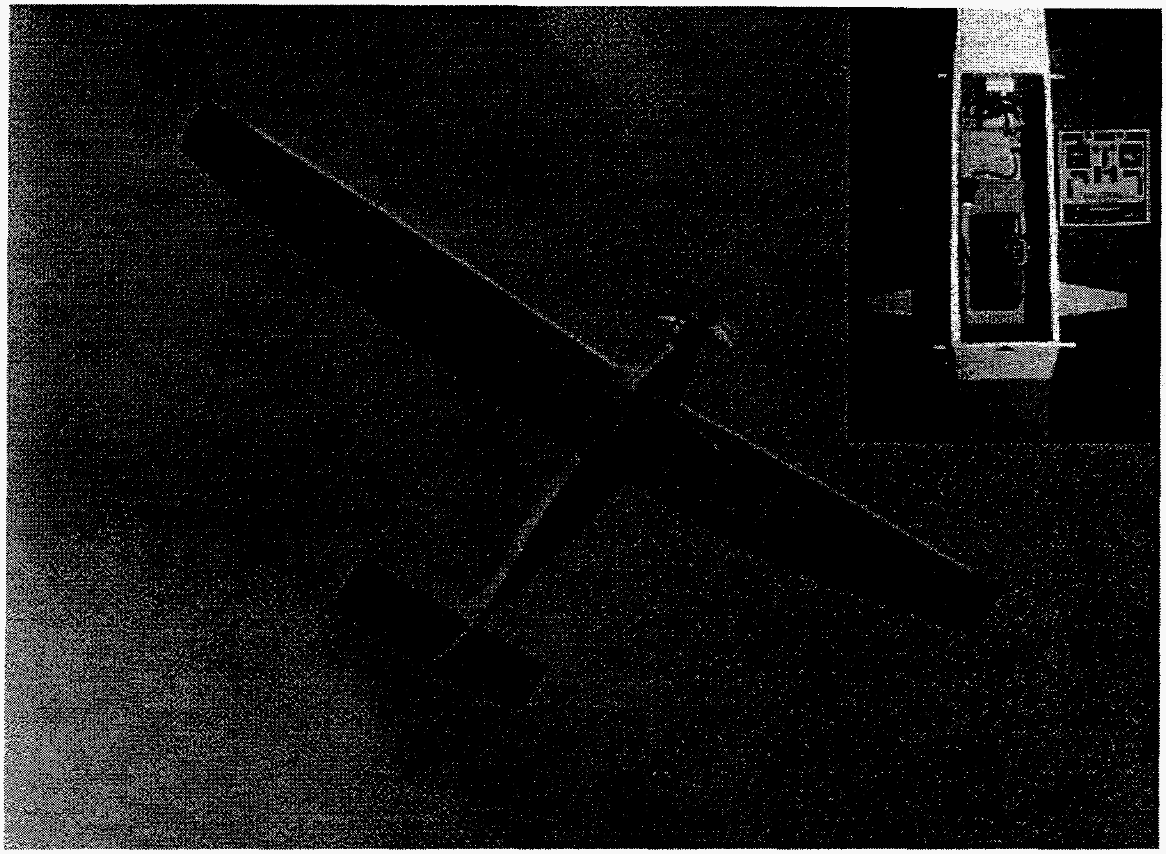

Figure 3. Simple UAV based on a hobby aircraft that has been equipped to take aerial photographs. The current system includes an onboard video camera optically coupled to the 35 mm camera view finder and a video transmitter so that the operator on the ground can frame the picture.

Figure 3 shows a radio-controlled airplane built at ORNL using a hobbyist design and modified to carry a 35mm camera, a video camera and a video transmitter. The video camera is mounted to look through the viewfinder of the 35 mm camera so that the operator on the ground can frame the picture. The principal advantages of using a UAV to collect aerial photography are low cost and ease of use. The entire UAV system --- plane, radio controller, camera, video equipment, and rectification software --- can be duplicated for less than $10,000.

One role for UAV aerial photography is to extend the useful lifetime of conventional aerial photographs. The UAV can be used to photograph any area that has changed since the last acquisition of full aerial coverage. Once the new photograph has been rectified, it can be digitally superimposed on the older image to update the coverage. Sequentially applying these "patches" then shows the evolution of the site.

Figure 4 shows part of Solid Waste Storage Area 6 (SWSA 6) before (left) and after (right) the image was updated using a picture taken by a UAV. Notice that the image on the right includes a new building and a number of additional waste canisters. SWSA 6 is still receiving waste; at the same time efforts are being made to limit off-site migration of contaminants through installation of waste caps and diversion ditches to limit groundwater infiltration. Consequently, it is important to facility managers to continually update the GIS coverage.

Figure 4. The boxed area on the original image (left) has been updated (right) using an aerial photograph acquired using the UAV show in Figure 3. Note the new building and the additional waste canisters.

UAVs can also be used to patch larger areas. After the individual images have been rectified, they can be pieced together to form a mosaic that covers a larger area (Figure 5). Currently, the images for the mosaic must be acquired by triggering a sequence of shots manually using the airplane's radio controller. As part of this project, BAI Aerosystems has modified their GPS navigation system to allow the plane to fly to preset waypoints and an automatic trigger of a sequence of photographs to cover the target area. This will be demonstrated at DOE's Portsmouth facility at the end of July, 1996.

UAVs provide inexpensive aerial photography, and inexpensive aerial photography encourages regular flyovers. This can lead to some interesting discoveries, as recent work at SWSA 4 provides illustrates. Most of the records for SWSA 4, including a map of waste trench locations, were lost in a fire. A number of remote sensing methods have been tried in order to map the trench locations, including airborne remote sensing and ground-based magnetic and electromagnetic surveys with sometimes conflicting results. This information was collected to identify the trenches responsible for several seeps where radioactive groundwater comes to the surface. The goal of an interim corrective action at SWSA 4 is to prevent further groundwater infiltration by injecting concrete grout into the trenches responsible for the seeps.

To get the drill rigs onto SWSA 4 workers poured gravel to create a new road and staging area for the trucks. A photograph taken by UAV shortly after the gravel was poured, collected simply to document the work construction work, showed that moisture from the trenches wetted the overlying gravel. Consequently, the shape of the underlying trenches was apparent in the moisture patterns seen in the gravel from the air. After the photograph was scanned and rectified, the location of these trenches were measured directly from the rectified image using a GIS.

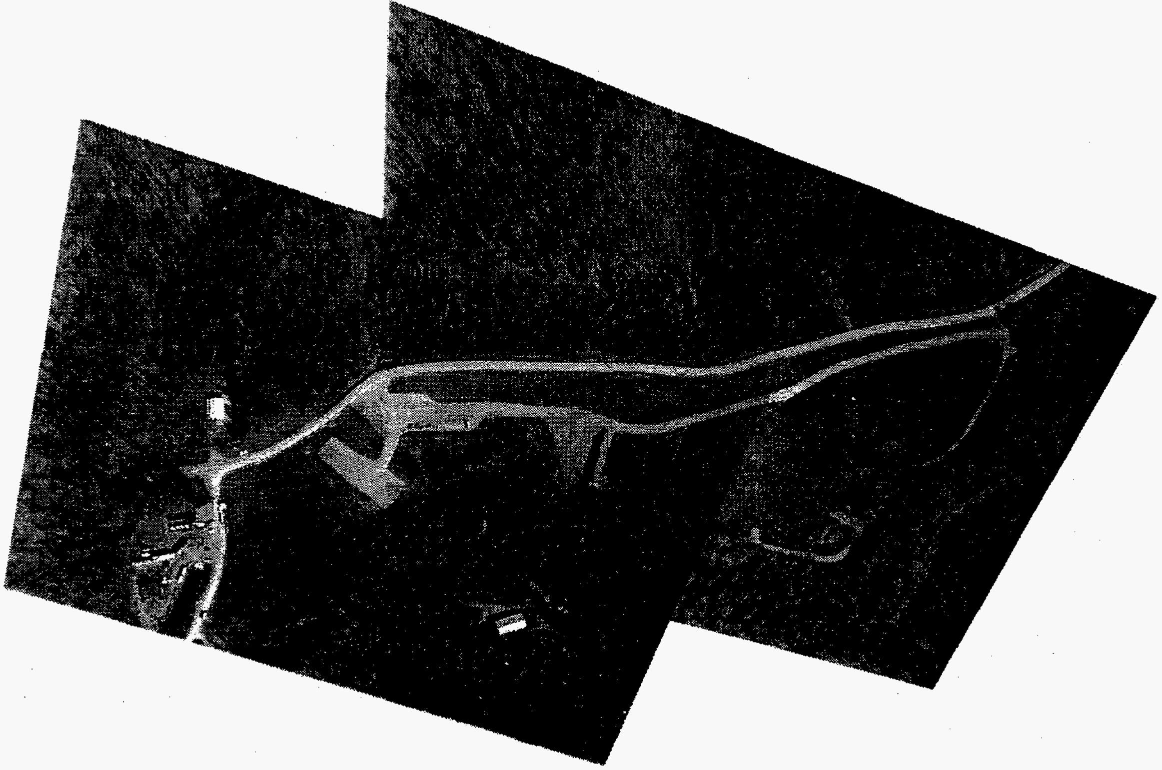

Figure 5. Two photographs of SWSA 4 that have been rectified and pieced together to form a single image that covers the entire burial ground. Image width is about 1 km.

Figure 6 shows a close-up section of an aerial photograph of one of the Seep Collection Stations (SCS) at SWSA 4, including part of the new gravel road and one of the gravel pads. The solid circles show the well drive-point locations selected based on the previously available information about the trench boundaries. For the trench on the left the moisture pattern seen in the gravel pad agrees with what was already known, but this photograph led site managers to revise the boundaries of the trench on the right. This fortuitous discovery would not have been made without UAV aerial photography. The moisture pattern is not apparent when viewed from the ground, and it would have been too expensive to collect new aerial photographs of SWSA 4 just to document construction activities.

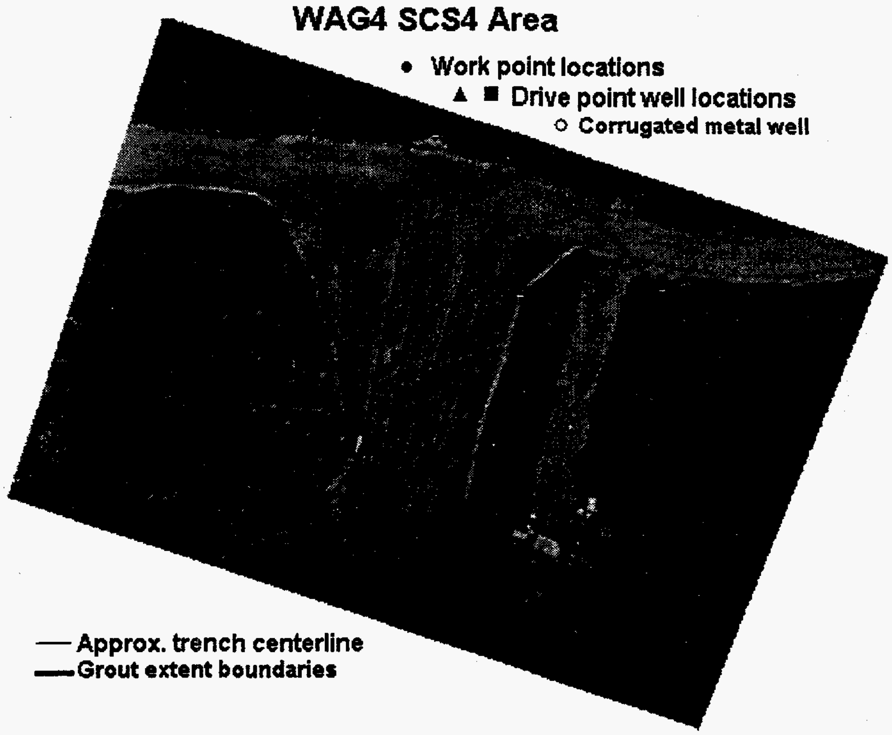

Figure 6. A close-up of the center of Figure 5 with the trench boundaries mapped from the moisture patterns and the proposed well locations superimposed.

Magnetic Surveys

One method commonly used to locate buried objects is to map small perturbations in the Earth's magnetic field created by the high magnetic susceptibility typical of drums and other steel canisters. Magnetic surveys have been carried out at on the ORR using both ground based magnetometers and magnetometers suspended beneath an manned helicopter (Doll et al., 1994; Nyquist and Beard, 1996). A comparison of airborne and ground based methods showed that airborne methods are economical for large areas and can reliably locate the boundaries of waste areas, but that surface magnetic data must be collected to provide sufficient resolution to resolve individual waste trenches (Nyquist et al., 1996).

Figure 7 shows a photograph of Solid Waste Storage Area 5 with known trench locations superimposed. The area labeled the "Undefined Trench Area" includes trenches, but the information about there locations, dimensions, and contents were lost is the same fire that destroyed the records for SWSA 4. The "Dump Area" does not include trenches, but contains assorted contaminated materials that were dumped into a large pit.

Figure 7. Aerial photograph of Solid Waste Storage Area 5 with known trench locations superimposed.

Figure 8 shows the vertical magnetic gradient measured at SWSA 5 in a series of passes using a magnetometer suspended beneath a manned helicopter. Notice that the magnetic data effectively delineates the boundaries of the burial ground, and the major concentrations of buried metal within the burial ground, but cannot resolve individual waste trenches.

Figure 9 shows the results of a walk-over survey using a standard commercial proton-procession magnetometer. The ground-based magnetic data has sufficient resolution to distinguish individual waste trenches. In fact, the survey found waste trenches not in the database.

Acquisition of the aerial magnetic data at SWSA 5 took roughly an hour; the walk-over magnetic survey more than a week. Clearly there is an incentive to develop a UAV that could fly close enough to the ground to collect high-resolution magnetic data and still acquire data quickly. In August, 1996, we are planning to demonstrate the use of a small 3-component fluxgate magnetometer and data acquisition system developed by Geophex, mounted on a UAV developed at the University of Texas, Arlington (Barnhill, 1995). This UAV is designed to hover near the ground surface, so we anticipate data quality comparable to measurements made using ground-based magnetometers.

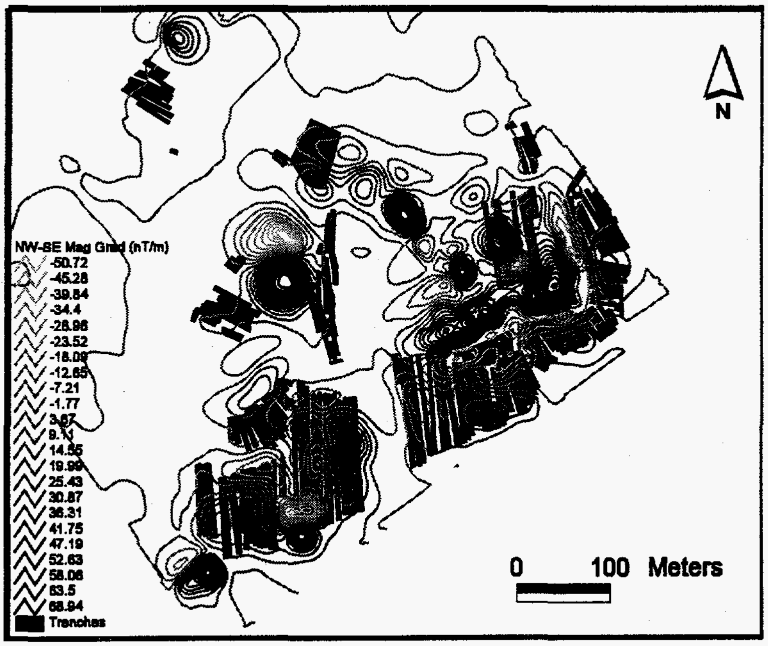

Figure 8. Vertical magnetic gradient measured at SWSA 5 in a series of passes using a magnetometer suspended beneath a manned helicopter.

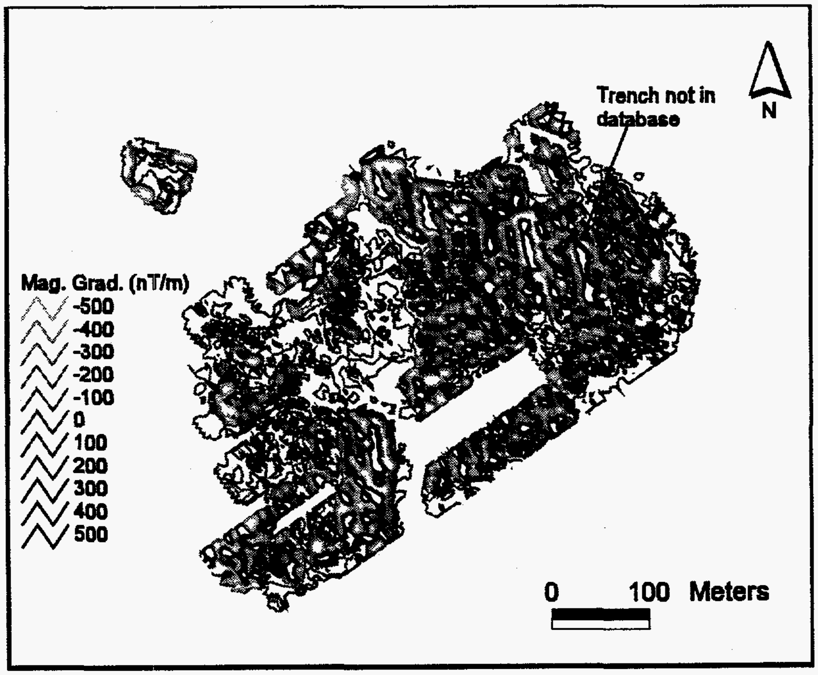

Figure 9. Walk-over vertical magnetic gradient data collected at SWSA 5.

Very Low Frequency Electromagnetic Data

Very Low Frequency Electromagnetics (VLF) is one of a family of electromagnetic induction methods. These methods are all based on the principle of broadcasting a low-frequency electromagnetic wave into the ground, thereby inducing electrical currents to flow in the subsurface. These currents produce a secondary electromagnetic field with amplitude and phase that depends on the electrical properties of the rock, soil, and any buried objects. This secondary field can be detected using a surface or airborne receiver. Thus the information about the electrical properties of the subsurface can be obtained remotely.

The problem with flying electromagnetic induction systems in a UAV is size and weight associated with carrying a large, high-power transmitter to induce the subsurface currents. The VLF method, however, takes advantage of the large VLF transmitters located around the world for long-range and submarine communication. These transmitters operate with carrier frequencies in the range of 15-25 KHz, frequencies ideally suited to electromagnetic prospecting.

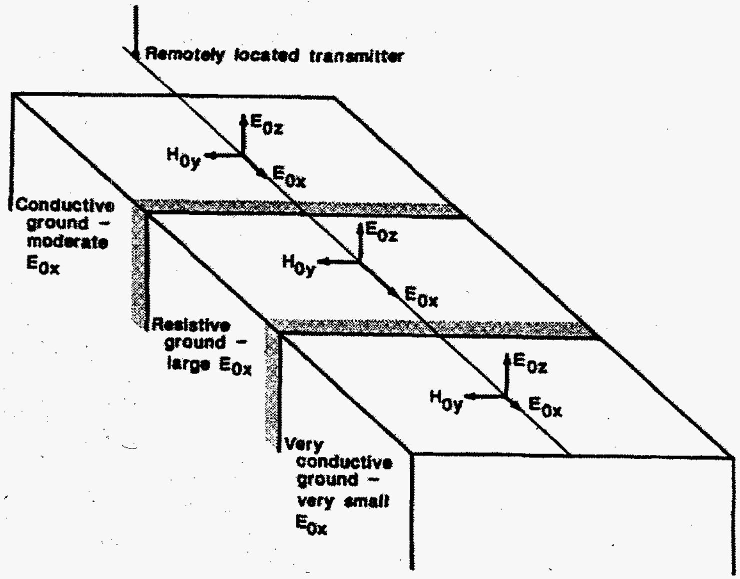

Figure 10. The effect of ground conductivity on VLF field strength. After McNeill and Labson et al., 1992.

Figure 10 shows how the ratio of electric field strength components of the VLF carrier wave change as a function of the conductivity of the ground beneath the receiver. Because the incident wave is broadcast by distant high-power VLF transmitters, all that must be carried on the UAV is a VLF receiver. Under interagency agreement with the US Department of Energy, the US Geological Survey, Denver Branch, is developing a miniature VLF receiver that will weigh only a few pounds (Figure 11). The initial field test conducted in a manned aircraft equipped with a conventional VLF prospecting system show that the miniature receiver produces high quality data. Field trials aboard a GPS-guided UAV are planned for early 1997.

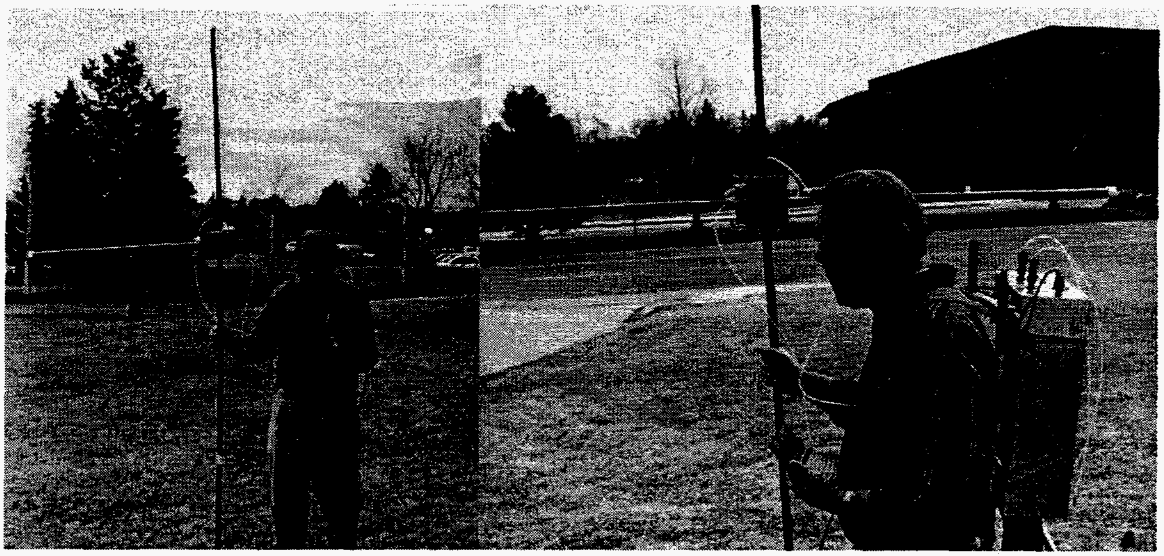

Figure 11. Prototype VLF receiver being developed by the U.S.G.S.

Discussion and Conclusions

Cost and safety are the critical factors that will determine the role UAVs play in future environmental work. As shown in this paper, small, inexpensive UAVs can be used for environmental site characterization and clean-up. Aerial photography and geophysical data collection are just two possible applications. Additional possibilities include: radiation measurements, chemical vapor analysis, and multispectral remote sensing. To be competitive, however, UAVs must be easier to use and less expensive than comparable manned systems. It is certainly possible for UAVs to compete. A recent cost/benefit analysis of this project concluded:

> The use of RPVs [Remotely Piloted Vehicles] for photographing sites is certainly applicable across all of the DOE complex. Since it is enabling, it is difficult to estimate the total cost savings to DOE, but its use will result in more efficient operations and better overall performance. If the RPV can be fully developed as a platform for miniature sensors with the reliability of conventional instruments, the cost savings resulting from implementing the technology would be substantial. If the average site that is surveyed is 10 acres, the cost savings is $12,000. If there are 500 surveys performed at DOE sites across the country per year, the net savings would be $6M. (McCown, 1996).

The same study concluded that UAVs could potentially fill a niche between ground-based and airborne geophysical data acquisition systems, acquiring the data cheaper than manned helicopter systems for sites up to about 670 acres in size. The costs of UAVs continues to decrease. In the near future UAVs may be able to compete with conventional airborne geophysical systems currently in use all over the world for mineral exploration.

In addition to cost, safety is a critical issue. As pointed out in an editorial by AUVSI president, Robert Michelson (Unmanned Systems, 1994), the FAA has not yet promulgated regulations governing UAV operation and safety requirements, and until they do, commercial applications of UAVs will remain scarce. DOE sites may represent an opportune stepping-stone on the path from military applications to commercialization. DOE must comply with the FAA, but most DOE facilities are large and remote, so the risk to the public is minimal.

As this project demonstrates, there are numerous potential applications of UAVs to environmental site characterization and monitoring. The issues of cost and safety will determine whether or not this potential is realized.

Acknowledgments

This work was performed at Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract number DE-AC05-96OR22464.

References

Albers, B.J., Nyquist, J.E., and Purdy, C.B. (1996), The Department of Energy's use of remotely piloted vehicles for environmental management (this volume).

Barnhill, D. M. (1995), UTA's 1995 aerial robotics competition entry. Proceedings of the 1995 AUVSI symposium, July 10-12, Wash. D.C., p.620-626.

Coobs, J.H. and Gissel, J.R. (1986), History of Disposal of Radioactive Wastes in the Ground at Oak Ridge National Laboratory. ORNL/TM-10269.

Doll, W.E., Nyquist, J.E., and Beard, L.P (1994), Airborne geophysical survey of the Oak Ridge Reservation, Tennessee. ES/ER/TM-123, 7 pp.

Walker, J.W. (1993), Low altitude large scale reconnaissance: a method of obtaining high resolution photographs for small areas. Published by: Interagency Archeological Services Division of the National Preservation Program, Rocky Mountain Office, National Park Service, Denver CO, 127 pp.

McCown, A (1996), Remotely Piloted Vehicles, Los Alamos National Laboratory, Environmental Technology Cost-Savings Analysis Project, LA-UR-96-2300, July, 1996, 11 pp.

McNeill, J.D. and Labson, V. F. (1991), Geologic mapping using VLF radio fields. In: Electromagnetic Methods in Applied Geophysics, M.N. Nabighian (ed.), part B, v2, p521-640.

Michelson, R.C. (1994), Time to burst the clouds. *Unmanned Systems*, Summer 1994, v12, number 3, p. 5.

Nyquist, J.E. (1994), A "model" geophysics program. Proceedings of the 1994 Symposium for the Applications of Geophysics to Environmental and Engineering Problems, Boston, MA, March 27-31.

Nyquist, J.E., and Beard, L.P. (1996), Clean enough for industry? An airborne geophysical case study. Proceedings of the 1996 Symposium for the Applications of Geophysics to Environmental and Engineering Problems, Keystone, CO, April 28 - May 2, p. 853-863.

Nyquist, J.E., Beard, L.P., and Johnson, D., (in press), Ground and airborne magnetic and electromagnetic surveys at a hazardous waste site. Proceedings of the 1996 Annual Meeting of the American Society of Civil Engineers.