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A Generic Multi-Electrode Automated/Semi-Automated Field Resistivity System

Douglas D. Werkema

A GENERIC MULTI-ELECTRODE AUTOMATED / SEMI-AUTOMATED FIELD RESISTIVITY SYSTEM

by

Douglas D. Werkema Jr.

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Douglas D. Werkema Jr.

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Douglas D. Werkema Jr., M.S.

Western Michigan University, 1998

Geophysical field exploration using electrical resistivity typically employs the use of four electrodes which are progressively relocated to positions that differ from a few meters to hundreds of meters. Consequently, field operations are tiresome and often lead to imprecise locations of electrodes and poor data quality. This project develops an automated field resistivity system.

This automation of resistivity measurements is accomplished by using multiple sets of field electrodes, a programmable switch box, remotely controlling the acquisition instrument and digitally storing the results. Controlling the process is the Acquisition Control© software, for Windows 95©. The prototype switch box has the capability to switch sixteen electrodes, four of which are selected at any one time via multiplexers. Once the data is rapidly taken via a laptop computer, it can be processed as new data is simultaneously being acquired, therefore yielding essentially real-time results and immediately guiding further investigations.

Results of this project show a working prototype which efficiently and accurately gathered data with time improvements of 500% to 600% over manual data acquisition. Overall, the development and testing of this prototype was a complete success and a patent is pending.

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INTRODUCTION

Problem

Geophysical exploration using electrical resistivity typically employs the use of four field electrodes. During a field survey, these electrodes are progressively relocated to positions that differ from a few meters to hundreds of meters. Consequently, field operations are tiresome and often lead to imprecise locations of electrodes and poor data quality. Therefore, improved field data acquisition techniques are needed to eliminate these labor intensive and sometimes imprecise procedures. This project develops a multi-electrode automated field resistivity system which removes the wearisome and primitive field acquisition procedures of the past, with state of the art automated acquisition.

Objective

The objective of this project is to automate the acquisition of resistivity data by designing a generic automated field resistivity acquisition system. The generic capabilities will enable the system to be used with industry standard equipment and allow unlimited data acquisition capabilities.

This objective can be divided into three parts: field electrodes, switch box and the controlling software. The criteria for the field electrodes is to use not just four electrodes, but multiple numbers of field electrodes, so that they only need to be positioned in the field once. Furthermore, these electrodes need to be inexpensive and versatile.

Next, a digitally controlled switch box must be developed to select the proper field electrodes for a resistivity reading. This switch box must also remain versatile such that an essentially unlimited number of electrodes can be input. Furthermore ,the inputs must be compatible with either surface or down-hole electrodes. Additionally, the switch box requires four outputs to connect to industry standard resistivity meters such as the Iris Syscal series, AGI Sting, or the ABEM Terrameter. Therefore, the resistivity acquisition is accomplished by these standard resistivity meters and the system proposed does not take a reading but simply facilitates the automation of efficient data collection. Equally important, the switch box must enable each electrode to be connected to any one of four possible outputs, such that any geometrical arrangement of electrodes is possible. Finally, this switch box must be digitally controlled, so that true computer controlled automation is accomplished.

The last component to the automated system is the controlling software. This software must remotely control the resistivity meter and the switch box while visually displaying the data in a user friendly format. Additionally, the data must be stored in a format compatible with current inversion and plotting programs. Furthermore, the software must be developed in a multitasking environment so that resistivity data can be acquired while other data are processed, thereby yielding essentially real time results.

The objective of this project is to construct a working prototype of this generic multi-electrode automated acquisition system.

CHAPTER II

THEORY

Geophysical Exploration

Geophysics is the study of the physics of the earth, its atmosphere and its space (Telford et al, 1990). Geophysicists investigate the physical properties, structure and composition of the earth and earth's materials. Geophysical exploration involves the application of the physical sciences to understanding the crustal material of the earth such that this knowledge can be utilized by man (Jakosky, 1957).

Since the earth is composed of many different physical materials, geophysics has evolved into different methods which measure the contrasts of these physical properties. Geophysical exploration attempts to determine the nature and distribution of the materials affecting these measurements (Burger, 1992). For example; variations in elastic moduli and density effect seismic waves propagate, density differences cause gravitational acceleration variations, the magnetic susceptibility of materials is also detectable by surface instruments, as are, temperature variations, radiation affects, electrical conductance or resistance and permittivity. These variations of earth materials properties are detectable by the exploration geophysicists using the proper detection instrument (Burger, 1992). The value of geophysics is its ability to acquire information about the subsurface non-invasively (i.e. without excavation).

Historically, geophysical exploration probably began with Gilbert's discovery that the earth behaves as a great irregular magnet and Newton's observation of the falling apple (Telford et al, 1990). Likewise, Jakosky, (1957) suggested its beginnings may be rooted in ancient Chinese and medieval literature. Since then however, non-invasive investigations of the subsurface have evolved from the use of the divining rod, to relying on science and the natural properties of materials. With the development of these fundamental laws of science and material properties, the science of geophysical exploration has given us what we know of the earth's composition and the location and extent of resources for human consumption. Most specifically, the demand for mineral and petroleum resources has fueled the exploration work (Jakosky, 1957 and Telford et al, 1990). In the past few decades, there has been an increasing focus on near surface exploration, that is the upper few hundred meters of crustal material. This exploration has been mainly sparked by ground water, environmental, geotechnical, and archaeological reasons (USEPA, 1993). Also, this latest interest in geophysical exploration has shown an increase in the manufacturing of precision near surface geophysical exploration instrumentation. This project focuses on complementing the current instrumentation used in the measurement of the electrical properties of earth materials. Specifically, the conductance or resistance of the earth's materials.

Electrical Methods

Historically, Gray and Wheeler in 1720, conducted electrical studies of rocks and recorded their particular conductivities (Jakosky, 1957). Following this study, many advances have been made in the application of electrical methods to further characterize and understand the subsurface. Pioneers in this advancement were; Watson, 1746; Robert Fox, 1815; Conrad Schlumberger, early 1900's; F.H. Brown, early 1900's; H.R. Conklin, 1917 Crosby and Leonardon, 1928 (Jakosky, 1957 and Burger, 1992). Further developments in computer and electronics technology has spurred subsequent advancements such as instruments that record continuously with high degrees of accuracy. Additionally, the economic incentives of the petroleum and mineral industries fueled innovative techniques of acquisition and interpretation (Jakosky, 1957, Burger, 1992).

Geophysical exploration using electrical methods is applied in a wide variety of disciplines including: mineral exploration, petroleum exploration, groundwater studies, and environmental studies. In fact, no other surface geophysical method has been used more widely than electrical and electromagnetic induction methods to the study of ground water and contaminated sites (USEPA, 1993). Electromagnetic methods utilize the lower frequency radio waves and the audio portions of the EM spectrum and are not covered in this project. Electrical methods applies to techniques in which electrical currents are injected into the ground via two current electrodes which are in direct galvanic contact with the earth. Typically, two additional electrodes, the potential electrodes, are used to measure the potential drop across certain geometric arrangements. The subsurface materials and structure cause variations in resistance to current flow and cause distinct variations in the potential difference measurements (Burger, 1992). Resistance variations from the surface to more than 15 km depth in typical crustal material is controlled by aqueous electrolytic conduction. This conduction is a function of the formation material, porosity and degree of saturation and is related in the general form of Archie's Law:

$$F = \rho_r / \rho_e = a\,\phi^{-m}, \qquad \text{(eqn. 1)}$$

where: F is the formation factor
ρ_r is the resistivity of the rock
ρ_e is the resistivity of the solution in the pores of the rock
a and m are constants peculiar to the rock type
ϕ is the porosity
(Ward, 1990)

Electrical methods operate using direct current (DC) which is alternately switched from positive to negative creating a square wave. This 'commutated' DC typically operates at low frequencies, around 10 Hz. Electrical methods can be further subdivided into induced polarization (complex resistivity or IP) and self-potential (SP). This project focuses on DC electrical resistivity.

<u>Direct Current Electrical Resistivity</u>

Historically, DC electrical resistivity (ER) dates back to the turn of the century. Near surface ER investigations in groundwater and environmental investigations began in the 1930's with a large influx in the focus on environmental studies in the last few decades (USEPA, 1993; Ward, 1990). DC electrical resistivity measures the resistance to flow of electricity in subsurface material. The calculated result of an ER survey is an apparent resistivity (ρ_a) measurement (measured in Ohm meters (Ωm) or Ohm feet (Ωft), because it is the sum or average of the subsurface material below a certain plotting point. The exact depth is unknown and therefore the reading is a summation of the resistivity of the earth as a factor of the geometric arrangement of the electrodes. This geometric factor accounts for the dimensional term (meters or feet) included with the resistance units (Ω) above. The geometric factor is unique to the arrangement or array of electrodes placed in the field. This relationship can be formulated as below:

$$\rho_a = (\Delta V / I) * K \qquad \text{(eqn. 2)}$$

where, ΔV is the potential drop

I is the current used

K is the geometric factor per type of electrode array .

(Ward, 1990)

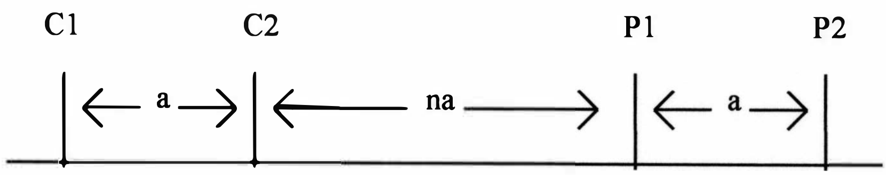
Typically, ER surveys are conducted with four electrodes: two current electrodes, indicated as C1,C2 or A, B and two potential electrodes, noted as P1, P2 or M, N. Other surveys such as pole – dipole, and mise-a'-la-masse(Ward, 1990, Telford, 1990)are considered three electrode arrays because one current electrode is fixed and located at a great distance. This study focuses on the four electrode arrays.

Electrode Arrays

There have been many electrode arrays or configurations used in ER surveys. This project focuses on two array types: Dipole Dipole (axial or polar) and Wenner Profile. Each array has its unique differences and is utilized for different reasons. The USEPA (1993), Zohdy et al. (1974), Ward (1990), and Telford et al. (1990) discuss the precise advantages and disadvantages of array types. Ward (1990) and Telfrod et al. (1990) present derivations of the geometrical factor (K) and the corresponding apparent resistivity (ρ_a) formula for different arrays.

Dipole Dipole

Zohdy, et al. (1974) describes six basic types of the dipole dipole array: azimuthal, radial, parallel, perpendicular, equatorial and axial or polar. This project only utilizes the axial or polar dipole dipole array. In this particular dipole dipole array, the electrodes are configured in a straight line. The distance between the current electrodes (C1 and C2) and the distance between the potential electrodes (P1 and P2) is varied while the distance between the respective electrodes remains constant. This is shown in Figure 1. Surveys utilizing the dipole dipole array produce a resulting pseudosection of the earth's crust which is simply a display method for the raw field data (Telford et al.,1990; Ward, 1990; Burger, 1993).



$$K = \pi n a (n + 1)(n + 2)$$

$$\rho_a = K(V / I)$$

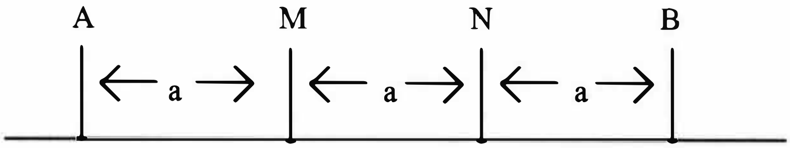
Figure 1. Dipole Dipole Array Geometry, Geometric Constant (K), and ρ_a Formula.

Wenner Profile

The Wenner array was first proposed for geophysical exploration by Wenner in 1916. Figure 2 displays the four electrodes, A, M, N, and B positioned on the surface of the ground in a straight line such that the distance between each electrode is constant and equals the spacing denoted as 'a' (Zhody, 1974; Ward, 1990; Telford, 1990). The horizontal profile is completed to measure any lateral changes in the earth's resistivity at a fixed electrode spacing. Therefore, the effective depth of penetration is approximately constant, while the whole array (all four electrodes) is relocated along a straight line and is subject to near-surface resistivity variations along the profile.

Field Procedures

Direct current electrical resistivity method, specifically electrical resistivity, conventionally employ the use of four electrodes oriented in the particular array asnecessary. Once the electrodes are properly positioned, a reading is taken to



$$K = 2\,\pi\,a$$

$$\rho_a = K\,(\,V\,/\,I\,)$$

Figure 2. Wenner Array Geometry, Geometric Constant (K), and ρ_a Formula.

determine the apparent resistivity of the ground at a particular location (plot point). Field surveys using four electrodes require the relocation of all the electrodes to new positions, which may differ from a few meters to hundreds of meters from the initial positions. Consequently, field operations are very exhaustive and can lead to erroneous positioning of electrodes and poor data quality.

Dipole Dipole

A dipole dipole survey involves many electrode movements. If only four electrodes are used they are positioned in line according to the dimensions necessary and a measurement is taken. Subsequently, the potential electrodes are moved one ‘n’ position away and another reading is taken. This is continued until the greatest specified ‘n’ spacing is reached (Figure 3). Then the current electrodes are moved one ‘a’ spacing along the line and the procedure repeats itself starting at n=1 (Figure 4).

Wenner Profile

A typical Wenner profile involves the placement of the four electrodes at pre-

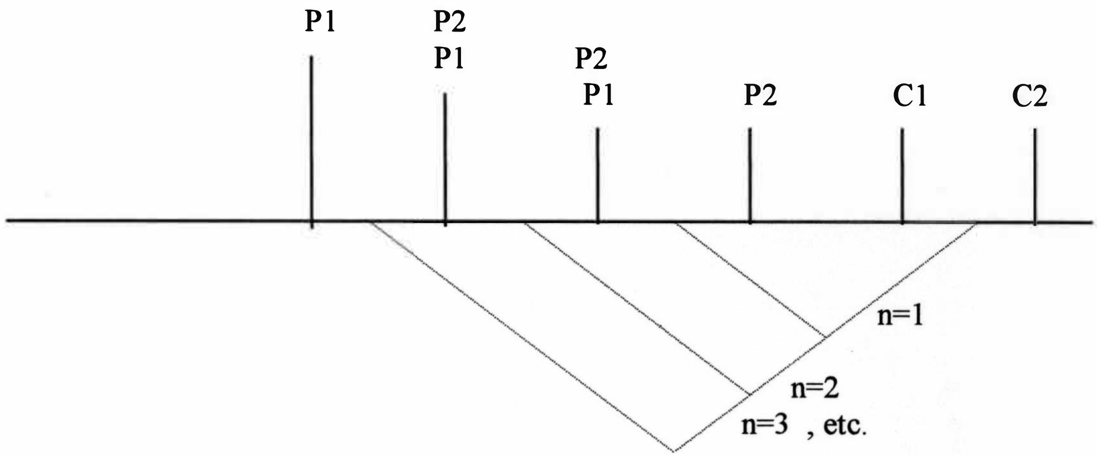


Figure 3. Expanding Dipole Dipole to n=3.

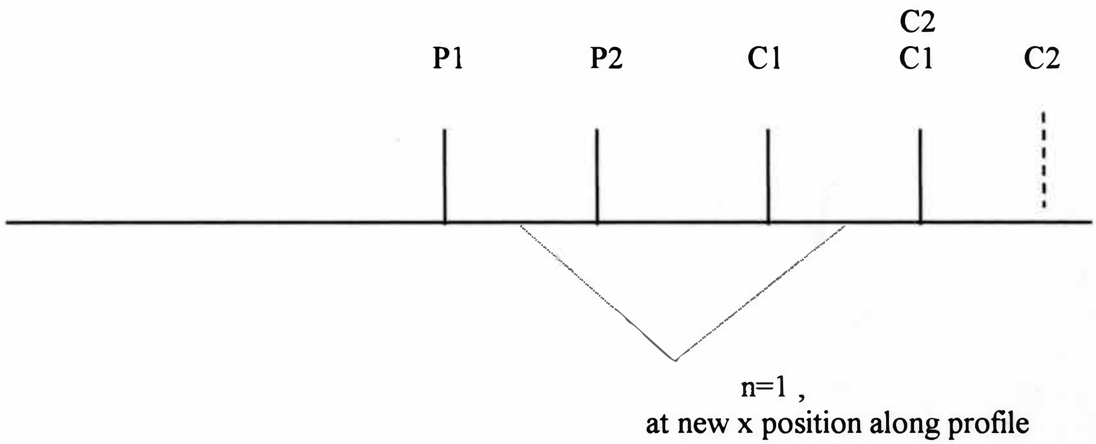


Figure 4. Movement of Potential and Current Dipole Along Profile. At this point, the potential dipoles are expanded out to the indicated 'n' expansion, as in Figure 3.

defined spacings. After a reading is taken, the electrodes are relocated to the next position, usually a distance of 0.5a, 1a, or 2a further along the line where another reading is recorded. Figure 5 shows the increment of movement along the profile which can be equal to the 'a' spacing or more or less. From an automated perspective, only 'a' spacing movements are truely efficient. Otherwise, additional electrodes must be positioned. The Wenner profile procedure may continue for 100's of meters dependent on the length of the survey. As one can readily observe, surveys using this method can become very tiresome. Exhaustion in the field leads to poor data quality and a wasted effort in terms of time and money. This problem can be corrected by using more electrodes with individual wires leading back to the instrument. Surveys are then completed by replacing wires on the acquisition instrument and selecting the appropriate electrode for the particular plot point. This greatly increases the data quality because much less traversing along the survey line is required.

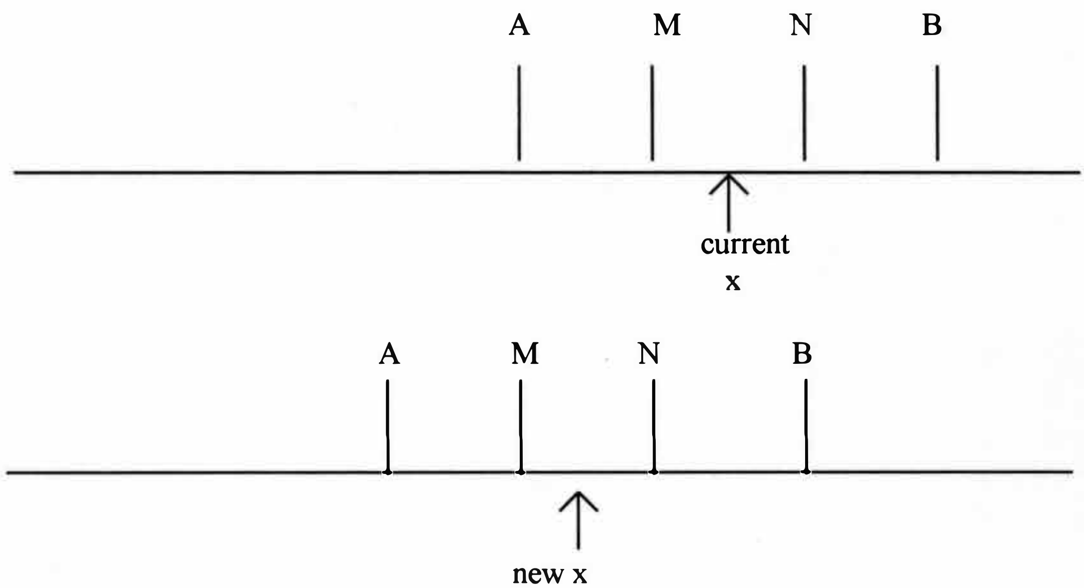


Figure 5. Wenner Profile, Indicating Movement of Electrodes.

CHAPTER III

REVIEW OF RELATED LITERATURE

Presently, there are several multi-electrode systems available in the geophysical industry; Iris Instruments, Advanced Geosciences, Inc., Geoscan Research, ABEM and OYO Corporation, as well as those which have been developed by the University of Waterloo, University of Birmingham, University of Leicester, University of Wisconsin – Milwaukee, the Southwest Research Institute, and Lawrence Livermore National Laboratory . However, most systems are not compatible with different resistivity acquisition instruments, arrays (surface or downhole), or operate in the multitasking environment of Windows 95®, and most are bulky and expensive.

Multi-Electrode Systems in Industry

Iris Instruments

Iris Instruments (1998) offers a multi-electrode resistivity system for use with their resistivity meters, the Syscal Junior, Syscal R1+, and the Syscal R2. Iris Instruments describes the system as an Intelligent Node system for automatic acquisition of preset or programmable sequences of field measurements (Iris Instruments). With a 16 channel multinode unit which can be connected in series with up to 16 additional units, 256 switchable nodes are possible. Each electrode consists of a stainless steel rod and an addressable bus which are connected via multi-conductor cable which is available in segments of 5 or 10 meters. Each electrode can be assigned to a current (A or B) or to a potential (M or N) position. The cost of the electrodes and the controlling system is on the order of $11,000.

Additionally, Iris offers a continuous profiling resistivity system (CORIM) which consists of a set of electrode carpets and a trolley which contains a portable PC, a controller multiplexer, and battery. Six electrode carpets are connected in series and then connected to the trolley. The trolley is then attached to a vehicle for towing. One electrode carpet is used as a transmitter and the others are receivers. In this manner, the fixed length array is towed and data is acquired and stored on the PC. The CORIM allows for rapid continuous profiling on smooth terrain with fixed electrode spacing. This system is very efficient, however it is also very dedicated to the electrode array type and the required hardware.

Advanced Geosciences, Inc. (AGI)

AGI (1998) markets their Swift™ Automatic Smart Electrode System. This system is designed for efficient acquisition of large scale resistivity data. The system is composed of one interface box and up to 254 electrode switches ("smart electrodes"). The smart electrodes are placed on electrode stakes and are connected by a multi-lead cable to a central interface unit. The multi-lead cable includes 6 wires: A, B, M, N and two control lines. Each smart electrode contains an addressable switch to activate the particular electrode. The Swift™ system is controlled either directly by AGI's Sting™

earth resistivity meter or by an external MS DOS computer. Resistivity measurements are taken by the Sting™ and can be stored in the internal memory or to the hard disk of the field computer. Common array types are available on the Sting™ or the user can program custom arrays on the computer. The cost of the switching mechanism approaches $10,000. The system has been tested and shown to be very efficient and yields quality results. As indicated this is a very expensive system, which is customized for use with AGI resistivity instruments and their multi-core cable.

Geoscan Research

Geoscan Research (1997) recently introduced a fully automated resistivity system primarily for shallow archaelogical work. This system includes a resistivity meter, multiplexers, probe arrays, and processing and display software. The resistivity meter can take up to four readings per second and is capable of fully automated data collection. The multiplexer utilizes solid state relays and can use predefined arrays or user defined arrays. The probe arrays are constructed modularly. The processing and analysis software is integrated into the above system to ease field processing. Although this system is fully integrated, it cannot be configured with other resistivity meters, processing systems or probes. Therefore, the user must have a complete Geoscan survey system to complete a survey.

ABEM

ABEM Instrument AB (1998) in Sweden offers the ABEM SAS 4-32 Multimac. This system is a multi-electrode resistivity system, which utilizes the ABEM Terrameter SAS 300C, an ABEM Geomac III computer or field laptop, and the ABEM SAS 4-32 Multimac. The Terrameter SAS 300C is ABEM's IP and resisitivity acquisition instrument. The computer, either the ABEM Geomac III or a laptop, controls the switching process. The SAS 4-32 Multimac consists of a set of two-conductor current and potential cables, 40 clip-on electrode switchers and a distributor box. The electrode switchers are addressable and attached to ABEM steel electrodes. Standard Multimac arrays are designed for Schlumberger and Wenner arrays. However, ABEM will customize and design suitable arrays for the user's particular applications. This is a dedicated system which is not very flexible. Only certain array types are possible and only ABEM equipment is compatible.

OYO Corporation

Goebuchi et al. (1988) introduced a new resistivity meter, which features fully automatic measurement and a built in analysis program. This electrical prospecting system utilizes a 16-bit microprocessor to conduct measurement and analysis automatically in the field. Developed to improve the signal to noise ratio in field measurements, this system called the McOHM II, consists of an electrode switchover scanner, a resistivity meter, a vertical exploration analyzer and a printer/RS-232C output section. All operations are controlled via a 16-bit microprocessor.

Measurement is automatic with analysis of measurement error and the user must select which electrode array is to be used. The following choices are possible: Offset Wenner (Wenner + Eltran + Staggered methods), the Schlumberger and dipole methods. The McOHM II does not require a mini-computer or laptop because the ROM base determines resistivity structure from measurement values automatically. The transmitter transmits current from a 200v converter supplied from a 12v battery, passing through a polarity switching circuit and into the ground. The receiver section measures current and potential digitally, as the signal goes through a low pass filter through an isolation amplifier and to an A/D converter. The scanner section is the switching mechanism and determines which electrodes are to be used in the measurement. The control section, acting as a CPU for the entire system, controls all operations. Finally, the processing portion processes the data for quick analysis. A drawback of this system is that to expand to more electrode types and processing algorithms the ROM base must be expanded and reprogrammed. The actual electrode connections and maximum number of electrodes possible could not be determined. Since the system is based on a dedicated computer, the number of electrodes must be limited to the ROM base. Also the operation of all acquisition is completely specific to McOhm II and cannot be integrated with other instruments.

Multi-Electrode Systems in Academia and Research

University of Waterloo

Schneider, et al. (1993) developed an automated high resolution DC resistivity system at the University of Waterloo for use as a spatial and temporal monitoring technique in hydrogeologic field experiments. The main elements of this system include resistivity measurement hardware, multiplexer banks, surface and in situ electrode arrays and controlling software which automates the system. The switching element or multiplexer bank uses SPST (single pole, single throw) relays for the multiplexing of four-point (A, B, M, N) resistivity measurements. This switching is completed through line multiplexing where an array of 16 relays are connected as 4 groups of 4:1 multiplexers for a matrix. The inputs (A, B, M, N) are switched to the line multiplexed outputs which are connected to a relay at every fourth electrode in a staggered manner. A four-point measurement can be made at intervals of electrode 'a' spacings along a profile at odd increments of electrode 'a' spacings. Using this system, a 25 electrode array can be implemented with only 44 relays configured as 11 banks of 4:1 multiplexers with 1 per electrode (with 3 relays leftover) and 16 for the line multiplexer bank. This configuration requires only (16 - n) relays per n electrodes. A total of 8 relays must be closed at once in order to take a measurement; 4 to configure the line multiplexer and 4 to select the electrodes. Which electrodes are selected determines how the line multiplexer is mapped. This scheme of multiplexing electrodes is efficient in component use but limited because only in-line arrays can be used where the 'a' spacing is constant. Additionally, the system can only be configured for use with 25 field electrodes.

The basic system tasks such as the configuration and control of the multiplexer network, the measuring of resistivity at selected intervals, the storage of the data and the reduction and analysis of the data, are controlled by the software. This system includes its own resistivity meter which generates a current waveform and measures the current and potential . The output voltage maximum is +/- 140 volts and measurements are made using a 0.5 second stepped square wave. The data acquisition control program is written primarily in Microsoft Quick Basic v4.0®. This process consists of reading the RELAY.CFG file to define the switching configuration of the system, reading the .SCN file to define the measurement parameters for this scan, and then executing the series of measurement instructions that follow in the SCN file. The name of the .SCN file to be used and the desired output file name are passed to SCAN on the command line, allowing the program to be called from batch files, running automatically without user interaction. Data are written to disk in ASCII format. Recorded for each measurement are: current, potential, apparent resistivity, their respective standard deviations, electrode position, and the time of the measurement. Additional processing utilities are developed specifically for verification of data quality, data format conversion, data transformation, and data plotting.

Comparing this Waterloo system to the one proposed in this project reveals many differences. The system can only be used with in-line arrays (i.e. sequentially ordered electrodes), the current source has limited output power of 140 v., and is therefore only useful with small "a" spacings and low contact resistance at electrodes, and cannot be used with industry standard resistivity equipment (i.e., Syscal, etc.).

University of Birmingham

Griffiths and Turnbull (1985) present a multi-electrode array for resistivity surveying. The ABEM SAS 300 Terrameter is used as the resistivity meter and a field computer controls the acquisition and switching. This multi-electrode array system, consisting of an eight-core cable (Barker,1981) made up from 20 separate 50 meter sections, are each reel mounted. Each reel is placed near an electrode, enough cable is unwound from each reel to enable connection to an adjacent reel. and electrical continuity is provided throughout the full length of the array. A short section of single conductor cable connects each electrode to its control and switching unit, which is housed in a weather tight box in the hub of the reel. Each set of five control units is powered from a 12 v battery box, and a total of four battery boxes are required for the full twenty-electrode array. The electrodes, equally spaced along the survey line, are isolated from the next and thereby minimizing voltage loss due to cable resistance. The multi-core cable carries the power lines, two current and two potential conductors and one additional conductor to operate the switching. Current and potential conductors are connected directly to the ABEM SAS 300 Terrameter. Each control box contains a Mostek type SCU microprocessor which is used to switch one of four reed relays and connect the associated electrode to the required measuring line. These microprocessors are controlled via field computer (laptop). Software, written in

Microsoft Quick Basic v4.0®, allows the user to take resistivity measurements by the operation of a single key stroke, which takes and records a reading, and advances the electrodes to the next step. The resulting data are then stored on the laptop hard drive. Any desired configuration of four electrodes can be used and the measurements can be made in any sequence. This system, although very versatile, is limited to the ABEM SAS Terrameter 300 and to arrays of twenty electrodes.

Later, Griffiths et al. (1990) introduced a newer version of the above system which employs an array of 20 equally spaced electrodes that can be extended to 32 electrodes. Lighter and easier to use, this system eliminated the previous need for heavy battery boxes by introducing small rechargeable battery packs mounted to the reel hubs. Also, seven conductor cables are used as opposed to eight. Four conductors are used to connect the appropriate electrode (A, B, M or N) to the resistivity meter, two are used for communication from field control computer, and the remaining line is used as the system ground. Additional improvements claim that any suitable resistivity meter and any IBM-compatible laptop computer can be used with the array and that this new version has the ability to position the computer and resistivity meter at any point on the cable. Easing field acquisition, continuous profiling is possible by relocating the twenty electrodes as progressing along a survey line. For longer profiles, a 'roll along' technique can be implemented by leap frogging the electrodes and cable from behind the computer to the front of the computer. This new system, termed the microprocessor-controlled resistivity traversing (MRT) system, has been successfully applied in Nigeria by Griffiths, et.al., (1990) and

Olayinka and Barker (1990). These applications prove that the MRT system can be readily adapted to field conditions and can be used in more than just a fixed spacing Wenner array. This MRT system, although an improvement, still requires separate reels and batteries for each electrode. Furthermore, the limitation of thirty-two electrodes does inhibit the ultimate use of this system.

University of Leicester

Meju and Montague (1995) introduced a flexible automated or semi-automated resistivity data acquisition and analysis (ARDAA) system. This system is developed for use with any four-electrode output resistivity meter. The main component of the system is a Digital Switching Unit (DSU) which is interfaced into a portable IBM compatible field computer and a resistivity meter. This electronic switch box consists of two layers of relays. The first layer determines if an electrode is to be used for current or potential and the second layer sets the electrode position. Each layer has four operational sections; demultiplexing, memory, relay switching and display. The field computer controls the DSU via the parallel port. The data analysis process utilizes inversion routines by Meju (1995). Electrodes are connected to the system using the existing multicore cable system (Barker, 1981) or modern cable systems with connected electrode switches and decoders. The DSU uses data tables, which can be modified to suit different electrode configurations. A semi-automated operation mode, which allows the user to visually inspect the incoming data, is sequential and begins with the operator input of the array type and cycle time. Then layers 1 and 2 are set, the resistivity meter is activated and there is a delay to allow the resistivity meter to cycle through its measurement. Finally, there is an audible signal and additional delay, allowing the user to inspect the data. The fully automated mode requires the computer to record and process the field data as it is acquired. This mode yields in-the-field determination of the survey results and guides further investigations. The authors discuss a time savings of 43% when operating in automatic mode, and comment on the potential use of such a system in remote-site monitoring. This system, built for $500.00, yields good data quality and was proven to decrease field acquisition time. However, this system is limited to only being used with multi-core cables and the acquired data is dedicated to the inversion routine by Meju (1995), although other routines could conceivably be used.

University of Wisconsin – Milwaukee

Winkelman (1981) shows a computer automated lake resistivity system, which automatically records the apparent resistivity, self potential and temperature of the water at eight second intervals. The instrument, controlled via FORTRAN routines, includes a large computer, CRT, an A to D converter, eight inch floppy disk drive, and a boat. Obviously, this system is rather archaic and would not accomplish the goals set forth in this project. However, it is a good example of the evolution of automated resistivity survey systems.

Taylor (1985) modified the marine resistivity system for use on land by including a small garden tractor (18 HP) which is used to tow an instrument trailer and six electrode carts. The electrode carts provide the coupling of the individual current and potential electrodes to the ground. Measurements are taken by driving the tractor and towing the carts, which are aligned in the form of an inverted Schlumberger array. The instrument trailer contains the control systems and acquisition systems, which acquire and store the data. One immediate drawback of this elaborate system is the $10,000 cost. Additional drawbacks include limited operation on only relatively flat homogeneous soil so as not to damage the electrode carts. Also, although the system can acquire data rapidly if the conditions are right, only one array configuration is possible on each pass of the tractor.

Southwest Research Institute

Laine, et al. (1985), developed an automated resistivity survey system for use in pole-dipole surveys. This automation is accomplished by placing all current source electrodes in the ground at the prescribed survey locations. These electrodes are connected via “special cable” so that the current can be switched sequentially to each current electrode while the potential measuring dipole remains at a fixed station. After readings are obtained from current injected at each source electrode, the potential pair is moved to the next location and the current electrodes are switched again. At each potential dipole location the data are stored magnetically for later processing. The operation involves two field workers. One field worker sequentially moves the potential dipole while the other worker stays at a base area and records the data digitally, operates the system control unit and operates the transmitter. This system, which utilizes its own transmitter, receiver, control unit, electrodes and special wire, was successfully tested in Texas to yield good results.

Lawrence Livermore National Laboratory

The Zombie system(Daily et al., 1998) was developed for rapid data acquisition in electrical resistance tomography (ERT) where the underground distribution of electrical resistance is measure from buried electrodes. The Zombie system includes a transmitter, receiver, multiplexer and a laptop computer controlling the acquisition procedure. The transmitter outputs a square wave and the receiver, which supports up to 16 modular detectors, uses one channel to measure the transmitted current and 15 channels for simultaneous potential measurements. A modular multiplexer system is used to switch sets of 30 electrodes. Each electrode has its own wire lead to the multiplexer system, thereby eliminating multicore cables and enabling the use in ERT surveys. This system was shown to rapidly acquire ERT data, however it does require it's own transmitter, receiver, and appears to be designed just for use in ERT surveys.

In conclusion, the above systems, having been constructed in order to efficiently acquire resistivity (and sometimes IP and SP) measurements, are very unique, each built for the particular needs of the scientist. Because of their unique properties, few have been engineered for use with other resistivity systems and all require unique hardware, software, and electrodes or wires to operate. These systems, because they do not offer a generic approach to automated resistivity acquisition, are limited in use. Also, most do not utilize the multi-tasking environment of the Windows 95® operating system nor the other capabilities of current laptop computers.

CHAPTER IV

DESIGN

Overview

Initially, a manually switched sixty-four electrode system was developed and used at many sites. This system utilizes copper electrodes and precut wires that lead back to a mechanical switch box and then to the acquisition instrument (Iris Syscal R2) where the readings are taken and recorded. Subsequently, the operator arranges the electrodes only once within the particular geometry, mechanically switches to the appropriate electrodes, and finally takes a reading. The above system has been field tested and shown to accurately accumulate data in one-third the man hours required by conventional methods. The mechanical switch box utilized rotary switches which allowed the user to select the appropriate electrodes to be used for the next reading. Although, this system was a great improvement, there were still many drawbacks. For example, the switch box was only configured for surveys utilizing the square array which, developed by Habberjam (1979), uses four electrodes positioned at the corners of a square. Additionally, the acquisition procedure required manual switching and manual operation of the resistivity acquisition instrument (Iris Syscal R2). Therefore, the acquisition of data was very limited and required user manipulation of the electrodes and operation of the instrument. Consequently, improvements were necessary to expand the usefulness of the instrument and cut back on the manual labor.

A generic multi-electrode automated / semi-automated field resistivity system was added to the initial system by computerizing the switching mechanism, remotely controlling the acquisition instrument and digitally recording the results. Because this system is designed to be generic, any array type can be used or programmed by the user. Additionally, the system has the capacity to work with resistivity acquisition equipment which can be slaved to a laptop PC, and the resulting data is stored in a format compatible with many of the processing software packages available today. Software, written in Microsoft Visual Basic v5.0® (1997) for Windows 95® integrates the above hardware and controls the acquisition process. This software is intended to allow the user to choose which acquisition instrument will be used, which electrode array, the number of electrodes, take the readings in progression down the survey line and display the results in tabular format. The data are saved on the laptop computer hard drive or 3.5" diskette in tab delimited format and is therefore easily exported to any spreadsheet or conventional plotting and processing programs such as: Surfer for Windows® and Geosoft Mapping and Processing System®.

The prototype switch box developed has the capability to accept sixteen lines, any four of which are selected via multiplexers and reed relays for each reading. The switching process is optically isolated from the computer so that potentially no electrical harm can be done to the laptop computer in the field. Additionally, this prototype is configured to remotely control the Iris Syscal R2 resistivity meter. Once the data are rapidly taken via a laptop computer, it can be analyzed in the field, therefore yielding essentially real-time results which can immediately guide further investigations. Since the software operates in the Windows 95® environment, previous data can be processed while the present data are simultaneously being acquired.

Hardware

In order for this system to be generic and capable of all array types or electrode configurations, each field electrode must have the capability to be switchable to any one of the A, B, M or N terminals of the acquisition instrument. Additionally, the digital switching box must be made compatible with other resistivity acquisition instruments. Although this prototype will initially be functional with the Iris Sycal R2, the design must be flexible to achieve the ultimate goal of complete versatility with other acquisition instruments. Considering this criteria, it is noted that all resistivity acquisition instruments require the connection of the current electrodes and potential electrodes, A, B, M or N. Therefore the switchbox, having four outputs, can be connected to the corresponding terminals of any resistivity acquisition instrument.

The prototype is designed with the initial capability to switch 16 field electrodes. These electrodes are then selected via the software to be switched to either the A, B, M or N terminals. Control of the switchbox is via a parallel cable connected to the parallel port (LPT) of the field computer (laptop). The serial port

(COM) of the computer is connected to the Iris Syscal R2, or another acquisition instrument. This configuration is shown diagrammatically in Figure 6.

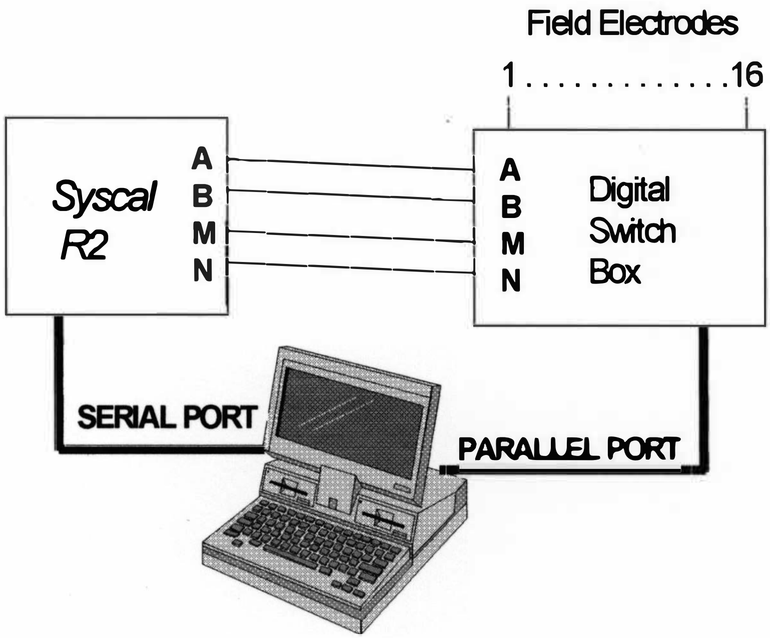


Figure 6. Field Layout of Electrodes and Computer.

Field Electrodes and Wires

The field electrodes are connected to the switch box through each electrode's individual wire. That is, each electrode has its own 22 gauge wire connecting it to the switch box. This type of connection eliminates the need for expensive multicore cable and the user can plug in one's own electrodes and wire without an additional purchase of special electrodes and cable. Furthermore, this design maintains the systems versatility, because both downhole probes or surface field electrodes are possible inputs.

Figure 7 shows the custom field electrodes which are made of type K, 1/2 inch copper pipe, shaped into a T with an alligator clip attached for connection to the wire.

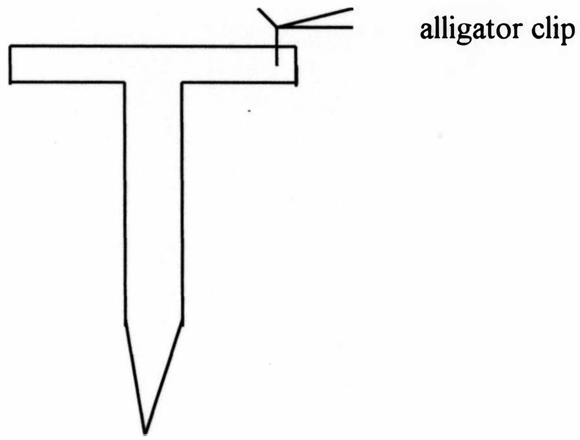


Figure 7. Schematic of Copper Electrode.

This particular electrode, although not required of the system, is an example of only one possible electrode design which can be used with the proposed system.

The wire used to connect the electrodes to the switch box is 22 gauge stranded copper which is cut to fixed lengths in increments of 5 meters. These lengths have sufficient leads to allow smaller spacings and are properly labeled to assure correct connection with the switch box. The ends of each wire have individual connections and the end nearest the switchbox contains a banana plug for insertion into a banana jack in the switch box. The end which connects to the electrode is stripped of its insulation and a bead of solder is applied to maintain the copper strands. As with the electrodes, this is just the author's individual design of the field wires. Other designs are possible.

Field surveys performed using long lengths of wire positioned close and parallel to other wires can result in capacitance effects and inductive coupling, if the ground is conductive. This electromagnetic coupling is of concern with high frequency signals. This problem is remedied by setting the resistivity meter to use long delay times before taking a reading. Therefore, used in this low frequency configuration, the electromagnetic transient is not a factor.

Switch Box

The switch box can be divided into two parts: the computer interface and the multiplexing of the electrodes. In order not to “reinvent the wheel”, the computer interface portion is accomplished via a kit sold by Take Control , Inc. This board kit allows computer control via a LPT port of 64 digital outputs. By way of simple BASIC code any combinations of 64 digital outputs are selected. This prototype uses only 16 of the 64 outputs. The 16 digital outputs are used to control 4:16 multiplexers which then drive relays which select the electrodes to the proper terminal (A, B, M or N).

The mutiplexers used are National Semiconductor MM74C154 4-line to 16-line decoder / demultiplexer. Four of these demultiplexers are used to switch 16 electrodes. This is necessary because each electrode has four possible configurations, either, A, B, M, or N. Additionally, 64 reed relays are required (4 x 16). Even though the TakeControl, Inc. (1998) computer interface board has the capacity of 64 digital outputs, only 16 are used in this prototype to keep the initial development costs down. Unfortunately these demultiplexers have an active low state when selected and 74HCT04 hex inverters are necessary to invert the output of the demultiplexers from low to high. Once the output is inverted it is used to drive opto-isolators, PS2502-4, which then drive P1A3A Series 10 power reed relays. Each electrode is connected to one of these. Because these relays can switch a maximum voltage of 300 VDC and a current maximum of 2 amps, care must be taken to keep the output driving voltage of the resistivity acquisition instrument below these threshold levels. Although, this voltage limit is higher than all the other multi-electrode systems available on the market (or only those which disclose the voltage limit), it does not support all the possible output voltages from the Iris 250W DC/DC converter. As an additional safeguard, the opto-isolators provide 5000 volts isolation of the computer, interface board and demultiplexers from the resistivity meter. This protects the computer and switching circuitry from the high voltage output of the resistivity meter. Figure 8 shows the switch box circuit diagram.

Software

The controlling software, Acquisition Control©, designed to operate in the multitasking environment of Windows 95®, is programmed in Microsoft Visual Basic v5.0® (1997), which enables graphical user interface (GUI) and is therefore very user friendly. Certain custom controls, necessary for the data display and communication protocols were programmed in Microsoft Visual C++ v5.0® (1997). The software

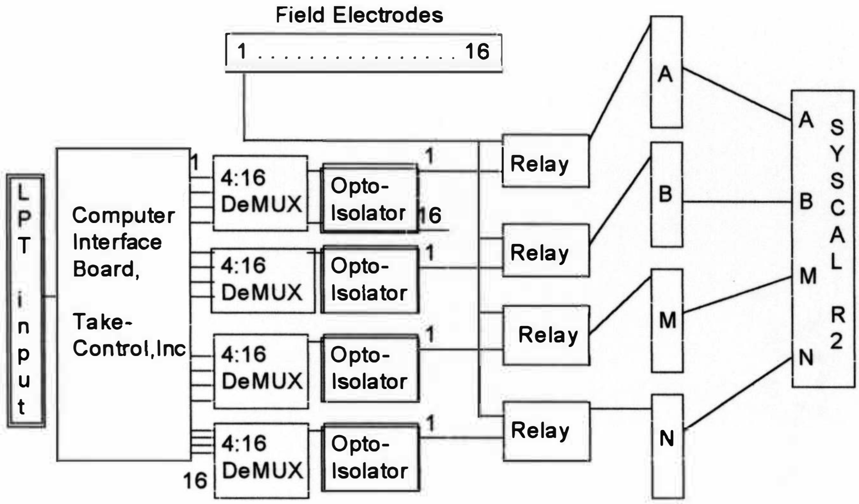


Figure 8. Switch Box Circuit Diagram.

must also be designed to control the resistivity acquisition instrument and the digital switch box. Since this project focuses on the development of a prototype, only the Iris Syscal R2 resistivity system is used. However, the software is designed to enable the configuration of additional resistivity acquisition systems, although, this will require significant programming of additional modules to support other instruments.

Since the software must operate the Syscal R2 remotely, most of the necessary functions, selection of array type, spacing for each array type, units of measurement and continuity check (Rs check) must be made available through the software. Additional parameters required during a survey involve the number of signal pulses to include for each reading and a setting of the lower limit of the output voltage (voltage flag). Further settings for the resistivity acquisition instrument can be set on the instrument before the survey commences. For the Syscal R2, these settings include timing selection, battery check, waveform selection, type of IP values, type of readings (running or cumulative), and sign of voltage.

In addition to the parameters required for the remote operation of the Syscal R2, the controlling software also stores the data in tab delimited format. The name and location of the storage file is determined by browsing any disk drive available and is similar to the Save As... menu choice in the File menu of typical Windows programs. Also included is the name of the survey location, the number of field electrodes used in the survey, and the date and time of the survey. Since only four-electrode arrays are currently possible, the number of electrodes possible must be greater than four.

The Acquisition Control© software is presently only able to configure two array types; dipole dipole and Wenner profile. Since, the purpose of this project is to prove that this type of remote automated acquisition is possible, the use with only two array types is sufficient.

Software Operation

To begin operation of this system, the Iris Syscal R2 must be connected and configured for remote operation and the switch box must be connected via a parallel cable. The initial operating parameters are entered into the program via the Acquisition Control Form, as shown in Figure 9. Notice that the dipole dipole array type and the corresponding Dipole Dipole Setup is the default. Figure 10 shows the Wenner Profile array type and the corresponding Wenner Profile Setup.

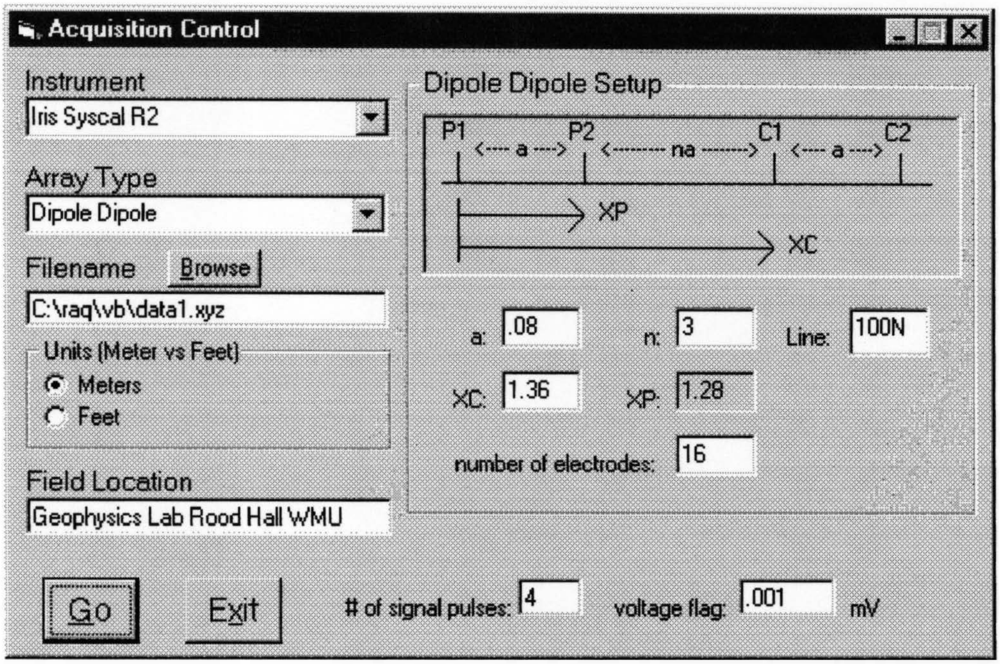


Figure 9. Acquisition Control Form With Dipole Dipole Setup.

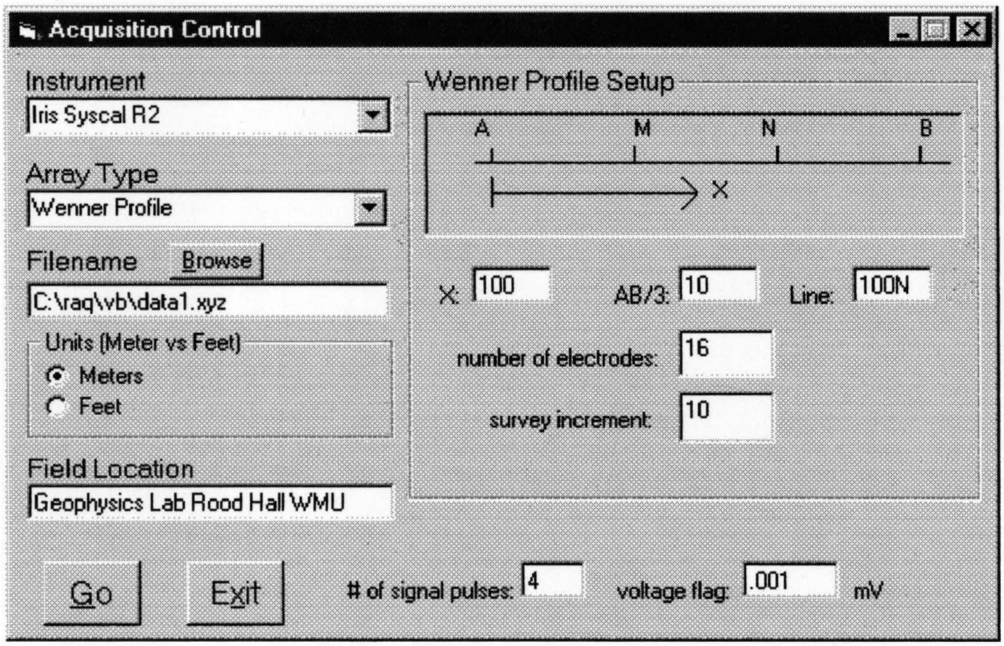


Figure 10. Acquisition Control Form With Wenner Profile Setup.

Upon completion of initial set up parameters in the Acquisition Control Form, the user must press the Go command button to proceed with the data acquisition. Next, the Data Display Form appears covering the whole screen and displaying the data acquisition in real time. This is shown in Figure 11. Located in the caption of the form is the name and location of the file to which the data will be stored. The top of this form contains the header information for the survey, including the survey location, array type, significant spacing information, line location and date and time at which the survey began. This header information is also stored in the data file.

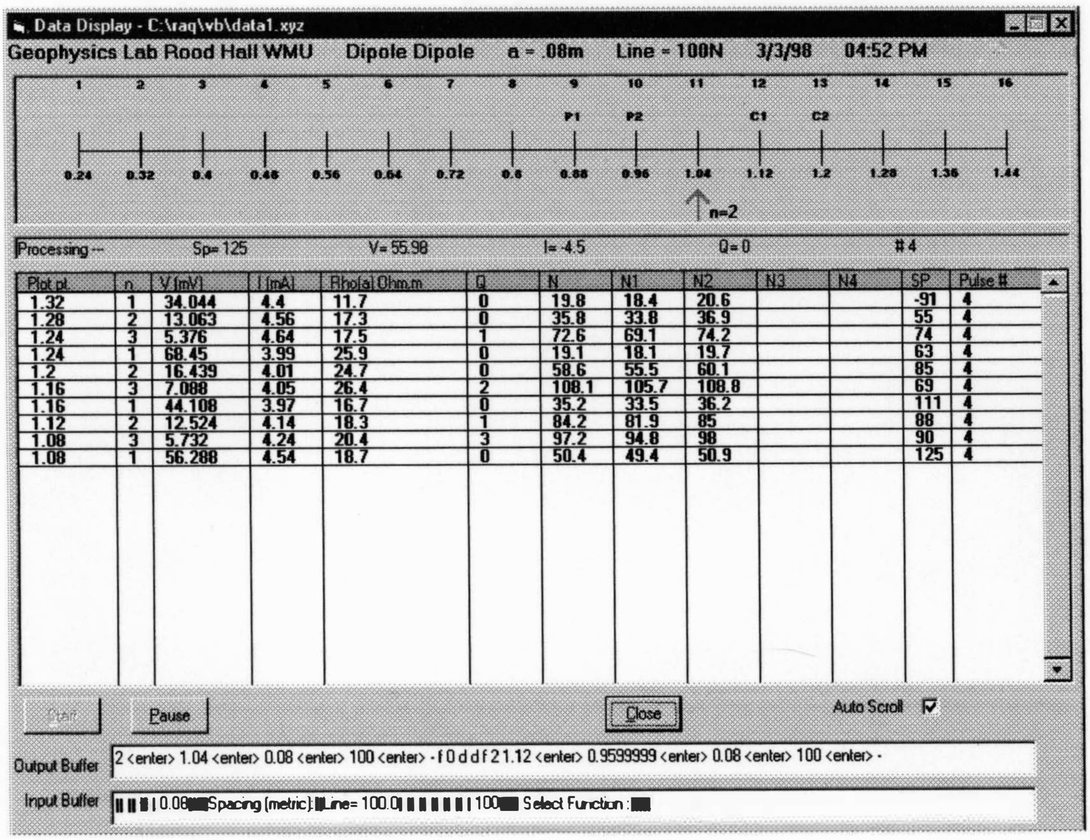


Figure 11. Data Display Form.

Below the header information is a picture of the electrodes in the field per the input data in the Acquisition Control Form. Labeled below each electrode is the field location of each electrode and above the electrode is the electrode number. Also indicated is the location of the present plot point by a red arrow and the active potential and current electrodes. If the dipole dipole array is used, labeled next to the plot point arrow is the current 'n' expansion integer value.

Occupying most of the display screen is the tabular display for the data. Before data are accumulated, the column labels are shown. These labels are unique to the array type. Specifically, dipole dipole column headings are: Plot pt., n, V (mV), I (mA), Rho(a), Ohm.m, Q, N, N1, N2, N3, N4, SP, and the Pulse #, and Wenner profile headings are the same less the column for 'n'. At the bottom of this display are three comand buttons: Start, Pause, and Close. The Start button begins the survey, but quickly loses emphasis while the Pause button gains emphasis. The Close button exits the Data Display form and shows the Acquisition Control Form. Also, there is a check box on the bottom of the screen to enable or disable automatic scrolling of the data. At the absolute bottom of the screen are two text boxes which show the Output Buffer and the Input Buffer. The Output Buffer shows what is being sent to the instruments and the Input Buffer shows input from the resistivity acquisition instrument.

Once the Start button is pressed the program checks for file duplication based on the filename entered in the Acquisition Control Form. If the filename is found, the user is prompted to Append data to the end of this file, Replace the existing file with new data, or Select a new file name. Figure 12 shows this form. When this file check is complete, the resistivity instrument (Iris Syscal R2) is configured for the array type and parameters input from the Acquisition Control Form.

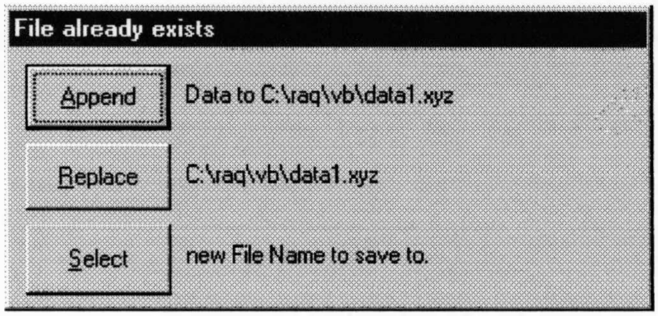


Figure 12. File Check Form.

After the resistivity instrument is set up, the first data point is acquired. First the switch box is configured to enable the proper electrodes. Next the resistivity instrument begins the acquisition. The output signal from the resistivity meter is sent per the set output voltage and the proper number of signal pulses is generated until this flag is exceeded. The acquisition is then stopped and the results are read and input into the data display table. After display, the survey header information is stored to file and the first data row is stored into the data file. At this point, the display shows the relocation of the present potential and current electrodes and the switch box switches to the next electrodes corresponding to the visual change. Next, the data collection is repeated, except for the storage of the header information to the file, which is only done once at the beginning of the survey.

While the survey is automatically running, the user has a few options. One option is to sit back and monitor the data as it is visually displayed in tab delimited format. Another option shown in Figure 13, enables semi-automated operation by pausing the data collection, perform a Rs check (for electrode continuity) and continue the survey at the current plot point. Also, the data collection can be stopped automatically if the voltage drops below the voltage flag indicated in the Acquisition Control Form. If this occurs the Pause Form, Figure 13, appears and the operator can increase the output voltage on the resistivity meter, continue or abort the survey.

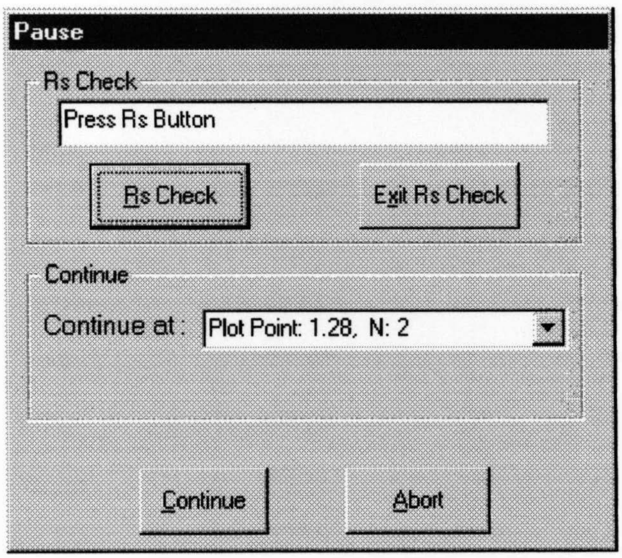


Figure 13. Rs Check and Pause Form.

Upon completion of the survey, the software displays a message indicating the successful completion of the survey. The user can then review the data in the Data Display Form by scrolling through the data. In addition, the user can close the Data

Display and select a different array type and redo the survey with a different array. Finally, the user may wish to exit or minimize Acquisition Control© and import the data into a spreadsheet program for processing or another program for graphical display. Appendix A shows a flow chart representing Acquisition Control©.

CHAPTER V

TESTING

Laboratory Test

Upon completion of diagnostic testing during the design of both the software and hardware a field model was tested in the Western Michigan University Geophysics Laboratory. The purpose of the laboratory testing was to compare the speed and quality of manually acquired data with data acquired automatically. The axial dipole dipole and the Wenner array were tested using a 4' x 8' x 4' water filled tank to simulate the subsurface. A floating plexiglass platform with screws, 2 cm apart, penetrating through the bottom were used for electrodes. Corresponding wires, attached to each electrode, lead back to the switch box. The acquisition system was set up as shown in Figure 6.

Wenner Array Test

The automatic acquisition system was configured to perform a Wenner array with a = 0.02 m and an initial x position (plot point) of 1.00 m. The total elapsed time from initial execution of Acquisition Control© to final completion and storage of data in tabular format was five minutes, not including electrode set up and placement in the water tank. This set up time was considered constant for both automatic data acquisition and manual data acquisition. Upon completion of the automatic survey, the electrodes were unplugged from the switch box and then manually plugged into the Iris Syscal R2 four at a time in sequential progression along the survey. The manual procedure from the initial data gathering to the completion of the data in tabular format required twenty-five minutes. Therefore, the five minutes necessary for automated data collection represents a time improvement of 500%.

The raw data, included in Appendix B, and the resulting plotted data, shown in Figure 14, reveal that the data is essentially identical and no quality is lost with the

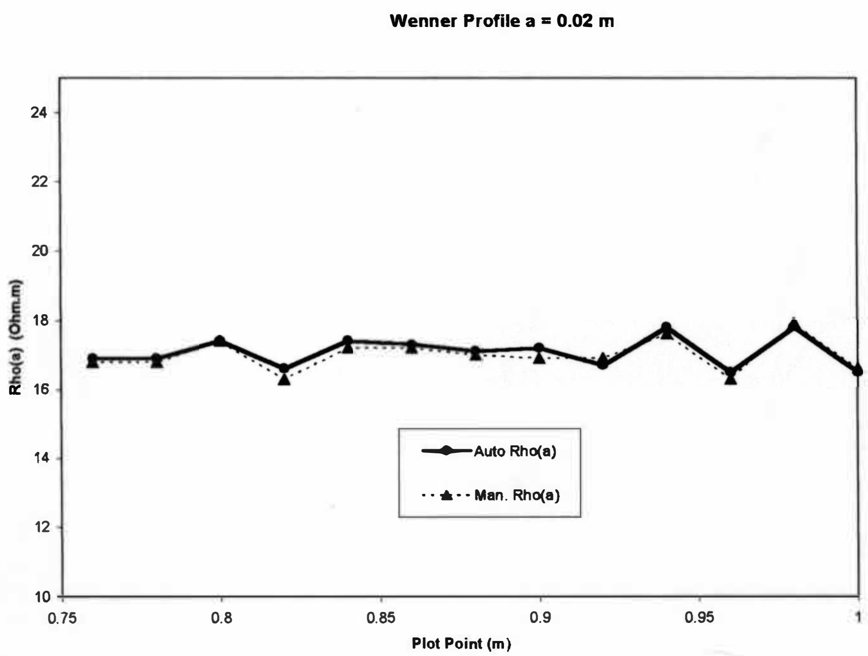


Figure 14. Wenner Array Test Results Plot.

automated system. Even though the test was performed in a tank of water, the results do show variations along the profile. These variations are probably due to electrode spacing and size effects. Additionally, the screws used for the electrodes were not stainless steel and electrode oxidation was observed, which would have caused the contact resistance to increase with time. The average apparent resistivity calculated for automatically and manually acquired data is 17.085 Ωm and 16.992 Ωm, respectively. This represents a 0.5 % difference, which is slightly over the 0.3% tolerance of the current and voltage from resistivity meter (Syscal R2). Hence, this laboratory test shows that the prototype system developed for this project successfully acquires Wenner profile data with increased speed and efficiency.

A second test of the Wenner array was performed in the water tank to simulate the effects of an object with higher resistivity than the background resistivity of the tank. This effect was produced by placing a plastic pipe underneath the floating electrode tray. This pipe impedes the current flow in the tank and results in a higher apparent resistivity. The pipe was positioned at approximately 0.91m along the profile at a depth of 1 cm below the tray. Figure 15 shows the comparison of the automatic data to the manual data. Inspection of this plot shows that both the automatic and manual data reveal the presence of the resistive pipe. However, the manual data show higher apparent resistivities than the automatic, although the trends of both curves are similar. The average apparent resistivity for the automatic and manual data are 18.354 Ωm and 18.985 Ωm, respectively. These results indicate a 3.3% difference between the means which is 3% higher than the Syscal R2 tolerance (0.3% for each I and V). The exact reason for this difference is unknown and further tests are warranted.

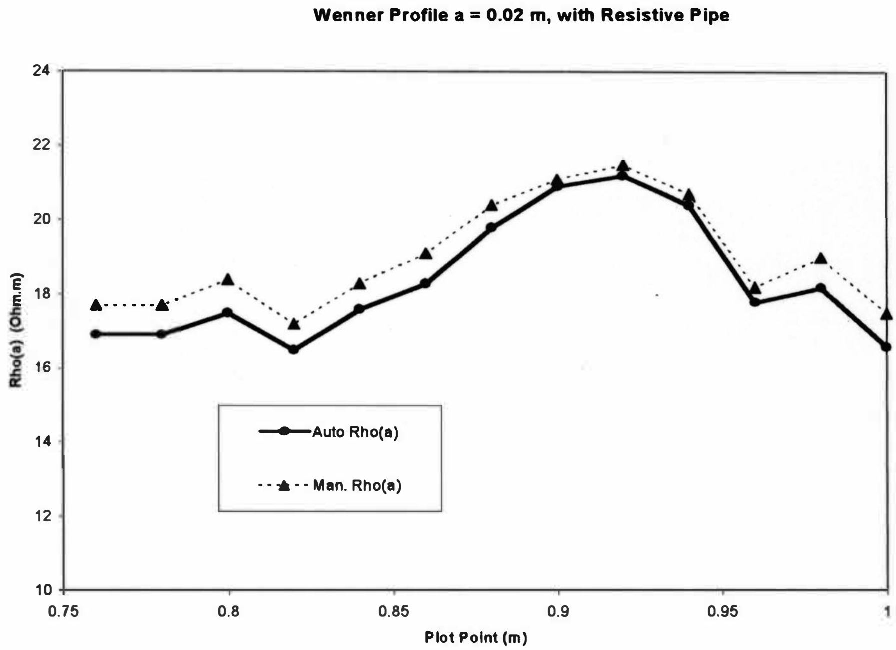


Figure 15. Wenner Test Results Plot with Resistive Pipe at 0.91 m.

Dipole Dipole Array Test

Using the same water tank set up as in the Wenner Array Test, a dipole dipole array was tested. The 'a' spacing equaled 0.02m, the 'n' expansion factor increased to three and the initial plot point was 9.9m. During this test, the automated data were collected and stored in ten minutes, whereas the manual data required one hour to complete and store in tabular format (see Appendix C for raw data). Additionally, a second set of automated data were collected to compare for repeatability. Figure 16 shows the comparison of these data sets for an expansion of n=1. Variations along the profile are attributed to electrode spacing effects as mentioned above. The automated data show good repeatability. The average apparent resistivity for Auto1 and Auto2 were 18.677 Ωm and 18.738 Ωm, respectively, indicating repeatability of 0.3%. Comparing these data sets to the manually obtained apparent resistivity of 17.931 Ωm resulted in a 3.9% difference. This is also greater than the tolerance of the Syscal R2 and needs further investigation.

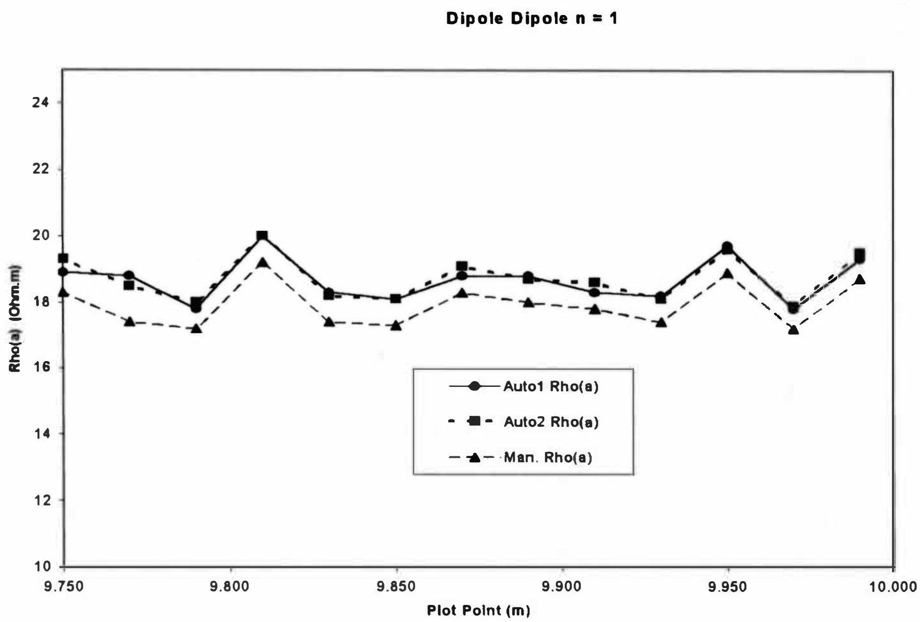


Figure 16. Dipole Dipole n = 1 Test Results Plot.

Overall, the dipole dipole results show good repeatability in the automatic mode. However, the comparison to the manually gathered data shows differences exceeding the instrument tolerance. The efficiency of the automated data gathering shows a time improvement of 600% when comparing the 60 minutes require during manual operation to only 10 minutes through the automation of measurements.

CHAPTER VI

DISCUSSION AND CONCLUSION

Discussion

Results of this project show a working prototype of the multi-electrode resistivity acquisition system. The hardware design successfully acquires quality data, allowing the switching for different array types while providing protection for the field computer from large voltages supplied during DC electrical resistivity surveys. Additionally, the switching circuitry is not limited to only in-line arrays, but can be configured for any electrode arrangement thereby maintaining a generic ability. The software was proven to be successful in controlling both the switch box, resistivity acquisition instrument (Iris Sycal R2) and display and storage of the data in tabular format. The software also contains the ability to operate in the multi-tasking Windows 95® environment and operate the acquisition system in automated or semi-automated modes. Furthermore, the laboratory testing showed that the resistivity acquisition system efficiently and accurately gathered data with a time improvement of 500% to 600% over manual acquisition time. Operating the Syscal R2 with a shorter pulse length could nearly double this advantage. Overall, the development and testing of this prototype was a success. Initial cost estimate for the materials needed for construction of the prototype switch box are approximately $600.00. The cost for materials for 64 copper electrodes, wire for four lines 100 meters long with 16 electrode connections, cart to transport electrodes and a field table was approximately $600.00. Approximately $350.00 would be necessary to upgrade the prototype to enable switching to 64 electrodes. Therefore, the combined materials cost for an automated system utilizing 64 electrodes would be approximately $1550.00. However, it is important to note that this estimate is only for materials.

Conclusion and Recommendations

The applications of this project are widespread. This project has demonstrated the necessary switching circuitry, software algorithm, and efficiency achieved by automated resistivity acquisition. Further improvements are now possible.

Initially, a field power supply needs to be developed to supply the switch box power independent from the battery used to drive the resistivity measurements. Secondly, the upgrade to sixty-four electrodes will enable the device to acquire data over larger areas. Fortunately, this is just a matter of purchasing the required hardware components and physically wiring them together; however, improved relays with the capacity to handle greater voltages would be required for systems using more than 2 amps at 300 volts. Another improvement would be in consolidating the hardware. This can be accomplished through the manufacturing of dedicated integrated circuits representing the circuitry of the multiplexers, hex-inverters and optoisolators. These components, once combined into a single integrated circuit (IC), can then be configured on a circuit board with sockets for the reed relays. This improvement will decrease the size of the switch box to approximately the size of the Iris Syscal R2 resistivity meter. Finally, to maintain versatility, an improvement is necessary to configure the 64-electrode switch box to be connected in series with additional 64-electrode switch boxes so that an essentially unlimited number of electrodes can be used. This is conceptually possible because the Take Control, Inc. computer interface board does have the potential to gang additional boards together.

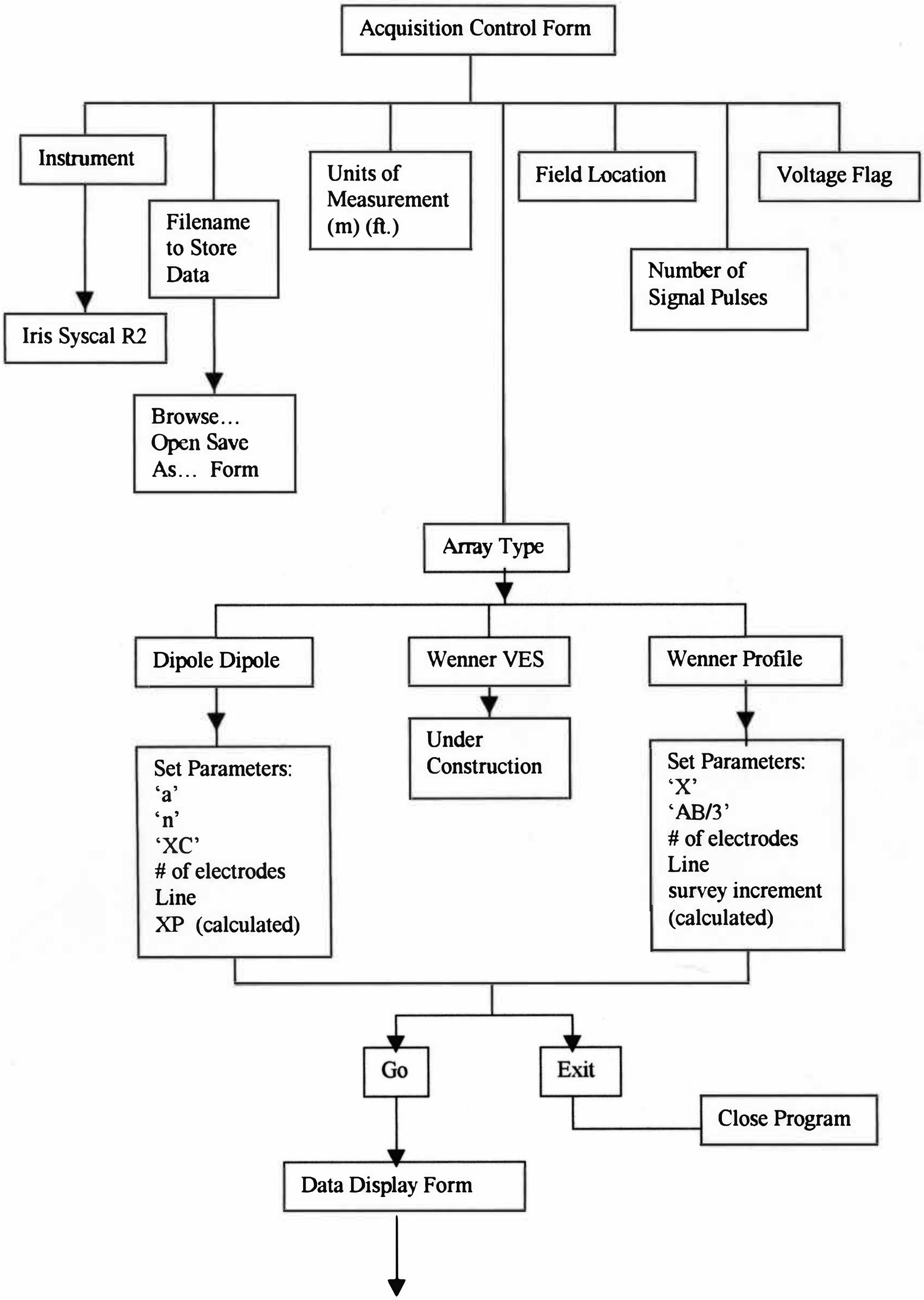
Improvements to the software can also be very widespread. Additional routines for array types and user programmable array types can be adopted. Furthermore, modules can be developed for use with other resistivity meters. Beyond the adaptation for conventional array types, a vast improvement would be to program the system to gather three-dimensional apparent resistivity data. By positioning the field electrodes into an evenly spaced grid, then using the switch box and controlling software to acquire apparent resistivity data, 3-D results will be readily and efficiently possible. It then follows that this measurement can be repeated over time and essentially yield four-dimensional results.

An overall cost estimate for this system proposed has not been determined. However, since the only components are the switch box and the controlling software, a large capital investment is not necessary. The greatest expenses would be the acquisition instrument (Iris Syscal R2) or equivalent and a field computer (laptop) operating under Windows 95®. The additional cost for components necessary for automation would be greatly outweighed by the greater efficiency and quality of data that would be possible.

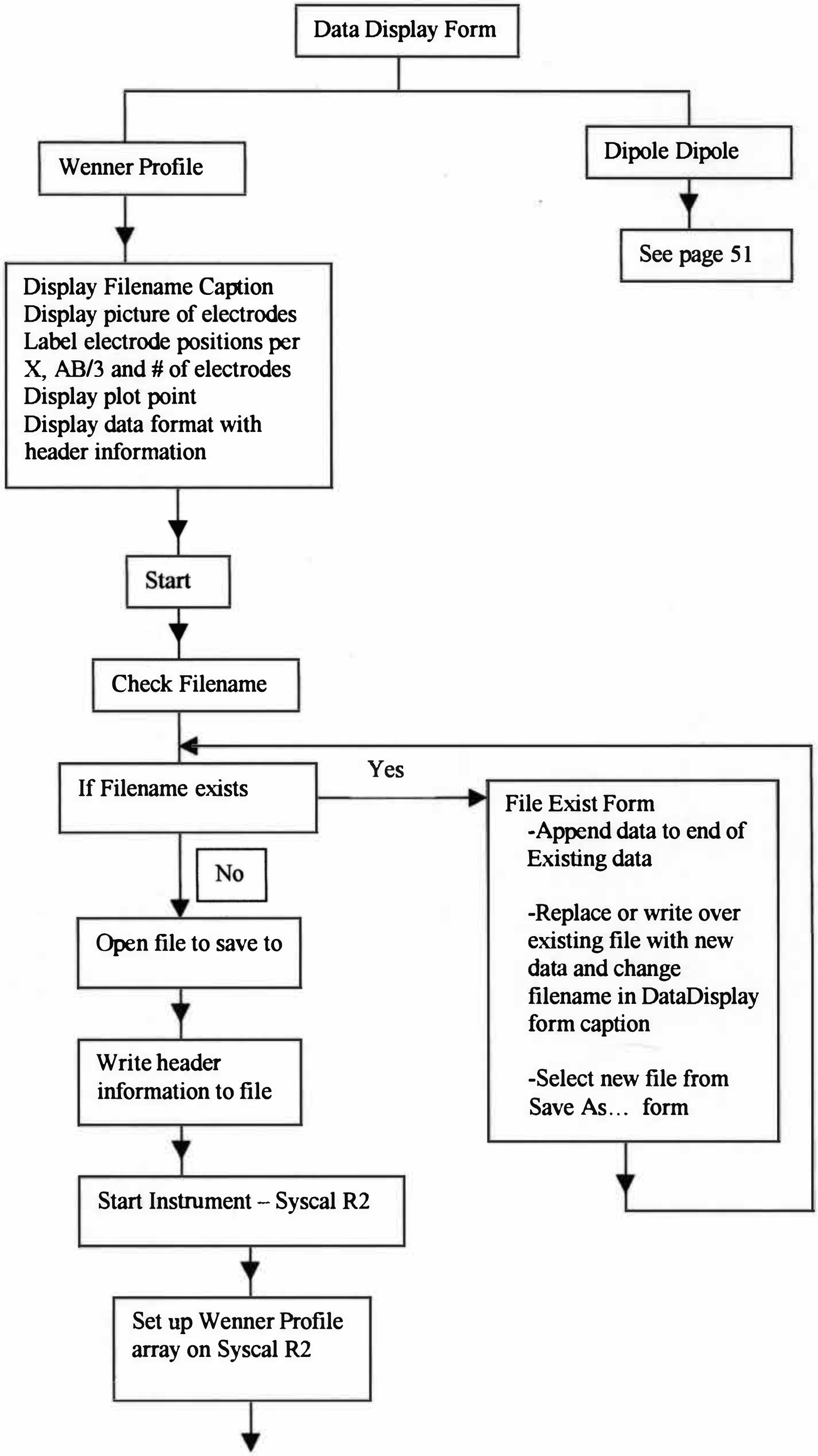
Overall, the successful development of this prototype has far reaching applications into areas of electrical resistivity prospecting that are just beginning to be explored. As with the historical improvements of geophysical instrumentation, this project is possible through the improvements in the computer and electrical engineering technologies. It is through this multi-disciplinary approach that advances in the geophysical exploration instrumentation can be made. Finally, this innovative system has proven to ease field acquisition techniques, maintain accurate readings, and reduce investigation time, reduces the cost and increases the profit margin for surveys involving electrical resistivity techniques as geophysicists seek to non-invasively characterize the subsurface.

Appendix A

Software Flow Chart


Acquisition Control Form
Instrument
Iris Syscal R2
Filename to Store Data
Browse... Open Save As... Form
Units of Measurement (m) (ft.)
Field Location
Voltage Flag
Number of Signal Pulses
Array Type
Dipole Dipole
Set Parameters: 'a' 'n' 'XC' # of electrodes Line XP (calculated)
Wenner VES
Under Construction
Wenner Profile
Set Parameters: 'X' 'AB/3' # of electrodes Line survey increment (calculated)
Go
Exit
Close Program
Data Display Form

Appendix A. cont.



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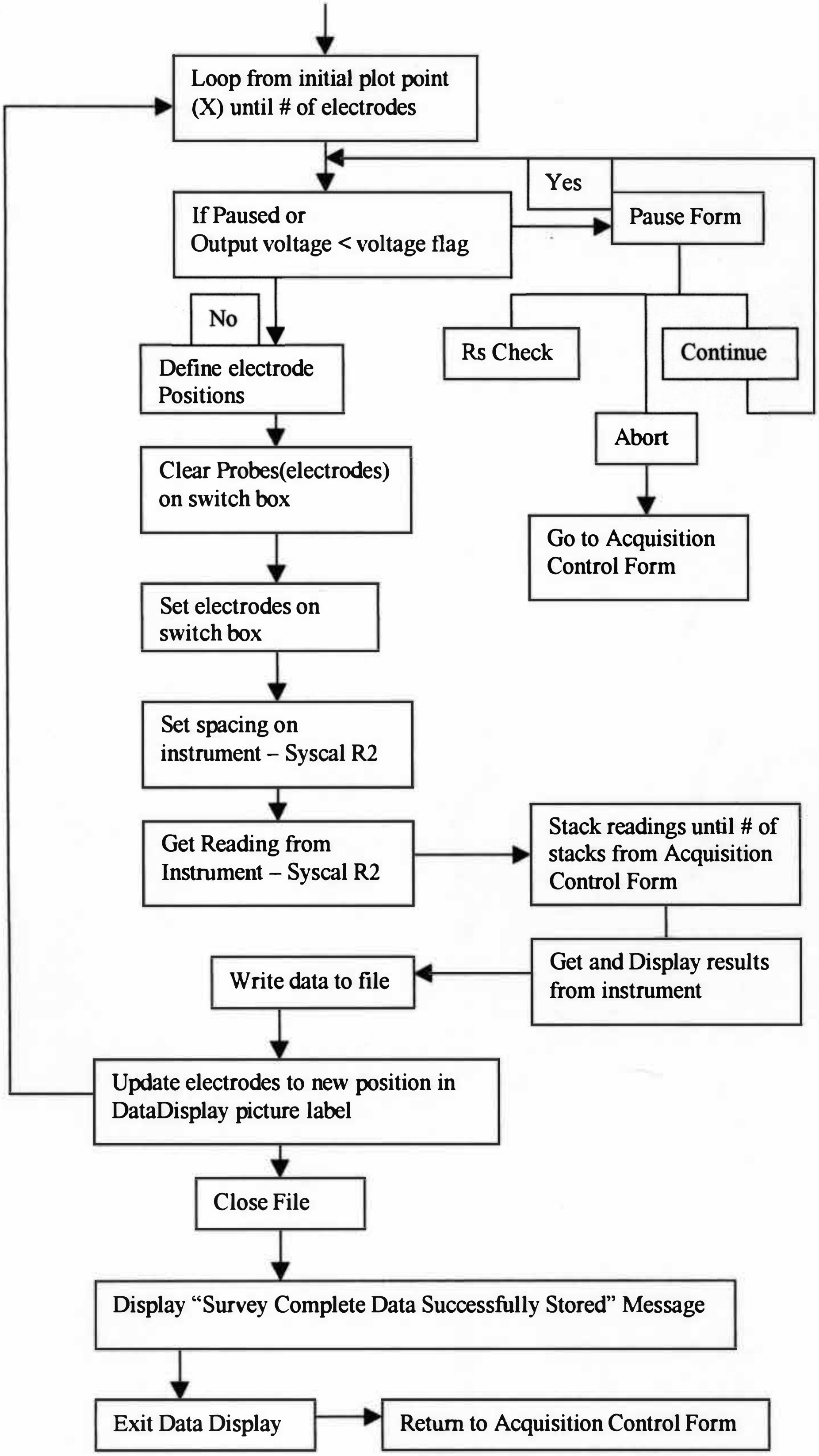
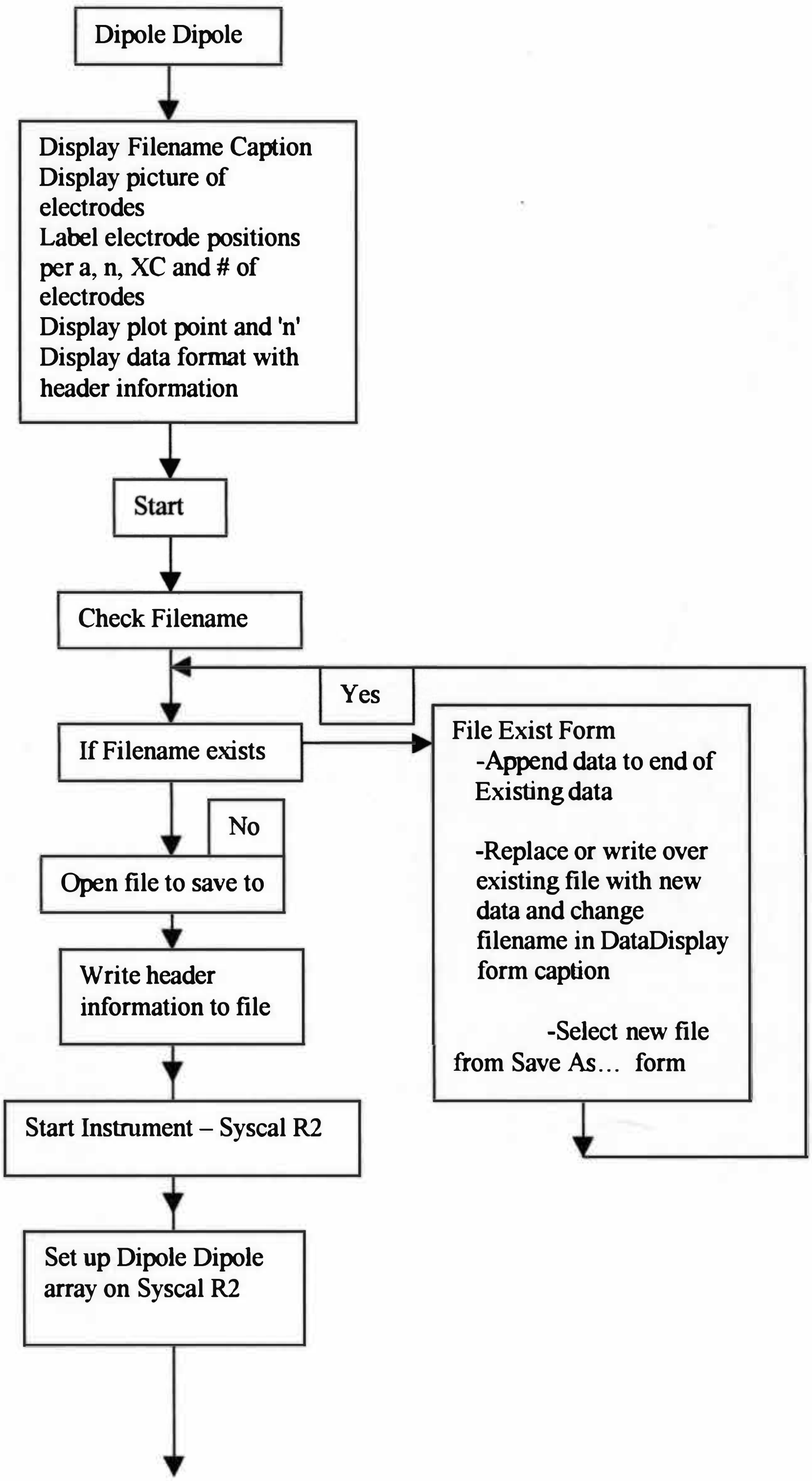
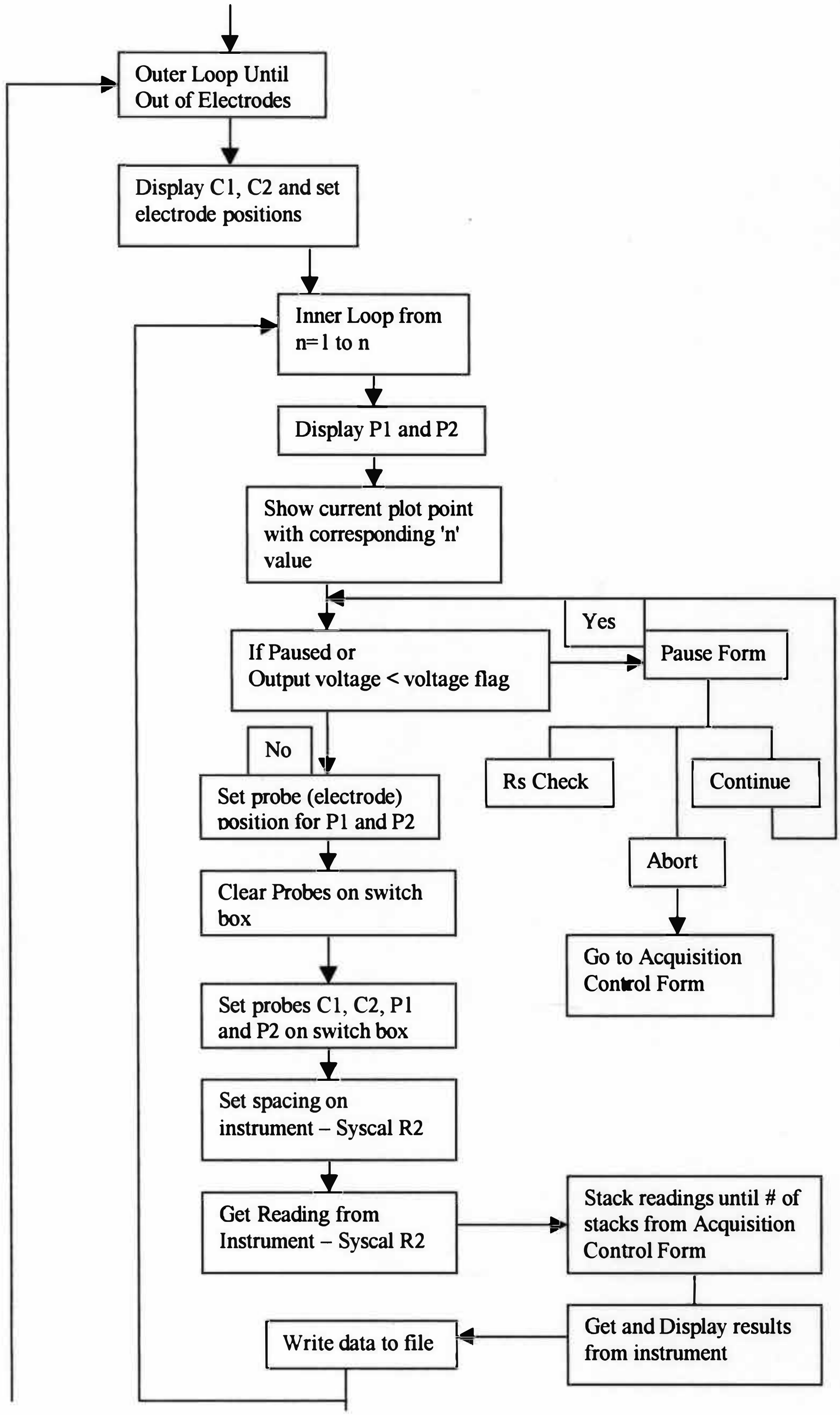


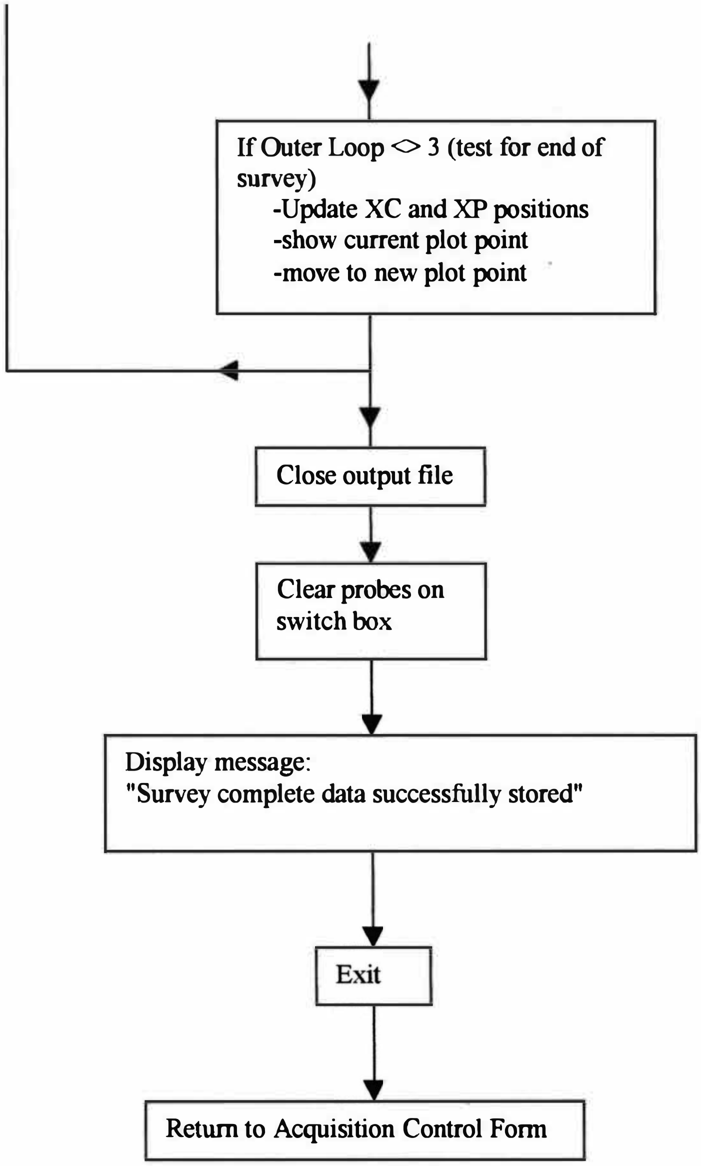
Appendix A. cont.



Appendix A. cont.



Appendix A. cont.



Appendix B

Raw Wenner Array Test Data

Geophysics Lab Rood Hall WMU Wenner Profile .02m Line = 100N Increment = .02 3/13/98 10:20 AM

Plot pt.	V (mV)	I (mA)	Auto Rho(a)	Q	N	N1	N2	SP	Pulse #	Plot pt.	Man. Rho(a)
1.00	175.751	1.34	16.5	0	-6.7	-7	-6.6	107	4	1	16.6
0.98	181.818	1.28	17.8	0	-7.4	-7.2	-7.6	-126	4	0.98	17.9
0.96	179.034	1.36	16.5	0	-4.8	-4.8	-4.7	-47	4	0.96	16.3
0.94	184.77	1.29	17.8	0	3.4	3.5	3.5	-114	4	0.94	17.6
0.92	166.362	1.26	16.7	0	-16	-16	-17	-3	4	0.92	16.9
0.90	186.682	1.37	17.2	0	-3.7	-3.9	-3.5	7	4	0.9	16.9
0.88	180.18	1.32	17.1	0	-5.9	-5.6	-6.2	-73	4	0.88	17
0.86	178.924	1.3	17.3	0	-3.4	-3.3	-3.7	24	4	0.86	17.2
0.84	183.955	1.33	17.4	0	-9.6	-9.6	-9.6	-56	4	0.84	17.2
0.82	164.712	1.25	16.6	0	-4.5	-4.3	-4.6	-86	4	0.82	16.3
0.80	163.696	1.18	17.4	0	-11	-11	-12	-45	4	0.8	17.4
0.78	173.209	1.29	16.9	0	-10	-10	-11	-84	4	0.78	16.8
0.76	119.987	0.89	16.9	0	-9.5	-9.4	-9.6	39	4	0.76	16.8
		Mean	17.0846							**Mean =**	16.9923

Geophysics Lab Rood Hall WMU Wenner Profile .02m Line = 100N Increment = .02 3/13/98 11:43 AM with Resistive Pipe

Plot pt.	V (mV)	I (mA)	Auto Rho(a)	Q	N	N1	N2	SP	Pulse #		Man. Rho(a)
1.00	160.289	1.21	16.6	0	-4.2	-4.6	-4.1	-42	4		17.5
0.98	164.6	1.14	18.2	0	-7.7	-7.3	-7.9	-13	4		19
0.96	169.804	1.2	17.8	0	-4.8	-4.8	-4.7	-36	4		18.2
0.94	190.838	1.17	20.4	0	-1.3	-1.6	-1.3	-52	4		20.7
0.92	190.378	1.13	21.2	0	-6.7	-6.5	-6.9	-16	4		21.5
0.90	206.984	1.24	20.9	0	-4.8	-5.1	-4.6	-26	4		21.1
0.88	196.848	1.25	19.8	0	-5.9	-5.7	-6.2	-19	4		20.4
0.86	177.744	1.22	18.3	0	-7.1	-6.7	-7.5	-11	4		19.1
0.84	175.488	1.25	17.6	0	-3.7	-4.1	-3.5	-34	4		18.3
0.82	158.089	1.21	16.5	0	-3.3	-3.5	-3.2	-40	4		17.2
0.80	155.919	1.12	17.5	0	-6.5	-6.7	-6.3	-40	4		18.4
0.78	164.852	1.23	16.9	0	-4.2	-4.7	-4.1	-44	4		17.7
0.76	109.704	0.82	16.9	0	-6.5	-6.8	-6.3	7	4		17.7
		Mean =	18.3538							**Mean =**	18.9846

Appendix C

Raw Dipole Dipole Array Test Data

Geophysics Lab Rood Hall WMU Dipole Dipole a = .02m Line = 100N 3/14/98 01:23 PM

Automatic Data

Plot pt.	n	V (mV)	I (mA)	Auto Rho(a)	Q	N	N1	N2	SP	Pulse #
9.990	1	65.289	1.27	19.3	0	0.4	1.1	0.1	-55	4
9.970	1	49.248	1.04	17.8	0	4.2	4.1	4.3	-59	4
9.950	1	53.542	1.03	19.7	0	4.1	4.7	3.8	-28	4
9.930	1	45.595	0.95	18.2	0	3.3	4.2	2.8	-67	4
9.910	1	44.301	0.91	18.3	0	5.1	4.7	5.4	-39	4
9.890	1	56.076	1.13	18.8	0	4.2	5.1	3.8	-46	4
9.870	1	58.446	1.17	18.8	0	0.8	1.2	0.6	-64	4
9.850	1	53.494	1.12	18.1	0	2	1.6	2.2	-39	4
9.830	1	52.819	1.09	18.3	0	3	3.9	2.6	-36	4
9.810	1	53.206	1	20	0	-0.3	0.1	-0.6	-59	4
9.790	1	47	0.99	17.8	0	3.2	3.7	2.9	-47	4
9.770	1	54.267	1.09	18.8	0	3.4	4	3.1	-131	4
9.750	1	54.438	1.08	18.9	0	5.8	5.4	6.2	-116	4
	Mean	52.9016	1.0669	18.6769						

Manual Data

xc	xp	Plot Point	n	v	I	Man. Rho(a)
10	9.98	9.99	1	57.275	1.16	18.7
9.98	9.96	9.97	1	43.964	0.96	17.2
9.96	9.94	9.95	1	49.915	1	18.9
9.94	9.92	9.93	1	42.176	0.91	17.4
9.92	9.9	9.91	1	44.344	0.94	17.8
9.9	9.88	9.89	1	55.966	1.17	18
9.88	9.86	9.87	1	57.011	1.17	18.3
9.86	9.84	9.85	1	49.164	1.07	17.3
9.84	9.82	9.83	1	47.736	1.03	17.4
9.82	9.8	9.81	1	51.487	1.01	19.2
9.8	9.78	9.79	1	46.33	1.02	17.2
9.78	9.76	9.77	1	52.116	1.11	17.4
9.76	9.74	9.75	1	53.162	1.09	18.3
			Mean	50.0497	1.0492	17.9308

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