The DART project: Developing the roadmap for archaeological remote sensing in the 21st century

Aerial and geophysical survey have substantially increased our understanding of the nature and distribution of archaeology. However, there is variable understanding of the physical, chemical, biological and environmental factors which produce the archaeological contrasts that are detected by the sensor technologies. These factors vary geographically, seasonally and throughout the day, meaning that the ability to detect features changes over time and space.

Detection of Archaeological Residues using remote sensing Techniques (DART: www.comp.leeds.ac.uk/dart) is a three year, £815,000 Science and Heritage funded initiative led by the School of Computing at the University of Leeds. The Science and Heritage programme (www.heritagescience.ac.uk) is funded jointly by the Arts and Humanities Research Council (AHRC: www.ahrc.ac.uk) and the Engineering and Physical Sciences Research Council (EPSRC: www.epsrc.ac.uk). To examine the complex problem of heritage detection DART has attracted a consortium consisting of 25 key heritage and industry organisations and academic consultants and researchers from the areas of computer vision, geophysics, remote sensing, knowledge engineering and soil science.

Enhanced knowledge of archaeological residues is important for the long-term curation and understanding of a diminishing heritage. There are certain geologies and soils which can complicate the collection and interpretation of heritage remote sensing data. In some of these 'difficult' areas traditional detection techniques have been unresponsive. DART will develop a deeper understanding of the contrast factors and detection dynamics within ‘difficult’ areas. This will allow the identification of appropriate sensors and conditions for feature detection. The successful detection of features in ‘difficult’ areas will provide a more complete understanding of the heritage resource which will impact on research, management and development control.

Detection techniques rely on the ability of a sensor to measure the contrast between an archaeological residue and its immediate surroundings or matrix. Detection is influenced by many factors – changes in precipitation, temperature, crop stress/type, soil type and structure and land management techniques. DART will increase the foundational knowledge about the remote sensing of sub-surface archaeological remains. This will increase the understanding of how archaeological residues can be detected and the impact that physical, chemical, biological and environmental processes have on the detection process.

The programme of research has been designed specifically to identify contrast factors that may allow the detection of archaeological residues (both directly and by proxy) using sensing devices. To determine contrast factors, samples and measurements will be taken on and around different sub-surface archaeological features at different times of the day and year to ensure that a representative range of conditions is covered. Field measurements will include geophysical and hyperspectral surveys, thermal profiling, soil moisture and spectral reflectance. Laboratory analysis of samples will include geochemistry and particle size. Models will be developed that translate these physical values into spectral, magnetic and electrical measures in order to determine detection parameters. This will allow DART to address the following research issues:

- What are the factors that produce archaeological contrasts?
- How do these contrast processes vary over space and time?
- What processes cause these variations?
- How can we best detect these contrasts (sensors and conditions)?

The key will be to understand the dynamic interaction between soils, vegetation and archaeological residues and how these affect detection with sensing devices. This requires understanding how the archaeology differs from, and dynamically interacts with, the localised soils and vegetation and how these differences can be detected.

In order to achieve these goals 5 Work Packages have been established:

WP1 PROJECT INITIATION Determination of sites, the sampling programme and analysis techniques will be determined by the consortium during this WP. A multi-staged programme of sampling during different season, climate, crop and land-use/cover conditions over a period of 12-14 months will occur. Sites will be chosen on the basis of contrasting Archaeological Residues (ARs), soil and land management conditions. For logistical purposes, sites will be chosen in clusters of three or four. Each cluster will have a c. 20km radius which means that multiple sites visits can be achieved in a day. The consortium will further develop a risk register constructed during proposal-writing which will be used to inform subsequent decisions.

WP2 DATA COLLECTION AND LABORATORY ANALYSIS Measurements will be taken using probes and sensors, and samples will be taken for laboratory analysis (bulk samples and monoliths). Standard and specific geotechnical and spectroradiometry tests will be conducted. In addition the archaeological residues and surrounding material will be characterised in order to understand archaeological formation/deformation and pedological processes. ARs will be recorded in line with Institute for Archaeologists (IfA) guidelines.

WP3 DATA ANALYSIS Multi-temporal models will be developed that translate the geotechnical parameters into spectral, magnetic and electrical measures in order to determine contrast parameters. Environmental dynamics will be identified and their impact characterised.

WP4 DECISION SUPPORT TOOL Understanding the signal behaviour for different ground or crop (type and stress) conditions will allow the development of a deductive framework that enhances survey strategies (conditions and sensors). With the appropriate historical data and resource metadata, the same tool will be adapted to improve the discovery of high potential resources held in photographic and other image archives. Knowledge engineering techniques and ontologies will be used in the decision tools.

Ontologies (e.g. soil type, AR type) will be specifically utilised to map signal response, environmental conditions and heritage feature type.

WP5 EVALUATION Locations of evaluation areas will be supplied by heritage partners and will include the excavation in Perth and Kinross conducted by Glasgow University. Aerial hyperspectral and ground geophysical surveys will be deployed based upon recommendations from the decision tools. The surveys will be interpreted and evaluated.

DART has been awarded three PhD studentships:

PhD Studentship 1: Civil Engineering, University of Birmingham

Supervisor: Dr. Nicole Metje

Co-supervisor: Dr Keith Wilkinson (Department of Archaeology, Winchester University)

Nature and scope of doctoral thesis

This PhD research will try to establish the relationships between geotechnical soil parameters and sensor attenuation for a range of different soils and properties. It is hypothesised that knowledge of the geotechnical soil characteristics will allow the prediction of the geophysical properties of the soil. In order to establish these relationships, both laboratory and in-situ tests will be conducted measuring, amongst others, Atterberg limits, moisture content and particle size distribution, and geophysical properties of the soil. The in-situ tests will focus on measuring the moisture content and temperature over a full year in order to gather information on the seasonal variation and the impact on prospection. The idea is that a better understanding of the material that the ARs are situated in and the RS signals need to travel through will allow a much more informed choice of the most appropriate RS technologies and their optimal operating state. If the link between geotechnical and geophysical properties can be made, then the British Geological Survey nationwide geotechnical database will provide information which can be used to calibrate geophysical sensors for local conditions leading to improved sensitivity and archaeological residue detection.

Contribution of the PhD research to the project as a whole

This project will provide a better understanding of the soil which will allow the choice of appropriate sensors and their fine tuning to the local conditions, hence improving their effect. A thorough understanding needs to be gained of the impacts of the soil characteristics, the moisture content and density on the electromagnetic signal penetration at different frequencies. These results will be compared against the measurements from the in-situ probes measuring temperature and moisture content. By generating mappings between these empirical geotechnical data with the nationwide geotechnical soil characteristics from the BGS database (containing, for example Atterberg limits, moisture content and particle size distribution) the research will provide a useful way of determining the suitability of different geophysical techniques for particular locations. A greater understanding of the relationship between geotechnical soil characteristics and geophysical sensor readings will produce a step change in prospection methods by allowing sensors to be fine tuned for the most effective detection.

The further benefit of the laboratory-based experimentation is that it provides a control for the field based measurements. The range of in-situ measurement variation will be partially determined by the local environmental conditions, over which we have no control. The laboratory-based experimentation will allow the simulation of in-situ measurements. These can be used if the environmental dynamics during the sampling phase are poor. This stage, therefore, reduces the risk of poor research outcomes associated with poor environmental conditions. This PhD research will contribute significantly to the overall project. The ARs are located within the soil and a better understanding of the interaction of the ARs with the surrounding soil matrix and in turns the impact on signal attenuation and penetration through the soil is vital to make a step change in the location of ARs in difficult soil conditions. This will support the other work packages as they investigate novel applications and configurations of different RS technologies.

In addition to collecting data under WP2 this PhD project will make a substantial contribution to WP3: Data Analysis. This links the data collection phase to the decision support tool in WP4.

The PhD Student will have a principal and co-supervisor within Birmingham as well as a third supervisor from elsewhere in the consortium. The student will meet with their supervisors at Birmingham at least once a month, much more frequently at the beginning of the PhD. There are formal review procedures after 9 months and 24 months. In addition, the PhD student has to prepare a website as well as present at school and university research conferences. The school and university have an induction procedure and a wide variety of training courses and opportunities for career development. The postgraduate tutor monitors students regularly and ensures that appropriate resources (including computational resources, and travel funding for conferences) are available to the student. Postgraduate mentors are available to support the student's welfare. Postgraduate students will communicate regularly with the rest of the DART project through the monthly project meetings and will attend a number of the quarterly investigator meetings.

The scope, focus and progress of all DART PhD projects will be monitored by the quarterly investigator meetings and the DART steering committee.

PhD Studentship 2: School of Computing, University of Leeds

Supervisor: Professor Anthony Cohn

Co-supervisor: Dr Keith Wilkinson (Department of Archaeology, Winchester University) and Dr. Anthony Beck (School of Computing, University of Leeds)

Nature and scope of doctoral thesis

This PhD research will address modelling sensor responses from physical measurements to enhance electromagnetic archaeological detection.

DART aims to advance the understanding the impact of environmental and temporal dynamics on soil/vegetation properties and how these impact on the detection of ARs. This will provide foundational data allowing the determination of the appropriate sensors and conditions for the detection of archaeological residues in different soils and under different crops. This knowledge will allow the use of under utilised remote sensing technologies (i.e. hyperspectral sensors) and provide a step-change in the detection of Archaeological Residues in environments traditionally described as poor or marginal.

This PhD project aims to develop a theory of data analysis and interpretation to facilitate those aspects of sensor response which are relevant to AR detection. Multi-temporal models will be developed that translate the geotechnical parameters into spectral, magnetic and electrical measures in order to determine contrast parameters. Environmental dynamics will be identified and their impact characterised. Data fusion techniques will be utilised to determine the factors that lead to contrast detection, the impact these factors will have on the sensor spectrum and the nature of any contrast dynamics. This knowledge will be distilled into domain ontologies which will become the core reasoning framework for the decision support tools in PhD project 3 (below) and WP4.

Contribution of the PhD research to the project as a whole

This project will provide a better understanding of soil, vegetation and environmental dynamics and their impact on detection within the sensor spectrum. This will build on the work outlined in PhD project 1 (above) and will allow an understanding of which sensor configurations will detect archaeological contrasts under different conditions. Models will be developed to articulate how archaeological contrast varies under different conditions. These models will be benchmarked against the measurements from the in-situ probes and the laboratory data (empirical and simulated (from PhD project 1)). By generating mappings between changing conditions and archaeological contrast this research will provide a useful way of determining the suitability of different geophysical and remote sensing techniques.

In addition to collecting data under WP2 this PhD project will make a substantial contribution to WP3: Data Analysis. This links the data collection phase to the decision support tool in WP4. The student will have support from the whole consortium as well as the PI as supervisor and the Project Champion at Leeds who will act as co-supervisor (as allowed for under Leeds' regulations). At Leeds students also have an advisor with whom they meet biannually. There are formal review procedures at the end of each year. Students are members of a research group and are expected to attend the regular group seminars and to present at these too as they progress. There are also Institute and School level events too including annual research away days. The Faculty and University have an induction procedure and a wide variety of training courses and opportunities for career development. The postgraduate tutor monitors students regularly and ensures that appropriate resources (including computational resources, and travel funding for conferences) are available to the student. Postgraduate students will communicate regularly with the rest of the DART project through the monthly project meetings and will attend a number of the quarterly investigator meetings.

The scope, focus and progress of all DART PhD projects will be monitored by the quarterly investigator meetings and the DART steering committee.

PhD Studentship 3: Division of Archaeological Sciences, University of Bradford

Supervisor: Dr Chris Gaffney

Co-supervisor: Professor Anthony Cohn and Dr. Anthony Beck (School of Computing, University of Leeds)

Nature and scope of doctoral thesis

This PhD research will address knowledge-based approaches for the integration and prediction of data related to archaeological prospection.

Environmental and soil conditions affect the various archaeological prospection techniques differently. This project (PhD3) will lay the foundations for the development of decision tools that link soil properties as studied in PhD1 and PhD2 with remote sensing (RS) and geophysics data of the studied sites and their AR. RS information is being acquired as part of the overall project, geophysics measurements are collected as part of this PhD. Direct comparison will be made between the hyperspectral data and earth resistance area surveys for the whole of the test areas; and between in-situ soil data, resistivity imaging and GPR profiles around the location of the buried sensors.

Two approaches are envisaged for the knowledge management of the large quantity of information available. The first tool ('static') will utilise the domain ontologies; general soil information for the sites; historical environmental and vegetation records; and metadata from aerial image archives in order to reduce the search space within those archives for the identification of ARs. It will be tested against archive material with known ARs. The second tool ('live') will utilise the domain ontologies; live soil measurements; geophysical and remote sensing surveys; and satellite-derived environmental and vegetation data for the planning of prospection strategies. This latter tool will predict, based on environmental estimates, what AR types can be detected, with which techniques or sensors and at what times. It will be tested by deriving a programme of bespoke hyperspectral flights and geophysical surveys in an unstudied area and comparing results with known ARs.

This PhD project will combine research in knowledge management and geophysical data analysis, and will create prototypes of two decision tools.

Contribution of the PhD research to the project as a whole

This PhD project will make a substantial contribution to 'WP4: Decision support tool', and the two tools developed will be utilised to evaluate the science in WP5. The comparison of soil data, environmental information, geophysical areasurveys, resistivity and GPR imaging, aerial archaeology, and archaeological evaluation of the ARs gives

PhD3 a central role in the integration of all project data. The decision tools created will be essential for the synthesis of the project's results.

As an integrative part of the project, the student will have support from the whole consortium. In particular, the student will be supervised by the Bradford Co-I (geophysics and data processing) as well as the PI (knowledge management). The Project Champion will act as a third co-supervisor.

At Bradford, students are assigned to a team of advisors with whom they meet regularly, at least quarterly. Due to the proximity between the universities of Bradford and Leeds the joint supervision with Cohn and Beck can easily be accommodated. There are formal review procedures at the end of each year, with an MPhil/PhD transfer viva at the end of the first year. The student will be a member of the Archaeological Prospection Research Group and will participate in, and contribute to regular group seminars. There are also Divisional and School level events which the student will attend. The School and University have an induction procedure and a wide variety of training courses and opportunities for career development. The Divisional Head of Postgraduate Programmes monitors students regularly and ensures that appropriate resources (including computational resources, and travel funding for conferences) are available to the student.

All postgraduate students will communicate regularly with the rest of the DART project through the monthly project meetings and will attend a number of the quarterly investigator meetings.